

## 20. DATA REPORT: INITIAL RESULTS OF POLLEN ANALYSES FROM SITES 1018, 1020, 1021, AND 1022<sup>1</sup>

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### INTRODUCTION

The climatic effects of major geologic events of the last 6 m.y., such as the variations in arctic and Antarctic icecaps and the uplift of major mountain ranges, are reasonably well documented in the marine realm. On land, however, such evidence is limited, and chronostratigraphic control is minimal. Only ~12 widely separated floras are available to reconstruct discrete events in the evolution of vegetation and climate of California and Oregon forests during the late Neogene, an interval in which major climatic changes are reflected in the replacement of Miocene mesophytic forests by temperate coniferous forests (Axelrod, 1977). Cores taken on the California margin during Leg 167 provide an opportunity to continuously monitor vegetation of the northwest coast of North America (using marine pollen assemblages), to set the terrestrial vegetation and climate records in accurate age frameworks provided by other components in the cores, and to directly relate late Neogene changes in oceanic and terrestrial processes. The primary objective of this survey of pollen from Ocean Drilling Program (ODP) Holes 1018A, 1020C, 1021B, and 1022C is to present an initial overview of the evolution of vegetation on the northern California margin from the upper Miocene to Holocene.

### BACKGROUND

Natural vegetation of coastal California ranges from xeric southern oak woodland to mesic northern rain forests. In Southern California, a diverse and complex mosaic of scrub oak (*Quercus*), oak woodland savanna, and oak-dominated foothill woodlands with isolated groups of closed-cone pine and cypress (e.g., *Pinus radiata* and *Cupressus pygmaea*) interfinger with chaparral and lowland sage scrub. At higher elevations, conifer forests develop: open pine woodland with small, isolated stands of incense cedar (*Libocedrus decurrens*) is succeeded upslope by parklike mid-montane conifer forests of scattered pine and incense cedar, upper montane juniper (*Juniperus occidentalis*) woodland, and subalpine coniferous forests with lodgepole pine (*Pinus contorta*; Barbour and Billings, 1988; Barbour and Major, 1977; Franklin and Dyrness, 1973; Kuchler, 1977).

The unique redwood (*Sequoia sempervirens*) forests of coastal Northern California, which include other conifers such as western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and Douglas fir (*Pseudotsuga menziesii*), are replaced inland in drier situations by oak woodland and at higher elevations by montane forest formations with fir (*Abies*), hemlock, Douglas fir, pine, and evergreen oaks (Barbour and Major, 1977). Just north of ~42°N in Oregon, western hemlock and Sitka spruce are the major tree species along the Pacific Ocean, with hemlock dominating the coast and

spruce more prominent inland. Common forest associates include Douglas fir, western red cedar (*Thuja plicata*), and, in disturbed and riparian areas, alder (*Alnus*). Above the narrow band of lowland forest are montane and subalpine forests of fir (*Abies concolor* and *Abies amabilis*), pine (*Pinus ponderosa* and *Pinus lambertiana*), and mountain hemlock (*Tsuga mertensiana*).

The two end-members of coastal California vegetation (southern California oak woodland and Pacific Northwest conifer forests) reflect regional differences in mean annual temperature and precipitation (first-order controls of vegetation distribution). South of ~40°N–42°N, mean annual temperatures and precipitation average 19°C and 30 cm, and upper montane temperature and precipitation are ~8°C and 57 cm. To the north on the Oregon Pacific coast, mean annual lowland temperature and precipitation are ~12°C and ~300 cm, and subalpine temperatures and precipitation average ~10°C and 140 cm (Elford, 1974; Sternes, 1974). The south–north transition from excess evaporation to excess precipitation reflects the frequency and intensity of frontal storms south and north of the atmospheric and oceanic polar fronts (Lawford, 1993).

Near the Pacific Ocean, temperature and effective precipitation are moderated by fog associated with upwelling and by seasonal variations in sea-surface temperatures (SSTs) of the southward-flowing California Current and the poleward-flowing, seasonal Davidson Current (Barbour et al., 1980; Barbour and Major, 1977). South of ~42°N, northerly winds drive near-coastal persistent seasonal upwelling; to the north, upwelling intensity is more variable. Off California and Oregon, waters north of 40°N–42°N are subarctic in type, with mean SSTs of ~12° to ~13°C; off Southern California, mean SSTs of ~14° to ~15°C reflect the presence of subtropical waters (Mortyn et al., 1996). Changes in the California Current system during the last glacial are reflected in changes in Pacific maritime vegetation. The virtual absence of coastal redwood in Northern California in glacial-age pollen records, for example, is probably related to decreased fogdrip associated with decreased nearshore upwelling and to lower SSTs (Adam et al., 1981b; Gardner et al., 1988; Sancetta et al., 1992). During oxygen isotope Stage 3, brief warming events in California and Oregon appeared correlative with interstadial events in waters offshore (Doose et al., 1997; Gardner, 1997; Gardner et al., 1997; Kennett and Ingram, 1995; Lyle et al., 1992; Sabin and Pisias, 1996; Thunell and Mortyn, 1995).

### MATERIALS AND METHODS

Initially, four sites were sampled: Hole 1018A (36°59.300'N, 123°16.653'W; 2478 meters below seafloor [mbsf]), Hole 1020C (41°0.051'N, 126°26.063'W; 3038 mbsf), Hole 1021B (39°5.248'N, 127°46.985'W; 4212 mbsf), and Hole 1022C (40°4.842'N, 125°20.558'W; 1926 mbsf) (Fig. 1; Table 1). Sample spacing ranged from one sample per core in Holes 1018A and 1021B to three samples per core in Holes 1020B and 1022C. Standard marine pollen-processing procedures, including the addition of measured quantities of an exotic tracer to determine pollen concentration (pollen grains/gram dry weight sediment [gdws]), were preceded and succeeded by

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sieving through 7- $\mu$ m nylon monofilament screening (Heusser and Stock, 1984). Pollen types representing  $\geq 35$  taxa were identified to the lowest taxonomic level possible; for example, specific identification of *Tsuga* (*T. heterophylla* and *T. mertensiana*) and familial identification of grasses (Gramineae), chenopods (Chenopodiaceae), and composites (Compositae). Excluding the papillate thick-exined grains of *S. sempervirens* (coastal redwood) and inaperturate pollen of other genera in the Taxodiaceae, Cupressaceae, and Taxaceae (*Juniperus*, *Torreya*, *Cupressus*, *Libocedrus*, *Chamaecyparis*, and *Thuja*), taxa that cannot be satisfactorily separated using light microscopy are here referred to as juniper-cypress. Other groups of pollen and spores include herbs (Gramineae, Cyperaceae, and Compositae), chaparral (sclerophyllous shrubs such as *Ceanothus*, *Adenostoma*, *Rhus*, and other members of Anacardiaceae, Rhamnaceae, and Rosaceae), and ferns (Polypodiaceae). For this initial survey,  $\geq 100$  pollen grains were identified in each of 327 samples from Sites 1018, 1020, and 1022. (Data files are available from the ODP Data Librarian.) Because pollen concentrations in samples from ODP Hole 1021B were extremely low (ranging from 100 to 1000 gdw), pollen data from this hole are not discussed in this report. Pollen percentages are based on the total number of pollen grains identified in each sample. Percentages of fern spores (and other pteridophytes such as *Lycopodium* spp. and *Selaginella selaginoides*) are calculated on the total number of pollen grain and spores identified in each sample.

Age control varies from the well-constrained chronologies provided by a combination of calcareous nannofossil, planktonic foraminifer, radiolarian, and diatom datums (Sites 1018 and 1020) and by

paleomagnetic reversals (Site 1020) to estimated ages of ODP Hole 1022C (M. Lyle, pers. comm., 1998; Lyle et al., Chap. 32, this volume).

## RESULTS AND INTERPRETATION

Pollen is abundant and well preserved in late Neogene sediments deposited on the northern California continental margin, with more pollen at the site closest to California vegetation than at sites farther offshore. Mean pollen abundance at Site 1018 (12,000/gdws) is two and three times larger than at Sites 1022 and 1020, respectively (Figs. 2–4). These differences in the amounts of pollen reflect differential pollen productivity of plant assemblages from which the pollen is derived, as well as pollen sedimentation (e.g., initial pollen dispersal and subsequent fluviomarine transport; Heusser and Balsam, 1977; Heusser, 1983, 1988). At Site 1018, the high concentrations of pine and juniper/cedar types, both from heavy pollen producers, contribute to the large amount of pollen in sediments deposited at this near-shore site (Fig. 2). The hydrodynamic efficiency of buoyant pine pollen is seen in the usual offshore increase in the relative abundance of pine (Traverse, 1988). Mean pine percentages from Leg 167 drill sites off Northern California increase from 37% at  $\sim 76$  km to 74% at 364 km. The overall increase in pollen concentration at  $\sim 4$  Ma in Hole 1022C sediments may reflect tectonic movement of the core site, changing the distance between the paleodeposition site and source vegetation (Lyle, Koizumi, Richter, et al., 1997), as well as changes in the vegetation onshore (e.g., increased cedar/juniper in regional vegetation during the last  $\sim 3.8$  m.y.).

Pliocene and Pleistocene pollen spectra are composed of taxa that are morphologically similar to taxa that presently grow on the north coast of California (Figs. 5–7). Miocene pollen assemblages from Hole 1022C (samples from Core 167-1022C-33X to Section 41X-1) include exotics such as *Liquidambar*, *Pterocarya*, *Carya*, and *Tilia* (Fig. 6), extant taxa that became extinct in the north coast forest (Axelrod, 1977). Paleoecologic interpretations of these pollen spectra are based on several assumptions: (1) the diagnostic components of pollen assemblages from marine cores, like those from terrestrial cores, reflect the composition of onshore vegetation formations (C.J. Heusser, 1978; L.E. Heusser, 1978a, 1978b, 1983, 1988; Heusser and Balsam, 1977); (2) modern climatic tolerances of vegetation with pollen spectra similar to fossil pollen spectra provide a reliable foundation for reconstructing past vegetation and climate; and (3) changes in late Neogene vegetation of California reflect regional and global climatic change (precipitation and temperature) (Axelrod, 1977; Huntley and Webb, 1988; Raven and Axelrod, 1978).

Pollen assemblages from Holes 1018A, 1020C, and 1022C deposited during the last  $\sim 5$  m.y. reflect a latitudinal difference in vegetation, not unlike that of the present. In the southernmost site, open oak woodlands with abundant shrubs and herbs (including chaparral and sage types) are better represented than north coast forest elements such as hemlock, spruce, and redwood (excluding two samples) (Fig. 5). In the northernmost site (Fig. 7), these relationships are reversed, and hemlock, spruce, and redwood are more prominent than oak and shrub/herbs. Other taxa associated with north coast rain forests, alder and ferns, are also better represented in the north than in the south. Oscillations in the general south–north gradient in effective precipitation and temperature implied by these data are inferred from the

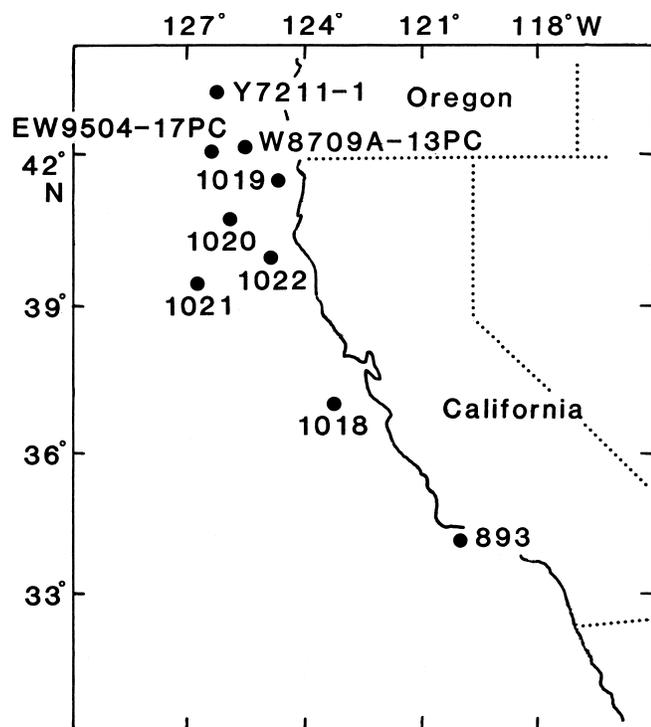


Figure 1. Map of the northeast Pacific continental margin showing location of ODP sites.

Table 1. Leg 167 drill sites analyzed for pollen.

Site	Location	Distance from shore (km)	Water depth (m)	Position
1018	Sediment drift south of Guide Seamount	76	2476	36°59.3'N, 123°16.653'W
1020	Eastern flank, Gorda Ridge	167	3050	41°0.051'N, 126°26.065'W
1021	Outer Delgada Fan	364	4215	39°5.25'N, 127°46.993'W
1022	Delgada Slope	87	1927	40°4.85'N, 125°20.558'W

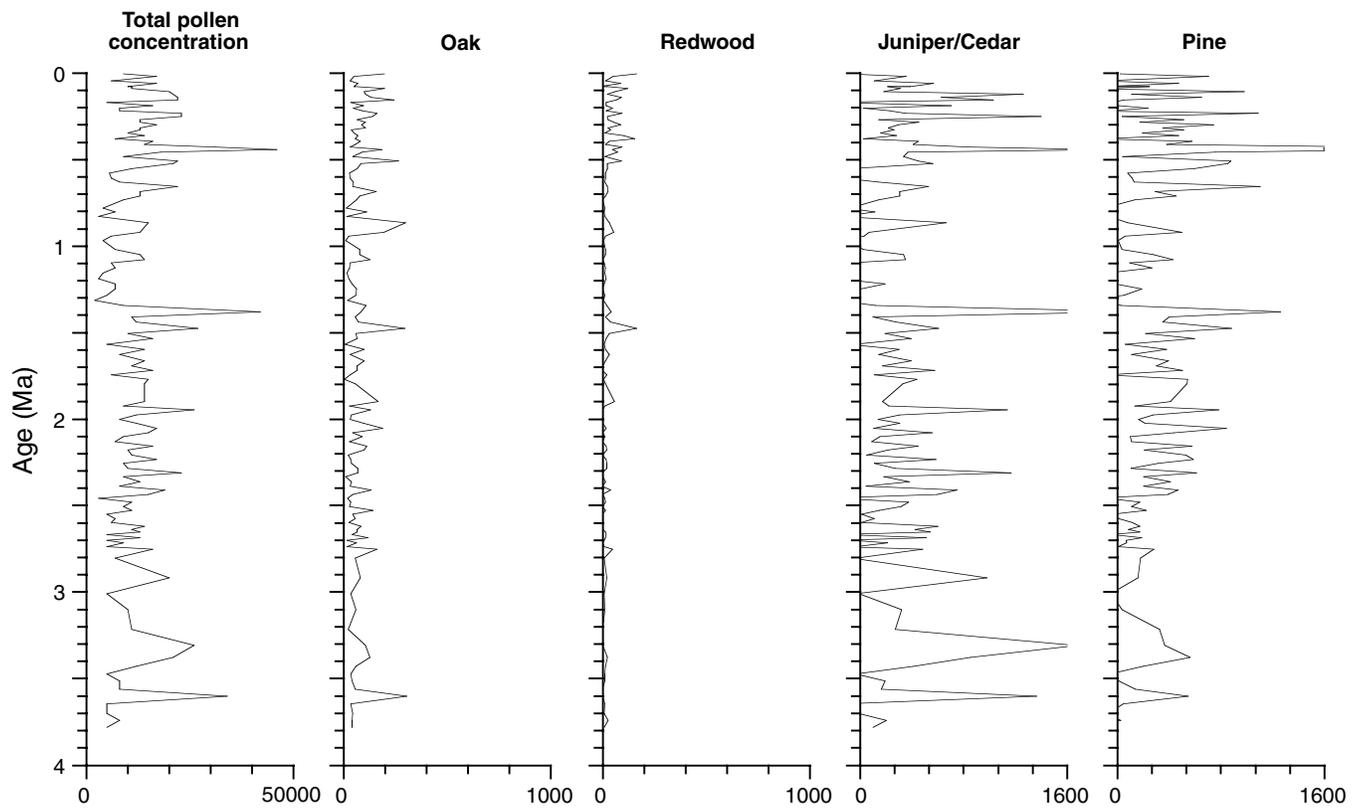


Figure 2. Total pollen concentration (pollen grains/gram dry weight sediment) and pollen concentration of selected pollen types from Hole 1018A cores.

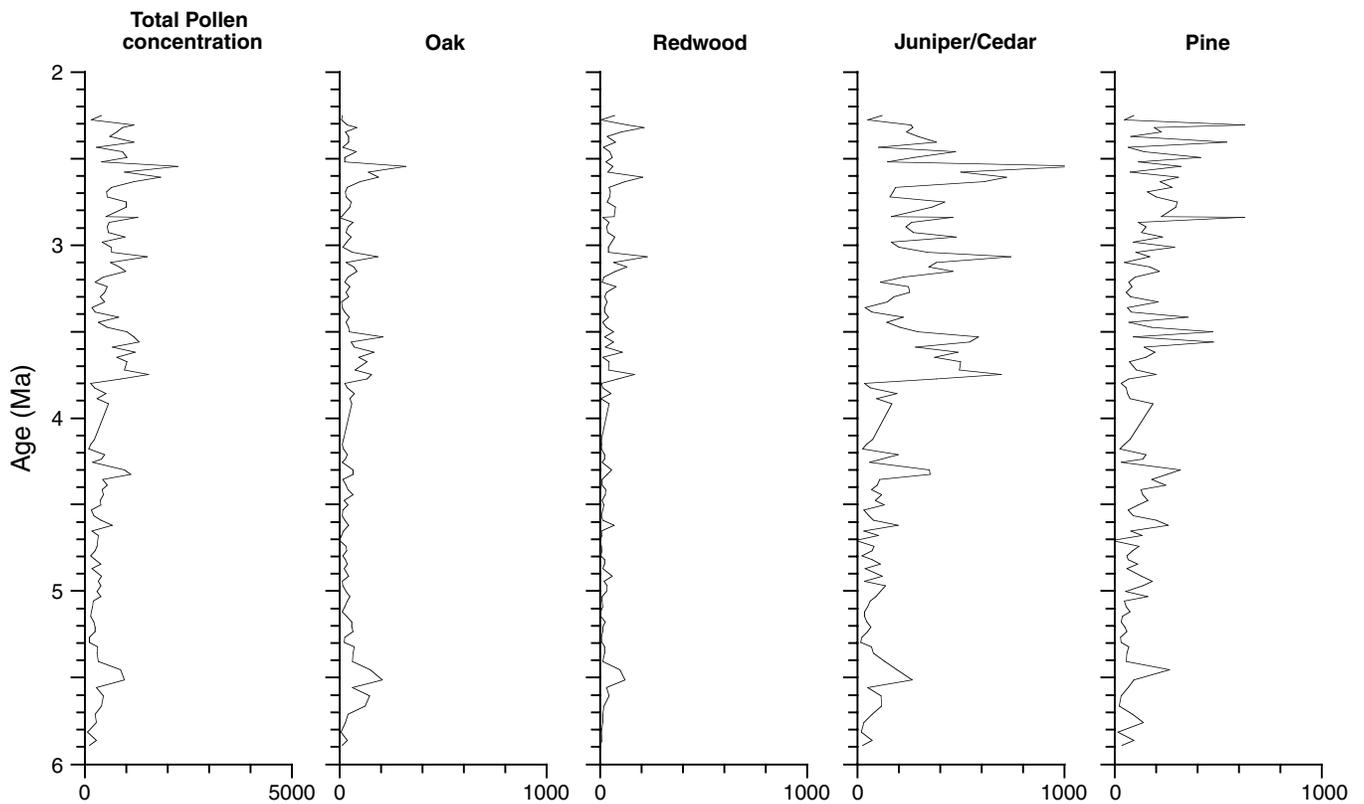


Figure 3. Total pollen concentration (pollen grains/gram dry weight sediment) and pollen concentration of selected pollen types from Hole 1022C cores.

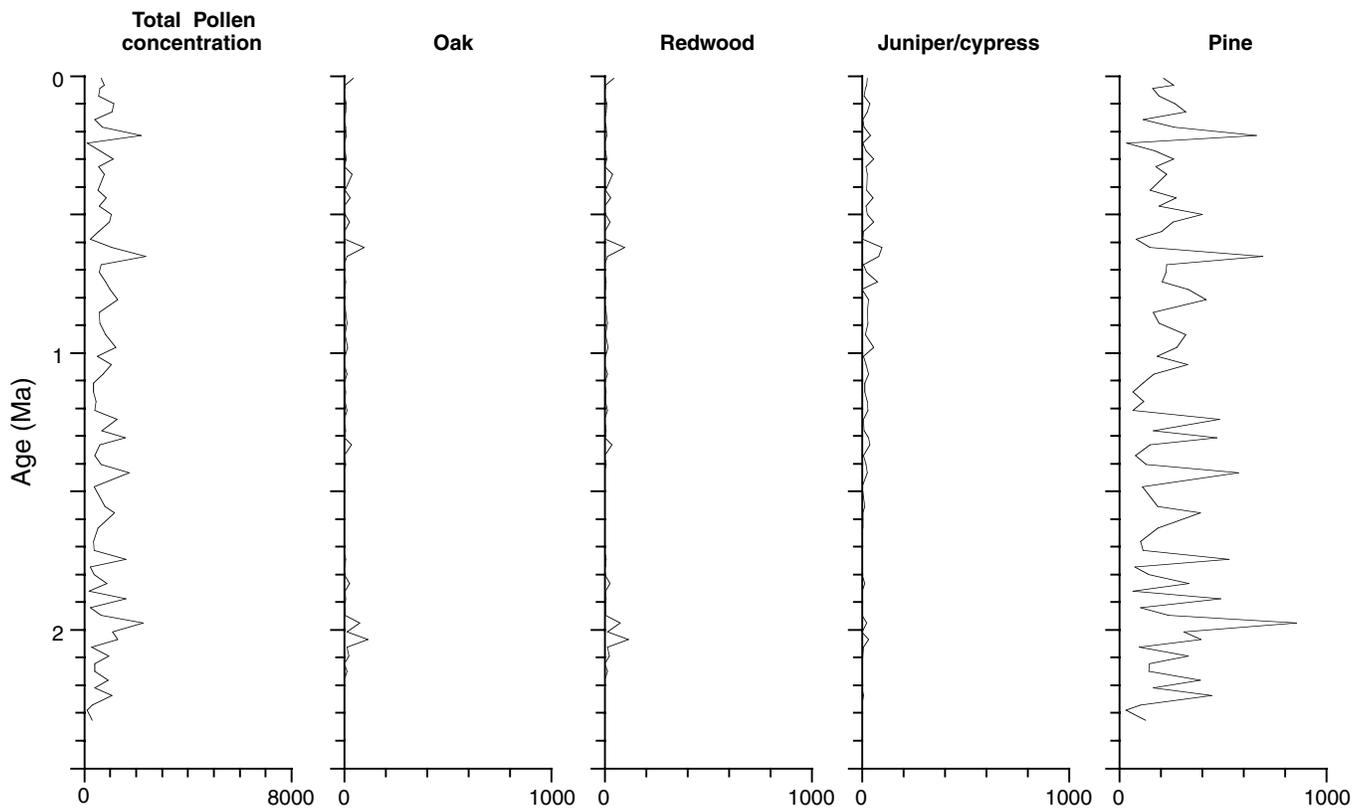


Figure 4. Total pollen concentration (pollen grains/gram dry weight sediment) and pollen concentration of selected pollen types from Hole 1020C cores.

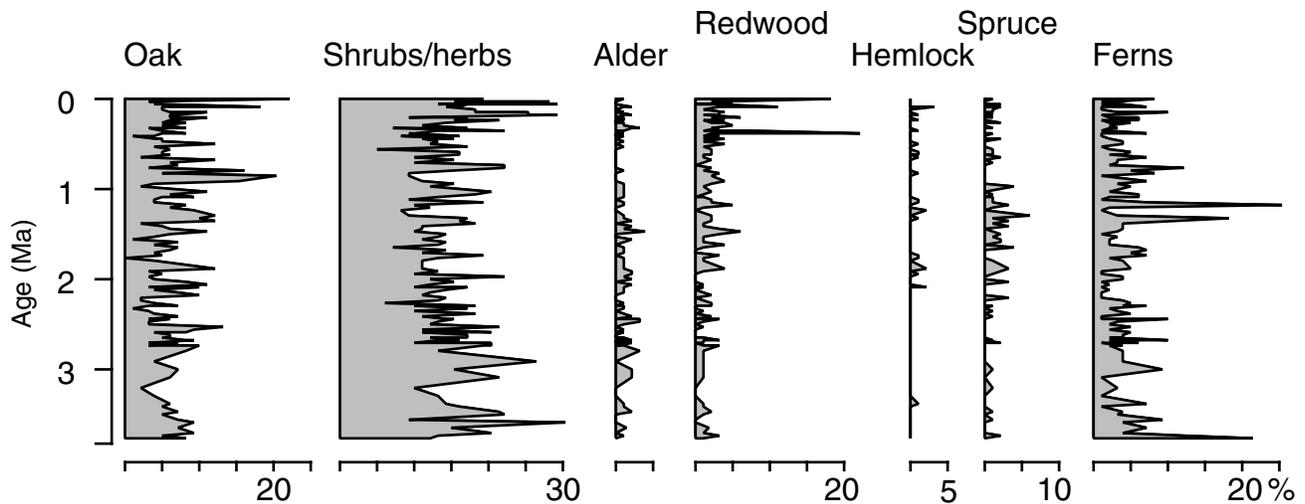


Figure 5. Pollen percentage diagram of selected types from Hole 1018A cores.

high variability in oak, redwood, juniper/cypress, and pine pollen concentration and relative abundance (Figs. 2–7). Oak and redwood peaks presumably correspond to temperature maxima in Central California; in Northern California, hemlock, alder, and redwood maxima are associated with temperature and precipitation maxima (Adam et al., 1981a; Adam and West, 1983; C.J. Heusser, 1985; L. Heusser, 1988; L.E. Heusser, 1998).

A change in vegetation and/or climate in coastal California during the late Pliocene is inferred from the greater and/or more persistent abundance of redwood, hemlock, and spruce after ~2 Ma, possibly reflecting reduced evapotranspiration associated with the general

global cooling trend (Sites 1018 and 1020). This does not seem to be associated with an obvious event in global climate records, such as ice volume. The early Pliocene decrease in oak and redwood and increase in shrubs and herbs between ~5.0 and ~3.8 Ma are interpreted as evidence of cooling and decrease in effective summer precipitation. The subsequent rise in oak suggests that temperatures were comparatively higher during the mid-Pliocene than during the early and late Pliocene. The high-frequency variations in the pollen data imply climate oscillations; however, comparison with late Pliocene climate oscillations in the northern California interior is precluded by the imprecise chronology of both data sets.

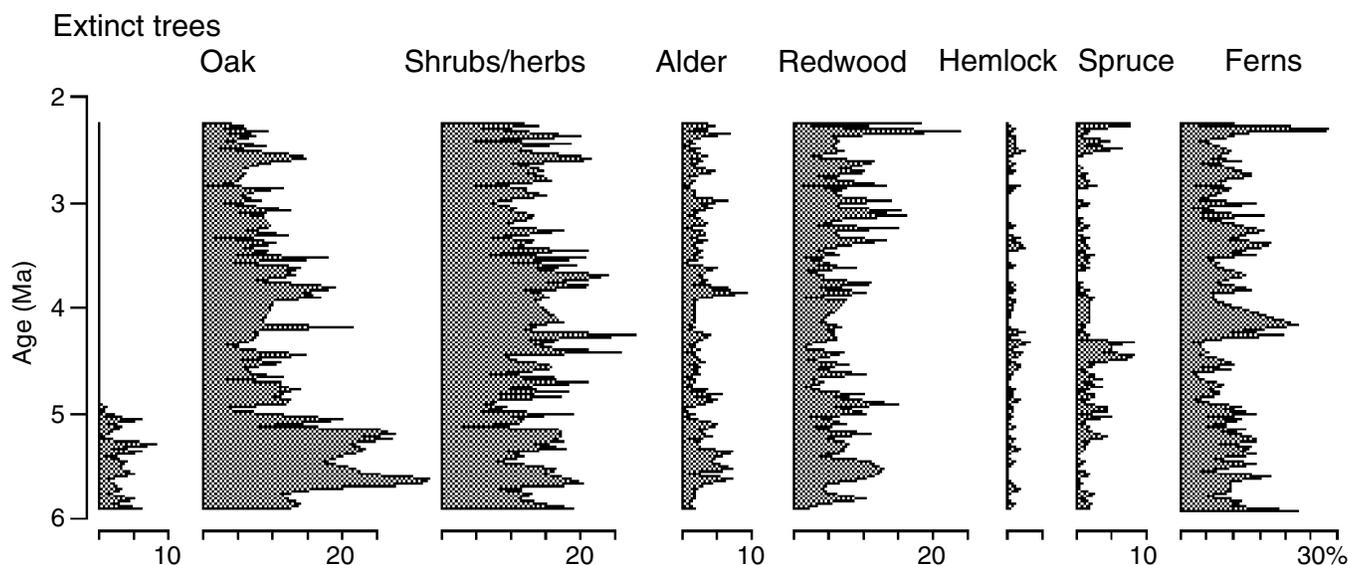


Figure 6. Pollen percentage diagram of selected types from Hole 1022C cores.

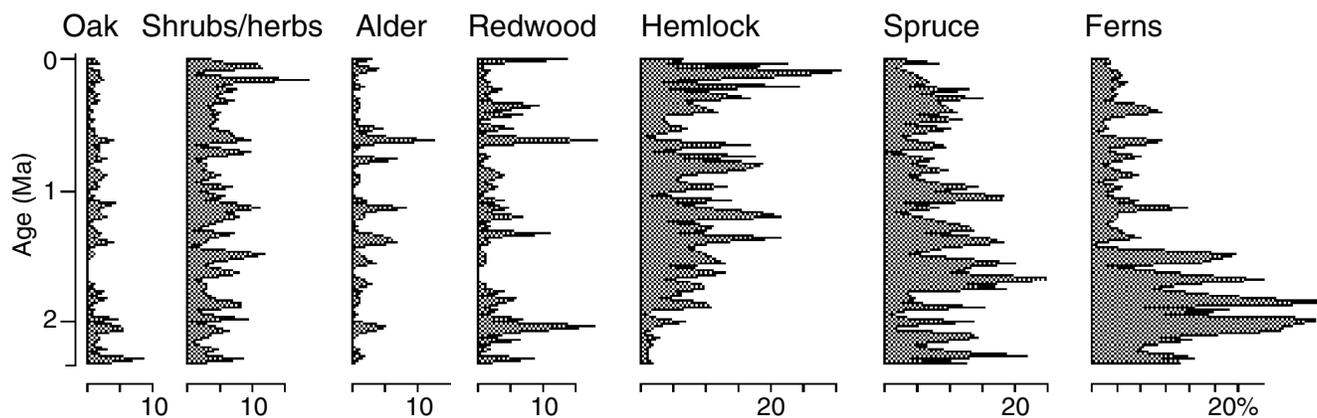


Figure 7. Pollen percentage diagram of selected types from Hole 1020C cores.

Late Miocene pollen assemblages from Hole 1022C that are distinguished by the presence of taxa no longer extant on the northwest coast of North America, accompanied by high percentages of oak (Fig. 6), obviously have no modern analog on the California coast. Climatic parameters of living taxa similar to the Miocene relicts (those of the mesophytic forests of subtropical China, for example) suggest that late Miocene climate on the north coast of California was more equable than that of the Pliocene and Pleistocene (Wang, 1961). Reduced seasonality in precipitation and temperature during the Miocene has also been inferred from the presence of “Arcto-Tertiary” taxa in California and Oregon Miocene floras (Axelrod, 1977; Axelrod and Bailey, 1969; Chaney, 1951; Raven and Axelrod, 1978).

To synthesize the climatic evolution of north coastal California for the last 6 m.y., the ratio of oak pollen percentages to oak + pine pollen percentages for Sites 1018 and 1022 is shown in Figure 8. The relationship between these taxa provides an index of vegetation and associated climate, with higher values indicating warm, equable environments (Adam and West, 1983; Axelrod, 1977). The late Neogene increase of pine in California was ascribed to displacement of mesic Tertiary coastal forests in response to cooling and drying—associated, at least in part, with late Pliocene elevation of California mountain ranges (Raven and Axelrod, 1978). Although precise interpretation of the nature and timing of events in this composite record from Hole 1022C is constrained by the subjective nature of the cli-

mate index, broad sampling intervals, and limited age control, the climate index provides a starting point for comparing terrestrial and oceanic signals from the California margin.

Climates of Northern California reflect broad late Neogene global climate trends such as an overall cooling from a late Miocene climatic optimum (~6–5 Ma), a Pliocene warming (between ~4.0 and ~3.5 Ma), and late Pliocene–Pleistocene high-frequency temperature oscillations. If the age model for Site 1022 is valid, then timing of Pliocene warming in coastal California inferred from pollen data deposited on the continental margin and Northern California (Axelrod, 1944) apparently precedes the mid-Pliocene warming event (~3.15 and ~2.85 Ma) identified in various geologic records elsewhere (Poore and Sloan, 1996). However, the warming event in coastal California may coincide with warming at ~4 Ma in Japan and offshore waters, when relict Tertiary taxa made their final appearance (Heusser and Morley, 1996), and with early Pliocene warming events reported elsewhere (e.g., Ciesielski and Grinstead, 1986; Zubakov and Borzenkova, 1988).

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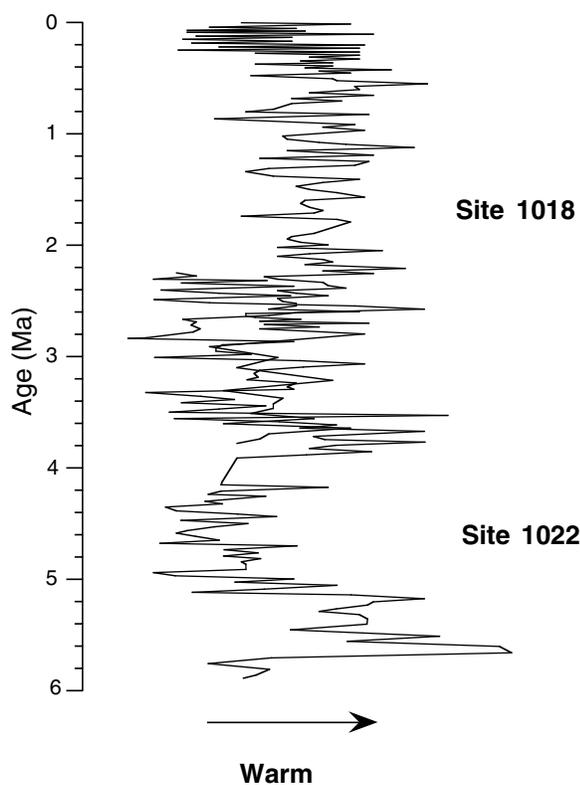


Figure 8. Composite climate index from Sites 1018 and 1022. The ratio of oak/(oak + pine) provides an indication of climate equability. Higher values imply greater warmth and more evenly distributed precipitation. Lower values imply greater seasonal fluctuation in temperature and precipitation.

understanding the development of California vegetation and climate during the late Neogene. Thanks also to J. Morley and the other reviewers of the paper. Funding for this research was provided by JOI/USSAC.

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