
On the origin and development of steppe vegetation in China

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An evaluation on the origin and evolution process of Chinese steppe vegetation is carried out based on the pollen data documented from the Tertiary of China. Original steppe of China dates back to the later stage of Paleogene in Northwest China, where pollen floras exhibit an arid tendency even in the earlier stage of Paleogene. The first occurrence of steppe also coincided with some major environmental changes around the Eocene/Oligocene boundary, such as the herald of Himalayan movement, the retreat of Tethys from the west part of the Chinese Continent, etc., while the development of the steppe was extensively confined by the afterward orogeny and climate fluctuations. Case studies from seven key areas are put forward to show some detailed changing procedure of the steppe vegetation in China.

Key-words—Steppe vegetation, Origin, Palaeoclimate, China.

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सारांश

चीन में वृक्षहीन वनस्पति का उद्भव एवं विकास

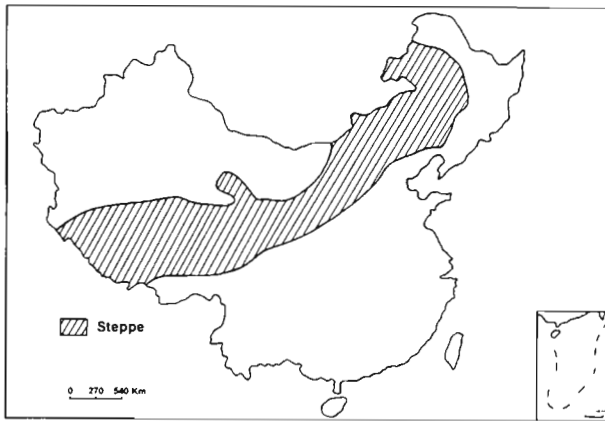
वांग वीमिंग

चीन के तृतीयक कल्प से प्राप्त परागाणुओं के आँकड़ों पर आधारित चीन में वृक्षहीन वनस्पति के उद्भव और विकास का मूल्यांकन किया गया है। चीन की मूलभूत वृक्षहीन वनस्पति उत्तर पूर्व चीन में पुरानूतन काल की अन्तिम चरण की है जहाँ परागाणु वनस्पतिजात मरुस्थली परिस्थितियाँ व्यक्त करते हैं। वृक्षहीन वनस्पति की प्रथम उपस्थिति आदिनूतन/अल्पनूतन सीमा पर हुए पर्यावरणीय परिवर्तनों के आस-पास मिलती है। इसी शोध-पत्र में सात मुख्य क्षेत्रों में चीन में हुए वृक्षहीन वनस्पति में परिवर्तन भी प्रदर्शित किये गये हैं।

It is one of the paleobotanist's major duties to reconstruct the past vegetation on the earth. Nevertheless, restricted fossil evidence often greatly confines the related efforts to go further. Steppe is a main vegetational type in China. Its origin and development are considered to be close connected with the initiation and subsequently evolutionary course of the angiospermous herb, as well as the environmental variations (Wang & Zhang, 1990). Rich fossil material collected from certain key areas, along with some newly developed related data, enable in the present paper to study the evolutionary process of steppe vegetation in China. Because herbaceous plant megafossils are only found by chance in the strata, this paper is mainly based on the palynological approach.

STEPPE VEGETATION, ITS MODERN DISTRIBUTION IN CHINA AND ECOSYSTEM

As a major landscape unit, steppe vegetation covers nearly 30 per cent of the whole land area in China. China's natural grassland locates mainly in the north and west part of the country. They stretch from the Da Xingan Lin Mts. in Northeast China, and then successively westward: the west part of the Northeast Plain, Inner Mongolia Plateau, Ordos Plateau, Loess Plateau, and end at the southwest edge of the Qinghai-Xizang (Tibet) Plateau. They stride across 23 degrees of latitude (28°N to 50°N) (Liu, 1990), occupying a distinct area between desert and forest (Text-figure 1). The distribution of present steppe



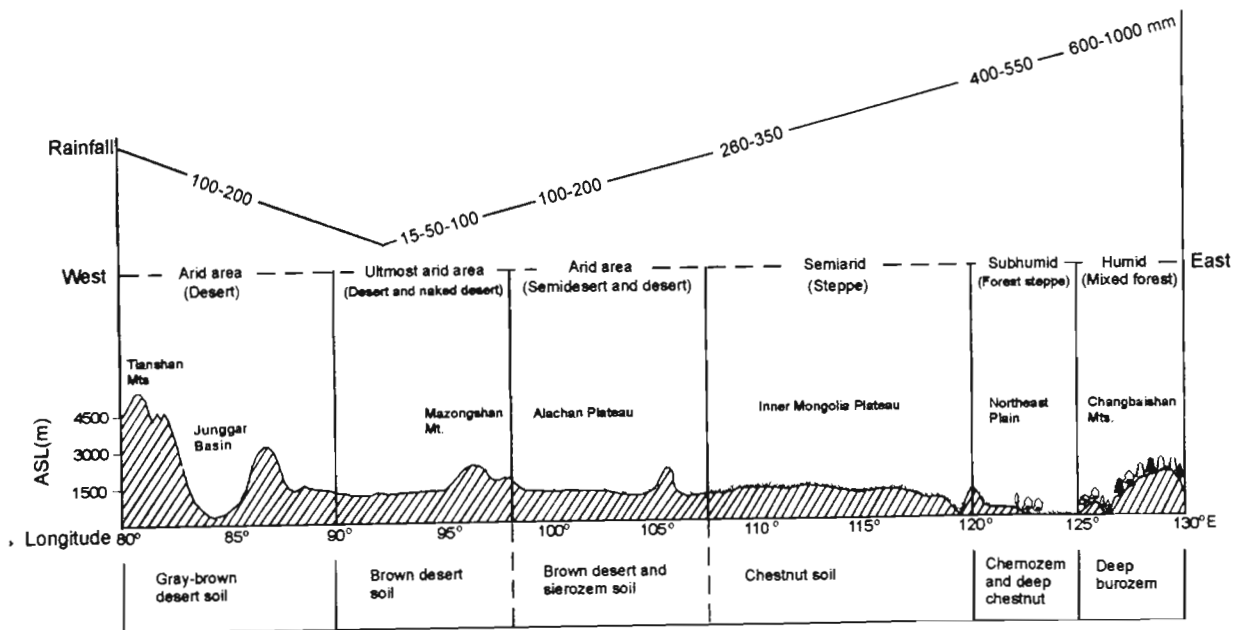
Text-figure 1—Sketch map showing modern distributive area of steppe vegetation in China.

vegetation is basically consistent with the disposal of water and heat.

Modern steppe is a plant community consisting of multi-year herb (occasionally xerophytic semi-frutex) under low temperature and arid condition (Wu, 1980). It generally occurs in too arid conditions for the development of closed forest, but not so adverse as to prevent the development of a closed perennial herbaceous layer that is lacking in desert (Coupland, 1974). The climate of natural grassland exhibits marked periodicity of precipitation, both

intraseasonally and interseasonally (Borchert, 1950), with a mean annual precipitation in temperate region usually ranging from 250 to 750 mm (Coupland, 1974). At the same time, relief and soil texture determine the predominance of vegetation. Forests are found on well-drained habitats, slightly raised ground, the sides of the river valleys, with porous soil, whereas meadow steppes occupy badly drained, flat sites with a relatively heavy soil (Walter, 1984).

The forest, forest-steppe, steppe and desert zones of the temperate, warm temperate region of China are readily distinguishable from one another on a climatic basis (Text-figure 2). The forest zone reveals the absence of a period of drought, whereas steppe zone always indicates the presence of such a period. In forest steppe zone, a dry period is always recognizable. Thus, steppe and desert occupy the continental regions. In a continental climate, the temperature amplitude is greater and the summers are hotter, but the winter is much colder, so that the annual mean temperature is lower than that in oceanic regions of same latitude. This is accompanied by a decrease in annual rainfall and more arid summer.



Text-figure 2—Schematic rainfall, vegetation and soil profile from west to east in the temperate region (ca. 40°-45°N) of China (reconstituted after Hou, 1988).

MAIN ENVIRONMENTAL CAST TO THE ORIGIN AND DEVELOPMENT OF STEPPE VEGETATION IN CHINA

Chinese natural grassland belongs to part of the Eurasian steppe. Two factors are suggested to greatly control its origin and afterward development, i.e., the evolutionary course of the plant kingdom itself, and the environmental changes, especially the climatic alterations of the earth. At the beginning of the Tertiary, the angiosperms were mostly in their original form and their living condition was rather even. Later, as a series of major changes caused by orogeny and climatic fluctuations in geographic and ecological conditions, the plants got more chances to make their further development and evolution (Wang & Zhang, 1990).

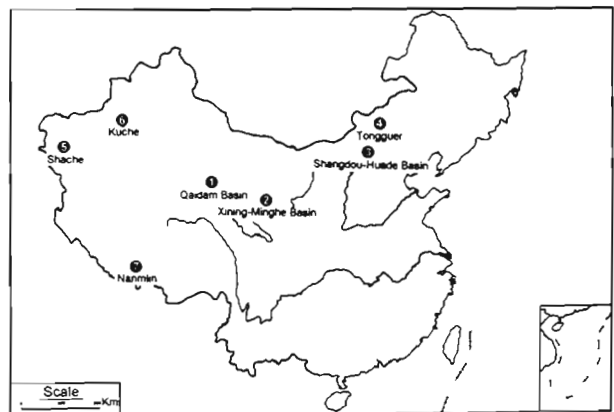
The Paleogene geographic and climatic patterns of China were mainly a continuation of those in the Cretaceous. At the beginning of the Tertiary, the Middle Asian Plain was still subsided in the sea. The sea water was restricted to the west part of the Chinese continent, south of Xizang and west of Xingjiang. The mountains formed in Paleozoic or Mesozoic were leveled after a long period of denudation, such as Altaishan, Tianshan, Kunlunshan and Qilianshan in the Northwest, Qinling in the Middle, and Helanshan and Yinshan in the North (Wu, 1980). Climatically, Paleogene was dominated by a planetary circulation system in the continent, and an arid subtropical climate prevailed over all south and northwest China (Wang, 1984). The temperature at that time was commonly warmer, and the northern boundary of tropical and subtropical zones located in a much higher latitude than today (Leopold, 1969). The Chinese Continent also lay mostly within the tropical and subtropical zones except part warm temperate area in North China (Wu, 1980).

Affected by the Himalayan movement, the Tethys retreated from the west part of the Chinese Continent at the terminal Eocene. Under the huge northward drifting forces of the South Continent, the crust of the Middle Asian Plain began to uplift, and new mountains and plateaus gradually took their embryonic forms. At the same time, these mountains formed former also experienced extensive uplift movement.

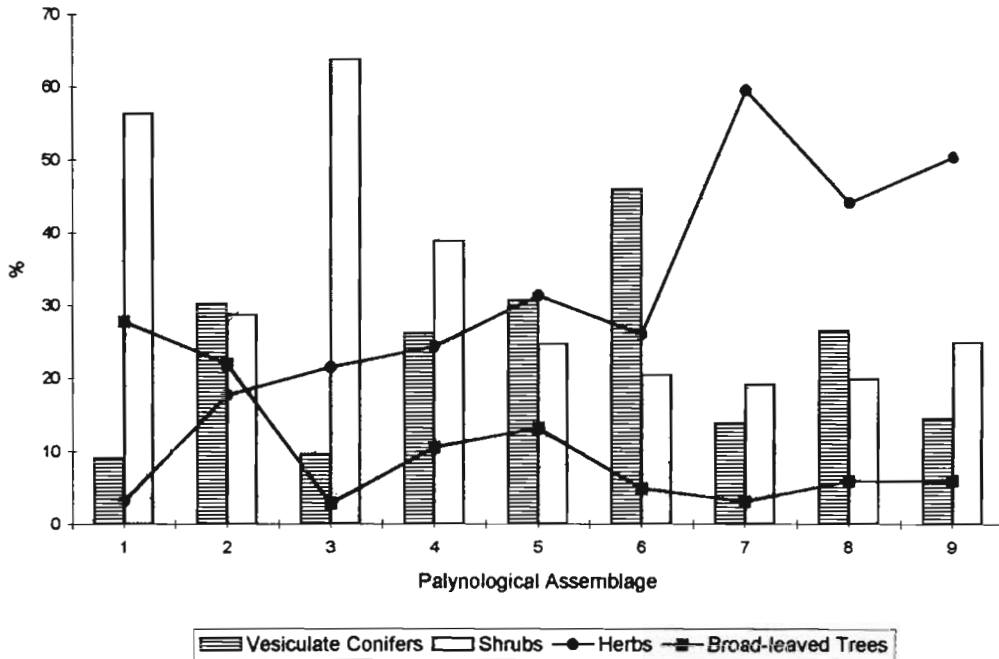
Climatically, the warm global climate had already begun a long and irregular slide into the glaciations which characterized the Late Cenozoic at the close of the Mesozoic (Frakes, 1979), and East China and South China underwent an intensive monsoon circulation system established around Paleogene/Neogene boundary (Wang, 1984).

The steppe was thus formed under a special developing stage of both plant kingdom and environment. Angiospermous herbs date back before the Oligocene worldwide, but they were not thriving to form a steppe until Late Paleogene. Original steppe vegetation of China was first recognized from the Qaidam Basin around the Eocene/Oligocene boundary. It coincides with some major events, such as the closing of the Tethys, significant increase in the size of Eurasia and the new area ratio between the continent and the Pacific Ocean, and the beginning uplift of Qinghai-Xizang Plateau, etc. Components of the vegetation then were rather monotonous with their distribution mostly isolated in shrub or limited to some open ground.

Since its occurrence, steppe vegetation gradually expands itself eastward and westward, but it was somewhat affected by the remaining Tethys climate in the west, and the intensifying monsoon climate in the east before the Middle Miocene. It also experienced a series of extension and concentration because of the afterward climatic fluctuation. During the late Early Miocene-earliest Middle Miocene climatic optimum, it concentrated a lot or even disap-



Text-figure 3—Sketch map showing palynostratigraphic localities cited in the paper.



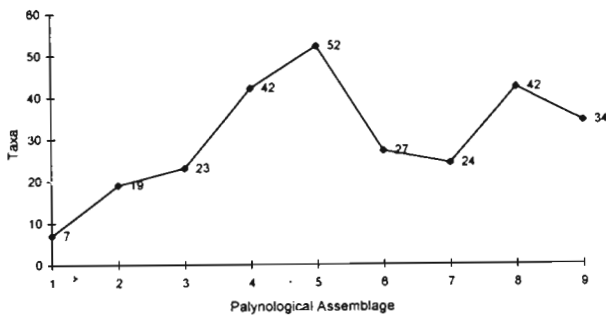
Text-figure 4—Pollen diagram showing average content of vesiculate conifers, shrubs, herbs and broad-leaved trees in each assemblage of the Tertiary of the Qinghai (recalculated on data of Zhu *et al.*, 1985).

peared in some places. The climate in the Pliocene seems to fluctuate more often, with a general tendency becoming drier and colder, and the steppe vegetation correspondingly displayed a relatively wide distribution. Meanwhile, certain new types came into existence and most of the modern developed forms took shape at the family level. But the Pliocene steppe was more or less still isolated in other vegetation types and the extensive steppe was rather limited. It is only in the Quaternary, as a result of glacial climate and extensive upmovement of Qinghai-Xizang

Plateau, Tundra and alpine meadow appeared on the plateau, while desert and steppe had their full spread in North China. The previous Tertiary steppe was gradually replaced by deserts in some parts of Northwest China, such as Xinjiang Uygur Autonomous Region and Qinghai Province, with the remaining part fully developed in Songliao Plain, Inner Mongolia Plateau and Huangtu Plateau, which late on became part of the present Eurasian steppe vegetation region.

CASE STUDIES OF TERTIARY PALYNOFLORAS

Here cited are the Tertiary palynofloras of seven representative sites as the case studies for the current discussion. Pollen record from the Qaidam Basin shows the first sight of the original steppe in China. Site 2 to Site 6 exhibit the following development of the steppe vegetation in different areas, and Site 7 implies the vegetational feature before the Quaternary in the plateau area (Text-figure 3). As the pollen names mentioned in the text are generally given out in the forms of organ- or form- genus, an appendix is attached at the end of the paper to display their affinities.



Text-figure 5—Taxonomic diversity of the major herbaceous pollen in the Tertiary of the Qaidam Basin, Qinghai (recalculated on data of Zhu *et al.*, 1985).

Qaidam Basin of Qinghai

Nine palynological assemblages were recognized from the well-developed Tertiary strata in the Qaidam Basin (Zhu *et al.*, 1985). The first four assemblages are distinguishable by the predominant occurrence of shrub pollen, while herbaceous pollen show an increase upward, and turn out to become the most important elements from assemblage 5. The broad-leaved trees keep lower throughout the Tertiary (Text-figure 4). The strata in the basin were represented by four formations, and their age assignment is mainly based on biostratigraphic study, and further refined by the paleomagnetic dating (CNPC, 1992; Ye *et al.*, 1993; Table 1).

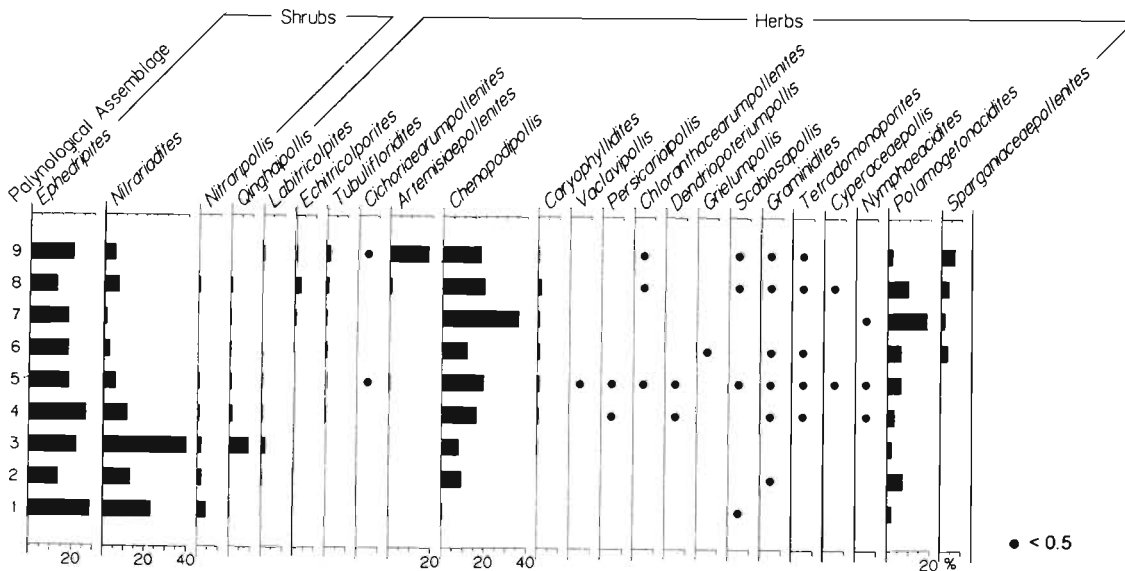
Though the real percentage of a certain plant type in the palynological assemblage which could be used to determine a vegetational type is still a controversy, it is still believable that assemblage 5 has already indicated the occurrence of the first steppe because of its big content of the herbaceous pollen with highest taxonomic diversity (Text-figure 5).

The original steppe in the Qaidam Basin is suggested to be mostly isolated in shrub or limited to some open ground. The development of the Tertiary vegetation in the Qaidam Basin shows a process of changes from shrub and forest in the Paleocene-Early Eocene, to shrub in the Middle-Late Eocene, steppe

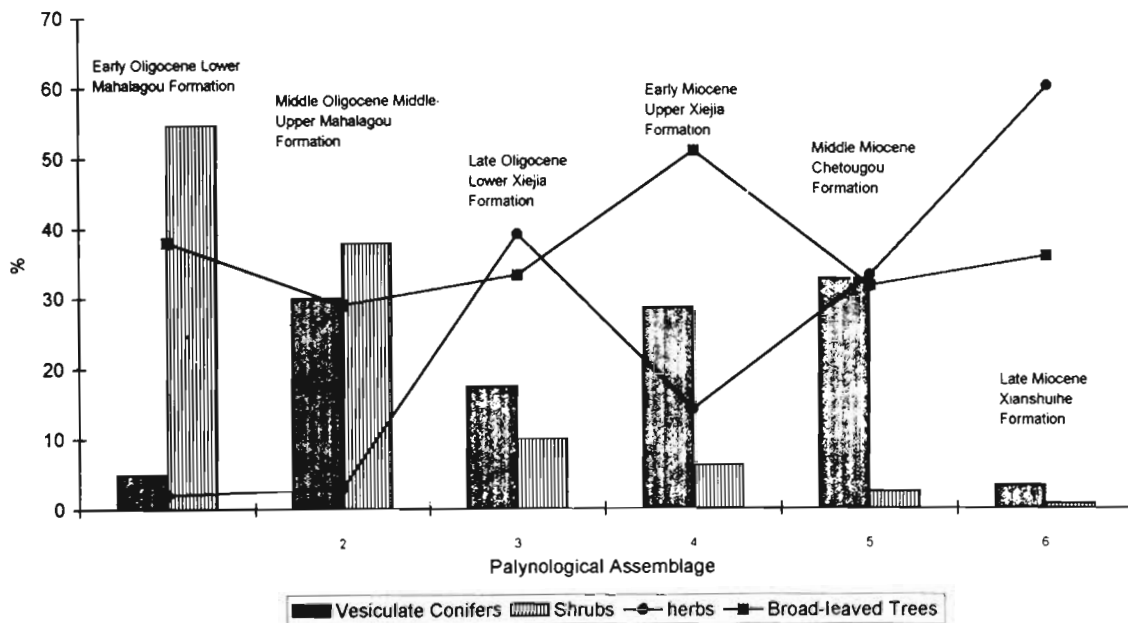
Table 1—Tertiary stratigraphy, corresponding palynological assemblages and vegetational types of the Qaidam Basin, Qinghai

Age	Strata	Palynological Assemblage	Vegetational Type
Pliocene	Shizigou Formation	9	Steppe and semidesert
	Upper Youshashan Formation	8	
Miocene	Lower Youshashan Formation	7	Steppe and Shrub
		6	
Oligocene	Upper Ganchaigou Formation	5	
Eocene	Lower Ganchaigou Formation	4	Shrub
		3	
		2	Shrub and Forest
Paleocene	Upper Lulehe Formation	1	

and shrub in the latest Eocene-Middle Miocene, and steppe and semidesert in the Late Miocene-Pliocene (Table 1), and the representative plants for each vegetational type are featured by *Nitraria* and Fagaceae, *Nitraria*, Chenopodiaceae, and Asteraceae and Chenopodiaceae respectively (Text-figure 6).



Text-figure 6—Pollen diagram showing average content of main shrubs and herbs in the Tertiary of the Qaidam Basin, Qinghai (recalculated on data of Zhu *et al.*, 1985).

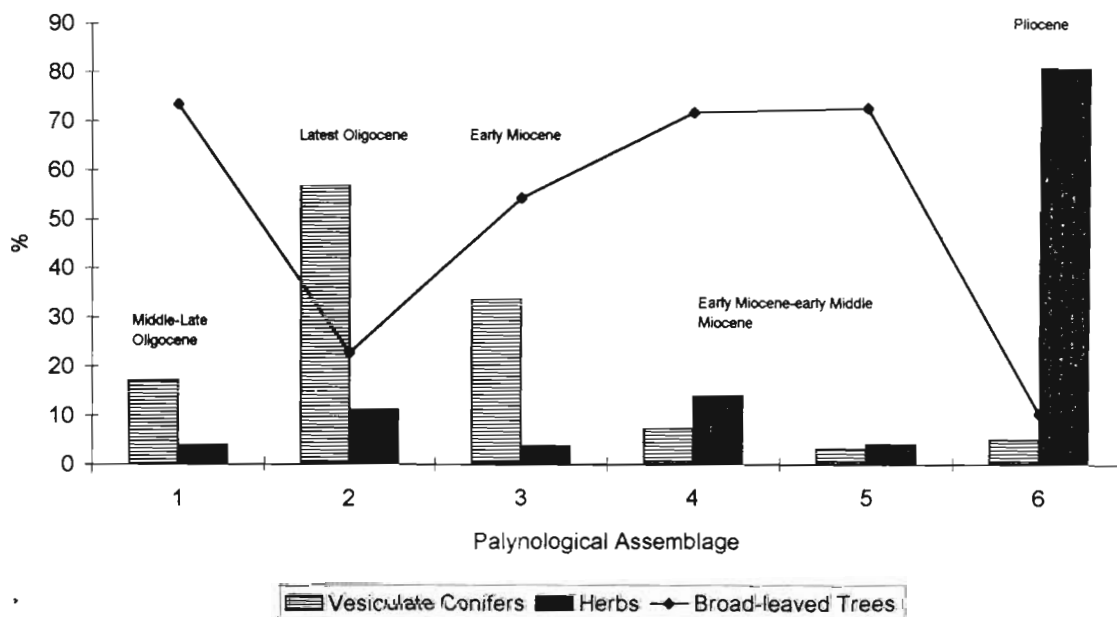


Text-figure 7—Pollen diagram showing average content of vesiculate conifers, shrub, herbs and broad-leaved trees in the Tertiary of Xining-Minghe Basin, Qinghai (recalculated on data of Sun *et al.*, 1984).

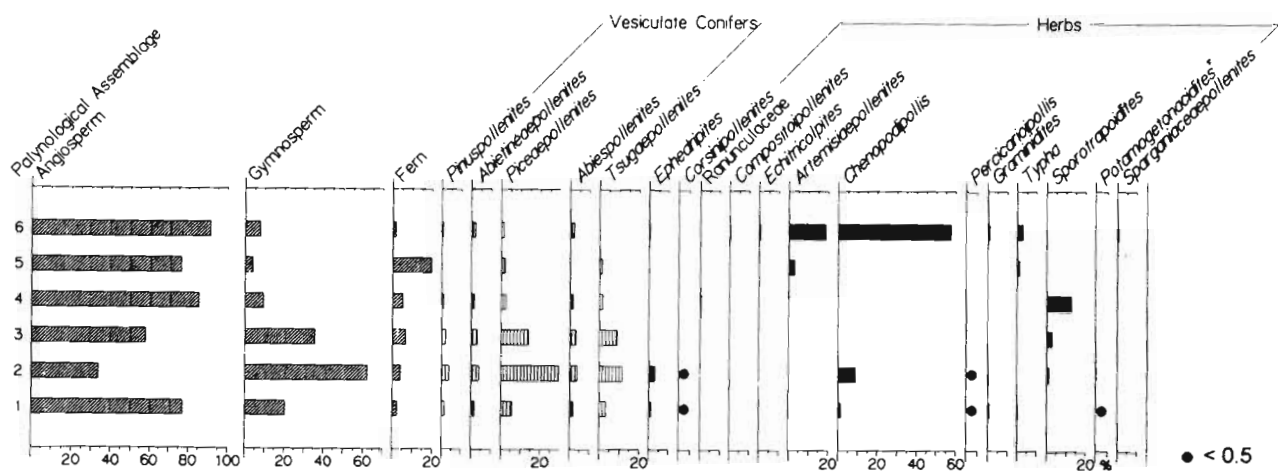
Xining-Minghe Basin of Qinghai

Pollen data from the Tertiary of Xining-Minghe Basin exhibit an interesting vegetational variation among shrub and forest, steppe and forest, and forest.

In the Early-Middle Oligocene, the vegetational type was represented by shrub and forest. Steppe subsequently replaced the shrub to constitute steppe and forest in the Late Oligocene. Experienced a significant retreat in the Early Miocene, the steppe gradually



Text-figure 8—Pollen diagram showing average content of vesiculate conifers, herbs and broad-leaved trees in each assemblage of the Tertiary of the Shangdou-Huade Basin, Inner Mongolia (recalculated on data of Wang & Zhang, 1990).



Text-figure 9—Pollen diagram showing average content of main vesiculate conifers and herbs in each assemblage of the Tertiary of the Shangdou-Huade Basin, Inner Mongolia.

played an increasing role from the Middle Miocene (Text-figure 7). The distribution of the steppe vegetation was somewhat comparable to the present forest-steppe region, i.e., a macromosaic of deciduous forest stands and meadow-steppe. At first, the former predominated, and the steppes formed scattered islands. However, as the time went on, the more arid the climate became, the more the situation tended to be reversed, until finally, small islands of forest might be left in a sea of steppe.

So the occurrence of the steppe vegetation in the Xining-Minghe Basin was later than in the Qaidam Basin. During the Early Miocene, vegetation in the Xining-Minghe Basin was partially affected by the warm and humid monsoon climate. Late on, with the further development of the intensifying continental climate, steppe got more and more fully developed.

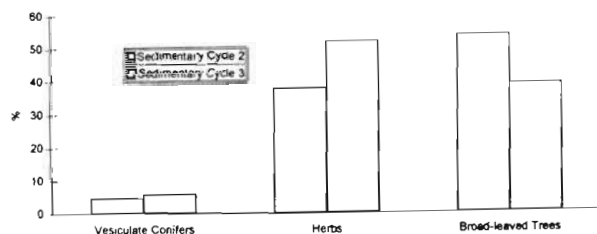
Shangdou-Huade Basin and Tongguer Area of Inner Mongolia

Palynological assemblages from the Middle Oligocene-early Middle Miocene of the Shangdou-Huade Basin are mostly comparable with those in the East China (Wang & Zhang, 1990), while the one from the Pliocene definitely indicates the development of the steppe vegetation in the basin (Text-figures 8, 9). Because there is a stratum barren between the lower Middle Miocene and the Pliocene, we are not able to judge the flora from that period.

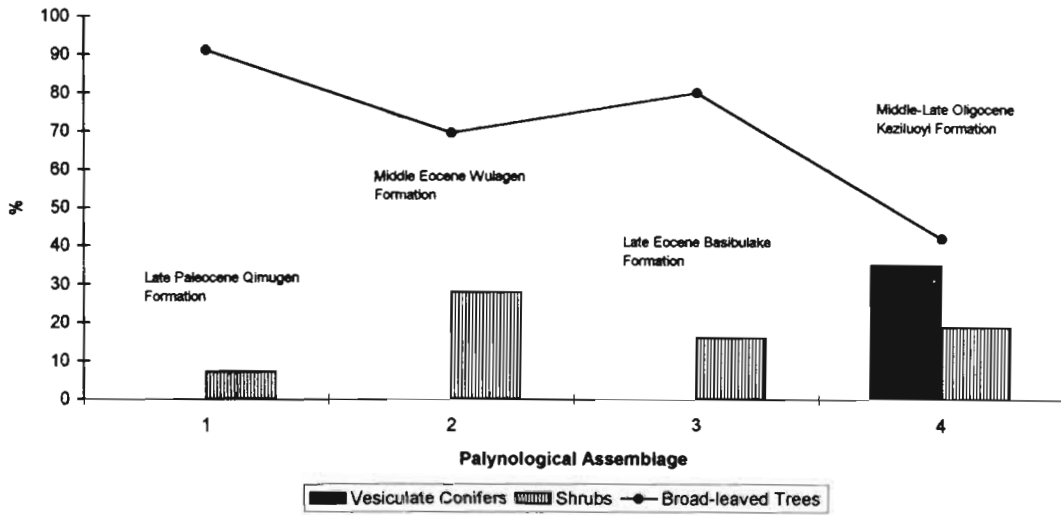
It is notable that pollen evidence was late revealed from the Middle/Late Miocene Tongguer Formation (Wang, 1990). Fossil pollen were extracted from the sedimentary cycles 2 and 3 of the formation, which indicate the occurrence of forest and steppe in the area (Text-figure 10). Thus, the steppe vegetation in the Inner Mongolia may date back to the Miocene time.

Shache and Kuche areas of Xinjiang

Pollen assemblages from the Late Paleocene to Oligocene of the Shache area show no sign of steppe vegetation, but forest, or forest partially mingled with shrub (Text-figure 11). In the Tertiary Kuche area, herbaceous pollen were all along not important till the Miocene (Text-figure 12). This may partially indicate that both of the areas were still under influence of the remaining Tethys climate before the Miocene.



Text-figure 10—Pollen diagram showing average content of vesiculate conifers, herbs and broad-leaved trees in two sedimentary cycles of the Middle/Late Miocene Tongguer Formation, Inner Mongolia (based on Wang, 1990).



Text-figure 11—Pollen diagram showing average content of vesiculate conifers, herbs and broad-leaved trees in the Paleogene of the Shache Area, Xinjiang (based on data of Zhao *et al.*, 1982).

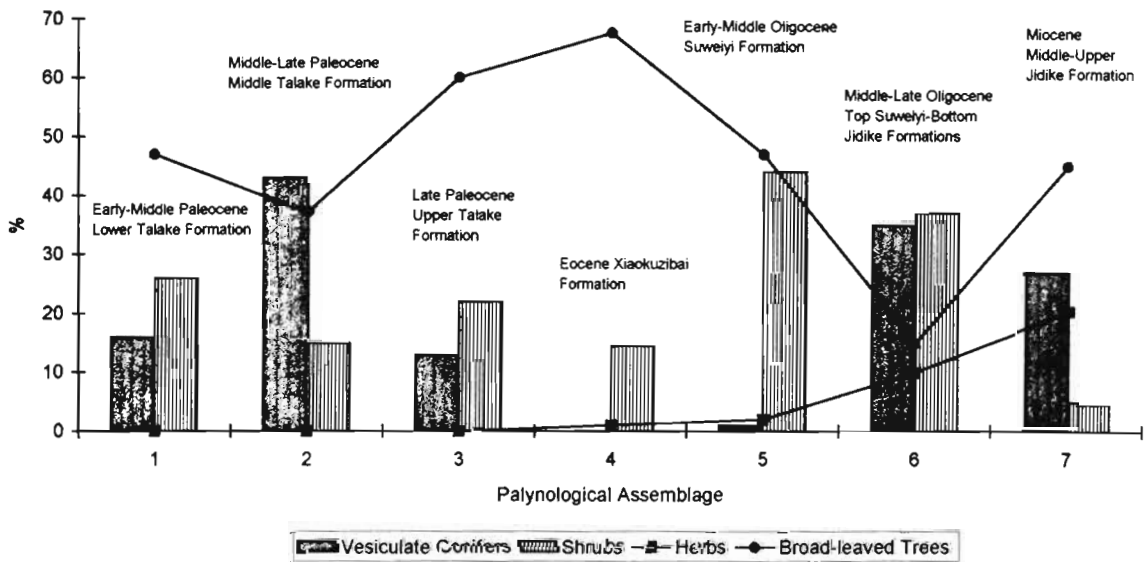
Nanmlin Area of Xizang

Pollen assemblages from the Upper Oligocene to the Middle Pliocene of the Nanmlin area are distinguished by the increase of vesiculate conifers, accompanied with certain amount of broad-leaved trees and ferns. Though herbaceous pollen show an increase in the Pliocene pollen flora, its content still keeps lower (Text-figure 13). Since modern vegetation of the area is developed with steppe, it can be thus deduced that the modern vegetation was formed only

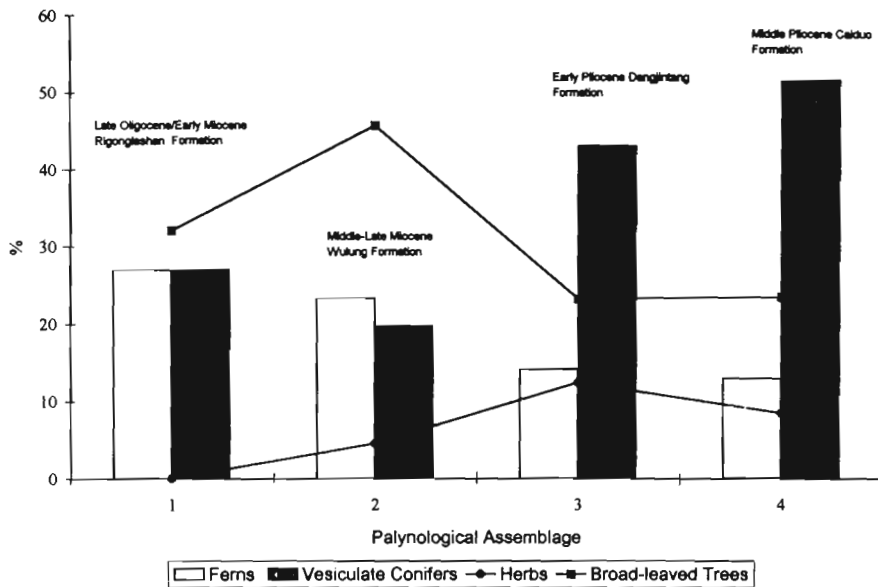
after the intensive uplift movement which took place in the Quaternary.

CONCLUSION

Original steppe vegetation of China made its first occurrence in the Qaidam Basin region around the Eocene/Oligocene boundary. It coincides with some major environmental events, such as the closing of Tethys, significant increase in the size of Eurasia and the new area ratio between the continent and the



Text-figure 12—Pollen diagram showing average content of vesiculate conifers, herbs and broad-leaved trees in the Tertiary of the Kuche Area, Xinjiang (based on data of Zhao *et al.*, 1982).



Text-figure 13—Pollen diagram showing average content of vesiculate conifers, herbs and broad-leaved trees in the Tertiary of the Namlin Area, Xizang (recalculated on data of Song & Liu, 1982).

Pacific Ocean, and the beginning uplift of Qinghai-Xizang Plateau, etc.

Since its occurrence, steppe vegetation gradually expands itself eastward and westward, but it was still affected by the remaining Tethys climate in the west, and the intensifying monsoon climate in the east before the Middle Miocene. During its long process of development, the steppe vegetation experienced a series of extension and concentration as a result of the climatic fluctuations.

The formation of alpine steppe is consistent with the intensive upward movement of the Qinghai-Xizang Plateau in the Quaternary.

Appendix—List of main shrub and herb taxa mentioned in the text, and their affinity

Shrub

- Ephedraceae (*Ephedra*)
- Ephedripites* Bolchovitina ex Potonié
- Zygophyllaceae (*Nitraria*)
- Nitrariadites* Zhu et P. Xi
- Nitrariipollis* Sun et Y.-Z. Xi

Herb

- Umbelliferae
- Qinghaipollis* Zhu
- Labiatae
- Labitricolpites* Ke et Shi

- Asteraceae (Compositae)
- Compositoipollenites* Potonié
- Echitricolporites* van der Hammen ex Germeraad, Hopping & Muller
- Tubulifloridites* Cookson ex Potonié
- Cichoriaearumpollenites* Nagy
- Artemisiaepollenites* Nagy
- Chenopodiaceae
- Chenopodipollis* Krutzsch
- Caryophyllaceae
- Caryophyllidites* Couper
- Vaclavipollis* Krutzsch
- Polygonaceae
- Persicarioipollis* Krutzsch
- Chloranthaceae
- Chloranthacearumpollenites* Nagy
- Rosaceae
- Dendriopoteriumpollis* Song et Zhu
- Grielpollis* Song et Zhu
- Dipsacaceae
- Scabiosapollis* Sung & Zheng
- Poaceae (Graminae)
- Graminidites* Cookson ex Potonié
- Typhaceae
- Tetradomonoporites* Chitaley ex Krutzsch
- Cyperaceae

Cyperaceae *pollis* Krutzsch
 Nymphaeaceae
Nymphaeacidites Sah
 Potamogetonaceae
Potamogetonacidites Sah
 Sparganiaceae
Sparganiaceae *pollenites* Thiergart

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