From The Reconstruction of Past Environments, J. J. Hester and J. Schoenwetter (assemblers)' Fort Burgwin Research Center, Taos, N.M. Publ. No 3, pp. 66-73.

PS Martin. box copy 1

A map is not complete until all parts are identified; and I think this will mean the geologist has more complete understanding of the relations than he would otherwise.

Haynes: Quite true, but in extending the sections be sure they are complete. A planned map of the site area should be a certainty.

Hester: Another common problem is, if you have a particular geologic environment for fossils and these fossils are sent to someone else for identification (as, for example, snails), perhaps the description of the environment should go with the samples, stating that the snails were found in an alluvial deposit and, in your opinion, may be redeposited. If you do not communicate this to the person identifying the snails, it could lead to a certain amount of ecological error in interpretation.

Haynes: Quite true. This is the same as a carbon sample which comes out of a soil zone, especially with respect to humic acids. It should be made very clear where the sample came from, soil conditions, and so forth.

Martin: How serious has wind erosion been in the postpluvial erosion of dry lakes?

Malde: In lake basin sequences there is some evidence for removal of material from the lake floor during the period sometimes referred to as mid-Wisconsin. When the lake dries out, extensive dune areas form along the margin. How much actual removal of material is represented I do not know. At least a few inches. In the case of Death Valley, movement of the salt crust by the wind is indicated by accumulated salt in areas thousands of feet above the basin floor, the only possible source. This represents several inches of material removed from the floor of the basin.

Damon: Wilcox playa, on its margin, has a desiccated, mud-cracked zone almost identical to the floor of the playa at the present time; and this is now about five feet above the floor of the playa. I interpret the meaning of this to be that there has been five feet of deflation, and I think this is a minimum. The playa floor does go through a period of desiccation in response to the changes in water table.

Haynes: On the margin it is very distinct. If you look at it carefully, you will see that the mud cracks are almost identical to what you find at the present time on the floor.

Wendorf: Another problem is involved here. The center of the basin is the only place where pollen is preserved, presumably because it is moist. There has been moisture in the lake at least to the modern floor level. Isn't this a reason for working in the center of the lake? Doing the best you can with what is available?

Leopold: Along with suggestions such as those Vance has made, I think it seems like an awfully good idea to consider choosing a central drilling locality and a marginal one, too, and compare. In some of my cores, pronounced, unique zones of spruce were used as stratigraphic markers. It was possible to examine other smaller features, and the evidence permitted tests of internal consistency of the lake sediments.

Potter: Dr. Sears suggested that there has been a problem, if the lake had been completely drained. If we have pollen evidence and spores of aquatic forms continuously present, then there is no problem. This evidence ought to be available to show that there was or was not a continuity of water in the central area of San Augustine Lake. Since the water retreated, there has been wind erosion in the lowest part of the playa.

Wendorf: The analysis of material indicated the lake went dry at some interval during the Altithermal?

Potter: I think it possible, yes.

Malde: I mentioned that evaporites occur in orderly sequences, depending on the salinity of the lake. Extensive cores from numerous basins in the Mojave Desert are now available. If you look at these, you see a number of chemical analyses plotted along with other material. It is quite impressive in respect to what is represented in terms of history of the lake. This information should be obtained whenever pollen analysis is done.

Martin: Don't you think the cores, logged by Smith and others, from the Mojave desert show changes in salt content that could be related to position of shoreline?

Malde: They can be translated into water depth, but there is the problem of correlation and tracing of a layer from a central region to the shore.

Damon: Evaporites are not necessarily deposited in a layer in sequence. In fact, the Wilcox Playa core contains sodium salts throughout. There is also evidence of the conversion of sulphates to sulphide by bacterial action. Sodium sulphate is very soluble and comes to the surface in wet areas. Through evaporation it encrusts roots and covers the surface in low areas. I think that a lot of the surface salt material is blown right out of the playa later and does not stay there. After every storm, of course, you see the white slick of sodium sulphate, but it does not last very long; and anybody who has seen the dust devils playing around appreciates the possibility of removing this material.

Wendorf: The High Plains may be atypical because of the heavy winds in the area, but there are unusually extensive dunes piled up on the east and southeast sides of the lake basins. I think it would be very difficult to analyze the section and determine any uniformities of the basin sediments on the basis of material that was in them, because they have obviously been deflated, filled in, and deflated many times.

Martin: In the volcanic district of central-eastern Arizona there is a cluster of small basins; their pollen record has been studied by Jim Schoenwetter and Dick Hevly. Some of the basins are seasonally dry and others are semi-permanent, with water standing in them much longer than in the playas of southern New Mexico and southeastern Arizona. Each basin has a small dune area on the northeast side of the playa or lake. In Laguna Salada there is a continuous postglacial pollen record to a depth of three meters, which suggests reasonably continuous pollen deposition. We hope that radiocarbon dating of the postglacial sediments will resolve the question of whether or not deposition was broken by episodes of desiccation and wind erosion.

Findley: Are these dunes similar to the ones on the northeast shore of Lake Cloverdale in southwestern New Mexico, with artifacts on top of them?

Schoenwetter: On the western side of one playa and on the northern side of another we have found artifacts exposed at the surface. The artifact-bearing sediments continue down for about half a meter; and the stratigraphy is quite uniform and charcoal lenses occur. There is no evidence of deflation having brought the artifacts down to their present position. Apparently, if there was anything on top of them, which seems likely, it was removed. A radiocarbon date from one site is about 1500 B. C. Another one has a pollen spectrum which does not look like anything younger than about 5,000 B. C., but I cannot give that date with absolute confidence. The artifacts are not sufficiently distinctive to give any kind of a real date.

POLLEN ANALYSIS AND THE FULL-GLACIAL LANDSCAPE*

By Paul S. Martin

Pollen analysis is a paleoecological technique with which students of the Pleistocene in glaciated regions are relatively familiar. In unglaciated areas, not only is pollen analysis quite new, but despite the efforts of archaeologists and vertebrate paleontologists much remains to be learned about Pleistocene stratigraphy. Questions of isolation, evolution, and dispersal, commonly posed by biogeographers, go begging in the absence of adequate paleoclimate evidence. The interpretation of Pleistocene climatic history, outside the glacial boundary, has been fraught with discord. What effect did the glacial period have on arid America?

MAJOR CLIMATIC CHANGE, OR MINOR?

According to Huntington (1907), "It is a well established fact that not only in glaciated regions, but in other parts of the world as well the glacial period was preeminently a time of rapid climatic changes. Everywhere the changes must have produced results of some sort, even where there were no glaciers." The classic studies of Gilbert (1890) and Russell (1885, 1889) established that pluvial events in western North America could be linked stratigraphically to local glaciation in the Wasatch Mountains and in the Sierras. Final proof that high lake levels in unglaciated America were contemporaneous with continental glaciation awaited the results of radiocarbon dating (Flint and Gale 1958, Broecker and Orr 1958). On the basis of glacial cirque depression, the record of pluvial Lake Estancia, and certain fossil evidence, Antevs (1954) proposed a 900 to 1200 m. (3000 to 4000 ft.) lowering of life zones in New Mexico during the glacial maximum. While most authors invoke major climatic changes to account for the pluvial lake levels (Meinzer 1922, Leopold 1951, Flint and Gale 1958), or to explain relict distributions of plants and animals (Merriam 1890, Hubbs and Miller 1948, Deevey 1949), there has existed uncertainty, owing to a lack of fossil evidence, as to what happened to the vegetation zones of western North America during the coldest, wettest part of the glacial period.

Despite Huntington and the geological evidences of major climatic change in unglaciated regions, the correlative of a major change in vegetation zones during the Pleistocene has been by no means universally accepted. In arid America, plant ecologists, in particular, have sung a different tune. Regarding southern Arizona, Spalding (1909) believed that desert plants had been growing essentially in their present localities for some time and that, through the Tertiary and Pleistocene, generally arid conditions prevailed there. Shreve (1919) discounted vertical displacement in interpreting the similarity between boreal communities found in two of the higher mountains in southern Arizona, and later concluded (1951), "There is evidence that the area concerned [the Sonoran Desert] has been desert at least since the Miocene." Clements (1916) acknowleged that, while major shifts in plant zones might have occurred in the Northern Rockies near the margin of the continental ice sheet, the changes in there was less climatic change in the Pleistocene of the far west than in the northeast, and that in the far west the climates in the latter half of the Pleistocene differed little from that of the present. Epling (1944), Cain (1944), and Axelrod (1950) largely discount major biotic change in the Pleistocene of arid North America. Gentry (1957) and Dice (1939) speak of shifts in biotic zones, but neither author specifies a vegetation displacement of 900 to 1200 m., as Antevs (1954) inferred from geological evidence.

The reason for discord in climatic interpretation may lie in the scarcity of fossil plant remains in fans and playas (Tolman 1909, Blissenbach 1954, Shreve 1951), which comprise the main Pleistocene deposits. Pleistocene plant remains, most of which are undated,

*Contribution No. 80, Program in Geochronology, University of Arizona; this research supported in part by National Science Foundation grant G21944. I am especially grateful to P. E. Damon for assistance and advice regarding certain critical radiocarbon dates.

* the ... of New Mexico were probably ... Clements (1936) ...

have come mainly from caves in the desert*, from tar pits, or from coastal deposits. Considerable uncertainty exists regarding correlations to Pleistocene events elsewhere. Vertebrate paleontologists commonly assign their Pleistocene faunas simply to early (Blancan), middle (Irvingtonian) or late (Rancholabrean) Pleistocene.

The problem of precise correlation looms large in the case of the spectacular tar pit faunas of California, typified by Rancho la Brea. Virtually all paleontologists and ecologists who have examined them agree that relatively little climatic change can be inferred from the La Brea fossils (summary in Stock 1961). In discussing climatic change in the Southwest, it appears that some authors have assumed that, because the Rancho la Brea fauna is of Pleistocene age and can be correlated with the Wisconsin stage, it is a full-glacial fauna and represents the time of maximum climatic change at high latitudes. If this were the case, a conclusion of little or no climatic change in southern California during the last glacial-pluvial maximum would be entirely warranted.

The period of maximum ice advance during the Wisconsin occurred in eastern North America roughly 20,000 years ago, with rapid expansion and retreat of the fluctuating ice margin occurring between 23,000 and 17,000 years ago (Flint 1963). Six thousand years are more than enough to completely transform biotic zones. If climatic change in unglaciated regions was also greatest 23,000 to 17,000 years ago, only fossil evidence of this age is relevant to the question of what happened during the glacial maximum. Older or younger fossil beds of Wisconsin age may not reveal the full impact of glacial-pluvial climates on the biota of arid America. In the case of Rancho la Brea, Howard (1960) reports radiocarbon dates of between 14,000 and 15,000 years B.P. from wood of a tree associated with the extinct fauna. While these dates fall within the late-glacial period when tundra invaded New England and northwestern Europe, they nevertheless represent a time of ice melt and climatic warming. Possibly, part of the Rancho la Brea beds represents the full-glacial of 20,000 years ago, but, unless this can be shown, the fauna cannot be accepted as evidence of climatic conditions in southern California during the last glacial maximum.

THE ROLE OF POLLEN ANALYSIS

The combined use of radiocarbon dating and of pollen analysis makes it possible to overcome two of the major difficulties which hamper Pleistocene climatic interpretations in arid America—the matter of a sound correlation with events elsewhere, and the erratic distribution of fossils sensitive to climatic change. In the arid Southwest (Arizona, New Mexico, and adjacent parts of the bordering states), pollen analysis has been employed recently in the study of flood plain alluvium, cave earth, dry lake beds (playas), spring mounds, and archaeological trash, as well as the sediments of permanent lakes, the optimal source of a pollen record in glaciated areas. Bogs are scarce, but it is possible to find them in the arid Southwest, not only in certain high mountains, where boreal plants grow and bogs might be expected, but also at lower elevations, such as along the San Andreas fault in the chaparral of southern California (Saul 1961).

In general, the dominant types in both the modern and the full-glacial pollen record of the Southwest are few. One must rely on frequency changes to reflect climatic and vegetational change. Admittedly, the palynological method raises some sticky problems in interpretation. Certain plant associations will not be revealed by pollen analysis; for example, aspen pollen is seldom preserved in sediments. However, recent studies on the modern pollen rain of natural plant communities in the Southwest provide criteria for distinguishing the major units of vegetation (Bent and Wright 1963, Dixon 1962, Maher 1961, Martin, Schoenwetter & Arms 1961). Alpine deposits combine large amounts of herb pollen with spruce and pine; boreal forest deposits have little herb pollen and usually over ten per cent of spruce and fir; ponderosa pine parkland samples yield mainly pine pollen; woodland composed of pinon-juniper-sagebrush sheds a natural pollen rain of all of these genera; and, although as much as twenty per cent of the relative pollen rain in grassland deposits may be pine, the dominant types are herb and shrub pollen – the cheno-ams, composites, and, of course, grasses. The late Pleistocene pollen record should reveal the history of these vegetation types.

The modern vegetation types or plant formations whose history can be revealed by pollen analysis are essentially those types mapped by Shantz and Zon (1924). Included are 1) desert – Chihuahuan, Sonoran, Mojave, and Great Basin; 2) grassland – short grass plains and mixed prairie of west Texas, and the desert grassland of the Mexican boundary; 3) woodland – either encinal, chaparral, or pinon-juniper; 4) ponderosa pine "forest" – the trees of which often form an open, rather than a closed, canopy, in other words, a pine parkland or relatively dense savanna; and 5) boreal forest – dominated by spruce, fir, Douglas fir, limber pine, or aspen. (Fig. 24). A total of nine full-glacial pollen records is available, two of them unpublished. In five of the tables I have included surface pollen counts from plant communities which may represent ecological equivalents of the full-glacial spectra.

*Wells and Jorgensen's discovery of juniper and other plant remains in Pleistocene pack rat middens in the Mojave Desert ". . . may have unique value as a check on the palynological approach to Pleistocene ecology in the arid Southwest." (Wells and Jorgensen, 1964, p. 1172). The authors interpret their record as representing a late Pleistocene lowering of the woodland zone by 600 m.

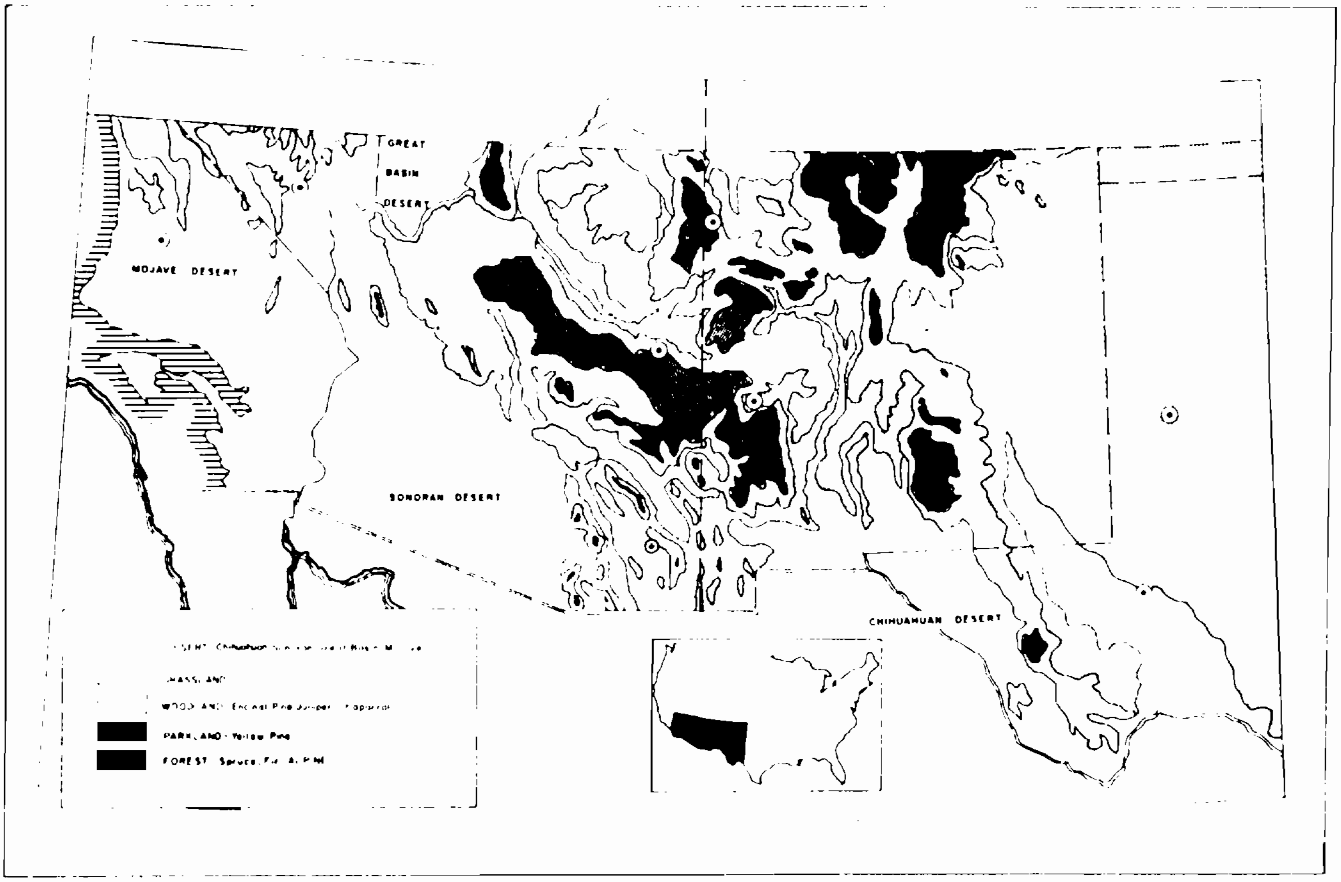

Fig. 24. Modern vegetation types of the American Southwest; circles show locales of full-glacial pollen records.

THE DESERT

One of the first pollen studies of a Southwestern playa was made at Searles Lake by Roosma (1958). From a more detailed, unpublished analysis of Searles Lake by E. B. Leopold, I have assembled counts of the parting mud unit, radiocarbon-dated as 10,000 to 24,000 B.P. (Flint and Gale 1958). The average count of fourteen levels from the parting mud (excluding unknowns) is compared with a series of surface samples collected at various elevations through the Panamint Mountains (Table 3, Fig. 25). Between elevations of 1800 and 1950 m., the elevation occupied by pinyon-juniper woodland containing sagebrush (*Artemisia tridentata*) soil-surface samples in the Panamint Mountains contain a pollen record more like the parting mud counts at Searles Lake than any other surface samples examined on the transect (Fig. 25). A vertical displacement of at least 1200 m. would be needed to bring pinyon-juniper communities in the Panamint Mountains down to the level of Searles Lake.

A modern, soil-surface sample from the Panamint Valley (elev. 480 m.), at about the same elevation as Searles Lake, is similar in pine pollen frequency to the Searles Lake parting mud record (see Table 3). While it is intriguing to find the fossil and modern counts so close in quantity of pine pollen, the scarcity of *Artemisia* and the abundance of other *Compositae* (especially of the desert shrub, *Franseria dumosa*) serve to distinguish the modern pollen rain in the Mojave Desert from the glacial age parting mud. Both

Table 3

SEARLES LAKE, CALIFORNIA

	Modern	Full-glacial	Modern equivalent, Panamint Mts.
Pinus	43	52	36
Juniperus	4	9	11
Cheno-ams	10	8	7
Artemisia	3	14	26
Other *Compositae*	28	6	11
Others	12	11	9
N	200	6000	800
Vegetation	Mohave Desert	Piñon-juniper woodland	Piñon-juniper woodland

Comparison of Modern and Full-Glacial Pollen Spectra, Searles Lake, California.

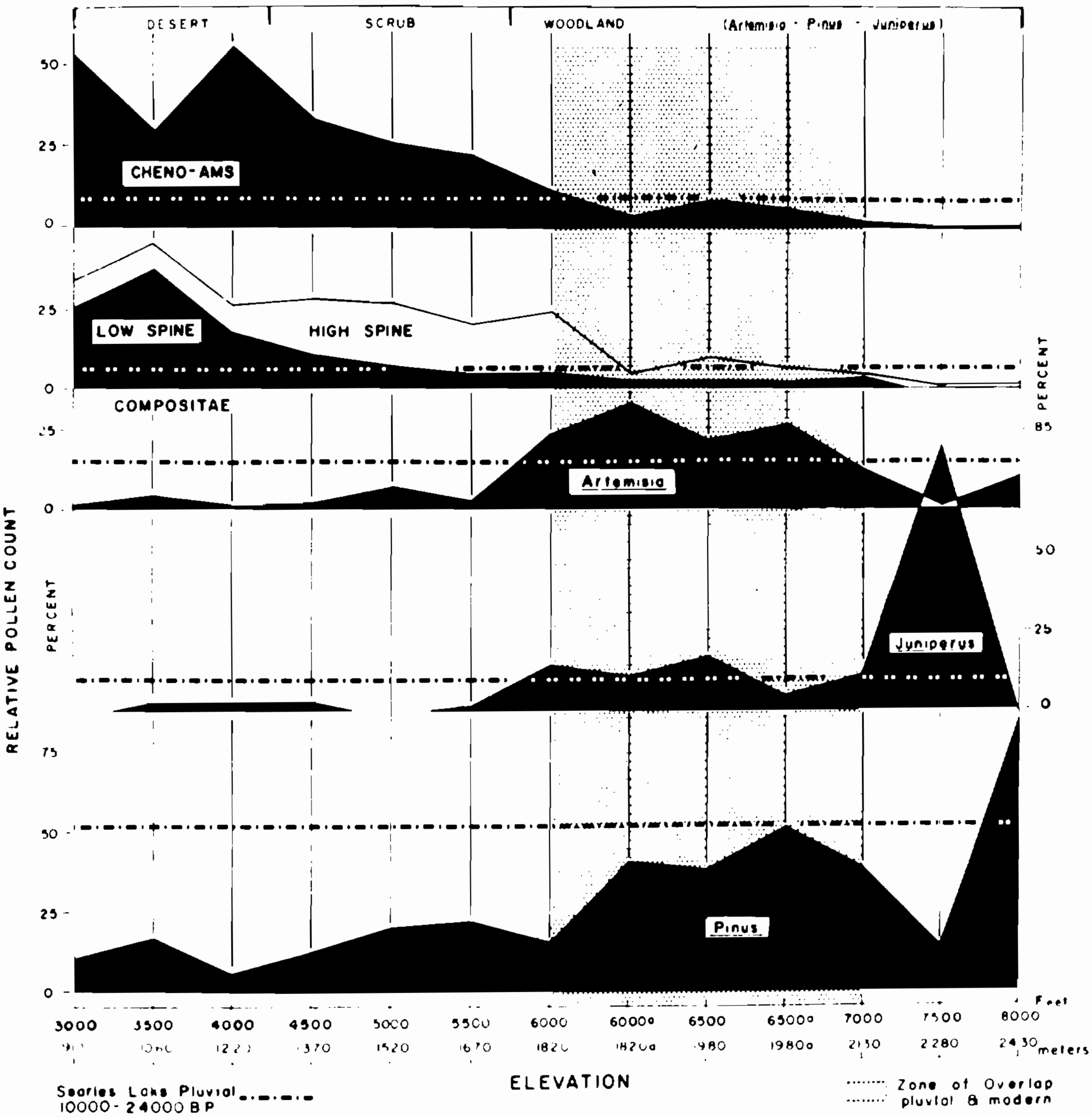

Fig. 25. Panamint Mountains modern pollen rain.

long-distance-transport of pine from adjacent mountains, and feeble pollen production by desert shrubs account for the relatively high frequency of pine pollen in the modern pollen rain of the Mojave Desert.

A second full-glacial record from the Mojave Desert is available near Las Vegas, Nevada. Pollen samples, collected during the recent excavation of the Tule Springs site by the Nevada State Museum, and analyzed by P. J. Mehringer and myself, show a higher frequency of pine pollen than the full-glacial samples from Searles Lake (Table 4). The modern pollen counts represent an average of three separate, soil-surface collections along Las Vegas Wash, elev. 700 m., an area dominated by *Larrea, Franseria,* and *Atriplex*. According to C. V. Haynes the pollen spectra which lie near the top of a buried playa lake deposit can be associated with UCLA 536 (*ca.* 22,600 B.P., unpublished). In addition to pine pollen, certain strata in the playa unit contain a high frequency of sedge and cattail pollen and a low percentage of fir, *Abies*. No modern equivalent samples are available; ponderosa pine usually grows above 2200 m. elevation in the adjacent Charleston Mountains, and the full-glacial pollen record suggests that ponderosa pine parkland descended over 1000 m., virtually to the elevation of the Tule Springs site, during the Wisconsin glacial interval.

Table 4

TULE SPRINGS, NEVADA

	Modern	Full-glacial
Pinus	9	73
Gramineae	0	7
Cheno-ams	17	1
Compositae	58	10
Others	16	9
N	600	400
Vegetation	Mojave Desert	Pine-parkland

Comparison of Modern and Full-Glacial Pollen Spectra, Tule Springs, Nevada.

LOW ELEVATION GRASSLAND

Perhaps the most spectacular record of pluvial-postglacial change is seen in the pollen stratigraphy of the Llano Estacado in Texas and New Mexico, first studied by Hafsten (Wendorf 1961). Rising from 760 m. elevation in the south to 1400 m. elevation in the north, the Llano Estacado is an unrelieved grassland. Eroded scarps above the Pecos Valley are occupied by scattered juniper, pinyon, and oaks. The modern pollen rain, sampled in a series of livestock tanks by Hafsten, is dominated by herbs, particularly the *Compositae* and grasses. Despite the absence of pine growing in the region, Hafsten found pine pollen to be common in stock tanks, in frequencies of ten to thirty-two per cent, the result of wind-transport.

Full-glacial counts shown in Table 5 represent levels possessing the highest pine frequency found in Hafsten's cores. The Rich Lake profile is associated with L-513A, 17,400 ± 600 B.P., at a depth of four to four and a half feet. This level accompanies a pine pollen record of 88 per cent, *Picea* (spruce) of five per cent, and *Artemisia* of four per cent. High pine counts, lacking radiocarbon dates, but also considered to be of equivalent age, the Tahoka pluvial, are present in cores from Tahoka Lake and Crane Lake. In these, spruce and *Artemisia* are replaced in part by pine. A modern pollen equivalent can be found in the surface of Muskee Lake in the central Rockies of Colorado, elev. 2617 m. The Muskee Lake record contains fifteen to twenty per cent less pine and more grass and other non-arboreal types than the Llano Estacado. According to Pennak (1963), Muskee Lake is surrounded by open ponderosa pine forest containing a very few aspens, *Populus tremuloides*, and a sparse ground cover. Presumably, a similar community occupied the Llano Estacado 20,000 years ago.

Invasion of the Llano by pine parkland would require at least 1000 m. vertical displacement in vegetation. Such a change is in accord with the 1200 m. vertical displacement in vegetation zones which Antevs (1954) proposed for New Mexico at the latitude of Santa Fe. Through an ecological lapse, Antevs postulated tall grass prairie, rather than pine parkland, in the New Mexican short grassland during the Wisconsin glacial maximum.

The Llano Estacado might be considered a special case. It is notably windy country, and unusual wind velocities during the season of pine pollen shedding could intensify the long-distance-dispersal of pine pollen, and thus explain, in part, the high frequency of pine pollen during the pluvial period. However, a similar pollen record can be found in the less exposed, and less wind-swept, desert grassland of southern Arizona. Full-glacial sediments from the Willcox Playa (elev. 1260 m.) contain little besides pine pollen (Martin 1963). The modern pollen rain represents dust from the top of the barren playa within one mile of the drill site (see Table 6). The full-glacial pollen sample comes from between 1.9 and 2.1 m. and is

Table 5

LLANO ESTACADO, TEXAS

	Modern		Full-glacial			Modern
	WT-4	Crane Lake Surface	Rich Lake 1.40-1.80 m	Tahoka Lake Bison level	Crane Lake 2.0 m	Equivalent, Colorado Rockies
Pinus	10	9	88	94	88	74
Picea	0	0	5	2	0	3
Gramineae	18	8	2	1	3	10
Cheno-ams	48	55	0	0	1	
Artemisia	4	3	4	1	2	5
Other						
Compositae	12	16	1	1	4	
Others	8	9	0	0	2	8
N	448	676	546	456	284	
Vegetation	Mixed Prairie		Pine Parkland			Ponderosa pine "forest"

Comparison of Modern and Full-Glacial Pollen Spectra, Llano Estacado, Texas.

Table 6

WILCOX PLAYA, ARIZONA

	Modern	Full-glacial	Modern Equivalent, Catalina Mts.
Pinus	17.5	99.0	68.4
Picea	0.0	0.2	0.0
Quercus	5.5	0.2	6.0
Juniperus	1.0	0.2	0.2
Gramineae	19.0	0.2	4.4
Cheno-ams	25.0	0.2	3.9
Compositae	28.2	0.0	10.1
Others	4.2	0.0	7.0
N	401	410	586
Vegetation	Desert grassland	Pine parkland	Pine forest

Comparison of Modern and Full-Glacial Pollen Spectra, Wilcox Playa, Arizona.

directly associated with A-352, 23,000±500 B. P. Below 1.9 m. pollen samples from both the middle and edge of the Willcox Playa contain ninety-nine per cent pine pollen with numerous *Botryococcus* colonies. The remaining types include pollen of *Picea, Abies*, juniper, and *Artemisia*. Even shallow spring deposits within a few hundred feet of the uppermost level of the playa shore contain very high counts of pine pollen, plus a low percentage of spruce and fir pollen (Hevly and Martin 1961).

Although some Colorado mountain lakes studied by Pennak contain eighty per cent pine pollen, and pine percentages from surface samples at 2700 m. in the Chuska Mountains may approach ninety per cent (Bent and Wright 1963), I'm unaware of a modern lake in the Southwest which contains ninety-nine per cent of pine pollen, and which might be compared with the record from the Willcox Playa. At 2370 m. in the Catalina Mountains in ponderosa pine-Douglas fir-white fir forest soil, surface samples are dominated by pine, but also include appreciable amounts of non-arboreal pollen types -- *Compositae*, cheno-ams and grasses (Table 6). Fresh snow samples from the Catalina Mountains contain abundant pollen of *Franseria*. The relatively high frequency of both cheno-ams and low-spine *Compositae* (cf. *Franseria*) in the higher elevations of the Catalina Mountains must represent wind-transport from the adjacent Sonoran Desert. Long-distance-transport of desert plant pollen into the San Juan Mountains and the Sangre de Cristo Mountains has been reported by Maher (1961) and Dixon (1962). Long-distance-transport of desert herb pollen would not occur in an extensive region of pine parkland to the degree seen in the relatively small montane pine stands of the Southwest at present.

HIGH ELEVATION GRASSLAND

The Mogollon Rim of the southern edge of the Colorado Plateau harbors ponds, small dry lakes, and one large dry lake. The latter, known as the San Augustin Plains, was the first Southwestern playa to be studied for fossil pollen (Clisby and Sears 1956). The vegetation types surrounding the San Augustin Plains include saltbush-grama, grama grassland, and, at higher elevations, pinon-juniper and ponderosa pine (Potter 1957). A surface sample from Clisby and Sears' drill site is dominated by cheno-am pollen (Table 7). A full-glacial spectrum from the nineteen to twenty foot level (5.8-6.1 m.) of the BHM core, elevation 2060 m. represents counts by Clisby and Sears (1956 and unpublished) directly associated with Y-1053, 23,070±650 B.P. Pine and spruce were virtually the only pollen types found. A modern equivalent may be found at Silver Lake Gate Bog, Colorado, 900 m. elevation above, and 700 km. to the north of, the San Augustin Plains (Pennak 1963). The bog grades into dense Englemann spruce forest, with subalpine fir, limber pine, and lodgepole pine in the vicinity. To account for the abundance of spruce in the San Augustin Plains record, we may postulate a boreal forest, with spruce growing around the San Augustin Lake 20,000 years ago.

A much smaller basin north of the Mogollon Rim in Arizona is under study by R. H. Hevly, who has kindly provided the pollen count shown in Table 8. Vegetation at Laguna Salada (1900 m. elev.) is similar to that in the vicinity of the San Augustin Plains with more juniper and less saltbush and alkali sacaton. No radiocarbon date of full-glacial age is available, but a maximum in spruce and fir pollen occurs at a depth of 170-190 cm. in eroded lake shore deposits 80 cm. below A-256, 7300±110 B.P. (Hevly 1962). The "full-glacial" peak in spruce also occurs at a depth of 3 cm. in a core from the middle of Laguna Salada. The counts resemble those from Silver Lake Gate Bog (2979 m.) somewhat more closely than do Clisby's counts from the San Augustin Plains. The "full-glacial" zone from Laguna Salada and the full-glacial record from the San Augustin Plains are quite similar; both reveal boreal forest of spruce and pine at lower elevations, and in a much drier site than such vegetation occupies today.

Table 7

SAN AUGUSTIN PLAINS, NEW MEXICO

	Surface	Full-glacial	Modern Equivalent, Catalina Mts.
Pinus	22	77	81
Picea	!	21	8
Gramineae	4	0	5
Cheno-ams	60	0	0
Artemisia	0	0	3
Compositae	5	0	0
Others	9	2	3
Vegetation	Grama Grassland	Boreal Forest	Spruce Forest

Comparison of Modern and Full-Glacial Pollen Spectra, San Augustin Plains, New Mexico

Table 8

LAGUNA SALADA, ARIZONA

	Modern	Full-glacial	Modern equivalent Colorado Rockies
Pinus	23	72	81
Picea & Abies	!	14	8
Juniperus	30	2	—
Gramineae	10	3	5
Cheno-ams	21	3	—
Compositae	16	5	3
N	850	600	..
Vegetation	Juniper Grassland	Boreal Forest	Spruce-pine Forest

Comparison of Modern and Full-Glacial Pollen Spectra, Laguna Salada, Arizona.

PINE PARKLAND

Only one full-glacial pollen record is available within the ponderosa pine belt (see Table 9). The locality is at Deadman Lake in the isolated Chuska Mountains of northwestern New Mexico (Bent 1960). The modern pollen rain is dominated by pine, but contains an appreciable amount of non-arboreal pollen, particularly in view of the elevation (2640 m.) and vegetation of the site. As in the case of the Catalina Mountains, the San Juans, and the Sangre de Cristos, it is likely that the relatively high frequency of non-arboreal types in a community dominated by such a prolific pollen producer as ponderosa pine represents wind-transport of desert soil and pollen into the Chuska Mountain Lakes. Without the long-distance effect, the relative frequency of pine pollen would be much higher.

Table 9

DEADMAN LAKE, CHUSKA MOUNTAINS, NEW MEXICO

	Modern	Full-glacial
Pinus	67	34
Picea	[illegible]	7
Gramineae	6	4
Cheno-ams	11	6
Artemisia	9	46
Other		
Compositae	3	2
Others	4	1
N	1087	576
Vegetation	Pine Parkland	Subalpine Woodland?

Comparison of Modern and Full-Glacial Pollen Spectra, Deadman Lake, Chuska Mountains, New Mexico.

Long-distance-transport may also explain the unusually high frequency of *Artemisia* during the full-glacial period when pine pollen is much less abundant, spruce has increased, and the main change is seen in the abundance of *Artemisia*. A pollen count (Table 9) from 3.17 m. associated with A-268, 24,700 ±3900 B.P., extending between 312 and 318 cm. in Bent's core is slightly too old to be "full-glacial" as I have defined it. But the pollen counts from spectra above 312 cm. which lie within the desired range are not very different. A C-14 sample from 1.60-1.80 m. (A-388) was 19,400 ± 1800 B.P. (Bent and Wright 1963). The modern sample is the sum of counts from the surface to 10 cm.

Bent considered the possibility of a subalpine environment dominated by a high-altitude species of *Artemisia* as an explanation for its unusual frequency. At the same time, possibility of some *Artemisia* pollen blowing in from lower elevations must be considered. The record very closely resembles Maher's pollen counts from the San Juan Mountains at and below a radiocarbon date of 14,000 years (Maher 1961). These counts represent the earliest record of pollen deposition in Molas Lake (3200 m.), following deglaciation of the San Juans. In both areas, the ~~modern and~~ full-glacial or late-glacial counts differ vastly from the postglacial records. While some uncertainty remains regarding the source of the *Artemisia* pollen, an alpine environment and a treeline depression of 800 m. are inferred by Bent and Wright (1963).

A FULL-GLACIAL VEGETATION MAP

Nine pollen spectra, thought to be of full-glacial age (Tables 3-9), differ drastically from modern or postglacial counts in surface samples collected in the same area. To find a modern pollen count similar to the full-glacial pollen spectra, it is necessary to sample lake sediments or soils 800 to 1200 m. higher in elevation than the fossil localities. The pollen type most likely to reveal the full-glacial change is pine; *Artemisia* and *Picea* also increase in frequency in certain full-glacial age deposits from the Southwest. The full-glacial pollen spectra can be used in making a fossil pollen map (Fig. 26) and a vegetation map (Fig. 27). The procedure follows that used in mapping Valders age fossil pollen spectra (Leopold 1958) and in mapping late Pleistocene vegetation zones in eastern North America (Martin 1958).

The Southwest is a region of complex topography, profound regional climatic variation, and, consequently, considerable biotic diversity. As a result, the present vegetation pattern is reasonably complex (Fig. 24), and there is no reason to doubt that the full-glacial pattern was, also. The full-glacial pollen record (Tables 3-9) reflects major shifts in vegetation at each station, but does not establish whether the shifts were symmetrical. Some areas may have undergone relatively more change than others, especially if changing storm tracks intensified precipitation in regions now in a rainshadow. The increase in pine pollen at Tule Springs is greater than that at Searles Lake, despite the fact that both lie at about the same elevation and the same latitude in the Mojave Desert. Furthermore, the full-glacial pollen record, as we know it, leaves ample room for extrapolation. In interpreting Figure 27, the reader should bear terest such as the Sonoran Desert. In the case of the many isolated mountains of the Southwest it is quite probable that biotic zones were displaced at least 800 m. in each. But we have pollen-stratigraphic evidence of this only in the Chuska Mountains. Most of the desert mountain ranges lack suitable basins for Pleistocene sediments.

Biogeographers may inquire about the fate of the Sonoran Desert. Elements of the Great Basin Desert, such as *Artemisia* and *Sarcobatus*, can be found in southern California during full-glacial time, but where did the Sonoran Desert saguaro, paloverde, brittle bush, and bur-sages go? Not only is the full-glacial history of the Sonoran Desert unknown, but, because

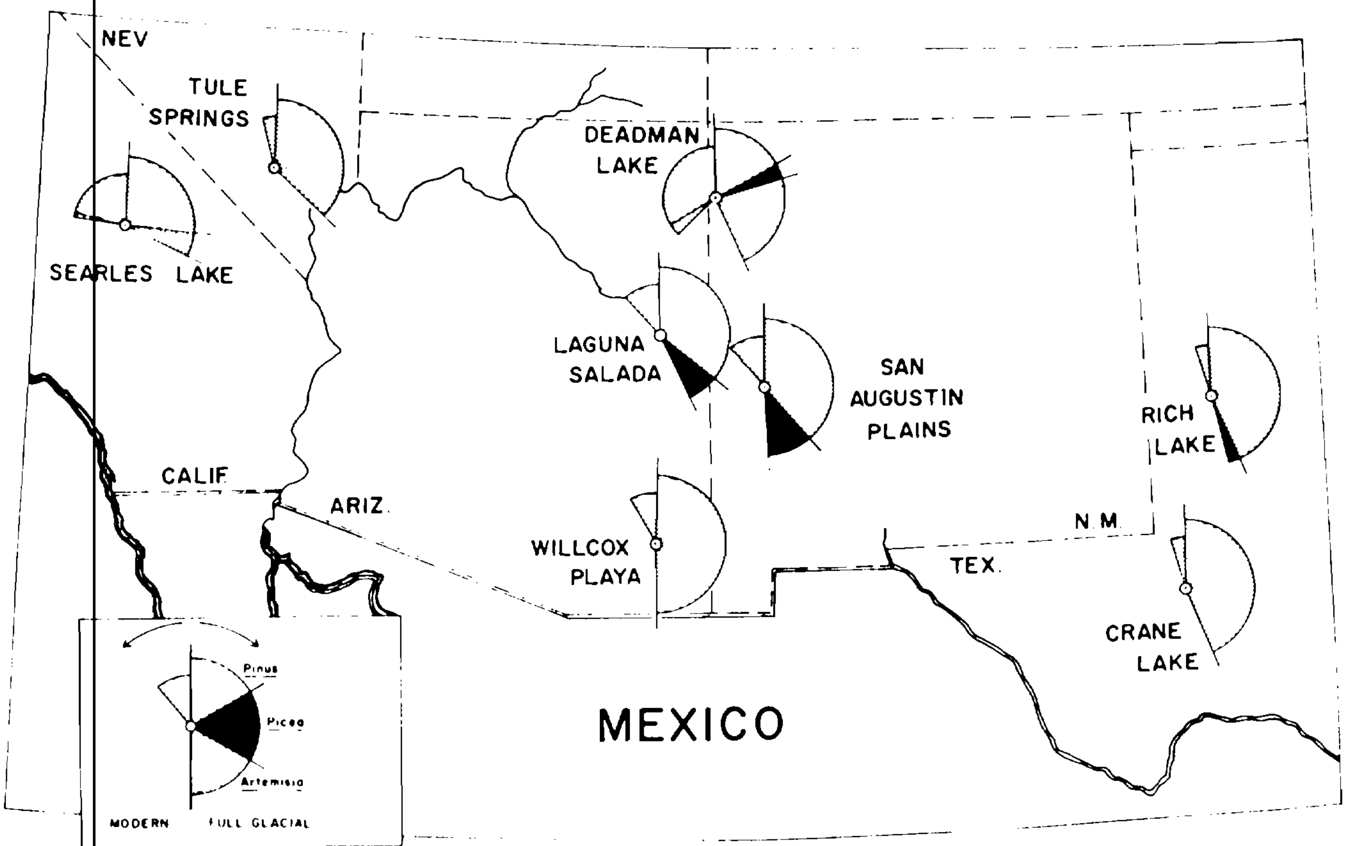

Fig. 26. Modern and full-glacial pollen spectra from the American Southwest.

of the nature of its dominant species most of which are animal-, rather than wind-pollinated, we are not likely to find pollen evidence in the basin sediments commonly studied. Furthermore, while I have mapped the area presently occupied by Sonoran Desert as grassland during the full-glacial, it is equally likely that the area was covered by sagebrush and greasewood.

While any full-glacial map is certain to provoke questions of the sort mentioned above, I would stress that the available pollen evidence is internally consistent. No full-glacial record fails to reveal a major change in pollen composition. The change in Southwestern pollen spectra from the full-glacial to the present agrees with the pattern of Wurm-Wisconsin climatic changes recorded elsewhere in the northern hemisphere (Flint and Brandtner 1961). In the past, the dilemma of the Pleistocene paleoecologist and biogeographer has been how to find meaning in a literature characterized by much disputation and little evidence. The fossil pollen record, in connection with radiocarbon dating, should go far toward overcoming the lack of evidence. It provides abundant support for the view that major transformations in the vegetation zones of arid America accompanied late Pleistocene glaciation.

DISCUSSION

Dahl: How much will you have to displace vegetation to get pinyon-juniper down to Searles Lake?

Martin: 1200 meters or a little more. The elevation of Searles Lake at its highest point was 690 m., approximately 200 m. above the present dry lake bed. Modern vegetation comparable to the fossil pollen record of Leopold may be found at an elevation of 1800 to 2000 m.

Dahl: The thing I am wondering about: suppose that precipitation during the glacial ages was higher in the Rocky Mountains than today. The depression of the firn line is estimated to be over 3,000 feet. The temperature depression during the glacial ages need not have corresponded to that associated with a normal altitudinal difference of 3000 feet, since more heat would be required to melt the additional winter snow.

Potter: I object to your using as logic the fact that you have a repetition of two or three sites with the presence of pine and spruce, and from this drawing a line through vast areas of Texas and Oklahoma and Colorado, and I suppose farther north, if the map was bigger. The pine forest has invaded all types of soil: