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Preliminary research on lacustrine deposits and lake evolution on the southern slope of the West Kunlen Mountains

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Abstract

Based on field investigations and data obtained from more than 100 samples in the laboratory, the characteristics of lacustrine deposits and the distribution, genesis and evolution of lakes on the south slope of the West Kunlun Mountains have been discussed from the viewpoint of sedimentary stratigraphy and stratigraphic chronology.

Lakes on the south side of the West Kunlun Mountains are distributed in depression basins along a wide east-west tectonic valley. Water comes from melted ice and snow. The genesis of the lakes is tectonic, but Tianshuihai Lake is a thermo-thaw lake.

By analysis of lacustrine sedimentary stratigraphy and C^{14} chronology, Tianshuihai Palaeo-Lake might have existed since the early Quaternary. Guozha Lake, Aksayqin Lake and Tianshuihai Lake as well as North Tianshuihai Lake were connected together then. The deposit model is an up-accumulation pattern. Up to the late Pleistocene, the unified paleo-lake had been separated and disappeared gradually. The lake level has grown and declined repeatedly since the last glaciation. A period with high lake level existed about 36000 yr. B.P. There is a lacustrine deposited layer, dark-gray clay, in the drilled core profile. Then, the lake level declined. A purple sand and gravel layer was deposited. The lake level rose again about 21000 yr. B.P. A clay layer of dark-gray lake-facies appeared again. In the western part of North Tianshuihai Lake, about 4800 m a.s.l., there is a lake terrace about 40 m higher than today's lake level. On the southeast side of Guozha Lake at about 5800 m a.s.l., there is also a lake terrace 3 m above the existing lake level. During the Holocene, lakes shrank by stages, presenting several circular lake terraces or lakeshore traces.

1. Introduction

In the summer of 1987, the authors, as members of the Sino-Japanese Joint Expedition to West Kunlun, investigated the modern lakes and paleolacustrine deposits on the southern slope of the West Kunlun Mountains.

The West Kunlun Mountains are located at the northwest margin of the Qinghai-Xizang Plateau, bordering the Xinjiang from Tibet. Most peaks are above 6000 m a.s.l.; the highest, called Kunlun Peak, is 7167 m a.s.l. (85°55'E, 35°19'N). The climate is cold and dry. The mean annual precipitation is only 20.6 mm at Tianshuihai on the south slope (4900 m a.s.l.; data from 1965－1970); and 35 mm at Hetian on the north slope (1326 m a.s.l.; data from 1954－1970). The mean annual temperature is below -5°C on the plateau surface, and about -13.9°C near the snowline. The existing glaciers on this massif are well-developed and concentrated. There are 408 glaciers on the north slope, covering an area of 1954.63 km^2, and 244 glaciers, 1347.67 km^2 in area on the south slope. Most of them are valley glaciers; some big ice caps have developed there, too.

Due to a severe environment, rugged terrain and absence of local population, detailed field investigations and research have not been carried out before. A few western explorers came here at the beginning of this century, and reported the existence of glaciers and lakes. In the summer of 1985, the Sino-Japanese Joint Glacial Expedition to West Kunlun Mountains conducted a brief investigation in this area, and published some papers on glaciology, permafrost and paleogeography.

This paper deals with the lacustrine deposits and lake evolution on the south slope of the West Kunlun Mountains, and further discusses the relationship between lake evolution and climatic-glacial changes from the viewpoint of sedimentary stratigraphy and chronology.

2. Distribution, genesis, and characteristics of modern lakes

Lakes on the south slope of the West Kunlun Mountains occur mainly in the tectonic basin within the wide valley formed by faults in the W—E direction (Fig. 1). From west to east, the lakes are: North

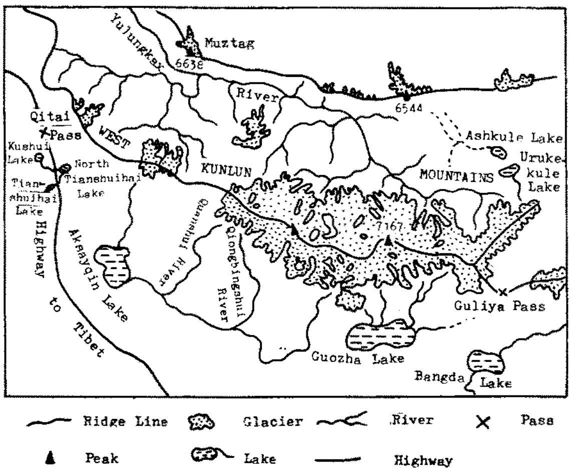

Fig. 1. Location of lakes on the south slope of the West Kunlun Mountains.

Tianshuihai Lake (separated into five small lakes now) with total area of 4 km^2, Tianshuihai Lake, area of about 1 km^2 and 3.5 m in maximum depth; Aksayqin Lake, 160 km^2 in area and 12.6 m in maximum depth; Guozha Lake, 244 km^2 in area and 81.9 m in maximum depth; and Bangda Lake, 106 km^2 in area and 21.6 m in maximum depth. The water in these lakes comes mainly from melted ice and snow. According to data of the Glacial Inventory of China, there are 12 glaciers with area of 3.69 km^2 and the ice volume of 0.1104 km^3 in the drainage basin of North Tianshuihai Lake; 10 glaciers with area of 1.80 km^2 and ice volume of 0.0326 km^3 in the drainage of Tianshuihai Lake; 129 glaciers with area of 709.08 km^2 and ice volume of 136.2698 km^3 in the Aksayqin Lake drainage basin; 62 glaciers with area of 544.34 km^2 and the ice volume of 92.2799 km^3 in the drainage basin of Guozha Lake; and 90 glaciers with area of 170.34 km^2 and ice volume of 15.5528 km^3 in the Bangda Lake drainage basin. In the warm season, a vast amount of meltwater flows into the lakes, and the lake level rises. For example, the water level of Guozha Lake rose 0.14 m from July 19 to August 28, 1987, observed by Cao Zhentang. This is equal to $3416 \times 10^4 m^3$ of water flowing into the lake. Except for evaporation on the lake surface, the water volume would be more than that.

As the West Kunlun Mountains are located on a plateau in the interior of a continent, the climate is very dry. Strong solar radiation causes strong evaporation. These factors strongly affect the chemical properties of lake water. Chemical analysis (Table 1) shows that several large lakes have been become salt lakes. The type of lake water chemistry is as follows: Cl^-—Na^+ type for Bangda Lake and Aksayqin Lake with mineralization degrees of 100393.96 mg/l and 54259.65 mg/l respectively; an obvious difference exists between the south and the north parts of Guozha Lake; Cl^+—Na^+ type in the north part with mineralization degree of 11658.01 mg/l, and Cl^-, HCO^-—Na^+ and Mg^{2+} type in the south part with mineralization degree of 3840.96 mg/l.

There are several types of lake genesis on the south slope of the West Kunlun Mountains. The large lakes such as North Tianshuihai Lake, Aksayqin Lake, Guozha Lake, and Bangda Lake are of tectonic origin. But, Tianshuihai Lake, a small lake, is a thawing lake. At the present time, the ground ice layer exposes in the lower part of the cliff bank of the lake. More than 1 m thickness of ground ice was found at a depth of 13 m in a drill hole at the bank of the lake. It is concluded that there exists permafrost beneath the bottom of the lake that is only 3.5 m deep. In addition, there are many small glacially eroded lakes and moraine-dammed lakes near the periphery of existing glaciers.

Table 1. Main chemical composition of lake water of the south slope of the West Kunlun Mountains.

Site of sample	Content of Anion (me/l)					Content of cation (me/l)					Total content of anion and cation (me/l)	Degree of Mineralization (mg/l)	Value of PH	Water chemical type
	Total	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Total	Ca^{2+}	Mg^{2+}	K^+	Na^+				
Guliya Lake	1.403		1.1916	0.0742	0.1379	1.5102	0.8372	0.3447	0.1892	0.1391	2.9139	113.53	7.90	HCO_3^-—Ca^{2+},Mg^{2+}
Meltwater of Guliya Glacier	0.5631		0.5286	0.0148	0.0197	0.5722	0.4235	0.1083	0.0056	0.0348	1.1353	44.56	7.49	HCO_3^-—Ca^{2+},Mg^{2+}
Northeast part of Aksayqin Lake	934.0183	6.5348	31.0403	860.8650	35.5782	893.3007	0.7880	50.6290	33.2481	808.6356	1827.319	54259.65	8.53	Cl^-—Na^+
Northwest part of Aksayqin Lake	844.2533	0.4132	19.8927	791.60	32.3474	854.7387	0.7880	48.0682	31.9693	773.9130	1698.9920	50531.98	8.48	Cl^-—Na^+
North part of Guozha Lake	183.8242	1.3550	26.6333	133.5825	12.2534	181.1444	0.2659	22.6944	8.1841	150.0	364.9686	11658.01	9.18	Cl^-—Na^+
Middle part of Guozha Lake	59.7893	3.0752	14.1075	37.9968	4.6098	60.0649	0.1281	10.1159	2.8644	46.9565	119.8542	3840.96	8.92	Cl^-,HCO_3^-—Na^+,Mg^{2+}
Southeast part of Guozha Lake	53.8182	2.8830	12.7236	33.2472	4.9644	53.8453	0.3250	9.3260	2.4552	41.7391	107.6635	3457.50	8.94	Cl^-,HCO_3^-—Na^+,Mg^{2+}
Bangda Lake	1728.4149		27.6287	1682.15	18.6362	1732.0795	0.0197	242.29	54.9872	1434.7926	3460.4944	100393.96	8.30	Cl^-—Na^+

3. Stratigraphy of lacustrine deposits of five lakes on the south slope of the West Kunlun Mountains

3.1. North Tianshuihai Lake

Five small lakes, linked by stream to each other, are scattered, with lake level at 4800 m a.s.l.. Its source is connected with Tianshuihai Lake by a stream, and the lower end is joined to Kushui Lake in the Xiaoerke Valley. Around the lake basin, there are several accumulation terraces and paleo-lake cliffs. Toward the center of the lake basin, many circular paleo-lake shore traces can be seen clearly, which reflect lake level fluctuations. A section of terraces was made at the western bank of the lake (Fig.2). According to the C^{14} dating, the age of the sediments on the terrace at 4835 m a.s.l. is 17480±155 yr. B.P. The C^{14} dating was conducted in Isotopic Chronological Laboratory of Geography Department of Lanzhou University; most of them used the organic material, and a few did the calcareous material in sediments. The age of deposits at the depth of 1.5 m beneath the basin bottom at about 4802 m a.s.l. is 17360±180 yr.

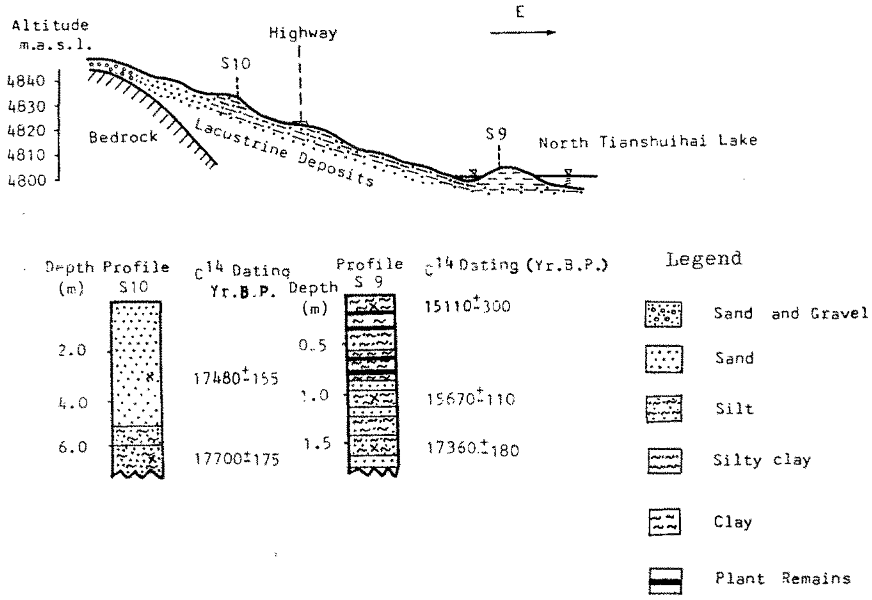

Fig. 2. Profile of deposits and terraces on the western side of North Tianshuihai Lake.

B.P., and 15110±300 yr. B.P. at the upper layer. This shows that the lake level of 17000 yr. ago was at least 40 m higher than today, and that these terraces are regressive-erosional ones. The changes of sedimentary facies also show that, during periods of high lake level, sands with gravels were deposited in the lakeside area, sands in the shallow lake bottom, and silty-clay in the deeper part. The terraces were formed later in the stable stages during the lake shrinking.

3.2. *Modern Tianshuihai Lake*

Modern Tianshuihai Lake is small with lake level at 4836 m a.s.l., supplied by some springs at the foot of the mountain in the southwest direction. However, there was a huge lake before, called Tianshuihai Paleo-Lake. Based on the outcrops of lacustrine deposits, this paleo-lake was joined together with North Tianshuihai Lake, Kushui Lake in the Xiaoerke Valley to the northwest, and Aksayqin Lake to the east, and even connected with Guozha Lake. A clear trace of paleo-lake shoreline reached about 4880 m a.s.l., but, at present, a vast lacustrine accumulated plain stretches in the area. By analysis of the characteristics of Quaternary geology and geomorghology in the lake basin and history of lakes on the whole North Tibet Plateau, we believe that the Tianshuihai Paleo-Lake had existed since the beginning of the Quaternary, and by Late Pleistocene it was separated and disappeared gradually. The whole core of SI1 drilled at Tianshuihai, 15m in depth (Fig. 3), consists of lacustrine clay with gray color. The clay 80 cm deep below the ground surface has a C^{14} dating age of 46850±2970 yr. B.P., which could represent the youngest deposits of the Tianshuihai Paleo-Lake. The core profile of SI2, drilled at the low bank of the modern lake, 9.5 m in depth (Fig. 4), reveals the outline of lake level changes since 40000 yr. B.P. The deposits between the depths of 9.5 m and 8.3 m are gravels with sandy layers. The size of gravels is generally 2−5 mm, and 2−3 cm in maximum in diameter. These gravels are rounded to a certain extent and arranged in order, which shows the characteristics of fluvial deposits at the lakeside during periods of low lake level. A sand layer lying between 8.3 m and 7.6 m in depth, having shallow lake facies, shows that the lake level began rising. Then, the core of 7.6 m to 7 m changed to the deposits of deep lake facies, gray clay layer. Its age of C^{14} dating is 36750±1320 yr. B.P.. These three layers represent the cycle of the lake level changes from low to high. The deposits from 7 m to 1.5 m change to

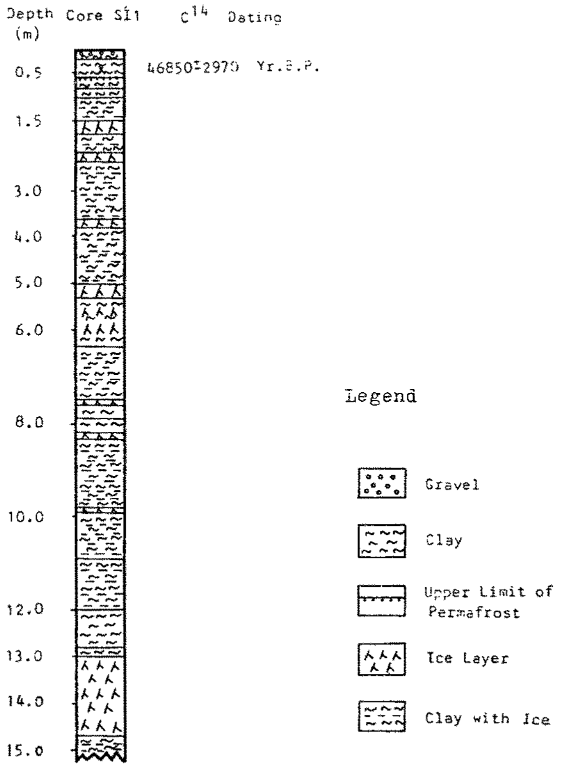

Fig. 3. Profile of core SI1, modern Tianshuihai Lake.

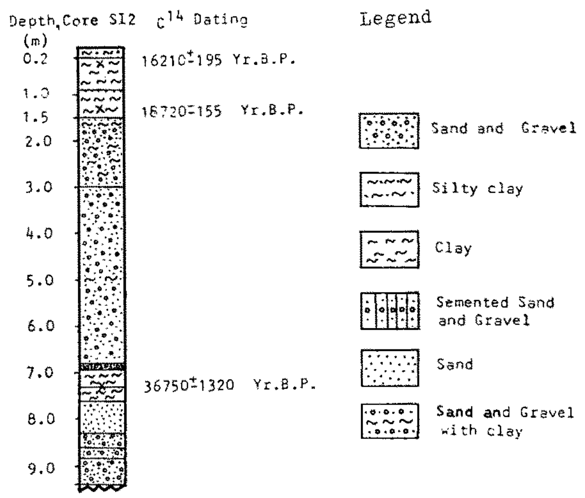

Fig. 4. Profile of core SI2, modern Tianshuihai Lake.

purplish red sand and gravel again, showing the lake shrinking and the lake level dropping. From 1.5 m to 0.2 m, it is gray lacustrine clay, and contains some fossil plant remains. This layer represents a period of high lake level and expanding lake: The C^{14} dating is

18720±155 yr. B.P. in the lower part of this layer, and 16210±195 yr. B.P. in the upper part of it. In addition, some C14 datings of dark gray lacustrine clay were obtained near Tianshuihai: they are 20000±170yr. B.P., 18420±245 yr. B.P., 16530±145yr. B.P., and so on. These strongly suggest that a period of high lake level existed during 21000 yr. B.P., to 15000yr. B.P.

3.3. *Aksayqin Lake*

The lake-level of Aksayqin Lake lies at 4844m a.s.l. The authors went near the center of the lake by rubber boat to measure the depth and take samples from the bottom, and found a black clay layer of 9 cm thick and a yellow sand layer at the bottom of the lake. On the west side, there are several terraces with clear traces of paleo-lake shoreline. But, a wide lacustrine plain stretches on the east side, because of sand and mud deposition by the stream coming from the east into the lake. At the north bank, the authors found the sand and clay layers (Fig. 5). Among them, the age of black clay layers is 34735±820 C^{14} yr. B.P. and of black sand layer is 22522±670 yr. B.P. This also shows that the lake level was high about 35000 yr. B.P., identical with the result obtained from the area of Tianshuihai Lake. Moreover, in the section of terrace 1 in the northeast side of the lake (Fig. 6), the C^{14} age of gray clay at 1.25 m deep is 18520±305 yr. B.P., and 16235±120 yr. B.P. at the top. This also shows that a period of high lake level existed about 15000 years ago.

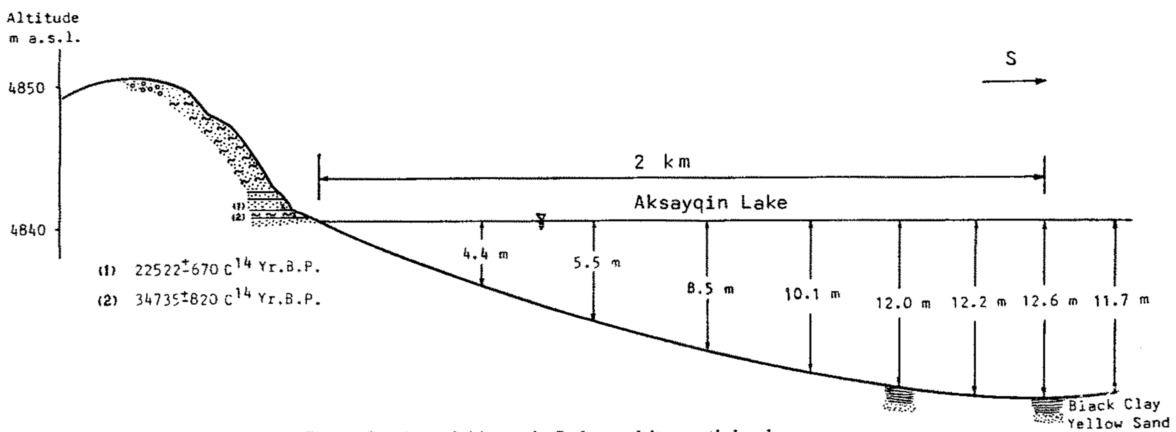

Fig. 5. Section of Aksayqin Lake and its north bank.

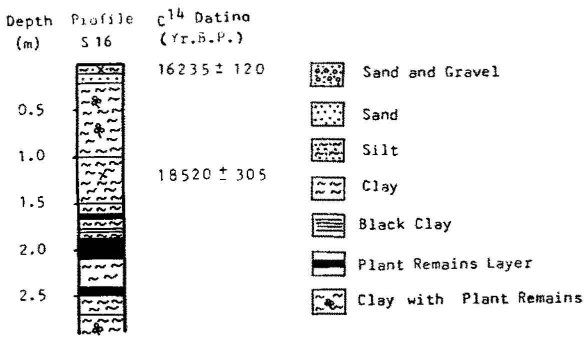

Fig. 6. Profile of lacustrine deposits of terrace 1 on the northeast side of the Aksayqin Lake.

3.4. *Guozha Lake*

Guozha Lake, with a lake level of 5080 m a.s.l., occupies also a tectonic basin surrounded by bedrock slope. The lake is very deep with a steep subaquatic slope (Fig. 7). Taking samples from the lake bottom, the authors found that the bottom material at 81.9 m deep is yellow silty-clay. We took bottom sediments 30 cm thick at 17.4 m depth. The upper part is yellow silty-clay, and the lower part gray clay. The water temperature at the bottom is 7℃.

During the stage of high lake level, water drained away toward the west along the valley, and joined Tianshuihai Paleo-Lake. Only on the southeast side of the lake, there are three terraces (Fig. 7). Terrace 1 is about 1m higher above the modern lake level. The material of the upper part is a gravel layer, of about 20 cm thick, and the lower part is a red sandy clay layer.

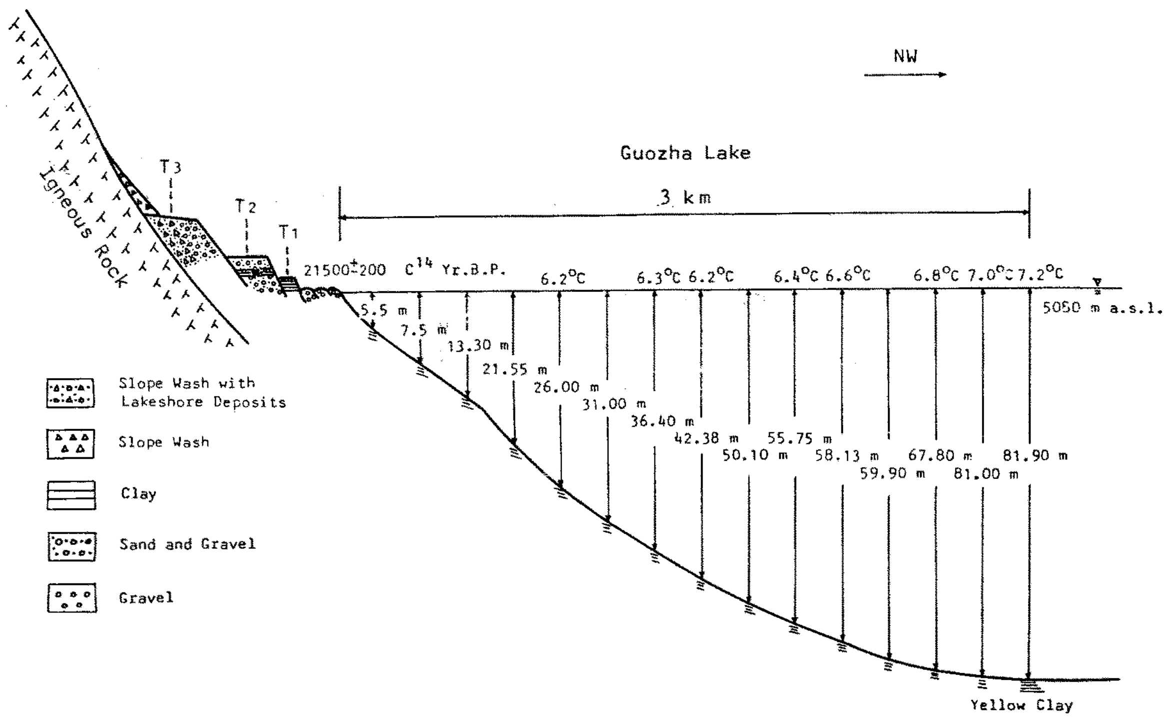

Fig. 7. Section of Guozha Lake and its terraces.

Terrace 2 is about 3 m higher above the lake level. Both the upper 2 m and the lower part are sand and gravel layers. Between these two layers, there is a layer of red clay of about 20 cm thick, red above and gray clay below; its C^{14} age is 21500 ± 200 yr. B.P. Terrace 3 is about 10 m higher above the lake level. It is composed of sand and gravel, formed from mixed slope deposits and alluvial deposits as lakeside sediments.

3.5. Bangda Lake

The modern lake level of Bangda Lake is 4902 m a.s.l. The terraces are very well-developed around the lake (Fig. 8). Even on the bedrock around the lake basin, several terraces and cliffs are clearly, cut at almost 200 m higher than the modern lake level. It is difficult to say whether the high paleo-lake level suffered from neotectonic movement or not. However, periods of high lake level might have existed. Obser-

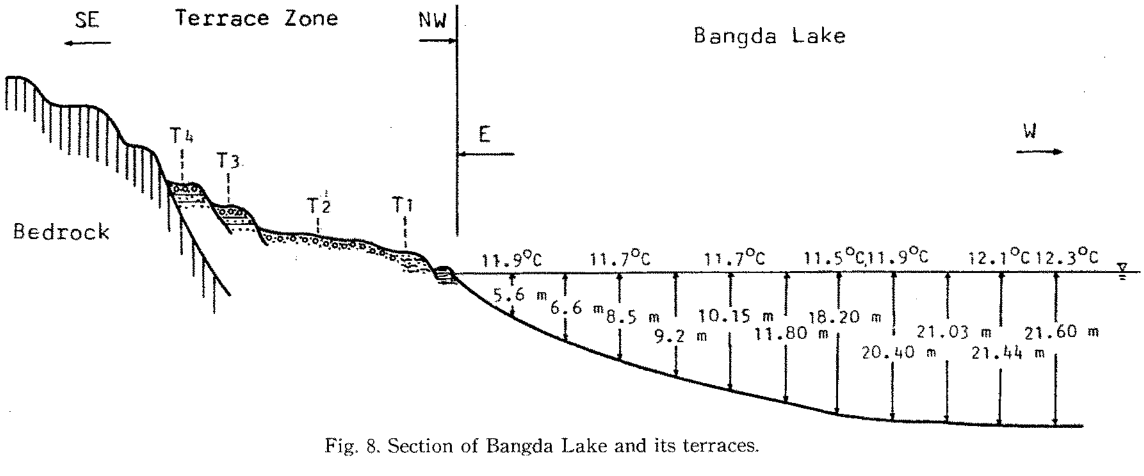

Fig. 8. Section of Bangda Lake and its terraces.

vations suggest that Bangda Lake, Puer Lake, and Dulishi Lake on the east side were once connected together. Within the lake basin, there are 4 depositional terraces with altitudes of 4905 m, 4921 m, 4940 m and 4965m a.s.l. respectively. Especially, on the broad surface of terrace 2, there are several paleo-lake shorelines in ridge shape formed in the stable stages of the lake shrinking process. Terrace 1 was formed at the base of Terrace 2. C^{14} ages of the light gray clay layer in the section dug on Terrace 1 (Fig. 9) were 15900±120 yr. B.P. and 15880±115 yr. B.P. It might be deduced that the lake level then reached, at least, the height of Terrace 3 when these clay layers were deposited, about 40 m higher than today's. This is identical with the result from North Tianshuihai Lake.

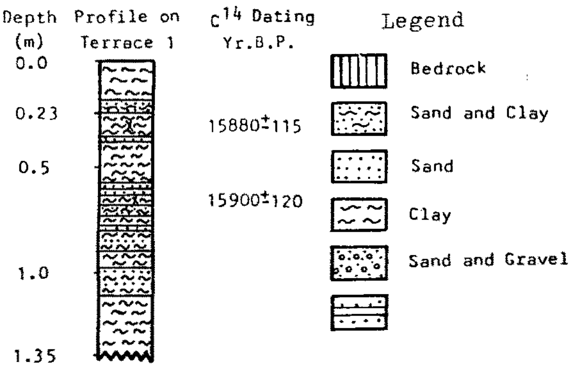

Fig. 9. Profile on Terraces 1 of Bangda Lake.

4. Evolution of lakes on the south slope of the West Kunlun Mountains

Evolution of the lakes on the south slope of the West Kunlun Mountains is closely related both to the tectonic uplift of the Qinghai-Xizang Plateau and the global climatic changes. The changes of lakes on the Plateau can be divided in several periods.

(1) Early and Middle Pleistocene: According to the result of Zheng Mianping's research (Zheng *et al.*, 1983), within the Tibet, the greatest area of lakes was 1/5 or more of the total area of Tibet or more at that time, ten times as large as the total area of modern lakes. Therefore, they called this period an "extensive lakes and rivers period". Lakes on the south slope of the West Kunlun Mountains also grew. Great Tianshuihai Paleo-Lake, connected to Kushui Lake to the west and North Tianshuihai Lake in the north, Aksayqin Lake and even Guozha Lake in the east, were about 3000 km^2 in total area. And the total area of modern lakes is about 410 km^2, only 1/7−1/8 as big as the Paleo-Lake. Consequently, we call this age of lake expansion the "great lake period". During that period, although alternate warm-cold changes of climate occurred, it was generally damp.

(2) Up to Late Pleistocene: The altitude of mountains of the marginal part of the Plateau (such as the Himalayas, the Gangdis and the Karakoram) reached near their present height, which could obstruct warm-damp air masses from the Indian Ocean. The climate gradually became drier and drier. In addition, with uplift of the Plateau, the headward erosion of the river made part of the water of Tianshuihai Paleo-Lake flow into the Karakax River northward along the Gunshi River. As a result, up to about 47000 yr. B.P., the great Tianshuihai Paleo-Lake was disappeared and separated to several small lakes. The vast lake basin became a stretch of lacustrine plain (C^{14} age of the lacustrine clay at the top of SI1 core drilled on the plain is 46850±2970 yr. B.P.). This is a great change and a turning point in the evolution of lakes on the south slope of the West Kunlun Mountains. After the decay of the unified paleo-lake, each separated lake presented a period of high lake level again about 35000 yr. B.P. This is indicated by the following C^{14} dates: 36750±1320 yr. B.P.: the lacustrine clay layer in the SI2 core drilled at Tianshuihai; 34735±820 yr. B.P.: the lacustrine clay in the profile on the north side of Aksayqin Lake; 30935±1700 yr. B.P.: a tract of gray lacustrine clay covered by moraine, on the east side of Chongce Glacier, northeast of Guozha Lake. This period of the high lake level corresponds to the interglacial substage of the last glaciation. The climate was clearly warm during that period, both on the plain in eastern China and the mountains in the western part. Due to the warm climate, glaciers on the West Kunlun Mountains melted and retreated quickly. A large amount of meltwater flowed into lakes, resulting the lake expansion and lake-level rise. Later, the lakes shrank.

Up to about 21000 yr. B.P., with climate becoming colder, the glaciers began advancing. C^{14} dating of the moraine on the south side of the Chongce Ice Cap gave the age of 21046±716 yr. B.P., and that of the end moraine in front of Guozha Glacier 20106±385 yr. B.P. This cold period, in which mean annual temperature was about 6−10℃ lower than today, and glaciers developed on a large scale on the earth, is called the last the glaciation maximum. But, it is surprising that this cold period was a period of high lake level on the south slope of the West Kunlun Mountains. All C^{14} ages of the gray clay on the lacustrine accumulation terrace are between 21000 yr. B.P. and 15000 yr. B.P. The lake levels of North Tianshuihai Lake and Bangda Lake were, then, at least 40 m higher than today's.

In the area of Chaiwobao Lake in Xinjiang Province, Wang *et al.* (1986) researched the relationship between the advance and retreat of glaciers and the lake level changes. They also found that the period of the last glaciation maximum was also a period of high lake level. In our view, possible reasons for the high lake level during the cold stage are: 1) the area of glaciers increased enormously in that time, and this caused a feedback effect to the solar radiation balance; 2) with increasing glacial area, the run−off of meltwater grew in large quantities; 3) at the same time, the amount of evaporation decreased greatly. As a result, a huge amount of water flowing into lakes made the lake-level rise. Later, lakes shrank once more.

(3) Since the beginning of Holocene: As the interglaciation came the lakes shrank by stages, finally becoming many salt lakes. A series of circular paleo-lake shoreline was left around each lake basin.

In short, the three main stages of the evolution of lakes on the south of the West Kunlun Mountains were: 1) the "Great Lake Period"; 2) the "Lake-level Fluctuation Period"; 3) the "Lake Shrinking Period", corresponding to Early and Middle Pleistocene, Late Pleistocene and Holocene, respectively.

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