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LAST GLACIATION AND MAXIMUM GLACIATION IN THE QINGHAI–XIZANG (TIBET) PLATEAU: A CONTROVERSY TO M. KUHLE'S ICE SHEET HYPOTHESIS

Shi Yafeng (施雅风) Zheng Benxing (郑本兴) Li Shijie (李士杰)
(Lanzhou Institute of Glaciology and Geocryology, CAS, Lanzhou 730000, PRC)

ABSTRACT: Since the late 1950's, many Chinese scientists have explored the remains of the Quaternary glaciation in the Qinghai–Xizang (Tibet) Plateau and its surrounding mountains. In the main, 3–4 glaciations have been recognized. The largest one occurred in the Late Middle Pleistocene with piedmont glaciers, ice caps and trellis valley glaciers in many high peak regions. But here is no evidence of a unified ice sheet covering the whole plateau as described by M. Kuhle. Due to the further uplifting of the Himalayas and Qinghai–Xizang Plateau the climate became progressively drier, diminishing the extension of glaciers during the Late Pleistocene. The elevation of the snow line during the Last Glaciation was about 4,000 m on the south, east and northeast edges of the plateau and ascended to 5500 m on the hinder northwest of the plateau. The thermal effect of the big plateau massif, the sharp increase of aridity from the southeast rim to the northwest inland area and the abrupt decrease of precipitation during the Ice Age largely account for the distribution of the Quaternary glaciers in the Qinghai–Xizang Plateau. The neglect of Chinese literature may be one of the causes accounting for M. Kuhle's misinterpretation on the environment of the Quaternary glaciations in the Qinghai–Xizang Plateau.

KEY WORDS: Quaternary glaciation, dispersed mountain glaciers, the Qinghai–Xizang Plateau

I. INTRODUCTION

Since the late 1950s, Chinese scientists in glaciology, geomorphology and Quaternary geology have made extensive investigations on existing glaciers and Quaternary glaciation in the Qinghai–Xizang Plateau (Fig.1), from which over 200 papers have been published to

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describe Quaternary glaciations in west China, especially in the Qinghai–Xizang Plateau. These scientists all negated the hypothesis by E. Huntington[1], E. Trinkler[2], V. M. Sinitsun[3] that there was a continuous ice sheet covering the whole plateau, but agreed with the idea proposed by Sven Hedin[4–5] and H. von Wissmann[6] that, although there were more extensive glaciers during the Pleistocene characterized by ice caps, trellis valley glaciers and piedmont glaciers, they were not connected to each other to form a unified ice sheet. The unique arid climatic condition in the inland parts of the plateau and intensive uplift of the plateau and its surrounding areas account for some particular features of glacier development in the plateau. M. Kuhle[7–10] surprisingly brought up again the idea that there was a unified ice sheet during the Pleistocene in the plateau. For most Chinese scientists, this hypothesis is not acceptable. This paper gives a brief outline of the ideas of some Chinese scientists in contrast to that of M. Kuhle.

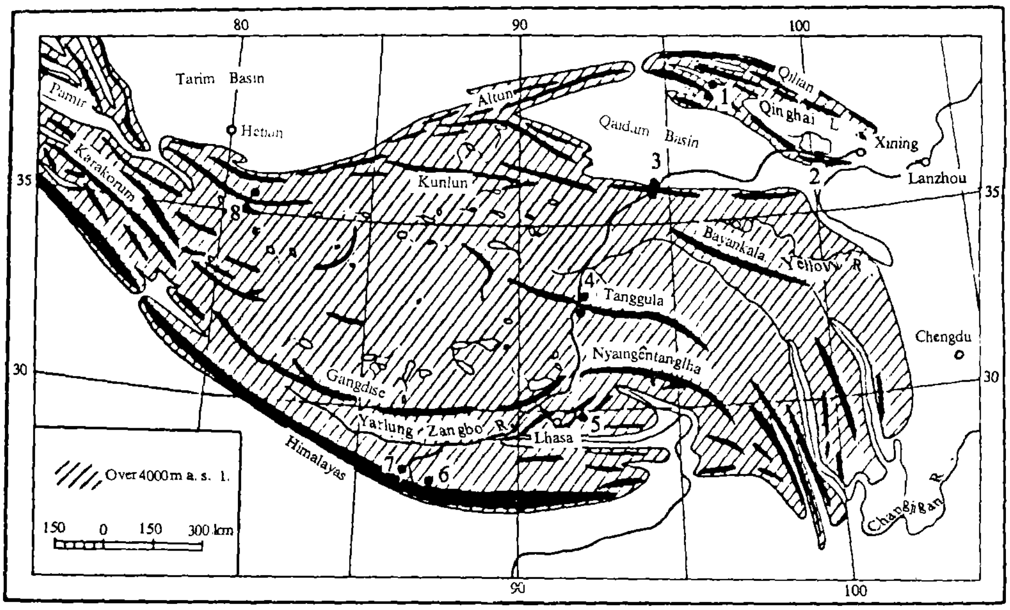

Fig.1 Sketch map of the Qinghai–Xizang (Tibet) Plateau

1.Dunde Ice Cap, 2.Qinghai Nanshan, 3.Nachitai, 4.Both sides of Tanggula Mountain, 5.Mangxiongla Mountain Pass, 6.Qomolangma area, 7.Xixiabangam area, 8.West Kunlun Mountain

II. TWO OPPOSITE IDEAS: DISPERSED MOUNTAIN GLACIERS OR A UNIFIED ICE SHEET

Fig.2 shows M. Kuhle's hypothesis[9–10] of a unified ice sheet on the plateau. He considered that the snowline during the Last Glacial Maximum (LGM) was generally

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1,100–1,500 m lower than that at present, dropping to 4,000 m on the south slope of the Himalayas and 3,700 m on the north slope of the Qilian Mountain. Since the average altitude of the plateau is around 5,000 m, there is no doubt that the height of the plateau was above the snowline in the Last Glaciation. There should be, therefore, a unified ice sheet with an area of 2–2.4 million km^2 (except the Qaidam Basin and the Zangbo Valley) and a thickness of 700–1200 m.

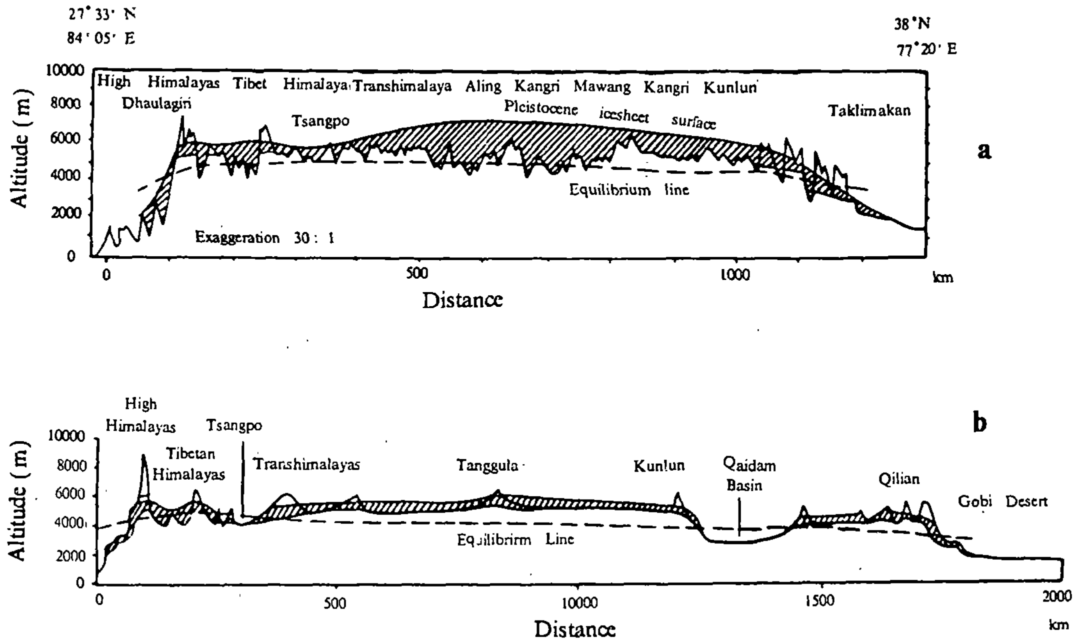

Fig.2 Kuhle's maximum extension of the Pleistocene glaciation in High Asia

a. West profile b. East profile

We have reconstructed the snowline for the Last Glaciation using the evidence of well–preserved cirques floors and the positions of terminal moraines. The results showed that the snowline in the Last Glaciation was 300–1,200 m lower than that at present, and only about 500 m lower in the inland parts of the plateau. The spatial pattern of snowline elevation in the Last Glaciation was similar to that at present (Fig.3). The existing glacial area in the plateau and nearby area including the Himalayas, Karakorum, Hindukush and Pamir is about 95,000 km^2 [11] which is 4% of the total area of High Asia. There are no exact data about the glacial area during the Pleistocene. According to the Quaternary Geologic Map of Xizang Autonomous Region (1:2,500,000) by Li Bingyuan et al.[12], the glacial area was about 297,000 km^2 or 25% of the total area. We consider that in the Pleistocene there were dispersed glaciers developed in the plateau and its surrounding mountains (Fig.4), with characteristics similar to modern glaciers in Alaska.

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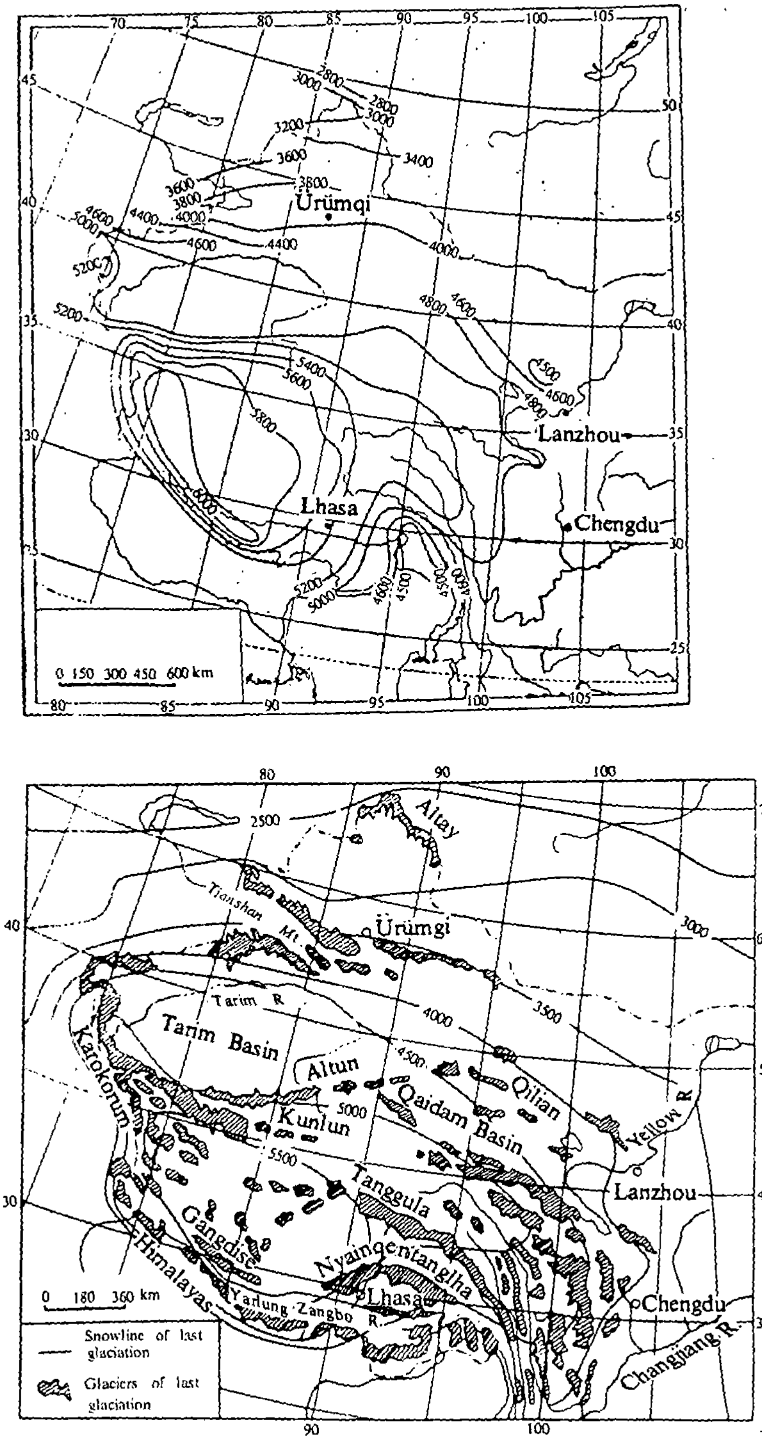

a

b

Fig.3 Sketch map of snowline elevation at present and in Last Glaciation Maximum in West China

a. Present snowline b. Snowline in LGM

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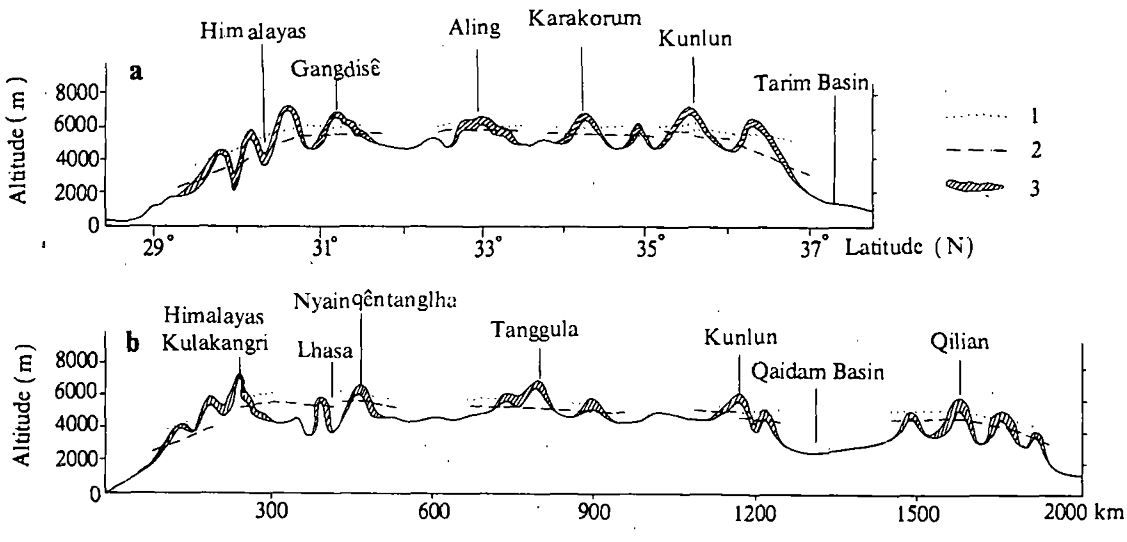

Fig.4 Real extension of Pleistocene Glaciations in High Asia

a. West profile b. East profile

1.Existing snowline, 2.The snowline in LGM, 3.The extension of the Maximum Glaciation

III. THE CRITERIA FOR RECOGNIZING THE EXTENSION OF MOUNTAIN GLACIERS

Mountain glacier traces formed in the Early and Middle Pleistocene are difficult to be identified because of their later destruction. The LGM is no more than 20,000 yr. B.P., in the area where lithology is suitable (e.g. massive sandstone, limestone, granite, gneiss, etc.), cirques, glacial troughes, lateral moraines, terminal moraines and moraine—dammed lakes are relatively well—preserved, especially in semi—arid area in northwest China. The LGM terminal moraines recognized by geomorphology method through our study are verified by ^{14}C dating is 14,930± 320 yr. B.P. from the sample in the terminal moraine dammed lake deposits which is at an altitude of 5,300 m and 6.5 km away from the present glacial terminal (5,350 m) of Chongce Glacier; underneath the terminal moraine, there is another lacustrine deposit, in which ^{14}C dating of organic material is 30,935 ± 1,700 yr. B.P. These data clearly indicate that the terminal moraine was formed during the LGM between 15,000—30,000 yr. B.P. (Fig.5)[13]. In this area, modern snowline is between 5,700 m and 6,200 m. Based on the glacial extension indicated by the mentioned terminal moraine, the snowline in the LGM in this area was only 200—300 m lower than that at present.

In diamict deposits, glacial deposits and debris flood deposits are difficult to be distinguished. For many times, we have found that debris flood deposits at lower altitude were

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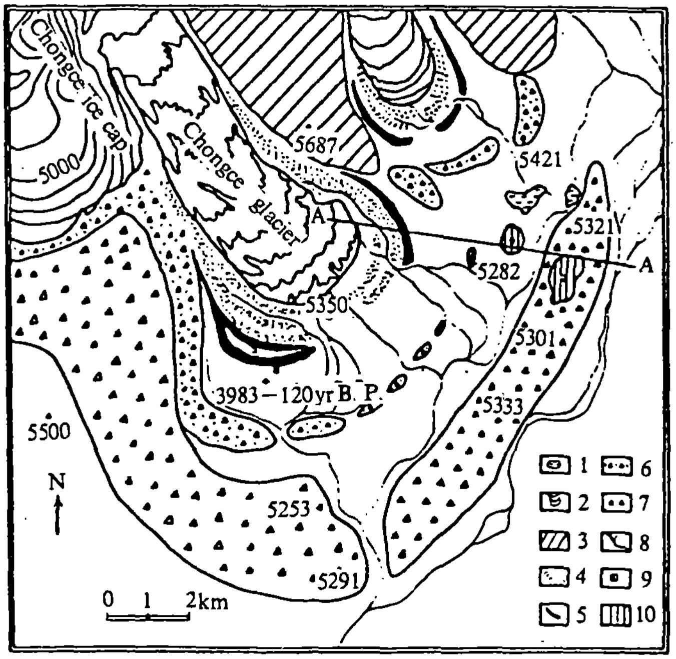

1. lake 2, glacier 3. bedrock 4. poraine of Little Ice Age 5. moraine of Reoglaciation 6. moraine formed before 8000 yr. B.P. 7. moraine of Last Glaciation 8. atream 9. sampling spot for ^{14}C dating 10. Lacustrine deposit

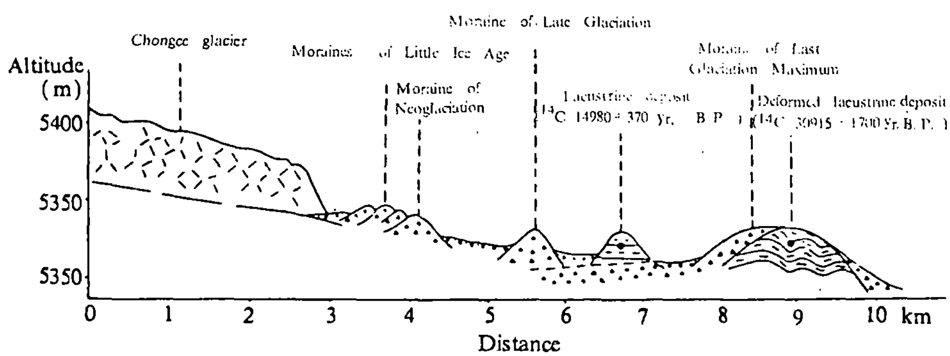

Fig.5 Sketch map of moraines of Chongce Glacier (35° 13′ N, 81° 11′ E) during Last Glaciation and post glacial period in south slope of West Kunlun Mountains

a. Distribution of glacial deposits b. A−A section from a.

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mistaken as glacial deposits. Cheching Kuhle's evidences of the LGM snowline depression based on his expeditions in the northeastern and southern parts of the Qinghai–Xizang Plateau, we can also find that some debris flood deposits were mistaken as glacial deposits.

In Nachitai (35° 34′ N, 94° 27′ E) which is beside the Qinghai–Xizang Highway on the north slope of the East Kunlun Mountain, the diamict at 3,540–3,640 m was named as Nachitai moraine of younger glaciation by M. Kuhle. He considered that at that time the glacier was 42 km long and snowline was 4,000 m, which was 1,150 m lower than at present (5,150 m). But according to Li Shijie (Fig.6), most of the boulders in the deposits are round, sub–round, some are sub–angular. They clearly dip to the upreaches. These features are not consistent with that of glacial deposits. The evidences from geomorphology, lithology and sedimentology studies indicate that these deposits at the outlet of the branch valley are debris flood deposits and exclude the possibility of glacial deposits from the East Kunlun. In this sector of East Kunlun, bed rocks are schist, slate, etc. which are easy to be eroded, so the real LGM moraines are not preserved and difficult to be distinguished.

In Qinghai–Nanshan (36° 21′ N, 99° 20′ —100° 43′ E), there is no existing glaciers. M. Kuhle[8] calculated that the modern snowline there is 4,700–4,950 m, and the LGM (equal to M. Kuhle's younger glaciation) snowline was between 3,690 m and 3,825 m, 1,000–1,150 m lower than that at present. He thought that glaciers at that time extended to the shore of Qinghai Lake at 3,200 m. According to Shi Yafeng's study, modern snowline in this area should be 4,600–4,800 m, which is close to M.Kuhle's calculation. But the snowline in the LGM should be 4,000–4,2000 m calculated from the elevation of the floors of the well–preserved cirques, which means that the snowline dropped only 600 m in the LGM in this area, and that there were only some cirque glaciers and small cirque–valley glaciers, no piedmont glaciers developed. The diamict at the shore of Qinghai Lake is debris flow deposits instead of glacial deposits. From $\delta^{18}O$ analysis and pollen analysis from the core in Qinghai Lake, the lake was under cold–arid climate and almost dried during LGM[14]. This means that Qinghai Lake was not at its high level period in the LGM as M.Kuhle guessed.

The Kakitu massif (38° 05′ N, 96° 26′ E) is located in the southwestern part of the Qilian Mountain, where the Dunde Ice Cap may culminate at 5,330 m with an area of 57 km^2. The end moraines of the Last Glaciation piled up at the altitude from 4,100 m to 4,500 m in the southern foreland as M. Kuhle[8] described, and from 3,950 m to 4,200 m in the northern. In other ridges to the south and north, the end moraines of the Last Glaciation also reached to the margins of the broad intermontane valleys. Outside them, there exist glaciofluvial deposit fans. Based on this, the depression of the snowline during the Last Glaciation Maximum was about 500–550 m in the Kakitu massif, and more in the surrounding areas. The glacierized area of the LGM is estimated about 3,000 km^2 in this massif, but M. Kuhle[8] imagined an ice sheet covering the whole Qilian Mountain.

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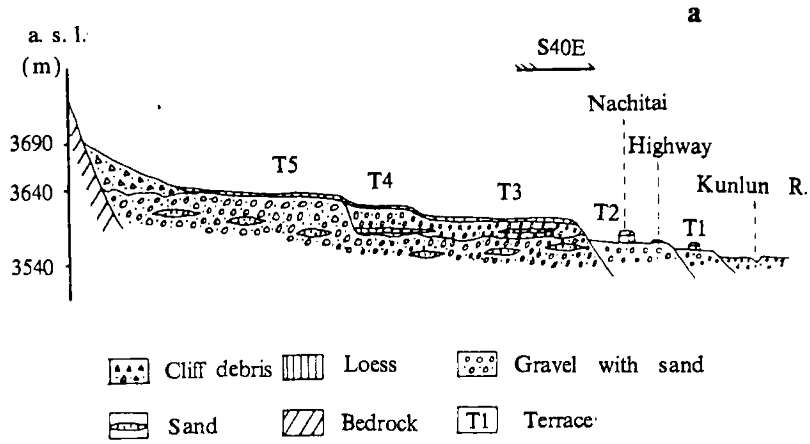
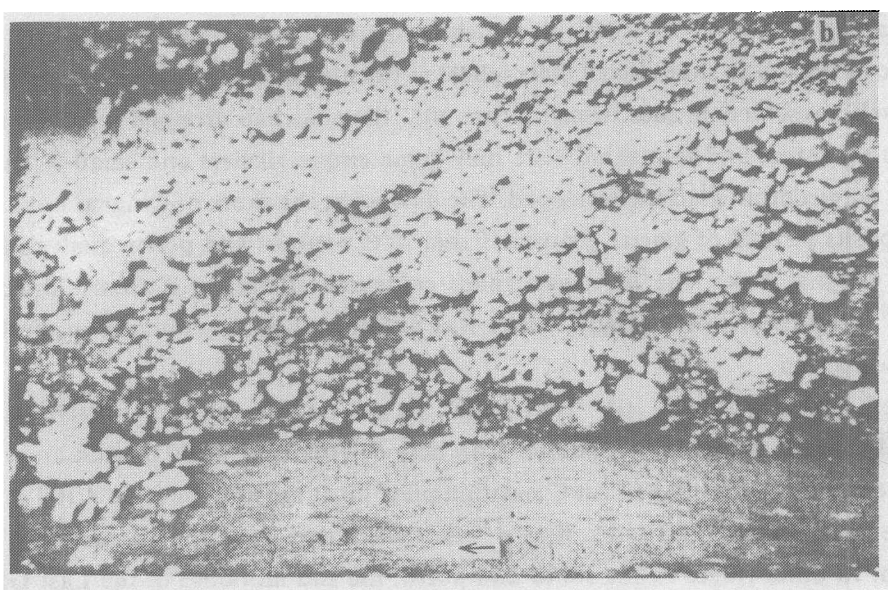


a. Debris flood deposits fan



b. A photo section of the debris flood deposits.
Note the roundness of boulders and the dip angle upward.

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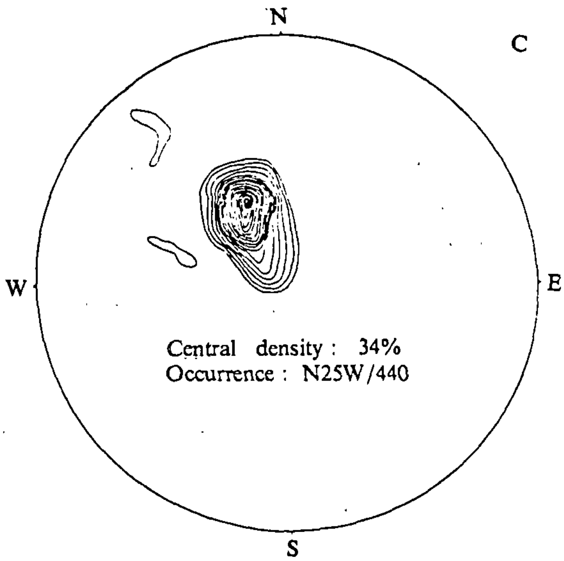

c. Isodensity diagram in stereographic projection of the boulders occurrence in the deposits

Fig.6 Diamict profile at the outlet of a branch valley near Nachitai, north slope of East Kunlun (Li Shijie)

There is no existing glacial near Lhasa (29° 45′ N, 91° E). M. Kuhle thought that modern snowline there would be 5,700 m. Kuhle said that he found terminal moraine[10] (Fig.3) in a branch valley near Lhasa. Based on this, he determined that the snowline in the LGM was 4,575–4,725 m, which was 1,200 m lower than modern snowline. Besides, he has drawn a snowline of 4,500 m for the LGM along the altitude of Lhasa. But according to Zheng Benxing's observation, the diamict deposits in this branch valley are debris flow deposits instead of glacial deposits. The snowline in the LGM indicated by the cirques in the Lhasa Nanshan was 5,200 m. There are clear small ice cap traces from the LGM at the pass of the Mamxiongla Mountain (29° 40′ N, 92° 30′ E, 5,200m a.s.l.), east of Lhasa. Many glacial terminals overflew from the ice cap extended to the altitude of 4,600–4,800 m, the snowline in the LGM calculated based on the glacial traces there was 4,900–5,000 m, which is 400–500 m lower than at present (5,400–5,500 m) (Fig.7).

M. Kuhle proposed an idea of ice marginal ramps. He took the marginal ramps, which are mostly covered by alluvial fan, as characteristic landmarks of glacier terminal. He used satellite pictures to distinguish these landmarks and thought that the procedure was successful[8–9]. We think that it is dangerous to mark glacial extension by using this method if there is no detail field investigation. Because in northwest China the variability of precipitation, and tectonic uplift are intensive, overlapped and steep debris flood alluvial fans are well developed at the piedmonts of high mountains. Erratic with striation were sometimes

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found in these fans. These features are similar to Kuhle's ice marginal ramps. If these fans of debris flood deposits were taken as ice marginal ramps, the extension of glaciation would be greatly exaggerated.

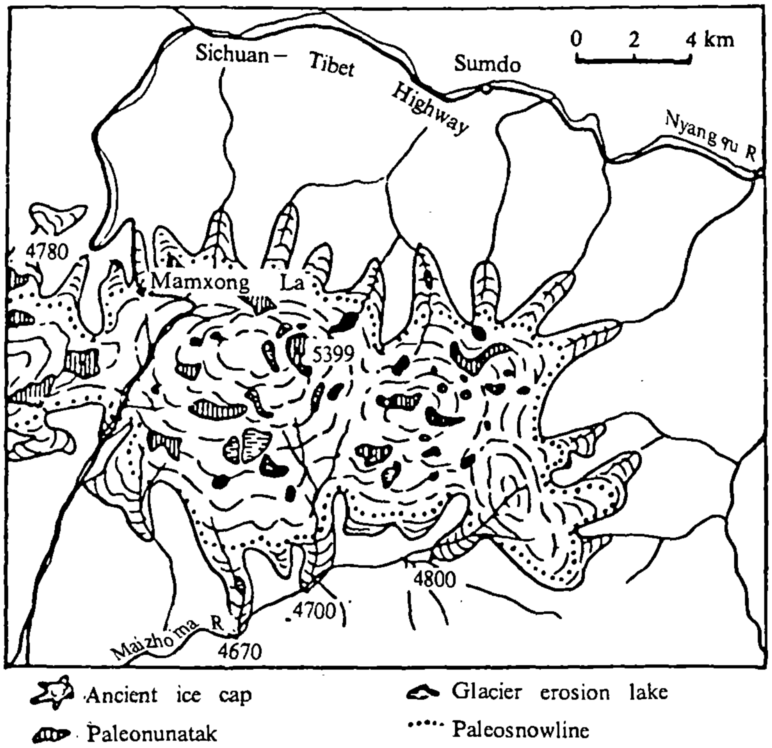

Fig.7 A former ice cap at the pass of Mamxiongla Mountain (from Zhen Benxing, 1986)

IV. WHY SNOWLINE DROP IN THE LGM WAS SMALLER IN THE INLAND OF THE PLATEAU

The snowline drop in the LGM was 1,000–1,2000 m or more around the rim of the south and southeast Qinghai–Xizang Plateau, the southern slope of the Himalayas and the west Pamir, 500–800 m in the Qilian Mountain in the north–east edge of the plateau, 500 m in the inland of the plateau and only 300 m in some regions such as the north slope of Qomolungma and Xixiabangma, the south slope of the West Kunlun and some high mountains in the northwestern part of the plateau. Why there is so much difference?

1. During the Quaternary Glaciation, South Asia Monsoon Became Much Weaker and Precipitation Decreased. These Features Strongly Influenced the Snowline in the Inland of the Plateau.

Various methods have been used to calculate the temperature drop for the LGM in the

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plateau. Cui Zhijiu[15] estimated by studying periglacial phenomena that it was 5.5–6.4℃ on the south slope of the Tanggula Mountain and 3℃ in the northern part of the plateau. Wang Fubao calculated that the drop reached 5–6℃ by comparing the south boundary shifting of the permafrost[12]. In the Eryuan West Lake located in the southeast side of the plateau (26° N, 100° E), pollen analysis indicates that temperature decreased by 5℃ between 15,000–12,000 yr. B.P.[16]. Based on the snowline drop of 1,000–1,200 m in the eastern and southern peripheries of the Himalayas, we consider that the estimation of temperature decrease of 5–6℃ is reasonable.

The precipitation in the plateau obviously lessened during the Last Glaciation. Cheng Kazao and J. M. Bowler[17] found from their study in the Charhan Salt Lake deposits in the Qaidam Basin that before 24,000 yr. B.P., i.e. the warm interval of the Last Glaciation there was a relative wet period, resulting in a big freshwater lake, but it was succeeded by a arid and salt forming period during 24,000–9,000 yr. B.P. The appearance of KCl and $KCl.MgCl_2.6H_2O$ indicated that the arid condition was intensive and salt lake developed to almost a dried stage in 16,000 yr. B.P. After 9,000 yr. B.P., the climate became wet again, new salt lake developed in its south margin where freshwater supply was abundant. This is contradicted to M Kuhle's conjecture that the Qaidam Basin was a big lake filled with ice melting water in the LGM. An example of wet period during warm interval from ^{14}C dating of peat in a lake core near Nomhong (36° 48′ N, 96° 27′ E), southeast of Qaidam Basin may be cited. The ^{14}C dating of peat is 35,530 ± 540 yr. B.P. This is an example in consistence with the climatic analysis of Xizang during the Last Glaciation by H.Flohn[18]. He cited core analysis findings from the Indian Ocean and found that the summer monsoon was weak during the LGM. The higher salinity in the Bay of Bengal indicated a reduction of freshwater inflow and thus decrease of precipitation in the extended catchments of the Ganges, the Brahmaputra–Yalungzangbo and the Irawaddi–Salween. This coincides with the worldwide arid phase of the LGM, but contradicted to M. Kuhle's ice sheet hypothesis. On the basis of Chinese literature, H. Flohn made an estimation that the glacial area in the plateau was about 20–40% of the total area. This is close to reality.

Fig.8 shows a curve calculated from the relationship between the average temperature from June to August and average annual precipitation at the equilibrium line of the existing glaciers in west China. It is seen from the feature that at the equilibrium line if annual precipitation decreases from 2,500 mm to 1,000 mm, corresponding summer temperature would decrease from 4℃ to 2℃, which could be converted into a relative snowline shift of about 340 m; if annual precipitation decrease from 1,000 mm to 300 mm, temperature difference will be up to 4℃, corresponding relative snowline shift will be about 680 m. It can be seen that even substantial decrease in precipitation may not produce important influence on snowline in the high precipitation area, such as the eastern part of the plateau, the south slope of the Himalayas and the west Pamir, while small decrease in the low precipitation area will strongly influence snowline in the inland, the northwestern part and northeastern

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part of the plateau where precipitation fluctuated between 300 mm and 800 mm.

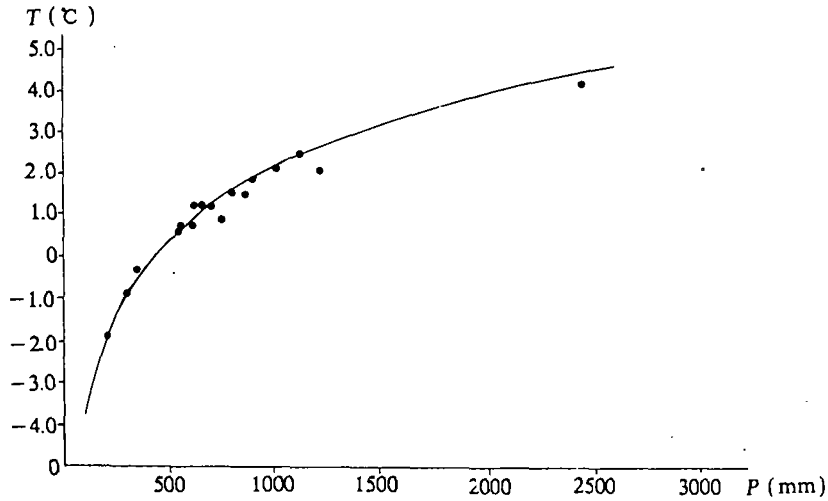

Fig.8 Relative curve between summer temperature and annual precipitation at the equilibrium line of existing glaciers in West China (after Shi 1988)

All the evidences mentioned above, including the large decrease in temperature and intense salt formation in the LGM in the Qaidam Basin, and almost dried Qinghai Lake during the LGM indicate strongly that there was big decrease in precipitation in the LGM. This is an important reason why the LGM snowline drop was relatively small in the inland of the plateau.

2. The Influence of the Intensive Uplift of the Plateau, Especially the Surrounding High Mountains, on Climate and on Snowline Is Another Reason.

From the study by Li Jijun et al.[19], the Qinghai–Xizang Plateau was about 1,000 m a.s.l. in the Late Pliocene, and was uplifted intensively afterwards, reached to the present height of 4,500–5,000 m a.s.l. through the Quaternary. The uplift magnitude of the plateau was 1,000 m in the Early Pleistocene, 1,000 m in the Middle Pleistocene and 1,700 m in the Late Pleistocene and the Holocene respectively, which showed an accelerated uplift process of the plateau. The uplift magnitude of the surrounding mountains, such as the Himalayas, the Karakoram and the West Kunlun, should be larger.

The heating of the atmosphere by the plateau makes surface temperature obviously higher than its nearby free air temperature at the same elevation. At 30° N, the average sea level surface temperature is 18.3℃ while the temperature converted to sea level from air temperature of Xizang at the same latitude reaches 25℃, which 6.7℃ higher than the former. In the plateau, the high temperature center locates in the western part of the plateau

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where the highest modern snowline in the Northern Hemisphere is found.

The uplift of the plateau strongly influenced precipitation distribution at the early stage of uplifting, the plateau raised the air mass on the windward side and stimulated the increase of precipitation. On the south slope of the Himalayas, the maximum precipitation zone is between 1,000 m and 2,000 m, precipitation decreases beyond this altitude; a secondary precipitation maximum appears at the horizon of convective clouds because of intensive convection. It appears in the cirque at 6,160 m in the south slope of the Qomolungma, precipitation there being almost 3 times that at 5,300 m[20]. The precipitation barrier function of the high mountains is quite evident. On the north side of the Himalayas, the precipitation is only 10% of that on the south side. In the West Kunlun, the precipitation on the south slope is only 1/ 5 of that on the north slope. Even at the altitude of 6,000 m in the Qomolungma, the precipitation on the north slope is only 1/ 3 of that on the south slope which results in a big snowline difference between the south slope and the north slope (snowline on the north slope is 500 m higher than that on the south slope). In the plateau, the lowest snowline appears at the big bend of the Yarlung Zangbo in southeast Xizang being the passage way of the Bengal Bay air mass. The snowline there is as low as 4,500 m.

We will mainly discuss the influence of the plateau uplift on the LGM snowline. If the estimation of a 1,700 m uplift during the Late Pleistocene and the Holocene by Li Jijun[19] as mentioned above holds good and the uplifting is assumed to be equally distributed in different periods in the Late Pleistocene and the Holocene, the uplift magnitude will be about 100 m per 10,000 years. Considering that the uplift caused by the shrinkage of most glaciers during the post glacial period, the uplift magnitude should be larger in some highest mountains such as the Himalayas, Karakorum, the West Kunlun. Taking the Qomolangma Peak as an example, the snowline calculated from cirque floors for the LGM is only 200—300 m lower than that at present within 30 km on the north slope, but 50 km away from the peak, the snowline drop is quickly increased to 500 m[20]. This indicates that the uplift magnitude in the Qomolangma Peak may be 200—300 m larger than that of the plateau. The barrier function of high mountains to precipitation, the intensive uplift of the Himalayas and the West Kunlun etc. may be another reason why the snowline drop decreased to 200—300 m on the hinterland of the plateau.

V. THE MAXIMUM GLACIATION IN THE PLATEAU

The Maximum Glaciation in the plateau appeared in the second or third glacial from the Last Glaciation when large piedmont glaciers, ice caps or trellis type valley galciers developed. But there was no unified ice sheet formed. Some examples are in the following:

1. On the north slope and the northeast slope of the Xixiabangma Peak, four glaciations were recognized through expeditions by Chinese scientists[21—23,14]. Valley glaciers developed in the Last Glaciation and in penultimate glaciation, large piedmont glacier i.e.

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Maximum Glaciation developed in the third glaciation from the last. Because of the limitation of cold–arid condition and old age of the glaciations mentioned above, no dating is available for them. But the Maximum Glaciation can be classified into the Middle Pleistocene based on geomorphological and sedimentological sequence.

Fig.9 shows the moraine platform of the Maximum Glaciation (i.e. Nyanyaxungla

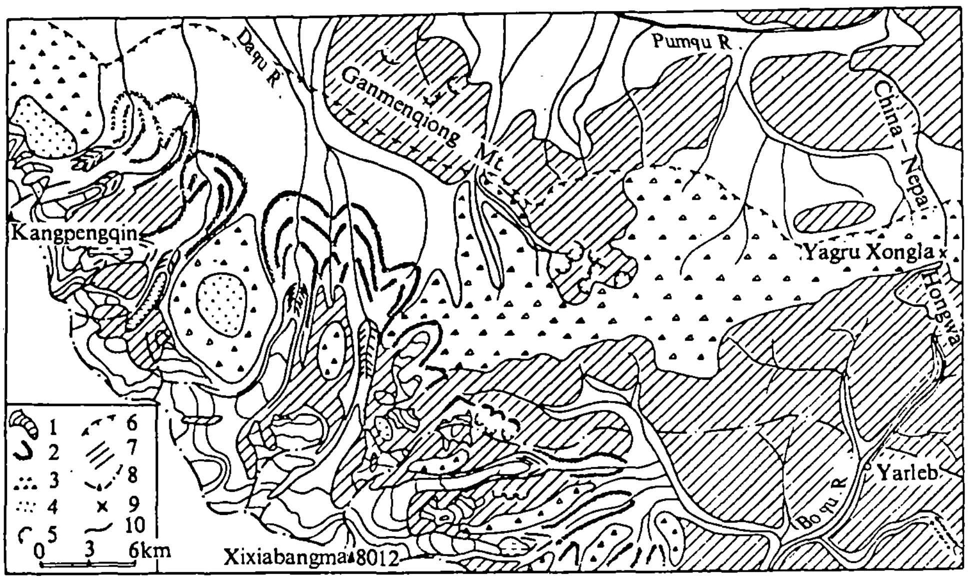

Fig.9 Sketch map of Last Glaciation and Maximum Glaciation on north slope of Xixiabangma

1.Existing glacier, 2.End moraine of Last Glaciation (Qomolangma II), 3.Moraine platform of Maximum Glaciation (Nyanyaxungla Gl.), 4.Highest moraine platform of Xixiabangma Glaciation, 5.Cirque of Last Glaciation, 6.Lower limit of Maximum Glaciation, 7.Mountain, 8.Ridge and peak, 9.Pass, 10.Highway

Glaciation). The till is up about several score to 100 m thick. The major part of boulders are mainly granite–gneiss, epidolerite with diameters within 2 m. Augen–gneiss, which is common in the till of the Last Glaciation are rarely found in the platform. The moraine platform directly covers the sandstone formation containing *Quercus semicarpifolia* of the Pliocene. The surface of platform is quite flat, obviously undergoing planation during the interglacial. The platform declines 6° northward and extends 15 km. Its south margin is separated by valley from the Xixiabangma, reaching 6,000–6,100 m a.s.l. and is covered by existing flat top glaciers. Its north margin decreases to 5,200 m. Obviously, the platform was evidently tilted so that the longitudinal dip ratio of the platform is larger than that of existing glacial valley which cuts into the platform. The maximum glacial platforms extensively distribute on the north slope of the Xixiabangma. It clearly indicates that there

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were large piedmont glaciers developed there in the past. Its extension reached 1,140 km^2, which is three times the area of the Last Glaciation (376 km^2).

M. Kuhle[10] completely overlooked the geomorphic and sedimentological sequences of the moraine platform and classified Nyanyaxungla platform into an ice marginal ramp of the late glacial till within 15,000 yr. B.P., besides, he stated that moraine was 600 m thick. This evidently deviates from reality.

2. The Meidika Basin at the intersection of 31° N and 92° E can be taken as a typical example of ice cap formed during the Maximum Glaciation in the plateau (Fig.10). The basin is 5,000 m a.s.l., while the mountains in the southern part average 5,400–5,500 m. The largest extension of glaciers belonged to the second glaciation from the last, i.e. Guxiang Glaciation in this region. During this glaciation, moraine hills and lakes extensively distributed in the basin. The most remarkable feature is the drumlins in the basin which were dispersed in an area of 3–4 km wide and 15 km long. Each drumlin is 5–10 m high and several tens to 200 m long. Estimated from the erratic 400 m above the valley, the glacial thickness was 500 m then. The glacial area was about 3,600 km^2 or more. The glacial termini from the ice cap reached to 4,700 m a.s.l.[11].

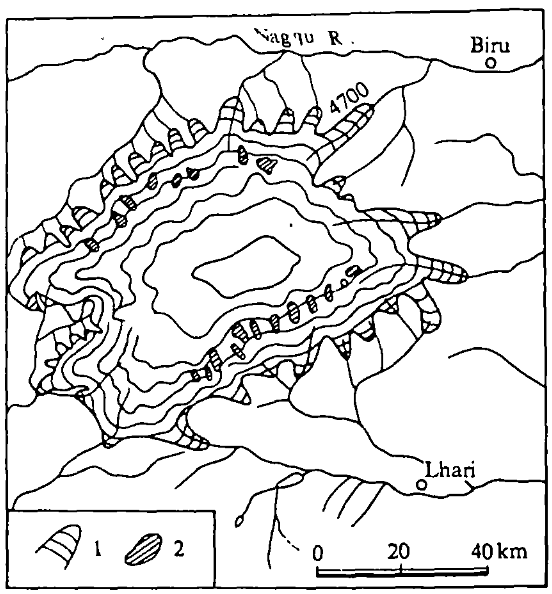

Fig.10 An ice cap of Maximum Glaciation in Meidika Basin in Xizang (from Li & Zheng 1986)

1. Glacier, 2. Nunatak

3. The Boduizangbo Basin in Bomi County in southeastern Xizang (29° N, 95° E) can be taken as an example of trellis valley glaciers (Fig.). The mountains there are up to 6,000 m or more. Because of abundant precipitation, modern snowline reaches to

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4,400–4,500 m. The river deeply cuts the mountain to 2,600 m a.s.l. The modern glacial area there is 1,195 km^2. Two clear Pleistocene glaciations were recognized. In the Last Glaciation (called Baiyu Glaciation), the length of main glacier was 80 km long and the area reached about 2,461 km^2, about twice as modern glaciers. The ^{14}C dating of warm interval from lacustrine deposits is 36,000 yr. B.P. The second glaciation from the last (called Guxiang Glaciation) was represented by a moraine terrace 500 m above the river. The length of Guxiang Glacier reached 100 km and the area 2,848 km^2, about 2.4 times as modern glaciers. At that time, main glaciers and branch glaciers connected each other, formed trellis or net valley glaciers.

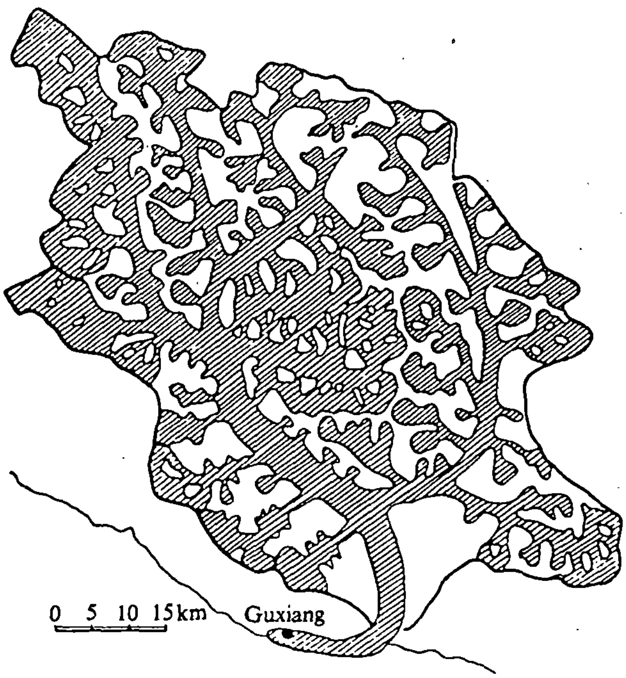

Fig.11 Trellis glaciers during Maximum Glaciation in Bodoizangbo, SE. Xizang (Li Jijun et al. 1986)

4. The Tanggula Mountain (32° 40′ N, 92° E) with an altitude of 6,621 m is the highest mountain in the inland of the plateau. The existing glacial area is 2,082 km^2 with snowlines from 5,700 m to 5,800 m. Since the average height of the plateau on the two sides of the mountain is up to 4,700–5,000 m, small drop of snowline will cause evident increase in glacial area. Li Jijun et al.[11] found that the second glaciation from the last (called Zhajiazangbu Glaciation) was the period with largest glaciers. He estimated that the glacial area was up to 35,000 km^2 or more, 17 times as much as the existing glacial area at least (Fig.12).

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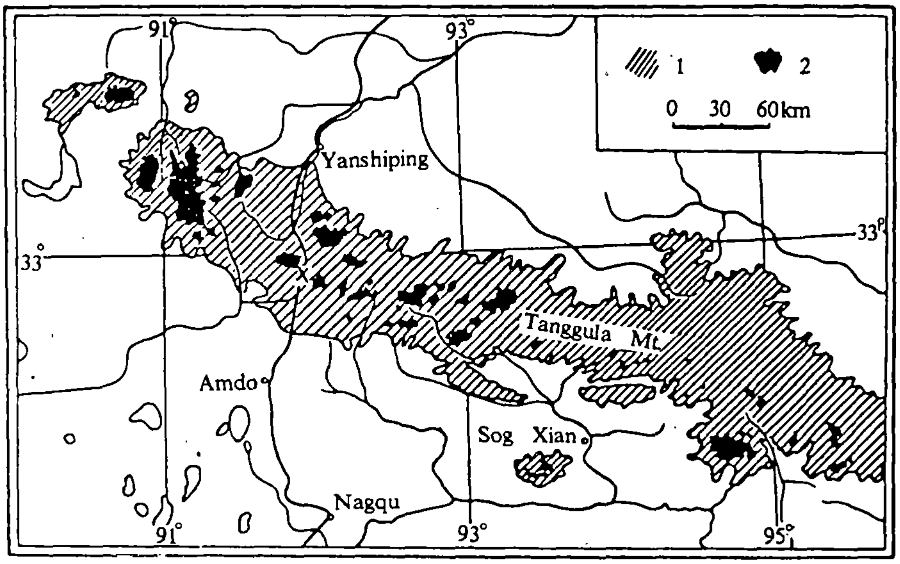

Fig.12 Maximum Glaciation in Tanggula Mountain

(Li Jijun et al. 1986. Slightly modified)

1. Glacier extension of Maximum Glaciation 2. Existing glacier

Summing up what we discussed in the above, even during the Maximum Glaciation in the Middle Pleistocene, the glacier in the plateau was still dispersed valley glaciers, piedmont glacier and ice caps centered by high mountains, and perhaps a large scale ice cap or a small ice sheet existed in the head area of the Huanghe (Yellow) River, due to the flat highland and richer precipitation there. The glacial area during the Maximum Glaciation was several or tens of times as the existing glacial area. These facts directly opposite to M. Kuhle's hypothesis of a unified ice sheet.

VI. CONCLUSION

On the basis of studies in the Qinghai–Xizang Plateau by Chinese scientists from the 1950s to the present, the snowline drop in the Last Glaciation was up to 1,000 m or more in the southeastern margin of the plateau and on the south slope of the Himalayas, 500–800 m in the Qilian Mountain and in the northeastern margin of the plateau, about 500 m in the hinterland of the plateau, but only 200–300 m on the north slope of the middle part of the Himalayas, on the south slope of the West Kunlun and in some regions in the western part of Xizang. During the Pleistocene glaciations, only dispersed mountain glaciers developed and centered by high mountains. The reasons are that precipitation decreased during the Pleistocene glaciations and the intensive uplift of the plateau especially of the surrounding mountains raised the snowline in the plateau. The Maximum Glaciation was the second or

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third glaciation from the last. During the Maximum Glaciation, extensive piedmont glaciers, trellis valley glaciers and ice caps developed. The glacial area in the Xizang Autonomous Region was about 1/ 4 of its total area.

The unified ice sheet hypothesis proposed by M.Kuhle is not coincident with the reality in the plateau. Many snowline values were calculated by mistaking debris flood and alluvial fans as glacial termini. The idea of ice marginal ramps by M.Kuhle can be easily confused with cut deposit fans of debris flow and alluvial fan. He did not consider the influence on snowline by arid climate in the inland of the plateau. He completely ignored the research findings about the Qinghai–Xizang Plateau by Chinese scientists, which may be one of the reasons why he insistently proposed the ice sheet hypothesis, although he had explored the Qinghai–Xizang Plateau several times.

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