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A LATE PLEISTOCENE AND HOLOCENE POLLEN RECORD  
FROM LAGUNA DE LAS TRANCAS,  
NORTHERN COASTAL SANTA CRUZ COUNTY, CALIFORNIA

by

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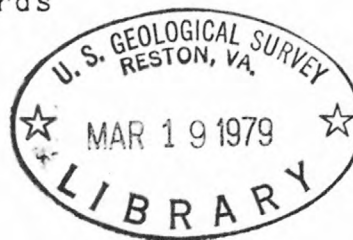
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Abstract.-- A 2.1-m core from Laguna de las Trancas, a marsh atop a landslide in northern Santa Cruz County, Calif., has yielded a pollen record for the period between about 30,000 B.P. and roughly 5,000 B.P. Three pollen zones are recognized; the earliest is characterized by high frequencies of pine pollen and is correlated with a mid-Wisconsinan interstade of the mid-continent. The middle zone contains high frequencies of both pine and fir (Abies, probably A. grandis) pollen and is correlated with the last full glacial interval (upper Wisconsinan). The upper zone is dominated by redwood (Sequoia) pollen and represents latest Pleistocene to middle Holocene. The past few thousand years are not represented in the core. The pollen evidence indicates that during the full glacial period the mean annual temperature at the site was about 2°C to 3°C lower than it is today. We attribute this small difference to the stabilizing effect of marine upwelling on the temperature regime in the immediate vicinity of the coast. Precipitation may have been about 20 percent higher as a result of longer winter wet seasons.

The Quaternary vegetation history of coastal California is not well understood. Several fossil floras have been published (Chaney and Mason, 1930, 1933; Mason, 1934; Warter, 1976; see Johnson, 1977 for a review), but the detailed history of vegetation change is not yet known. In large part, this uncertainty reflects the limitations of the pollen record. Only four pollen diagrams have been published (Heusser, 1960; Adam, 1975); none covers more than the past 8,000 years. In this paper, we report on a pollen analysis of a 210-cm core from Laguna de las Trancas in northern Santa Cruz County (fig. 1) that covers the period 30,000 B.P. to roughly 5,000 B.P. Its pollen content indicates marked changes in vegetation.

#### THE SETTING

The general environmental setting of the study area has been described by Hecht and Rusmore (1973). Laguna de las Trancas lies in a small depression at the head of a landslide about 7 km southeast of Point Año Nuevo (fig. 1). It is situated on a marine terrace (170 m above sea level) one kilometer inland from the present coastline. A radiocarbon date of 29,500  $\pm$  560 years (USGS-153) on a piece of pine wood from a depth of 312 cm near the base of the marsh deposits indicates that the marsh was formed approximately 30,000 years ago. The landslide event may have been associated with movement along the nearby Ben Lomond or San Gregorio faults. The bedrock in the immediate vicinity of the marsh is the Santa Cruz Mudstone of Clark (1966), a siliceous organic marine mudstone of late Miocene and early Pliocene age (Greene, 1977).

The topography of the coastal area is rugged, especially to the north, where the coastline intersects the San Gregorio fault, and where steep cliffs rise from the beach to an elevation of 180 m. The marsh itself is located on a narrow interfluvium between Waddell and Scott Creeks, two small but perennial



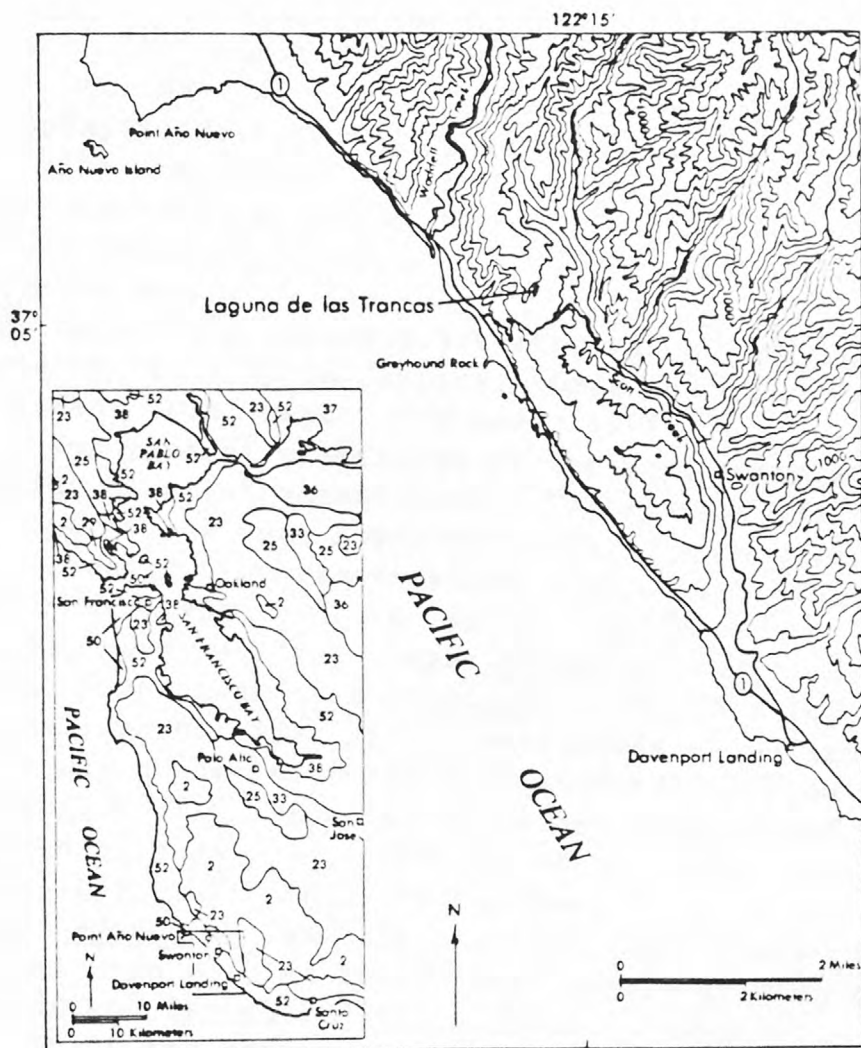


Figure 1.—Map showing the location of Laguna de las Trancas. Inset map shows the location relative to San Francisco Bay; numbered regions indicate vegetation types, and are taken from the vegetation map of California by Kuchler (1977; reproduced by permission). Vegetation types are: 2, Redwood forest (*Pseudotsuga-Sequoia*); 9, Coastal cypress and pine forests (*Cupressus*, *Pinus*); 23, Mixed hardwood forest (*Arbutus-Quercus*); 25, Blue oak-digger pine forest (*Pinus-Quercus*); 29, Chaparral (*Adenostoma-Arctostaphylos-Ceanothus*); 33, Valley oak savanna (*Quercus-Stipa*); 36, California prairie (*Stipa* spp.); 37, Tule marsh (*Scirpus-Typha*); 38, Coastal saltmarsh (*Salicornia-Spartina*); 50, Northern seashore communities (*Elymus*, *Baccharis*); and 52, Coastal prairie-scrub mosaic (*Baccharis*, *Danthonia-Festuca*). Base for large map is taken from USGS Davenport and Año Nuevo 7.5-minute quadrangles.

streams that rise in the Santa Cruz Mountains about 20 km from the coast. They occupy steep-walled valleys, the mouths of which have been drowned by the postglacial rise in sea level.

The area has a Mediterranean-type climate that is characterized by winter rain and summer drought. Mean annual rainfall is about 77 cm, mostly falling between November and April (Rantz, 1971). Temperature extremes are rare, and seasonal averages range from 17 °C in September to 9 °C in January. Coastal fog is common in summer (U.S. Dept. Commerce, 1977).

The present vegetation of the area forms a complex mosaic of plant communities. The general distribution of some of the more important taxa is shown in figure 1. Locally important along the coast is a shrub community (type 50) in which the dominant species locally are coastal sage (Artemisia californica) and coyote bush (Baccharis pilularis). Farther inland the coastal shrub gives way to a coniferous woodland (type 9) in which the local dominant is Monterey pine (Pinus radiata). This species has a very restricted natural distribution and is found at only three localities along the California coast. Here at Point Año Nuevo, Pinus radiata is at the northernmost limit of its natural range; its total range covers an area of less than 60 km<sup>2</sup> (Fowells 1965, p.390).

There has been considerable discussion as to the causes for the very localized distribution of Monterey pine (Moulds, 1950; McDonald, 1959; Stebbins, 1965), but it is generally agreed that summer drought is an important limiting factor. Evidence of this was apparent on the eastern margins of the Año Nuevo population during the early fall of 1977. Several individuals showed signs of stress in the form of yellow needles and premature needle fall, probably in response to the unusually severe drought of the two preceding years. In the main part of the stand, however, there was no evidence of drought stress;

furthermore, there is no indication that the Monterey pine is a species that is doomed to an early extinction (compare Ornduff, 1974). Reproduction is everywhere evident, and no other tree species appears to be better adapted to this particular environment. Occasional Douglas fir (Pseudotsuga menziesii) and live oaks (Quercus agrifolia) are found among the pines, and in some places a mixed hardwood forest has developed (type 23, fig. 1); neither appears to have any consistent competitive advantage. Beneath the pines there is a discontinuous shrub layer that consists largely of California lilac (Ceanothus thyrsiflorus), California holly (Heteromeles arbutifolia), hazelnut (Corylus rostrata), and poison oak (Rhus diversiloba).

Farther inland, floristic composition is largely a function of slope, aspect, and available moisture. On the more mesic sites, redwood (Sequoia sempervirens) is the dominant species (type 2); it is often found in association with madrone (Arbutus menziesii), tanbark oak (Lithocarpus densiflora), and the California bay (Umbellularia californica). On drier sites, Douglas fir (Pseudotsuga menziesii) and knobcone pine (Pinus attenuata) are locally common, as are several species of oak (Quercus agrifolia, Q. chrysolepis, Q. wislizenii). Natural hybrids between Pinus radiata and P. attenuata have been reported from near Point Año Nuevo (Fowells 1965, p.394). On very dry sites, chaparral species are dominant, including chamise (Adenostoma fasciculatum), coyote bush (Baccharis pilularis) and manzanita (Arctostaphylos spp). Chaparral species are also locally common in abandoned pastures and in areas that have recently been cleared by logging or fire.

The two permanent streams that run through the area, Scott and Waddell Creeks, are fringed by a riparian woodland that includes broadleafed maple (Acer macrophyllum), California buckeye (Aesculus californica), red alder (Alnus rubra), cottonwood

(Populus trichocarpa), box elder (Acer negundo ssp. californicum), willows (Salix spp.), and the California nutmeg (Torreya californica).

Since the beginning of European settlement, the vegetation of the area has been drastically modified by human disturbance. Large areas on the marine terraces and in the valley bottoms have been cleared for agriculture. In other areas the vegetation has been variously affected by logging, grazing, and changes in fire frequency.

#### METHODS

A core was taken from the central part of the marsh with a 10-cm-diameter piston corer. The marsh itself normally consists of a floating mat of Typha and Scirpus approximately 75 cm thick. Of this, the upper half is living roots and the lower portion coarse peat. Because the mat as a whole was too loosely consolidated to be successfully cored with our equipment, we began coring at a depth of 105 cm below the water surface. Below this depth the sediments were reasonably compact, and a 210-cm core was recovered in five sections. By the fall of 1977, after 2 years of severe drought, the marsh had dried out completely, and the water table was about a meter below the ground surface. The upper part of the sediments was sampled at that time, but no analyses of the top part of the section have been completed.

As can be seen from figure 2, the core shows marked changes in lithology. The upper 90 cm (105 to 195 cm) consists largely of silt with an increasing proportion of coarse plant debris toward the surface. Between 195 and 210 cm there is a sand layer with some clay lenses. This material is loosely consolidated and was successfully recovered only after several coring attempts. Below the sand layer is almost a meter of brown clay and a basal 10 cm of silt. Bedrock was not encountered, but the sediments below 315 cm were too



compact to be recovered with our equipment.

The core was split and sampled at 5-cm intervals for pollen analysis. Constant volume samples of 2.5 cm<sup>3</sup> were taken from the undisturbed central portion of the core, and tablets containing a total of 25,000 Lycopodium spores were added to each sample as a control (Stockmarr, 1971). The extraction procedures followed were basically those described by Faegri and Iverson (1975); in brief, samples were treated with HCl (10 percent), HNO<sub>3</sub> (10 percent) and

Depth in centimeters	Lithology	Pollen zone
105	Peat and black silt	Redwood zone
150	Increasing silt	
160	Black silt	
160	Black silt	Pine fir zone
195	Sand and clay	
210	Loose sand	
	Brown silty clay	Pine zone
	Discontinuity	
250	Brown silty clay	
280	Pine fossils	
	Brown silty clay	
305		
315	Brown silt	

Figure 2.--Generalized lithology of the Laguna de las Trancas core.

acetolysis. The pollen-rich residue was then stained with 1 percent safranin and mounted in silicone oil. In general, pollen preservation was good, although at certain levels, particularly the sandy levels, there was a high proportion of broken grains.

At least 250 fossil grains were counted at each level. Because of the large numbers of certain pollen types present, a ratio method of counting was followed. For most levels, the count was made up to a total of 100 control grains. For some levels, however, the ratio of pollen grains to controls was too large to make this count feasible, in which case only 50 or, more rarely, 25 controls were counted. For very abundant types, such as pine, the count was stopped at 100 pine grains; the number of controls was recorded, and the count continued excluding pine. When the count for a level was complete, the pine/control ratio was then used to estimate the pine total. This method has the advantage of allowing for a better representation of minor taxa.

#### POLLEN TYPES

In this analysis, 26 pollen or spore types are assigned to known genera, 18 to family or subfamily, and 3 to groups of families. In addition, 15 unknown but distinctive pollen types were observed; none of them, however, accounted for more than one percent of the total count at any level.

Perhaps the most frustrating feature of fossil pollen analysis in California is the problem posed by the Taxaceae, Cupressaceae, and Taxodiaceae. Their pollen grains are very similar and are often lumped together as TCT pollen (for example, see Helley and others, 1972). In this study, however, we distinguish between Sequoia and TCT pollen on the basis of the thicker exine in Sequoia grains. Our TCT category probably includes Cupressus, Juniperus and Torreya, and possibly Calocedrus, which has been found as macrofossils in deposits at Mountain View in San Mateo

County dated at 21,000 to 24,000 years B.P. (Helley and others, 1972).

We did not attempt to make any distinctions within the genus Pinus. Ting (1966) has proposed that statistical analyses of morphological characters can be used to identify California pine pollen to the species level. Even when using reference material, however, we were unable to distinguish the pollen of several of the pines now growing in the vicinity of the marsh (Pinus radiata, Pinus attenuata, Pinus ponderosa), and we therefore did not attempt to identify fossil material below the generic level. As we indicate later, this taxonomic problem complicates the interpretation of the pollen diagram.

Several different sizes of grass pollen were present, and three size classes were arbitrarily established (Gramineae A, grains <25  $\mu$ m; Gramineae B, 25 - 40  $\mu$ m; and Gramineae C, grains >40  $\mu$ m). Because of the wide range of possibilities no attempt is made in this paper to relate them to particular genera. The Compositae are a floristically diverse group in coastal California, and this diversity is reflected in the pollen record. Here we follow tradition (for example, Martin, 1963) in recognizing only four types: "High-spine" Compositae, Liguliflorae, "Low-spine" Compositae or Ambrosia-type, and Artemisia.

Typha latifolia pollen is distinctive insofar as it retains the tetrad arrangement and is therefore listed as a separate type. Unfortunately, Typha angustifolia pollen cannot be distinguished from Sparganium pollen or from some broken Typha latifolia tetrads, and we therefore include all Typha-like monads in the Typha/Sparganium category.

The curves in the pollen diagram represent changes in percentages rather than "absolute" values. The pollen sum includes all arboreal types but excludes herbs and aquatics. Unknown and indeterminate pollen and spores are included in the diagram under

"unknowns."

## RESULTS AND DISCUSSION

Pollen diagrams derived from small marshes such as Laguna de las Trancas are more difficult to interpret than diagrams from lacustrine or marine environments. Marsh diagrams reflect two kinds of vegetation change: changes in the upland vegetation and changes in the marsh itself. In order to avoid confusing local and regional effects, we excluded aquatic pollen types from the pollen sum and calculated their values as percentages of the total nonaquatic pollen. In the discussion that follows, we consider the upland record first. The diagram (fig. 3) can be divided into the three zones shown in fig. 2: a pine zone (levels 315-215) at the base, a pine-fir zone (levels 210-160), and a redwood zone (levels 155-105). We do not have radiocarbon dates for the critical zone boundaries, but we tentatively suggest the following chronology:

- (1) The pine zone = 30,000-24,000 B.P., corresponding to an interstade of the mid-Wisconsinan;
- (2) The pine-fir zone = 24,000-12,000 B.P., corresponding to the main glacial advance of the upper Wisconsinan in the mid-continent (full glacial); and
- (3) The redwood zone = latest Pleistocene to Mid-Holocene (12,000 to perhaps 5,000 B.P.)

As the core does not include the peat mat that at present covers the marsh, the past several thousand years are not represented in the diagram. Level 1 represents a composite surface sample taken to provide comparison with the present.

The basal pine zone

Pine pollen percentages in the lowest meter of the core are persistently high. As we indicated, we do not feel that it is possible to distinguish between the closed cone pines (Pinus radiata, P. attenuata, P. muricata) on pollen morphology alone; theoretically, therefore, any combination of these species, and perhaps hybrids between them, could have been present



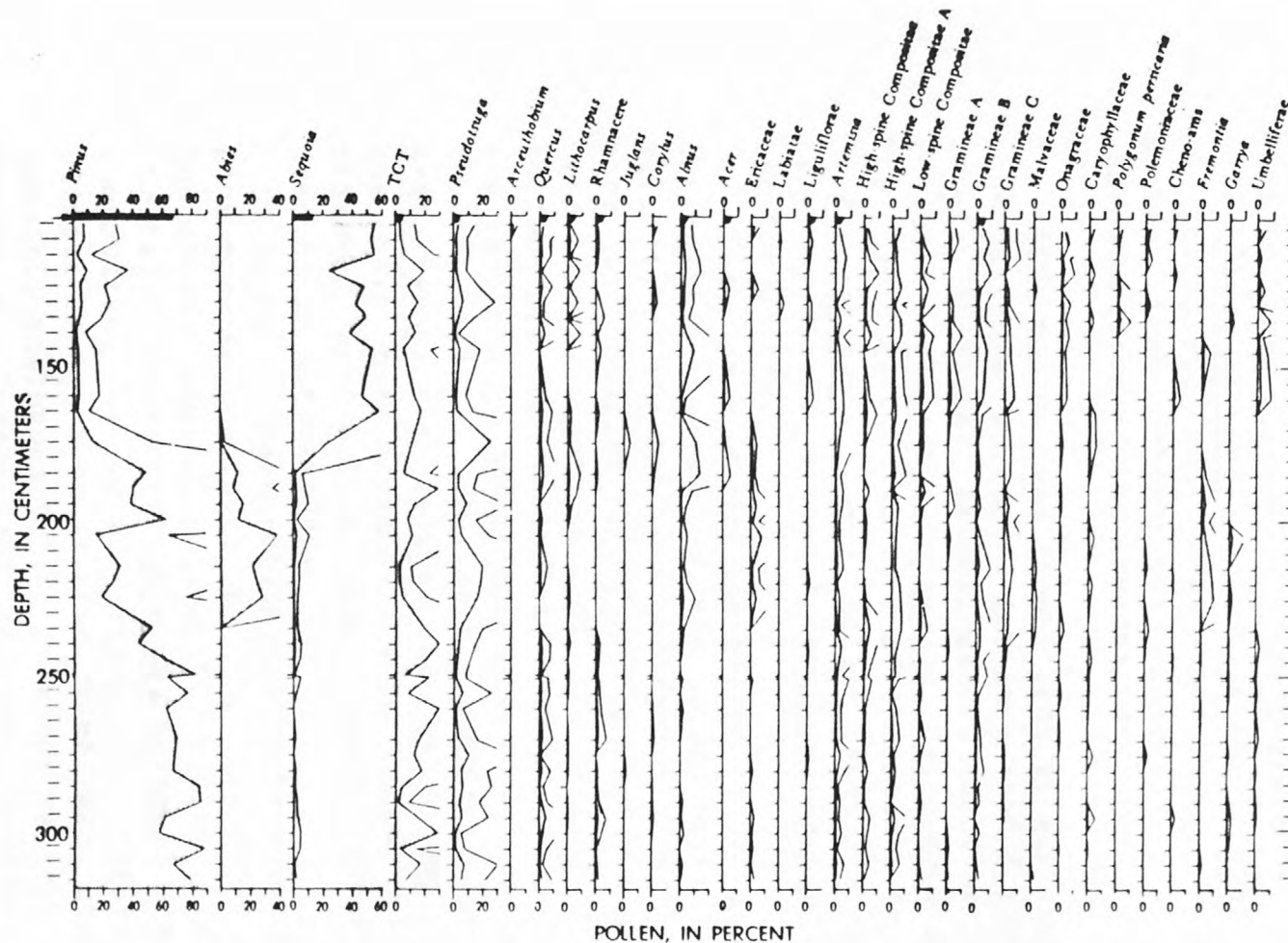


Figure 3.--Pollen diagram for the major nonaquatic pollen types in the Laguna de las Trancas core. The horizontal scale is the same for all curves, and is for the darkly-shaded curve; the lightly-shaded curve is a 3X exaggeration of the dark curve. Depth is shown in centimeters below the water surface at the time the core was taken; the depth scale does not apply to the top sample plotted in bar-histogram form (level 1); that sample is a composite modern soil-surface sample. Frequencies less than 1 percent in level 1 are represented by a dot. The pollen sum for the modern sample excluded pollen of Plantago, which did not occur in the fossil samples.

in the area at this time, as could other species such as Pinus ponderosa, P. sabiniana, and perhaps even P. contorta. Fortunately, however, we can be reasonably certain that one of the pines present was the knobcone pine (Pinus attenuata). During the coring operation, an incomplete cone was recovered at 280 cm with cone scales that show the minutely spinose tip characteristic of the species (H. Schorn, oral commun., 1975).

TCT pollen was encountered at all levels in this zone but never accounted for more than 5 percent of the total. As stated, several genera could be represented, including Juniperus, Cupressus, Calocedrus and Torreya. The only other pollen type of importance in this zone is Pseudotsuga. Several pollen types are conspicuously rare or absent, including Sequoia, Quercus, Gramineae, and Compositae.

Taken as a whole, the pollen record indicates that during this time period, the upland vegetation in the vicinity of the site was coniferous forest dominated by pine and Douglas fir. The Douglas fir may have been a more important component of the vegetation than the pollen diagram indicates, because its pollen is large and is commonly underrepresented on pollen diagrams (Baker, 1976). Similarly, chaparral species such as Arctostaphylos manzanita and Adenostoma fasciculatum may have been present on drier sites, but we have not observed any pollen from these insect-pollinated species in our samples.

Detailed paleoecological interpretation of the pine zone is precluded by the taxonomic imprecision concerning the pine and TCT pollen. In view of the limited importance of Sequoia, Quercus, Gramineae, and Compositae, we would tentatively suggest that the climate of the area at that time was cool and dry, possibly analogous to the interior valleys of the Coast Ranges of Oregon and northern California. Another possibility is that there may be no modern analog for

the pine zone at Laguna de las Trancas .

The pine-fir zone

At the 210-cm level, there is a marked change in pollen frequencies. Pine declines in importance, and fir and Ericaceous pollen suddenly increase. This level also marks a change in lithology as the basal brown clay gives way to the overlying loose sand and silt.

The discovery of fir pollen was unexpected. Fir is not now native to the Santa Cruz Mountains, and the nearest natural stand is 100 km to the south in the Santa Lucia Mountains. We do not believe, however, that the fir pollen found at Laguna de las Trancas represents the Santa Lucia fir (Abies bracteata). Comparison with modern reference materials suggests that the Laguna de las Trancas fir is more likely to be Abies grandis, the grand fir. This species has a wide distribution in the Pacific Northwest and ranges down the California coast to the Russian River, a distance of 150 km north of Laguna de las Trancas. In northern California, the grand fir is largely restricted to the coast. It is found in association with redwood below elevations of about 600 meters, and with Bishop pine (Pinus muricata) in the immediate vicinity of the coast (Griffin and Critchfield, 1972).

Unfortunately, the Ericaceous pollen cannot be identified to species. In view of the similarity between the fir and Ericaceae curves, we suggest that the following are likely possibilities: Labrador tea (Ledum glandulosum), huckleberry (Vaccinium spp.) and salal (Gaultheria shallon). All are locally common along the northern California coast, especially in sandy, low-pH environments. The Ericaceae are primarily insect pollinated, and whatever was responsible for the Ericaceous pollen at Laguna de las Trancas must have been growing in close proximity to the marsh. In our experience, chaparral Ericads such as manzanita (Arctostaphylos spp.) are not well

recorded in the fossil pollen record.

As in the basal pine zone, Douglas fir pollen was encountered at all levels; in one sample, it accounts for 32 percent of the total tree pollen. It can be safely assumed, therefore, that Douglas fir was an important component of the vegetation. Also of interest is the increase in grass and high-spine Compositae pollen; we take this as clear evidence that the vegetation around the marsh was not completely closed forest.

Taken as a whole, the pine-fir assemblage suggests that during the last full glacial interval the vegetation of the Laguna de las Trancas area was very similar to that which is found today about 2.5° farther north, along the northern coast of California. The fir pollen is the most convincing evidence of climatic change, and suggests that the full glacial climate in the vicinity of the marsh was on average at least 2 to 3 °C cooler than at present. This estimate is based on a simple comparison between the mean monthly temperature curves for Fort Bragg and Santa Cruz (fig. 4), is only a minimum value. Fort Bragg is located directly on the coast, whereas during the last glaciation the Laguna de las Trancas site was several kilometers inland, and the moderating effect of the ocean upon the climate must have been less than at Fort Bragg.

The lithology of the core also provides evidence of environmental change during the last full glacial interval. The high sand concentration in the pine-fir zone can be interpreted in several ways. If it is fluvial in origin, it could indicate changes in rainfall in the watershed and more effective erosion and transport of sand-sized sediment. It could also be attributed to a lowering of the water level in the marsh and an increase in the transport of sand into the central area of the marsh. A third possibility is that the sand is aeolian in origin. No sedimentological



studies have been carried out on the Laguna de las Trancas core, and we are not able to definitively state how the sand was deposited in the marsh. We suggest, however, that it was blown in. The watershed area of the marsh is very small (<10 ha) and it seems unlikely that, even with a significantly different precipitation regime, there would be a marked increase in the amount

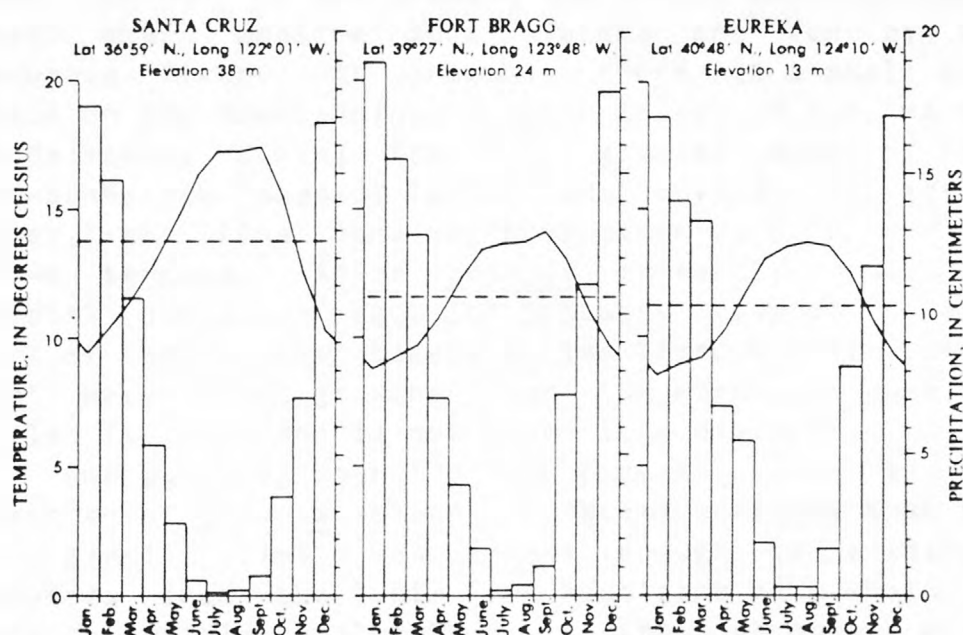


Figure 4.--Comparison of climatic data for Santa Cruz, Fort Bragg, and Eureka, Calif. Data are from U. S. Department of Commerce (1964); values used are climatic normal values, with the exception of the Fort Bragg temperature data, which are for a period of 25 years. Shaded vertical bars are mean monthly precipitation, solid curve displays mean monthly temperatures, and dotted lines show mean annual temperatures.

of surface runoff and erosion. A more plausible explanation is that during the last full glacial interval, active sand dunes were more extensive along the central California coast than they are today. During the period 30,000 B.P. to 10,000 B.P., the combined Sacramento and San Joaquin drainage reached sea level west of the Golden Gate. The sand supply to the coast must have been considerably greater than it is today. In this respect, the central California coast during the last full glacial interval may have been similar to the present day Oregon and Washington coast, where massive dune systems are fed by the Columbia River. At present, there is a small dune field on Año Nuevo Point, 7 km northwest of the marsh. Conceivably, during the full glacial much of the now-submerged coastal plain was covered by active dunes, and some sand may have blown up as far as the 170-m terrace. Abies grandis currently grows on coastal dunes in Oregon and probably occupied the same sort of habitat near Laguna de las Trancas. Fir trees must have been growing near the marsh, because fir pollen is large and is not blown long distances.

One puzzling aspect of the pine-fir zone is the absence of Sequoia pollen. It seems unlikely that the full glacial climate was severe enough to eliminate redwoods from the Santa Cruz Mountains as a whole. A more plausible explanation is that stronger winds restricted this salt-sensitive species to more sheltered, inland locations. It is generally agreed that circulation of the atmosphere was intensified during the full glacial (see, for example, Wilson and Hendy, 1971; Lamb and Woodroffe, 1970), and average wind speeds were probably higher than along the California coast than they are today, particularly in summer. The absence of redwood pollen in the pine zone may also be a reflection of stronger onshore winds.

Spruce (Picea) is absent from the pine-fir zone.

Mason (1934) reported Sitka spruce (Picea sitchensis) needles and twigs in his Tomales flora but failed to find cones, and suggested therefore that at that location the species might have been at the southern limit of its Pleistocene range. Tomales Bay is 140 km north of Laguna de las Trancas and the flora has since been dated at  $29,050 \pm 1,100$  B.P. (Berger and Libby, 1966). Spruce pollen has recently been discovered in early Holocene sediments from Bolinas Lagoon (Byrne and Bergquist, unpublished data).

At present, Sitka spruce and grand fir grow together in coastal Oregon (Fowells, 1965), but spruce does not extend as far south along the coast as fir in California (Griffin and Critchfield, 1976). A similar distributional relation may have existed during the full glacial.

Taken as a whole, the pine-fir assemblage indicates a southward displacement of species ranges of at least 150 km during the last glaciation. This estimate is significantly less than Warter's (1976) 320 km estimate based on paleobotanical evidence from La Brea and Carpinteria. If both grand fir and Sitka spruce were displaced comparable distances along the coast, however, the coastal temperature change was probably not much greater than our estimate. The climatic difference between Fort Bragg and Eureka is rather small (fig. 4), and the main southern limit of Sitka spruce lies between those two sites (Griffin and Critchfield, 1976). Because Sitka spruce did not reach Laguna de las Trancas during the last full glacial, we suggest that the full-glacial climate at Laguna de las Trancas was milder than the present climate at Eureka. The implication is that average monthly temperatures were depressed by  $2^{\circ}\text{C}$  to  $3^{\circ}\text{C}$  along the coast, and precipitation was about 20 percent higher, with the increase occurring primarily in the form of longer winter rainy seasons (compare figure 4). This estimate is significantly less than the CLIMAP full glacial

temperature depression estimate for the California coast of 9 to 11 °C (Gates, 1976). If our 2 °C to 3 °C estimate is correct, it suggests that coastal California, unlike most other areas of North America, experienced a full glacial climate that was not very different from that of the present. Presumably, then as now, the Pacific Ocean had an important moderating influence. One important reason why the temperature depression may not have been great is that sea-surface temperatures close to the California coast are strongly influenced by coastal upwelling, and the upwelling water undoubtedly changed temperature much less between interglacial and glacial intervals than did the normal ocean mixed surface layer farther offshore.

In the same context, we should emphasize that the Laguna de las Trancas pollen diagram records primarily changes in coastal climate and should not be extrapolated inland. The presence of fir at Laguna de las Trancas, for example, does not mean that boreal forest species or community distributions migrated southward through California as a whole during the full glacial. In fact, the available evidence shows that they did not. A recently analyzed core from Clear Lake contains very little spruce or fir pollen in the levels dating to the full glacial. Similarly, spruce pollen is absent from late Pleistocene sections of a core from Osgood Swamp, near Lake Tahoe (Adam, 1967).

There is an interesting parallel here with the late-Pleistocene vegetation history of eastern North America. The discovery of spruce cones and pollen in Pleistocene sediments in Louisiana was formerly thought to be evidence of a southward, en masse, migration of the Boreal Forest (Deevey, 1949). More recently, it has been interpreted as the result of a more localized migration down the Mississippi Valley where cold-air drainage coming from the Laurentide Ice Sheet would have provided climatically favorable conditions (Delcourt and Delcourt, 1975). In a similar but more



persistent way, the cool-summer climate of the California coast allows for a southward extension in range of "northern" species.

#### The redwood zone

Above 160 cm the importance of both pine and fir drops sharply and redwood increases. Also the lithology of the core indicates a shift from the high sand concentrations of the pine-fir zone to an increasing proportion of silt.

Redwood clearly dominated the vegetation of the area at this time; pine, Douglas fir, and oak are rare. On the other hand, both grass and Compositae pollen reach consistently high values. We infer that redwood was dominant on the more mesic sites and that drier sites were open grassland. Chaparral species were probably also present, but unfortunately this vegetation type is not clearly recognizable in the fossil record.

The two most significant aspects of the redwood zone are the high redwood percentage and the virtual absence of pine. The redwood rise can be logically explained as simply the response to an amelioration of climate during the early Holocene. If the previous discussion regarding the absence of redwoods during the full glacial is correct, it follows that a reduction in the strength of onshore winds would allow the redwoods to move out of the more protected locations and expand westward toward the coast. The absence of pine is less easily accounted for.

At present, Monterey pine is the dominant tree in the immediate vicinity of the site, accounting for 80 percent of the modern pollen rain (level 1 in fig. 3). During the early and middle Holocene, however, the situation was clearly different. The low pine percentages in the redwood zone are conclusive evidence that pines were not present in the immediate vicinity of the marsh at this time. Pines produce abundant wind-dispersed pollen and are usually overrepresented

in pollen diagrams.

Axelrod (1967) has hypothesized that the present restricted distribution of the closed-cone pine forest is a result of postglacial climatic change. More specifically, he suggested that during the cooler full glacial, the closed-cone pines were widely distributed along the coast, and that as the climate became hotter and drier during the mid-postglacial period (the xerothermic), they were restricted to the areas of their present disjunct distributions. The Laguna de las Trancas record supports this hypothesis in part, but not entirely.

The main problem with the xerothermic hypothesis is that the high redwood percentages in the Holocene argue against persistent drought along the coast during this period. By this we do not mean to say that the middle Holocene climate was not different from that of the present, but rather that it was not different enough to account for the disappearance of the pines.

A more plausible explanation is that the change from glacial to postglacial climate caused the pine decline. With the exception of Pinus attenuata, all the closed-cone pines are adapted to cool-summer climates. They are found today along the coast, where summer fogs ameliorate the effects of summer drought. During the interstadial conditions of the mid-Wisconsinan and the full glacial conditions of the upper Wisconsinan, a cool-summer climate probably was characteristic of most of the California coastline. During the early postglacial, however, summer droughts must have become more severe, and the closed-cone pines would have been restricted to especially favorable sites. At this time sea level was still well below its present level, and the ancestors of the Monterey pines that are now found at Laguna de las Trancas could have been 10 to 20 km to the west. As sea level rose during the Holocene, the pines could have migrated eastward to assume their present distribution. In other words, the

pine curve in figure 3 is probably best explained as being a reflection of changes in climate and related changes in sea level.

#### The Aquatic sequence

The aquatic diagram (fig. 5) shows marked changes in pollen and spore frequencies, which we interpret to be primarily a reflection of hydrosereal succession. For purposes of discussion, two stages can be recognized.

The first stage coincides with the basal pine zone (levels 315-210) and represents open-water conditions.

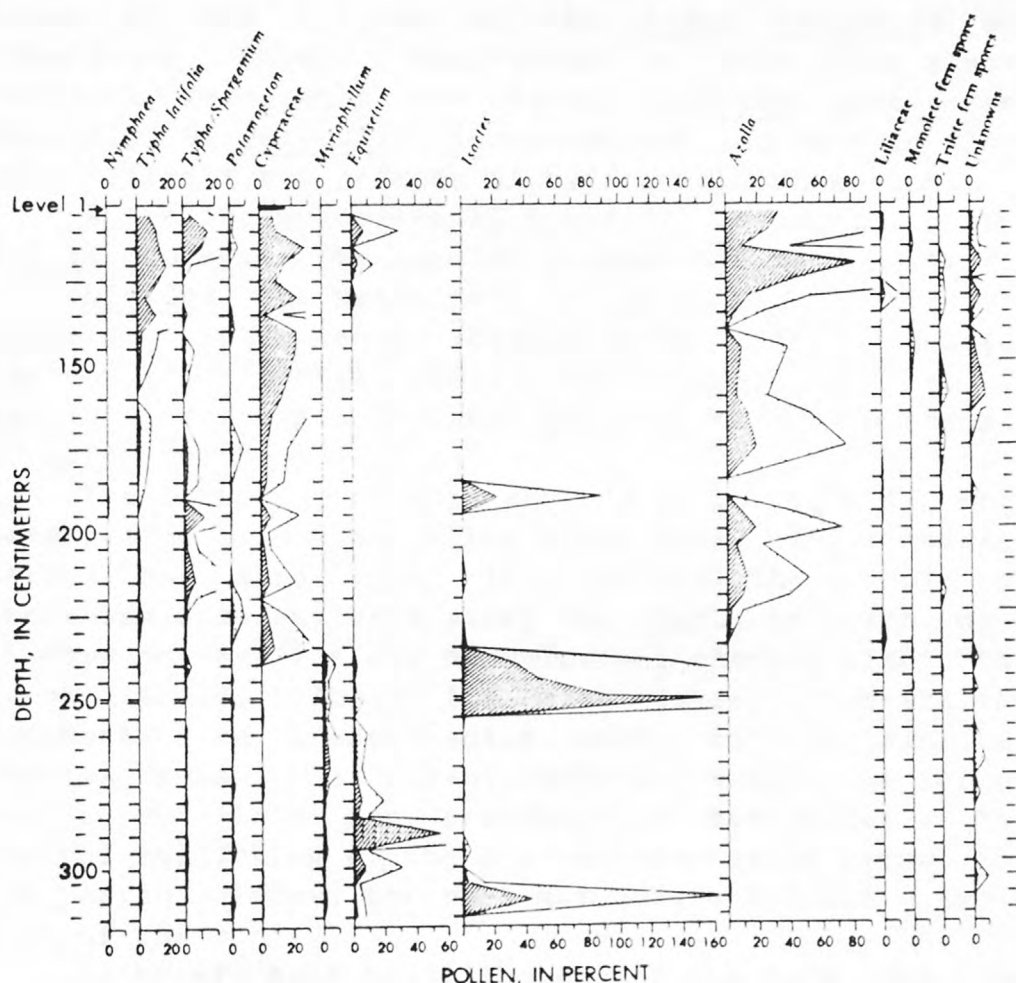


Figure 5.--Diagram for the aquatic types in the Laguna de las Trancas core. Depth and percentage scales are the same as for figure 3.

The pond was probably not very deep at this time (<4 m?) but it was deep enough to prevent the establishment of marsh plants such as Scirpus and Typha. The only aquatics consistently present were Equisetum and Myriophyllum. The lithology of the core also indicates that the marsh had not yet formed. Except for a silty layer below 305 cm, the sediments are fine grained and contain little organic matter.

The second stage includes both the pine-fir and redwood zones and is characterized by an expanding area of marsh around the edges of the pond. This is well shown in the diagram by the Typha latifolia and Cyperaceae curves. Cyperaceae in this case almost certainly represents the Tules (Scirpus acutus and possibly S. validus). The irregular increase in Alnus also reflects the process of hydrosere succession.

A similar successional trend is evident in the Azolla curve. The species represented here is Azolla filiculoides, the water fern. Azolla is a floating aquatic, but needs shallow water for successful reproduction (Bonnet, 1957). The frequent changes in Azolla percentages probably reflect short-term changes in water depth.

The lithology of this section of the core is more complicated than that of the basal zone. As we suggest here, the sand layer is probably the result of increased dune activity along the coast, in which case it does not reflect any hydrological changes within the marsh itself. Above the sand layer, however, the sediments are predominantly silty and contain an increasing amount of organic material toward the top of the core. This can probably be attributed to the gradual shallowing of the pond and increased extent of the marsh. Today, the peat mat covers all but a small part of the pond.

In brief, both the lithology of the core and the aquatic pollen record reflect the progressive filling of the pond and the expansion of the marsh. At the



same time, this process of hydrosereal succession was complicated by regional changes in climate. We recognize the danger of circular reasoning here, but suggest that at least one of the curves in figure 5 shows changes in frequency that are best interpreted as resulting from climatic change rather than hydrosereal succession.

The Isoetes curve is irregular and shows three major peaks. The peaks in themselves may or may not be meaningful, but it is probably significant that Isoetes is restricted to the basal pine and pine-fir zones. In the eastern United States Isoetes is reported as being important in lake deposits that date to the last full glacial (Frey, 1953). Unfortunately, the climatic tolerance of Isoetes is not yet well understood, and we therefore cannot draw any specific conclusions from its occurrence at Laguna de las Trancas.

#### SUMMARY AND CONCLUSIONS

A 210-cm core was taken from a small freshwater marsh in Santa Cruz County, Calif. Radiocarbon dates indicate that the core represents the period between 30,000 B.P. and roughly 5,000 B.P., and therefore includes the last full glacial period. Pollen evidence shows that marked changes in vegetation and climate have occurred during this time. Three pollen zones are identified: a pine zone, an intermediate pine-fir zone and an overlying redwood zone. These zones are tentatively correlated with a mid-Wisconsinan interstadial, the last Wisconsinan glacial maximum (full glacial), and the early and middle Holocene of the mid-continent.

The discovery of fir (Abies grandis) pollen in the full glacial section of the core indicates a southward displacement of at least 150 km. Climatically, this is equivalent to a mean monthly temperature depression of at least 2 °C to 3 °C. The lithology of the core also reflects environmental changes during the full glacial. The fir pollen curve coincides with a sand

layer, which is interpreted as evidence of widespread dune activity along the coast during this time period.

The near-absence of pine pollen in the upper part of the core indicates that pines did not grow in the vicinity of the site during the early Holocene, and the present distribution of Monterey pine must therefore be only a few thousand years old. The pollen evidence indicates that the present fragmented distribution of the closed-cone pines is not the result of altithermal drought but rather a consequence of the shift from glacial to postglacial climate combined with the local effects of changing sea level.

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