The Holocene Palaeoclimatic change in southern vicinity of Tengger Desert

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Abstract Through stratigraphy and chronology studies on Hongshui River section located at the southern vicinity of Tengger Desert, and based on the analysis results of TOC, TIC, elements, stable oxygen isotope that possess a high resolution of 40—50 a, the paleaoclimatic change history during last 8 000—3 000 a has been reconstructed.

Keywords: **Tengger Desert, Holocene, Paleaoclimate.**

THERE is abundant paleaoclimate information recorded in the alluvial-fluvial-lacustrine deposits in arid areas. Because of the extreme natural environments in the area, the climatic change processes may possibly be printed sensitively in the continuously deposited sections. Applying multiple scientific methods to reveal this information is of very important scientific meanings for the study of the paleaoclimatic environment change history and calculating the future climate change tendencies in the arid areas. Hongshui River section, which is located at the southern vicinity of Tengger Desert, is one of the most suitable outcrops in the area that enable us to conduct paleaoclimate reconstruction.

1 Study area and method

The study area, which administratively belongs to Wuwei City and Minqing County, is located at the transit between Tengger Desert and Wuwei alluvial-fluvial fan. In the north direction, there are vast arid areas including Tengger Desert, in the southeast, Loess Plateau, and in the southwest direction, the high mountain and plateau. Climatically, the area is situated at the intersection among the arid-hyparid of northwest China, southeast arid-semiarid and southwest cold high mountain-plateau. Therefore, the area is very sensitive to the climatic changes and is an ideal locality for the study of the regional even global climatic changes.

The Hongshui River section is situated on the east bank of Hongshui River bridge which is on the high way from Wuwei to Minqing(38°10′46″N, 102°45′53″E), 1 460 m above the sea level. The annual average temperature is 7.8℃ and the annual average precipitation is 140 mm; it is a typical arid continental climate condition. Hongshui River, which is flowing from southeast to northwest, actually is a river formed by streams coming out from Wuwei alluvial-fluvial fan; it joins the main river, Shi Yang River at Ying Panpao. Because of the movements of the dunes from northeast to the river and the southwestward erosion by the springs, a long stretched outcrop along the river has been formed. The section is a typical Holocene section in the area (figure 1).

The studied Hongshui River section is 6.2 m in thickness and it can horizontally be traced a long distance. The strata can be clearly divided into 5 layers from the bottom to the top. First layer, from 6.20 to 5.00 m, is a layer of alluvial-fluvial siliceous sand -gravel with cross-bedding; the second layer, from 5.00 to 3.35 m, is composed of fluvial-alluvial sand with interbedded gravel, bedding developed and silty clay balls and tree roots can be seen in it; the third layer, from 3.35 to 1.98 m, can be divided into two parts; the lower part was composed of silty-clay with enriched roots, then transited upward into clayey-silt and wind transported fine sand from 2, 25 to 1.98 m (in this layer, there are two peat layers which appeared from 3.35 to 3.20 m and 2.74 to 2.68 m); the fourth layer, from 1.98 m to 1.10 m, is a layer of typical lake deposits which are rich in grayish-white carbonate and fossil mollusks; the fifth layer, from 1.10 to 0 m, was shallow water deposited clay silt to silty clay with fine bedding; their components are uniform with few changes. From this carefully measured section continuous samples have been taken. In the lower part, from 6.20 to 5.00 m, we took a sample every 10 cm, and from 5.00 m to the top, we took one sample every 5 cm. Totally there are 101 samples obtained and analyzed which include geo-

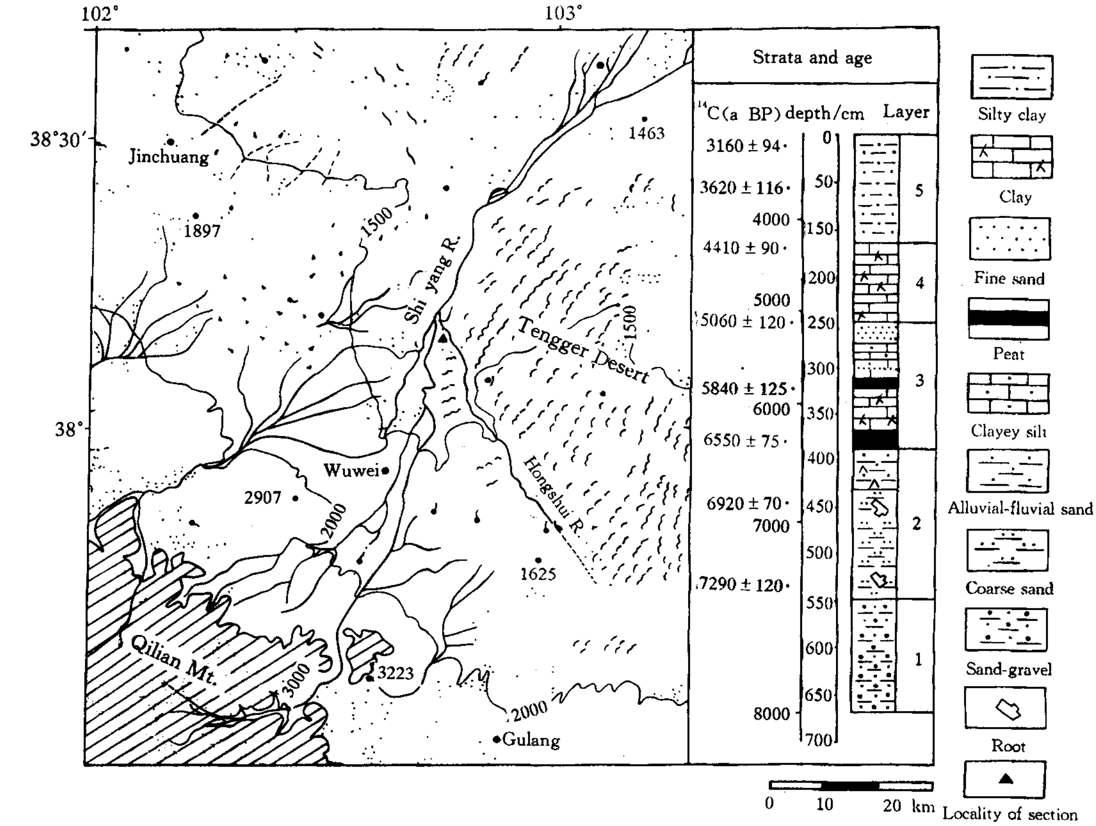

Fig. 1. Locality and stratigraphy of Hongshui River section.

chemical environmental indices and pollen identifications. 9 organic C-14 dating results were obtained (table 1).

Table 1 C-14 dating results on Hongshui River section

Depth/cm	7.5	57.5	122.5	127.5	192.5	277.5	325	400	475
Age/a	3 160 ± 94	3 620 ± 116	4 410 ± 90	4 520 ± 122	5 060 ± 120	5 840 ± 125	6 550 ± 75	6 920 ± 70	7 290 ± 120

The depth-age correlation analyses results show that the coefficient is 0.992, there is no hiatus in the section. The analyzed results can provide a resolution of 40—50 a climatic change history between 8 000 to 3 000 a.

2 Geochemical analyses results and environmental indices

ICP method has been used for elements analyses, such as Al, Fe, Ca, Sr, Mg, Mn, P(PO4), K, Na. TOC and TIC have been analyzed by common laboratory processes; stable isotope $\delta^{18}O$ of the carbonate in clayey section has been measured by mass spectrometer MAT252.

The content of $CaCO_3$ and its related elements, Ca, Sr, Mg, have been chosen as the indices of water dynamics, water depth and water property, TOC as the indices of organic productivity which is related with the precipitation and temperature, the element content of Fe as the indices of Eh-pH conditions, the content of element Al which is related with the content and type of clay minerals as weathering intensity[1], and the $\delta^{18}O$ of carbonate in clay section as the index of temperature, whose decrease indicates a temperature increase, the increase means of lowing of the temperature. All these indices can be summarized in figure 2.

3 Pollen analyses results

Based on the analyses of palynomorphs and variation of pollen concentrations, the following sporo-

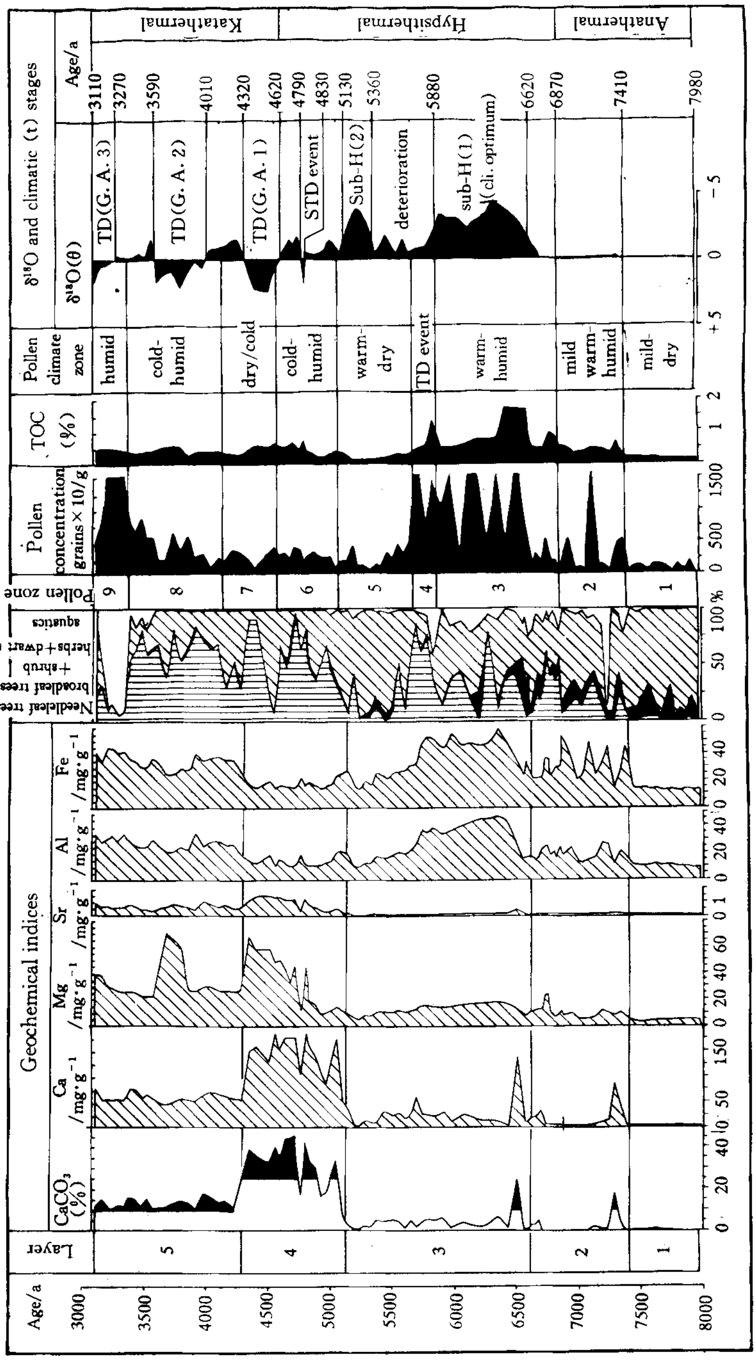

Fig. 2. Climatic environmental indices of Hongshui river section and climate stage division.

pollen assemblage zones may be recognized.

Zone 1. 7 890—7 410 a, generally speaking, the pollen concentration is very low. Sporo-pollen assemblage, in steppe taxa, notably *Artemisia* and *Chenopiaceae* indicates an arid climatic condition.

Zone 2. 7 410—6 870 a, pollen concentration is higher than that in zone 1. The content of steppe taxa decreased relatively but the pollen content of wetland taxa, *typha* increased. Traces of needleleaf trees, broadleaf trees, shrubs' pollen, together with high proportions of wetland taxa reflect a grassland vegetation, increased moisture and a mild warm-humid climactic condition with drastic oscillations.

Zone 3. 6 870—5 880 a, during this time, pollen concentration is the highest and various species were the most developed in the section. Decrease in the steppe taxa species coincides with a slight expansion of needleleaf trees, broadleaf trees and shrubs that indicate the development of the forest. On the other hand, this zone is also characterized by the abundance of wetland and aquatic indictors. All these reflect a forest-grassland under a warm-humid climatic condition. Among it the climate from 6 620—5 880 a was the warmest and most humid stage that can be regarded as the climate optimum stage recorded in Hongshui River section.

Zone 4. 5 880—5 680 a, pollen concentration is also relatively high. The content of needleleaf trees, such as *Piece* increased considerably, indicates a drastic temperature decrease which represents an abrupt climate cooling event in Middle Holocene Megathermal.

Zone 5. 5 680—5 080 a, pollen concentration is low. The predominant taxa in this zone are *Artimisia*, *Chenopiaceae* and traces of wetland taxa. This sporo-pollen assemblages show an arid steppe vegetation and indicate a warm-dry climate.

Zone 6. 5 080—4 580 a, pollen concentration is low. The content of needleleaf trees, which mainly are *Pinus* and *Picea*, increased greatly, some of the grass species can also be seen. Generally the vegetation is a type of needleleaf trees, indicating that the temperature decreased than zone 5 and the climate was cold and humid.

Zone 7. 4 580—4 140 a, pollen concentration is low. The species of dry grassland and needleleaf trees dominated alternatively, indicating a climate condition with drastic dry-cold fluctuations.

Zone 8. 4 140—3 370 a, pollen concentration is low. The pollen assemblages show it was a needleleaf-tree-dominated vegetation and represented a cold-humid climate condition.

Zone 9. 3 370—3 110 a, in this zone, the wetland taxa, such as *Typha*, increased greatly to make up 80% of the total pollen. This situation indicates that the moisture increased considerably than before and is a humid stage.

4 Holocene paleaoclimate reconstruction in the vicinity of southern Tengger Desert

Based on the stratigraphy analyses, chronology establishment, element, TOC, TIC content variations, carbonate $\delta^{18}O$ measurement and pollen identification and assemblage divisions, the history of climate change in the vicinity of southern Tengger Desert has been reconstructed as follows.

From 7 980 (the bottom age of the studied section) to 6 870 a is the Anathermal period that can be divided into two stages. Before 7 410 a, the stratum was composed of alluvial-fluvial siliceous materials, and their grains are much more coarse. The chemical contents of $CaCO_3$, TOC and elements Ca, Sr, and Mg are very low. The element contents of Al and Fe are only 10 and 15 mg/g respectively, and there are very few content changes in different samples. This evidence suggests that the environment humidity was very low, the vegetation was very sparse and the organic productivity was very small. This stage coincides with pollen zone 1. All these data reflect a mild dry climate condition. From 7 410 to 6 870 a, the materials were alluvial to shallow water deposits. $CaCO_3$ and Ca, Sr contents of some samples increased but most of them were near zero. Both the minimum and the maximum values increased. This stage correlates to the pollen zone 2 that reveals a climate condition characterized by increased humidity and strong fluctuations of temperature.

From 6 570 to 4 620 a is the Hypsithermal period recorded in the section. The stratum includes the upper part of layer 2, layer 3 and part of layer 4. It was composed by two peat-lake deposited layers topped by silt to wind-transported sand, and then changed into typical lake deposits again. Fig. 2 shows that in the strata from sand layer downward, the content of $CaCO_3$, element Ca, Sr, and Mg are all very low except for a few samples, but the content of element Al, Fe and TOC get their maxima in the section, which are 48 mg/g, 58 mg/g and 15.4%, respectively. The value of $\delta^{18}O$ also reaches its lowest, −10.3‰. This stage corresponds to the pollen zones 3—6 that show a clear climatic environment change process. Based on these properties and according to the changes in $\delta^{18}O$, the Hypsithermal period can be divided into the following different stages: from 6 870 to 6 620 a, the temperature was increased, then, the first high temperature period occurred and climate optimum formed during 6 620 to 5 880 a. Stratigraphically it was composed of two peat layers and the interbedded lake deposits. The content of TOC, Al and Fe all reached their maximum values; $\delta^{18}O$ was the lowest value. These climatic indices show a warm and humid climate. From 5 880 to 5 360 a, the strata were composed of stagnant lake-swamp silty clay to shallow lake clayey silt. The content of Al, Fe and TOC were decreased and the $\delta^{18}O$ increased with a fluctuation. All these show that the temperature during this time decreased and three cold stages were formed. At the same time, it became drier and drier. Among these three cold stages, the earliest one coincides with pollen zone 4, which represents a strong temperature decrease stage. From 5 360 to 5 130 a, it was the second warmest stage, where the stratum was composed of fine eolian-transported sand which indicate southward expansion of the movable sand dunes; it is the geological evidence of the climatic deterioration. Low and stable $\delta^{18}O$ values show it was a stage of high temperature. Pollen analyses results indicate that the vegetations were mainly *Artimisia* and *Chenopiaceae*, which grow under a warm-dry climatic condition. From 5 130 to 4 620 a, it was a time when the lake fully developed, the content of TOC increased and the $\delta^{18}O$ values were higher than those of the second warmest stage, meaning that the temperature decreased somewhat than before. The pollen assemblage was composed of needleleaf trees, which were mainly *Pinus* and *Picea*, and indicate a cold-humid climate. During this period, there existed a strong temperature decrease event from 4 830 to 4 790 a, prior to the deterioration of the Holocene Hypsithermal.

From 4 620 to 3 110 a (top of the studied section) is the Katathermal period. There were three long lasting strong temperature decrease stages that occurred from 4 620 to 4 320 a, 4 010 to 3 590 a and 3 270 to 3 110 a. This period coincides with the pollen zones 7—9 and experienced dry/cold, cold-humid and humid climate change processes.

5 Discussions

Along with the deepening of the scientific research on Holocene, the three periods division concepts of the Holocene, which includes Anatheraml period of early Holocene, Hypsithermal period of Middle Holocene and Katathermal period of Later Holocene, have been widely accepted. However, the division of this 10 ka Holocene is very different from others. For example, the beginning age of the Hypsithremal period is between 10 ka to 7.5 ka, and the ending age is from 5 to 2 ka[2]; the differences are as big as 2 500 to 3 000 a. Some authors even regarded the divided three periods based on the temperature as equal to that divided by bioclimatic condition controlled by both temperature and precipitation, such as climate optimum. These misuses and misunderstandings have made the concept of Holocene more and more complex[3, 4]. With the this exception, the differences of the indices, such as pollen, $\delta^{18}O$ of ice core, which have been used to divide the Holocene, the representativeness, continuity, resolution and the reliability of the information recorded by the studied section[3, 5], are all to be taken into account.

In this study, the concepts of Anathermal, Hypsithermal(Megathermal) and Katathermal have been used to maintain the continuity, consistency and integrity. Some special changes were treated as sub-order events.

Except the above division of the Hypsithermal duration on the records of Hongshui River section, a broad Megethermal period can be separated out if some cold time and deteriorated climatic situations with unbalanced humid-temperature collocations are included[2]. This broad Megathermal lasted from 7 410 to 4 010 a and coincides with that in center Inner Mongolia, but is later than that in northeast and north China[7—9]. The reconstructed Holocene climate change history from Hongshui River section in vicinity of southern Tengger Desert indicates that the main frame of the climate change is similar. But on the other hand, there are also some distinguished differences reflecting the climatic sensitiveness of the studied area which is located in the inner continent and influenced by two different circulation systems——Asian monsoon and westly. The climate optimum of the megathermal occurred from 6 620 to 5 880 a, the highest temperature centered at 6 290 a, and at 6 060 a the temperature dropped. Between 5 880 to 5 360 a, the climate became drier and the temperature decreased, and the low temperatures occurred at 5 660, 5 560 and 5 380 a. These three times temperature decreasing events can be correlated with the Dongde ice core records on high mountains. Among them, the earliest one, which coincidesd with pollen zone 4, was much more effective and can be correlated with the dramatic temperature decrease in north and northwest China studied by Yang Zhigen and Hong Xueqing; it can also be correlated with the glacier advances during 5 700 and 5 530 a in Tianshan Mts. in west China[10, 11], and coincides with the second New Glacier at Ca. 5 800 a by Denton. Therefore, it was a climate deterioration period with high frequency and magnitude property during the Middle Holocene Megathermal[2], which might be crucial to the human civilization. During 5 360 to 5 130 a, the second sub-hypsithermal occurred, the stratigraphical and geochemical evidence shows it was a warm-dry period. Pollen analyses results also revealed that *Artimisia* and *Chenopiaceae* were the main components during the time, which have been provided to present a warm-dry climate condition based on the resent study results[6]. In this aspect, what is different from previous conclusions is that the period was a cold-dry moment. From 5 130 to 4 620 a, though the temperature was lower than before, the humidity increased. The short but strong temperature decrease during 4 830 to 4 790 a indicates the decline in the Megathermal in Middle Holocene and was the presage of the temperature decrease between 4 620 to 4 320 a. Afterwards, the temperature and humidity increased from 4 320 to 4 010 a and there formed a mild warm-humid stage. But later, the temperature decreased again between 4 010 to 3 590 a, which might be correlated to the interval of glacier advance during 4 100 to 3 950 a on nearby high mountains, e.g. the enlargement of Gulia ice cap at $(3\ 983 \pm 120)$ a[12]. Although the temperature rose again somewhat after 3 590 a, it decreased considerably at 3 270 a, and there formed another cold stage that might be correlated to the mountain glacier advances during New Glacier between 3 100 to 2 500 a. At Ca. 3 000 a, which was as important as a pivot time, the climate in studied area deteriorated further, desertification processes prevailed, sand dune intruded and erosion occurred. During the last Ca. 3 000 a, the climate possibly took a turn sometimes but never recovered as favorable as before.

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