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RESPONSE OF RIVER TERRACES TO HOLOCENE CLIMATIC CHANGES IN HEXI CORRIDOR, GANSU, CHINA①

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ABSTRACT: The Hexi Corridor is a Cenozoic foreland basin system at the northeast front of the Qinghai-Xizang (Tibet) Plateau. The Shiyang River, Heihe River, Beida River and Shule River, rising in the Qilian Mountains, developed two Holocene terraces each in the plain area of the Hexi Corridor. ^{14}C ages of alluvial fills show that the lower terraces formed between 5.57 ka B.P. and 3.15 ka B.P., the higher terraces formed between 12 ka B.P. and 8 ka B.P., and there was downcutting period from 8 ka B.P. to 6 ka B.P.. Comparing the alluvial terraces with the Holocene climatic changes, it is concluded that the downcutting period was coincident with the stable warmer and wetter climate, and the aggradation took place when the climate was changing either from drier to wetter or from wetter to drier. It is the climatic changes that caused the variations of vegetation density, soil erosion, and river sediment yields which controlled the aggradation and degradations of the rivers.
KEY WORDS: river terraces, climatic changes, Hexi Corridor

I. INTRODUCTION

The Hexi Corridor is a Cenozoic foreland basin system at the north front of the Qilian Mountains. Rivers in the Hexi Corridor mostly rise in the Qilian Mountains, flow from the south to the north, and disappear in deserts in the north. The terraces studied in this paper are located on the lower plains which are tectonic depressive areas in the Hexi Corridor.

The present climate in this area is continental arid. The mean annul precipitation is 162 mm in Wuwei, 125 mm in Zhangye and 86 mm in Jiuquan from east to west. Precipitation in the Qilian Mountains of over 4000 meters above sea level is over 500 mm. The melt water from snow and glaciers on high mountain is an important supply to the rivers.

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The Shiyang River has two terraces in the plain area. On a section on the left bank of the Shiyang River, the alluvial fill of the T_2 is unconformable on the Late Pleistocene series. Radio carbon ages show the sludges in the upper part of the Late Pleistocene series formed 21.29 ± 0.87 ka B.P. The lower part of the alluvial fills, 4 meters thick, are yellow middle-fine sands interbedded with silt clays. The silts from the Lower of the lower parts of the alluvial fills have been dated to be about 12.38 ± 0.09 ka B.P. by the ^{14}C dating method. The upper part of the fills are brown silt clays with ^{14}C age of 9.32 ± 0.09 ka B.P. near the bottom (Cao, 1989) (Fig. 1a).

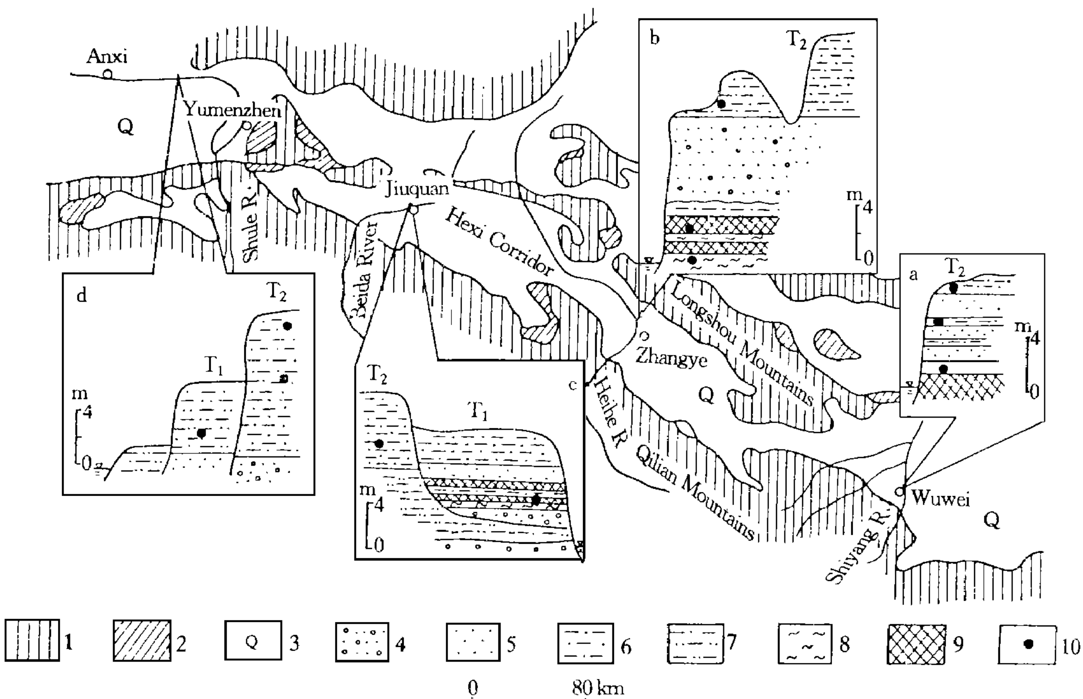

Fig. 1 Geomorphologic map and river terrace sections in the Hexi Corridor

1 Rock mountain 2. Hill of Tertiary sediments 3. Quaternary sediment basin 4. Gravel 5. Sand 6. Silt 7. Silt clay 8. Sludge 9. Peat 10. Location of ^{14}C dating samples

Similar to the Shiyang River, the Heihe River also developed two terraces in the plain area. A natural section shows the structure of the higher terrace in the east of the Pingyuan village. The T_2 fill rests unconformably on sludge and peat soil. Two ^{14}C ages from the top of the soil are 15.83 ± 0.26 ka B.P. and 13.23 ± 0.16 ka B.P. The lower part of the T_2 fills was dated to be 9.36 ± 0.33 ka B.P. (Cao, 1989) (Fig. 1b).

The Beida River has two terraces on the left bank in the north of the Jiuquan City. The lower part of the higher terrace (T_2) is of gray sand gravels. The gravels are 5– 8cm in sizes and well rounded. The middle part of the T_2 fills, 7.4 meters in thickness, is of gray middle sands. The upper part of the T_2 fills are yellow fine sands, ^{14}C age of its lower part is 10.78±0.1 ka B.P. The bottom of the lower terrace (T_1) is of rounded gravels with size of 3- 5 cm, containing animal fossils and broken rough potteries of the Shajin Culture. The lower and middle part of the T1 fills, 2.3 m thick, are of black, gray clays and peats. The ^{14}C age of the peats is 5.77±0.12 ka B.P.. The upper part of T_1 fills, 3.5 meters in thickness, ^{14}C ages ranging from 3.03±0.06 ka B.P. to 3.53±0.06 ka B.P. (Cao, 1989), is claysilts containing gravels, animal fossils and potsherds (Fig. 1c).

The Shule River has two terraces in the north of Bulongji. The lower part of the high terraces (T_2), over 1.5 meters thick, is gray sands and gavels. The gravels are well rounded and their general size is 3- 5 cm. The middle part of the T_2 is yellow and gray middle and fine sands with cross bedding. The upper part of the fills is yellow claysilts. Two ^{14}C ages from the lower and the upper part of the T_2 are 10.9±0.12 ka B.P. and 8.68±0.75 ka B.P. respectively. The lower part of the lower terrace (T_1) is of sands and gravels with a thickness over 0.5 meter. The middle part of T_1, 1.7 meters thick, is black peat, which is dated to be 5.68±0.08 ka B.P. (Cao, 1989). The upper part of T_1 is yellow silt with a thickness of 2.4 meters (Fig. 1d).

As mentioned above, in the down-warped plain area, all rivers have two terraces. The river terraces indicate that the rivers in the Hexi Corridor Plain have two times of aggradation and degradation processes respectively during the Holocene. ^{14}C ages show that the first aggradation took place from 12 ka B.P. to 8 ka B.P., the second 6 ka B.P. to 3 ka B.P., and the first degradation was during 6 ka B.P. and 8 ka B.P., the second happened after 3 ka B.P..

Table 1 ^{14}C ages of river terraces in Hexi Corridor (ka B.P.)

	Shiyang River	Heihe River	Beida River	Shule River
T_2	9.32±0.08	11.5±0.09 9.36±0.33	10.78±0.1; 7.86±0.1	11.0±0.1; 10.9±0.12 8.68±0.075
T_1			5.77±0.12; 5.68±0.08 3.53±0.06; 3.03±0.06	3.15±0.06

III. PALAEOCLIMATE

In China, 8.5- 7.2 ka B.P. is a transitional period from warmer to cooler. 7.2- 6.0 ka B.P. is a stable warmer period. From 6.0 ka B.P. to 3.0 ka B.P., the climate was relatively warmer, but there were some fluctuations. For example, the climate fluctuated greatly during 6.0- 5.0 ka B.P., and there were some cold events during 5.0- 4.0 ka B.P.. Since 3 ka B.P., temperature decreased greatly (Shi *et al*., 1992).

Synchronous changes in global temperature occurred in the Holocene and had disparate regional effect on precipitation(COHMAP, 1988). For example, after the Wisconsin glacial, general climatic warming produced drier conditions in parts of Canada and the Great Basin of the united states, while increased monsoon activity is suggested from palaeoecological records in the southwestern United States(Chatters *et al.*, 1986). In China, it is recognized that in the Megathermal, the precipitation was richer, and the general climatic warming produced wetter condition. For example, in the northwestern China, during the Megathermal, the Kumukuli Lake and Chaiwopu Lake had high water levels, and precipitation was 70% - 80% in the Qinghai Lake, 40% in the Daihai Lake, more than present (Shi *et al.*, 1992; Shi, 1990; Wang *et al.*, 1990).

Fossil pollen analyses in the Hexi Corridor show that, before 7.2 ka B.P., percentage of ligneous plants, herb and pteridophyte were 17.5%, 75%, 7.5% respectively in the Wuwei basin, and 11.8%, 74.8% and 13.4% in the Zhangye basin; between 7.2 and 3.15 ka B.P., they were 28%, 26.2% and 45.8% in the Wuwei basin, and 38.8%, 35.8% and 25.3% in the Zhangye basin; since 3.15 ka BP, the percentage of ligneous plants increased at first and declined later, while the herb had a negative trend(Cao, 1989). These data suggest that in the middle Holocene, about 7.2- 3.15 ka B.P., the climate was warmer and wetter in the Hexi Corridor. This is similar to the general trend of climatic changes in China.

IV. DISCUSSION AND CONCLUSION

The main controls to the formation of river terraces are tectonic movement, climatic changes and erosion basement changes(Brakenridge, 1989). The river terraces obviously response to the climatic changes where the tectonic is stable(Chatter and Hoover, 1986; 1992; Martin, 1992; Dethier *et al.*, 1988; May, 1889). In the Hexi Corridor Plain, a tectonically down-warped region, the tectonic movement is not advantageous to the development of terraces, and the erosion basement of the rivers has been relatively stable in the Holocene, so the fluvial terraces have been mainly controlled by the climatic changes.

Table 2 Climatic changes and river actions in the Hexi Corridor

Stage	Age(ka B.P.)	Climate	River action
1	11.5- 8.68	Transiting from cooler and drier to warmer and wetter	T_2 filling
2	8.68- 5.77	Stable warmer and wetter	Downcutting
3	5.77- 3.03	Transiting from warmer and wetter to cooler and drier	T_1 filling

Comparing the river terraces in the Hexi Corridor Plain with the climatic changes, it can be found that the aggradation took place when the climate was transiting. The lower terraces were formed between 5.57 ka B.P. - 3.15 ka B.P., which was a transitional period from warmer and wetter to cooler and drier, and the climatic fluctuation was great. The high terraces were formed between 12 ka B.P. and 8 ka B.P., when the climate transited from cooler to warmer and fluctuated greatly. The degradation took place when the climate was stable warmer and wetter.

Fluctuations of temperature and precipitation can result in variations of vegetation density, soil erosion, and runoff and sediment yields of rivers. All of these variations can cause the aggradation or degradation of the rivers. When the climate is stably warmer and wetter, runoff and vegetation density are higher, sediment yield is lower. This results in enlargement and incision of the channels. When climate changes from cooler and drier to warmer and wetter, the runoff increase because of the increase of precipitation and melt water, the soil erosion becomes stronger and sediment yield getting higher because the vegetation has not recovered yet, floods can cause deposition in the plain area with low river bed slope angle. When the climate changes from warmer and wetter to cooler and drier, because sediment yields increased as both hillslope and channel erosion increased, and runoff decreased, deposition in the channels may be resulted. When the climate is stably cooler and drier, runoff decreased as precipitation and snow melting reduced, though the frost weathering can produce a great deal of debris, the competence of river is lower, the deposition in the middle downwarped plain is limited.

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