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Quaternary Lake Deposits of Nam Co, Tibet, with a Discussion of the Connection of Nam Co with Ring Co-Jiuru Co

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Abstract Shorelines are widespread and lake deposits and lake geomorphology are well developed on the northern Tibetan Plateau. Through field observations of lacustrine deposits of Nam Co—the highest and largest Quaternary lake in Tibet, the authors found four-step shore terraces composed of sands and clays with well-developed horizontal bedding and 3–12 m, 15–22 m, 25–30 m and 35–45 m higher than the lake surface respectively, lacustrine deposits resting on the bedrocks and 60–150 m higher than the lake surface, and up to ~50 levees composed of oblate lakeshore gravels. Moreover they found lacustrine and lakeshore deposits making up the terraces and levees on the bottoms of wide dividing valleys connecting Nam Co with the Rencoyuema, Rencogongma and Jiuru Co northwest of Nam Co (the valley bottoms are 20 m, 90 m and 60 m higher than the above-mentioned three lakes) and on slopes north of it, i.e. terraces II and III of Nam Co. Thus they confirm that Nam Co and Ring Co-Jiuru Co had connected with each other several times, i.e. formed a unified large lake several times, rather than had been different lakes connected only by river channels. From indications such as the distribution of the highest shoreline and lake deposits and geomorphology, the authors conclude that the total area of the old large lakes on the northern Tibetan Plateau is a few times larger than that of the modern lakes and that the last-stage old large lakes formed in the interglacial interval of the last glaciation.

Key words: Tibet, Nam Co, Quaternary, lake deposits, old large lake

1 Introduction

Tibet has the greatest number of lakes in China, and the interior drainage area of northern Tibet has the greatest number of lakes and large lakes in Tibet. Of these lakes Nam Co (co means lake in Tibetan and Nam Co mean heavenly lake in Tibetan), located in the southeastern part of the interior drainage area, is the largest (1940 km^2 in area) and highest (4718 m above sea level).

According to observations of eroded pillars and shorelines of the old lakes and newly formed tie spits, Xu Jinzhi (1937), a famous geographer who investigated Nam Co the earliest, thought that Nam Co had risen twice in the past, but that now the lake surface is the lowest in its history.

Han Tonglin (1970) reported that at least three-step shore terraces can be recognized in Xungqên and Duojiagunba on the northwestern bank of Nam Co, which are 20 m, 40–50 m, 100 m and 40 m, 100 m and 150 m higher than the lake surface respectively. He found *Radix auricularian* Linne in terrace-III lacustrine deposits at the Xungqên section and ostracods such as *Limnocythere* sp., *Eucandona* sp. and *Cyprinotus* sp. in terrace-I deposits, and according to the fact that the highest terrace in the neighbouring area is 300–500 m above the lake surface, he inferred that the lakes in northern Tibet underwent a "pan-lake stage", with the lake waters occupying 2/3 of the area of the western part, but the paper does not mention the locality.

In the book *Geomorphology of Xizang (Tibet)* the Scientific Expedition of the Chinese Academy of Sciences to the Qinghai-Tibet Plateau (1983) reported the existence of second-step terraces (5–10 m and 20 m above the lake surface) along the banks of Nam Co and third-step terraces (the height data absent) on the Duoqiong and Duoqing domes of the Zhaxiduo Peninsula; therefore, it is considered that such small remnant lakes as Tong Co, Esuo Co and Qubucha Co on the northwestern bank of Nam Co were originally component parts of Nam Co and that some large lakes, including Nam Co and Siling Co, in the southeastern part of the Qinghai-Tibet Plateau had been connected by river channels and once been a part of the Nujiang River exterior drainage system, but no concrete data

substantiate this idea.

In the book *Rivers and Lakes of Tibet* the Scientific Expedition of the Chinese Academy of Sciences to the Qinghai-Tibet Plateau (1984) reported the existence of eight old lake levees on the northwestern and eastern banks of Nam Co, and according to the presence of eight to ten old levees for most plateau lakes it is further inferred that eight to ten relatively serious drying processes have occurred roughly since the Middle Pleistocene.

Zheng Mianping et al. (1983, 1989) made a systematic summing-up of the lakes of the Qinghai-Tibet Plateau, especially Bangkog Co, Siling Co, Chabyêr Caka, Chagcam Caka, Da Qaidam Lake and Xiao Qaidam Lake and Qarhan Playa. He held that the lake basins of the Qinghai-Tibet Plateau had experienced four stages, i.e. the Palaeogene to Miocene or Early Pliocene, Pliocene to early–mid Early Pleistocene, mid–late Early Pleistocene to early Late Pleistocene and mid–late Late Pleistocene to Holocene. Of these lakes Siling Co-Nam Co still appeared as a connected exterior drainage lake by the early–mid Late Pleistocene.

In summing up the evolution of the plateau lakes, Li Bingyuan (1998, 2000) also distinguished four stages which are largely the same as those distinguished by Zheng et al., but the data of the late Early to middle Late Pleistocene stage in the northern Tibet interior drainage area are lacking. On the basis of the distribution of the highest shorelines of 12 large lakes on the plateau he estimated the area of the lakes in the large-lake stage, which was generally a few to more than ten times larger than that of the modern plateau lakes, but these lakes were not connected with each other. According to ^{14}C dating, he suggested that the ages of these large lakes in the large lake stage are close to each other, most of which range from 40 to 25 ka B.P. and some of which might continue into 20 ka B.P.; they correspond to three deep-sea oxygen-isotopic stages and interglacial intervals of the last glaciation. He listed the comparisons of the high shorelines and water divide cols of a number of lakes between Nam Co and Siling Co and suggested that the water of Nam Co flowed into Siling Co through the Rencoyuema Lake and others during the high lake surface phase, but he did not mention anything about Nam Co—the highest large lake in Tibet—during the high lake surface phase.

Using the data of ^{14}C dating obtained recently, Zheng et al. (2000) further presented the evidence that the period of 40–28 ka B.P. of the Qinghai-Tibet Plateau was the "pan-lake stage", but they did not give any data about the Nam Co area.

We found in the field work that lake deposits and geomorphology are well developed along the banks of Nam Co, so Nam Co is an ideal area for the study of the lake evolution. Quaternary lake evolution is an important component part of plateau evolution; therefore, it has special significance in the study of global environmental change and has become one of the hot-spot problems in the study of the plateau palaeoclimate and palaeoenvironment, and its study is also an effective way for the study of climatic and environmental changes during the Recent. The key problem in the study of plateau lake evolution is the indications of major events and their ages. Therefore, the lake deposits and geomorphology in the period when the area of the lakes was largest and the lake surface was highest are direct evidence for the existence of old large lakes on the northern Tibetan Plateau and their ages and evolutionary processes are one of the problems that both the Chinese and foreign geoscience communities follow with interest.

2 Quaternary Lake Deposits and Geomorphology of Nam Co

Multi-step accumulation terraces and pedestal terraces composed of lacustrine sands and clays are distributed along the banks of Nam Co, and a few dozen levees composed of lakeshore gravels are arrayed encircling the lake (Fig. 1); in addition, there are such erosional landforms as wave-cut platforms, notches, stacks and cliffs and layered karst caves related to lake surface changes.

2.1 Shore terraces and lake deposits

Multi-step shore accumulation terraces and pedestal terraces composed of lacustrine sands and clays are distributed in the plains along the banks of Nam Co and on bedrock tops, slopes and pediments. There are four-step shore terraces, which are widespread along the lake and can be well correlated; they are 3–12 m, 15–22 m, 25–30 m and 35–45 m above the lake surface respectively. The areas where terrace IV is exposed continuously include the lower Zuoquka River plain, northern bank of the Marjiong River, northwestern slope of Tajiguri Hill, i.e. eastern bank of the lower

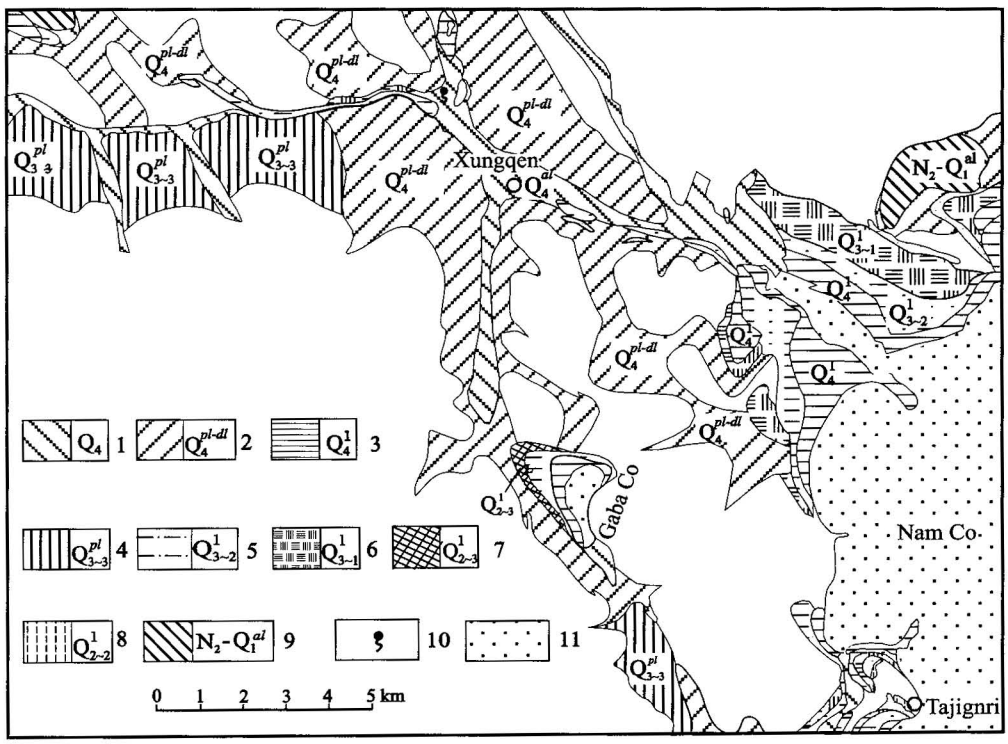

Fig. 1. Distribution of Quaternary deposits on the northwestern bank of Nam Co and in the eastern segment of the Xung Qu (Qu means river in Tibetan)-Nag Qu valley.

1. Holocene lacustrine deposits; 2. late Late Pleistocene lacustrine deposits; 3. early Late Pleistocene lacustrine deposits; 4. late Middle Pleistocene lacustrine deposits; 5. middle Middle Pleistocene lacustrine deposits; 6. Holocene alluvium; 7. Holocene diluvium and slope wash; 8. late Late Pleistocene diluvium; 9. hot spring and sinter deposits; 10. Pliocene or Early Pleistocene fluvial deposits; 11. Nam Co.

Zhalongtang River (Plate I-1), southeastern cape of the Duoma Peninsula and southern foothills of Angbeng and Angqian. The localities where terrace IV is exposed continuously are Narbang, both banks of the lower Bo Qu, southern bank of the Marjiong and Rida. Among the four-step terraces, terraces I, II and III are all accumulation terraces, while terrace IV is also an accumulation one in plains (but bedrocks are usually incompletely exposed) but is a pedestal one on slopes and pediments of bedrock hills, consisting of clearly microbedded and well-sorted sands, silts, clays, sandy loams and loams. At some localities, e.g. at terrace I on the northern bank of the Marjiong (Plate I-2), diatomaceous earth layers were found; whereas at some localities, e.g. at terrace II of the lower Bo Qu (Plate I-3), fossils containing spiralia (possibly *Radix auricularia* Linne) were seen, and many layered leaves of herbal plants (Huang and Liang, 1983) were found in such localities as terrace II of the lower reaches of the Zhalongtang River.

Besides the four-step terraces formed by complete terrace surfaces and slopes composed of lacustrine deposits, terraces V and VI 60–150 m above the lake surface (Fig. 2) were found on tops, slopes and pediments of several bedrock hills, such as Duma, Marjiong, the west slope of Tajiguri Hill (Plate I-1), Nipu, Angbeng, Angqian and Gamalong (Plate I-4), along the banks of Nam Co. These lacustrine deposits have very distinct sedimentary features: they all consist of greenish grey sands, silts, clays, sandy loams and loams with well-developed horizontal bedding and, in some cases, even clear microbedding, and now they vary in thickness from 1–2 m to 1–2 cm and become thin upwards. Usually, together with slope washes, they form small steps of varying height on bedrock slopes; therefore it is difficult to recognize their continuity and tell which step of terrace they belong to. So no detailed division is made in this paper.

2.2 Shore levees and lakeshore deposits

Resting on relatively flat lake terrace surfaces less than 40 m above lake level (all) along the banks of Nam Co are a few dozen levees composed of lakeshore gravels, of which more than ten larger levees are distributed

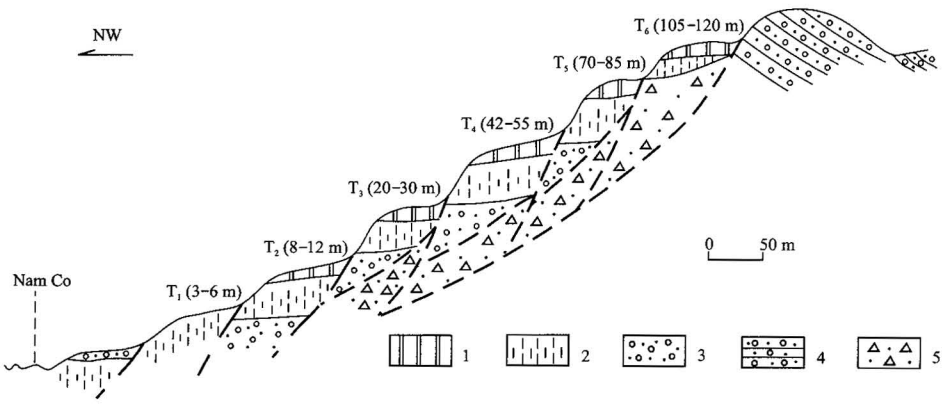

Fig. 2. Diagrammatic cross section of shore terraces at Narbang on the northwest bank of Nam Co.

1. Soil layer; 2. clay layer; 3. sand and gravel layer; 4. sandy conglomerate; 5. diluvium and slope wash.

almost all the way continuously along the lake banks. This phenomenon is well displayed on remote sensing images and may also be clearly observed in the field. According to our observation, as many as 30–50 levees may be present along the northwestern bank of Nam Co; for example, the northern bank of the Tajiguri has nearly 50 levees (Plate I-5), and the old lake bay in the lower reaches of the Zhalongtang, southern and northern banks of the Marjiong, southeastern bank of Duma and Narbang, the mouth of Xung Qu, southern bank of the Rida and lower reaches of the Zuoquka each have ~30 levees. These levees are mostly composed of oblate gravels 5–10 cm in long diameter.

Additionally, there are also a number of lake levees composed of oblate gravels along the banks of several somewhat larger but still small lakes which are separated from and encircle Nam Co, e.g. there are a few dozen levees in Co Gaba and at least over five levees in Co Anggo.

2.3 Other lake geomorphology

Along the banks of Nam Co and on its mid-lake isles, we may see a variety of erosional landforms and lake geomorphology, e.g. wave-cut platforms, stacks, notches and cliffs. They are mostly ~30 m a.l.l., forming the rear edges of terrace III. It seems that the lake surface during their formation remained stable for a relatively long period of time. On the topographic map and remote sensing images, we can also see a wave-cut cliff ~30 m above the lake surface on the southern bank of Nam Co and note that the lake waves cut glaciers and glaciofluvial deposits. The order and relative ages of the erosions still need detailed investigation.

3 Quaternary Lake Deposits and Terraces in the Xung Qu-Nag Qu Valley in Northwestern Nam Co

3.1 Lake deposits and geomorphology

The Xung Qu-Nag Qu valley in the northwestern part of Nam Co is a dividing valley connecting the Nam Co basin and Ring Co-Jiuru Co basin to its west (Fig. 1). Xung Qu and Nag Qu empty into Nam Co and Ring Co-Jiuru Co respectively. This valley is ~30 km long and 1.5–3.5 km wide, striking nearly E–W. Its eastern segment is connected with a WNW-trending valley. Near Qiugong—the divide of the valley—and its eastern and western sides, there occur Quaternary lacustrine deposits which form the top of terrace II of Nam Co and the bottom of the wide valley (Plate I-7). It has an elevation of 4378 m above sea level (a.s.l.), being 20 m higher than the lake surface of Nam Co.

From Fig. 1 we can also find that a third-step lake terrace 25 m higher than the lake surface of the modern Nam Co is preserved on the northern bank of the Qiugong divide. It also consists of typical lacustrine sands and clays and on it lies a lake levee composed of lakeshore gravels, but the gravels are less rounded, possibly because the old lake surface there was not wide enough and the action of old wind waves could not be very strong. Owing to the downcutting of the river, first-step terraces with a relative height of 1–3 m are developed in modern riverbeds in the lower reaches of Xung Qu and Nag Qu.

3.2 Other Quaternary deposits and geomorphology

Some branching creeks that empty into Xung Qu and Nag Qu on the southern side of the Xung Qu-Nag Qu valley also have their own features. In the west, diluvial fans formed by the Elong and Suobuduosa creeks after they went out of the mountain passes have been cut into alluvial platforms 5–6 m above the river surface (see

Fig. 1), and first-step terraces and floodplains 1–2 m above the creek surfaces are well developed on both sides of various creeks within the platforms. In the east, after going out of the mountain pass, Gulongmaqian gave rise to a typical diluvial fan and five branching channels on the fan, with the west branch of the westernmost channel emptying into the Nag Qu and its east branch and the rest four channels on the east into Xung Qu, and none of the five branching channels cut down the fan. The Kulongxiama and Jialong creeks farther to the east do not cut down either. It must be pointed out that all these river deposits are superimposed on terrace II of Nam Co, which is now the bottom of the valley; therefore the deposition should have occurred after the recession of the lake.

4 Evidence for the Existence of Old Large Lakes on the Northern Tibetan Plateau

Most modern lakes on the northern Tibetan Plateau are enclosed saline or brine lakes, around which are distributed lakeshore sands and gravels left over from lake recession or old shorelines formed by wave-cut cliffs or lake terraces composed of silty clay. These geological and geomorphological features are indications for reconstructing the height of the old lake surface and calculating the area of the old lakes.

During our field geological survey and mapping along Nam Co, especially on its northwestern bank, from June to August 2000, we found not only four steps of wide lake accumulation terraces or pedestal terraces 3–12 m, 15–22 m, 25–30 m and 35–45 m higher than the lake surface respectively, but also lacustrine deposits 60–150 m higher than the lake surface on several bedrock hillslopes, which possibly form terraces V and VI; besides, we also found a few tens of gravelly levees distributed around the lake. Moreover, on the northwestern and northern banks of Nam Co, we found that the dividing valley and cols connecting Nam Co with Ring Co and Jiuru Co and Nam Co with Sên Co and Bam Co are made up of deposits of second-step terraces ~ 20 m higher than Nam Co and that the third-step terrace ~25 m higher than the lake surface of Nam Co and gravelly levee resting on the terrace are preserved north of the col. In 2001 we found a lacustrine deposit layer on the divide between Nam Co and Sên Co in the field which is more than 100 m higher than the present surface of Nam Co. This indisputably proves that Nam Co (its surface is 4718 m a.s.l.) and Ring Co (including the Rencoyuema with a surface elevation of 4648 m a.s.l. and Rencogongma with a surface elevation of 4650 m a.s.l., which are separated by a shore levee but are connected by a small creek) and Jiuru Co (which has a surface elevation of 4678 m a.s.l. and is connected with Ring Co by a creek), whose surfaces are 70 m and 40 m lower than that of Nam Co respectively, as well as Sên Co and Bam Co (4555 m) had been actually connected with each other several times during the accumulation of the third- and second-step shore terraces, i.e. these lakes had several times combined to form a unified large lake rather than had been different lakes connected by river channels.

On the basis of an integrated analysis of over 200 1 : 100000-scale and over 20 1 : 250000-scale topographic maps and remote sensing images of northern Tibet, we have found that the topographic-geomorphologic and remote sensing image features of the dividing valley between Siling Co and Ring Co, Jiuru Co and Bam Co and that between the Zhari Namco and Xuru Co and Lagkor Co are essentially consistent with those of the dividing valley between Nam Co and Ring Co, Jiuru Co, Sên Co and Bam Co known in the field, so it may be inferred that they are also composed of shore terrace deposits, but it remains to be verified in the field.

As stated above, Nam Co is the highest large lake in the southern part of the interior drainage area of the northern Tibetan Plateau. It and other large lakes such as Siling Co are separately connected with other lakes by wide valleys and the elevations (a.s.l.) of the dividing cols within these wide valleys are all lower than the height, 4850–4870 m a.s.l., of the old lake surface of Nam Co; therefore we infer that in some phases of the Mid–Late Pleistocene the several extant large lakes in the southern part of the northern Tibetan Plateau, including Nam Co, Siling Co, Zhari Nam Co, Xuru Co and Tangra Yumco, and large numbers of their neighbouring medium-sized and small lakes were not connected only by rivers but joined several times to form one or two unified lakes, each covering an area of 30000–50000 km^2 or more, with a total area of 70000–90000 km^2. The one or two old large lakes that had existed several times are called by us the "old Qiangtang Lake" or "old East Qiangtang Lake" (Table 1) and "old West Qiangtang Lake" (Table 1). The old large lake(s) then receded and was disintegrated with

the uplift and climatic deterioration of the Qinghai-Tibet Plateau and gradually evolved into the present one.

5 Relations of the Combination and Separation of Nam Co and Ring Co-Jiuru Co with Old Large Lakes of the Northern Tibetan Plateau

As we have found the distribution of lacustrine deposits up to 130–150 m higher than the modern lake surface along Nam Co, and the dividing valleys between Nam Co and Sên Co and Bam Co north of it and between Nam Co and Jiuru Co and Ring Co west of it are only 85 m and 20 m higher than Nam Co respectively and lacustrine layers were found there, we have reasons to infer that Nam Co was connected with Sên Co and Bam Co north of it and with the Jiuru Co and Ring Co west of it in the geological past. But at what time they were connected is a scientific problem that needs to be seriously proved.

In the field we found lake deposits and shore terraces in the divide place of the Xung Qu-Nag Qu valley connecting Nam Co with Ring Co-Jiu Co west of Nam Co and confirmed that Nam Co and the Jiuru Co and Ring Co west of it were actually large lakes connecting with each other during the formation of terraces III and IV of Nam Co, and the wide dividing valley (8 km in width) between Ring Co and Mujiu Co (there are rivers flowing into the Co Ngoin in Siling Co basin) west of it has an elevation of merely 4700 m a.s.l., only less than 50 m (4650 a.s.l.) higher than the Rencogongma. Therefore we have reasons to postulate that Nam Co and Siling Co had connected into a single large lake during the phases of formation of terraces III and II of Nam Co, rather than were two lakes connected only by rivers. Additionally, lacustrine strata 4700–4800 m a.s.l. (now the elevation of the divide of the interior and exterior drainage areas is 4695 m a.s.l.) have also been found in the Jiuro Co-Ring Co divide, Nam Co-Sên Co divide, southern Nag Qu and western Amdo, which further proves the existence of old large lakes on the northern Tibetan Plateau.

The above-mentioned two phases and the phases of accumulation of terrace IV deposits and still higher lake deposits of Nam Co were the few high lake surface stages of old large lake development in the northern Tibetan Plateau. In the highest lake surface stage, Nam Co was connected with Sên Co and most old large lakes in the southeastern part of the northern Tibetan Plateau, e.g. the old Siling Co, old Gyaring Co, old Uru Co, old Dagzê Co and old Ngangzê; these old lakes are generally referred to as the "old East Qiangtang Lake". Likewise, the old Tangra Yumco, old Zhari Nam Co, old Taro Co, old Chabyêr Co and old Dong Co in the southwestern part of the northern Tibet Plateau were also connected then, called the "old West Qiangtang Lake". Even in a particular interval, were the "old East Qiangtang Lake" and "old West Qiangtang Lake" once connected with each other, forming the real "old Qiangtang Lake" (Fig. 3).

The "pan-lake stage" or "large lake stage" occurring in the interglacial interval (40–28 or 40–25 ka B.P.) of the last glaciation proposed by Zheng Mianping (1989, 2000) and Li Bingyuan (2000) is only the last development stage before the disintegration of the "old Qiangtang Lake" in its evolution, and the areal extent and lake surface height of the old lake were greatly reduced as compared with that in its preceding stages, especially in the stage when the lake covered the largest area. The age, distribution, surface height and environment of the old Qiangtang Lake in the period with the largest extent and highest lake surface are just the prime objects of research for our next step. The age of the last large lake phase is most likely to have taken place in the interglacial interval (40–28 or 40–25 ka B.P.) of the last glaciation as viewed from the second-step lake terrace and its overlying river deposits deposited from the branches to its south and geomorphological features, as well as the features of

Table 1 Main features of the old East and West Qiangtang lakes on the northern Tibet Plateau

Old lake	Location			Main modern lakes and their elevations (m a.s.l.)	Surface elevation (m a.s.l.) of highest lake surface	Area (km^2) of lake surface during old lake phase
	Region	Lat.°N	Long.°E			
East Qiangtang Lake	SE Qiangtang Plateau	30.4 – 33.8	85.4 – 91.8	Siling Co (45307 m), Nam Co (4718 m), Bangkog Co, Pongcê Co, Yagedong Co, Gyaring Co, Bam Co (4555 m), Sên Co, Ring Co	4868	~50000
West Qiangtang Lake	SW Qiangtang Plateau	30.2 – 33.5	83.0 – 87.2	Zhari Nam Co (4613 m), Tangra Yumco (4535 m), Xuru Co (4714 m), Ngangzê Co (4683 m), Lagkor Co, Taro Co, Ngangla Ringco	4864	~30000

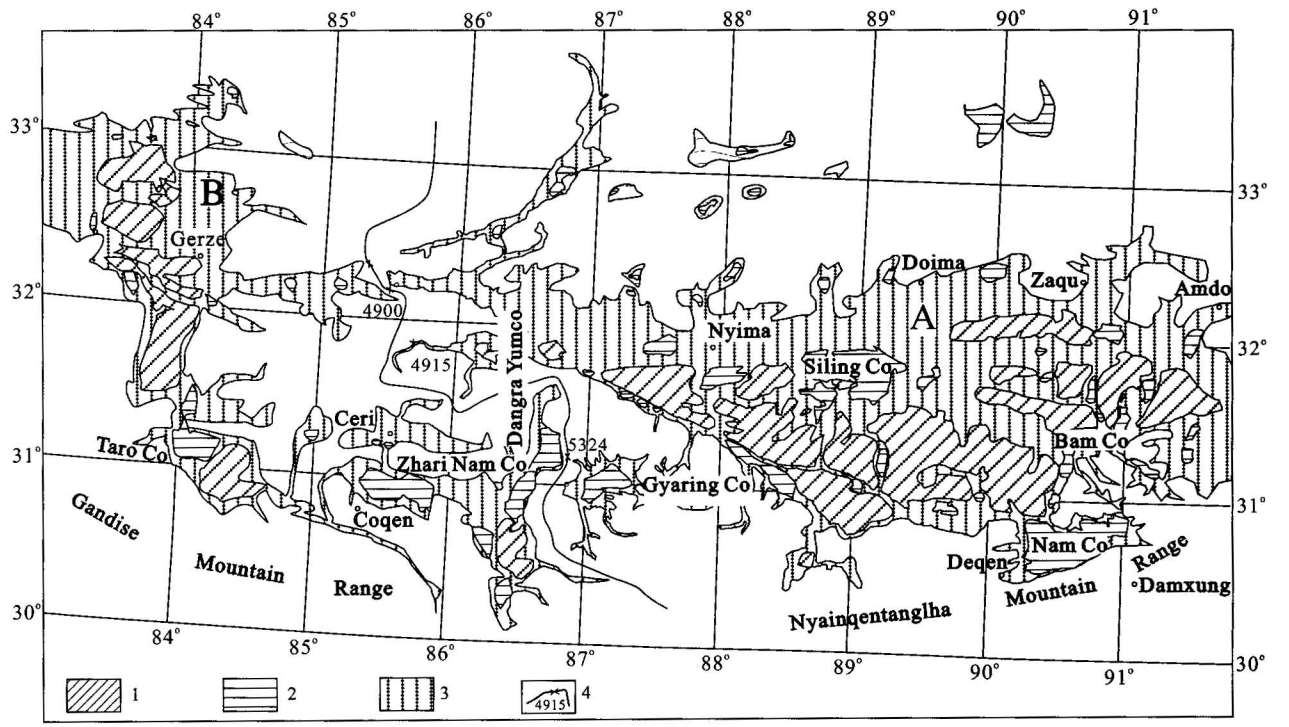

Fig. 3. Diagrammatic map of the "old Qiangtang Lake" on the northern Tibetan Plateau.

A. Old East Qiangtang Lake; B. old West Qiangtang Lake.
1. Islands in the old lake; 2. modern lake; 3. extent of the old lake; 4. divide.

tills discovered on the 30 m high lake terrace in the intersection between the southeastern bank of Nam Co and the northwestern slope of the Nyainqêntanglha Mountains. But this also needs further verification.

Acknowledgements

This research represents the stage results of the large-scale land and resources survey project "Investigation of the Quaternary Environmental Evolution of the Nam Co area in Tibet" (No. DKD2001006) and "1 : 250000 Regional Geological Survey of Damxung" (No. DKD9901001) carried out by the Chinese Academy of Geological Sciences. We are grateful to Wang Baosheng, director of the Tibetan Bureau of Land and Resources; Yang Chaobin, chief engineer of the Bureau, Ping Cuo, director of the Training Centre of the Tibetan Bureau of Geology and Mineral Exploration and Development, Li Quanwen, responsible person of the Lhasa Work Station of Safety and Security, China Geological Survey and Wang Jianping, leader of the Regional Geological Party, Henan Bureau of Geology and Mineral Exploration and Development for their warm help and full support during our field work and to all the members of the project group of 1 : 250000 mapping of the Damxung Sheet, Institute of Geomechanics, for their great assistance in the research.

Chinese manuscript received Sept. 2001
accepted Jan. 2002
edited by Wang Zengji
translated by Fei Zhenbi
English manuscript edited by Liu Xinzhu

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Explanation of Plate I

1. Terrace IV composed of sands and clays and lacustrine deposits resting on the Cretaceous limestone slope and 60–150 m higher than the lake surface on the western bank of Nam Co, on the south slope of Tajiguri Hill.
2. Terrace I of Nam Co composed of sands and clays in the lower part and diatomaceous earth in the upper part, on the north bank of Marjiong.
3. Terrace II of Nam Co, on the north bank of the lower reaches of the Bo Qu. The lower part consists of lacustrine sands and clays with well developed horizontal bedding, > 2m in outcrop thickness; the middle part is composed of shallow-lake coarse sands and gravels, containing complete shells of spiralia (possibly *Radix auricularian* Linne) and honeycomb-shaped nodules, 0.3–0.4 m thick; the upper part is a shore gravel bed, 1–1.2 m thick, forming a shore levee.
4. Lacustrine sediments 60–150 m higher than the lake surface on the northeastern bank of Nam Co, Ganmalong.
5. Up to 50 shore gravelly levees on the western bank of Nam Co, and on the northern slope the Tajiguri Hill.
6. Oblate gravels forming the shore levee at the Duoma cape.
7. Terraces II and III of Nam Co near Qiugong, the divide of the dividing valley of Nam Co and Ring Co—Xung Qu-Nag Qu valley. Terrace III is composed of lacustrine sands and clays, overlain by lakeshore gravels. The flat lowland of the valley bottom with grass on the right side is the top of terrace II forming the divide.

(All the photos were taken by Zhao Xitao except Photo 4 by Wu Zhenhan).

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Plate I