62. PRELIMINARY POLLEN ANALYSIS OF DEEP SEA DRILLING PROJECT LEG 64, HOLE 480, CORES 1–11[1]

Roger Byrne, Geography Department and Museum of Paleontology, University of California, Berkeley, California

ABSTRACT

Preliminary analyses of 56 samples from the upper 49 meters of Hole 480 (Cores 1–11) show marked changes in pollen frequencies and concentrations. The largely varved cores (1, 2, 3, 10, and 11) are characterized by low concentrations and pollen types such as Gramineae, Low-spine Compositae and Cheno/Ams. The largely homogeneous section (Cores 3 through 10) contains higher pollen concentrations and is dominated by TCT (probably *Juniperus*) and *Artemisia*. *Picea* pollen is also present in this section. The record as a whole is thought to represent most of the last glacial cycle.

INTRODUCTION

Prior to the present study and the companion studies of Heusser (this volume, Pt. 2) and Sirkin (this volume, Pt. 2), the Gulf of California had received very little attention from palynologists. In the mid-1960s Cross et al. (1966) analyzed the pollen and spore content of ~250 core-top samples and outlined the distribution of the dominant types. Unfortunately, this pioneer study was not followed by an analysis of downcore material. To date, therefore, our knowledge of late Quaternary vegetation change in northwestern Mexico has been based on the terrestrial record. Especially important here has been the palynological work of Martin and his associates at the University of Arizona (Martin, 1963; Martin and Mehringer, 1965; Hevly et al., 1965; Mehringer et al., 1967; Meyer, 1973; Fine, 1978).

The terrestrial pollen record clearly shows that there were major changes in vegetation and climate in this area during the late Quaternary, although the detailed nature of these changes is still far from clear. One problem here has been the limited number of depositional environments favorable for pollen preservation. In a semiarid climate such as this there are few lakes or marshes, and research has therefore been focused primarily on alluvial fills, cave deposits, and spring mounds. Several long cores have been recovered from playa lakes in the southwest—for example, Wilcox Playa in Arizona (Martin, 1963)—but pollen is not always well preserved in playa sediments, especially interglacial and postglacial sediments. In general, therefore, the pollen record for the areas adjacent to the Gulf of California is both spatially and temporally incomplete.

The deficiences of the fossil pollen record are to a certain extent compensated for by an unusually rich macrofossil record. Particularly important here has been the work of Wells, Van Devender, and others on packrat (*Neotoma*) middens (Van Devender and Spaulding, 1979). The *Neotoma* evidence clearly shows that during the late Wisconsin much of what is now the Sonoran Desert was occupied by pinyon pine and juniper, the implication being that the climate of the area was then significantly cooler and/or wetter than it is today. As we shall indicate later, the Site 480 pollen record provides further evidence of significant climatic change in northwestern Mexico during the late Quaternary. The sensitivity of the Site 480 pollen record presumably reflects its location on the southern margins of the Sonoran Desert Zone (Fig. 1).

This paper represents a preliminary report on the pollen content of 56 samples from the upper 49 meters of Hole 480 (Cores 1–11). The analysis was restricted to this section in order to provide a relatively detailed view of the last glacial cycle (Sangamon to Holocene). According to Schrader et al. (1980), Isotope Stage 5e is probably located between Cores 11 and 13.

METHODS

All of the samples analyzed, with one exception, were taken from the central 6 cm × 1 cm section of the core (Soutar et al., this volume, Pt. 2). An attempt was made to take constant-volume samples (2 cm × 1 cm × 1 cm), but slight variations in the thickness of individual slabs made this difficult, and volume was therefore determined by displacement. The mean sample volume was 1.6 cm^3. The excellent X-ray coverage of these carefully sectioned core slabs made it possible to determine the number of varves in each sample with a high degree of accuracy. The probable error in varve counting is assumed to be less than 10% for most samples.

Before extraction procedures began, a constant number of lycopodium spores was added to each sample as a control (Stockmarr, 1971). Subsequently standard techniques were utilized (HCl 10%, KOH 10%, HF 48%, HNO_3 35% cold, and acetolysis). The residues were stained with safranin and mounted in silicone oil. The most troublesome aspect of the extraction procedure was the persistent presence in some samples of fine-grained, acid-resistant organic matter. This fine-grained material tends to clump during acetolysis and if present in quantity makes counting very difficult. It can be removed with cold HNO_3 70% (4 min. in an ultrasonic bath) but this procedure is risky because it can also remove some of the less resistant pollen. A safer technique is to disaggregate the organic fraction with sodium pyrophosphate ($Na_4P_2O_7$) and wash through a 7 μm mesh nylon screen (Cwynar et al., 1979). The disaggregation is best done after the HF treatment.

All counts were made on a Leitz Dialux microscope at 400× magnification. The total count at each level was at least 150 grains and usually over 400 (Appendices A and B). On taxonomic questions we have largely followed the precedents of Martin (1963). The record is

[1] Curray, J. R., Moore, D. G., et al., *Init. Repts. DSDP*, 64: Washington (U.S. Govt. Printing Office).

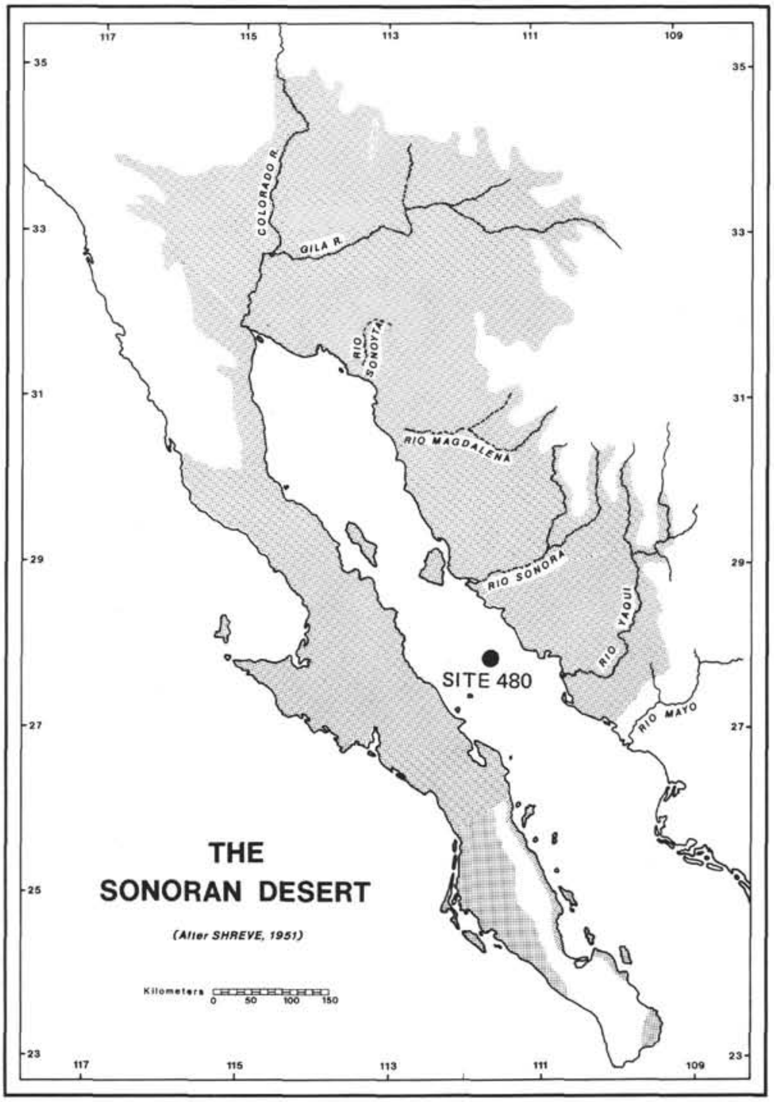

Figure 1. Sonoran Desert areas of Mexico, showing location of Site 480.

dominated by 7 familiar types: *Pinus*, TCT (probably mainly *Juniperus*), *Quercus, Artemisia*, Chenopodiaceae/*Amaranthus*, Gramineae, and low-spine Compositae (probably mostly *Ambrosia*). In addition, the counts include a large number of rare types (see Appendix B), many of which are still "unknown." One unknown type which is listed as "Type 65" is common at some levels. It may represent Euphorbiaceae and/or Rutaceae. Rare types with potential as paleoclimatic indicators include *Picea, Dodonaea, Rhizophora, Bursera, Simmondsia*, and *Idria*. Plates 1 and 2 illustrate some of the pollen types encountered.

RESULTS AND DISCUSSION

The Chronology Problem

As is indicated elsewhere in this volume (see Site 480 chapter, this volume, Pt. 1), the time period represented by the Site 480 section is not yet clearly established. There are two basic problems here: (1) the gap between the sediment/water interface and the top of Core 1, and (2) the uncertainty as to the sedimentation rate in the nonvarved sections.

In order to try to resolve the first problem, a pollen sample was taken from Sample 480-1-1, 0–2 cm and carefully scanned for alien pollen types. As we have shown elsewhere (Mudie and Byrne, 1980), alien pollen types can provide useful chronological markers. However, in this sample none was found and we tentatively conclude, therefore, that the top of Core 1 predates the period of European contact (i.e., has a minimum date of 450 y. B.P.). It is hoped that the chronology for the whole Site 480 section will eventually be derived by isotopic analyses, but no such chronology is presently available, and as an interim substitute we propose a chronology that is based on pollen stratigraphy or, more specifically, pollen concentrations.

As has been shown by Mehringer et al. (1977), pollen concentrations (grains/cm^3) can be used to provide a rough estimate of sedimentation rates in undated sections of cores if pollen influx rates (grains/cm^2•y.) are known for adjacent well-dated sections. Mehringer used this technique to estimate the time represented by volcanic ash layers in lake sediments in the northwestern United States. Here we suggest that the same technique can be used to estimate the time represented by the largely homogeneous unit in Cores 3 through 9. For example, the mean annual pollen influx in Cores 1 and 2 (as determined by varve counts on 12 pollen samples between 0.60 m and 9.82 m) is 1250 grains/cm²•y. (Table 1). This is probably a reasonable estimate of the Holocene average. If one makes the unlikely assumption that annual influx rates were the same in the homogeneous unit that extends from 13.4 meters to 43.0 meters in Cores 3 through 9, and presumably represents most of the last glacial, an estimate of time included in this section can be obtained by dividing the mean pollen concentration per cm³ (Table 2) by the mean annual Holocene influx and multiplying the resulting number by the number of cm in the section. The resulting estimate is ~90 ky.

As can be seen from Table 3, the mean annual influx in varved sections of the core adjacent to homogeneous sections ("transitional" sections) is 2048 grains/cm²•y., considerably higher than the Holocene average. This increased influx is probably attributable to the closer proximity of the coastline during periods of lowered sea level and possibly also to the increased importance of wind-pollenated taxa in the areas adjacent to the central Gulf.

If the "transitional" influx of 2048 grains/cm²•y. is assumed to be typical of the homogeneous unit, the estimated time equivalent is approximately 55 ky. Furthermore, if one allows 14 ky. for the largely varved section between Sample 480-3-3, 91-93 cm (13.42 m) and the top of Core 1, and an additional 6 ky. for the varved section from Sample 480-10-1, 31-33 cm (43.07 m) to 49 meters (both crude estimates), the total time represented in the section analyzed is ~75 ky. (Table 4). This estimate is clearly an approximation, but it does provide a basis for a discussion of the pollen record.

Pollen Stratigraphy

The pollen counts are shown graphically in Figures 2, 3, and 4. Because of the uncertainty about the sedimentation rate in the homogeneous sections, the results for the full 49 meters are presented as a percentage diagram (Fig. 2). The upper 13 meters, however, are mostly varved and the counts for this section are, therefore, given both as percentage and absolute influx diagrams (Figs. 3, 4).

Table 1. Holocene pollen influx rates, Hole 480.

Core/Section (interval in cm)	Depth (m)	Pollen Influx (grains/cm²•y.)
1-1, 0-2	0.60	1435
1-1, 135-137	1.36	1429
1-2, 43-45	1.94	1042
1-2, 131-133	2.82	1292
1-3, 68-70	3.69	693
2-1, 70-72	5.46	878
2-1, 142-144	6.18	1272
2-2, 33-35	6.59	1068
2-2, 101-102	7.26	1453
2-3, 25-27	8.01	1317
2-3, 92-94	8.68	1342
3-1, 31-33	9.82	1785
Mean Holocene influx		1250

Table 2. Pollen concentrations, Hole 480.

Core/Section (interval in cm)	Depth (m)	Conc./cm³
3-3, 91-93	13.42	30,500
4-1, 62-64	14.88	48,620
4-1, 134-136	15.60	60,310
4-2, 96-98	16.72	48,140
4-3, 18-20	17.44	37,500
4-3, 55-57	17.81	44,000
4-3, 92-94	18.18	27,500
5-1, 15-17	19.16	51,750
5-2, 0-2	20.51	31,710
5-2, 38-40	20.89	38,140
5-2, 76-78	21.27	37,570
5-3, 109-111	23.10	21,330
6-1, 35-37	24.11	55,000
6-2, 38-40	25.64	47,070
6-2, 116-118	26.42	32,930
6-3, 75-77	27.51	43,920
7-1, 36-38	28.87	38,180
7-1, 112-114	29.63	41,690
7-2, 25-27	30.26	35,180
7-2, 93-95	30.94	25,420
7-3, 27-29	31.78	27,830
7-3, 111-113	32.62	47,930
8-1, 58-60	33.84	47,170
8-3, 65-67	36.91	24,690
8-3, 108-110	37.34	48,430
9-1, 120-122	39.21	33,290
9-2, 121-123	40.72	24,150
10-1, 31-33	43.07	11,080
Mean homogeneous concentration		37,893

Table 3. Pollen influx rates in transitional sections, Hole 480.

Core/Section (interval in cm)	Depth (m)	Pollen Influx (grains/cm²•y.)
3-2, 30-32	11.31	1666
3-3, 40-42	12.91	2072
5-3, 109-111	23.10	1645
6-2, 116-118	26.42	1920
7-1, 36-38	28.87	3000
7-2, 93-95	30.94	2178
7-3, 27-29	31.78	1855
Mean transitional influx		2048

Table 4. Pollen influx rates, Zone C, Hole 480.

Core/Section (interval in cm)	Depth (m)	Pollen Influx (grains/cm²•y.)
10-1, 130-132	44.06	1872
10-2, 26-28	44.52	2561
10-2, 100-102	45.26	2133
10-3, 20-22	45.96	1192
10-3, 99-101	46.75	2088
11-1, 56-58	48.07	1628
11-1, 101-103	48.52	2616
11-1, 136-138	48.87	2512
Mean interstadial influx		2075

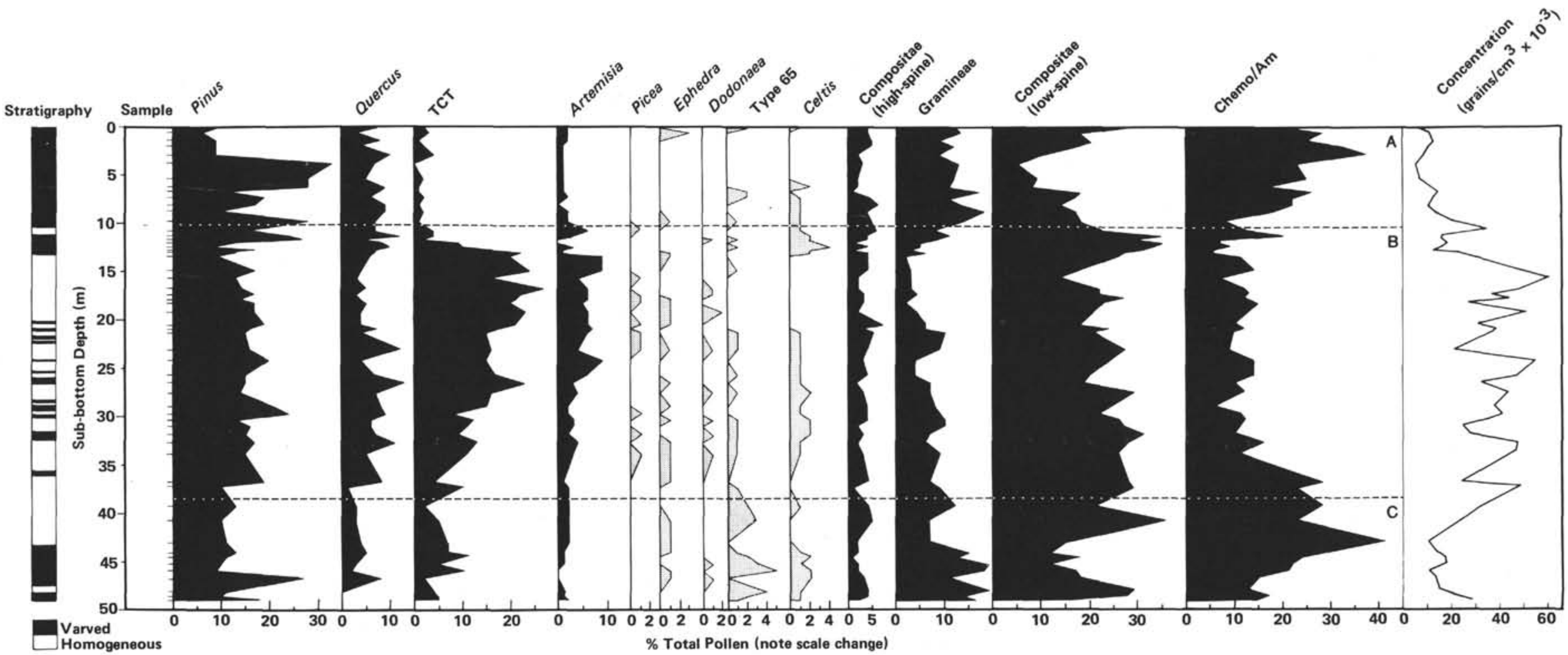

Figure 2. Pollen percentage, Site 480, 0 to 50 meters, showing Pollen Zones A, B, and C.

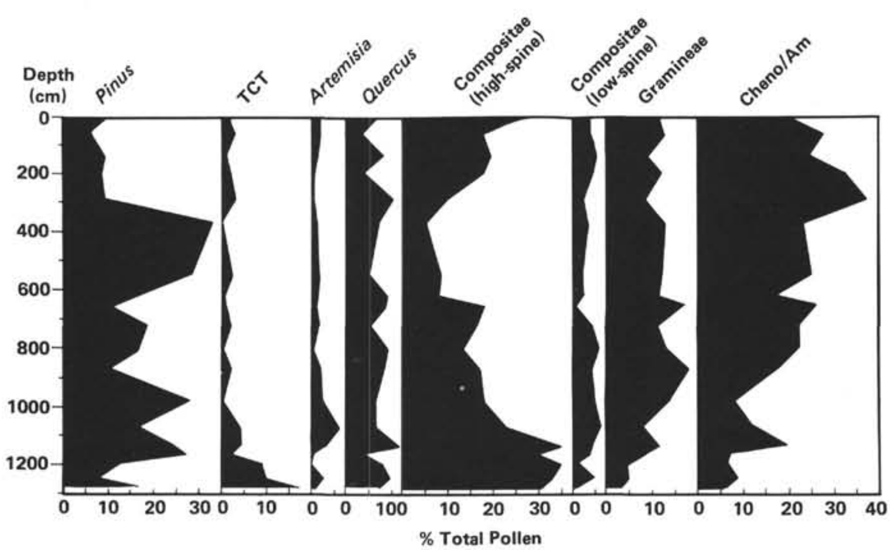

Figure 3. Pollen percentage, Site 480, 0 to 12 meters.

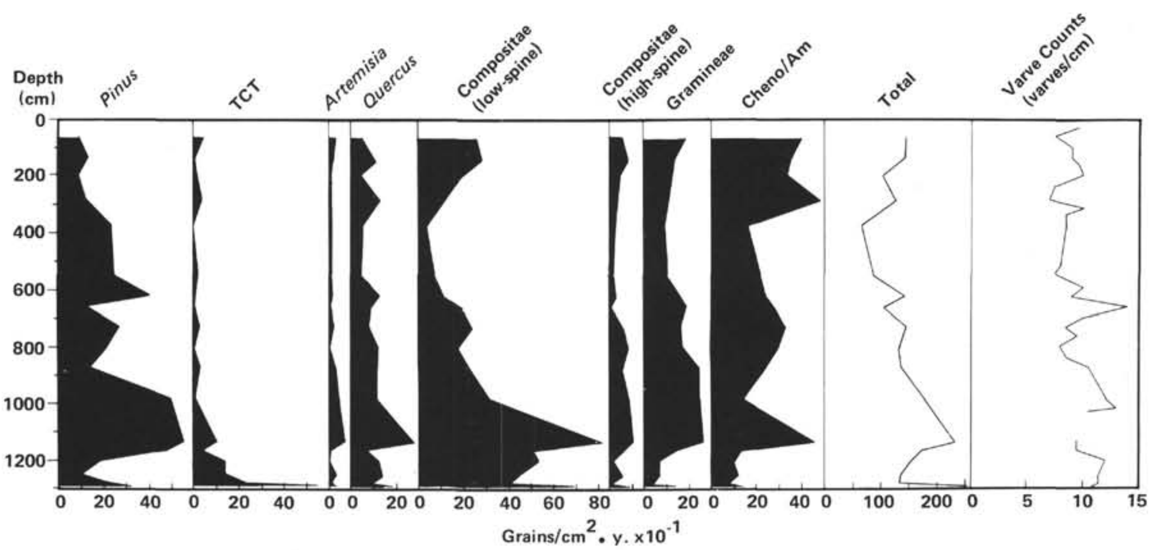

Figure 4. Pollen influx, Site 480, 0–12 meters.

Pollen records from marine cores are usually more complacent than terrestrial records because they reflect the history of vegetation change over large areas. Fortunately, the Site 480 record is not a complacent one. For purposes of discussion three main pollen zones are recognized (Fig. 2). The zone boundaries are arbitrarily based on the variable importance of three paleoclimatically significant pollen types, *Picea*, TCT (presumably *Juniperus*), and *Artemisia*. All three are indicative of cool-temperate climatic conditions and are largely restricted to the homogeneous parts of the section. The dates assigned to the zone boundaries are clearly tentative, especially in the case of the B/C boundary.

Zone C (75,000–60,000 y. B.P.)

This zone is characterized by the absence of *Picea* pollen and by low values for both *Artemisia* and TCT pollen. Herbaceous types dominate the record, notably cheno/ams, low-spine Compositae, and Graminae. Unfortunately, all of these pollen types are taxonomically very broad, and paleoecological interpretation is therefore difficult. The record as a whole indicates an interglacial or an interstadial episode with climatic conditions not very different from those of the present. The prominent minimum in low-spine Compositae at ~44 meters and the subsequent rise in cheno/ams has a parallel in Zone A between 6 meters and 3 meters and presumably represents a shift toward a warmer climate. Certainly, the low arboreal pollen values indicate that it was too warm and dry for woodland vegetation in the areas adjacent to the central Gulf.

Zone B (60,000–10,000 y. B.P.)

The C/B boundary is arbitrarily drawn at 38 meters, because this marks the beginning of a gradual increase in TCT, *Artemisia*, and *Picea*. These cool-climate indicators all reach their highest percentage values between Samples 480-5-3, 109–111 and 480-3-3, 91–93 (23.10 to 13.42 m sub-bottom) and then decline rather abruptly. This gradual rise and rapid decline is reminiscent of numerous late Quaternary climatic records and presumably reflects the last glacial cycle.

Of particular interest in Zone B is the occurrence of spruce (*Picea*) pollen. There are only two species of spruce currently native to Mexico (*P. chihuahuana* and *P. mexicana*) and both have localized distributions in the Sierra Madre. *P. chihuahuana*, the species most likely represented in the Site 480 samples, is limited to several small stands in the Sierra Madre Occidentale. It is now restricted to elevations above 2300 meters where, according to Gordon (1968), the climate is characterized by cold, dry winters, warm summers, and rainfall throughout the year, with the highest monthly totals occurring in summer.

The more or less regular occurrence of spruce pollen in Zone B suggests that spruce had a significantly wider distribution in Mexico during the late Pleistocene. The actual magnitude of this expansion cannot be determined from the Site 480 data alone, but it seems likely that at least the higher sections of the Yaqui and Mayo drainage basins were occupied by spruce during the last glacial episode. Another possibility is that spruce was brought to the central Gulf via Colorado River drainage during periods of glacially lowered sea level. We should note, however, that spruce pollen has also been reported in late Pleistocene sediments in the Basin of Mexico, and long distance transport in that particular case would not seem to have been likely (Clisby and Sears, 1955).

In view of the *Neotoma* evidence referred to earlier, the rise in *Artemisia* and TCT-type pollen (probably *Juniperus*) in Zone B was not unexpected. What is surprising are the low values for both *Pinus* and *Quercus*. Apparently the latitudinal displacement of northern species was not paralleled by a corresponding altitudinal displacement in the Sierra Madre.

Another interesting feature of Zone B is that some desert and subtropical woodland species apparently remained in the central Gulf area throughout the last full glacial. The best evidence for this is the *Dodonaea* curve (Fig. 2). *Dodonaea* was encountered in small but consistent quantities in most of the Zone B samples.

The unusual combination of subtropical (e.g., *Dodonaea*) and cool-temperature (e.g., *Picea*) pollen types in the Zone B samples suggests that the during the last glacial period the central Gulf area was characterized by climatic conditions that have no modern analog. In other words, the overall cooling of climate did not lead to a wholesale displacement of species; rather, some species migrated more than others, and the resulting combinations represented mixed communities that were adapted to basically different climatic regimes.

Another interesting feature of the Zone B assemblage is the abrupt decline of temperate types between Samples 480-3-3, 27–29 cm and 480-3-2, 98–100 cm (12.78 to 11.99 m sub-bottom). Apparently, there was a very rapid warming of climate at this time. Also of interest is the minor reversal between Samples 480-3-2, 61–63 cm and 480-3-1, 31–33 cm (11.62 to 9.82 m sub-bottom). TCT, *Artemisia*, and *Picea* all increase in this section, as does the total pollen concentration (Figs. 2, 3). Conceivably this late-glacial reversal was synchronous with the Younger Dryas of Western Europe or the Two Creeks of North America.

Zone A (10,000–450 y. B.P.)

The age of the boundary between Zones A and B has not yet been precisely dated, but an extrapolation of varve counts, assuming a ~450-y. gap at the top of Core 1, indicates a date of ~10,000 y. B.P. All of the samples analyzed in this section were varved, and it was therefore possible to determine mean annual influx values. The influx diagram (Fig. 3) is especially interesting insofar as it clarifies some puzzling features of the percentage diagram (Fig. 4). The latter suggests that pine increases toward a maximum in the mid-Holocene and remains high until about 3 meters depth. In the influx diagram, there is no Holocene pine rise. The high pine values in the percentage diagram are clearly an artifact of the net decline in nonpine pollen (Fig. 3). In absolute terms, pine pollen influx actually decreases during this period.

Probably the most significant feature of Zone A is the prominent low-spine Compositae minimum and corresponding cheno/am increase between 6 and 3 meters (6000–3000 y. B.P.?). Martin (1963) reported a similar inverse relationship in several Arizona pollen diagrams and interpreted it to represent an Altithermal effect involving heavier rainfall and arroyo cutting. His analysis of modern pollen samples in the southwest has shown that low-spine Compositae are often associated with cienegas (marshy areas) on alluvium-filled valleys, whereas cheno/ams are associated with alkali soils and dissected valley systems.

The general correspondence between the Site 480 Holocene record and Martin's Arizona diagrams is reassuring and is strongly indicative of a regional change in climate of the kind Martin proposed. Also relevant here is the tendency toward thicker varves in this part of the section (Fig. 3). According to Baumgartner et al. (1978), varve thickness in the Guaymas Slope sediments is positively correlated with Río Yaqui discharge.

In the top 2 meters of Zone A, net pollen influx increases and low-spine Compositae once again dominate the record. Samples in this section were carefully scanned for possible evidence of agricultural activity but nothing conclusive was encountered. Cross et al. (1966) reported locally abundant *Zea* pollen in some of their surface samples but we are inclined to believe that their *Zea* are more likely to be algal cysts. Thin-walled, Gramineae-like palynomorphs are common in the near-surface sediments and can be confused with pollen grains.

The Chronology Problem Reconsidered

As was suggested earlier, the pollen concentration data indicate that Cores 1 through 11 represent at least the last 75 ky. The pollen frequencies also support this interpretation. However, one major uncertainty remains. The question is whether or not Pollen Zone C is equivalent to a mid-Wisconsin interstadial (Isotope Stage 3) or a late phase in the Sangamon interglacial (Isotope Stage 5a).

If the largely homogeneous unit from Cores 3 through 9 ($\sim$13.5 m to 43.00 m) is assumed to be equivalent to only the late Wisconsin (Isotope Stage 2), then the interval of time represented by it would be $\sim$15 ky. Isotope Stage 2 began $\sim$25,000 y. B.P. (Ruddiman and McIntyre, 1981), and there are probably at least 14,000 varves above the homogeneous layer in Cores 1, 2, and 3. This would indicate a glacial sedimentation rate roughly twice as high as that of the Holocene.

If, on the other hand, the largely homogeneous unit of Cores 3 through 9 is equivalent to the whole of the Wisconsin glacial interval (Isotope Stages 2, 3, and 4), its basal date should be around 73,000 y. B.P. (Ruddiman and McIntyre, 1981). This, in turn, would suggest that the base of the section analyzed here should date to around 79,000 y. B.P., because Cores 10 and 11 contain at least 6000 varves. If this interpretation is correct, the glacial sedimentation rate was roughly half that of the Holocene.

The uncertainty surrounding the chronology of the Site 480 section may soon be resolved by isotopic dating. On the basis of the pollen evidence presented here, it seems reasonable to conclude that the early estimate of Schrader et al. (1980) is probably not too far out and that Isotope Stage 5e is indeed located somewhere between Cores 11 and 13. The presence of sand at this level prevented the recovery of Core 12, and direct corroboration of this prediction is therefore not possible, at least not at Site 480. Fortunately, the sand unit was largely recovered at nearby Site 479.

CONCLUSION

The main conclusion derived from the present study is that the Site 480 pollen record does provide a sensitive index of late Quaternary climatic change. The record indicates that during the last 80 ky., the vegetation of the area adjacent to the central Gulf has changed significantly in response to what is interpreted to be a large part of the last glacial cycle. Cool-temperature woody taxa, such as *Picea, Artemisia*, and TCT (probably *Juniperus*), reach high values in the homogeneous sections of the core, whereas the varved sediments contain a pollen assemblage that is dominated by cheno/ams, low-spine Compositae, and Graminae.

The absolute influx values determined for the Holocene section emphasize the shortcomings of percentage frequency diagrams and also confirm some of the earlier pollen work in the southwestern United States. Most important here is the duplication of Martin's (1963) "Altithermal" effect involving a decrease in low-spine Compositae and an increase in cheno/ams.

To date, detailed interpretation of the Site 480 pollen record is hampered by the uncertainties concerning the chronology. However, when these problems are resolved it should be possible to reconstruct the history of late Quaternary vegetation change in the central Gulf area with considerable accuracy. Furthermore, it should be possible to cross-correlate the Site 480 record with the much longer Site 479 record and in this way provide a continuous record of change for the last million years. Work along these lines is currently in progress.

ACKNOWLEDGMENTS

I would like to thank Andrew Soutar for assistance in core sampling and Diane Araki for help in sample preparation. I also thank Sally Peterson for photographic assistance, Adrienne Morgan and Jacob Bendix for graphics, and Dianne Byrne for text editing and data tabulation.

This paper is based on work supported by the Division of Atmospheric Sciences, National Science Foundation, under Grant ATM-7919871.

REFERENCES

Baumgartner, T., Soutar, A., and Schrader, H., 1978. Paper presented at the California Cooperative Oceanic Fisheries Investigations Meeting, Idyllwild, California.

Clisby, K. H., and Sears, P. B., 1955. Palynology in southern North-America Part III: Microfossil profiles under Mexico City correlated with sedimentary profiles. *Bull. Geol. Soc. Am.*, 66:511-520.

Cross, A. T., Thompson, G. G., and Zaitzeff, J. B., 1966. Source and distribution of palynomorphs in bottom sediments, southern part of the Gulf of California. *Mar. Geol.*, 4:467-524.

Cwynar, L. C., Burden, E., and McAndrews, J. H., 1979. An inexpensive method for concentrating pollen and spores from fine-grained sediments. *Can. J. Earth Sci.*, 16:1115-1120.

Fine, B., 1978. Vegetation and modern pollen spectra in Sinaloa and Nayarit, Mexico [Unpubl. ms.]. Department of Geoscience, University of Arizona, Tucson, Arizona.

Gordon, A. G., 1968. Ecology of *Picea chihuahuana* Martinez. *Ecology*, 49:880-896.

Hevly, R. H., Mehringer, P. J., Jr., and Yocum, H. G., 1965. Modern pollen rain in the Sonoran Desert. *J. Ariz. Acad. Sci.*, 3:123-135.

Martin, P. S., 1963. *The Last 10,000 Years: A Fossil Pollen Record of the American Southwest:* Tucson (University of Arizona Press).

Martin, P. S., and Mehringer, P. J., Jr., 1965. Pleistocene pollen analysis and biogeography of the Southwest. *In* Wright, H. E., and Frey, D. G. (Eds.), *The Quaternary of the United States:* Princeton, N.J. (Princeton University Press), pp. 433-451.

Mehringer, P. J., Jr., Blinman, E., and Petersen, K. L., 1977. Pollen influx and volcanic ash. *Science*, 198:257-261.

Mehringer, P. J., Jr., Martin, P. S., and Haynes, C. V., Jr. 1967. Murray Springs: A mid-postglacial pollen record from southern Arizona. *Am. J. Sci.*, 265:786-797.

Meyer, E. R., 1973. Late Quaternary paleoecology of the Cuatro Cienegas Basin, Coahuila, Mexico. *Ecology*, 54:982-995.

Mudie, P. J., and Byrne, R., 1980. Pollen evidence for historic sedimentation rates in California coastal marshes. *Estuarine Coastal Mar. Sci.*, 10:305-316.

Ruddiman, W. F., and McIntyre, A., 1981. Oceanic mechanisms for amplification of the 23,000-year ice-volume cycle. *Science*, 212: 617-627.

Schrader, H., and the Shipboard Scientific Party, Leg 64, 1980. Laminated diatomaceous sediments from the Guaymas Basin slope (central Gulf of California): 250,000-Year climate record. *Science*, 207:1207-1209.

Shreve, F., 1951. *Vegetation of the Sonoran Desert.* Carnegie Inst. Wash. Pub. 591.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, 13:615-621.

Van Devender, T. R., and Spaulding, W. G., 1979. Development of vegetation and climate in the southwestern United States. *Science*, 204:701-710.

APPENDIX A
Pollen and Spore Counts, Hole 480

Pollen Type / Core/Section (interval in cm) Sub-bottom Depth (m)	1-1, 0–2 0.01	1-1, 59–61 0.6	1-1, 135–137 1.36	1-2, 43–45 1.94	1-2, 131–133 2.82	1-3, 68–70 3.69	2-1, 70–72 5.46	2-1, 142–144 6.18	2-2, 33–35 6.59	2-2, 101–102 7.26	2-3, 25–27 8.01	2-3, 92–94 8.68	3-1, 31–33 9.82	3-1, 121–123 10.72	3-2, 30–32 11.31	3-2, 61–63 11.62	3-2, 98–100 11.99	3-2, 147–149 12.48
Pinus	44	12	35	48	30	67	82	64	22	70	51	35	104	78	72	67	61	33
Picea	0	0	0	0	0	0	1	0	0	0	0	0	1	4	0	0	0	0
TCT	10	6	4	10	9	0	6	2	2	7	2	7	2	20	13	6	43	43
Ephedra	2	6	1	0	0	0	0	0	1	1	0	0	2	0	0	0	2	2
Fraxinus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Acer	0	1	1	0	1	0	0	0	0	0	0	0	0	1	2	0	7	4
Quercus	34	7	31	22	33	15	15	20	17	21	28	30	25	32	36	10	39	43
Juglans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Liquidambar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Platanus	1	0	2	0	2	0	1	0	0	0	0	0	0	4	0	0	0	0
Rhamnaceae	1	1	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	3
Dodonaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simmondsia	2	0	0	0	0	0	0	0	0	0	0	0	5	0	2	0	0	0
Bursera	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2	0	0
Celtis	5	1	0	1	1	0	0	4	1	2	3	2	2	6	6	4	17	19
Salix	0	1	2	0	2	1	1	0	2	4	0	0	1	1	1	0	1	0
Alnus	3	1	0	2	0	1	0	1	0	2	0	4	5	3	1	1	0	0
Artemisia	9	4	6	4	2	2	4	3	2	6	1	7	9	30	9	1	0	11
Ambrosia	138	36	76	102	31	11	25	18	37	63	1	60	67	110	105	72	170	143
High-Spine Compositae	20	8	21	26	8	7	6	5	2	16	8	15	18	29	13	9	7	19
Low-Spine Compositae	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0
Malvaceae	1	0	0	0	2	0	0	2	1	1	0	0	0	0	0	0	0	0
Arceuthobium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dalea	1	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Eriogonum	1	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0	2
Rumex	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Plantago	6	4	7	1	0	0	0	0	1	1	0	0	2	2	0	1	0	2
Polemoniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Allionia	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Navarettia	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Rhus	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0
Rutaceae	9	0	0	0	0	0	1	0	5	8	0	0	4	0	0	2	0	5
Gramineae	59	26	36	67	28	26	35	26	35	43	40	63	52	38	34	21	23	21
Cheno-Am	107	56	95	182	120	47	73	39	53	85	68	62	31	59	59	18	32	38
Sarcobatus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Typha-Sparganium	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1
Cyperaceae	1	0	0	0	0	0	1	0	0	3	0	2	1	0	0	1	4	2
Liliaceae-Agavaceae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	3
Selaginella	0	3	0	0	0	1	0	0	0	0	0	0	1	0	0	3	1	0
Trilete spores	1	1	1	1	2	0	1	3	0	1	0	0	2	0	0	2	10	0
Pediastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Indeterminate	12	15	18	22	11	10	11	21	15	17	27	19	20	19	18	15	34	17
Unknown	31	18	49	69	36	12	21	21	12	21	24	42	17	28	16	10	34	17
Total pollen	499	201	386	563	323	201	290	229	203	378	303	349	375	482	300	245	486	433
Control	650	250	400	800	400	400	650	300	200	400	400	400	300	200	275	200	400	400
Grains/cm^2/y.	NA	1436	1430	1043	1292	693	879	1272	1068	1454	1317	1342	1786	NA	1667	1750	1519	1353
Conc./$cm^3 \times 10^{-1}$	NA	1058	1287	1043	923	591	659	1145	1450	1260	1045	1396	2083	3443	1667	1633	1800	1604

Appendix A. (Continued).

3-3, 27–29 12.78	3-3, 40–42 12.91	3-3, 91–93 13.42	4-1, 62–64 14.88	4-1, 134–136 15.60	4-2, 96–98 16.72	4-3, 18–20 17.44	4-3, 55–57 17.81	4-3, 92–94 18.18	5-1, 15–17 19.16	5-2, 1–2 20.51	5-2, 38–40 20.89	5-2, 76–78 21.27	5-3, 109–111 23.10	6-1, 35–37 24.11	6-2, 38–40 25.64	6-2, 116–118 26.42	6-3, 75–77 27.51	7-1, 36–38 28.87	7-1, 112–114 29.63	7-2, 25–27 30.26	7-2, 93–95 30.94
59	58	40	108	105	96	141	44	65	70	85	43	78	95	293	101	71	80	88	130	49	49
0	0	2	2	4	2	5	3	4	1	4	1	3	6	5	1	1	1	2	3	0	0
61	99	86	149	125	182	183	66	76	95	92	46	80	95	228	112	106	90	62	46	48	35
0	3	3	2	1	1	2	3	2	4	3	1	2	4	5	3	4	2	4	1	4	0
0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	1	0	2	1	1	2	0	0	0	0	2	0	1	2	2	1	1	0	2	1	1
26	32	27	26	27	37	25	12	21	15	16	20	19	70	58	43	58	39	33	49	22	20
0	1	0	0	1	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	1	0	4	1	0	0	0	0	0	0	0
1	0	0	0	0	1	2	0	0	0	1	0	0	0	0	3	0	0	0	9	4	0
0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	2	0	1	1	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2	0	0	1	0	0	0	3	0	1	0	0	0	0	2	0
0	0	0	0	0	5	6	0	0	7	0	1	1	3	2	2	0	4	1	1	2	0
7	10	1	3	1	0	1	0	0	1	2	0	6	7	14	6	6	10	2	8	9	6
0	0	1	0	0	2	2	1	0	0	0	0	1	1	7	0	2	0	0	0	3	1
2	0	1	1	1	0	0	0	1	1	1	1	0	0	0	4	1	1	0	0	0	0
3	6	38	56	35	42	50	18	19	26	26	20	34	24	127	42	13	20	9	11	13	8
110	124	110	116	107	148	183	83	90	89	80	63	113	154	350	135	86	165	100	120	100	82
4	16	17	23	13	13	25	9	10	10	29	8	27	24	41	25	9	19	16	24	14	6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1	1	0	0	0	1	2	2	1	0	0	0	0	0	0	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	1	0	0	0	3	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
3	2	0	3	1	2	2	2	0	0	1	0	1	0	2	2	0	1	1	0	1	0
0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	2	0
0	1	0	7	2	2	3	0	0	0	0	0	4	6	4	4	2	3	2	1	4	3
12	26	8	16	25	20	29	10	0	0	0	0	54	49	53	24	31	42	35	48	37	32
22	24	48	88	56	81	110	36	8	15	25	17	54	53	203	91	45	68	27	60	46	35
0	1	0	2	1	2	2	0	56	52	44	33	0	0	13	3	0	0	1	0	0	0
0	0	0	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
2	4	0	1	1	1	4	0	0	0	0	0	2	1	2	2	0	2	1	0	1	2
1	2	0	2	1	0	0	0	0	1	1	0	0	1	2	2	0	0	0	2	3	0
0	2	4	0	5	2	3	3	4	0	0	0	2	0	5	1	1	0	0	1	0	0
0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
25	18	14	11	23	13	14	8	12	11	14	5	23	21	40	17	11	9	19	9	11	7
15	21	23	9	13	16	11	5	13	12	12	4	20	19	26	26	8	12	13	17	6	16
356	456	427	632	784	674	825	308	385	414	444	267	526	576	1485	659	461	571	420	542	387	305
400	300	200	200	200	200	300	100	200	100	200	100	200	400	400	200	200	200	205	200	200	200
1148	2073	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1646	NA	NA	1921	NA	3000	NA	NA	2179
1319	2280	3050	4862	6031	4814	3750	4400	2750	5175	3171	3814	3757	2133	5500	4707	3293	4392	3818	4169	3518	2542

Appendix A. (Continued).

Pollen Type / Core/Section (interval in cm) Sub-bottom Depth (m)	7-3, 27–29 31.78	7-3, 111–113 32.62	8-1, 58–60 33.84	8-3, 65–67 36.91	8-3, 108–110 37.34	9-1, 120–122 39.21	9-2, 121–123 40.72	10-1, 31–33 43.07	10-1, 130–132 44.06	10-2, 26–28 44.52	10-2, 100–102 45.26	10-3, 20–22 45.96	10-3, 99–101 46.75	11-1, 56–58 48.07	11-1, 101–103 48.52	11-1, 136–138 48.87
Pinus	51	117	86	60	35	62	31	29	45	50	58	42	51	26	31	36
Picea	4	2	4	0	0	0	1	0	0	0	0	0	0	0	0	0
TCT	30	86	62	12	35	11	15	19	22	49	28	48	3	9	16	10
Ephedra	0	4	4	3	1	1	2	2	2	0	2	5	1	0	0	0
Fraxinus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acer	2	3	4	0	1	0	2	0	0	0	0	0	0	0	0	1
Quercus	36	34	43	4	0	15	9	10	18	17	19	11	15	9	9	9
Juglans	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Liquidambar	2	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0
Platanus	0	0	2	0	0	1	0	0	0	0	0	0	0	0	1	0
Rhamnaceae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Dodonaea	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Simmondsia	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0
Bursera	2	0	3	1	1	0	0	1	0	0	3	0	1	0	0	0
Celtis	7	6	4	0	1	5	1	1	2	7	4	9	3	3	4	2
Salix	0	0	3	1	0	0	0	0	2	0	2	1	2	1	0	0
Alnus	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1
Artemisia	7	26	16	4	6	9	5	4	5	3	5	1	0	2	3	4
Ambrosia	105	191	148	90	100	96	112	40	39	81	67	85	33	65	87	33
High-Spine Compositae	11	16	19	13	5	18	15	5	6	4	9	11	5	10	11	4
Low-Spine Compositae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malvaceae	0	0	2	2	0	0	0	0	0	0	1	1	0	0	1	0
Arceuthobium	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Dalea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriogonum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Rumex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plantago	2	2	0	0	0	0	0	0	0	0	3	0	1	0	1	0
Polemoniaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allionia	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Navarettia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Rutaceae	2	4	4	1	3	8	10	1	2	11	16	23	0	9	7	3
Gramineae	23	37	52	21	30	54	22	19	50	61	109	88	21	43	43	33
Cheno-Am	32	106	61	89	78	130	73	109	93	111	126	103	29	29	54	30
Sarcobatus	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Typha-Sparganium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	0	1	2	2	2	1	1	1	2	1	1	1	0	0	0	0
Liliaceae-Agavaceae	0	0	0	0	1	2	0	1	0	1	2	0	0	2	2	0
Selaginella	0	0	3	0	3	0	0	1	0	0	0	0	0	0	0	0
Trilete spores	0	0	1	2	0	0	0	0	1	0	0	0	0	0	0	0
Pediastrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	5	18	23	6	13	34	5	13	12	11	32	25	7	12	17	12
Unknown	12	11	12	9	17	19	9	9	35	53	26	34	17	14	22	20
Total pollen	334	671	566	321	339	466	314	266	337	461	576	489	188	228	314	201
Control	200	200	200	200	100	200	200	400	400	400	500	606	200	212	200	100
Grains/cm^2/y.	1856	NA	NA	NA	NA	NA	NA	NA	1872	2561	2133	1193	2089	1629	2617	2512
Conc./$cm^3 \times 10^{-1}$	2783	4793	4717	2469	4843	3329	2415	1108	1404	1707	1800	1137	1343	1520	2243	2871

APPENDIX B
Infrequently Appearing Pollen and Spores, Hole 480

	No.	Core/Section (interval in cm)	Depth Sub-bottom (m)
Abies	1	3-1, 31-33	9.82
Aesculus	1	11-1, 101-103	48.52
Lithocarpus	1	6-1, 35-37	24.11
	1	10-2, 26-28	44.55
Garrya-Fremontia	3	4-3, 18-20	17.44
	3	8-1, 58-60	33.84
Rhizophora	1	2-2, 101-102	7.26
	1	11-1, 56-58	48.07
Rosaceae	1	5-1, 15-17	19.16
	1	7-2, 25-27	30.26
Acanthaceae	1	5-2, 76-78	21.27
	1	8-3, 108-110	37.34
Myrica	1	3-3, 91-93	13.42
	1	6-2, 116-118	26.42
Liguliflorae	1	3-3, 91-93	13.42
Caryophyllaceae	1	4-3, 18-20	17.44
Rubiaceae	1	4-3, 18-20	17.44
Leguminosae	1	2-2, 101-102	7.26
Labiatae	1	10-3, 20-22	45.96
Salvia	1	3-2, 30-32	11.31
	1	7-3, 27-29	31.78
Polygonum	1	1-2, 131-133	2.82
	1	2-1, 70-72	5.46
Nyctaginaceae	2	4-3, 18-20	17.44
	1	5-2, 0-2	20.51
Umbelliferae	1	4-1, 62-64	14.88
Onagraceae	3	7-3, 111-113	32.62
Alternanthera	1	3-2, 147-149	12.48
	1	10-2, 100-102	45.26
Isoetes	1	4-3, 55-57	17.81
Dryopteris	1	8-3, 65-67	36.91
	1	10-2, 100-102	45.26
	1	11-1, 136-138	48.87
Pteridium	1	1-1, 0-2	0.01
Athyrium	1	8-1, 56-60	33.84
Botrychium	1	3-3, 27-29	12.78
	1	6-2, 116-118	26.42
	1	8-3, 108-110	37.34
Monolete spores	1	3-2, 147-149	12.48
	1	3-3, 27-29	12.78

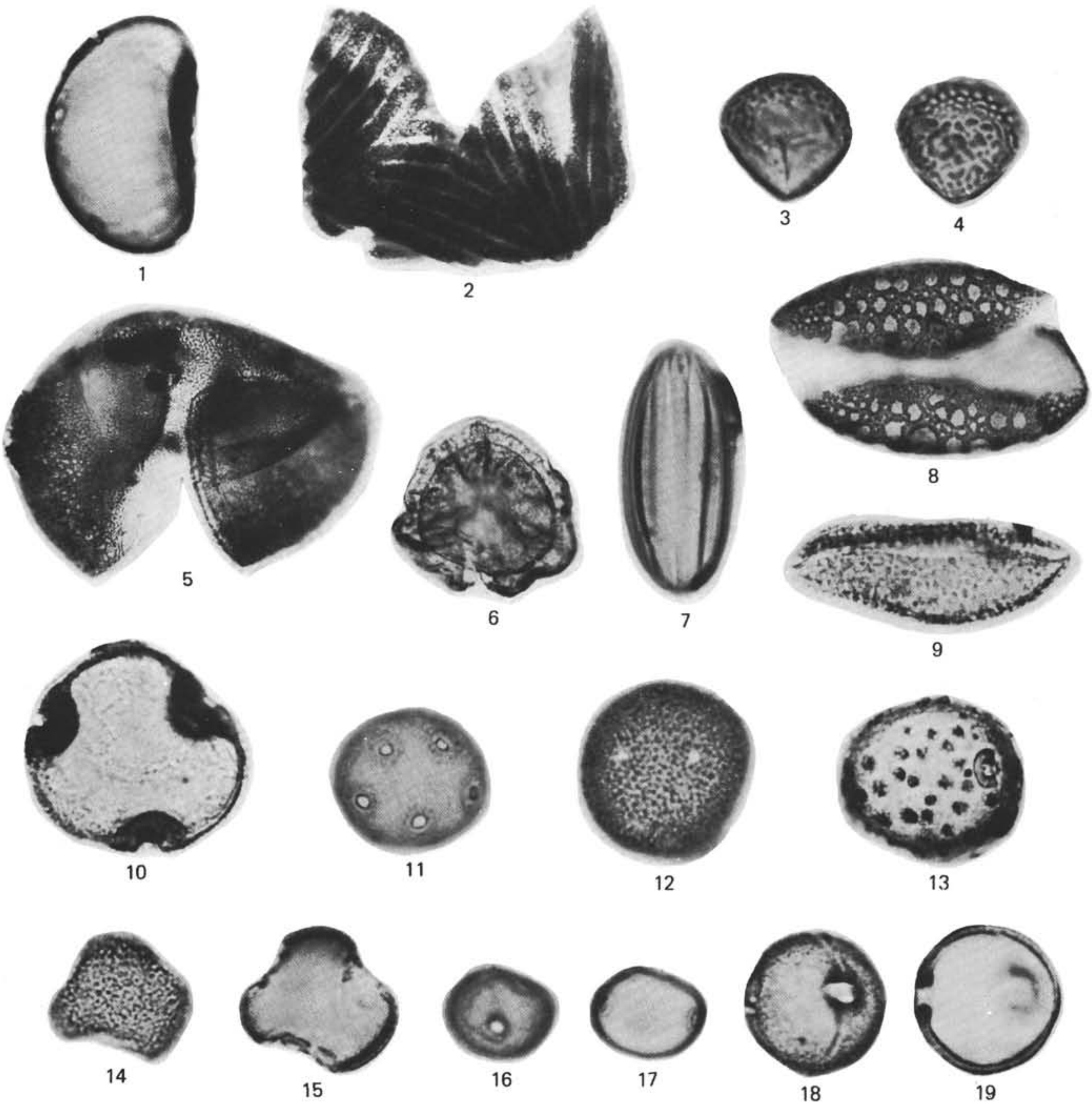

Plate 1. Pollen and spores from Hole 480, Cores 1-11. (All magnifications ×1000 unless otherwise indicated.) 1. *Dryopteris*, Sample 480-3-2, 30-32 cm. 2. *Ceratopteris*, ×500, Sample 480-3-2, 30-32 cm. 3-4. *Dicksonia*, Sample 480-7-3, 27-29 cm, (3) high focus, (4) low focus. 5. *Picea*, ×500, Sample 480-4-1, 62-64 cm. 6. *Selaginella*, ×500, Sample 480-5-2, 76-78 cm. 7. *Ephedra*, Sample 480-1-1, 0-2 cm. 8-9. Agavaceae (8) ×500, Sample 480-3-1, 121-123 cm, (9) Sample 480-3-3, 40-42 cm. 10. *Tilia*, Sample 480-3-2, 147-149 cm. 11. *Sarcobatus*, Sample 480-3-3, 40-42 cm. 12. Unknown periporate, Sample 480-5-2, 0-2 cm. 13. Malvaceae, Sample 480-4-3, 18-20 cm. 14-15. *Simmondsia*, Sample 480-1-1, 30-32 cm, (14) high focus, (15) low focus. 16-17. *Celtis*, Sample 480-1-1, 0-2 cm, (16) high focus, (17) low focus. 18-19. *Dodonaea*, Sample 480-3-2, 147-149 cm, (18) high focus, (19) low focus.

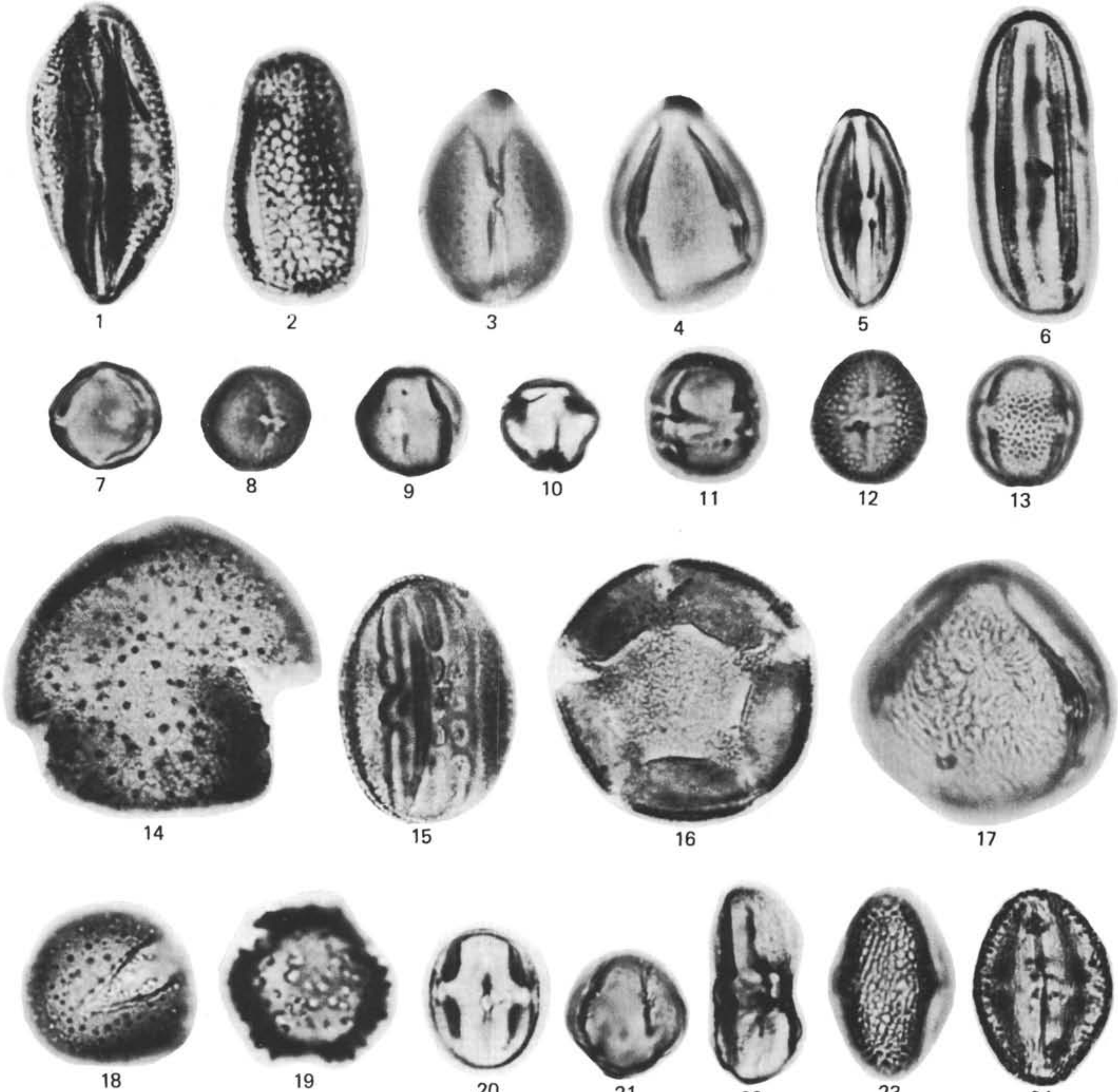

Plate 2. Pollen and spores from Hole 480, Cores 1-11. (All magnifications ×1000 unless otherwise indicated.) 1-6. Unknown tricolporates, (1) Sample 480-1-1, 30-32 cm, (2) ×1600, Sample 480-5-2, 76-78 cm, (3-4) Sample 480-1-1, 0-2 cm (3, high focus; 4, low focus), (5) Sample 480-4-3, 18-20 cm, (6) Sample 480-5-1, 75-77 cm. 7-8. Rhamnaceae/Rosaeceae, Sample 480-1-1, 0-2 cm. 9. Unknown stephanocolpate type, Sample 480-1-1, 30-32 cm. 10. Unknown tricolporate, ×1280, Sample 480-3-2, 98-100 cm. 11. *Rhizophora*, Sample 480-1-3, 33-35 cm. 12-13. Unknown tricolporate, Sample 480-3-3, 40-42 cm. 14. Caprifoliaceae, Sample 480-4-1, 33-35 cm. 15. Acanthaceae, Sample 480-1-3, 33-35 cm. 16. *Evolvulus*, Sample 480-6-1, 73-75 cm. 17. Unknown tricolporate, Sample 480-4-1, 134-136 cm. 18. Caprifoliaceae, Sample 480-6-2, 38-40 cm. 19. Unknown, Sample 480-2-2, 101-103 cm. 20. Unknown tricolporate, Sample 480-6-2, 38-40 cm. 21. Cactaceae type, Sample 480-3-1, 31-33 cm. 22. Umbelliferae, Sample 480-1-1, 30-32 cm. 23-24. Unknown tricolporate, Sample 480-1-1, 30-32 cm, (23) high focus, (24) low focus.