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Greatest lake period〃 and its palaeo-environment on the Tibetan Plateau

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Abstract: The ¨greatest lake period〃 means that the lakes are in the stage of their maximum areas. As the paleo lake shorelines are widely distributed in the lake basins on the Tibetan Plateau, the lake areas during the ¨greatest lake period〃 ?may be inferred by the last highest lake shorelines. They are several, even tens times larger than that at present. According to the analyses of tens of lakes on the Plateau, most dating data fell into the range of 40-25 ka BP, some lasted to 20 ka BP. It was corresponded to the stage 3 of marine isotope and interstitial of last glaciation. The occurrence of maximum areas of lakes marked the very humid period on the Plateau and was also related to the stronger summer monsoon during that period.

"Greatest lake period〃 and its palaeo-environment on the Tibetan Plateau LI Bing-yuan, ZHU Li-ping (Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China) The Tibetan Plateau is the biggest lake distribution area in China, in which lake evolution is one of the important compositions for plateau environmental changes. It is also very significant in the study of regional environmental evolution. To answer the questions that how and when the paleo lakes evolved, the indicators and their dating data of the important events must be identified. As the key items for detecting the past environment, they are also the most concerned problems in geo-sciences. 1 Evidences of ¨greatest lake period〃 Most of the lakes on the Tibetan Plateau are closed saline lakes and salt lakes, around which the paleo lake shorelines and lake plain or lake terraces are widely distributed. The paleo lake shorelines composed of sand-gravel or lake eroded cliffs and lake plain/terraces composed of silt or clay are relics during the processes of lake shrinkage, based upon which the paleo lake level height and lake area may be inferred. The paleo lake shorelines are usually distributed in parallel and concentric circle form with obvious landform features, and easily distinguished from field investigations, aerial photos even satellite images. Though the uprising of lake levels may destroy the lake shorelines left during former period, the highest paleo lake shoreline which marked the maximum water body in the lake was still preserved. There must be multi-times maximum water body period in the processes of the lake˘s evolution because the Tibetan Plateau had ever experienced multi-times cycles of tectonic movements and climatic changes. However, the relics of maximum lake water body in the early stages had been destroyed by the later tectonic movement and denudation. Thus, this paper only discussed the evidences and period of the last highest lake level, which we called the ¨greatest lake period.〃 Table 1 Main features of part of lakes on the Tibetan Plateau in the ¨greatest lake period〃 The paleo lake shorelines are widely distributed in the lake basins on the Tibetan Plateau. For example, there are more than 70 paleo lake shorelines in the Lungmu Co (Lake) basin which is situated at the northern foot of east Karakorum Mountains. These paleo shorelines are distributed in concentric circle form, in which the highest one is 5160 m asl, 160 m and 110 m above the present lake level of Lungmu Co and Sumxi Co, respectively. According to the highest paleo lake shoreline, the paleo Lungmu Co had included the present Lungmu Co, Sumxi Co and Mang Co during the ¨greatest lake period〃, of which the area reached 635 km2 and was 4.5 times larger than that at present. This is only one case on the Tibetan Plateau. Due to the regional differentiation of climatic environment and lake landform, the height of lake levels and the size of lakes were also different in the ¨greatest lake period.〃 Generally, the area of paleo lakes were larger and the relative height of paleo lake levels were higher in the middle and western part of Qiangtang Plateau while they were smaller and lower in northeastern Qiangtang and southern Tibet. In the eastern and southern parts of the Plateau, they were much smaller and lower (Table 1, Figure 1). Figur e 1 Distribution of the lakes in ¨greatest lake period〃 and present lakes on the Tibetan Plateau 2 Age of the ¨gre atest lake period〃 The ages of the ¨greatest lake period〃 were usually to be inferred based upon lake sediments a s it is difficult to find suitable dating materials on paleo lake terraces. Based upon this method, some researchers held that it should be in the early-middle Pleistocene[1,2]. Although lake sediments dating have made certain progres s, bifurcation still existed in determining the stage of the highest lake levels. Some thought that it was in the int erstitial of last glaciation, some thought in Holocene or early-middle Pleistocene. However, no definite conclusions have been made to the question that if the same ¨greatest lake period〃 existed among the lakes of the whole Tibeta n Plateau, then what exact time it would be. Thus, we selected some lakes which are distributed in different areas an d also have dating data to do analyses for discussing the evidence and age of the ¨greatest lake period〃 on the Tib etan Plateau. 2.1 The paleo Tianshuihai lake Some 30 samples were collected at the 13 sections in modern Tianshuihai and Tianshuihai North lakes which were in the middle part of the paleo lake basin. The 14C dating of the sediments wh ich were distributed in 0-2 m under the ground surface had concentrated to 2 stages (Figure 2). The sediments with ol der dating data may be found at the lake terrace with 4,840 m asl in the west of Tianshuihai army service station whe re a lake core (SI1) of 15 m deep had been drilled. At the site of 80 cm below the surface, 2 samples were collected and tested to be 46,850?2,970[6] and >40,045 a BP by 14C method. They were composed of deep lake facies clay and belo nged to the synchronous deposits with different faces compared with that at the highest lake shoreline which is only 20 m discrepant in height to the sampling sites. The 14C dating of other samples fell into the range of 15.5-18 ka B P except 13,960?266 and 7,430?210 a BP derived from the two samples collected at Tianshuihai and Tianshuihai North La ke bank. These sediments were shallow lake facies mudy silt alternated by remnant of much aquatic grass and formed th e younger lacustrine plain. They were production during period of lake˘s regression. These data reflected two develo pment stages of the paleo lakes. In addition, according to the ostracoda materials from TS95 core which was 1 km sout h to Tianshuihai army service station, the lake water was fresh before about 25 ka BP, and from fresh to light salin e during 25-22 ka BP, then sharply changed to be saline. Thus, it may be inferred that the paleo high lake level peri od started from 45 ka BP and lasted to 25-22 ka BP. 2.2 The paleo Bangdag Co Similar to the paleo Tianshuihai lake, t his lake was also situated on the southern flank of west Kunlun Mountains. It had been thought that the highest lake terrace of this lake was over 100 m above present lake level. The fourth terrace (T4) and the other lower ones were a ccumulation terraces while those higher above T4 were regarded as destructional terraces. Both kinds of terraces had been divided by faults. The 14C dating data were 15,880∮115 a BP and 15,900∮120 a BP, respectively by testing two g rayer samples at 0.3 m and 0.7 m under the surface on the terrace which is 3 m above present lake level. Thus, it wa s inferred that this accumulation terrace was formed in late Pleistocene and the upper destructional terraces in earl y-middle Pleistocene[6]. However, according to field observations and analyses of aerial photos, the paleo lake bank s of this lake were mostly composed of accumulation materials except a few eroded bedrocks in some local areas. Even the highest lake shoreline which was located in the northern part of the lake basin and was 110 m above present lake level was composed of gravels with good psephicity. In the southern part of the lake, the height of the highest lake shoreline was similar to that in the northern part. Thus, there were no distribution rules that the upper part was de structional terraces and the lower part was accumulation ones. In addition, no clear evidence supported that they wer e divided by faults. Another 14C dating was 15938∮126 a BP by testing a sample at 1-1.5 m under the surface on the l ake terrace which was 40 m above present lake level. This was similar to those two data mentioned above. Therefore, t he evolution of the paleo Bangdag Co was the same as that of the paleo Tianshuihai lake, e.g. the intensive regressio n of the lake occurred since 16 ka BP and the age of the highest lake level was coincided to that of the paleo Tiansh uihai lake. 2.3 The paleo Lungmu Co Some 30 14C dating data had been obtained in this paleo lake basin, in which 21 d ata were from samples at the terraces with heights of 95-12 m above present lake level. Except some individual ones, data from French laboratories were 7.0-8.0 ka BP while those from Chinese research units (Institute of Geographic Sci ences and Natural Resources Research, CAS and Nanjing University) were 11-12 ka BP. There was nearly 4 ka difference between them. Based upon the dating data, French scholars thought that the highest lake level of Lungmu Co occurred i n early-middle Holocene, e.g. 7.5-6 ka BP[5, 11]. However, we thought that it could only be sub-highest lake level a s the sampling site was below the watershed pass of Lungmu-Sumxi Co (about 5,100 m asl and 100 m above present Lungm u Co level). It is incorrect to consider this period as that of the united big lake which may be marked by the highes t lake shoreline of 5,160 m asl. In addition, in terms of the variations of carbonate salt in the core of Sumxi Co si nce 13 ka BP, the content of carbonate salt varied from 35%-45% in Holocene while they were less than 20 % between 1 3-10 ka BP, even no gypsum appeared[10]. It may be inferred that the lake water in paleo Lungmu Co between 13-10 ka B P was slightly fresh and the lake level was higher than that in Holocene. This is coincided to the data from Chinese scholars mentioned above that the lake regressed since 11-12 ka BP. Based upon this dating data and the general arid tendency since late Pleistocene on the Plateau, a rough calculation was made that the descending rate of Lungmu Co level was 6.5 m/ka since 11 ka BP, two times of that in Sumxi Co. Thus, the separated ages of these two lakes were about 15 ka BP and 14 ka BP, respectively while the highest lake level stage of Lungmu Co was 30-25 ka BP[3]. 2.4 The paleo Bangong Co The paleo highest lake shore in the east bank of this lake was composed of gray sand, in which a few whelk shells were found and 39 ka BP was dated by 14C while 46 ka BP by Th-U[12]. Another lacustrine profile in Tagutuqiong which was located about 30 km to the east of Bangong Co and between Kayi Co and Changmu Co was also analyzed. The 14C dating was 40,602?3,320 a BP from the plant remnants in the lower section of the profile while it was 25,560?674 a BP from potamogeton in the upper section. The analyses of ostracoda showed that the supplying water was gradually decreased after 29 ka BP[13]. Therefore, it may be inferred that the highest lake level of Bangong Co should occur between 40-29 ka BP[11]. 2.5 The paleo Qarhan lake The paleo Qarhan lake was situated in the Qaidam Basin (36.9?N, 95.3?E). The dating data determined by shells in the paleo lake shore, which were situated in the east of the Qarhan lake, were between 38,600∮680 a BP and 28,650∮670 a BP[4]. During that period, the lake water was fresh-light saline, which was reflected by the records of the microfossils of lamelibranch, pleopod and ostracoda. This at least proved that there existed a paleo Qarhan lake with larger size, higher level and much fresh water during 38-28 ka BP. According to the geo-chemical analyses of the CK1-81 core in this lake basin, the evaporation rock only appeared after 25 ka BP. Thus, it was thought that the period of the biggest lake might be traced back to 50 ka BP[7]. 2.6 The paleo Qinghai lake No representative paleo lake shoreline was found around the Qinghai lake. The lake shore facies were sand-gravels, which were 161, 141 and 120 m above present lake level[8, 14, 15] at the mountain foot in the southern part of the lake basin, were considered as the highest lake shore and formed 12 ka BP. But there were different opinions about this issue. According to the lake core composition, the river facies silt had ever arrived at the lake centre which was in the south-west part during 12.5-11.8 ka BP[16]. Thus, some thought that the lake level in that period was lower than the present level. However, some scholars, based upon the paleo lake salinity variations, thought that these high shorelines were not formed absolutely during the post-glaciation period. Some others thought that the highest shoreline did not occur in Holocene based upon the dating (14.8 ka BP and 11 ka BP) of loess on the platform which was 14 m above present lake level[8]. By comparison with the adjacent areas, it was inferred that the period of highest lake level of the paleo Qinghai lake may be corresponded to that of the formation of shell bank in Qaidam Basin (about 38 ka BP)[8]. According to the composition of Erlangjian section in this lake basin, an opinion was drawn that the lake was enlarged and deepened during 33,800?370-23,640?250 a BP[8]. As an integration, and combined with the other Quaternary sediments around the Qinghai lake, it was relatively credible that the highest lake level was around 40 ka BP. 2.7 The paleo Chabyer Caka According to 24 14C dating data from different sampling sites with varying elevations in this lake basin, Zheng Mianping thought that the highest lake shoreline was formed 27.5 ka BP, when the lake was still an exorheic fresh water lake. It was closed around 25 ka BP[4]. The same conclusion had been made that the highest lake level occurred before 29 ka BP (may trace back to 40 ka BP) based upon the systematic analyses of the sediments from ZK 91-2 core. The climate in this area tended to be desiccating after 22 ka BP[17]. 2.8 The paleo Serling Co and the lakes in east Qiangtang The highest lake shoreline in the Serling Co basin was 100 m above present lake level. This was thought to form around 30 ka BP, after which the paleo Serling Co was disjoined into Pangkog Co and present Serling Co. The former one evolved to be a saline lake around 18 ka BP[8]. There was no clear regression relic in the lake basins which were distributed in the Hoh Xil region, northeast Qiangtang. The highest lake shorelines, which were composed of sand-gravels, were only 2-10 m above present lake levels. For examples, the relative height was 8.5 m in the east of Wulanwula lake, 5 m in the south of Mingjing lake (bright mirror), 6 m in the southwest of Taiyang lake (sun), 4.5 m in the north of Kekao lake, 4 m in the east of Hoh Xil lake and 2-3 m in the east of Choinai lake. These lakes were mostly closed in the end of late Pleistocene according to the analyses of the landforms, sediments and a few 14C dating data[18]. 2.9 The paleo lake group in south Tibet To the lakes which were distributed to the south of the Gangdise Range, there was no ring paleo lake shorelines as representative as that in the middle and northern part of the Plateau. The paleo lake shorelines were mostly in dispersed distribution and lower in relative height. Among them, the highest relative height was 90 m and existed in the Chuocolong Co. The others were 80 m, 30 m and 10 m in the Baiku Co, Nariyong Co and Yamzhog Yumco. All of them were ever outflowing lakes during the highest lake level period[1,19] and closed later. For example, the Yamzhog Yumco was closed after the formation of the terrace which was 10 m above present lake level (14C dating was 3 ka BP)[19]. The 14C dating data from the sedimentary samples on the terraces of the lakes in southern Tibet were almost less than 10 ka BP. 3 The environment of ¨greatest lake period〃 and the paleo monsoon According to the analyses mentioned above, the event of the highest lake level ha

d generally occurred in the northwest, northeast and interior of the Tibetan Plateau. The periods of the highest lake level were difficult to be directly obtained. Most of them were inferred based upon the dating data derived from the lower sediments and the other environmental proxies. Though these data were not quite accorded with each other, they still ranged between 40 and 25 ka BP. This was just the period when the lakes reached their maximum size of the last time, e.g. the ¨greatest lake period.〃 There were also differences to the stages of the formation and disjointing of the greatest lakes. The earliest may reach 50 ka BP and the latest lasted to 30 ka BP even 20 ka BP. The terminating time of the highest lake levels were approximately 25 ka BP in northern Tibet and the middle-western Qiangtang, while those of south-east Tibet were mostly in Holocene due to the later closed time. This difference, to some degree, reflected regional precipitation variation which was influenced by the monsoon. The summer monsoon retreated from the middle and western part of Qiangtang earlier, and from the southern and eastern part of the Plateau much later. It had made the time difference to the desiccating development in different regions. The lake landform evolution and the closing degree also influenced the closing period of the lake. To the opened lakes with flat bottom and shallow water, climatic change between the ¨greatest lake period〃 and the others had only been reflected in the outflowing water quantities, and less obvious lake level fluctuation. By comparison with the global change, the ¨greatest lake period〃 was corresponded to marine isotope 180 stage 3 (MIS 3) and the interstitial stage of the last glaciation. At that stage, many of lakes were outflowing lakes with larger area and more fresh water, the area ratio of ancient and present lake even reach 13 times. The Lake Areas and lake level heights in the ¨greatest lake period〃 were much larger and higher than those of the warmest period in the Holocene were. The occurrence of the ¨greatest lake period〃 showed that the precipitation was much abundant during the last interstitial stage on the Tibetan Plateau. The pollen records of the sediments and the ?180 records of the ice core also documented this. In the Tagutuqiong section which was situated at the east of the Bangong Co, the northwest Tibet, pollens which were much richer in species and much more in quantity had reflected a warmer environment during 36-28 ka BP[20]. In another section situated at the Qinghai lake basin, the pollen species of arbor and middle herbage had obviously increased[21]. From the Guliya ice core records, it was around 35 ka BP that the climate was the warmest and the temperature was inferred to be 4?C higher than that at present[22]. There also appeared larger area freshwater lake in Tengger Desert which was situated to the north of the Tibetan Plateau. The high lake level was 30 m above that at present level during 39-23 ka BP[23]. These evidences showed that the climatic environment on the Tibetan Plateau in this stage was different to that in Antarctica and Greenland. The humid degree and the covered range were near or the same to those in the interstitial. In addition, the features of the ¨greatest lake period〃 had also reflection in the southeastern part of the Plateau and northern China[24]. Thus, it was quite affirmed that the precipitation was increased during the 3-stage deep-sea SPECMAP ?180 stages, but we need more data to discuss the temperature fluctuation[20]. As the elevation of the Plateau had been near the present height around 30 ka BP, it was impossible to contribute the climatic changes to the Plateau uplifting. The only explanation was that the much stronger summer monsoon had influenced most part of the Plateau, even to the inland of Northwest China. The Asian summer monsoon was quite susceptive to the difference of incident radiation derived from the earth orbit changing[25]. According to a calculated result from A. Berger[26], it was only in the period of 35-30 ka BP that the incident radiation in the region between 50?N-30?S was higher than that in the high latitude area. The increased incident radiation had extremely strengthened the Plateau˘s effect of heat source, resulting in enhancement of warm low pressure and traction of warm and humid summer monsoon coming from the Indian Ocean [27]. In addition, influenced by the increasing of Australia cold high pressure in the winter, the strong Australia high pressure may cross the equator and strengthen the Asia summer monsoon[28]. Under the action of the strong Australia high pressure and the incident radiation, the tropical ocean surface temperature rose and induced much evaporation. This produced a large amount of moisture source for the increased summer monsoon which might reach the Tibetan Plateau and its adjacent areas. It made the Tibetan Plateau a more special area than the others on Earth during the last interstitial stage (40-25 ka BP), and the ¨greatest lake period〃 appeared. References

关键词： Tibetan Plateau; greatest lake period; highest lake levels; interstitial of last glaciation; paleo-monsoon