On Kunlun-Yellow River tectonic movement*

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Abstract In the Kunlun Mountains Pass area, all the landform, structure, sedimentary facies and assembladge of organisms show that a violent tectonic movement occurred between 1.1—0.7 MaB.P. The movement leads to a large-scale uplifting first, and then fault-block rising and fault depression occurred suddenly in the northern Plateau. In the late period of this movement, sudden and tremendous uplifting raised this area over the critical elevation of 3 000 m and caused the appearance of the maximum glaciation in Quaternary. This uplifting is perhaps the driving force of the tremendous environmental change of tectonic-climatic circulation at the break of the early and middle Pleistocene in China.

Keywords: Kunlun Mountains Pass, 0.7 MaB.P., tectonic movement.

1 What is the forcing factor of violent environmental change at the break of the early and middle Pleistocene in China?

The so-called upper sandy loess in the Luochuan loess section in the Loess Plateau, which corresponds to the deep-sea oxygen isotope stage 18—16, was deposited in 0.8 MaB.P. The wide distribution of this loess layer shows a very cold event and grassland-desert environment. The scope of loess deposit spread and passed through the Taihangshan Mountains and Qinling Mountains first[1], and the inner Qinghai-Xizang Plateau (Ganzi) deposited loess too[2]. Liu and Din[3] compared the climatic substitutive mark in loess and deep-sea oxygen isotope curve and discovered that the winter-summer monsoon circulation in the East Asia and the global ice quantity had a stage coupling process since 2.5 MaB.P. and the coupling level strengthened step by step. The three break times were about 2.5, 1.6 and 0.8 MaB.P., respectively. They have matched very well since 0.8 MaB.P. The circulation of fossil monsoon increased its fluctuating amplitude, and the periodicity of the change was longer than before. During the middle Pleistocene, the old lakes in mountains basin, North China such as Yushe old lake, began to disappear, the climatic environment became bad and dry. In North China, the vegetable composition had renewed since

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Quaternary, but the evident change occurred in the middle Pleistocene[4]. Some subtropical trees, such as *Ginkgo*, *Metasequoia*, and *Liriodendron*, still remained in the North China before the Pleistocene, but disappeared afterward. In north Qinling Mountains, there were some *Tsuga* in the *Picea* and *Abies* forests in the early Pleistocene, but disappeared afterward. There were some broad-leaved evergreen trees in the broad-leaved deciduous forests of the interglaciation plants, but disappeared after that[5]. The climate underwent a break in the middle Pleistocene in China and the trend towards the present environmental characters began[4]. According to the analysis of six large deposition basins in China by Tong Guobang, the pollen climatic circulation in China can be divided into two periods. The second period began at 0.8 MaB.P. with the character of large high tall tree pollen, and amplitute fluctuating. The woody plant pollen decreased in the late period, and climate changed from high temperature and humid to cold and dry.

As to the Plateau itself, most mountains in it had entered cryosphere since the middle Pleistocene[6]. The area of ice sheet spread, and the snow sheet expanded too because of the marine climatic condition. The result is the increased reflection rate of the Plateau. As a cold source, the Plateau strengthened the winter monsoon, and the climate became dry and cold. For example, the shrink of the inner lake occurred in the middle Pleistocene[7]. The maximum lake occurred in 1.95—1.30 MaB.P. in the deposition center of Qaidum Basin. The area of lake decreased evidently after 1.0 MaB.P., and the deposition rate increased largely (from 171 to 440 mm/ka)[1)]. The sedimentary facies of cores RH and RM, which are located on the east side of the Maqu-Xidatan deep fault belt, show that the structure and environment changed evidently at 0.7 MaB.P. There was a long cold period (from 0.719 to 0.63 MaB.P.)[8] concurrent with the oxygen isotope stage 18. It was warmer before that time, but colder afterward. The sedimentary rate increased from 14.7 to 38 m/ka. All this shows the Plateau uplifted violently and the last but two glaciation, i.e. Wangkun Glaciation (0.719—0.525 MaB.P.) occurred[9]. This was just at the time of stages 18—16. In the Linxia Basin, which is located on the northeast side of the Plateau, a sharp and great increase in fluctuating amplitude of the climate occurred and the periodicity of the fluctuations changed abruptly from 41 ka before the middle Pleistocene to 100 ka afterward. Since then the climate fluctuated abruptly and tended to dry fast. The dry area appeared again[10].

In South China, broad fold or monoclinal structure was developed in the Zhanjiang Formation, and the Beihai Formation was uncomformable on it forming three or four terraces. There were many faults and compressional fracture zones in the Zhanjiang Formation. The volcanic rock of Shimaoling Period was distributed widely in South China. The sediment of Zhanjiang Formation changed from the continental-oceanic interaction to the alluvial-flood. The climatic mark indicated a tremendous change. According to Wan[11], there were complete different types of volcanic eruption, volcanic eruption belt in different directions and locations, and with different tectonic landform characteristics.

As a whole, the loess or the other sediment[12] and vegetation succession show evidently an increase in fluctuating amplitude and a longer fluctuating periodicity. The authors believe that the

1) Wang Yongjin, Wang Fubao, Li shengfeng, Research for the uplift process of the Qinghai-Xizang Plateau based on the sediment in Qaidum Basin in the late Cenozoic, 1995.

violent uplift of the Qinghai-Xizang Plateau caused by the Kunlun-Yellow River tectonic movement is the force of the environmental changes at the break of the early and middle Pleistocene, at least it is one of the main driving forces. It is also the exhibition of the tectonic-climatic circulation. We believe that the climatic pattern in China took a turn in the middle Pleistocene, and all the present environmental characters and varied trends have a close correlation with the Kunlun-Yellow River Movement.

2 Evidence of Kunlun-Yellow River tectonic movement

The main strata before the early Pleistocene are the Jingxiangu Formation (>2.5 Ma B.P.), the Qiangtang Formation (2.5—0.7 MaB.P.), and the Wangkun till (0.7—0.6 Ma B.P.)[13]. Afterward, the main strata are the Naij Tal Gou Formation (0.6—0.4 MaB.P.) and the Sanchahe Formation (0.4—0.06 MaB.P.). There are also late Pleistocene and Holocene strata in the Xiaonanchuan section and Reshui section.

2.1 Tremendous environmental change before and after 0.7 MaB.P. in Kunlun Mountains Pass area

2.1.1 The hemi-plateau environment in the period of Jingxiangu and Qiangtang Formation.

The Jingxiangu Formation consists of the alluvial fan system, while the Qiangtang Formation consists of the fan-delta system. Analysis1) of Ostracoda in the Jianxiangu Formation and the Qiangtang Formation shows the assemblage of Ostracoda is *Ilyocypris-Candona-Candoniella-Leucocythere-Limnocytherellina*, 10 genera and 26 species in all. It is similar to the assembly in Hongya section in Weixian County, in the classical Nihewan section in Haojiatai, Yangyuan County, Hebei Province. Most fossils in Nihewan section exist in the Qiangtang Formation. The assembly of Ostracoda in the Qiangtang Formation can be compared with that in the Gonghe Formation and Hadatan Formation in Qinghai Province, and the Sanmen Formation in Shanxi Province. According to Yin et al.[14], the mollusk fossils in Jingxiangu Formation and Qiangtang Formation have a high differentiation rate. There are 65 gastropods, and the assembly is similar to that of North China. The well-developed small water plants show that there might have been swallow lakes and rivers. So based on the assembly of fauna and flora, the environment can be compared with the mountains' basin lake and river environment represented by the Nihewan Formation in North China. So there should have been a warm and humid ecological environment, a stable tectonic movement background, at about 1 500 m a.s.l. Considering the existence of paleokarst (7.0—18.0 MaB.P.), the elevation should have been about 1 000 m above sea level[15]. So in contrast with the present plateau, it should be called semi-plateau at that time.

2.1.2 Plateau environment in the period of the Naij Tal Gou Formation (0.6—0.4 MaB.P.) and the Sanchahe Formation (0.4—0.06 MaB.P.).

The Naij Tal Gou Formation is 100 m in thickness, and composed of mainly debris flows. It is distributed around the Naij Tal with a typical section in the Hougou of Naij Tal. The Sanchahe Formation is widely distributed with horizontal occurrences in the Dongdatan, Xidatan, Xiaonanchuan and Yeniugou Valley. The maximum thickness of the Sanchahe Formation is about 300 m in the Xidatan Valley (according

1) Pang Qiqing, 1995, The analysis of ostracoda of the Jingxiangu Formation and the Qiangtang Formation.

to geophysical prospecting). The best natural section of the Xidatan Formation is located at the mouth of Yeniugou Valley about 63 m in thickness. The lower part of the section consists of sand and pebble, with blocky bedding, tabular cross-bedding and imbracate structure. Every succession of strata is 40—60 cm in thickness. In the upper section, the bedding of pebble is thinner and the bedding of sand is thicker, and there are only sand, silt and clay near the top of this section. There are fossil spire, water grass and ostracoda in the sediment. This set of alluvial strata in the middle and late Pleistocene shows the valley has been sinking slowly since the middle Pleistocene.

The sporopollens in the section are mainly Chenopodiaceae, *Ephodra*, Gramineae, and *Artemisia*. This shows a dry environmental condition. The coniferous forest appeared only at about 0.2 MaB.P. in the middle part of the section. There are only 5 genera and 5 species in the sediment, but each genus and species has a large population and the species of ostracoda are similar to those in modern conditions. The fossil analysis of Bivalve and Gasteropod shows the same character: a small differentiation and a large abundance. It is the result of high environmental pressure. The living beings which depend on fresh water almost disappeared, representing a high elevation and bad natural condition. This area uplifted to an elevation almost the same at the present (3 500—4 000 m) at that time. A tremendous environmental change had taken place in contrast with the period of the Qiangtang Formation. This reflected mainly the character of uplift in a large area in the early period of the Kunlun-Yellow River Movement.

2.2 Evidence of structure and landform

2.2.1 Analysis of sedimentary source. Wangkun till. Wangkun till covered directly the bedrock of the Jingxiangu Formation and the Qiangtang Formation. Statistics of the lithologic character shows that it is composed of granite-gneiss (33%—38%), quartzite (13%—15%) and some of shist, slate, phyllite and some pyroxenite (5%—9%). But the local composition is slate and sandstone of Triassic period and so is that in a large range on the south side. An interesting thing is the occurrence of granite-gneiss in the North Mountains of Xidatan cross the Xidatan Valley, while the source of pyroxentic is located 30 km west of the discovery place cross the Valley. The north-south direction of the long axis of the till shows the glacier flowed from north to south. All the above suggests that the source of glacier was to the north of the Kunlun Mountains ridge and there was no Xidatan Valley at that time. Today's Pass Basin was located at the foot of the mountains. Because of rift faulting, strike slipping and depression, the Xidatan Valley sank, and the headward erosion of Golmud River cut through the ridge of the Kunlun Mountains. In addition to the activity of faults south of the ridge, part of the till was transported by the flow water, so the pass basin formed.

The Jingxiangu Formation. Lithologic statistics show that there was about 70% metamorphic rock, as well as a little basalt in the Jingxiangu Formation. But the source of the basalt is located around the Naij Tal[1)]. So this suggests that in the Pliocene epoch, when the Jingxiangu Formation deposited, the water flowed from north to south in the Pass area, and there were no Kunlun Valley and Xidatan Valley. Now we can draw the conclusion that the watershed between

1) Pan Yusheng, Zhou Weiming, Xu Konghua, The Geological character and evolution of the Kunlun Mountains in the early Paleozoic era, 1996.

the Qaidum and the Pass Basin was located north of the Naij Tal before the early Pleistocene. The east-west Kunlun Valley formed in the late period of the early Pleistocene and at the same time the watershed migrated south to between the Yeniugou and the Xidatan. The Xidatan Valley formed and the watershed migrated to the ridge of Kunlun Mountains in the middle Pleistocene. The Golmud River has cut through the ridge of the Kunlun Mountains since the Holocene epoch, and the watershed migrated to south again. Fig. 1 is the bird's-eye view of the structure and landform in the Kunlun Mountains Pass area. Fig. 2 is the sketch map of strata, structure and the geomorphologic development in the Kunlun Mountains Pass area. This reflected mainly the uplift-rift and the sudden uplift in the middle period of the Kunlun-Yellow River Movement.

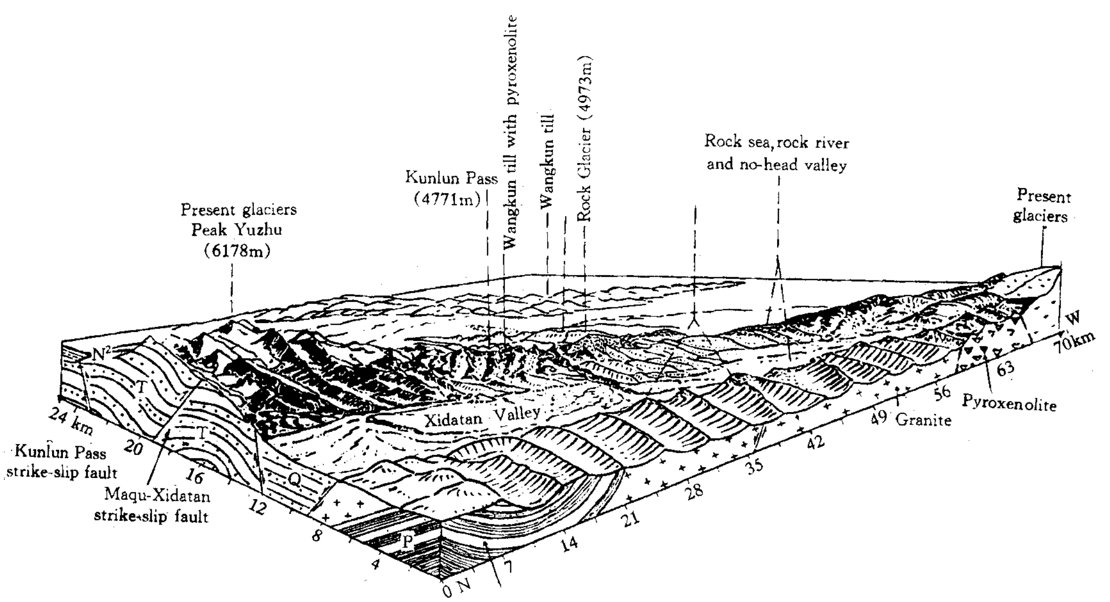

Fig. 1. Bird's-eye view of the structure and landform in the Kunlun Mountains Pass area.

2.2.2 Landform evidences. Figure 1 is the bird's-eye view of the structure and landform in the Kunlun Mountains Pass area. The east-west direction valley in the map is the Xidatan Valley. The South Mountains of the Xidatan (i.e. the ridge of the Kunlun Mountains) have a short and steep slope with glacier developed on it, and a long and gentle south slope with a thick bed of the Wangkun till on it, while the North Mountains of the Xidatan have a short and steep south slope with a rock river developed along it, and a long and gentle north slope with a U-shape valley along it. There is a block field on the top of the Mountains and till at the end of the U-shape valley. Upward the U-shape valley has a break at the ridge. There are neither main peaks nor cirques. This evident discoradance shows that there were tremendous changes before and after the development of the mountains. Instead of the Xidatan Valley, the main peak, i.e. the uplift center, was located in the place before the middle Pleistocene. The depression of Xidatan should occur after that time. So the till remains on the top of the south mountains. Considering the fact that the source of the Wangkun till is distributed in the North Mountains of the Xidatan, the depression of the Xidatan Valley should be during or after the glaciation. The maximum elevation of the till is

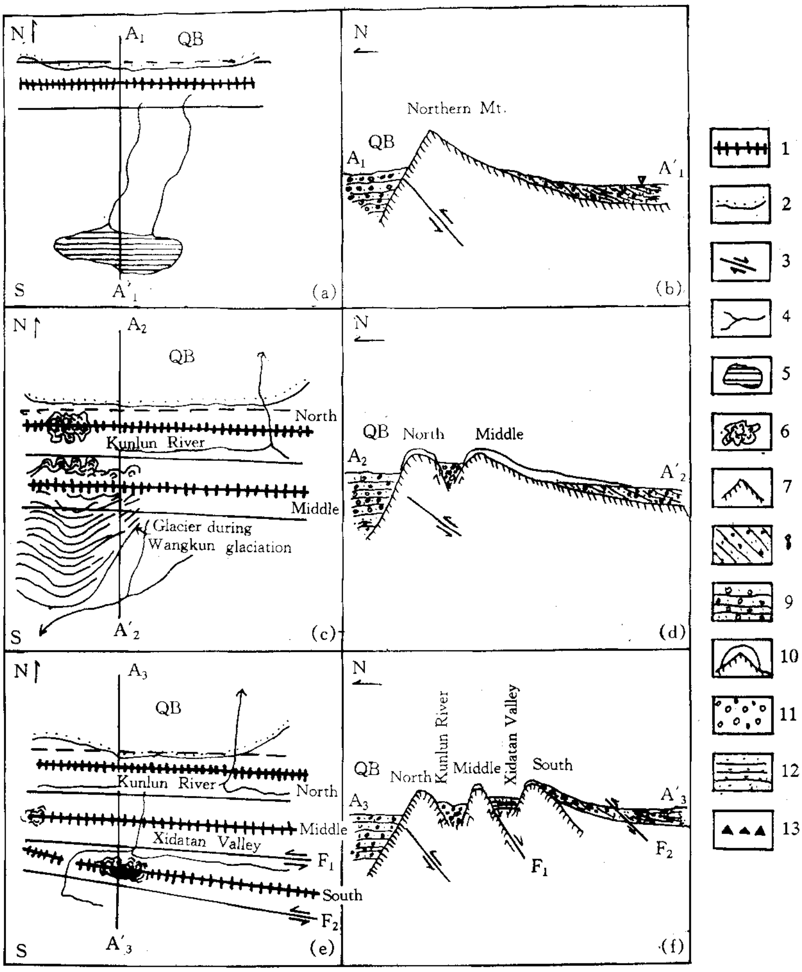

Fig. 2. The sketch map of strata, structure and geomorphologic development in the Kunlun Mountains Pass area.

5 300 m, and the elevation of the Xidatan surface is about 4 200—4 500 m. The thickness of sediment is about 300 m. Because the till should be distributed at the foot of the mountains at that time, the depression of the Xidatan should be over 2 000 m.

2.2.3 Evidences of sediment and structure. The Jingxiangu Formation and the Qiangtang Formation strata are distributed mainly in the Pass Basin. Analyses of sedimentary facies show that there are three tectonic evolution periods: early rifting period, steady subsiding period and shriveling and closing-up period. The early rifting period started at 5 MaB.P. Controlled by the tenso-shear stress field, the north side of the Pass Basin began to develop a series of normal faults and the bed of the basin sank violently. The uplift of the erosion area were quickly denuded, and then the coarse sediment at the bottom of the basin was formed. Following the decrease of the tectonic strength and the change of climatic conditions, the alluvial fan migrated north, the lake spread gradually, and then a transgressive succession formed with general coarsening-upward features. The steady subsiding period started at 2.1—2.5 MaB.P., and reached the maximum at 1.6 MaB.P. The shriveling and closing-up period started at 1.1 MaB.P. The area began to uplift slowly. The alluvial fan and fan-delta at the border of the lake prograded into the lake until the lake was completely filled.

The perfect section of the Jingxiangu Formation and the Qiangtang Formation is exposed around the former No. 62 Maintenance Squad of the Qinghai-Xizang highway. The strata trend SSW with an about 13-degree dip angle, discordance over the underlying Triassic strata. The elevation of the strata exposure is about 4 700—5 000 m, while the Naij Tal Gou Formation and the Sanchahe Formation, which deposited after the middle Pleistocene, are horizontal. This shows that the violent tectonic movement took place drawing the transition from the early to the middle Pleistocene, and caused the uplift of the Kunlun Mountains, tilted the Jingxiangu and the Qiangtang Formation and uplifted it to above the snow line (3500 m after Shi and Zheng[18]). Then it caused the broad development of glacier in the Plateau. So the till is discordant over the Qiangtang Formation. The Yeniugou Valley and the Xidatan Valley rifted afterward, then the Naij Tal Gou and the Sanchahe Formation deposited in it.

All the above evidence shows that the Kunlun-Yellow River Tectonic Movement passed through three uplift periods with the early period beginning 1.1 MaB.P. The elevation in Kunlun Mountains was not higher than 1500 m before that time. The surface of the Plateau uplifted over 3000 m at 0.7 MaB.P. and the maximum glaciation occurred. After that, the glaciation and tectonic movement ran at the same time till 0.6 MaB.P. Following the activity of the Maqu-Xidatan Strike-slipe Fault, fault-block mountain and fault depression valley were formed. The Xidatan Valley appeared. The till was uplifted to the top of the mountains. The result is the series of special landform and sediment mentioned above. This shows a sudden uplift in the middle period of the Kunlun-Yellow River Movement, and a fast uplift rate.

3 Significance in environmental change of the surrounding area

It has been stated in the past that the tectonic event drawing the transition from the early to the middle Pleistocene can divide the Quaternary into two tectonic periods: the Himalayan period and the New period[11]. The discovery of the Kunlun-Yellow River Tectonic Movement confirms that the movement between the early and middle Pleistocene is a very important one. We should fully consider its character and significance in the Quaternary environmental change.

If we think the Qinghai-Xizang Plateau uplift to be the critical elevation at the early Quaternary, and that the result is the formation of the Eastern Asia monsoon, which affects the environment of the Plateau itself and the surrounding area[16,17], then the Plateau uplifted to another critical elevation——3 000 m between the early and middle Pleistocene. The Plateau entered cryosphere[18] and formed the maximum glaciation. The area of glacier was 18 times today's. The total area of glacier was about 1.7 million km^2, and about 60% of the Plateau was white, and the reflection rate of the surface was about 0.6. In winter, the reflection rate of the surface of glacier was still 0.6. Based on calculation[19], the earth-air system of the Plateau was a cold source except from May to October during the maximum glaciation. The annual mean was also a cold source. But in the early Pleistocene, it was a cold source in winter but a strong warm source in summer, and the annual mean was a warm source. This big change of cold and warm sources must have caused big changes of atomspheric circulation. In summer, the west wind passed the north and south sides of the Plateau, but the north branch shrank and the south strengthened, with the result that almost all the west wind passed the south side of the Plateau. But now as well as in the early Pleistocene, the west wind migrated to the north side of the Plateau in summer, so the western part of the Plateau (specially the northwestern part), became dry, while the eastern part became humid, causing violent floods in the middle and lower parts of the Yangtze River[18]. In winter, because the reflection increased, the cold high and the anticyclone were strengthened, and the winter monsoon was strengthened too. The silt, formed by the repeated thawing and glacial milling, was flown by wind and deposited on the eastern side of the Plateau and the surrounding area.

The local drift sand on the northwestern side of the Plateau formed a large desert. On the eastern side of the Plateau, the wind blown loess became coarse and its deposition range exbanded. Periglacial loess began to appear on the eastern part of the Plateau, and the other environmental changes mentioned at the beginning of this paper occurred.

In addition, according to Liu et al.[20], both the East Asia and Australia have the same climatic record in the thermal maximum of Holocene. This perhaps is the result of the East Asia winter monsoon circulation in relation with the Mongolian high system passing through the equator and strengthening the Australian summer monsoon. The interaction between the monsoon climates of the southern and northern hemispheres through air currents passing the equator perhaps began to become evident at 0.6 MaB.P. Whether the strengthening of summer monsoon in the East Asian interglaciation and the change event of Australian climate were related with the tremendous movement. And what effects there had been from the opposite Hemisphere on these climate events needs further systematic investigation.

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