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Preliminary studies of Quaternary Glaciation and palaeogeography on the south slope of West Kunlun

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Abstract

According to data from field observations on the southern slope of West Kunlun in July 1985 and laboratory analyses, at least three glaciations since the Middle Pleistocene can be recognized. There was no glacier in this region in the Early Pleistocene. The maximum glaciation occurred during the Middle Pleistocene. The strong neotectonic movement happened from the end of the Middle Pleistocene to the beginning of the Late Pleistocene, so that the ancient Tianshuihai lake was separated from the Aksayqin basin. Since the Late Pleistocene, glacier development was restricted. In 16150±553 C^{14} yr. B.P. the ancient Litian Glacier was 29 km long, about 6 km longer than today, and in 21046±716 C^{14} yr. B.P. the Chongce flat topped glacier was about 1 km longer than today. During the Hypsithermal in the Holocene, the glaciers retreated, but they readvanced in the Neoglaciation 2720 years ago. Recently, although most of the glaciers are retreating, some glaciers still advance.

1. Introduction

West Kunlun Mountain lies between the Xinjiang and the Xizang. It is most magnificent and highest mountain in the northwestern part of Qinghai－Xizang Plateau, from the Yarkant River gorge to east longitude 83°30'. There are many glaciers with total area 8438 km² (Zheng 1986). This is one of the greatest glaciation centres on the Qinghai－Xizang Plateau, especially the glacier area of the West Kunlun main range between Tianshuihai and Guliya Pass, about 3300 km², or 30% of this mountain area. Many valley glaciers are about 20－30 km long and several flat topped glaciers are among the longest glaciers in China. According to research, during the Quaternary ice ages, the Palaeoglacier area was much larger than that of today.

At the beginning of the 20th century, Western scientists reported the remnants of Quaternary glaciation of the West Kunlun and its surrounding environment (Stein, 1912 ; Sobolevski, 1919 ; Trinkler, 1930 ; Norin, 1932 *etc.*).

In 1976, the Comprehensive Scientific Expedition of Qinghai－Xizang Plateau, Academia Sinica investigated these glaciers of the Quanshugu River headwaters. Zheng Benxing has suggested three glaciations on the south slope : the Kunlun Glaciation of the Middle Pleistocene, and the Quanshigou Glaciation and the Binshuigou Glaciation of the Late Pleistocene (Zheng *et al.* 1981).

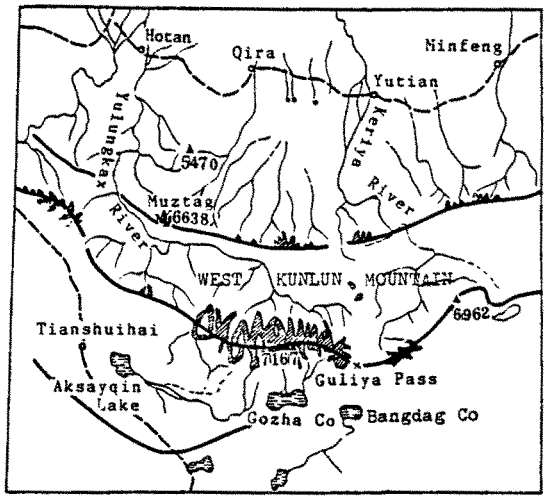

Fig. 1. Sketch map of the West Kunlun Mountains between Xingjiang and Xizang.

In 1985, the Sino－Japanese Joint Scientific Expedition went to the southern slope of the West Kunlun to study the existing glaciers, glacial geomorphology and permafrost (Fig. 1).

According to field observation and debris mineral data, clay mineral data, sporo－pollen analyses and C^{14} dating, the outline of geology and geomorphology, the remnants of palaeoglaciers, lake development, and the evolution of Quaternary glaciers and palaeoenvironment of the south slope of the West Kunlun were studied. The results are herewith presented for discussion.

2. Outline of geology and geomorphology

In view of tectonics, the West Kunlun belongs to the folded zone of the Hercynian movement (Chang *et al.* 1982). The palaeozoic group strata are complete, there are mainly clastic rocks, carbonate deposits with volcanic rocks of shallow－sea facies and alternating marine and continental beds. Both folding and faulting develop very much in West Kunlun. In this region are three tectonic zones : the geosyncline zone of North Kunlun, the palaeozoic crystalline rock zone of Central Kunlun, and the geosyncline zone of South Kunlun. There are three snow－copped mountain ranges conforming to the tectonic zone. The northern range is called Karatas－－Luistag Shan ; its highest peak is called Muztag (6638 m a.s.l.). The altitude of the mountain ridge relative to the Tarim Basin is about 4000－5000 m, so that it is very steep and its middle－lower section is covered by aeolian sand and loess ; it shows a desert mountain landscape.

The main mountain range is called Yulunkaxnanshan, the highest and the widest in West Kunlun ; its common height is over 6000 m. The highest peak, Mt. Kunlun 7167 m a.s.l., lies at the source of the Litian River. There are many glaciers 20－30 km long, and big flat－topped glaciers.

The southern range is about 5500－6000 m a.s.l. with several small glaciers.

There are many intermontane basins and wide valleys running E－W on both sides of the main range, such as Tianshuihai－Aksayqin Lake－Gozha Co basin on the south side, about 20－30 km wide, 4800－5200 m a.s.l. ; a large scale ancient lacustrine plain, and pluvial and fluvioglacial fans are formed.

Many ancient glacial deposits lie in front of the existing glaciers. The West Kunlun volcanic deposit is very famous. There are not any human inhabitants but there are many wild yaks, donkeys and Tibetan antelopes. It shows the high cold geomorphological landscape of the Qinghai－Xizang plateau.

3. The remnant of Quaternary glacier

On the south slope of the West Kunlun, located between Tianshuihai and Guliya Pass, are many existing valley glaciers extending into the piedmont or intermontane basin. However, the ancient glaciers were larger than today. We can see old lateral moraines and end moraines distributed along the U－shape valleys, wide moraine flatform and moraine plain on the piedmont ; even several boulders lie on the mountain－topped peneplain.

According to their geomorphological and stratigraphic features, their weathering and C^{14} dating of tills, three glaciations may be identified : from old to new, the Kunlun in the Middle Pleistocene ; the Qanshuigou and the Bingshuigou in the Late Pleistocene ; and the Neoglaciation in the Holocene.

Now we discuss the Quaternary glaciation of the Litian River and on the north of Gozha Co.

3. 1. Remnant of ancient glacier of Litian River and neighbour region

The Litian River originates from the terminus of Zhongfen Glacier, a big valley glacier composed of four big ice flows, its 23.4 km long and 241 km^2 in area. Its terminus lies at 5400 m a.s.l. The melt water flows into Aksayqin Lake through the Aksayqin Valley. The ancient moraines are distributed in the middle section of the Litian River and on the mountain topped peneplains on both sides (Fig. 2).

3. 1. 1. The Holocene end moraine

Modern moraines since the 17－19th Little Ice Age may be divided into two rows. The inside end moraine lies at 5400 m in height ; it is 300 m from Zhongfen Glacier. Its relative altitude is about 30－40 m ; its color is gray－black : The big boulders are composed of carbonaceous shale and granite. Dead ice exists 1 m below the surface of the moraine. The outside end moraine is 600 m from the glacier at 5360 m a.s.l. ; its color is yellow. The end moraine above connects to the inside lower lateral

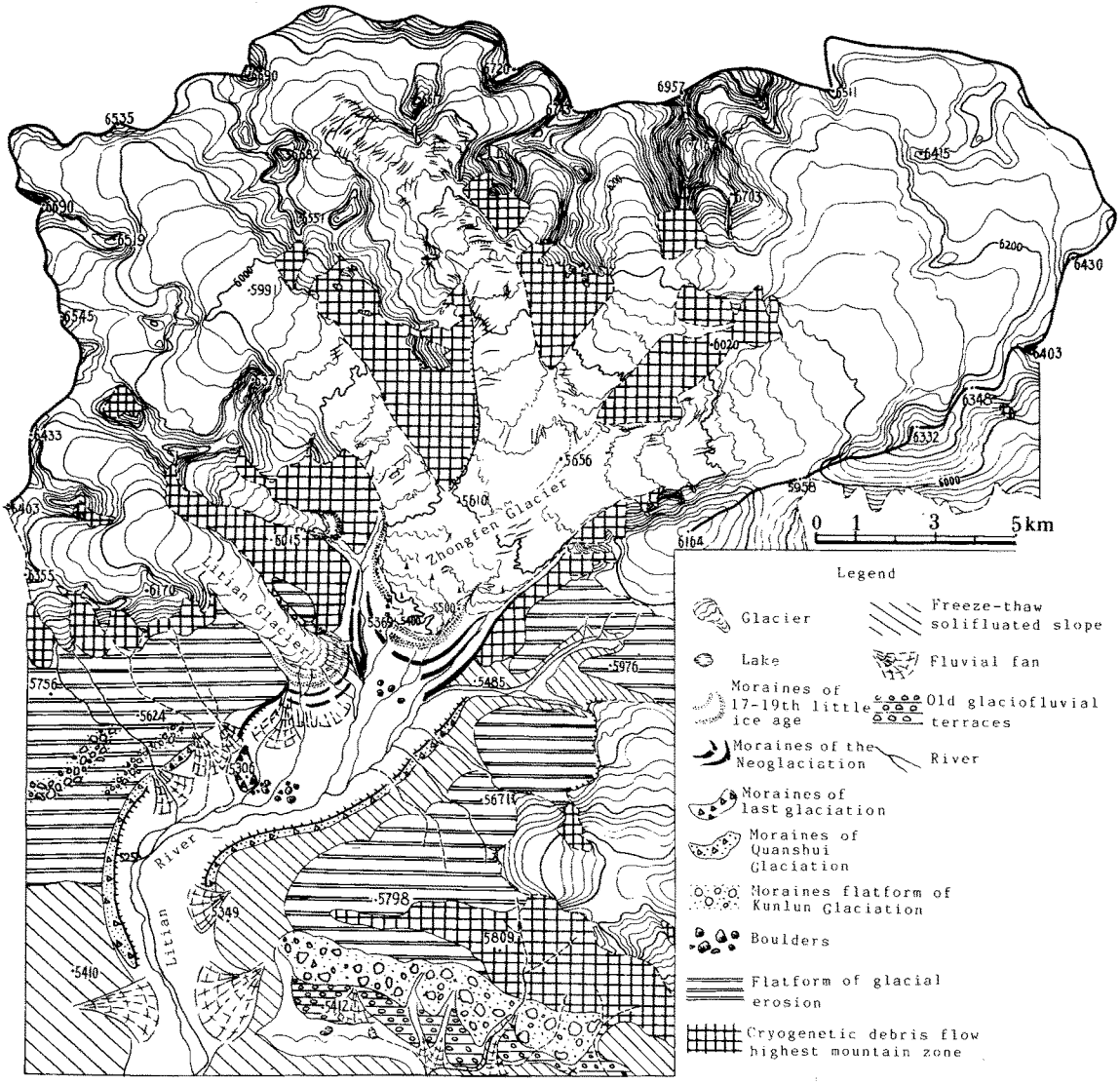

Fig. 2. Glacial Geomorphological Map of Zhongfen Glacier Region on the South Slope of West Kunlun.

moraine.

Two end moraines of Neoglaciation are 1 km and 2 km from Zhongfen Glacier at heights of 5350 m and 5340 m, respectively. They connect the middle lateral moraine in the upper part, and gave features similar to Neoglacial moraine of Chongce flat-topped glacier (2720±85 C^{14} yr. B.P.).

On the West bank of the Litian River, there are four arcuate end moraines in front of Litian Glacier corresponding to the Holocene. They are 50 m, 180 m, 600 m and 900 m from the glacier, 5400 m, 5390 m, 5327 m and 5320 m in height, respectively. The two glaciers mentioned above represent similar frontal fluctuation.

3. 1. 2. End moraine of the last glaciation

An end moraine lies at 5280—5306 m height, 26 m above the bed of Litian River, 500 m wide and 700 m long, 6 km from Zhongfen Glacier. The debris and boulders of the end moraine are composed of limestone, granite and shale. We could find striated boulders. According to C^{14} dating, the end moraine was formed at 1615±553 yr. B.P.. Therefore it belongs to the Last Glaciation.

3. 1. 3. Moraine terraces and higher lateral moraines of early stage of Late Pleistocene

Moraine terrace and higher lateral moraines are located about 20−40 m above the bed of Litian River and cut by fluvial gullies. The lowest part extended down to 5240 m a.s.l., therefore the ancient Zhongfen Glacier was 11 km longer than today. According to their morphological and weathering features, the higher lateral moraines could be compared with those of the Quanshuigou Glaciation.

3. 1. 4. Old till on the mountain−topped peneplain

On the mountain−topped peneplain from 5500 m to 5700 m a.s.l. located west of Litian River, there are two moraine belts. Their boulders are composed of mainly granitic porphyry from the alpine zone and quartzitic sandstone, shale and schist from the surrounding areas. The lower moraine belt lies at 5500 m a.s.l., 5−10 m thick and the higher moraine belts lie at about 5600 m a.s.l. 50−100 m wide. Between the moraine belts are varied the periglacial landforms such as the block field, stone strips and stone circles formed from local bed rock debris under cryogenic weathering and freeze−thaw action. From the facts mentioned above, erosion and deposition of the ice cap suggest that almost all debris and boulders were deposited on marginal belts with little subglacial till during ice cap retreat because the amount of debris transported by an ice cap is small.

According to interpretation of the air photos and the topographic map, the area of the ancient ice cap was about 2 times larger than today. Now several deep V−shaped valleys cut into the mountain−topped peneplain.

3. 1. 5. The palaeoglacial remnant of Senli Pass region

From the middle section of the Litian River to Senli Pass, there is a high broad valley running E−W, 8 km long, 2−2.5 km wide, 5400−5500 m high, and about 200−300 m above the bed of the Litian River. A high moraine plain 1.5 km wide exists on the north side of the valley. It boulders are composed of mainly granitic porphyry and sandstone. Several wide shallow dry gullies were formed on the high moraine plain, and cut high glaciofluvial terraces which suggest an ancient glaciofluvial lake. On the south−facing slope of the north mountain of the wide valley, however, cirques and U−shape valleys do not exist. Therefore we conclude that these boulders are the marginal deposit belt of the ancient ice cap of the north mountain in the Middle Pleistocene age.

3. 2. The remnant of ancient glacier north of Gozha Co

Gozha Co is the largest glaciofluvial lake, 224 km^2 in area and 5080 m in lake level height in the south piedmont of West Kunlun. North of Gozha Co are the longest valley glacier−Chongce Glacier, and the biggest flat−topped glacier−Guliya Glacier, on the south slope of West Kunlun. However, the ancient glaciers were larger ; these extended to the north margin of the present Gozha Co. The various moraines of different ages are represented as follows (Fig. 3).

3. 2. 1. Moraines since the last glaciation

There are two moraine lakes on the southern margin of Chongce Ice Cap, which is a flat−topped glacier. The big lake 5720 m in lake level height, 600 m long and 500 m wide, is located on the west side. The end moraine outside the big lake is 1.08 km from the glacier, about 30−40 m above the level of the big lake, and composed of yellow sandstone, limestone and granite. C^{14} dating of the moraine is 21046±716 C^{14} yr. B.P., showing that the end moraine was formed in the last glaciation. The end moraine connects to the end moraine outside the east moraine lake.

The end moraine of Neoglaciation is located north of two moraine lakes, 500−200 m from the glacier and formed 2720±85 C^{14} yr. B.P. It may be compared with the Xuedang advance (2980±150 C^{14} yr. B.P.) of the Neoglaciation in southeast Xizang (Zheng Benxing et al. 1981). But two small end moraines lying 120 m and 80 m from the glacier were formed in 17−19th century : Little Ice Age.

3. 2. 2. Higher moraine plain of early Late Pleistocene

The higher moraine plain 2−8 km wide, 5400−5800 m high is located outside the end moraine of the last glaciation. The boulders on the high moraine plain are composed of granite, limestone and sandstone. Some are 1−2 m in sizes.

3. 2. 3. Older moraine platform of Middle Pleistocene

The older moraine platform is 6−17 km from the glacier 5080−5400 m high, 100−300 m above the bed

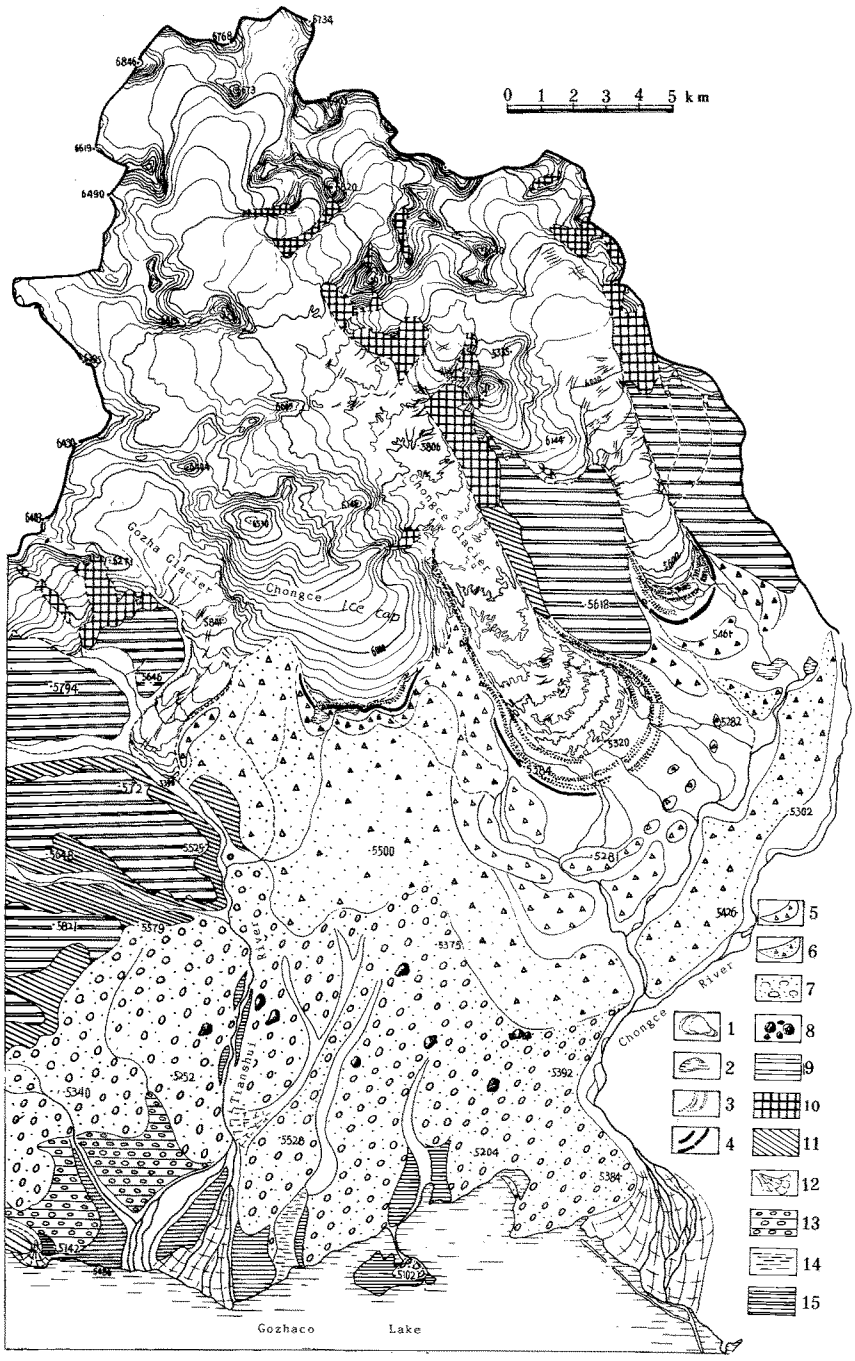

Fig. 3. Glacial Geomorphological Map of Chongce Glacier Region on the South Slope of the West Kunlun Mountains.

Legend: 1. glacier, 2. lake, 3. moraine of 17—19th century Little Ice Age, 4. moraine of the Neoglaciation, 5. moraine of last glaciation, 6. moraine of Quanshuigou Glaciation, 7. moraine platform of Kunlun Glaciation, 8. boulders, 9. platform of glacial erosion, 10. cryogenetic debris flow highest mountain zone, 11. freeze-thaw solifluated slope, 12. fluvial fan, 13. old glaciofluvial terrace, 14. marshland, 15. lower alluvial terrace.

of Tianshui River. Brown soil has developed on the moraine platform, growing some grass. The boulders on the platform have suffered strong weathering. There are several wide and shallow dry river-beds formed by cutting of glacial melt water during the late Pleistocene. From the above mentioned points, the older moraine platform may be compared with those of the Kunlun Glaciation in the Middle Pleistocene.

We could see various moraines in different ages since the Middle Pleistocene, when we investigated along the west bank of Chongce River, but detailed research should be done in the future.

4. Characteristics of minerals in tills of different period

According to the data of the mineral analyses in various tills, their characteristics of different periods are different as follows :

4. 1. In various tills from new to old, the content of limonite increases gradually, for example in the Litian valley, the content of limonite in heavy mineral of the modern moraine occupies 0.5%, 13% in the end moraine of the last glaciation, 25.5-28% in the higher lateral moraine of the early Late Pleistocene ; , and 50.5% in the old moraine on the mountain-topped peneplain of the Middle Pleistocene. This shows that the older the till, the stronger the weathering.

4. 2. In the various tills from new to old, the contents of unstable minerals decrease gradually, while the contents of the most stable minerals increase gradually (see Table 1.).

We can see from Table 1 that the contents of the most stable minerals in the till of Kunlun Glaciation is 2 times those of the last Glaciation. This shows that after the Kunlun Glaciation there was a long warm-humid climate in an interglacial period.

4. 3. In the various tills from new to old, the contents of light minerals are different. Feldspar is easy to weather ; its content decreases from 38% to 25. 5%. on the contrary, the quartz content increases from 22% to 33%.

4. 4. The clay minerals in tills of different periods are composed of mainly hydromica and chlorite. The kaolinite content is much less and the montmorillonite content is small. This shows the typical characteristics of clay minerals of the continental glacier region in Chan.

Generally speaking, the older the till, the higher the content of hydromica and kaolinite. The content of chlorite, however, shows the opposite trend. The Chongce River tills are an example (see Table 2).

Table 1. Contents of unstable and most stable heavy minerals in various tills, Litian Valley

Various Titlls	Contents of heavy minerals (%)			
most stable	unstable	stable	most stable	most stable
Q4 Modern	15.75	5.50	49.75	29.00
Q3 Last Glaciation	29.60	9.66	23.75	34.08
Q3 Quanshuigou Glaciation	18.60	7.75	24.50	48.17
Q2 Kunlun Glaciation	15.75	4,75	12.50	69.00

Table 2. Clay mineral content in the Chongce River till

Tills of different periods	Clay mineral content (%)		
	hydromica	chlorite	kaolinite
Modern moraine (Q4)	66-67	25	7
Neoglaciation (Q4)	71.8	20.1	8
Last glaciation (Q3)	71.4	19.7	8.9
Kunlun glaciation (Q2)	75.5	17.5	7

5. History of lake development

There is a zone Cenozoic Era sinking running E—W between the main range and the south range, where there are many lakes. From west to east they are called Tianshuihai Lake, Aksayqin Lake and Gozha Co. The geomorphological features of the three lakes are different. According to our research, the relationship of the history of lake development is close to the evolution of Quaternary glaciers and the neotectonic movement.

Based on the distribution of old lacustrine deposits near the Tianshuihai, the ancient Tianshuihai lake was a very big Z shape lake, 80 km long, 10 km wide and about 4,900 m high. However, at present there remain only many small salt lakes and a wide lacustrine plain. In the ease section of the old lake, the lacustrine layers had been deformed due to neotectonic movement. Aksayqin Lake is a salt lake 4,848 m high and 15 km long. There are three lake shore terraces at the west shore about 23 m, 20 m and 2.5 m above the present lake level respectively. There is a wide valley located between Aksayqin lake and ancient Tianshuihai Lake. The height of the highest lacustrine deposit of ancient Tianshuihai Lake is higher than the highest lake shore terrace of Aksayqin Lake.

Gozha Co is a big glaciofluvial lake about 100 km east of Aksayqin Lake. The wide Aksayqin valley extends to the east near Gozha Co, where we can see from air photos a dry river bed linking to the west shore of Gozha Co ; during high lake level, the lake water flows from the Gozha Co into the Adsayqin River.

From the above, it may be concluded that the ancient Tianshuihai Lake is older than Aksayqin Lake. According to sporo—pollen analyses of old lacustrine deposits, there was a warm climate in the Tianshuihai region.

The lacustrine profile if 15 km southeast of the Tianshuihai, it is 3.8 m thick, 4,900 m a.s.l., its strata dip 5—10° southwestward and may be divided into six layers, from top to bottom as follows :

1) grayish yellow silt	0.1 m thick
2) dry leaves layer	0.1 m thick
3) gray clay	1.5 m thick
4) dry leaves layer	0.1 m thick
5) gray clay	1.5 m thick
6) dry leaves layer	0.1 m thick

The total number of sporo—pollen in these layers is from 60—339. The arbor occupy 2.8—18.3%, mainly *Pinus*, *Betula* and secondly *Abies*, *Picea*. *Artemisia*, *Chenopodiaceae* and *Ephedra* are the principal grasses. However, a high cold desert environment occupies this region at present.

The fossilized plants of the upper section of old lacustrine shows that there was a warm—humid climate at that time. The *Betula*, *Pinus*, *etc*. formed a forest—steppe landscape on the piedmont plain in the Tianshuihai region. On the slope there was a temperate coniferous forest zone growing *Picea and Abies*.

Today in the Taibai Shan in Shannxi Province, located at about the same latitude with the south slope of West Kunlun, the distribution of *Pinus armandi* is 1000—2500 m a.s.l ; *Betula* forest grows on the slope 2300—2600 m a.s.l. The coniferous forest, mainly *Abies*, lies 2500—3500 m a.s.l.. On the south slope of Xiqing Shan, in the southern part of Gansu, *Pinus tabulaeformis* grows below 1600 m a.s.l., *Picea neiveitchii* and *Pinus armandi* grow at 1600—2500 m a.s.l. and *Picea* forest belt lies 2100—2600 m a.s.l. and the *Abies faxaniana* is growing 2500—3900 m a.s.l. (Natural Division Committee of Academia Sinica, 1960). From the comparision between the existing plants in these east mountains and the fossilized plants of West Kunlun, it may be concluded that 2500—3000 m a.s.l., and the mean annual temperature was about 18°C warmer than today, showing an interglacial environment. It may be compared with the second Qinshui He interglacial of East Kunlun (Tang *et al*. 1976).

The ancient Tianshuihai was an older lake, possibly formed before the early Pleistocene. At the end of the Middle Pleistocene and beginning of Late Pleistocene strong uplift occurred on the Qinghai—Xizang Plateau. That time, the ancient Tianshuihai basin was separated from the Aksayoin valley. The new Aksayqin lake appeared since that time. The ancient Tianshuihai Lake became smaller and smaller, because it lost a great deal of melt water. Since the Late Pleistocene Aksayqin lake had a new development history. However, the area of Gozha Co since the middle Pleistocene changed little.

6. The evolution of Quaternary Glaciers and palaeo-environment

According to studies of the evolution of Quaternary glaciers and the uplift of the Qinghai-Xizang Plateau (Li *et al*. 1979, Zheng *et al*. 1981 ; 1986), during the Middle Pliocene the Kunlun Mountains were not high, because the species of the *Hipparion* fauna found in Woma basin of Gyirong county belong to the same fauna as the *Hipparion* of North China in the Middle Pliocene at 500-1000 m a.s.l., but it is different from the Pliocene fauna in Siwalik, India (Ji, *et al*. 1980). This shows that during this period the Kunlun mountains were not high enough to form a barrier, the *Hipparion Gyirongensis sp*. could migrate freely, so the West Kunlun mountains were only about 500-1000 m a.s.l. (Table 3).

At the end of the Pliocene and beginning of the Early Pleistocene, although the Kunlun mountains were uplifted, they were still not high. During that time many big lakes such as old lakes of Kunlun Shankou and Qinshui He (Tang *et al*. 1976) near the Qinghai-Xizang highway, and Margo Caka and Margai Caka in North Xizang had appeared (Huang Cixuan *et al*. 1983b). Old Tianshuihai lake could be the another example.

During the Xixabangma Glaciation of the Early Pleistocene, many small piedmont glaciers and valley glaciers developed around the high peaks of the Great Himalaya, but there were no glaciers on Kunlun mountains because they were lower than the Himalaya (Zheng *et al*. 1981). Based on recent research, it is not plausible that glaciers developed in the Early Pleistocen in the Kunlun Shankou region (Li 1986).

At the beginning of the Middle Pleistocene, the West Kunlun mountains arose again. During the Kunlun Glaciation, on the south slope many large piedmont glaciers and flat-topped glaciers joined together from the upper section of Quanshuigou River to Guliya Pass. It was 2 times larger than today. The melt water of glaciers in this region flowed into the ancient Tianshuihai Lake through Gozha Co and the Aksayqin valley.

In the late middle Pleistocene - the great interglacial - the height of the Tianshuihai region was about 2500-3000 m, and a warm-humid environment growing *Pecia* and *Abies* on the slope and *Pinus* and *Betula* on the piedmont plain occurred. Estimated annual precipitation was about 1000-1500 mm and the mean annual temperature was 18°C warmer than today.

At the end of the Middle Pleistocene and the beginning of the Late Pleistocene, the neotectonic movement was very strong. The Great Himalaya had arisen over 5000 m a.s.l., forming a barrier to the incursion of the South Asian monsoon. The precipitation decreased in the extensive inner part of Qinghai-Xizang Plateau, so that the glacial development was restrained. But the main range of West Kunlun is higher and wider, its alpine zone could intercept much more vapour from the westerlies, and the glacier was still large there. During the Quanshuigou Glaciation, the ancient Zhongfen Glacier and Chongce Glacier were 34 km and 36 km long respectively, about 11 km and 8 km longer than today.

In the middle late Pleistocene - the last interglacial, there was a warm semi-humid with forest-steppe environment in North Xizang (Huang *et al*. 1983a)

During the last glaciation, Zhongfen Glacier was 29 km long in 1615±553 C^{14} yr. B.P., about 6 km longer than today. But the Chongce Ice Cap was about 1 km longer than today before the 21000 years. At that time there was a cold dry steppe environment in North Xizang. In the Chagcam Caka (Lake III) region *Artemisia* and *Chenopodiaceae* grew in 15400± 160 ---20000±350 C^{14} yr. B.P. and permafrost formed on the Qiang Tang Plateau.

In the Hypsithermal period of the Holocene, due warm climate these glaciers retreated slowly.

In 2,700 years ago, Neoglacial glacier advance occurred, and the glaciers were 200-1000 m longer than today, but they varied within a narrow range. Recently, although many glaciers still are retreating some glaciers have readvanced since the 1970's.

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Table 3. Paleogeographic environment of Pliocene and Quaternary on southern slope of West Kunlun

Time	Glacial & interglacial	Landform and sediments	Natural environment	Glacier feature	Elevation (m)
Htlocene (Q4)	Modern	Glaciers over 20 km in length, snowline from 5800 m to 5900 m	Cold montane desert steppe, cold and dry	Valley glacier ice caps	5000
	17-19th Little Ice Age	Modern moraines	Cond montane desert steppe, cold and dry		
Late Pleistocene (Q3)	Neoglaciation	Third end moraine (2720±85 C^{14} yr. Bp.) outside the Chongce flat topped glacier	Bush-steppe, warm and cool semi-arid	Glacier advance	
	Hypsithermal	The tills with caliche formed during the climatic optimum	Cold montane disert steppe, turn into warmer, semi-arid	Glacier retreat	
	Last glaciation (Binshuigou)	End moraine at 5300 m a. s. l. (16151±553 C^{14} yr. Bp.) in Litian valley	Cold montane desert steppe, cold and dry	Valley glacier piedmont glacier	4500
	Last interglacial	High lake shore of Aksayqin Lake	Steppe, warm and semi-humid		
Middle Pleistocene (Q2)	Quanshuigou	High lateral moraines in Litian valley, the platform moraine (5400−5800 m a. s. l.) outside the Chongce flat topped glacier	Steppe, cold and semi-humid	Great valley glacier middle piedmont glacier	4000
	Great interglacial	Old lacustrine sediments (upper) in Tianshuihai region, Ancient brown-yellew soil on the high platform moraine	Mixed forest of coniferous and broad leaf trees, brovn-yellow soil, warm and humid		2500−3000
	Kunlun	The two old till belts on the mountain top peneplane on the West of Litian valley, the high platform moraine cut by fluvial on the north of the Gozha Co	Steppe, cold and humid	Great piedmont glacier	
Early Pleistocene (Q1)		Older lacustrine sediments (lower) in Tianshuihai region	Forest of coniferous, warm and humid Steppe, cold and humid (in Kunlun Shankou)		2000

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