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21. PLEISTOCENE CLIMATIC CHANGES AS DEDUCED FROM A POLLEN ANALYSIS OF SITE 717 CORES[1]

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INTRODUCTION

Pollen from marine sediment has been used to the study of monsoon fluctuations in the Arabian Sea (Van Campo et al., 1982; Van Campo, 1986) and off the northwest African coast (Hooghiemstra, 1988). These studies reveal major changes in the monsoon cycle since the last interglacial period. However, fluctuations before 120 k.y. B.P. remain unclear. In this report, we document a dramatic climatic change that occurred around the beginning of the middle Pleistocene in the Bay of Bengal, based mainly on the results of pollen analysis from ODP Site 717 cores.

ODP Site 717 cores were recovered from the tip of the Bengal deep sea fan. The site (0°55'S, 81°23'E) is located about 700 km south of Sri Lanka (Fig. 1). Alam (1989) distinguishes two major phases of sedimentation within the Bengal Basin and pointed out that the second major phase started in the middle Miocene. It is generally assumed that sedimentation of the Bengal deep sea fan was strongly influenced by the uplift and erosion of the Himalayas. Sedimentation of palynomorphs was also influenced by river transport of the Ganges, Brahmaputra, and Irrawaddy Rivers.

The Bengal Basin is characterized by a very pronounced monsoon circulation system, with a northeast monsoon in winter and a southwest monsoon in summer (Figs. 1, 2). These winds are largely responsible for the transportation of windborne pollen in the area. Surface water circulation in the Bengal Bay and Andaman Sea is also dependent on the monsoonal wind patterns. During the northeast (winter) monsoon, a North Equatorial Current appears, while during the southwest (summer) monsoon, a Southwest Monsoon Current develops (Figs. 1, 2). These water currents influence the transportation and deposition of pollen and spores in the sediments on the ocean floor (Figs. 1, 2).

Due to the scarcity of wind-pollinated flowers, the very rich flora of the tropical rain forest is poorly preserved in the marine sediments. Mangrove pollen is, however, well preserved, because the major palynomorphs are transported by river and surface water currents. The distribution of mangrove swamps in the coastal area of the Bengal Bay and Andaman Sea is shown in Figure 1.

METHOD

In this report, we discuss the results of pollen analysis from the upper 200 m of cores from ODP Site 717. Nannofossil biostratigraphy yielded two age data within this interval, i.e., 470 k.y. B.P. at 67.5 mbsf and 930 k.y. B.P. at 198 mbsf (Cochran, Stow, et al., 1989). Thus the upper 200 m of Site 717 sediments span about 1 Ma. An additional age constraint is a tenuous interpretation that the upper 150 m of core display a normal polarity acquired during the Brunhes chron (Cochran, Stow, et al. 1989). This suggests an age of 730 k.y. B.P. for 150 mbsf, in relatively good agreement with a value of 141 mbsf predicted by interpolation between the biostratigraphic age data.

Palynomorphs were separated from the sediment matrix by the heavy liquid flotation method modified from Faegri and Iversen (1964). The processing sequence is as follows; measuring wet volume; HCL (10%) treatment; wash (in distilled water); sieve (through a 60 mesh sieve); wash; float (zinc chloride heavy liquid flotation; specific gravity 2.1); HCL (1%) treatment; wash; dehydration (acetic acid); acetolysis (boiled for 3 min in water basin in a solution of 1 part concentrated sulfuric acid and 9 parts acetic anhydride); dehydration; wash; mount.

The material was examined at 400× and when necessary, oil immersion was used. Generally more than 200 pollen grains were identified in each sample.

As well as observations using light microscope, the samples were also studied using a scanning electron microscope (SEM). Residual materials were fixed by Carnoy's fluid (3 parts ethyl alcohol and 1 part acetic acid) for 1 hr. The fixed material was washed with ethyl alcohol and then fixed by isoamylacetate for 30 min. A drop of the material was then put on a brass stage and allowed to dry naturally, and then coated using an by Au-Pd target for 2 min in the Ion Sputter Fine Coat.

A pollen diagram (Figs. 3, 4) was constructed in terms of percentages of the total pollen. Representative fossil pollen and spores are shown in Plates 1–4.

RESULTS OF POLLEN ANALYSIS

Euphorbiaceae, Gramineae, Cyperaceae, and spores show high concentrations throughout the pollen diagram. Based on the frequencies of characteristic species, the pollen diagram for the upper part of the ODP Site 717 cores were divided into three local pollen zones, X, Y, and Z from the bottom of the core upward (Figs. 3, 4).

Zone X: This zone is characterized by high values of *Podocarpus*, *Pentacea*, *Clidenia*, Meliaceae, Acanthaceae, and Gramineae, suggesting warm climate. *Podocarpus* is distributed widely in Southeast Asia, East Australia, East Africa, and South America (Fig. 2) and is one of the typical species of the Southern Hemisphere. Fossils of *Podocarpus* before the Eocene period have been reported from India (Fig. 2). It has been suggested that prior to the Eocene there was a *Podocarpus* forest in India and the coastal area of Arabia. *Podocarpus* subsequently became reduced in India due to the deterioration in the climate. It is interesting to note that *Podocarpus* still shows high concentrations in the lower part of pollen Zone X, indicating the existence of a *Podocarpus* forest. We suppose that a *Podocarpus* forest still remained in India as late as early Pleistocene and the pollen were transported by southwest monsoon into the Andaman Sea.

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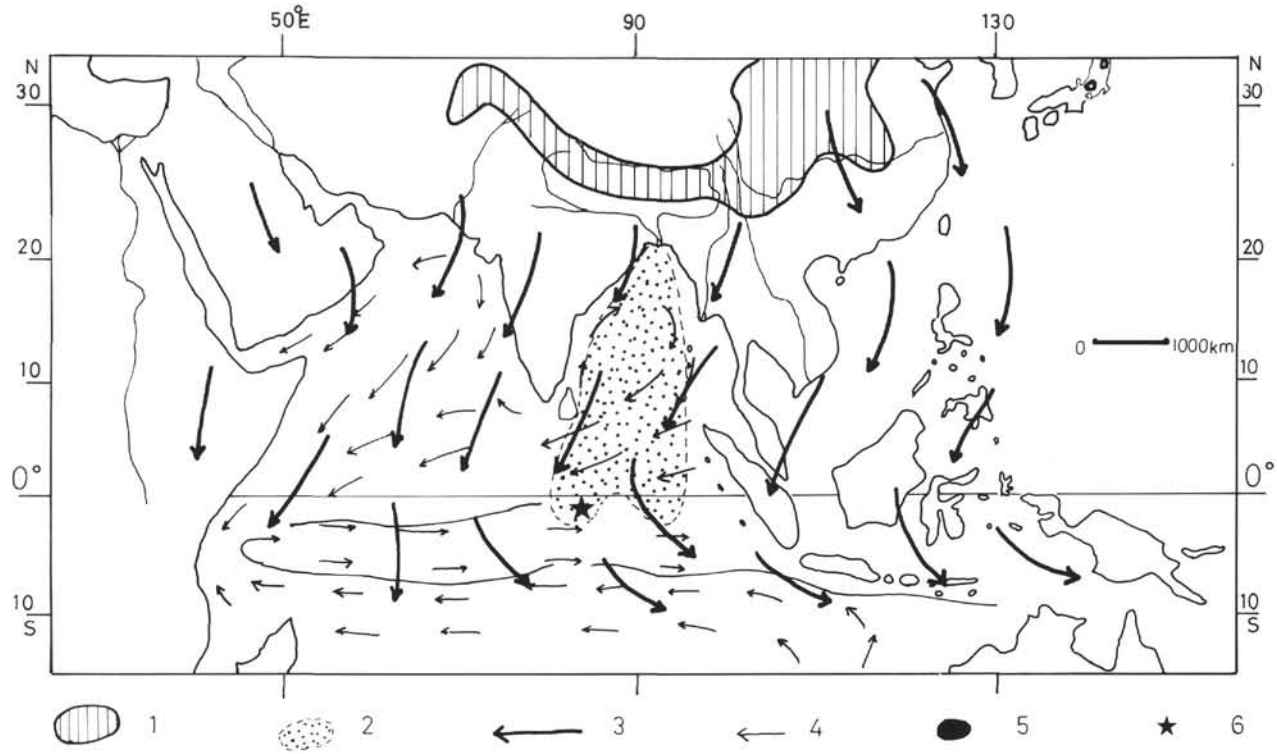

Figure 1. Map showing the distribution of *Picea* (after Hotta, 1974), the prevailing wind direction in January (after Kurashima, 1966), the Bengal deep sea fan (after Alam, 1989), the surface water circulation in February (after Koizumi, 1987), and the ODP Site 717. 1. Distributional area of *Picea*, 2. Bengal deep sea fan, 3. Prevailing wind direction, 4. Surface ocean currents in February, 5. Mangrove swamp, 6. The ODP Site 717.

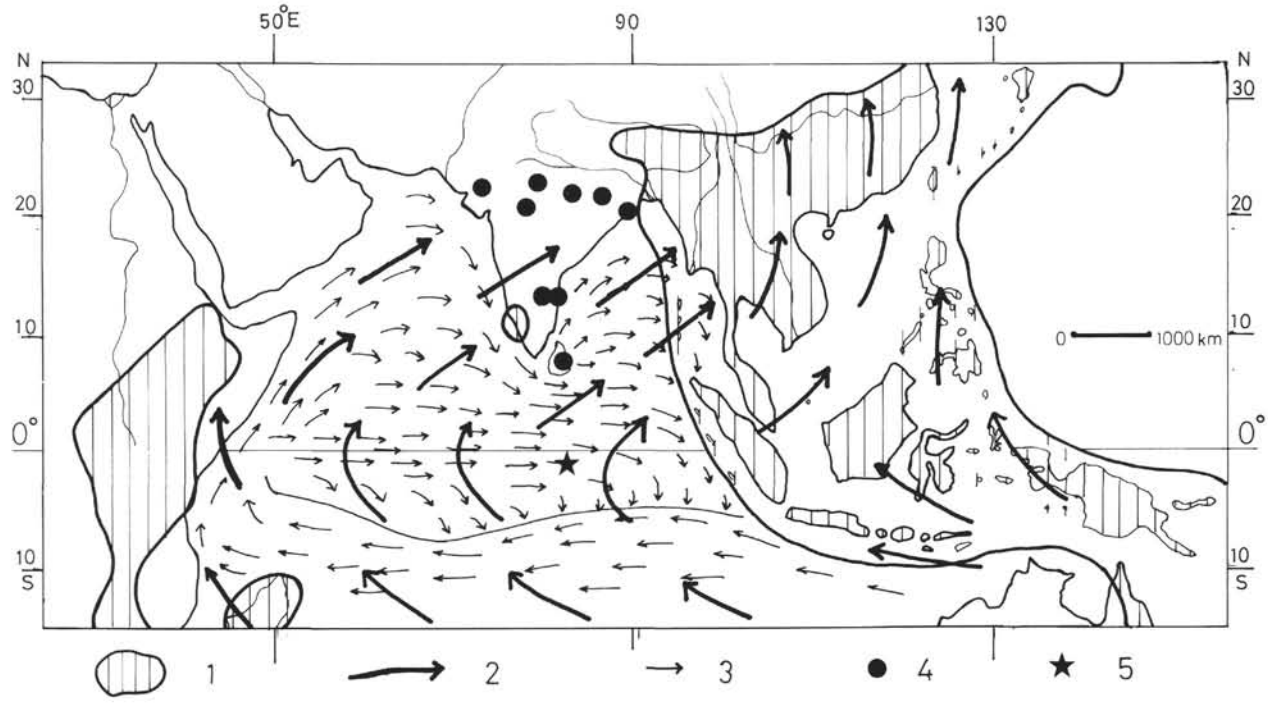

Figure 2. Map showing the distribution of *Podocarpus* (after Hotta, 1974), the prevailing wind direction in July (after Kurashima, 1966), the surface ocean current in August (after Koizumi, 1987), the fossil records of *Podocarpus* before Eocene (after Hotta, 1974), and the ODP Site 717. 1. Distributional area of *Podocarpus*, 2. Prevailing wind direction in July, 3. Surface ocean current in August, 4. Fossil records of *Podocarpus* before Eocene, 5. The ODP Site 717.

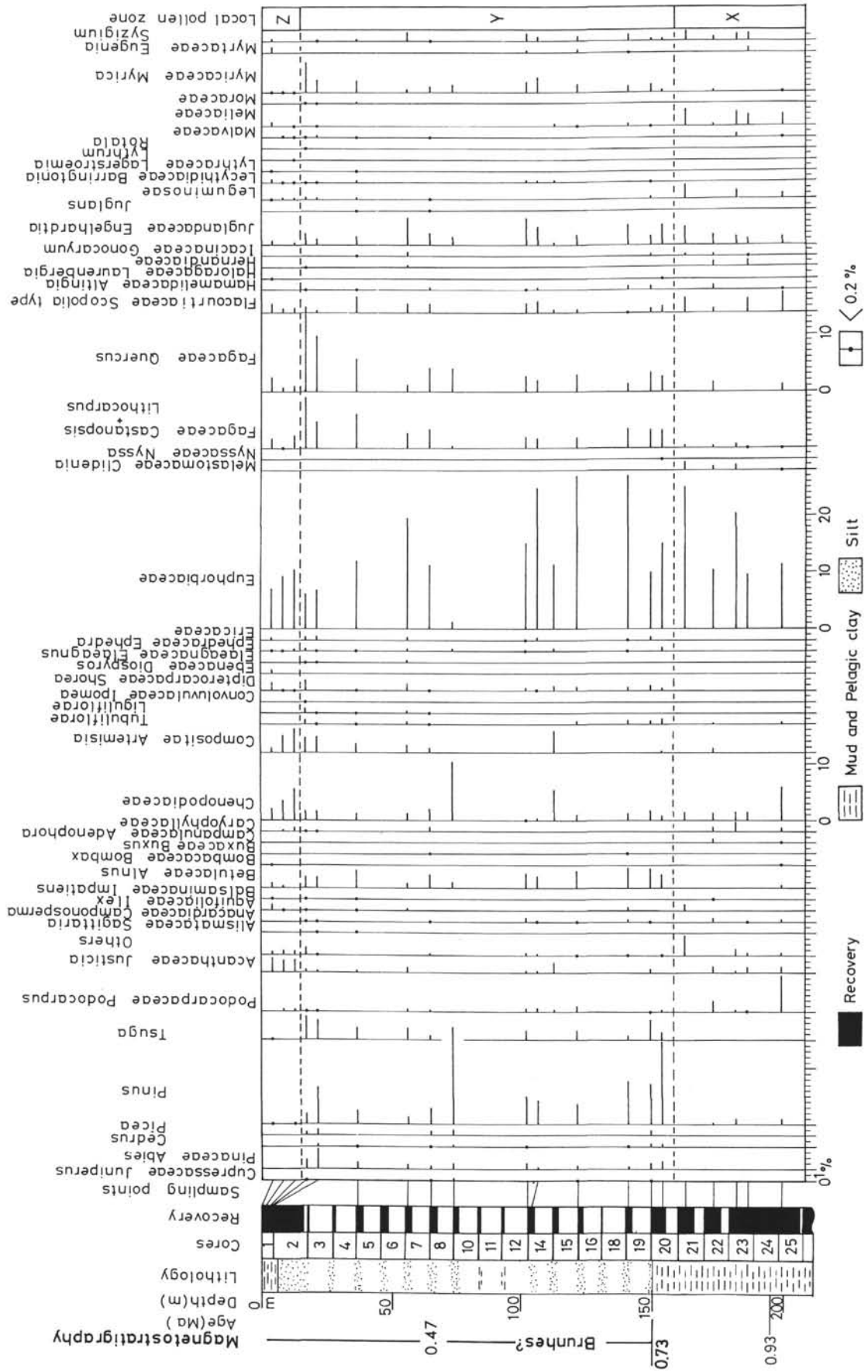

Figure 3. Pollen diagram from the ODP Site 717.

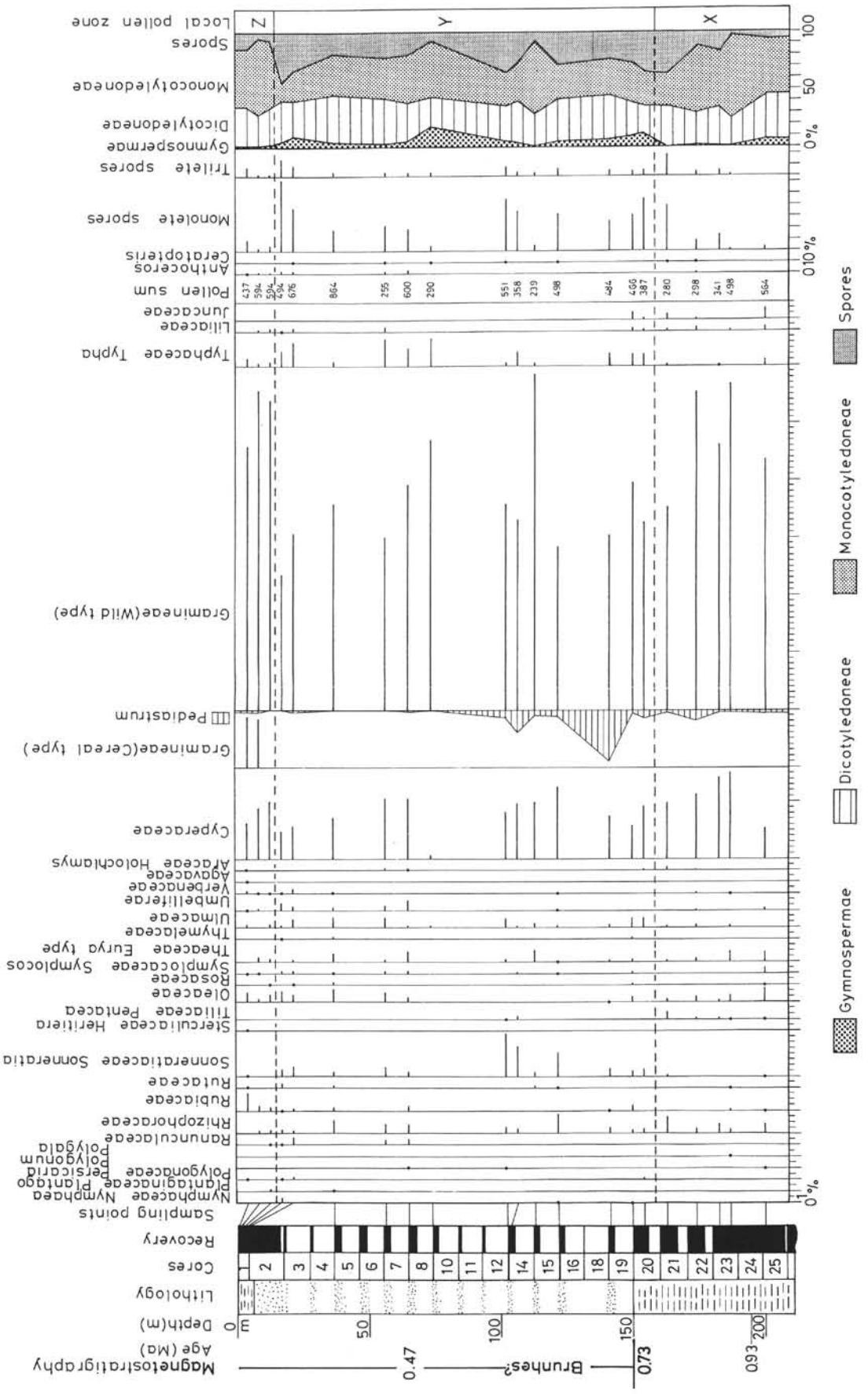

Figure 4. Pollen diagram from the ODP Site 717.

Zone Y: This zone is characterized by a notable increase in *Pinus* and the appearance of *Abies*, *Cedrus*, *Picea*, and *Tsuga*, and a decrease of *Podocarpus*. *Tsuga*, *Abies*, and *Picea* presently grow in the Himalayas at an altitude more than 2100 m and are characteristic species for the Northern Hemisphere (Fig. 1).

A decrease of *Podocarpus*, Acanthaceae, Meliaceae, and *Clidenia* and increase of *Pinus*, *Picea*, *Abies*, and *Tsuga* indicate that the climate became colder. *Alnus*, *Castanopsis* or *Lithocarpus*, *Quercus*, *Myrica*, *Engelhardtia*, *Barringtonia*, *Sonneratia*, Ulmaceae, *Myrica*, and monolete spores also increase. These dramatic vegetational changes happened at about the beginning of the middle Pleistocene. The remarkable increase of *Pinus* and the appearance of *Picea*, *Abies*, and *Tsuga* indicate that the climate became cold.

Another characteristic feature of Zone Y is a remarkable increase of *Sonneratia*, *Typha*, and *Pediastrum*. Two types of fossil pollen of *Sonneratia* can be distinguished, *S. alba* and *S. caseolaris*. *S. caseolaris* grows in a brackish environment (Chapman, 1976). The appearance of *S. caseolaris* and rapid increase of *Pediastrum* indicate a strong fluvial influences in deposition. The sediment matrix of the Zone Y is mainly composed of silt and marks an increase in grain size compared with Zone X. A noticeable increase of *Sonneratia* and *Pediastrum* associated with swamp forest pollen like *Alnus* and *Typha* indicate that a large proportion of the palynomorphs were transported from the Bengal coast by the northeast monsoon, Northern Equatorial Current and in suspension in the rivers. The increase of grain size in the sediment corresponds closely to the remarkable increase of *Pinus* and appearance of *Abies*, *Picea*, and *Tsuga*, although the changes in the palynomorphs took place slightly earlier than the increase of grain size in the sediment. Increase of grain size in the sediment matrix might be caused by the development of glaciation in the Himalayas in the cold climate, producing a large amount of debris. Eroded material would be transported by the Ganges and Brahmaputra Rivers into the Bay of Bengal.

Unfortunately recovery of the upper 200 m of the Site 717 cores are poor, so that we could not reconstruct the detailed climatic changes after the beginning of the middle Pleistocene, however, we can say that the climate became cold after middle Pleistocene and that therefore the monsoon circulation must have changed dramatically.

Zone Z: This zone is recognized by the sudden decrease of *Pinus*, *Abies*, and *Tsuga*. There is a similar but less dramatic decrease in *Alnus*, *Castanopsis*, or *Lithocarpus*, *Quercus*, *Engelharditia*, *Myrica*, *Sonneratia*, Ulmaceae, *Typha*, and spores, while Acanthaceae, Chenopodiaceae, and Gramineae increase. This zone may be Holocene and indicates a warm climate.

CONCLUSIONS

Studies of the pollen content of the upper 200 m of the ODP Site 717 core from the Bengal deep sea fan reveals a major climatic change occurred around the beginning of the middle Pleistocene. Before this time, climate was warm and southwest monsoon circulation was dominant. Afterward, the climate became cold and the glaciation developed in the Himalayas producing a large amount of debris. The sediment matrix of the ODP Site 717 cores are coarser after the beginning of the middle Pleistocene, suggesting an increase in the grain size of suspended matter of the Ganges, Brahmaputra, and Irrawaddy Rivers. This can also be related to the postulated period of glaciation based on the pollen analytical studies.

A remarkable increase of *Pinus* with the appearance of *Picea*, *Abies*, and *Tsuga* suggests the dominance of a northeast monsoon transporting palynomorphs from the foot of the Himalayas. After this time, mangrove pollen *Sonneratia* and *Pediastrum* increased,indicating the development of the North Equatorial Current and the strong influence of the suspended matter of the river. The documented dramatic climatic changes imply that there was also a corresponding change in the monsoon circulation of the area.

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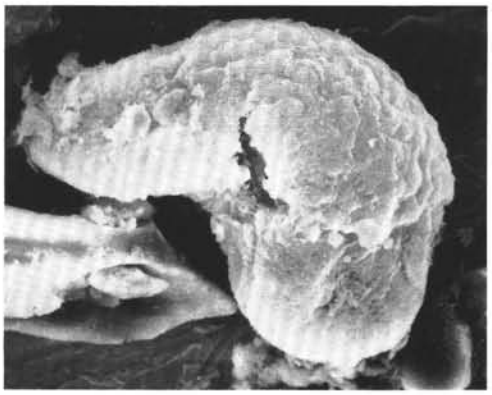

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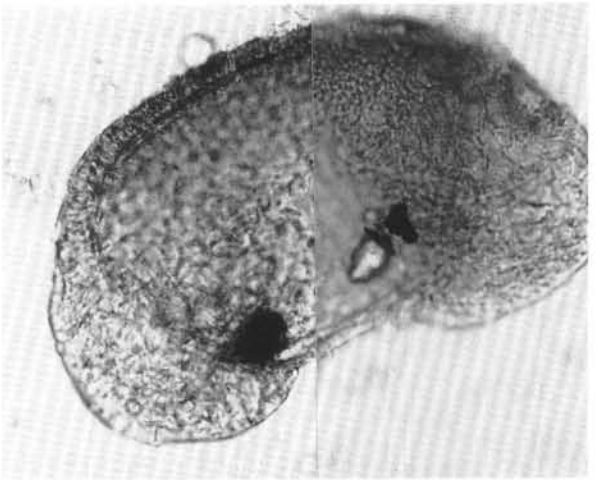

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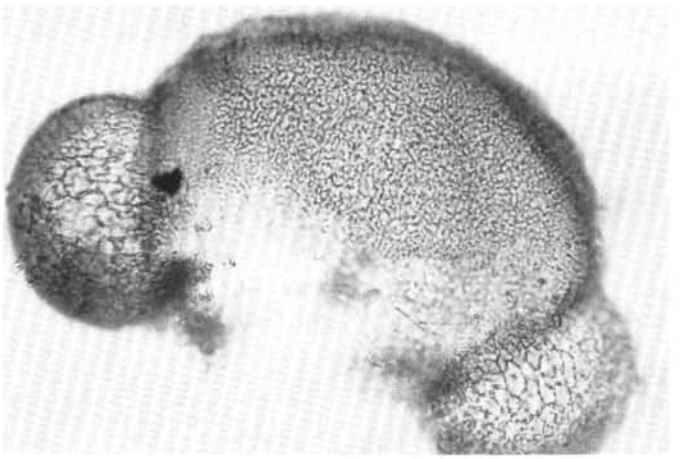

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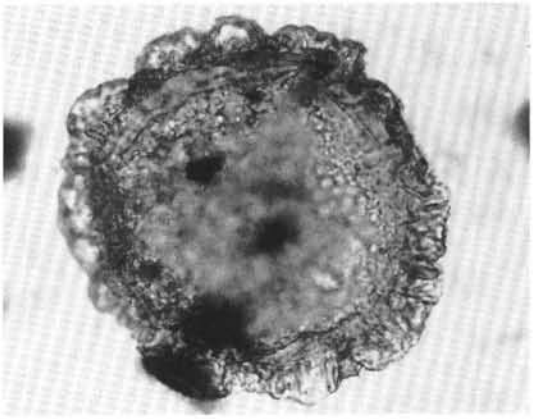

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Plate 1. Fossil pollen from ODP Site 717 cores. **1.** *Cedrus deodara* (SEM). **2.** *Cedrus deodara* (LM). **3, 4.** *Abies* (LM). **5.** *Pinus* (LM). **6.** *Tsuga* (LM). Bar is 10 μm.

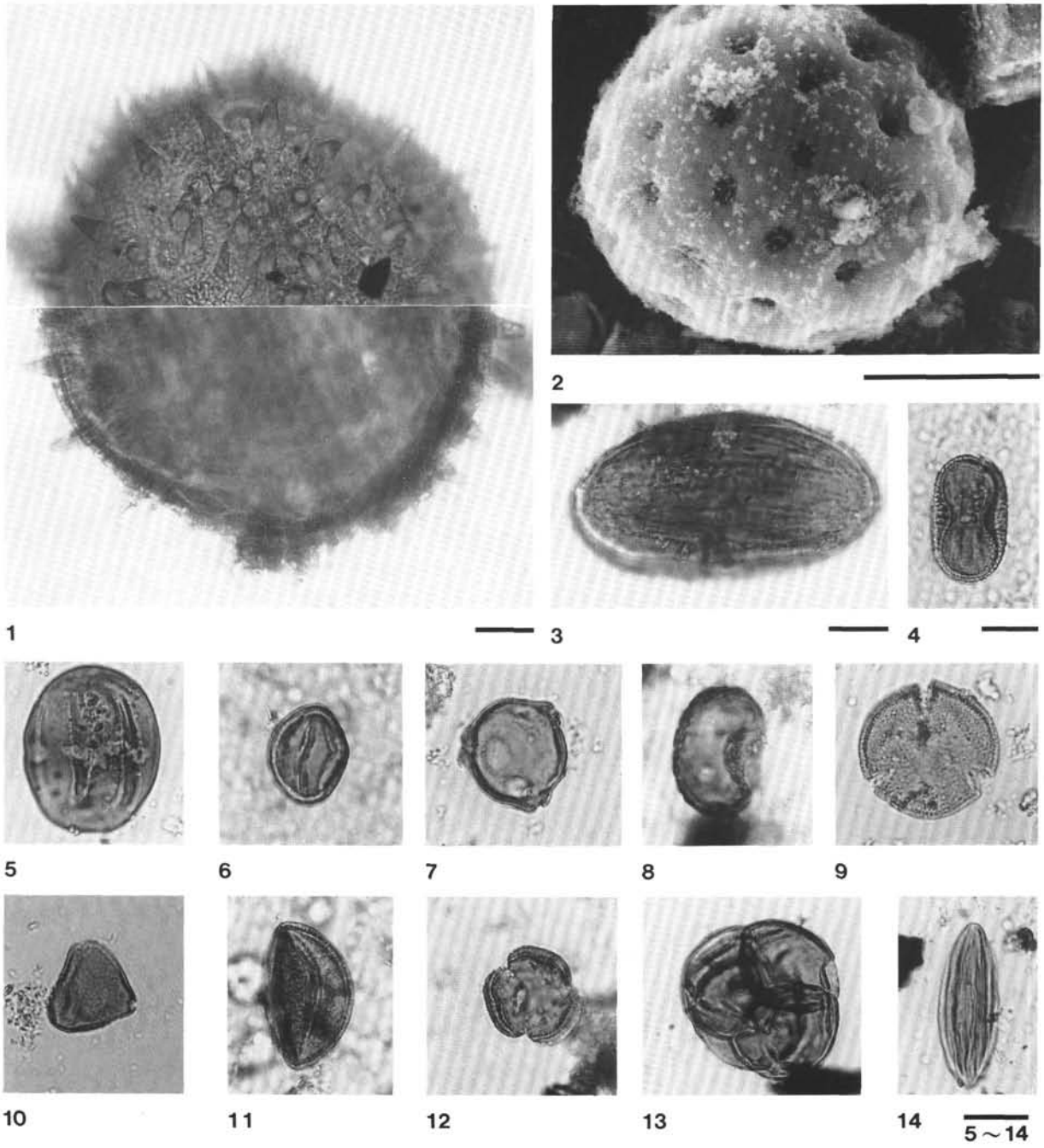

Plate 2. Fossil pollen from ODP Site 717 cores. **1.** Malvaceae (LM). **2.** Chenopodiaceae (LM). **3, 4.** Acanthaceae (LM). **5.** Meliaceae (LM). **6.** *Quercus* (LM). **7.** Myricaceae (LM). **8.** Ulmaceae (LM). **9.** *Pentacea* (LM). **10.** *Symplocos* (LM). **11.** Euphorbiaceae (LM). **12.** *Artemisia* (LM). **13.** Ericaceae (LM). **14.** *Ephedra* (LM). Bar is 10 μm.

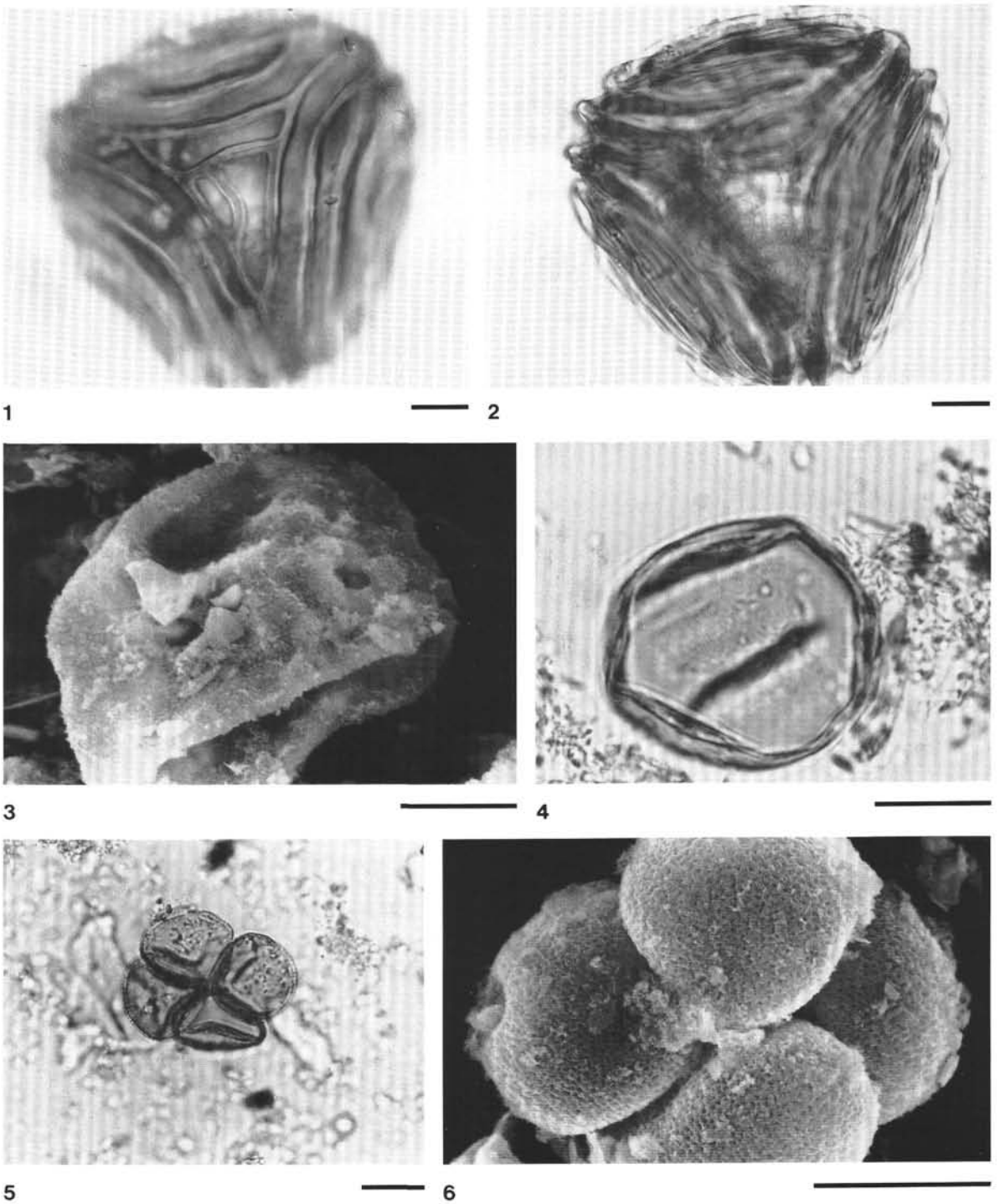

Plate 3. Fossil pollen and spores from ODP Site 717 cores. **1, 2.** *Ceratopteris* (LM). **3.** Gramineae (SEM). **4.** Gramineae (LM). **5.** *Typha* (LM). **6.** *Typha* (SEM). Bar is 10 μm.

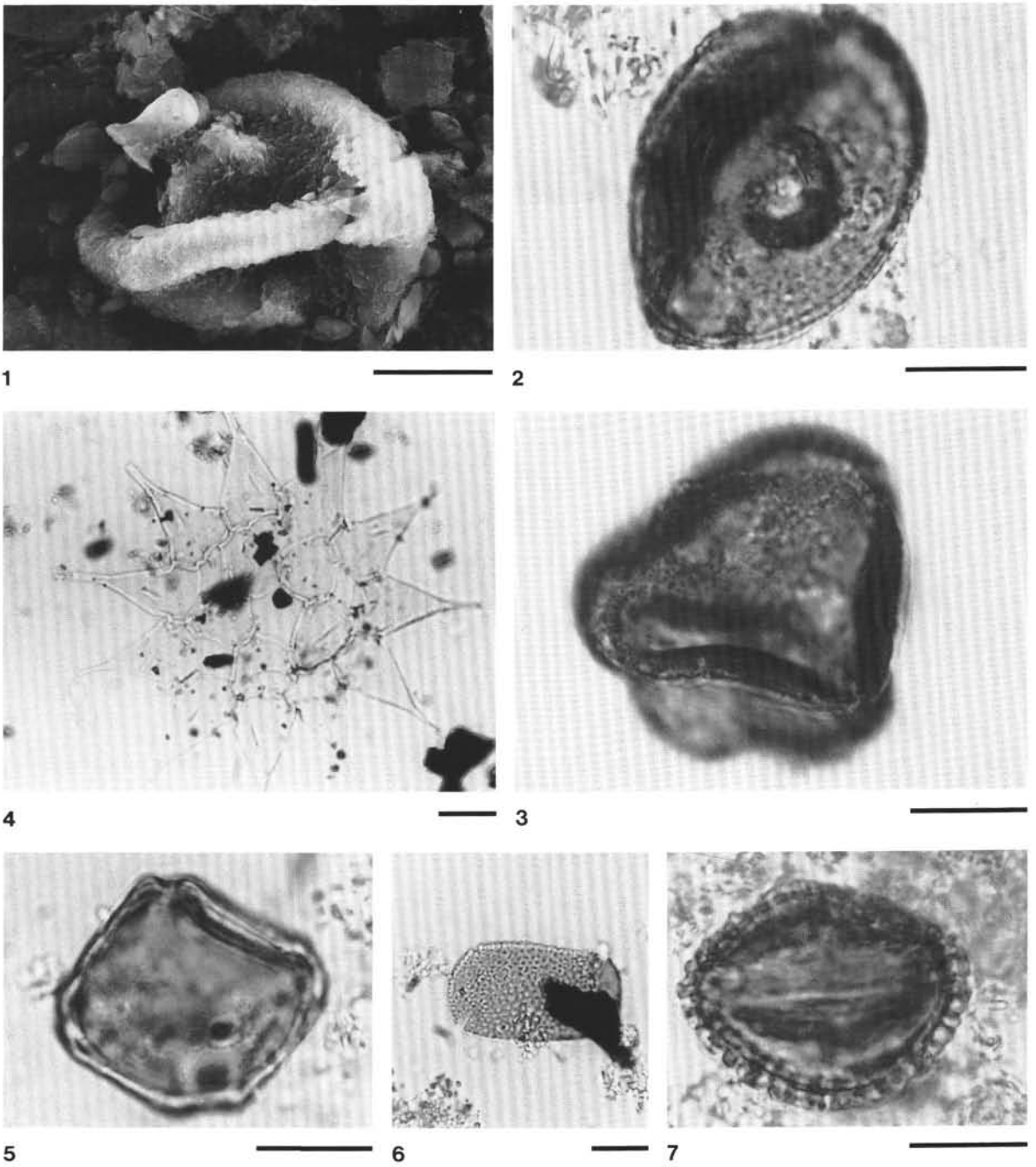

Plate 4. Fossil pollen and *Pediastrum* from ODP Site 717 cores. **1.** *Sonneratia* (SEM). **2, 3.** *Sonneratia* (LM). **4.** *Pediastrum* (LM). **5.** *Alnus* (LM). **6.** *Impatiens* (LM). **7.** *Ilex* (LM). Bar is 10 μm.