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# Vegetation evolution and human expansion on the Qinghai–Tibet Plateau since the Last Deglaciation

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ABSTRACT

The spatial patterns and changes of vegetation on the Qinghai–Tibet Plateau (QTP) since the Last Deglaciation (16–5 cal. ka BP) are reconstructed by fossil pollen records from 36 sampling sites. The modern analogues technique and isochrones of 15% of arboreal pollen are used. The results show that the plateau vegetation pattern has been meadow-steppe since ~14 cal. ka BP, which replaced desert-dominated pattern during the Last Glacial Maximum (LGM). Vegetation zones of QTP have moved and expanded from the southeast to the northwest, the edge to the hinterland, and low altitude to high altitude. The most significant expansion occurred during 14–11 cal. ka BP and 8–6 cal. ka BP, reached the westernmost extent at ~6 cal. ka BP, and then began to retreat to the east. In the meantime, human activities began to flourish in the northeastern margin of the plateau at ~14 cal. ka BP, the age of the earliest human remains of the plateau. The vegetation expansion during 8–6 cal. ka BP drove humans further to the hinterland and the western regions such as Kekexili and the Qiangtang Plateau. Moreover, the archaeological chronology of human remains in the eastern region is earlier than those from the hinterland. These all indicate that human activities have been greatly affected by changes and expansion of vegetation on the QTP.



## 1. Introduction

The study of prehistoric human activities on the QTP has been increasing in recent years, because the QTP is one of the world's geographical units with a unique natural environment and its harsh environment makes it one of the most difficult areas for human occupation (Brantingham and Gao, 2006; Madsen et al., 2006; Gao et al., 2008). Environment change has been suggested to be a very important factor which dominates human migration and expansion. The world's subtropical deserts were considerably wetter than toady during the early to mid-Holocene. The Sahara was reoccupied at ~10 cal. ka BP and its central region was occupied by hunter-gathers following the monsoonal rain as they moved northwards into the interior (Nicoll, 2004). The reduction of rainfall occurred across the North Africa, the Near East, and Arabia since ~6 cal. ka BP, and it ended the practices of Neolithic herding in the desert interiors of Arabia and North Africa and forced these people to move to the mountain uplands (Brooks, 2006). The earliest human activities on the coastal lowlands in the Peruvian Andes occurred around 11–12,000 years ago, and high elevation environments were attractive after 11 cal. ka BP years, which indicated environmental changes could drive humans to move from littorals to mountains (Aldenderfer, 1999).

The most notable change of vegetation happened on the QTP since the Last Deglaciation (Yu et al., 2000; Ni et al., 2010). The temporal–spatial vegetation variation on the plateau during the whole Holocene has been studied. Tang (2011) noted that in the early Holocene, the vegetation in the east of the plateau were dominated by mixed conifer and deciduous broad-leaved forest, and meadows or shrubs appeared in the middle of the plateau. There was a steppe vegetation landscape in the west. In the middle Holocene from the east to the west of the plateau, the vegetation was sequentially mixed conifer and deciduous broad-leaved forest or sclerophyllous broad-leaved forest-conifers, and mixed deciduous broad-leaved forest or shrub, meadow and steppe.

Moreover, human activities on the QTP suddenly became active since the Last Deglaciation and in the mid-Holocene. These human activities had even changed vegetation landscapes on the plateau (Miehe et al., 2009). This article aims to explore the intrinsic relationship between the vegetation change and the migration of

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humans by reconstructing in more detail the millennial-scale vegetation distribution from 16 to 5 cal. ka BP on the QTP.

## 2. Modern vegetation distribution on the QTP

The QTP, with an area of over 2.3 million km$^2$ and an average elevation of over 4000 m asl, is the largest and highest mountain plateau on Earth. Strongly controlled by monsoon and westerly circulation, the plateau climate presents horizontal gradients of warm and moist, cold and semi-humid, cold and semi-arid, and cold and dry from the southeast to the northwest. Vegetation distribution on the QTP is largely influenced by summer monsoon rainfall which comes from the southeast and southwest. It is characterized by a zonal pattern from the southeast to northwest following a gradient of decreasing moisture, ranging from forest, alpine shrub-steppe (meadow), steppe, to desert (Fig. 1) (Hou, 2001).

In addition, due to the complex topography with dozens of high mountains on the plateau and its edge, the vertical zonality of vegetation is distinct and diverse. The horizontal lowest zone of the vegetation in the southeast is forest, followed upward by alpine shrub, alpine meadow, alpine cushion belt, alpine sparse vegetation, and permanent snow cover, so the structure is complex. Alpine desert marks the lowest zone within the plateau, and the structure is extremely simple. The vertical zones in the southwest from the lowest are alpine steppe, alpine sparse vegetation, and permanent snow cover (Wu, 1980).

## 3. Vegetation changes since the Last Deglaciation

### 3.1. Methods and data

#### 3.1.1. Modern analogues technique of pollen – vegetation

The modern analogues technique (MAT) is one of the important methods to determine the paleo-environment (Guiot, 1990; Larocque and Bigler, 2004). Pollen analysis is a very useful approach to reconstruct vegetation types in the past (Moor et al., 1991). Data needed for reconstructing paleovegetation types are composed of fossil pollen, modern surface soil pollen, and modern surface pollen corresponding to modern vegetation types.

One of the most common modern analogues techniques (Guiot, 1990) uses the squared-chord distance (Euclidian distance between two points in the n-dimensional space defined by the square root of the pollen percentages) to determine the similarity between a given fossil pollen spectrum and each spectrum in the reference pollen dataset. Small non-similarity coefficient and lesser difference between the two indicate that modern vegetation types represented by the surface pollen and ancient vegetation types represented by the fossil pollen are the same or similar. The calculation formula of non-similarity coefficient is as follows:

$$d_{ij} = \sum_k \left(p_{ik}^{1/2} - p_{jk}^{1/2}\right)^2 \quad (1)$$

$d_{ij}$ is the difference distance between the surface pollen j and the fossil pollen i, k is the pollen type, $p_i$ is the proportion of the fossil pollen i, and $p_j$ is the proportion of the surface pollen j.

In the study, we average the vegetation variables estimated for the three best modern analogues by means of inverse weighting of the chord distance. Analysis is performed by using the Polygon2.2.4 software (Nakagawa et al., 2002).

#### 3.1.2. Data

Fossil pollen from 36 sites on the QTP since 16 cal. ka BP were used in our study (Table 1, Fig. 2). These data are selected on the basis of the validity of sampling. The fossil pollen were mainly collected from turf and closed lake sediments, which reflect the status of local and regional vegetation (Briks and Briks, 1980). Sampling resolution was roughly centennial-scale and used

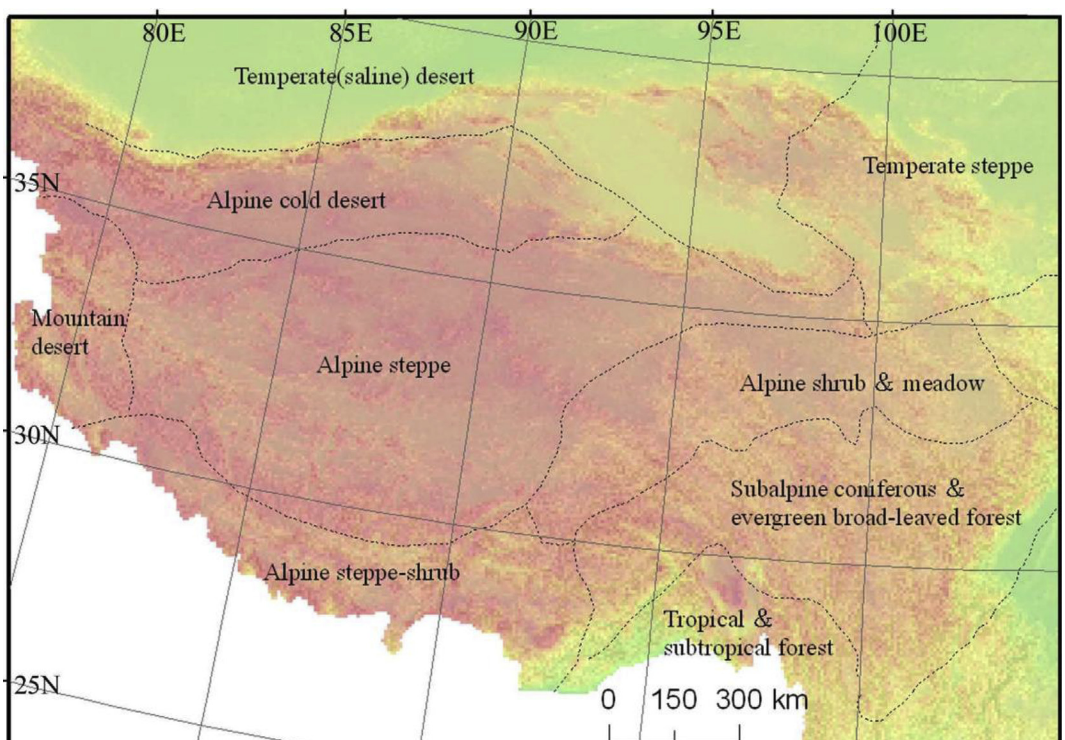


**Fig. 1.** Vegetation horizontal distribution on the QTP (modified from Hou, 2001).