DEPARTMENT OF THE INTERIOR
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Palynomorph Distributions in the Rincon Shale (Lower Miocene) of the Tajiguas Landfill Section, Santa Barbara County, California

By

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ABSTRACT

This report describes palynomorph assemblages from the Rincon Shale (lower Miocene) in southern California. The 12 samples examined are from the Tajiguas Landfill section, Gaviota and Tajiguas 7.5-minute quadrangles, Santa Barbara County. Changes in relative frequencies of dinocysts+acritarchs, microforams, gymnosperm pollen, angiosperm pollen, and pollen of the dry-soil indicator *Ephedra* provide some evidence that the distance from shore and presumably the water depth at the site of deposition increased during Rincon time; upwelling may have been more prominent above the site of deposition during the latter half of Rincon time; and onshore rainfall may also have increased. The terrestrial climate was probably summer-dry and possibly slightly warmer than now.

An interesting floristic aspect of the Rincon samples is the presence of Compositae (sunflower family) pollen of the *Mutisia* type and one other pollen species of the family. Several additional Compositae pollen species were present in the region by the end of the early Miocene (Srivastava, 1984).

INTRODUCTION

Neogene strata are widespread in southern California, but very little has been published about the palynology of these rocks (see Previous Palynological Work). This report concerns the palynomorph analysis of twelve samples from the Rincon Shale of the Tajiguas Landfill section, Gaviota and Tajiguas 7.5-minute quadrangles, Santa Barbara County, California (fig. 1). Details about the regional stratigraphic setting of the Rincon Shale, and about sampling of the Tajiguas Landfill section, were provided by Stanley and others (1992). In the landfill pit, the Rincon is conformably underlain by the Vaqueros Sandstone and conformably overlain by the Monterey Shale (Stanley and others, 1992). The biostratigraphy and absolute age of the Rincon in this section were summarized by Stanley and others (1994, p. 675-676), as follows: "The Rincon at the Tajiguas landfill is entirely of early Miocene age.... Samples from 0.38 and 0.84 m above the base of the Rincon yield planktic foraminifers of the lower Miocene N4-N5 (undifferentiated) zones of Bolli and Saunders (1985). Benthic foraminifers indicate that the entire Rincon at this locality is within the Saucesian benthic foraminiferal stage of Kleinpell (1938, 1980). Calcareous nannofossils from the lowest 43 m of the Rincon are poorly preserved but indicative of the lower part of early Miocene zone CN1.... The Rincon/Vaqueros contact can be no older than the Miocene/Oligocene boundary, dated at 23.8 Ma by Cande and Kent (1992). The tuff at the Monterey/Rincon contact probably is about ... 17.79 $\pm$ 0.10 Ma...."

The Rincon Shale is 449 m thick in the landfill section, where it "consists mainly of mudstone with subordinate semi-shale, siliceous shale, and dolomite" (Stanley and others, 1992,

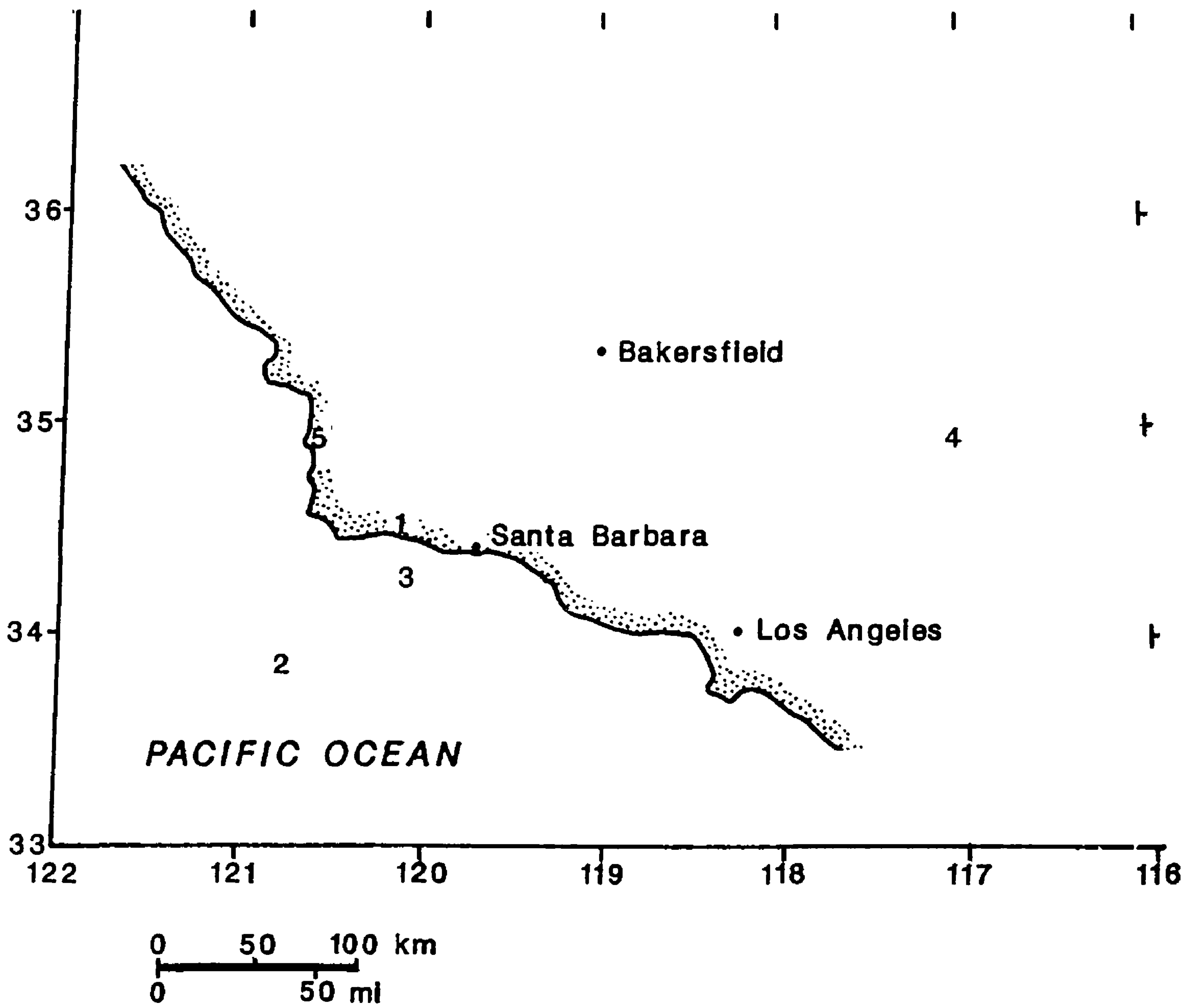

Figure 1. Map showing locations of (1) the Tajiguas Landfill section, (2) Site 467 of the Deep Sea Drilling Project (Ballog and Malloy, 1981), (3) cored upper Holocene sediments in the Santa Barbara Basin (Heusser, 1978), (4) the Barstow Basin (O'Connor, 1982), and (5) Lions Head (Srivastava, 1984).

p. 8). Twelve samples, from 3.45 to 380.07 m above the base of the Rincon in the landfill pit, were chosen for detailed examination. The stratigraphic positions of the samples examined are shown in figure 2. In addition to those shown in figure 2, the following samples processed by the U. S. Geological Survey were barren of palynomorphs, or else the palynomorph preservation was too poor to allow an analysis to be made:

Meters above base of Rincon Shale	Formation
459.53	Monterey
447.34	Rincon
342.45	Rincon
54.93	Rincon
8.62	Rincon

Previous Palynological Work

Only a few studies have been published on upper Tertiary palynomorphs from the southern California region, including those of Ballog and Malloy (1981), O'Connor (1982), and Srivastava (1984), and none of these examined material as old as the Rincon Shale. Ballog and Malloy (1981) examined 134 samples from the offshore Continental Borderland west of Los Angeles; their core section (Site 467 of the Deep Sea Drilling Project; fig. 1) included strata ranging from middle Miocene to Quaternary. In an abstract, O'Connor (1982) listed the main pollen taxa in the Miocene or Pliocene Barstow Formation in its type region (fig. 1). Srivastava (1984) studied palynomorphs from five samples of the Monterey Formation at Lions Head, northwesternmost Santa Barbara County (fig. 1). This part of the Monterey Formation is dated at 15-16 Ma, latest early Miocene (Srivastava, 1984), and therefore it appears to be slightly younger than the lower part of the Monterey that overlies the Rincon Shale in the Tajiguas Landfill section. Srivastava (1984) listed 21 taxa of spores and pollen grains and illustrated many of them with scanning electron micrographs. Many of these taxa were also found in the Rincon Shale samples.

D. R. Vork of Unocal Corporation made palynomorph analyses of an unspecified number of samples from the Rincon Shale in the lower part of the Tajiguas Landfill section (Stanley and others, 1994), but results of his analyses have not been published.

Several studies have been made of modern and Holocene palynomorphs from offshore Southern Californa, and these are discussed later in the paper. I wish to point out here that Vork (1984) used a 20 µm sieve to remove unwanted small bits of debris from his palynomorph residues from modern sediments of the Southern California continental borderland; however, many angiosperm pollen grains are smaller than 20 µm in smallest dimension. In their study of Holocene palynomorphs from marine basins off Southern California, Arends and Damassa (1980) divided specimens in their sample residues into those larger and smaller than 20 µm and observed a disproportionate amount of angiosperm pollen in the fraction smaller than 20 µm. They noted that their palynomorph counts, based only on the >20 µm fraction, were biased against the true representation of angiosperm pollen grains. Therefore, the ratios of dinocysts to spores+pollen presented by Arends and Damassa (1980) and Vork (1984) are not reliable, although it is possible that the geographic trends of the ratios observed by these authors may be similar to what the trends of the true ratios would have been.

METHODS

Processing Methods

Seven samples from 125.47 to 380.07 m above the base of the Rincon Shale in the Tajiguas Landfill section were processed for palynomorphs by the U.S. Geological Survey (USGS), Reston, Va., using the following treatments: (1) HCl to remove calcium and carbonate ions, (2) HF to remove silicates, (3) high intensity bursts of ultrasonic energy using a microtip inserted into the test tube, for a total of 30 seconds (Sheehan, 1992), (4) five short-term centrifugations in water containing a detergent, to float off fine particles (the float is later sieved to save any palynomorphs that may have stayed in the supernatant), (5) 2.1 s.g. heavy liquid, and (6) sieving the heavy liquid float using an 8 µm nylon sieve. The residue was mounted on slides with glycerine jelly.

Five samples, from 3.45 to 78.88 m above the base of the Rincon, were examined from among those processed for palynomorphs by Unocal Corporation, Houston, Tex. The Unocal and USGS processing methods were both designed to remove as much amorphous organic material (fecal pellets and other cloudy masses) as possible so that enough palynomophs could be found to make the analyses. The Unocal laboratory used HNO_3 oxidation to remove the amorphous organic material (Ballog and Malloy, 1981), whereas the USGS laboratory used an ultrasonic processor to disaggregate the amorphous organic material so the fragments could be washed away through a sieve. Visually, there was no obvious difference in palynomorph preservation between the residues that had ultrasonic treatment (USGS processing) as opposed to those that did not (Unocal processing). For example, in the residues that had undergone ultrasonic treatment, most bisaccate gymnosperm grains were still intact (the sacci had not been broken off), indicating that the ultrasonic treatment was not severe enough to destroy pollen grains. However, many microforams had been broken into fragments consisting of one to several chambers. For these broken specimens, the total number of chambers was counted and then divided by 7 to arrive at an estimate of the number of whole specimens.

Analytical Methods

Counts included all palynomorphs observed until at least 100 spores and pollen grains had been recorded; the same minimum number was counted by Heusser and Balsam (1977) in their study of palynomorphs from sediment surface samples offshore western North America. In contrast, in their study of middle Miocene to Quaternary palynomorphs from the Continental Borderland west of Los Angeles, Ballog and Malloy (1981) completed their counts when at least 100 total (marine + terrestrial) palynomorphs had been recorded. My counts are small, but I believe they are adequate because only a few basic categories were being recorded (fig. 2); therefore, reasonable estimates of the relative frequencies of these categories could be determined using 100-specimen counts.

Most spore and pollen taxa occurred in very low relative frequencies (table 1). Because of the small counts, distributions of sparsely represented spore and pollen taxa (3% or less of total spores+pollen) are presented in the form of presence-absence data.

PALYNOLOGICAL ANALYSES

Analyses of the Rincon Shale Samples

Two kinds of data are presented here. Figure 2 shows relative frequencies of seven categories of palynomorphs -- dinocysts (cysts of dinoflagellates) and acritarchs (remains of unknown organisms, mainly marine); microforams (acid-resistant chitinous shell linings of certain foraminifers, mainly planispiral and trochospiral types); tasmanitids (marine microplankton, planktonic green algae at least in part); scolecodonts (chitinous jaw apparatuses of marine annelid worms); pteridophyte (fern, club moss, spike moss) spores; gymnosperm pollen; and angiosperm pollen. Acritarchs are only a very small proportion of the category dinocysts+acritarchs. Figure 2 also shows relative abundance measures for two types of pine pollen. Table 1 presents relative frequency and presence-absence data for the spore and pollen taxa.

Dinocysts and acritarchs have distinctly higher relative frequencies in the lower half of the Rincon Shale than in the upper half (fig. 2). Previous studies show that the absolute frequency of dinocysts in marine sediments (number of specimens per gram of dried sediment) may be related to the productivity of motile dinoflagellates in the upper part of the water column, the environmental stability there (dinoflagellates are thought to form cysts partly as a response to seasonally unfavorable features of the environment), and the rate of sedimentation (Williams, 1971). Relatively few species of dinoflagellates produce preservable cysts (Arends and Damassa, 1980), but in modern marine sediments off Southern California, the absolute frequency of dinocysts is for the most part roughly correlative with the abundance of motile dinoflagellates in the water (Vork,

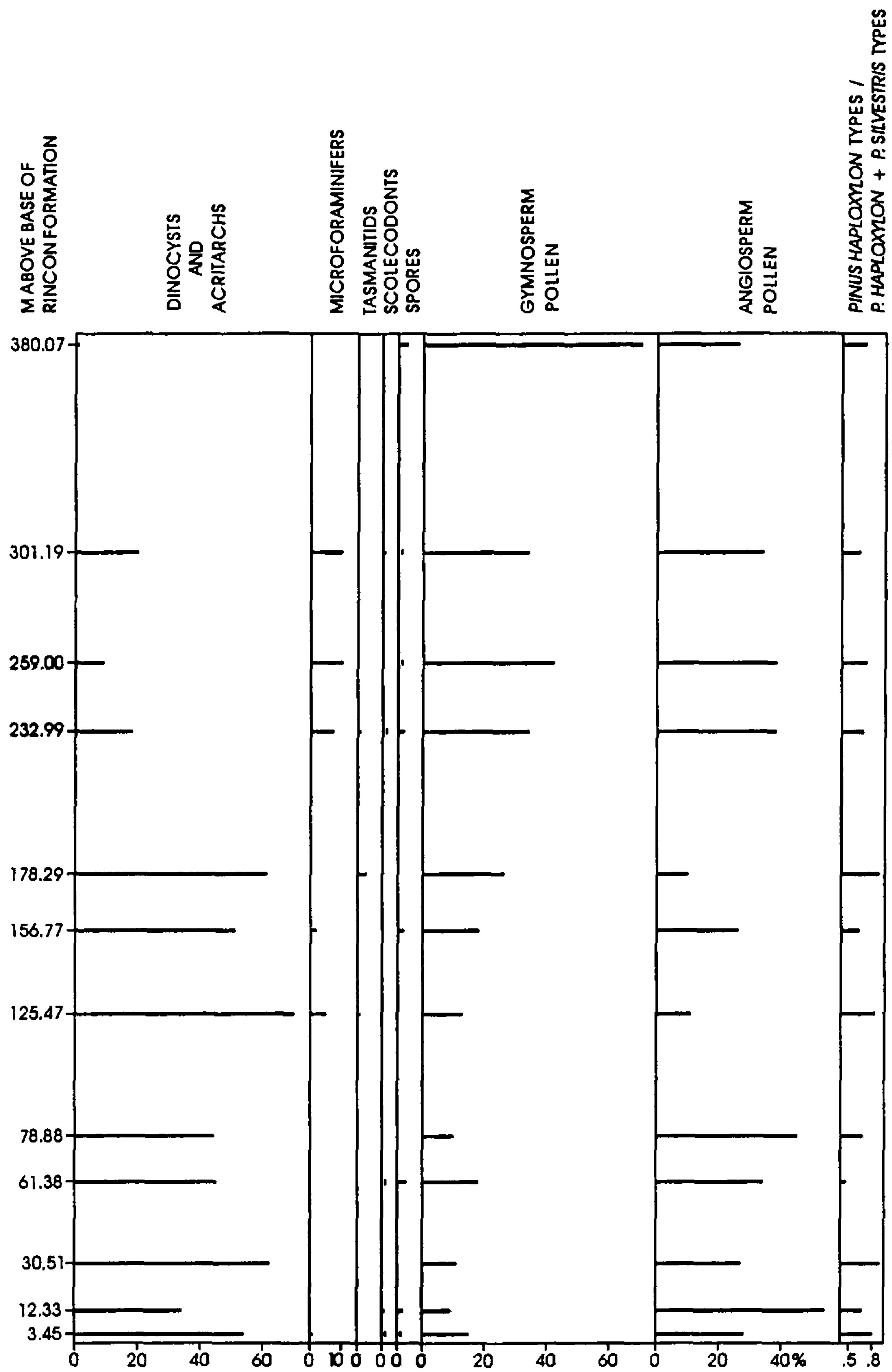

Figure 2. Relative frequencies of palynomorph groups in twelve samples from the Rincon Shale from the Tajiguas Landfill section. Relative frequencies less than 1% are shown by a small vertical bar.

Table 1. Distributions of spore and pollen taxa in 12 samples from the Rincon Shale. Numbers are percentages relative to total spores+pollen, to the nearest whole percent; percentages of 3% or less are shown by X. P, probable occurrence; ?, possible occurrence. Spores and pollen grains were too scarce to count in the sample from 125.47 m.

	Meters above base of Rincon Shale											
	3.45	12.33	30.51	61.38	78.88	125.47	156.77	178.29	232.99	259.00	301.19	380.07
Pteridophytes												
Psilate fern spores	X	X		X			X	P	X			X
Ornamented fern spores								X	X	X	X	
Lycopodium												X
Selaginella	X	X		4	X		X	X	X		X	
Gymnosperms												
Ephedra	9	4	6	X	X	X	X	X	X	X	X	X
Pinus	14	5	15	21	10	X	41	61	42	46	49	68
Podocarpaceae	X			X				X	X	X	X	X
Taxodiaceae-Cupressaceae-Taxaceae	6	X	7	8	6	X	6	9	4	6		X
Angiosperms												
Alnus					X							
Anacardiaceae types		X	4	?								
Bombacacidites and *Sandiegopollis*	X	X	6	X	X		X	X	X	X	X	X
Bursera types			X							X		X
Carya	X		?					X	X		X	5
Castanea-Castanopsis-Lithocarpus	?	X	X	X			X		X	X		
Chenopodiaceae-Amaranthaceae	X	5	X	X	X				X	X	X	X
Compositae, *Mutisia* type		X		X			X	X	X	X	X	
Compositae, short-spined									X			
Cupuliferoidaepollenites							X		X	X	X	
Elaeagnaceae	X	X	X							X		
Ericaceae		?										
Ilex					X							
Juglans		X	X									
Momipites coryloides												X
Onagraceae		X		?	X				X	X		X
Pterocarya			X				X					
Quercus	21	12	18	21	30		X	9	9	12	11	10
Reticulate monosulcate types				X					X		X	
Salix types	6	5	X	X	X							
Ulmus/Zelkova	X											X
Miscellaneous angiosperms	30	51	30	33	42	X	38	13	31	27	29	6

1984). In some cases the absolute and relative frequencies of dinocysts increase in areas of increased nutrient supply due to upwelling (Davey and Rogers, 1975; Melia, 1984). However, plankton tows have demonstrated that far fewer dinoflagellates live offshore Southern California than nearshore (Allen, 1941); therefore, offshore upwelling in this region does not produce standing crops of dinoflagellates nearly as large as those sometimes found inshore. Upper Holocene palynomorph assemblages from near the center of the Santa Barbara Basin (fig. 1) also contained very low absolute frequencies of dinocysts even though there is "upwelling [of] colder, nutrient-rich water above Santa Barbara Basin, particularly in spring and summer" (Heusser, 1978, p. 673) (however, these low absolute frequencies also resulted in part from the fact that the Santa Barbara Basin receives very high rates of detrital sedimentation, according to Schwalbach, 1982, cited by Vork, 1984). The Southern California pattern is in accord with the model proposed by Margalef (1978, cited by Powell and others, 1992) in which (at least in the offshore) diatoms dominate the phytoplankton in areas of turbulent, nutrient-rich water whereas dinoflagellates dominate in areas of non-turbulent, nutrient-poor water.

The ratio of marine dinocysts to terrestrial spores+pollen commonly but not always increases offshore (Davey and Rogers, 1975). Oceanic areas near river mouths may contain high *absolute* frequencies of dinocysts due to nutrient input from rivers (Heusser and Balsam, 1977), but the *relative* frequencies of dinocysts off river mouths may decrease because of the large input of terrigenous material, including spores and pollen, from the river water (Hart and others, 1994). The ratio of dinocysts to spores+pollen in offshore sediments is also sensitive to the amount of onshore precipitation because increased rainfall leads to greater river-borne delivery of terrestrial palynomorphs to the ocean (Versteegh, 1994). In areas of dry terrestrial climate, where airborne spores and pollen grains increase in importance relative to stream-transported grains, little pollen may be delivered to the sea if prevailing winds are onshore (Heusser and Balsam, 1977).

Vork (1984) found that in modern sediments of the Southern California continental borderland, distance from the coast or from river mouths was less important than the seafloor topography in determining absolute abundances of spores and pollen grains; high absolute frequencies of spores and pollen grains are in samples from lower slopes and especially from basin floors. Therefore, in these modern sediments the ratio of marine to terrestrial palynomorphs did not exhibit a clear pattern with respect to the coast. However, Arends and Damassa (1980), who worked in the same region as Vork but examined samples only from marine basins, found that the ratio of dinocysts+acritarchs to spores+pollen decreased offshore, apparently because dinoflagellates have higher absolute abundances inshore than offshore even in regions of upwelling.

Microforams are not very abundant in most samples from the Rincon Shale but increase to 7-10% of total palynomorphs in three samples from the upper half of the formation. Microforams are remains of benthic and planktic foraminifers (Powell and others, 1992) though apparently they represent mainly benthic species. Therefore, they form mainly autochthonous assemblages in areas of relatively flat seafloor (Traverse and Ginsburg, 1966), but in active margin settings they are frequently transported downslope by means of submarine mass-gravity flows. Decreasing absolute and relative frequencies of microforams may result from microbial degradation of the tests below the sediment-water interface (Powell and others, 1990), but no corrosion of the microforam test walls was observed in this study of the Rincon Shale. Microforams are relatively sparse in low-salinity coastal environments (Muller, 1959) but seem to have maximum absolute frequencies not far offshore, or in areas of upwelling, where total foraminiferal productivities are highest (Cross and others, 1966; Melia, 1984; Powell and others, 1990). In light of the lower dinocyst:spore+pollen ratios in the upper half of the Rincon Shale, the increased relative frequencies of microforams in this part of the section may indicate increased upwelling in the latter part of Rincon time.

Tasmanitids and scolecodonts were only sparsely represented throughout the Rincon section.

It has not been definitely established from sedimentary and faunal evidence whether relative sea level remained more or less constant within the bathyal zone during most of Rincon time (Finger, 1983; Pinkerton and Rigsby, 1991) or whether relative sea level continued to rise during deposition of the Rincon after an initial very rapid rise at about the beginning of the Miocene (Ingle, 1980). Based on decreasing dinocyst:spore+pollen ratios upsection in the Rincon, it seems more likely that distance from shore and presumably water depth increased during later Rincon time based on patterns in Holocene samples observed by Arends and Damassa (1980). It is also possible that rainfall increased during the latter part of Rincon time, leading to increased delivery of terrestrial pollen grains to the ocean.

Among the terrestrial palynomorphs (fig. 2; table 1), spores were found only in low relative frequencies throughout the Rincon section, and very few taxa of spores were present. The same is true in middle Miocene to Quaternary palynomorph assemblages of Deep Sea Drilling Project (DSDP) Site 467 (Ballog and Malloy, 1981), where spores were mainly about 1-3% and occasionally about 5% of total palynomorphs. Spores were also sparse in Holocene palynomorph assemblages from several marine basins off Southern California (Arends and Damassa, 1980). Spores are not transported very well offshore, probably because they are larger and have a thicker wall than many angiosperm pollen grains (Muller, 1959; Heusser and Balsam, 1977; Habib and others, 1994). In Holocene seafloor samples off the West Coast of North America, spores reached high relative frequences mainly off northern California and to the north, where the terrestrial climate is moist (Heusser and Balsam, 1977); in fossil material, increases in relative frequencies of spores have been interpreted to result from wetter terrestrial climates that favor the growth of ferns and other pteridophytes (Sladen and Batten, 1984). From this viewpoint, the low relative frequency of spores throughout the Rincon Shale does not support the suggestion made above that the observed increase in the spore+pollen:dinocyst ratio in the upper half of the Rincon Shale may have been due to an increase in terrestrial rainfall.

In modern sediments of the Southern California continental borderland, there appears to be little systematic relationship between the distance from shore and the relative frequencies of various pollen taxa (mainly measured by the ratio of pines:oaks) (Vork, 1984). However, as noted in the section of this paper on Previous Palynological Work, Vork's use of a relatively coarse sieve during sample processing makes this conclusion unreliable.

Gymnosperm and angiosperm pollen grains have similar relative frequencies in some samples particularly from the middle and upper parts of the Rincon Shale (fig. 2), but angiosperms were more abundant in the lower part of the formation, and gymnosperm pollen was much more abundant in the uppermost sample. Most gymnosperm pollen in the Rincon samples is from pines (table 1). Pine pollen floats remarkably well in water, much better than angiosperm pollen, and is easily carried offshore in the ocean (Hopkins, 1950; Cross and others, 1966; Traverse and Ginsburg, 1966); thus, the ratio of pine to angiosperm pollen commonly increases offshore (Heusser and Balsam, 1977; Arends and Damassa, 1980). Therefore, the increase in this ratio upward in the Rincon Shale seems to suggest increasing distance of the site of deposition from shore and presumably increasing water depth.

Pinus haploxylon types are nearly always more abundant than *P. silvestris* types (more than 0.5 in the farthest right column of fig. 2); this ratio between *P. haploxylon* and *P. silvestris* types is typical of the Tertiary in North America, whereas in the modern pollen rain, *P. silvestris* types are more abundant. Podocarpaceae, commonly represented by pollen in the Late Cretaceous and Tertiary of North America, became extinct in the United States sometime during the late Tertiary but remained in Mexico. Pollen grains of this family are rather rare in the present samples.

Ephedra (Mormon tea) pollen includes representatives of both the *E. distachya* type, having zigzag colpi with side branches, and the *E. breana*/*E. trifurca* type, which lacks colpi (see Steeves and Barghoorn, 1959). *Ephedra* grows mainly in regions of edaphic dryness. The higher ratio of *Ephedra* to *Pinus* pollen in the lowest three samples may indicate a drier terrestrial climate early in Rincon time than later. As noted above, increasing onshore rainfall in later Rincon time would explain at least in part the higher pollen:dinocyst ratio in the upper part of the Rincon. *Ephedra* pollen also had higher relative frequencies in the lowest three samples from the lower Miocene Rincon Shale than in the middle Miocene to Quaternary sediments of DSDP Site 467 (Ballog and Malloy, 1981), where it never seemed to be more than about 1-2% of total pollen.

Pollen grains of Taxodiaceae-Cupressaceae-Taxaceae (generally referred to as TCT; cypress, cedar, juniper) are common in most samples. TCT pollen never reaches 10% in the samples from the Rincon Shale, but it is 20-50% of total pollen in many samples from the middle Miocene to Quaternary of DSDP Site 467 (Ballog and Malloy, 1981).

Table 1 lists angiosperm taxa that could be identified more or less to family level and in some cases to modern or fossil genus or even to fossil species level. Comments on some of these taxa are given in the Taxonomic Notes section of the paper. The abundance of *Quercus* (oak) pollen is noteworthy, 9-30% of total spores+pollen in most samples. Similar relative frequencies of *Quercus* were found in the middle and upper Miocene of DSDP Site 467, but the relative frequencies decreased in the Pliocene and Quaternary (Ballog and Malloy, 1981). *Carya* (hickory, pecan) pollen is rare in the Rincon samples, whereas in the middle Miocene to Quaternary of DSDP Site 467, *Carya* was about 3-15% in some samples in the middle Miocene but became distinctly less abundant in the upper Miocene and higher in the section. In upper lower Miocene samples from the Monterey Formation (Srivastava, 1984), *Carya* apparently was generally more abundant than *Quercus*. *Castanea/Castanopsis/Lithocarpus* (chestnut, chinquapin) pollen is rather rare in the Rincon samples, but it reaches about 5% of total pollen in some samples from the middle and upper Miocene of DSDP Site 467. Chenopodiaceae/Amaranthaceae pollen (e.g., goosefoot, pigweed) is present in low relative frequencies in the Rincon samples and in the middle Miocene of DSDP Site 467, but in the DSDP section it is 5-10% of total pollen in many samples from the uppermost Miocene to the Quaternary.

The generally subtropical to tropical *Bombacacidites-Sandiegopollis* group was consistently present in the samples from the Rincon Shale and in upper lower Miocene samples from the Monterey Formation (Srivastava, 1984), but it was much more sporadic in the middle Miocene to Quaternary of DSDP Site 467 and never reached more than 1-2% of total pollen (Ballog and Malloy, 1981). In the Rincon samples, this group represents the families Bombacaceae and Sterculiaceae(?). Bombacaceae is a subtropical to tropical family typical of seasonally dry forests or savanna woodland; the family is extinct in the United States, but four genera still live in Mexico (Croizat, 1952). Some specimens in the Rincon material belong to the fossil pollen genus *Sandiegopollis*, with affinities to *Fremontodendron* (California, Mexico; slippery elm) and *Chiranthodendron* (Mexico); both genera are tentatively assigned to Sterculiaceae or possibly Bombacaceae. Another mainly tropical family is the Burseraceae, which is presently represented by one genus (*Bursera*, elephant-tree) and several species in southern California, southern Arizona, Mexico, and southern Florida.

The family Elaeagnaceae is represented by several genera in North America, but the specimens seen in the Rincon material presumably belong to *Shepherdia*, one species of which (*S. argentea* Nutt., buffalo-berry) presently ranges from the Great Plains westward to the Mojave Desert. Trees producing *Momipites coryloides* type pollen are extinct in the United States but still live in Mexico and Central America (genera *Oreomunnea* and *Alfaroa*, family Juglandaceae, the walnut family). This is the first record of *Momipites* that I know of in the Miocene of California. Similar pollen grains are common in the Miocene of Massachusetts and the Middle Atlantic States (Frederiksen, 1984). *Pterocarya* also belongs to the walnut family, and, like *Momipites*, this pollen type was also widespread in the Northern Hemisphere during the Tertiary, but this genus is now confined to the region from southeastern Europe to Japan. *Pterocarya* pollen is rare in the present material; the genus died out in North America during or at the end of the Pliocene. Onagraceae (evening-primrose family) contains a number of genera in the United States; in the Eocene, pollen of this family was far more abundant and diverse in southern California than in the East (Frederiksen, 1983, 1988).

Floristically, one of the most interesting aspects of the Rincon pollen assemblages was the presence of Compositae (sunflower family) pollen of two types. By far the most abundant of these taxa is the *Mutisia* type of Elsik and Tomb (1989), which, according to these authors, has its biostratigraphic range base in the uppermost Oligocene on the Gulf Coast. A second taxon was represented by one specimen of short-spined Compositae of *Ambrosia* (ragweed) type. Elsik and Tomb (1989, p. 281) stated that "*Aster/Helianthus* and fenestrate types [range upward] from the lower to middle Miocene," and several of these were illustrated by Srivastava (1984) from samples considered to be from the uppermost part of the lower Miocene. Unfortunately, because Srivastava's (1984) photographs are scanning electron micrographs, the critical exine stratification cannot be seen in his specimens. However, it seems clear that by the end of the early Miocene several more Compositae taxa were present in southern California than at the beginning of the Miocene.

Comparison with Upper Holocene Assemblages

Heusser (1978) provided palynomorph analyses of core samples from near the center of the Santa Barbara Basin (fig. 1). Table 2 shows mean values for palynomorph group relative frequencies in the Rincon Shale samples and from the highest subzone of the Santa Barbara Basin core; this subzone is stated to represent the time interval 2.263 ka to present. Distinct differences are present between the two sets of samples, mainly because the upper Holocene assemblages are dominated by angiosperm pollen, whereas dinocysts+acritarchs, gymnosperm pollen, and angiosperm pollen all have large relative frequencies in the lower Miocene assemblages. As pointed out previously, dinocysts are sparse in

Table 2. Comparison of mean palynomorph percent abundances in the Rincon Shale with those in upper Holocene sediments of the Santa Barbara Basin (Heusser, 1978).

	Rincon Shale, lower Miocene	Upper Holocene (Heusser, 1978)
Dinocysts and acritarchs	40	2
Microforams	3	4
Spores	1	3
Gymnosperm pollen	25	7
Angiosperm pollen	31	84

the upper Holocene basin sediments. The mean ratio of gymnosperm to angiosperm pollen grains is much higher in the lower Miocene samples than in those from the upper Holocene. Most of the gymnosperm pollen came from pines, which have probably grown mainly in mountains in southern California throughout the Tertiary. Although the Peninsular Ranges existed in the early Miocene, the Coast Ranges were still low (Oakeshott, 1978); therefore, there was considerably less total relief in the region than now. However, the low gymnosperm:angiosperm pollen ratio in the late Holocene is mainly due to the very high pollen productivities especially of Compositae, Chenopodiaceae-Amaranthaceae, grasses, and oaks (*Quercus*) (Heusser, 1978); composites and cheno-ams were probably scarce in the regional flora in the early Miocene (table 1), and no grass pollen at all was seen in the Rincon samples. Therefore, *Quercus* was the only heavy pollen producer among the angiosperms in the early Miocene.

Climatic Analysis

Most of the spore and pollen types found in the Rincon Shale represent taxa still living in California. The exceptions are Bombacaceae, Podocarpaceae, *Momipites coryloides*, and *Pterocarya*. The latter three pollen types had very broad climatic ranges in the Tertiary, but Bombacaceae seems always to have been predominantly subtropical to tropical. The presence of pollen of this family in the Rincon material may indicate a slightly warmer climate than now. *Ephedra*, Bombacaceae, and perhaps *Fremontodendron-Chiranthodendron* suggest at least seasonal dryness. This agrees with plant megafossil evidence that summer-dry climates in California originated early in the Miocene, and southern California then had a vegetation probably of savanna woodland or thorn scrub (Raven and Axelrod, 1978; Wolfe, 1985).

CONCLUSIONS

Dinocysts, gymnosperm pollen, and angiosperm pollen were all abundant in the samples from the Rincon Shale. The higher ratio of pollen to dinocysts in the upper half of the Rincon could result from smaller absolute abundances of dinocysts and (or) from higher absolute abundances of pollen (disregarding sedimentation rates, which would apply to both kinds of fossils). Smaller absolute abundances of dinocysts could be due to stronger upwelling and (or) greater distance from shore (and presumably deeper water) late in Rincon time. Increases in absolute abundances of pollen could result from increased transport of these grains to the site of deposition, probably because of increased rainfall over the western part of the continent; this hypothesis is supported by the smaller relative frequency of dry-soil indicator *Ephedra* pollen in the upper part of the Rincon Shale than in the lower part. A higher gymnosperm:angiosperm pollen ratio in the uppermost sample from the Rincon as opposed to the lower ratios in the lower part of the formation also suggest increased distance from shore in late Rincon time. Increased relative frequencies of microforams in the upper part of the Rincon may indicate increased upwelling leading to higher foram productivity and perhaps lower dinoflagellate standing crops.

Most pollen taxa identified in the Rincon Shale assemblages are still present in southern California; several taxa are extinct in that region but still live in Mexico. The terrestrial climate was probably summer-dry and possibly slightly warmer than now.

TAXONOMIC NOTES

The following notes refer to some of the taxa listed in table 1.

Anacardiaceae types are prolate retistriate tricolporate grains. An affinity with the family Anacardiaceae is probable at least in part for these specimens.

Reticulate monosulcate types are pollen grains that represent palms and other monocotyledonous families.

Salix types are prolate, more or less finely reticulate, tricolpate grains that probably represent *Salix* (willow) at least in part.

Miscellaneous angiosperms include poorly preserved specimens that could be identified as angiospermous but could not be further categorized, as well as a wide variety of pollen grains that were well preserved but could not be identified even to family. Many of these specimens were reticulate and tricolporate.

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