QUATERNARY PALYNOFLORAS AND PALEOCLIMATE OF THE QAIDAM BASIN, QINGHAI PROVINCE, NORTHWESTERN CHINA

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Abstract

A cool, arid climate featuring steppe vegetation characterizes the modern day temperate zone of northwestern China. In contrast, palynofloras indicate that the paleoclimate there was warmer and wetter during the Pleistocene than during the Holocene. To document vegetational and climatic changes during the Quaternary, fossil pollen and spores were systematically studied in sediments from the Qaidam Basin in the Qinghai Province at the northeastern margin of the Tibetan (Qinghai–Xizang) Plateau.

Pollen and spores in four cores from the Quaternary lacustrine deposits in the Qaidam Basin showed four distinctive pollen zones. The basal assemblage, Zone Q1, is dominated by taxa having tropical or subtropical warm, wet climatic affinity and is probably Early Pleistocene in age. The overlying assemblage, Zone Q2, is dominated by taxa having warm–temperate and semi–wet climatic affinity and is probably Middle Pleistocene in age. Zone Q3 is dominated by taxa having temperate and semiarid climatic affinity and is probably Late Pleistocene in age. The uppermost assemblage, Zone Q1, is dominated by taxa having cool–temperate, arid climatic affinity and is Holocene in age.

The modern vegetation of the high plateau is dominated by xerophytic and halophytic herbs and shrubs. The palynofloral assemblages show that this modern vegetation became established during the Holocene, when cool, dry conditions prevailed following Pleistocene deglaciation. This climatic cooling is interpreted as the result of continued Himalayan–Tibetan Plateau uplift in the Holocene. Modern vegetation zones are used as a basis for comparison with the fossil assemblages and suggest that the Qaidam Basin might have been elevated at least 2,000 to 3,000 m since the Early Pleistocene. Dabuxun Lake in the basin may have been elevated about 700 m in the past half million years. The pollen data therefore allow more precise dating of Himalayan–Tibetan uplift. Intense uplift at the end of Early Pleistocene is indicated and further uplift probably occurred in the middle substage of the Middle Pleistocene. The results of this study contribute to understanding Himalayan–Tibetan Plateau evolution, regional Quaternary correlations, and climatic changes around the globe.

INTRODUCTION

The climate of the high plateaus of northwestern China is cool and extremely arid. The Qaidam (Tsaidam) Basin at the northeastern edge of the Tibetan (Qinghai–Xizang) Plateau (Text-Figure 1) covers more than 120,000 km^2 and lies between 36°–39°N Latitude and 90°–98°E Longitude. It is an intermontane basin surrounded by the Altun, Qilian, and Kunlun mountains. The altitude of the surrounding mountains is 4,500 to 5,000 m, while that of the basin is 2,670 to 3,600 m.

Gobi (desert pebble pavement), deserts, salt lakes, salt marshes, and various windcarved landforms are widely distributed in the basin and form an unusual desert landscape. Having an annual precipitation of 20 to 40 mm and an annual potential evaporation of 3,250 mm, the climate of the basin is very dry. Because the elevation of the basin is so high, the continental climate is also cold (average annual temperature 0–5°C) and windy. Barren Gobi is widespread in the region, and plants only grow at lower elevations (2,670 to 2,800 m). The modern vegetation is characterized by xerophytic and halophytic shrubs and herbs, classified as the salt desert type (Geng, 1958) (Table 1).

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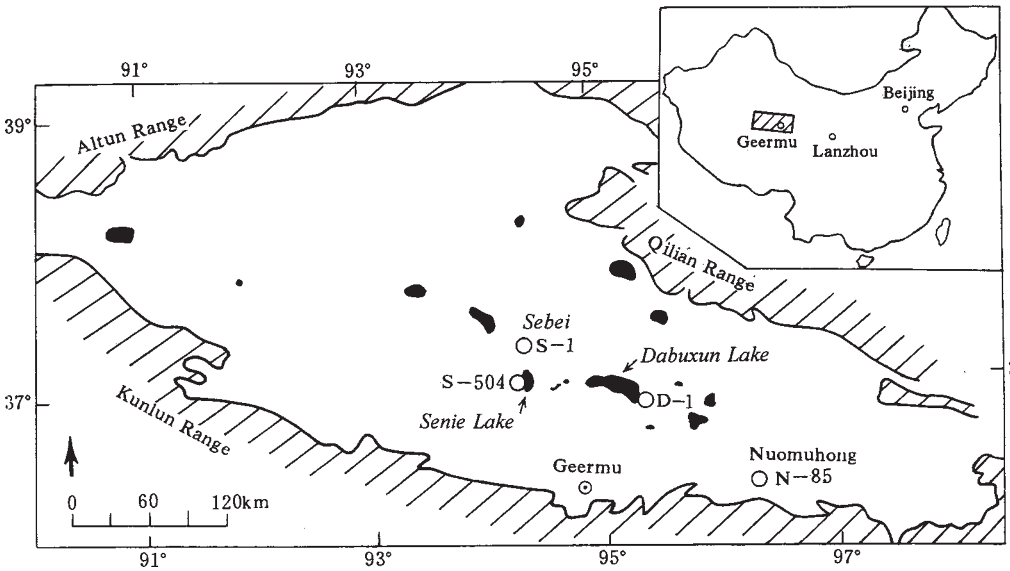


Text-Figure 1. Locations of the Sebei Arch S-1, Senie Lake S-504, Dabuxun Lake D-1, and Nuomuhong N-85 coreholes in the Qaidam Basin (solid black=salt lakes, open circles=drill holes).

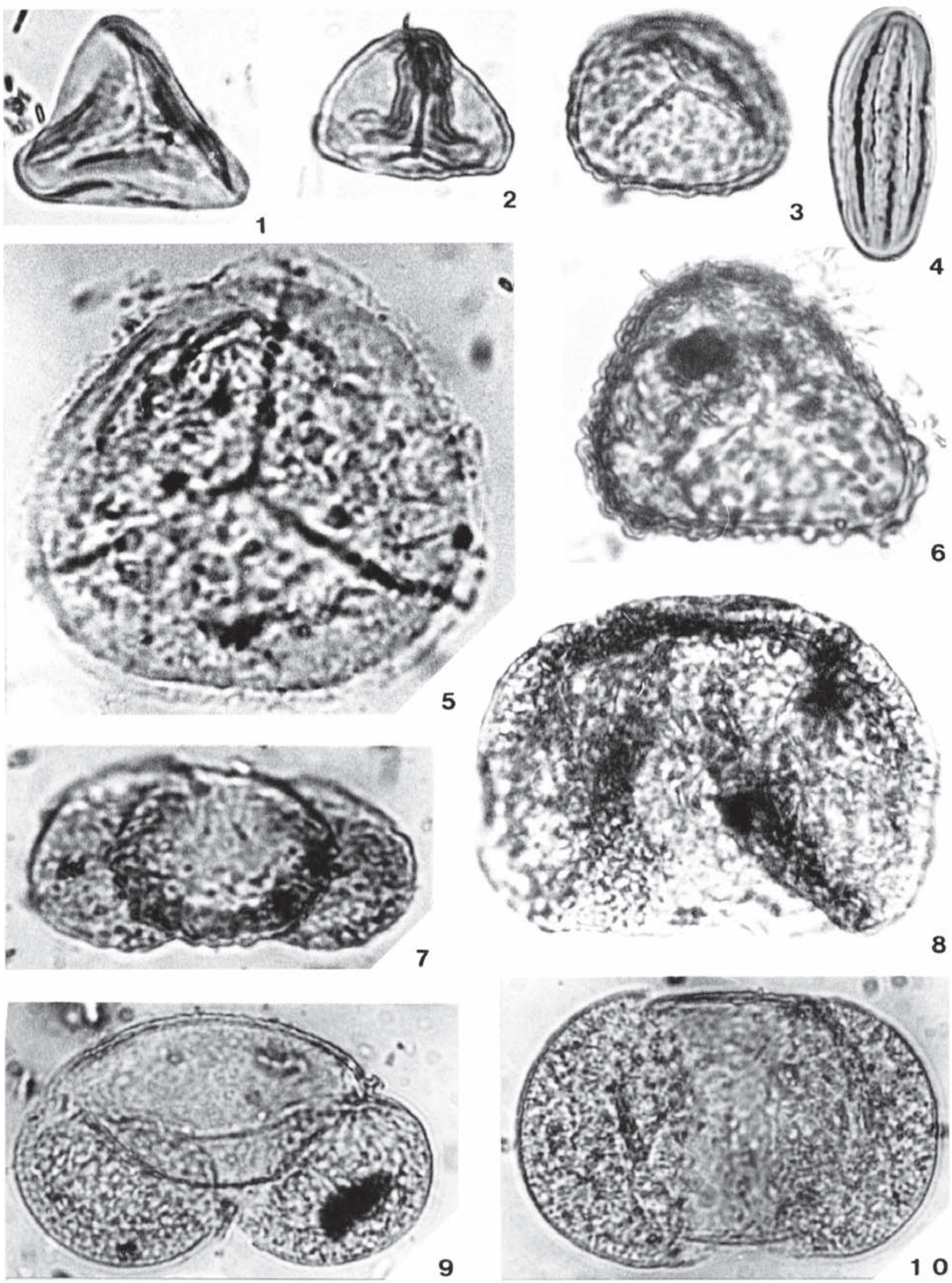
The Quaternary lacustrine deposits consist of gray, grayish green, and grayish yellow clays, silty clays, clayey silts, silts, and sand intercalated with dark carbonaceous shales in the lower part, and rock salt, peat, and gyttja in the upper part (Text-Figure 2). The total thickness of the Quaternary deposits may exceed 1,600 m. Paleomagnetic data were collected on 43 samples from the Dabuxun Lake D-1 corehole (0–528 m depth); Derbyshire et al. (1985) and Wang et al. (1986) reported that the magnetic inclination and natural remanent magnetization intensity curves indicated that all 528 m were deposited in the Brunhes normal polarity chron. These analyses interpreted that the most recent event (20–30 m depth) is consistent with the putative Gothenburg event which was dated 10–15 ka; the second event (60–75 m depth) is consistent with the Mono Lake event which was dated 20–30 ka; and the third event (160–205 m depth) is consistent with the Blake event which was dated 105–114 ka. The other three events (240–250 m, 360–370 m, and 475 m depths) could correspond to the Biwa I, Biwa II, and Biwa III events which were dated from estimates of deposition rates at 176–196 ka, 292–298 ka, and 350–367 ka, respectively. The age of the lowermost sample is about 500 ka. The C^{14} (0–20m depth) and Th^{230} (20–220m depth) ages are in accordance with these paleomagnetic data.

Vegetation studies have been useful for determining Himalayan–Tibetan uplift events and climatic changes. Li (1996) correlated collision, uplift, and vegetation from the Late Cretaceous to the Eocene. Hsu (1978) used subtropical pollen assemblages to constrain Late Miocene–Early Pliocene uplift. Mercier et al. (1987) incorporated other palynological studies to calculate uplift rates during the Pliocene–Lower Pleistocene. Raymo et al. (1988) used these data sets to show an increase in uplift rates in the past 5 million years, and Zheng (1989) correlated uplift with glaciation. Du and Kong (1983) and Chen and Bowler (1985) identified four climatic cycles over the past 30,000 years using palynological and geochemical analyses in

PLATE 1

Palynoflora in coreholes from Qaidam Basin. All figures x1,000.

1 *Microlepia* sp. (No. S-1-14-1) Zone Q1.
2 *Cyathea* sp. (No. S-1-14-2) Zone Q1.
3 *Osmunda* sp. (No. D-1-18-2) Zone Q3.
4 *Ephedra* sp. (No. N-85-21-5) Zone Q3.
5 *Selaginella* cf. *longipila* Hieron. (No. S-1-11-1) Zone Q1.
6 *Pteris vittata* Linn. (No. D-1-52-2) Zone Q2.
7 *Podocarpus neriifolius* Don. (No. S-1-14-4) Zone Q1.
8 *Dacrydium pierrei* Hickel (No. S-1-18-2) Zone Q1.
9 *Pinus* sp. (No. D-1-15-1) Zone Q3.
10 *Picea* sp. (No. D-1-7-1) Zone Q3.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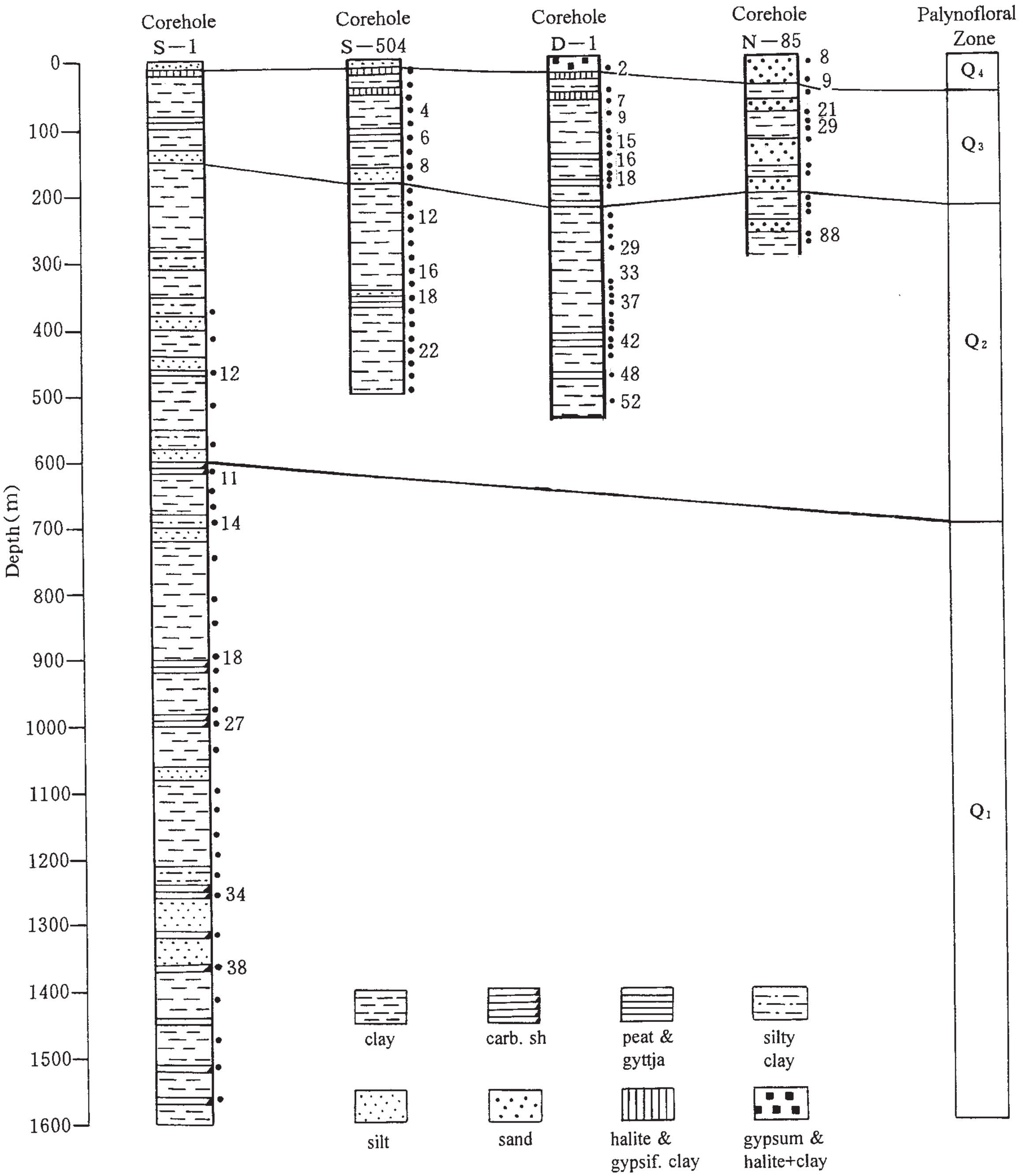


Text-Figure 2. Stratigraphic correlation based on lithology and palynofloras (dots along cores are samples; numbers indicate important samples; slide numbers in plates are based on these numbers, for example, Plate 1, 1. No. S-1-14-1 is sample 14 of the Sebei Arch No. S-1 corehole).

cores from Qarhan (saline) Lake in the basin. The cores studied here from the Qaidam Basin provide palynological information for the past 500,000 years and delineate 10 or more climatic cycles.

MATERIALS AND METHODS

Quaternary lacustrine deposits were sampled from four coreholes in the central and southeastern parts of the basin. These are the Sebei Arch S-1, the Senie Lake S-504, the Dabuxun Lake D-1, and the Nuomuhong N-85 coreholes (Text-Figure 1). All 187 samples were prepared by standard methods using 10 % hydrochloric acid, 40 % hydrofluoric acid, and 5 % potassium hydroxide. Acetolysis with acetic anhydride–sulfuric acid mixture (9:1) followed. Gravity separation with a cadmium iodide–potassium iodide solution (CdI:KI:H_2O = 10:9:9) was used to concentrate palynomorphs found in 105 samples.

Pollen identifications were based on morphological comparison with that of related living plants. More than 1,400 standard slides of pollen of living species comprise the reference collection at the Beijing Institute of Botany, Chinese Academy of Sciences (Wang et al. 1995), and were used for comparison. This approach is sufficient support for generic- and species-level identifications in this paper.

Paleoclimate reconstruction mainly relied on the ecological character of living taxa that can sensitively reflect climate conditions. The thermophilous taxa (e.g., *Juglans*, *Quercus*, *Betula*), the cold-resistant taxa (e.g., *Abies*, *Cedrus*), the xerophilous taxa (e.g., *Ephedra*, *Artemisia*, Chenopodiaceae), and the hydrophytic taxa in the assemblages were used to interpret climate changes. These data sets were used to construct temperature and humidity curves.

PALYNOFLORAS

Based on spore and pollen analyses of the core samples, the developmental history of the Quaternary vegetation of the Qaidam Basin is divided into four stages that were first defined as four palynofloral zones by Jiang (1988). From the base, these are:

Zone Q1 Palynoflora

62 genera were found in 25 samples from the Sebei Arch Sl corehole (600–1,600 m depth) (Text-Figure 2). In Zone Q1 (Table 2, Plates 1–4), arboreal pollen of *Pinus*, *Dacrydium*, *Podocarpus*, *Juglans*, *Carya*, *Betula*, *Quercus*, and *Castanea* are abundant in gray clays, silty clays, and dark carbonaceous shales (labeled "carb. sh." on Text-Figure 2). Shrub and herb pollen of *Ephedra*, *Ilex*, *Rosa*, *Lilium*, *Allium*, *Polygonum*, Chenopodiaceae, *Lathyrus*, and *Artemisia* are common. The relatively abundant spores are *Pteris*, *Osmunda*, *Microlepia*, *Selaginella*, *Crepidomanes*, and *Polypodium*. Hydrophytic and aquatic taxa including *Salvinia*, *Typha*, *Potamogeton*, *Alisma*, *Nymphaea*, and *Carex* are important in the assemblage in dark carbonaceous shales and gray clays.

This corehole contains the earliest Quaternary palynoflora in the region. Although the section cannot be dated precisely at present, the depth of the interval (600–1,600 m depth) and the geological information assigns an Early Pleistocene age.

Zone Q2 Palynoflora

Zone Q2 contains 67 genera in 10 core samples from the Sebei Arch S-1 corehole (150–600 m depth), 16 core samples from the Senie Lake S-504 corehole (180–500 m depth), 26 core samples from the Dabuxun Lake D-1 corehole (220–520 m depth), and 20 core samples from the Nuomuhong N-85 corehole (200–280 m depth) (Text-Figure 2). The abundant arboreal taxa (Table 2, Plates 1–4) are *Pinus*, *Picea*, *Cedrus*, *Betula*, *Alnus*, *Ulmus*, *Juglans*, and *Quercus*. The abundant or common nonarboreal taxa are *Ephedra*, *Nitraria*, *Salix*, *Tamarix*, *Polygonum*, *Allium*, *Lilium*, Chenopodiaceae, *Thalictrum*, *Artemisia*, Asteraceae, *Hemistepta*, *Ixeris*, and *Solidago*. *Typha*, *Potamogeton*, *Alisma*, *Sparganium*, *Carex*, and *Hydrocharis* represent the hydrophytic vegetation of this zone, particularly in peat and gyttja samples. Among these, *Potamogeton* and *Alisma* are abundant. In addition, *Pediastrum boryanum* occurs in the upper part of this section. The absence of thermophilic plants such as *Crepidomanes*, *Cyathea*, *Cyclosorus*, *Microlepia*, *Podocarpus*, *Dacrydium*, and *Desmodium* helps to define Zone Q2 (Table 2).

Paleomagnetic dating shows that the sedimentary section of Dabuxun Lake D-1 (220–520 m depth) ranges from approximately 500 to 130 ka (Wang et al., 1986).

Zone Q3 PalynofIora

Zone Q3 contains 73 genera in 9 core samples from the Senie Lake S-504 (10–180 m depth), 24 core samples from the Dabuxun Lake D-1 (20–220 m depth), and 52 core samples from the Nuomuhong N-85 (50–200 m depth) (Text-Figure 2). This palynoflora (Table 2, Plates 1–4) is rich in herbaceous species. The abundant coniferous pollen is of *Pinus*, *Picea*, *Abies*, and *Cedrus*. The common deciduous arboreal taxa include *Betula*, *Alnus*, *Corylus*, *Quercus*, *Castanea*, *Juglans*, and *Acer*. Dominants among the shrub and herb stratum include *Ephedra* and *Artemisia*. Herbaceous pollen of Chenopodiaceae, *Kochia*, *Acroptilon*, *Artemisia*, Asteraceae, *Brachyactis*, *Cacalia*, *Hemistepta*, *Ixeris*, *Solidago*, *Pedicularis*, *Polygonum*, *Allium*, *Lilium*, and *Lens* are abundant or common. Hydrophytic and aquatic taxa, including *Typha*, *Potamogeton*, *Alisma*, *Phragmites*, *Carex*, and *Sparganium* increase their importance in the palynoflora, particularly in peat and gyttja. Additionally, *Pediastrum simplex* and *Pediastrum boryanum* are well preserved and rather abundant. The main difference between Zones Q3 and Q2 is a relatively increased abundance of xerophytic plants such as *Ephedra*, *Artemisia*, and Chenopodiaceae (Table 2).

Combined paleomagnetic and radiometric dating show the sedimentary section of Dabuxun Lake D-1 (20–220 m depth) spans approximately 130 to 10 ka (Wang et al., 1986).

Zone Q4 Palynoflora

Based on the analyses of the Dabuxun Lake D-1 (0–20 m depth) and the Nuomuhong N-85 (0–40 m depth) (Text-Figure 2), Zone Q4 palynoflora (Table 2, Plates 1–4) is dominated by the xerophilous shrub *Ephedra* and herbaceous angiosperms such as Chenopodiaceae. Xerophilous shrubs and herbs, including *Artemisia*, *Nitraria*, *Tamarix*, Asteraceae, *Chrysanthemum*, *Ixeris*, *Pedicularis*, *Polygonum*, and *Allium*, are abundant or common in the palynoflora. The absence of spores and arboreal pollen is another characteristic of the palynoflora. Pollen of hydrophytic plants is rare in the assemblage, and takes the form of a few pollen grains of *Phragmites*, *Typha*, and *Carex*.

Paleomagnetic and radiocarbon dating show that the sedimentary section in the Dabuxun Lake D-1 (0–20 m depth) covered the entire Holocene, from approximately 10 ka to the present (Wang et al., 1986).

VEGETATIONAL CHANGES AND PALEOCLIMATE

The fossil spore and pollen assemblages from the Quaternary lacustrine deposits reflect the vegetational response to Quaternary climatic changes in the Qaidam Basin. The apparent vegetational changes reflected by the four palynofloral zones probably resulted from changing paleoclimatic conditions throughout the Pleistocene.

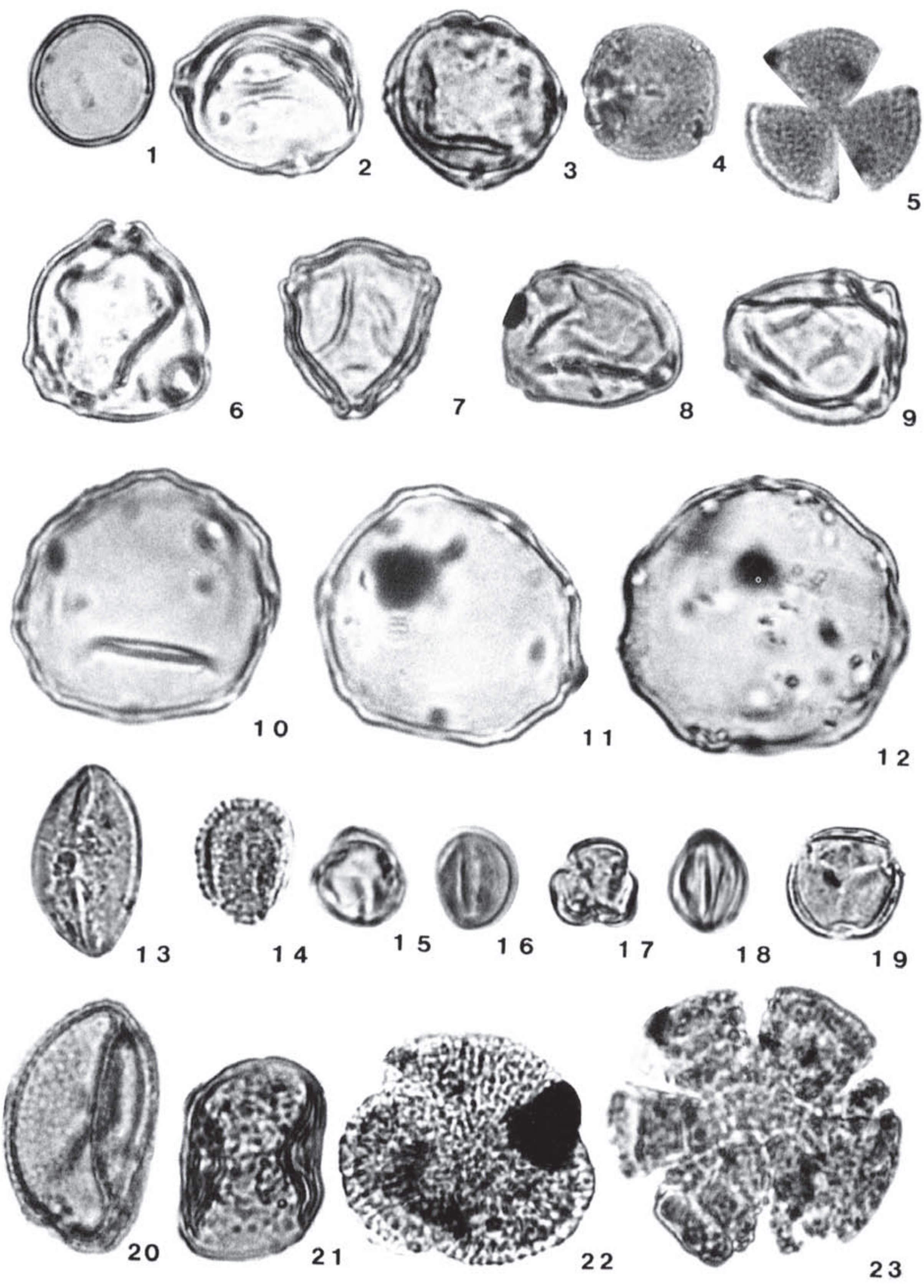
In the first stage, represented by the Zone Q1 palynoflora, the arboreal vegetation was mainly a mixed conifer–hardwood forest including *Pinus*, *Picea*, *Cedrus*, *Dacrydium*, *Podocarpus*, *Juglans*, *Carya*, *Betula*, *Alnus*, *Quercus*, and *Castanea*. Shrubs and herbs including thermophilous ferns grew within the forest or outside the forest. Aquatic plants represented by *Salvinia*, *Nymphaea*, *Potamogeton*, and *Alisma* were growing in ponds surrounded by stands of *Typha*. The vegetational landscape was extremely different from the modern desert landscape of the region. The occurrence of a mixed conifer–hardwood forest reflects a warmer and wetter climate than today. Moreover, the appearance of some tropical and subtropical plants, such as *Podocarpus*, *Dacrydium*, *Desmodium*, *Gardenia*, *Microtoena*, *Paraphlomis*, *Lepistemon*, *Crepidomanes*, *Cyclosorus*, *Microlepia*, *Cyathea*, and *Pteris* might indicate a tropical or subtropical warm and wet climate.

In the second stage, represented by the Zone Q2 palynoflora, the typical tropical and subtropical plants disappeared, reflecting climatic cooling that probably relates to glacial advance. The forest was dominated by needle-leaved trees, such as *Pinus*, *Picea*, and *Cedrus* mixed with such temperate deciduous trees as *Betula*, *Alnus*, *Acer*, *Ulmus*, *Juglans* and *Quercus*. Some ferns grew along with forest trees, perhaps in the understory. Xerophilous herbs and shrubs such as Chenopodiaceae, *Artemisia*, Asteraceae, *Allium*, *Polygonum*, *Ephedra*, *Nitraria*, and *Tamarix* were widespread in the basin, indicating the evolution of xerophilous steppe vegetation. However, hydrophytic plants including *Typha*, *Potamogeton*, and *Alisma* persisted through this stage. In the upper part of the section in Dabuxun D-1, a freshwater lacustrine facies is indicated at about 298 ka (Text-Figure 3) which suggests the glaciers had melted, the lake water had

PLATE 2

Palynoflora in coreholes from Qaidam Basin. All figures x1,000.

1	*Populus* sp. (No. D-1-9-1) Zone Q3.
2, 6	*Betula* sp. (No. D-1-18-4, D-1-16-2) Zone Q3.
3	*Alnus* sp. (No. D-1-9-1) Zone Q3.
4	*Ulmus* sp. (No. D-1-52-3) Zone Q2.
5	*Acer* sp. (No. D-1-37-1) Zone Q2.
7	*Carpinus* sp. (No. D-1-33-1) Zone Q2.
8, 9	*Corylus* sp. (No. D-1-52-2, D-1-9-3), Zones Q2 and Q3.
10-12	*Juglans* sp. (No. D-1-52-2, D-1-18-4, D-1-29-1), Zones Q2 and Q3.
13	*Allium* sp. (No. N-85-21-2) Zone Q3.
14	*Ilex* sp. (No. S-1-27-3) Zone Q1.
15, 16	*Castanopsis* sp. (No. 85-21-2) Zone Q3.
17, 18	*Castanea* sp. (No. N-85-21-7) Zone Q3.
19	*Quercus* sp. (No. N-85-29-3) Zone Q3.
20	*Lilium* sp. (No. D-1-9-2) Zone Q3.
21	*Lens* sp. (No. S-1-18-1) Zone Q1.
22	*Microtoena* sp. (No. S-1-27-3) Zone Q1.
23	*Mosla* sp. (No. S-504-22-1) Zone Q2.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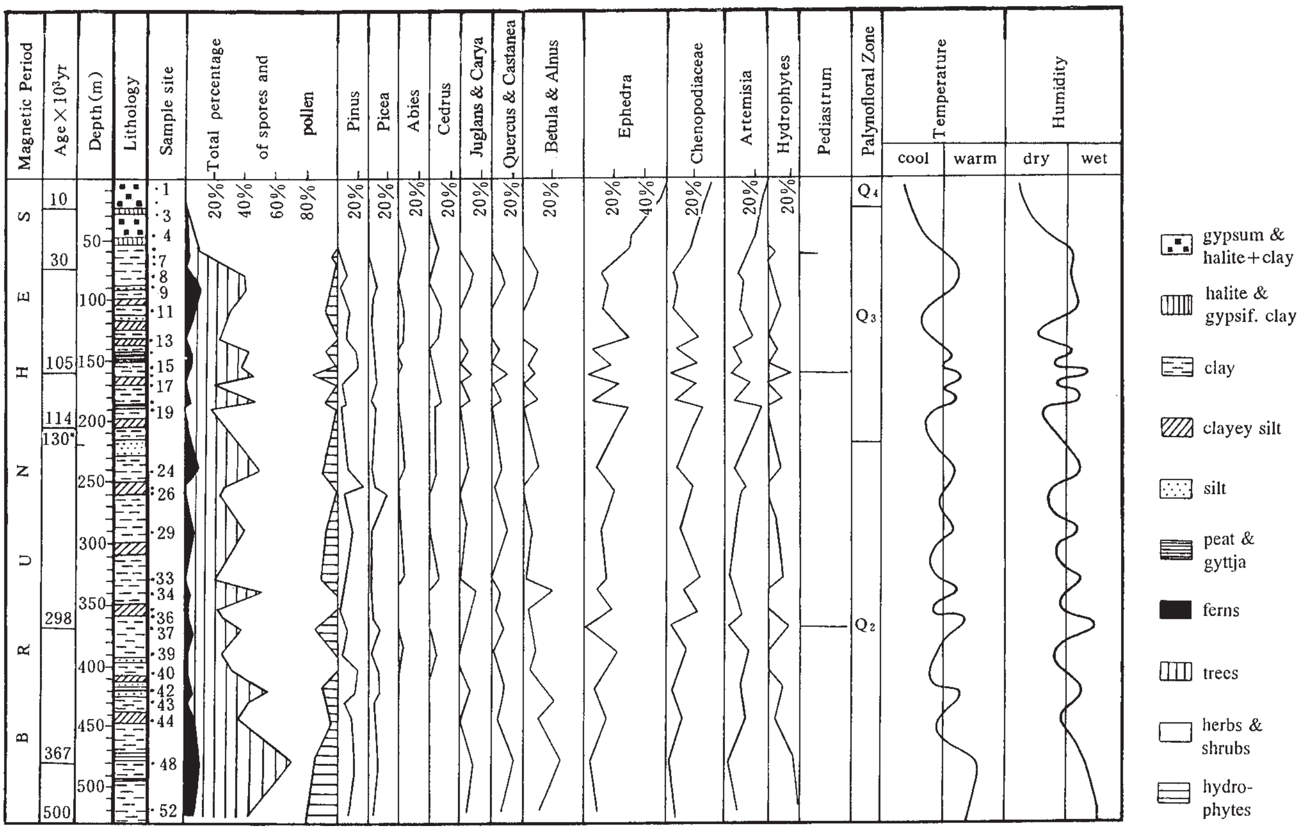


Text-Figure 3. Sporo-pollen diagram of Dabuxun Lake D-1 corehole in the Qaidam Basin (ages are based on paleomagnetic dating of Wang et al., 1986).

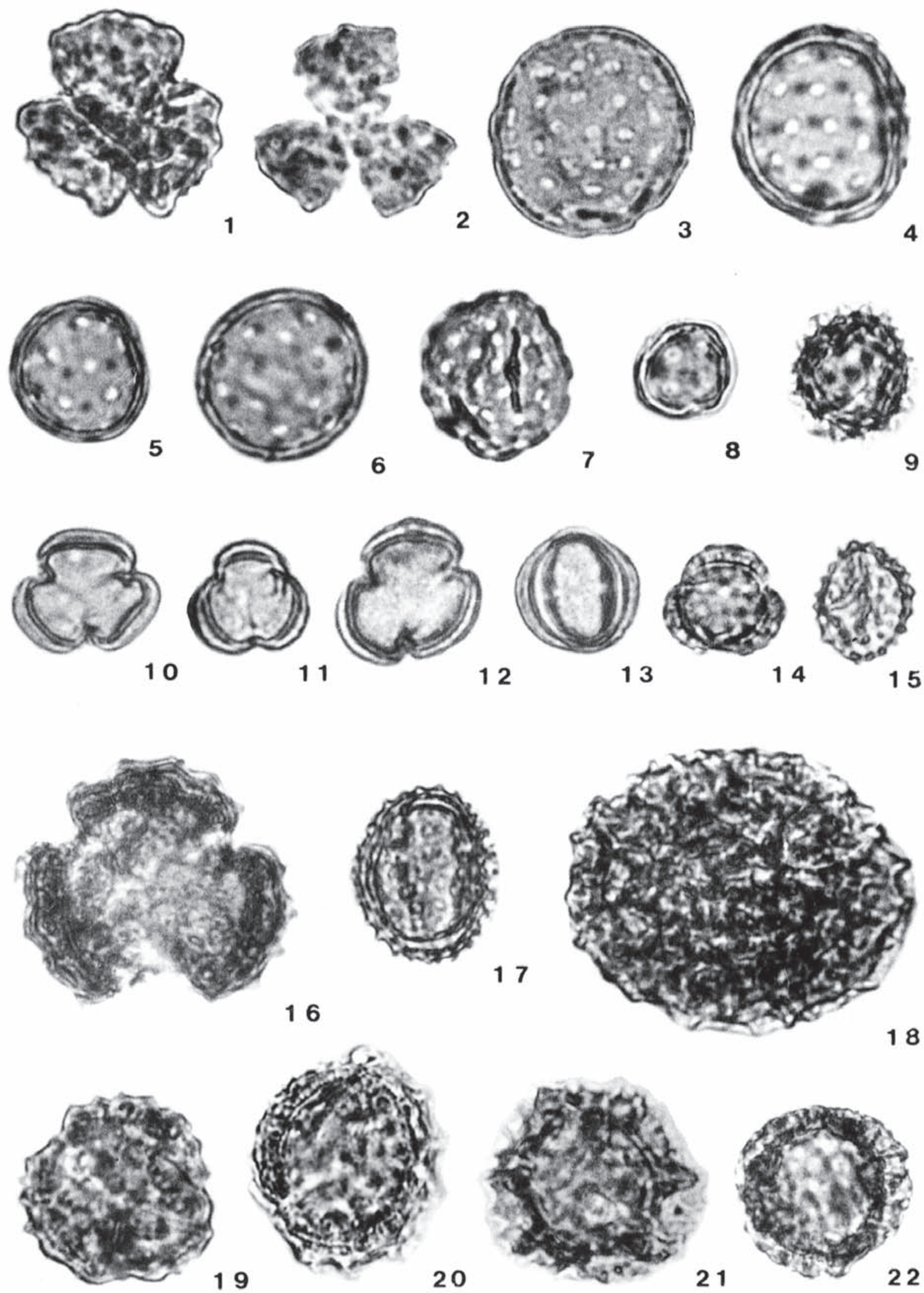
freshened, and freshwater algae such as *Pediastrum boryanum* appeared. The palynoflora of Q2 reflected a warm–temperate and semi-wet climate. Based on the sporo-pollen diagram of Dabuxun Lake D-1 (220–520 m depth), six climatic cycles occurred in this stage (Text-Figure 3).

The third stage, represented by the Zone Q3 palynoflora, is rich in herbaceous plants. According to the characteristics of the palynoflora, the composition of assemblages at this stage is somewhat similar to those of the second stage, but xerophilous steppe vegetation is more abundant. Pollen of tree taxa included that of a mixed conifer–hardwood forest including *Pinus*, *Picea*, *Abies*, *Cedrus*, *Betula*, *Alnus*, *Acer*, *Juglans*, *Quercus*, and *Castanea*. Hydrophytic and aquatic plants including *Typha*, *Potamogeton*, *Alisma*, *Phragmites*, and *Carex* occupied ponds and wetlands. By 105 ka (Text-Figure 3), freshwater *Pediastrum*

PLATE 3

Palynoflora in coreholes from Qaidam Basin. All figures x1,000.

1, 2 *Teucrium* sp. (No. N-85-21-3, No. D-1-29-1) Zones Q3 and Q2.
3 *Kochia* sp. (No. D-1-33-1) Zone Q2.
4–6 Chenopodiaceae (No. D-1-9-3, D-1-16-4, D-1-9-4) Zone Q3.
7 *Amaranthus* sp. (No. S-1-14-3) Zone Q1.
8 *Achyranthes* sp. (No. N-85-21-4) Zone Q3.
9 *Solidago* sp. (D-1-18-5) Zone Q3.
10-13 *Artemisia annua* L. (No. D-1-18-6, D-1-9-1) Zone Q3.
14, 15 *Brachyactis* sp. (No. D-1-18-6, D-1-18-3) Zone Q3.
16 *Arctium* sp. (No. D-1-18-6) Zone Q3.
17 *Chrysanthemum* sp. (No. S-1-11-1) Zone Q1.
18 *Lepistemon* sp. (No. S-1-38-1) Zone Q1.
19, 20 *Hemistepta* sp. (No. N-85-88-5, N-85-21-3) Zone Q2 and Q3.
21 *Ixeris* sp. (No. D-1-18-1) Zone Q3.
22 *Acroptilon* sp. (No. N-85-21-2) Zone Q3.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reappeared, but as a different species. Steppe vegetation included Chenopodiaceae, *Kochia*, *Acroptilon*, *Artemisia*, Asteraceae, *Brachyactis*, *Cacalia*, *Solidago*, *Pedicularis*, *Polygonum*, *Allium*, and *Ephedra*. The temperate and hydrophytic elements persisted and xerophilous herbs increased in the palynoflora, reflecting a temperate and semi-arid climatic pattern. According to the sporo-pollen diagram of Dabuxun Lake D-1 (20–220 m depth), four climatic cycles occurred in this stage, and the climate was trending towards cooler and drier conditions during the last substage of the stage (Text-Figure 3). Stable isotope analyses of samples from Dabuxun Lake also show a dry, cold climate in the Qaidam Basin during the last substage of the late Pleistocene from 19 to 11 ka (Yang et al., 1995).

The temperature changes reflected by the Zone Q3 palynoflora coincide essentially with the evolution of cool and warm events recorded by the Guliya ice core from the Qinghai–Tibetan Plateau. According to Yao et al. (1996, 1997), temperature fluctuations are reflected by $\delta^{18}O$ shifts in the Guliya ice core for the past 125 ka. From 125 to 75 ka, the Last Interglacial Age, three warm periods have been interpreted; from 75 to 10 ka, the Last Ice Age, a warm interglacial period is indicated between two cool glacial periods (Yao et al., 1996). These cool and warm events can also be shown in the present sporo-pollen diagram. There are three warm peaks in the time interval between 120 and 75 ka BP, and two cool peaks with one intervening warm peak in the time interval between 75 and10 ka BP in the sporo-pollen diagram of Dabuxun Lake D-1 corehole (Text-Figure 3).

During the fourth stage, the landscape reflected by the Zone Q4 palynoflora was distinctly different from those of the past three stages. The mixed forest was replaced by steppe vegetation that was mainly composed of Chenopodiaceae, *Artemisia*, Asteraceae, *Chrysanthemum*, *Ixeris*, *Pedicularis*, *Polygonum*, *Allium*, *Ephedra*, *Tamarix*, and *Nitraria*. A few hydrophytic plants including *Typha*, *Phragmites*, and *Carex* persisted in the stage, although *Pediastrum* was lacking. This vegetation is similar to that of the present, indicating a cool–temperate and arid climate (Text-Figures 3 and 4).

Judging from the palynofloras, the Early Pleistocene paleoclimate was a wet type, typical of the tropical or subtropical zone. The Middle Pleistocene paleoclimate was a semi-wet type typical of the warm–temperate zone. The Late Pleistocene paleoclimate was a semi-arid type typical of the temperate zone. The modern arid type of vegetation of the cool–temperate zone that characterizes the Qaidam Basin today was established in the Holocene.

This conclusion coincides essentially with the Quaternary palynofloral analysis of Young and Chiang (1965) in the adjacent Qinghai Lake basin. There, the relatively warm humid climate of the Early to Middle Pleistocene was followed by a colder and drier climate in the Late Pleistocene. The climatic cooling during the Middle Pleistocene and the Late Pleistocene may correlate with glacial ages, and the appearance of freshwater *Pediastrum* may indicate the onset of a wetter, interglacial warming. In the interglacial stage, glacial ablation resulted in the lake-water freshening and the appearance of *Pediastrum*.

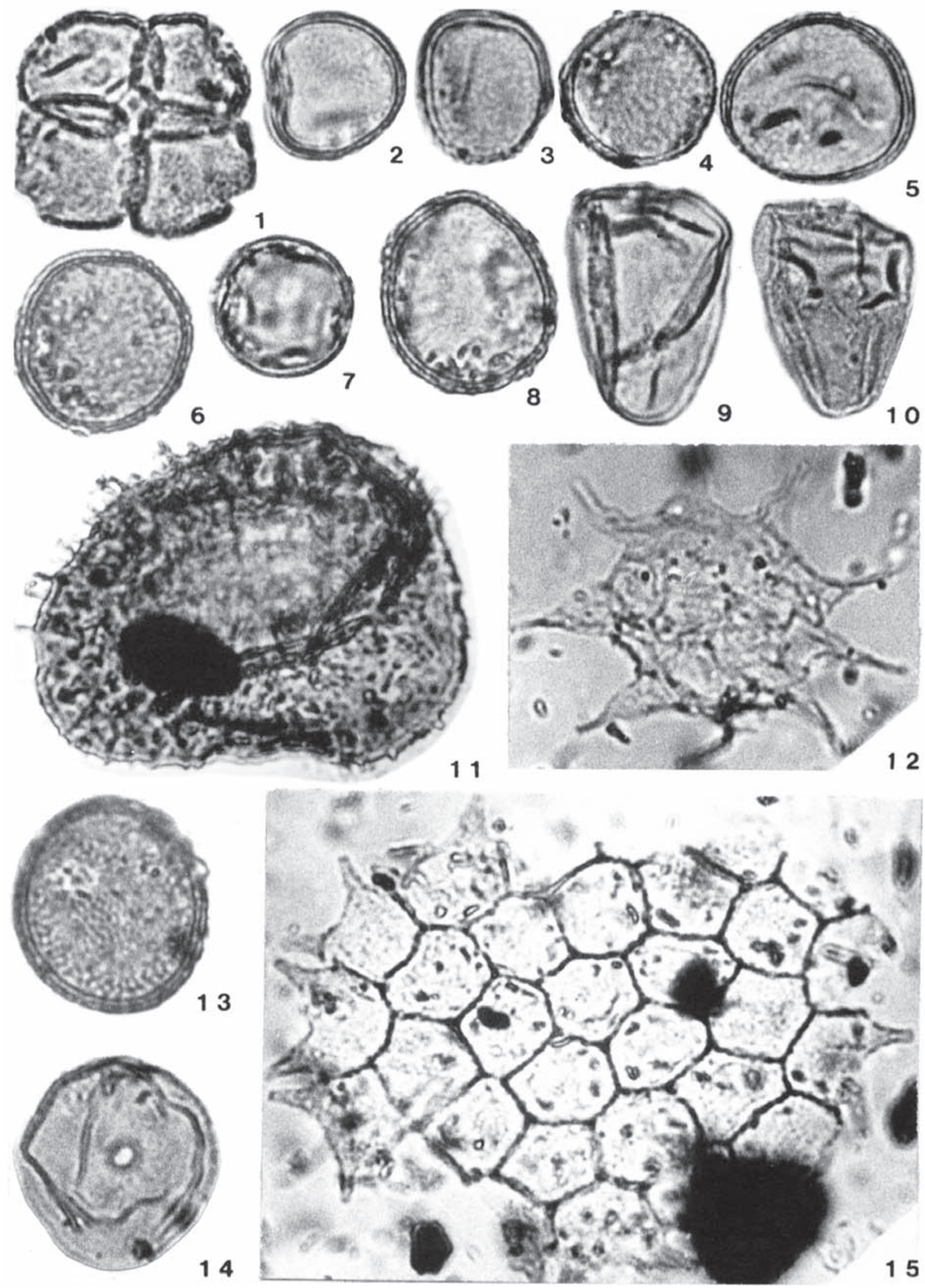
TOPOGRAPHIC CHANGES

Changes in Quaternary palynofloras are typically ascribed to the changing climatic patterns that affected the entire earth (Wright and Frey, 1965). However, vegetation in the Qaidam Basin was also affected by uplift of the Himalayan Mountains and Tibetan Plateau during Cenozoic sedimentation in the basin (Ferguson, 1993). The vegetation shifts are consistent with the uplift history of the region. Climatic cooling as shown in the vegetation during the Middle and Late Pleistocene could be the result of topographic uplift of the basin and the surrounding mountains at the end of the Early Pleistocene (Mercier et al., 1987; Li, 1996).

PLATE 4

Palynoflora in coreholes from Qaidam Basin. All figures x1,000.

1	*Typha latifolia* L. (No. S-1-11-5) Zone Q1.
2–4	*Potamogeton* sp. (No. D-1-9-1, D-1-9-4) Zone Q3.
5, 8	*Typha angustifolia* L. (No. D-1-9-4, D-1-9-1) Zone Q3.
6, 13	*Typha orientalis* Presl. (No. D-1-52-2, D-1-52-1) Zone Q2.
7	*Alisma* sp. (No. D-1-16-2) Zone Q3.
9	*Sparganium* sp. (No. D-1-33-1) Zone Q2.
10	*Carex* sp. (No. D-1-33-2) Zone Q2.
11	*Nymphaea* sp. (No. S-1-34-2) Zone Q1.
12	*Pediastrum simplex* (Meyen) Lem (No. D-1-16-6) Zone Q3.
14	*Phragmites* sp. (No. D-1-33-1) Zone Q2.
15	*Pediastrum boryanum* (Turp) Meyen (No. D-1-37-8) Zone Q2.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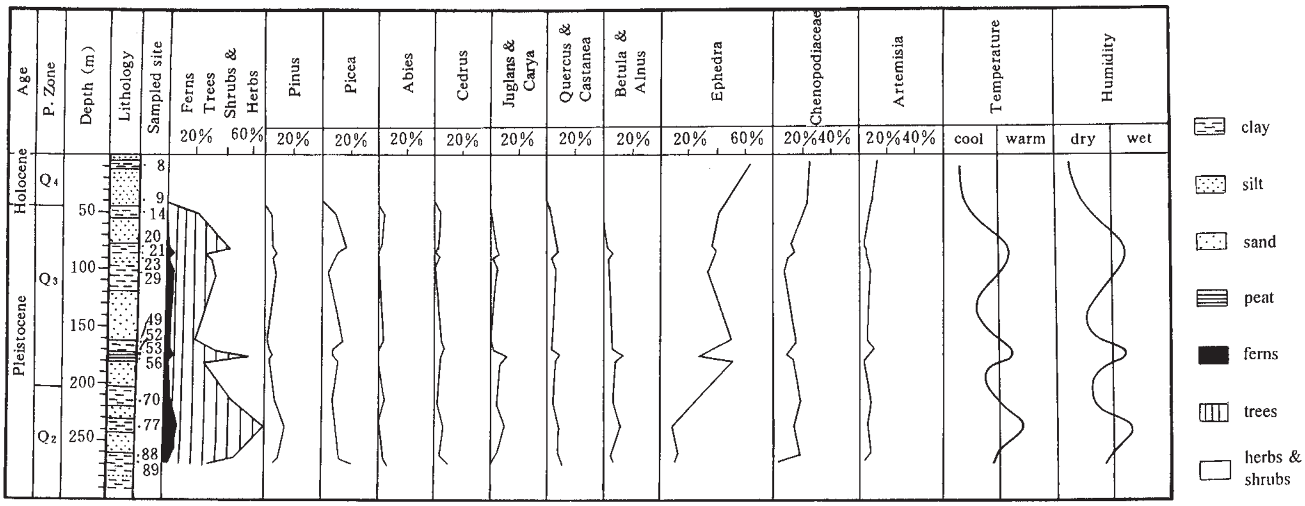

Text-Figure 4. Sporo-pollen diagram of Nuomuhong N-85 corehole in the Qaidam Basin.

Detailed topographic changes can be analyzed by assessing the altitudinal distribution of the typical plants of the palynofloras. For example, at the present time, the fern *Pteris cadieri* grows at lowland elevations between 200–500 m in South China; the tree *Podocarpus neriifolius* grows on the south slopes of the Himalayan Mountains ranging in elevation from 400–1,000 m, and the tree *Dacrydium pierrei* grows on ridges along Wuzhi Mountain of Hainan Island at 500–1,600 m elevation (Zhang et al., 1976; Tang and Liu, 1987; Wang et al., 1995). Fossil spores of *Pteris cadieri* and fossil pollen grains of *Podocarpus neriifolius* and *Dacrydium pierrei* were found in this study in Early Pleistocene gray clays and silty clays of the Sebei Arch S-1 corehole (700–1600 m depth) in the central part of the basin. At the present time, the elevation of the basin is about 2,670–3,600 m, and the surrounding mountains are situated at 4,500–5,000 m elevation. The reconstructed vegetation indicates that the elevations of the basin and the surrounding mountains in the Early Pleistocene would have been much lower than today if climate was not the causal factor.

Uplift values can be estimated using this vegetation analysis. We can assume that the elevation of the paleobasin floor was 350 ± 150 m, because the elevation of the modern fern *Pteris cadieri* is 200–500 m. The modern elevation of Sebei is 2,750 m and the depth of the spore-bearing core sample is 700 m, so the modern elevation of the sample is 2,050 m. Consequently, the elevation of the basin floor might have been uplifted 1,700 ± 150 m (from 350 ± 150 to 2,050 m) at the end of the Early Pleistocene. Uplift of the basin floor would have continued since then. This suggests that Sebei might have been uplifted 2,400 ± 150 m (from 350 ± 150 up to 2,750 m) since the Early Pleistocene. Because the Sebei area is center of Quaternary sedimentation in the basin, the extent of uplift for other parts of the basin should be even larger. Using the elevation of modern *Dacrydium pierrei* (on ridges of Wuzhi Mountain on Hainan Island, 500–1,600 m) and *Podocarpus neriifolius* (on south slopes of the Himalayan Mountains from 400–1,000 m) (Tang and Liu, 1987; Wang et al., 1995, Zhang et al., 1976), we can suggest that the elevation of the surrounding Early Pleistocene mountains was less than 2,000 m and those mountains might have been uplifted more than 2,500–3,000 m (from <2,000 m up to 4,500–5,000 m) since the Early Pleistocene. In addition, the fern *Pteris vittata* grows on calcareous soil at 2,000 m elevation in South China at present (Zhang et al., 1976), while the elevation of Dabuxun Lake in the central part of the basin is about 2,700 m. The occurrence of fossil spores of *Pteris vittata* in gray clays at 520 m depth in the Dabuxun Lake D-1 corehole from Dabuxun Lake would imply that the area might have been elevated about 700 m since 500 ka.

The relationship between tectonic collision, climatic changes, erosion, and vegetational shifts in the region is very complex (Brozovic et al., 1997; Chang et al., 1988; Treloar and Searle, 1993). The ultimate collision of the Indian Plate with the Eurasian Plate in the Miocene (Patriat and Achache, 1984) resulted in the massive upheaval of the Himalayas and the Qinghai–Tibetan Plateau, and led to the development of a monsoonal climate (Ferguson, 1993). The present study indicates that the intense influence of Himalayan tectonic motion existed in the region in the Cenozoic. Therefore, the pollen and spore data suggest strong uplift of the Himalayan Mountains at the end of the Early Pleistocene and another episode of uplift in the middle substage of the Middle Pleistocene. The northern part of the Tibetan Plateau would then be within the reach of winter monsoons from Siberia, which would account for climatic cooling and drying in the latter part of the Pleistocene. These palynological data therefore strongly implicate regional tectonics as an important mechanism for climatic change along the northern border of the Tibetan Plateau.

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TABLE 1. Modern flora of the Qaidam Basin (from Geng, 1958) (*Dominants, H=Halophytic, X=Xerophytic)

Hydrophytic plants
Eleocharis intersita Zins.
Phragmites communis Trin.

Herbaceous plants
Aconitum gymnandrum Maxim.
Acroptilon picris DC.*
Allium senescens L.* (X)
Aneurolepidium dasystachys Nevski* (X)
Artemisia salsoloides Willd. (X)
Chrysanthemum falcatolobium Hand.-Mazz.*
Gentiana straminea Maxim.
Glaux martima L. (X)
Gymnocarpos prewalskii Maxim. (X)
Halogeton arachnoides Moq.* (H)
Lagotis brachystachya Gaertn.*
Limonium aureum Kuntse (X)
Malcolmia africana Br.
Orinus kokonorica Keng (X)
Pedicularis brachystachys Bunge*
Polygonum statice Levl.* (X)
Salicornia herbacea L.* (H)
Suaeda salsa Pall.* (H)

Shrubs
Calligonum zaidamense Losinsk.* (X)
Ephedra przewalskii Staf* (X)
Eurotia ceratoides Mey.* (X)
Haloxylon ammodendron Bunge* (X)
Kalidium gracile Fenzl* (H)
Lycium ruthenicum Murr. (X)
Nitraria tangutorum Bobrow* (X,H)
Tamarix laxa Willd.* (X)

TABLE 2a. Hydrophytes of zones Q1, Q2, Q3, and Q4 compared to modern vegetation. [Q1 data from S-1 corehole; Q2 and Q3 data from D-1, S-504, and N-85 coreholes; and Q4 data from D-1 and N-85 coreholes] (+++ >10% Dominant, ++ 2–10% Abundant, + 1–2% Common, - <1% Rare, -- Absent).

HYDROPHYTES	Zone Q1	Zone Q2	Zone Q3	Zone Q4	Modern vegetation
Alisma	++	++	+	--	--
Carex	++	+	+	--	--
Eleocharis	--	--	--	--	+
Hydrocharis	--	+	--	--	
Nymphaea	+	--	--	--	--
Phragmites	+	+	+	--	+
Potomogeton	++	++	+	--	--
Salvinia	++	--	--	--	--
Sparganium	--	+	+	--	--
Typha	++	+	+	--	--

TABLE 2b. Ferns and fern allies of zones Q1, Q2, Q3, and Q4 compared to modern vegetation (see Table 2a for explanations).

FERNS & FERN ALLIES	Zone Q1	Zone Q2	Zone Q3	Zone Q4	Modern vegetation
Adiantum	--	+	--	--	--
Athyrium	+	--	--	--	--
Crepidomanes	++	--	--	--	--
Cyathea	+	--	--	--	--
Cyclosorus	+	--	--	--	--
Cystopteris	--	+	+	--	--
Isoetes	+	--	--	--	--
Microlepia	++	--	--	--	--
Osmunda	++	+	+	--	--
Pellaea	--	+	+	--	--
Polypodium	++	++	+	--	--
Pteris	++	+	--	--	--
Selaginella	++	++	++	--	--

TABLE 2c. Herbaceous plants of zones Q1, Q2, Q3, and Q4 compared to modern vegetation (see Table 2a for explanations).

HERBACEOUS PLANTS	Zone Q1	Zone Q2	Zone Q3	Zone Q4	Modern vegetation
Achillea	--	--	+	--	--
Achyranthes	--	--	+	--	--
Aconitum	--	--	--	--	+
Acroptilon	--	--	+	+	++
Adenostemma	+	--	--	--	--
Ainsliaea	--	+	+	--	--
Allium	+	+	+	+	++
Alyssum	--	+	--	--	--
Amaranthus	+	--	--	--	--
Anemarrhena	--	--	+	--	--
Aneurolepidium	--	--	--	--	++
Arctium	--	--	+	--	--
Asteraceae	--	+	+	+	--
Astragalus	+	--	--	--	--
Brachyactis	--	--	+	--	--
Cacalia	--	--	+	--	--
Caltha	+	--	+	--	--
Capsella	--	--	+	--	--
Chenopodiaceae	+	++	+++	+++	+++
Chrysanthemum	+	--	--	+	++
Cirsium	--	--	+	--	--
Cyathula	+	--	--	--	--
Elsholtzia	--	--	+	--	--
Filipendula	+	--	--	--	--
Galeopsis	--	--	+	--	--
Gentiana	--	--	+	--	+
Gerbera	--	+	+	--	--
Glaux	--	--	--	--	+
Gymnocarpos	--	--	--	--	+
Halogeton	--	--	--	--	++
Hemistepta	--	+	+	+	--
Hymenophysa	+	--	--	--	--
Ixeris	--	+	+	+	--
Kochia	--	+	+	--	--
Lagotis	--	+	--	--	++
Lathyrus	+	--	--	--	--
Lens	+	--	+	+	--
Leontopodium	--	+	+	--	--
Lepistemon	+	--	--	--	--
Lilium	+	+	+	+	--
Limonium	--	--	--	--	+
Lycopus	--	+	+	--	--

TABLE 2c (continued). Herbaceous plants of zones Q1, Q2, Q3, and Q4 compared to modern vegetation (see Table 2a for explanations).

HERBACEOUS PLANTS	Zone Q1	Zone Q2	Zone Q3	Zone Q4	Modern vegetation
Malcolmia	--	--	--	--	+
Mosla	--	+	--	--	--
Nigella	--	+	--	--	--
Orinus	--	--	--	--	+
Orychophragmus	--	--	+	--	--
Paraphlomis	+	--	--	--	--
Pedicularis	--	+	+	+	++
Phlomis	+	+	+	--	--
Polygonum	+	+	+	++	++
Portulaca	+	--	--	--	--
Salicornia	--	--	--	--	++
Solidago	+	+	+	+	--
Suaeda	--	--	--	--	++
Taraxacum	--	--	+	--	--
Teucrium	--	+	+	--	--
Thalictrum	--	+	--	--	--
Trollius	--	+	--	--	--
Xanthium	+	+	+	+	--

TABLE 2d. Shrubs and trees of zones Q1, Q2, Q3, and Q4 compared to modern vegetation (see Table 2a for explanations).

SHRUBS AND TREES	Zone Q1	Zone Q2	Zone Q3	Zone Q4	Modern vegetation
Abies	--	+	+	--	--
Acer	--	+	+	--	--
Alnus	+	++	+	--	--
Artemisia	+	++	+++	+++	+++
Betula	++	++	++	--	--
Carpinus	--	+	--	--	--
Carya	++	+	+	--	--
Calligonum	--	--	--	--	++
Castanea	++	+	+	--	--
Castanopsis	--	--	+	--	--
Cedrus	+	++	++	--	--
Cestrum	--	+	--	--	--
Chionanthus	--	--	+	--	--
Cladrastis	--	+	+	--	--
Corylus	--	+	+	--	--
Cycas	+	+	--	--	--
Dacrydium	++	--	--	--	--
Desmodium	+	--	--	--	--
Ephedra	+	++	+++	+++	+++
Eurotia	--	--	--	--	++
Gardenia	+	--	--	--	--
Ginkgo	+	+	+	--	--
Haloxylon	--	--	--	--	++
Ilex	+	--	--	--	--
Juglans	++	++	++	--	--
Kalidium	--	--	--	--	++
Keteleeria	--	+	--	--	--
Larix	--	--	+	--	--
Liquidambar	--	--	+	--	--
Lycium	--	+	+	+	+
Nitraria	--	++	++	++	++
Paulownia	+	--	--	--	--
Picea	+	++	++	--	--
Pinus	++	++	++	--	--
Podocarpus	++	--	--	--	--
Populus	--	--	+	--	--
Pseudolarix	+	+	+	--	--
Quercus	++	++	++	--	--
Rhus	+	+	--	--	--
Rosa	+	+	+	+	--
Salix	+	++	+	+	--
Tamarix	--	++	++	++	++
Tilia	--	+	+	--	--
Tsuga	+	+	--	--	--
Ulmus	--	++	+	--	--