TAO, Vol.5, No.3, 393-410, September 1994

Late-Holocene Pollen Records of Vegetational Changes in China: Climate or Human Disturbance?

KAM-BIU LIU[1] and HONG-LIE QIU[1]

(Manuscript in final form 23 March 1994)

ABSTRACT

Twelve C-14 dated pollen records are reviewed to reconstruct the vegetational and climatic changes in China over the last 2000 years. The interpretation of these pollen data is complicated by uncertainties about the effects of human disturbance on the vegetation, which may not be easily distinguished from the climatic signal. The data for the period 0-2000 yr B.P. suggest a continuation or intensification of the cooling trend that had already started by 4000 yr B.P., accompanied by moisture changes that seem to have varied regionally. The Little Ice Age, albeit well-documented from Chinese historical records, is poorly registered palynologically. A new pollen record from the Daiyun Mountain of subtropical southeastern China yields the most dramatic evidence of deforestation due to human disturbance occurring around 1100 yr B.P. Because of the long history of Chinese civilization, the impact of human activities should be carefully evaluated in making climatic inferences from Chinese pollen records.

(Key words: Palynology, Paleoclimate, Lake sediments, China, Human disturbance, Vegetation)

1. INTRODUCTION

Although over 200 Quaternary pollen records of various time spans and data quality are now available in China (Liu, 1988, 1992), relatively few have the necessary resolution and sensitivity to permit a quantitative reconstruction of climatic changes in the last 2000 years. Data resolution in most Chinese pollen records is limited by (a) inadequate dating control, especially for sediments of the 0-2000 yr B.P. time range, (b) coarse sampling intervals, and (c) insufficient taxonomic details in the published pollen data, e.g. selective omission of certain pollen taxa in a pollen diagram. Data sensitivity is limited by the fact that most pollen records come from fluvial (floodplain), coastal (deltaic), or marine sediments, whose

[1] Department of Geography and Anthropology, Louisiana State University, Baton Rouge, Louisiana 70803, U.S.A.

pollen assemblages are complicated by non-climatic factors such as lithological variations, differential preservation, changes in depositional environments, and changes in pollen source and provenance. Another major factor limiting data availability and sensitivity is the effect of human disturbance on the pollen records. Human activities may disrupt the depositional environments or the sedimentary records *per se*, or destroy and disturb the vegetation. Many otherwise useful pollen records are truncated at the top either because sedimentation is discontinuous or has ceased in the late-Holocene, or the uppermost part of the sediment profile has been disturbed by human activities (e.g., cultivation). During the last 3000 years of Chinese civilization the vegetation has been altered significantly and pervasively, much more so than that in Europe and in North America. What is the pollen evidence of human impacts on the Chinese vegetation? And how can the climatic signal be distinguished from the anthropogenic signal in the Chinese pollen records? This paper tries to address these questions by reviewing a dozen C-14 dated pollen records that cover the time interval of 0-2000 yr B.P. (Figures 1 and 2).

2. TEMPERATE FOREST REGIONS OF NORTHEAST AND NORTH CHINA

Pollen records from two bogs (Qindeli Bog, Gushantun Bog) (Sites 1 & 2) in the Mixed Conifer-Hardward Forest of Northeast China span the entire Holocene and part of the latest Pleistocene (Xia, 1988; J. Liu, 1989). Both sites show a dramatic increase in *Pinus*

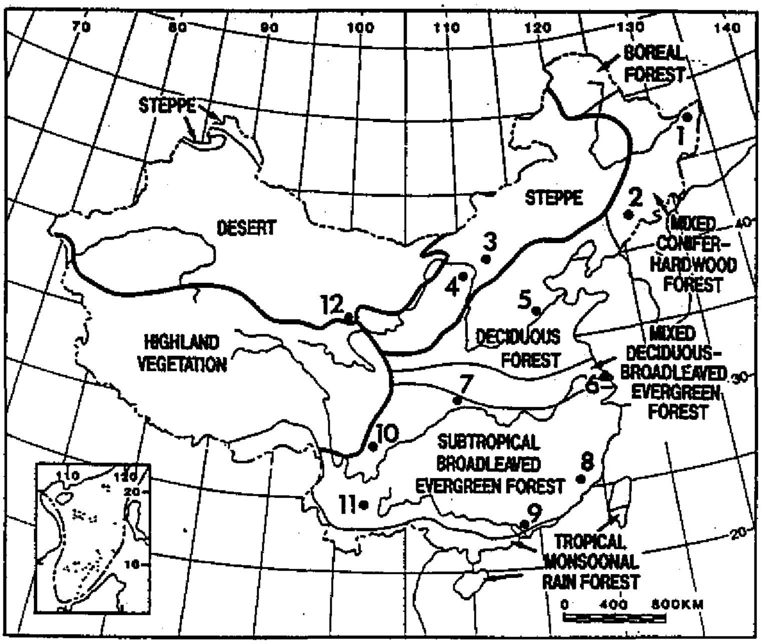

Fig. 1. Location map of the 12 pollen records reviewed in this paper in relation to the modern vegetation regions of China (After Liu, 1988). Site 1 = Qindeli Bog; 2 = Gushantun Bog; 3 = Luweichang; 4 = Pajianghaizhi; 5 = Huang 1 borehole; 6 = Qidong; 7 = Dashennongjia; 8 = Jiuxianshan dambo; 9 = Jiantan P30 borehole; 10 = Lake Shayema; 11 = Dianchi; 12 = Qinghai Lake.

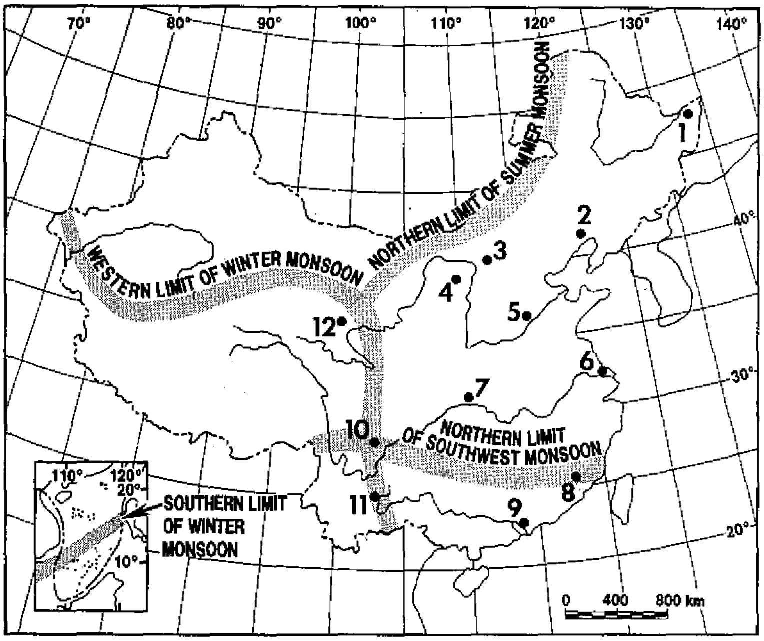

Fig. 2. Location map of the 12 pollen records reviewed in this paper in relation to the monsoon limits of China (After Ren *et al.*, 1979). For site names, see Fig. 1.

(pine) after 4000-5000 yr B.P., accompanied by an increase in *Picea/Abies* (spruce/fir) and a decrease in thermophilous hardwoods such as *Quercus* (oak), *Ulmus* (elm), and *Juglans* (walnut) (Figures 3 and 4). The trend of climatic cooling was accentuated after 2000-2500 yr B.P., as indicated by further expansion of the boreal conifers (spruce, fir, pine). No unequivocal evidence of human disturbance is detected in either pollen records for the last 2000 years, since both areas are not heavily settled even today. The only significant change in the pollen stratigraphy within the last 2000 years is an abrupt increase in *Pinus* and *Picea/Abies* at Qindeli Bog starting about 500 years ago (Figure 3). In view of the lack of response in the pollen curves of weeds like *Artemisia* (sage) and Gramineae (grass), this vegetational change is more likely to be attributed to Little Ice Age cooling than to human disturbance.

The North China Plain is the oldest and one of the most densely populated agricultural regions in China. The potential natural vegetation for the region, a warm-temperate deciduous forest, has been completely destroyed during the last 5000 years of intense human activities. A pollen record from the Huang 1 borehole (Site 5) on the Yellow River (Huanghe) floodplain in northern Shandong Province probably spans the entire Holocene (Xu *et al.*, 1991) (Figure 5). Pollen changes in this pollen diagram are hard to be interpreted directly in climatic terms due to frequent lithological changes and potential hiatuses in these alluvial deposits. The dramatic increase in *Pinus* at the top of the pollen record, accompanied by the virtual disappearance of deciduous trees like *Quercus*, *Corylus* (hazelnut), and *Liquidambar* (sweetgum) and an increase in Chenopodiaceae (goosefoot family) and fern spores, may indicate intensified forest clearance and secondary succession during the past millennium.

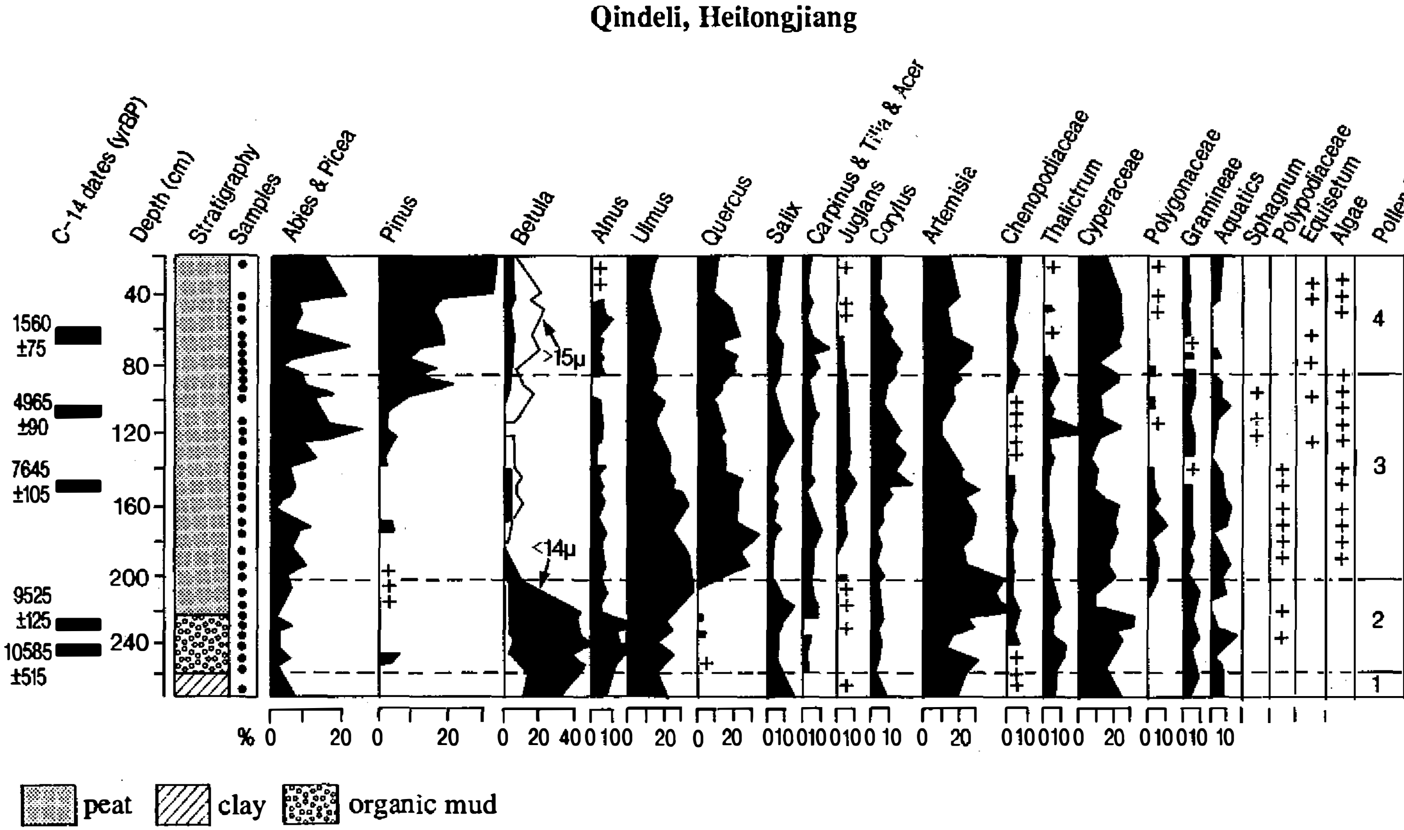

Fig. 3. Pollen diagram from the Qindeli Bog (Site 1). Pollen percentages for the trees are based on a sum of all arboreal pollen (AP) types; those for the herbs and aquatics are based on a sum of all non-arboreal pollen (NAP) types. Note variable percentage scales used for different pollen taxa (After Xia, 1988).

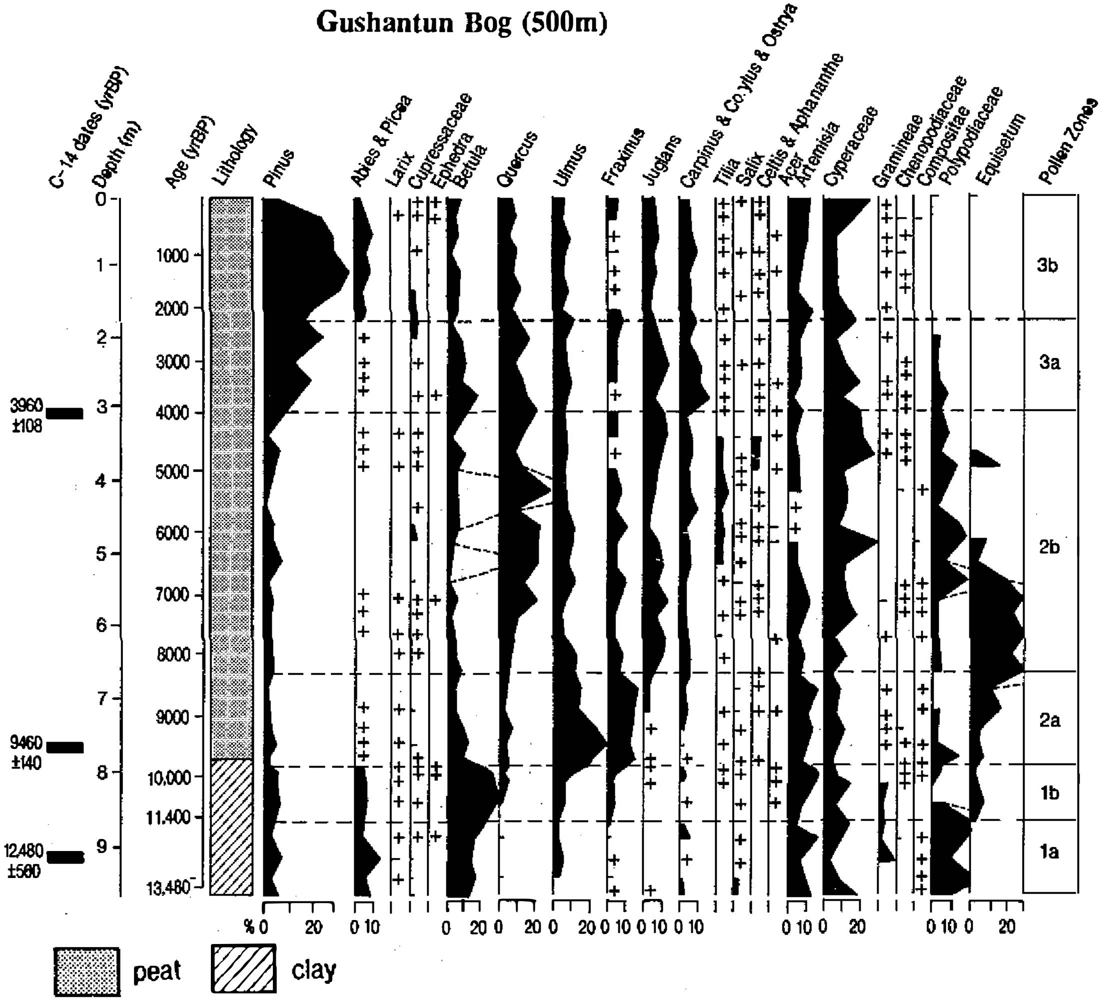

Fig. 4. Pollen diagram from the Gushantun bog (Site 2). Pollen percentages are based on a sum of all pollen and spores (After J. Liu, 1989).

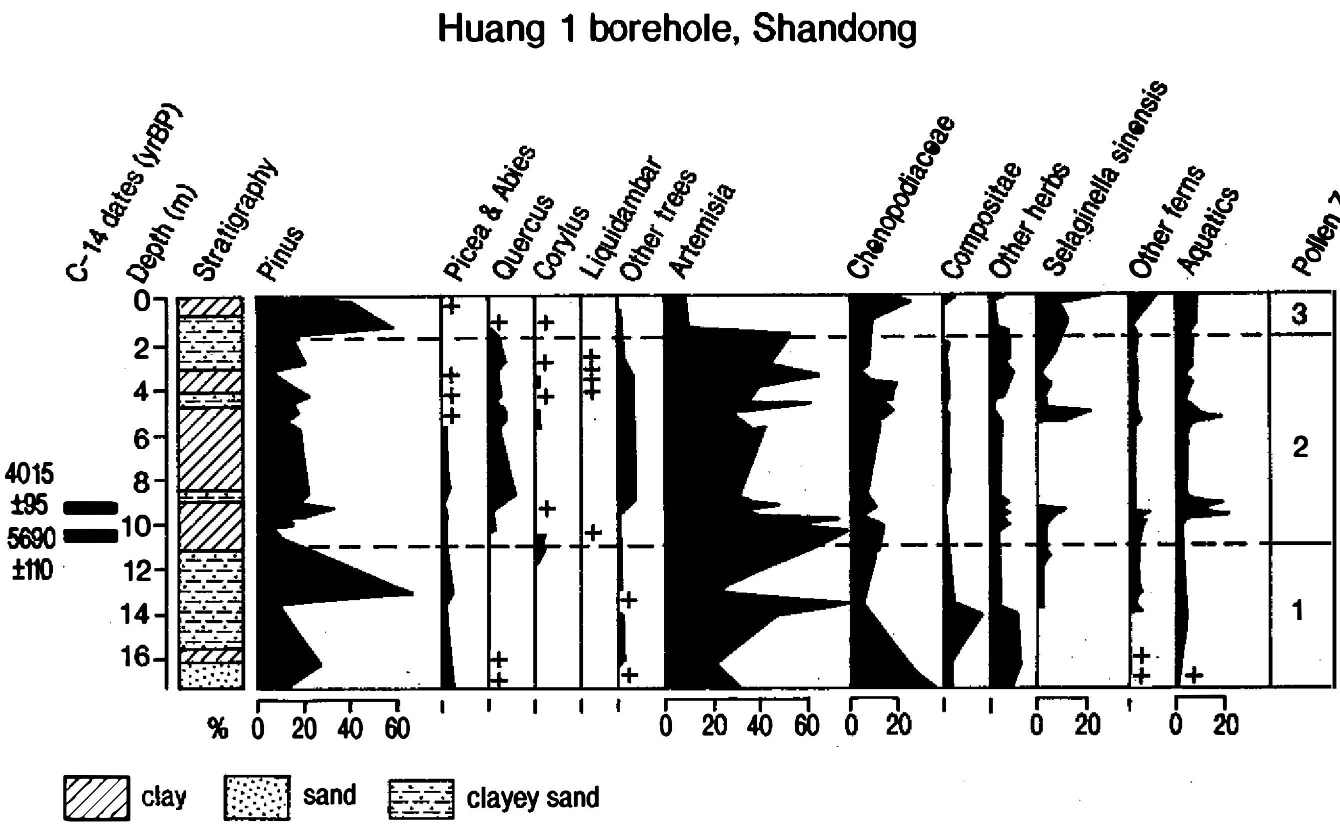

Fig. 5. Pollen diagram from the Huang 1 borehole (Site 5). Pollen percentages are based on a sum of all pollen and spores, except aquatics (After Xu *et al.*, 1991).

3. HUMID SUBTROPICAL MOUNTAINS AND FLOODPLAINS

A pollen record from the Yangtze River (Changjiang) delta (Site 6), another densely populated and intensively cultivated region of China, suggests a slightly cooler climate after 3800 yr B.P. (Liu *et al.*, 1992) (Figure 6). No clear evidence of climatic change or anthropogenic disturbance can be deciphered for the last 2000 years. An increase in Gramineae pollen and fern spores and higher total pollen concentrations in the uppermost part of the pollen diagram probably reflect increased pollen input from the local herbaceous vegetation growing on the deltaic plain and coastal wetlands as the Yangtze River delta prograded to the coring site several centuries ago. However, the uppermost meter of the core was not analyzed because the sediment was disturbed by cultivation and construction activities.

The interplay between climate and human activities in shaping the vegetative landscape of the Chinese monsoonal subtropics is remarkably well-illustrated by a recently completed pollen record from the Daiyun Mountains of Fujian Province (Qiu, 1994) (Site 8). The pollen core comes from a dambo (linear peat-filled depressions in subalpine headwater zones) at an elevation of 1360 m, where the modern vegetation is a pine woodland with a dense ground cover of *Dicranopteris* ferns and grasses, a typical secondary vegetation association in the hilly countries of the Chinese tropics and subtropics. Peat began to accumulate in the dambo after 4000 yr B.P. (Figure 7), probably as a result of climatic change towards cooler and wetter conditions upon the end of the mid-Holocene Hypsithermal. The pollen diagram suggests that from 4000 to 1100 yr B.P. the vegetation on the Daiyun Mountain was a subtropical mixed conifer-hardwood forest dominated by *Cryptomeria* (Japanese cedar), *Castanopsis* (chinkapin), *Quercus*, and *Tsuga* (hemlock). The pollen frequencies of these forest taxa declined abruptly about 1100 years ago, accompanied by a dramatic increase in *Pinus*, *Dicranopteris*, and Gramineae. This abrupt vegetation change coincides with one of the episodes of large-scale immigration of the Han Chinese to the hilly areas of Southeast China based on documentary and archaeological evidence, suggesting that deforestation was the cause. The occurrence of a clay layer contemporaneous with the vegetation change reflects intensified soil erosion on the denuded slopes around the basin. This study yields the first unequivocal evidence of human disturbance in the Chinese pollen record. An important implication of this study is that caution must be exercised in interpreting Chinese pollen data directly in climatic terms.

Two high-resolution pollen diagrams (Lake Shayema, Sichuan; Dianchi, Yunnan) from the Subtropical Broadleaved Evergreen Forest of Southwest China (Sites 10 & 11, respectively) provide detailed histories of vegetational changes since the late-Pleistocene (Jarvis, 1993; Sun *et al.*, 1986). Both records show an increase in *Pinus* and sclerophyllous broadleaved trees such as *Cyclobalanopsis* (evergreen oak), *Castanopsis/Lithocarpus* (chinkapin/tanoak), and *Quercus* that are tolerant of extreme rainfall seasonality after 4000 yr B.P., suggesting a reduction of monsoonal rain and the intensification of spring drought due to a weakened monsoon system. No major vegetational change attributable to climatic fluctuations occurred in the last 2000 years. The impact of human settlement and agriculture since 1000-1500 years ago was only weakly expressed in the sedimentary and pollen records by an increase in clastic contents and the occurrence of disturbance indicators (*Phyllanthus*, *Plantago*, Gramineae, *Pteridium*) and cultigens (*Cannabis*, *Fagopyron*). By contrast, a pollen record derived from a soil profile in a pristine subalpine fir forest at 3005 m near the summit of Dashennongjia in the northern subtropics (Site 7) suggests that a deciduous forest consisting of *Quercus*, *Acer* (maple), *Liquidambar* (sweetgum), and *Betula* (birch) was

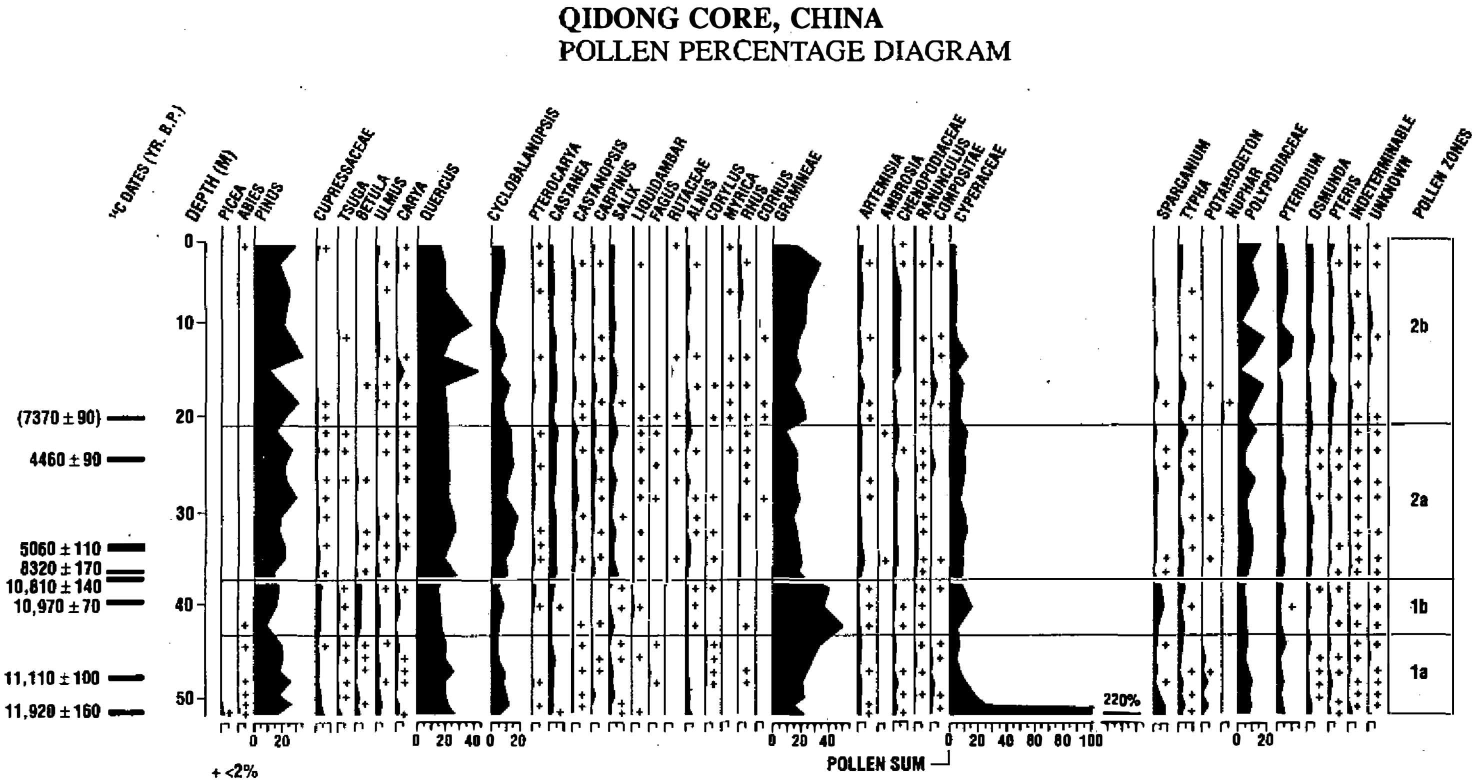

Fig. 6. Pollen diagram from Qidong, Yangtze River delta (Site 6). Pollen percentages are based on a sum of all terrestrial pollen taxa, excluding pteridophyte spores and aquatics (After Liu *et al.*, 1992).

Daiyun Mountains
Dehua, Fujian, China (Elevation: 1,360m)

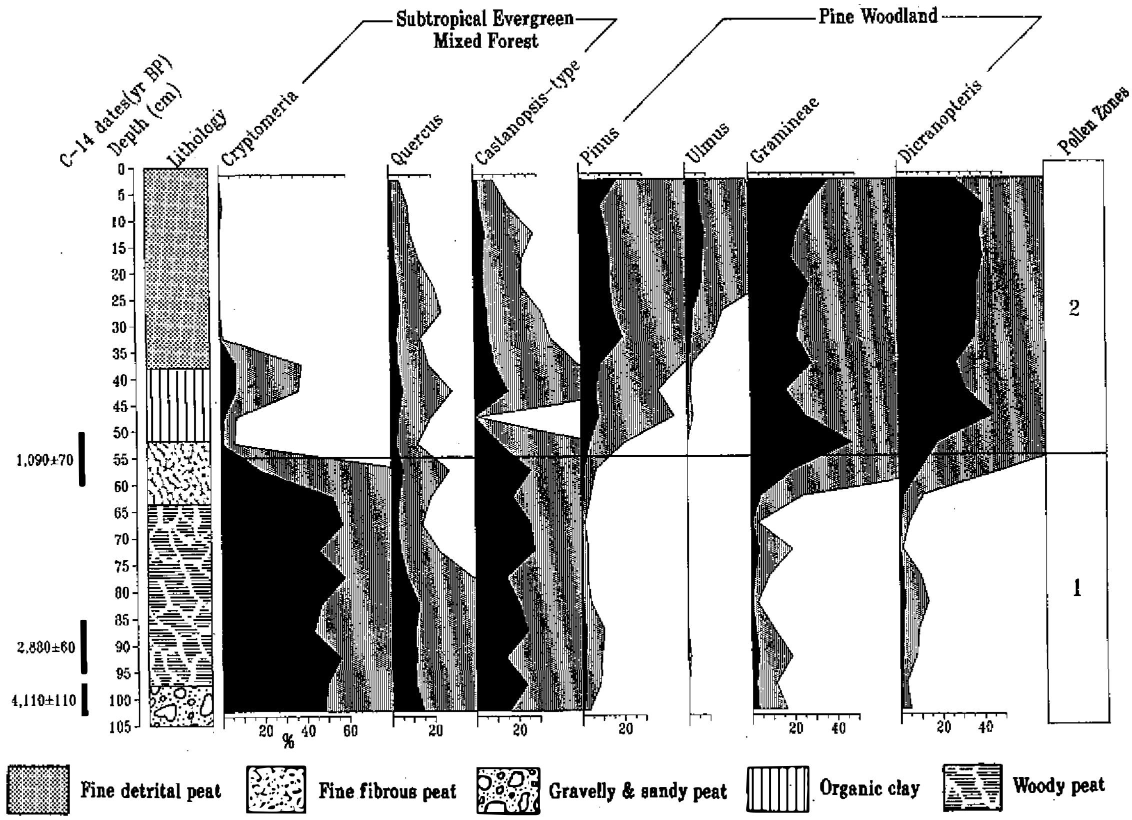

Fig. 7. Pollen diagram from the Jiuxianshan dambo in the Daiyun Mountains (Site 8). Pollen percentages are based on a sum of all pollen and spores (After Qiu, 1994). The lightly shaded pollen curves are 5X exaggerations.

replaced by the modern *Abies–Rhododendron* forest about 300-400 years ago (W. Li, 1991) (Figure 8). The record has been interpreted to reflect a climatic change towards cooler (by 2°C) and wetter conditions coincident with the Little Ice Age (W. Li, 1991). Anthropogenic activities in the Shennongjia Mountains have been minimal due to the precipitous terrain and inaccessibility of this region. However, uncertainties in dating and the interpretative problems inherent in soil pollen analysis preclude any firm conclusions.

Relatively few pollen records are available from the tropical and southern subtropical regions of Southeast China. The upper 6.2 m of a 22.3 m core taken from a floodplain deposit in the Pearl River (Zhu Jiang) delta (Site 9) spans the period 2500 to ca. 200 yr B.P. (Site 9). P. Li (1991) divided the pollen diagram into seven pollen zones and derived "semi-quantitative" climatic curves based on the changing ratios of various ecological-taxonomic groups in the profile. However, the pollen record is difficult to be interpreted in climatic terms due to complications from fluctuations in the fluvial-deltaic sedimentary environment and sea level

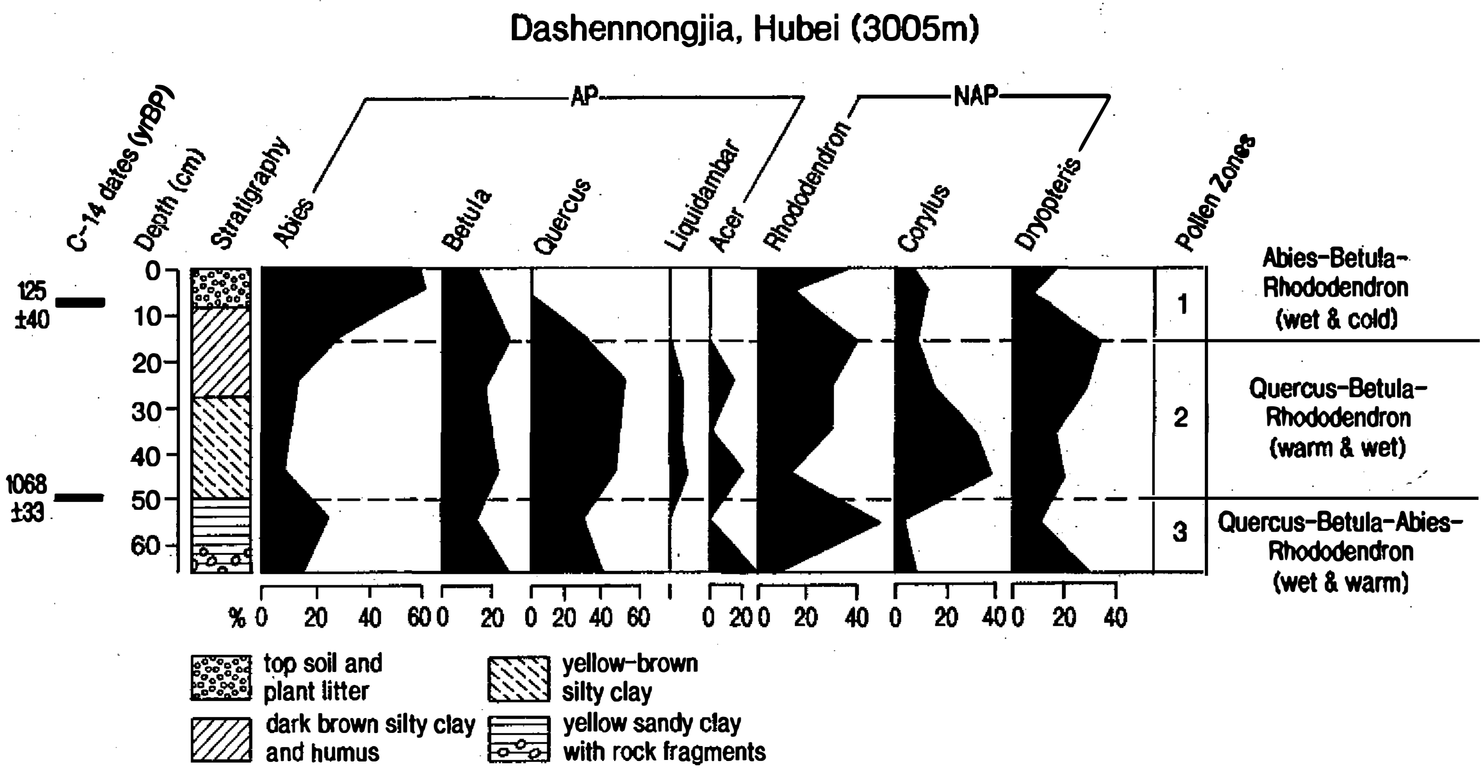

Fig. 8. Pollen diagram from Dashennongjia (Site 7). Pollen percentages for the trees are based on an arboreal pollen (AP) sum; those for the shrubs and pteridophytes are based on a sum consisting of all non-arboreal pollen (NAP) types (After W. Li, 1991).

changes, as suggested by the saw-toothed pollen curves for many taxa. The most obvious feature in the pollen diagram is the increase in fern spores (*Dicranopteris, Microlepia*) and Gramineae pollen after about 1000 yr B.P. (Figure 9). This is probably due to forest clearance and intensified land use in the Zhujiang Delta since the Tang Dynasty.

4. QINGHAI-TIBETAN PLATEAU AND INNER MONGOLIAN STEPPES

Even fewer pollen records exist in the Qinghai-Tibetan Plateau and the Steppe and Desert regions of China. A 4.5 m core taken from Qinghai Lake (Site 12), the largest salt lake in China, yields a pollen record spanning the last 11,000 years (Du *et al.*, 1989). The pollen diagram shows maximum abundance of tree pollen (*Pinus, Picea*) during the mid-Holocene (8000-3500 yr B.P.) indicating a warm and moist climate associated with a strengthened summer monsoon (Figure 10). It is followed by a significant decline in tree pollen and an increase in *Artemisia* and other desert elements after 3500 yr B.P., suggesting return to colder, drier conditions. Another major decline in *Pinus* and *Picea* pollen and increase in *Artemisia* and Chenopodiaceae pollen occurred after 1500 yr B.P. This further reduction in regional tree cover is probably due to climatic cooling and dessication, but human disturbance cannot be completely ruled out. The Neoglacial climatic changes inferred from the pollen record are also reflected in the oxygen isotope record from Qinghai Lake. Three negative excursions in oxygen isotope ratios at about 2800, 1700, and 1300 yr B.P. may correspond with glacial advances on the Qinghai-Tibetan Plateau at about 3000, 2000, and 1500 yr B.P. (Lister *et al.*, 1991).

A slight increase in tree pollen and aquatic pollen and spores at the top 20 cm of the Qinghai Lake core had been interpreted to suggest a return to slightly moister and warmer conditions about 500 years ago (Du *et al.*, 1989), but the data are somewhat dubious because of insufficient sampling resolution. Notably, two late-Holocene pollen records from near the forest/steppe ecotone of Inner Mongolia (Sites 3 and 4) also seem to suggest an increase in *Pinus* pollen relative to Chenopodiaceae and *Artemisia* after about 700 yr B.P. (Liu and Li, 1992; Jiang, 1992) (Figures 11 and 12). If this pollen change can be substantiated, it would suggest a slight increase in tree populations or an advance of the forest margin, implying an increase in moisture availability. However, this scenario contradicts with historical and archaeological evidences for a cold and dry climate during the Ming and early Qing Dynasties (ca. 600-200 yr ago), coincident with the Little Ice Age in China (Wang, 1992; Liu and Li, 1992; Chu, 1973). It should be pointed out that the resolution and sensitivity of the available pollen data are not adequate to resolve this conflict, and the dating control is poor. It is also notable that even in the relatively sparsely populated grasslands of Qinghai and Inner Mongolia, the impacts of human activities on the vegetation and hence on the pollen record may still be substantial.

5. DISCUSSION AND CONCLUSIONS

The dozen pollen records reviewed in this paper are chosen to represent some of the best from China for the period 0-2000 yr B.P. It is obvious that many are still sub-optimal in terms of dating control, sampling interval, and climate-sensitivity. The effects of human disturbance on the vegetation may not be easy to distinguish from the climatic signal. In the Chinese pollen record there lacks a regionally distinct, broadly synchronous, and clearly defined

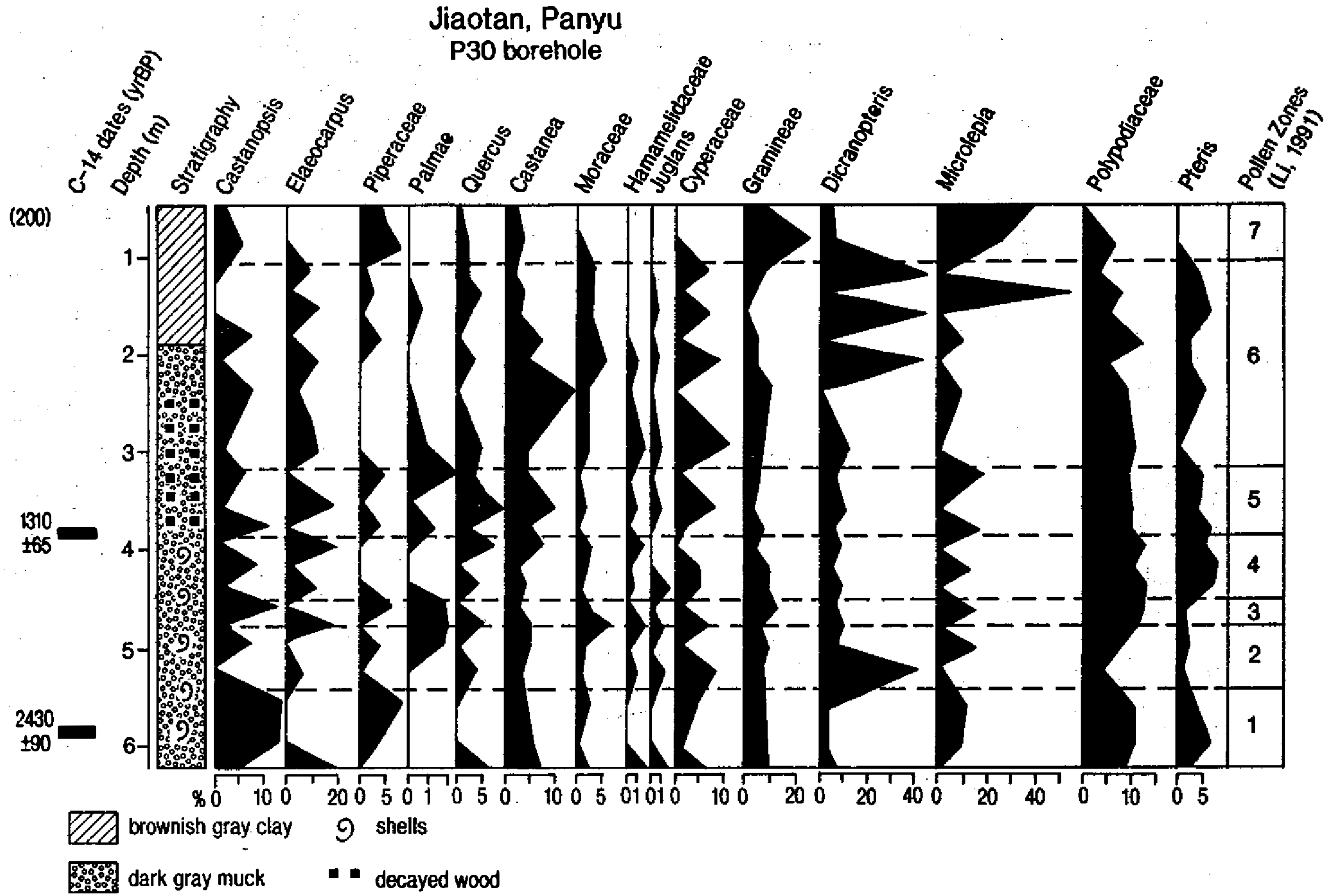

Fig. 9. Pollen diagram from the Jiantan P30 borehole, Pearl River delta (Site 9). Pollen percentages are based on a sum of all pollen and spores. Note variable percentage scales used for different pollen taxa. The top of the sediment profile is estimated to be more than 200 years old (After P. Li, 1991).

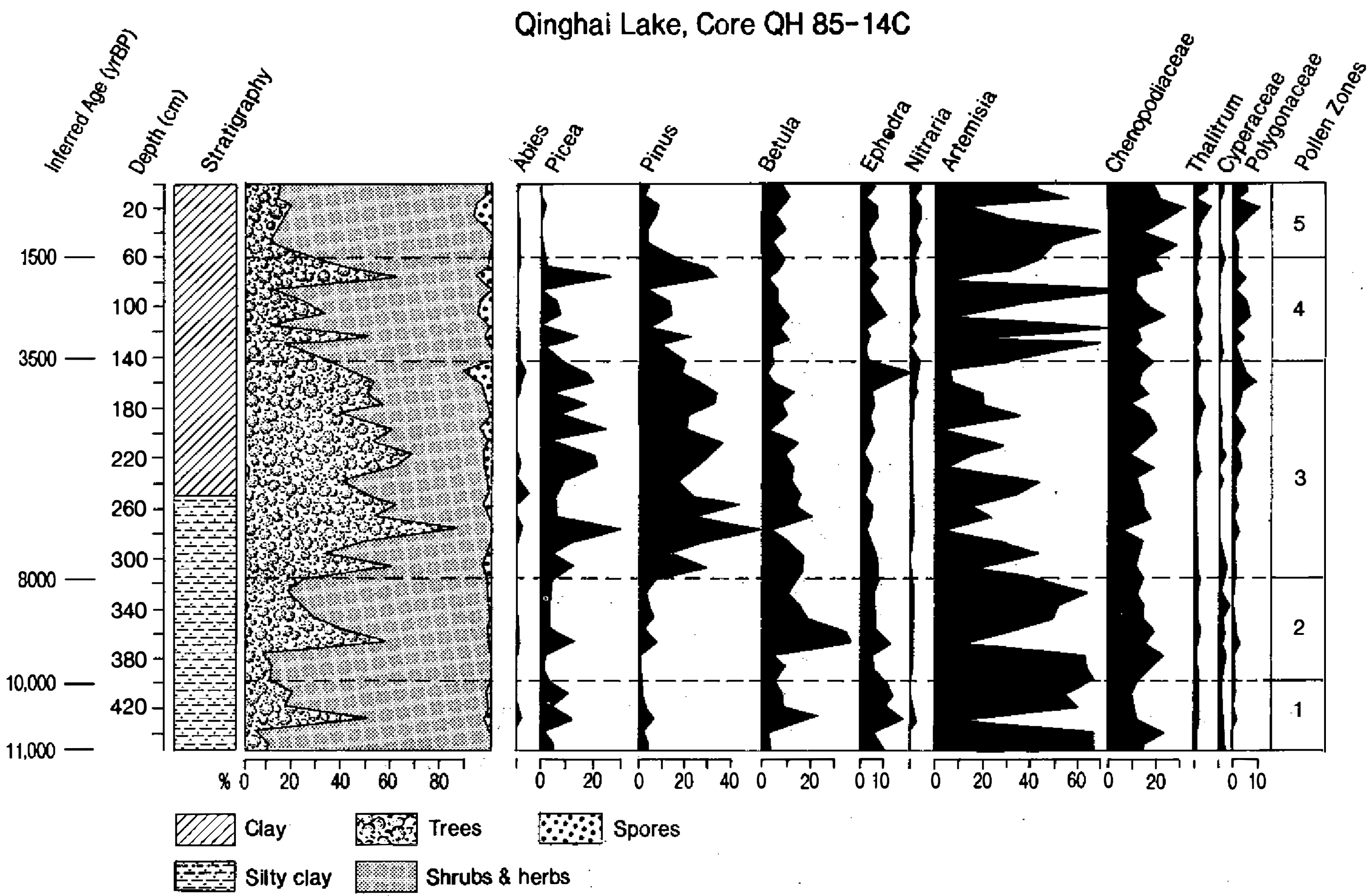

Fig. 10. Pollen diagram from Qinghai Lake (Site 12). Pollen percentages are based on a sum of all pollen and spores (After Du *et al.*, 1989).

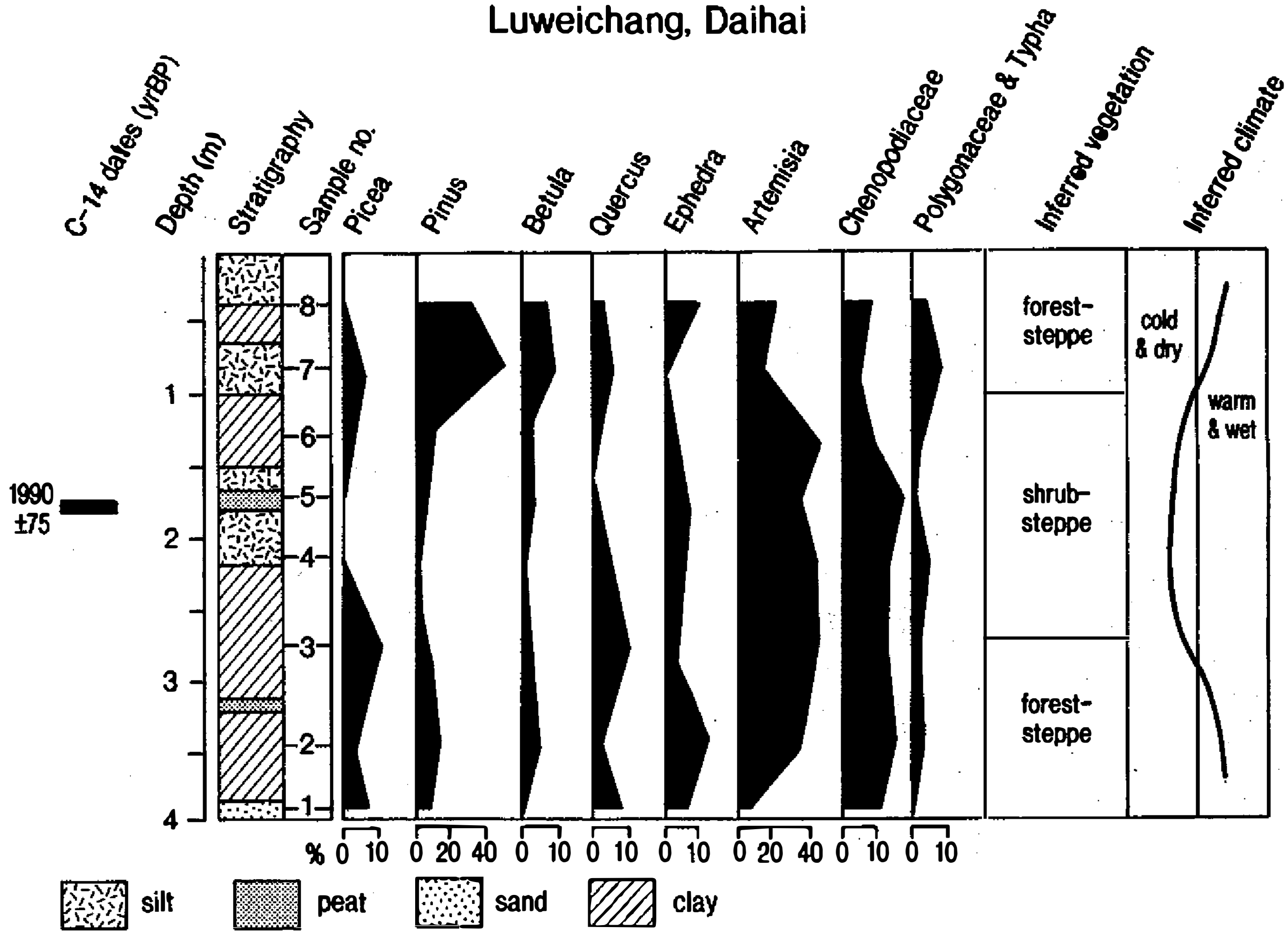

Fig. 11. Pollen diagram from Luweichang, Inner Mongolia (Site 3). Pollen percentages are based on a sum of all pollen and spores (After Liu and Li, 1992).

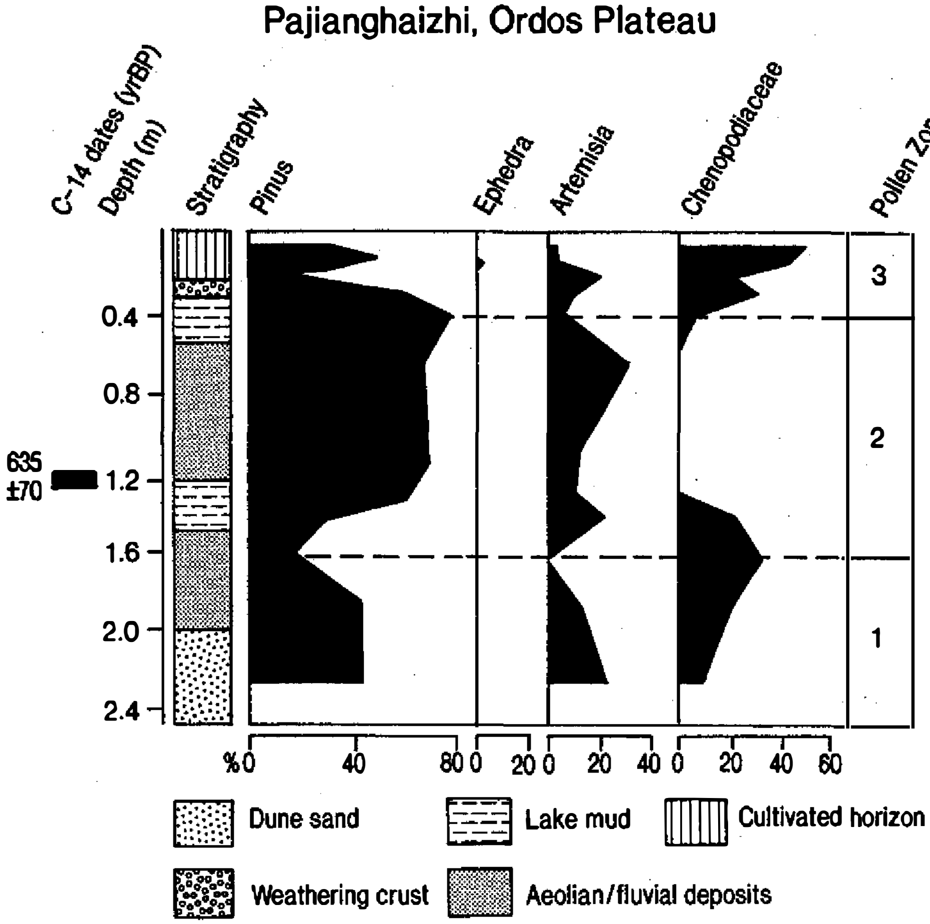

Fig. 12. Pollen diagram from Pajianghaizhi (Site 4). Pollen percentages for trees are based on a sum of all arboreal pollen (AP) types; those for herbs are based on a sum of all non-arboreal pollen (NAP) types (after Jiang, 1992).

pollen marker horizon for human disturbance or settlement comparable to the *Ambrosia*-rise in the North American pollen records (McAndrews, 1988), or the Landnam phase or the *Ulmus* decline in western Europe (Behre, 1988). Instead, the human impact on the Chinese vegetation over the last several millennia is pervasive, continuous, and cumulative, albeit large-scale and severe. Only in the Daiyun Mountains of Fujian (Qiu, 1994) is the human impact unequivocally registered palynologically–in this case by an abrupt decline in subtropical evergreen forest taxa and a dramatic increase in *Pinus*, grasses, and fern spores–taxa representing the modern secondary pine woodland. Because of the long history of civilization, the impact of human activities must be taken into consideration in interpreting the Chinese pollen records in terms of climatic changes for the last 2000 years.

Despite these limitations, the pollen records from various parts of China indicate a climatic change from a warmer period during the mid-Holocene to cooler conditions after ca. 4000 yr B.P. In the steppes and plateaus near the northern and western limits of the

Southeast and Southwest monsoon, the last 4000 years seem to be both cooler and drier, which is consistent with model-predictions of a weakening of the summer monsoon during the late-Holocene (Kutzbach and Otto-Bleisner, 1982). In eastern China where moisture stress is less important in controlling vegetation growth, the late-Holocene is characterized more by climatic cooling than by moisture changes which, if any, may suggest slightly wetter conditions.

Pollen changes in the last 2000 years basically suggest a continuation or intensification of the climatic trends that had already started by 4000 yr B.P. Human disturbance becomes an increasingly important factor in vegetation change during the last 1500-1000 years. The Little Ice Age, while very well documented in Chinese historical and phenological records (Chu, 1973; Wang and Zhang, 1992), is poorly registered palynologically. None of the pollen records reviewed in this paper contains any unequivocal, well-dated evidence for climatic changes that can be related to the Little Ice Age. The only pollen record that possibly shows vegetational changes coincident with the Little Ice Age comes from the soil profile in the Dashennongjia Mountains of central China (W. Li, 1991), but contemporaneity cannot be demonstrated due to insufficient dating control and coarse sampling interval in a sub-optimal pollen depositional environment. The pollen records from Qinghai Lake and the Inner Mongolian steppes (Du *et al.*, 1989; Liu and Li, 1992; Jiang, 1992) seem to produce mixed and dubious signals of vegetational changes during the last 700 years that encompass the Little Ice Age interval, but again inadequate dating control and poor data sensitivity in these records preclude any definite interpretation. In pollen records from the populous areas of the Chinese humid subtropics (Liu *et al.*, 1992; P. Li, 1991; Qiu, 1994), where the vegetation response to any short-term climatic change associated with the Little Ice Age was likely to be subdued, any climatic signal would have been overshadowed by aberrations due to human disturbance.

The pollen records so far available from China are rarely or only marginally qualified to be called "high resolution" if it is defined as well-dated reconstructions at the annual to decadal and century time-scales. Future work should focus on small, preferably meromictic, lakes located in sparsely populated regions near major ecotones and along the limits of the summer monsoon (Figures 1 and 2). In view of the rarity of such small, permanent lake basins in the semi-arid and arid parts of northern and northwestern China, the Qinghai-Tibetan Plateau, with its many salt lakes as well as freshwater lakes and the relatively undisturbed vegetation, may be the most promising land where a high-resolution pollen record of monsoon climate changes for the last 2000 years can be obtained.

Acknowledgments This research is supported by a grant from the Geography and Regional Science Program of NSF (SES-9001343), and grants from the National Geographic Society (#3369-86), the Association of American Geographers, and the LSU Summer Faculty Research Program. We thank M. L. Eggart for cartographic assistance.

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