MUSEUM OF NEW MEXICO
P. O. BOX 2087 SANTA FE, NEW MEXICO 87501

21 April 1967

Report to: Smithsonian Institution

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Title: Environment of the Valley of Oaxaca: Past & Present
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The modern environment of the Valley has been investigated in terms of its geomorphology, its climatology, and its phytogeography. There has also been some botanical study of the species of plants in the region. The geomorphological study was designed to allow recognition of geological distinctions which have relevance to the question of modern and pre-existing agriculture. The phytogeographic study was initiated as a means of recognizing vegetation-climatic units which would serve as a control on the pre-existing vegetation reconstructed through pollen analysis. The botanical study was initiated in order to allow identification of plant macrofossils and microfossils found with ancient cultural remains.

The Valley of Oaxaca is geomorphologically distinct from those valleys of the southern Mexican highlands which surround it. Surrounding valleys have steep sides, narrow floors, and flowing streams. The Valley of Oaxaca has a relatively wide floor, more flat land, and streams that are mostly dry. A typical cross-section of the Valley of Oaxaca shows four distinct physiographic zones: a floodplain, a zone of high alluvium, a piedmont zone, and the mountains.

The floodplain and the high alluvium combine to form a valley floor which may be up to 15 km wide. The two rivers which drain the Valley, the Upper Rio Atoyac, and the Rio Salado, formed this floor during the Pleistocene and/or Recent periods. Zapotec legend claims the existence of a large lake in the Valley at one time, and it has been seriously proposed that this lake influenced Monte Alban I culture in the region. The valley floor offers no geological evidence in support of the legend.

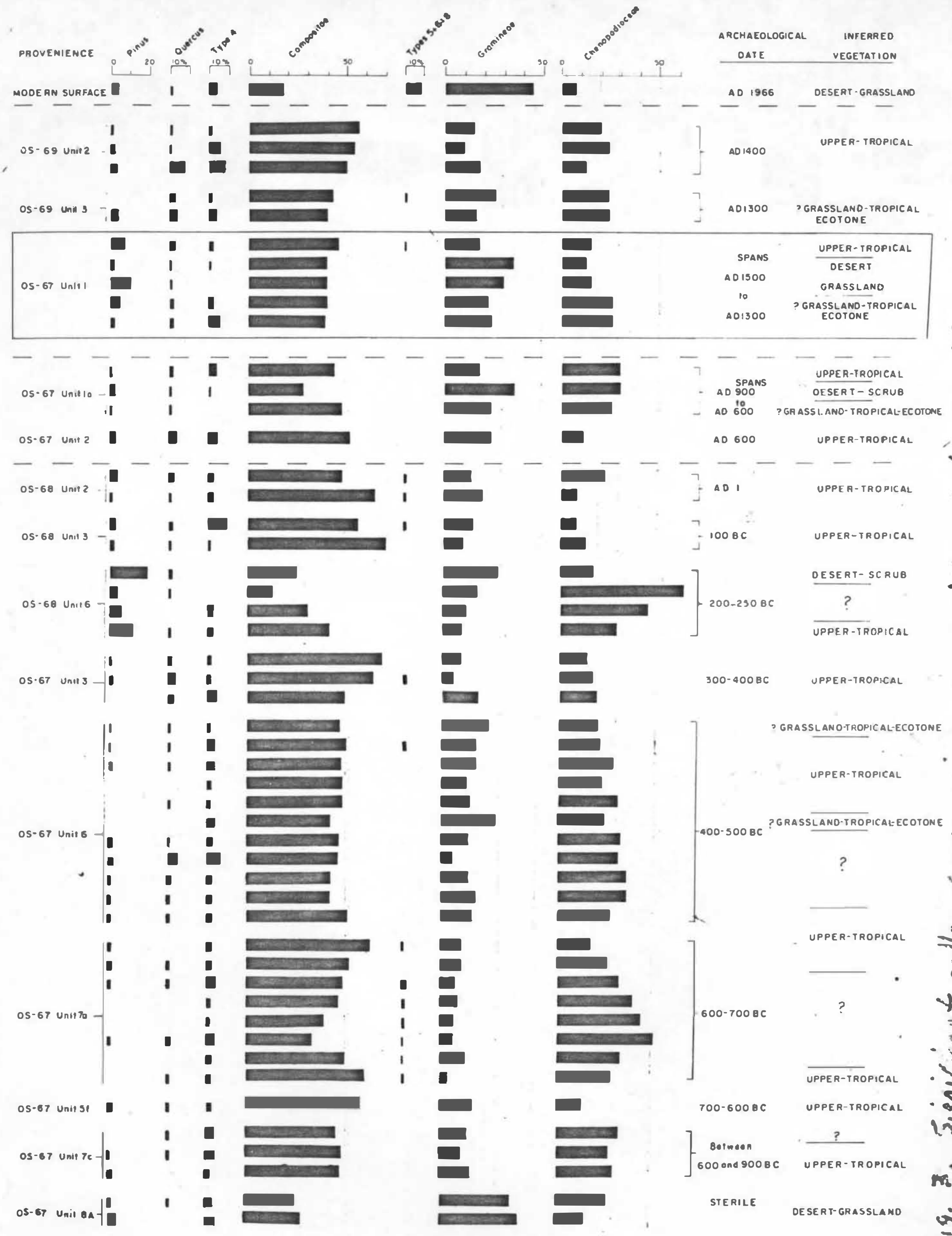

Fig. 3. Significant pollen frequencies from Mitla f loca[illegible]tes.

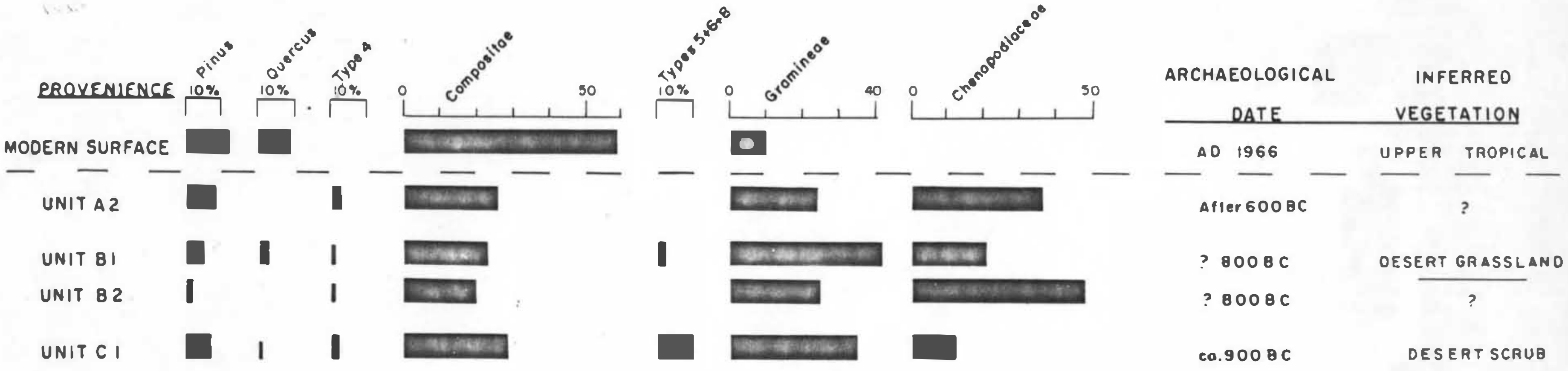

Fig. 4. Significant pollen frequencies from San Jose Mogote.

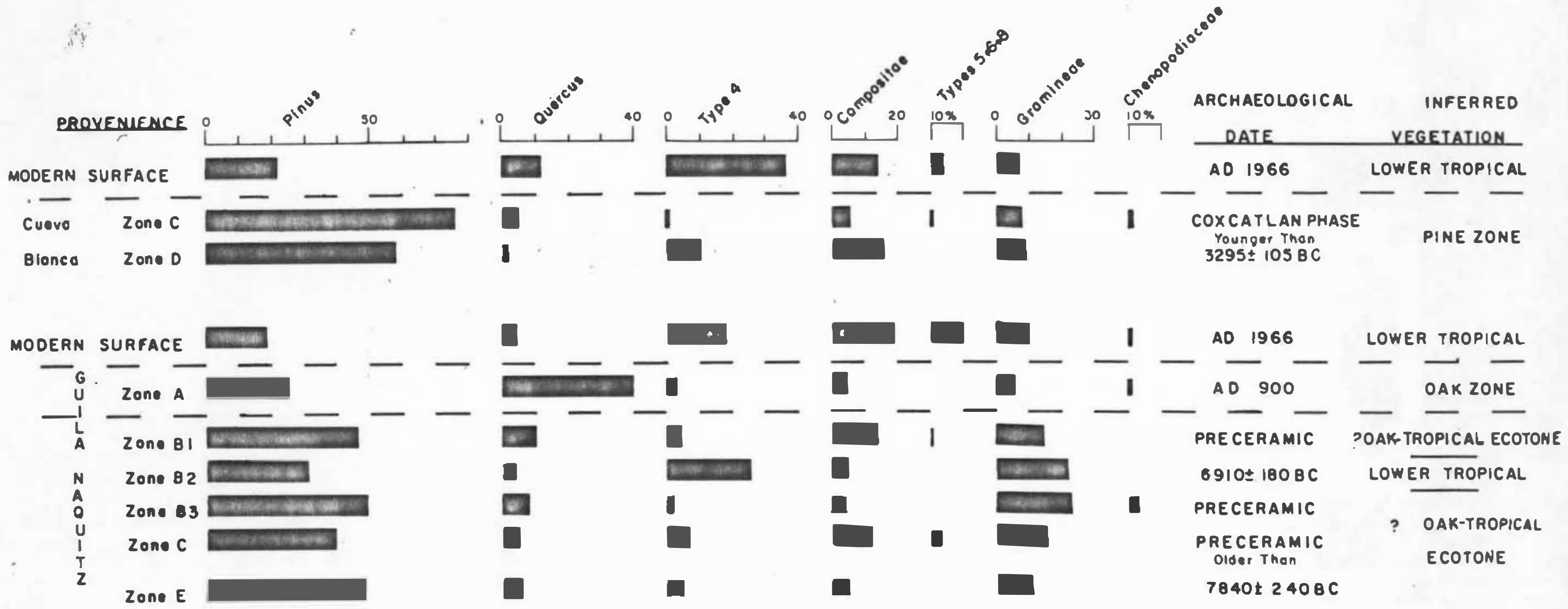

Fig. 5. Significant pollen frequencies from cave sites.

The floodplain physiographic unit is narrow, with a maximum width of 600 meters. It is incised only to a depth of 1-2 meters by major and minor drainages, with the result that wells need be no more than 3 meters deep along the floodplain. The bulk of the valley floor is composed of the thick deposits of the high alluvium. Here wells need be 2 to 10 meters deep to reach the water table. High alluvium is usually separated from the floodplain by a 1-3 meter step.

The soils of the valley floor range from reddish-brown on well drained fan gravels, through brown in most areas, to grayish-brown in the most arid sections. Most soils of the valley floor belong to the Brown Soils Group, but some tendency to Gray Desert Soils is locally seen. Soil profiles are poorly developed and alluvial structure is almost unaltered below the A horizon. Prismatic structure and some salt accumulation is found in the B horizon. Humus and nutrient levels in the soils of the valley floor are generally very low. The critical physical factor which influences use of the soils for agriculture thus becomes that of water holding characteristics.

The best agricultural soils, those which are finer grained and retain water longest, occur on the high alluvium in a band paralleling the river, but at a distance of 500-1500 meters away from it. Except where the high alluvium is more than 2km wide, this band of fine-grained soil extends to, and meets, the piedmont zone. Today, commercial crops are grown on the fine-grained soils. Irrigation of some form is practised because of the high water demands of these crops, but maize could probably be dry farmed. Those soils which are of coarsest grain support drought-resistant crops such as maguey. Intermediate soils are those principally used for subsistance crops with irrigation being practised.

The piedmont zone was probably formed during the Pleistocene as a series of coalescing fan gravels. These were subsequently dissected by streams to form low rounded spurs adjacent to the mountains and isolated hills. The piedmont zone has a slope of 1-2° and incorporates about 30 meters of relief; it grades into the mountain zone where valleys have up to 1000 meters of relief and slopes are steep.

The mountains are formed mainly of pre-Jurrassic metamorphic rocks, Cretaceous limestones, and Miocene ignimbrite tuffs. The tuffs are most extensive in the southeastern area of the valley. Here most of the caves occur which were archaeologically used for habitation. These tuffs provided the easily-worked building stone used for the palaces at Mitla.

Temperatures on the valley floor have a greater mean daily range (15^{o}C) than mean annual range (6^{o}C). The average temperature is 20^{o}C, with extreme minimums close to 0^{o}C. Thus there is slight probability of frost in any year, and then only at the higher elevations of the valley floor. Crops which cannot tolerate frost, such as sugar cane, find most favorable temperatures at lower elevations on the valley floor; continuous crops of maize are also well suited to such elevations, and maize is widely grown up to an elevation of 2300 meters. Above this, summer frosts can occur and wheat becomes a more reliable crop. At 3000 meters frosts are common throughout the year so that potatoes are the principle crop.

Mean annual rainfall varies from 490 mm to 740 mm (ca. 20 to 30 inches) on the valley floor, depending on elevation. For growth of annual crops without irrigation, however, the critical determinant is the ratio of rainfall to evaporation during the summer growing season. This ratio is extremely low in the southeastern part of the Valley. The most favorable ratio for dry farming occurs at 1800-2000 meter elevations where the land is moderately flat and neither too cold nor too dry for successful crops. These conditions are most widely found in the northwest portion of the Valley -- where the highest concentration of archaeological sites has been found. Today, rainfall is supplemented by irrigation in many parts of the Valley, using water derived from the mountains by streamflow or groundwater. Soil texture complicates this picture, but the areas most suited to long-continued year-round irrigation on the valley floor are those where the water table is highest and the risk of frost least. These conditions occur in the regions about Zaachila, Zimatlan, and Ocotlan. The highest percentage of irrigated land is found in these regions.

Soil erosion is not an agricultural problem in the Valley of Oaxaca. Farming is undertaken on the valley floor and the piedmont because of the availability of flat land. Here the aridity creates a sparse natural vegetation; clearing for agriculture does not encourage erosion in these areas since an equilibrium between vegetation cover and slope wash was established millenia ago. Erosion is only a matter of concern in regard to gullying of hillslopes and where dense vegetation at high elevations is cleared.

The "classical" scheme of phytogeographic classification in Mexico deals with eight units: cloud forest, pine zone, tropical deciduous forest, thorn scrub, grassland, desert, and rainforest. There is no rainforest or cloud forest in the Valley of Oaxaca. Species characteristic of all of the other units of this classification exist, sometimes in combinations with these units as defined by one authority or another. Other combinations also exist, and I have felt no hesitation in proposing a somewhat different classification scheme. My objective in this regard was twofold: to allow a classification which had utility for the pollen study, and to allow a classification which would be anthropologically meaningful.

Phytogeographic patterns are generally recognized in two fashions. Either the structure of the vegetation is emphasized (forest, savanna, prairie, desert) or the species composition is emphasized (pine zone, oak zone, mesquite zone). Neither of these emphases is particularly useful for anthropological purposes because the anthropologist is interested in a classification which reflects distinctions in types of economically useful plants and their quantity.

"Natural" phytogeographic patterns probably do not exist in the Valley. Millenia of intensive cultivation, combined with the use of domesticated herbivores, particularly sheep, goat and pig, during the past five centuries, has undoubtedly had much influence on vegetation.

Over the majority of the valley floor, cultivation has eliminated any respectable trace of natural vegetation. There are some localized areas where cultivation is impossible because of saturated or near saturated soil, but these do not support typical floras. Uncultivated floodplains and the edges of irrigation ditches also support specialized floras. The flora of mounds representing archaeological sites on the valley floor often appears undisturbed because the mounds are not plowed. The mounds are used for grazing, however, and may be weeded to remove non-useful plants. Long-abandoned fields, and marginally cultivable land, provide the best indices of the "natural" flora of the valley floor. Such land is available only in the extreme southeast portion of the Valley -- the most arid portion. In this area there are two plant associations. The lower elevation one is characterized by the frequent occurrence of nopal (the large pricklypear cactus) and huizache with mesquite; the upper elevation one is mostly mesquite with few huizache and few nopal -- nopal is replaced by the columnar pitayo cactus. Both of these associations fall into the desert unit of the classical scheme. The lower elevation one, however, is far more useful to man in collecting wild plant foods, particularly during the early summer months when nopal, mesquite and huizache are all ripe. Judging by the occurrence of various shade and food trees, the portion of the valley floor which is now under intensive cultivation may once have supported a tropical deciduous flora.

The piedmont zone contains a number of floristic units. Slope, exposure, elevation, and the nature of the substratum all seem to operate as controls on vegetative diversity in this physiographic unit. Rocky slopes in this zone support a very mixed association made up of species characteristic of all vegetation units that occur below about 2,500 meters. Copal may grow side-by-side with nopal, Mimosa alongside fig, or huizache with the morning glory tree. This rocky slope flora is heavily used by goats and sheep but as a source of wild plant food the rocky slope flora is rather less than of crucial value. Though many edible plants occur, they occur at wide intervals and sporadically. However, something edible will be available in the rocky slope flora at any time during the growing season.

Grasslands, mostly composed of species which are drought-tolerant (and so termed desert grasslands) also occur in the piedmont zone. These are now intensively grazed by cattle and sheep. They show little sign of overgrazing and no indication of having been formed through clearance. There is evidence that some of the desert grassland unit was used for cultivation in pre-historic time in the more arid part of the Valley. Fields of maguey today occur at and within the lower margin of the desert grassland unit, as do some maize fields, but the desert grassland provides almost no wild food resources.

The upper margin of the desert grassland grades into a floristic zone characterized by shrubs and low trees widely spaced in a ground cover of grass. The shrub and tree species involved are mostly of the tropical deciduous group, with very few thorny shrubs. This zone is well grazed; it offers wild plant foods, but these occur in other phytogeographic units in equal or greater quantity.

Another unit of the piedmont, which continues into lower elevations in the mountains, is that characterized by species usually accorded placement in the tropical deciduous forest, the thorn forest, and the desert zones. This phytogeographic unit is extremely variable in both its species composition and its density, and is best described in terms of two subzones. The lower of these contains no oak and has a more frequent occurrence of species that occur as part of the rocky slope and valley floor floras. This lower sub-unit is often characterized by edible leguminous shrubs of a number of genera. In general, this lower sub-unit is the most useful for wild food gathering as its species diversity and density combine to make it highly productive. The upper sub-unit of the Tropical Deciduous Forest and Scrub, as I am now calling it, contains most of the same species. It also has species peculiar to it (e.g., Fouqueria) and it contains oak. There are sufficient edible plants in this sub-unit to make it a good one for food collecting, though the lower sub-unit is far more productive. Neither sub-unit presently has much economic value.

The lowest phytogeographic unit of the mountains is that in which encino oak (a "sweet-acorn" [illegible] nant or as co-dominant with a species of broad leafed oak. The wild food potential of this unit is practically limited to acorns. Above this unit is one in which encino, broad leafed oak, or manzanita, may be dominant or may be co-dominant with each other or co-dominant with pine. This zone supports many varieties of shrubs with edible fruits and, before recent logging, probably supported pinyon. This highly variable phytogeographic unit has a wild food potential equal to or greater than that of the valley floor flora. Foods of this unit, however, become ripe after those of the valley floor and tropical units. This zone is also distinct in its wild food potential because of its areal variability. In some districts edible Ericaceous shrubs occur in very low frequency; in others they form the dominant plant type. There are probably very few districts within this phytogeographic unit where the full wild food potential may be realized. This unit has very little economic value today.

The higher phytogeographic unit of the mountains is characterized by pine and broad-leafed oaks; there are very few oaks of the encino type that provide sweet acorns. This pine zone may contain few or many pines; it may have a nearly closed tall forest canopy or an open low canopy, and it may have deep or shallow soils. It has a relatively low wild food potential but is of value as a lumber source.

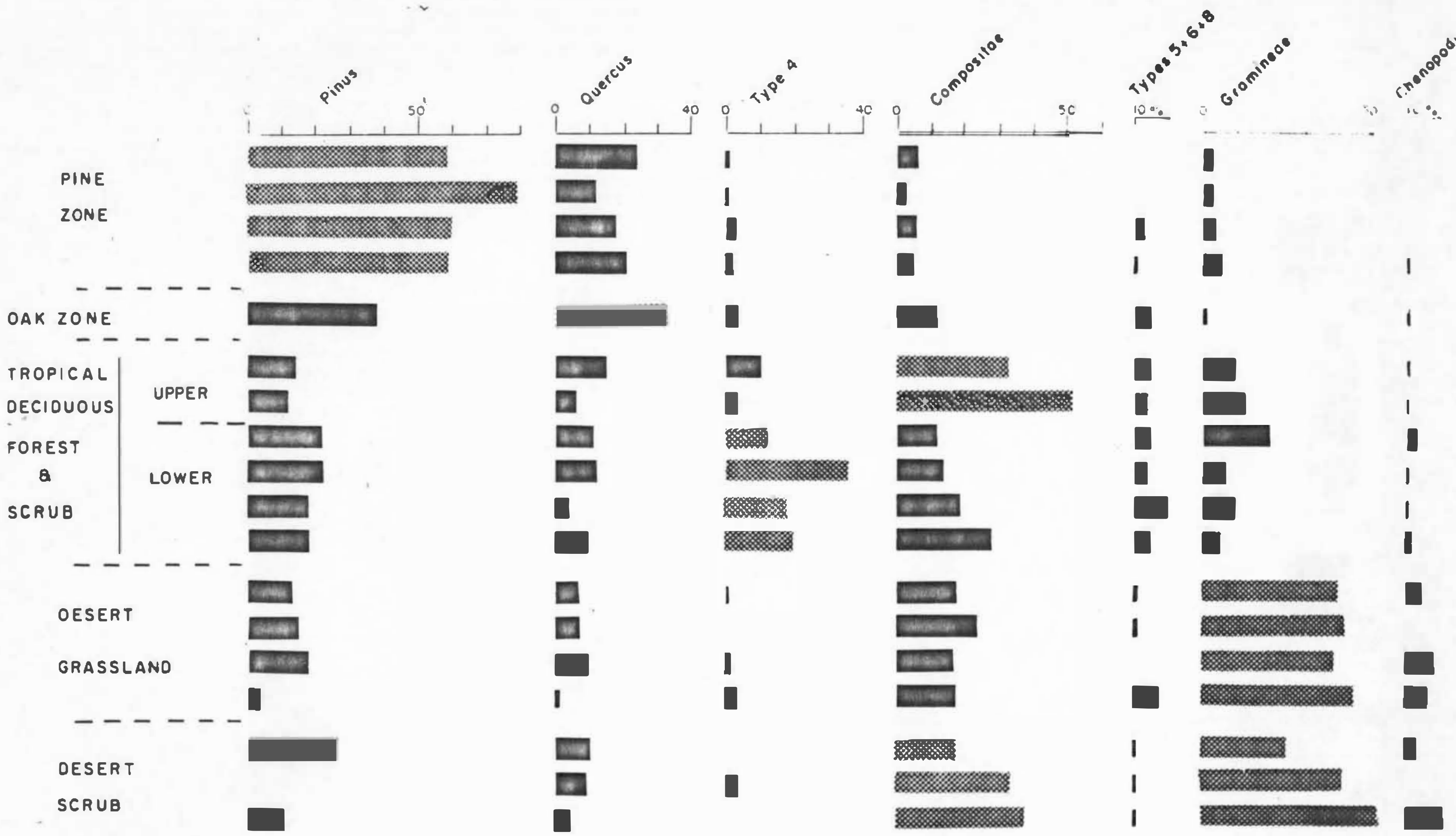

Fig. 1. Significant pollen frequencies of surface sed

In terms of wild food potential, it is thus seen that of the ten phytogeographic units there are five which offer both a variety and a quantity of wild plant resources. Two of these occur on the valley floor, two in the piedmont, and one in the mountains. The vegetation growing in the area of preceramic cave sites is that of the most productive phytogeographic unit. As will be seen, however, this was not generally the case at the time the caves were occupied. In any case, the plant foods of even the productive units ripen at different times of the year. To utilize all the productive zones efficiently a group would have to move upslope as the spring and summer months passed. Most of the plant foods available are storable and could be transported to a base camp.

Another classification scheme was devised for purposes of paleoclimatic research. Our concern here was with the recognition of phytogeographic units which express moisture values through their respective pollen rains. The analysis of surface pollen samples collected under known conditions of vegetation illustrated that six moisture units are clearly expressed by pollen rain (Fig. 1). All surface sediment samples from the pine zone contain large quantities of pine pollen. This is true whether or not pine is the dominant tree at the locality sampled. The single available sample from the oak zone contains significantly more oak pollen than samples from any other zone. Thus pollen spectra containing 30% oak pollen or more can be recognized as expressing less moisture than those which contain 50% or more pine pollen and more moisture than those which contain less oak and less pine pollen. I should like to emphasize the fact that the palynological expression of a vegetation pattern has nothing to do with the species composition of that pattern. The oak zone pollen sample was collected in a stand which had no pine whatever and about a 75% coverage of oak. There is, however, only 33% oak pollen and 38% pine pollen.

The upper sub-unit of the Tropical Deciduous Forest and Scrub zone can be easily distinguished from the lower sub-unit by virtue of its pollen rain. The upper sub-unit contains quantities of Compositae pollen, while the lower one contains quantities of an unknown type I am presently calling Type 4. The upper sub-unit, parenthetically, does not actually have a greater number of Compositae plants, and the lower one probably does not have large numbers of whatever plant is represented by Type 4. Again, the palynological and the floristic expressions of a phytogeographic unit are controlled by different factors.

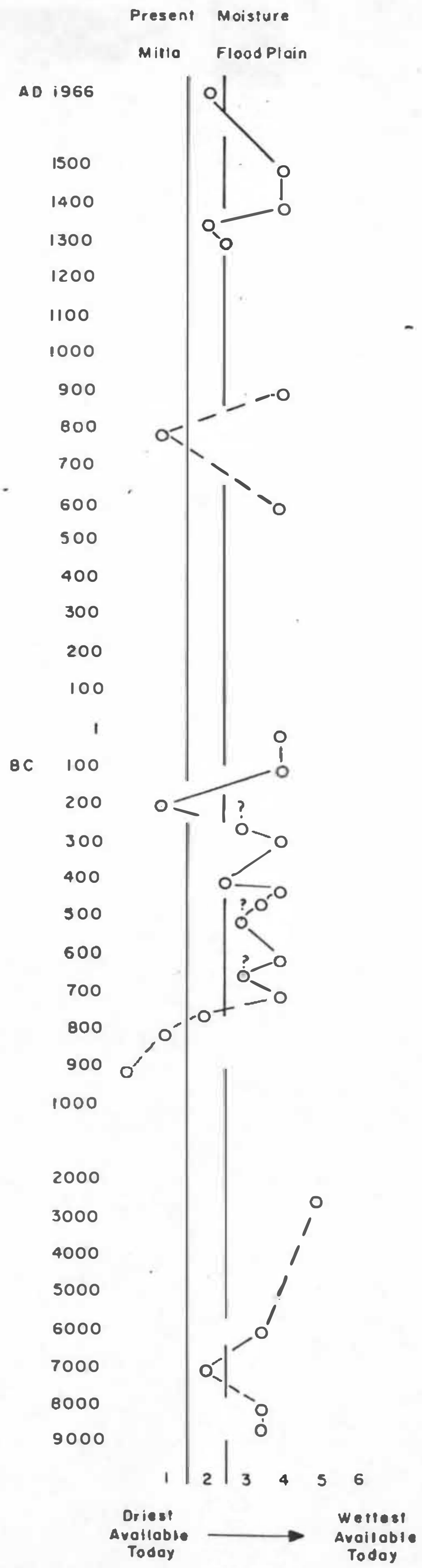

Fig. 2. Chronology of moisture fluctuations relative to the Mitla flood plain.

The palynological differentiation of the sub-units is, in fact, more obvious that the floristic ones.

The phytogeographic unit which has trees and shrubs spaced in a ground cover of grass is not significantly different in pollen spectrum from desert grassland samples. For the time being, I am combining them as one moisture unit called desert grassland. This unit is characterized by high frequencies of grass pollen. Both of the phytogeographic units of the valley floor in the arid portion of the valley have a similar palynological expression. Here both grass and Compositae pollen reach high frequencies. The pollen rain of the rocky slope flora - the most arid of the piedmont phytogeographic units - is like that of samples from the arid portion of the valley floor. Since the elevated rocky slopes receive more rainfall than the valley floor, it is obvious that the pollen record expresses available moisture from any source that plants use, not simply precipitation.

Now let us turn to the environment of the Valley of Oaxaca in the past.

I have already pointed out that there is no geological evidence supporting the Zapotec legend of a lake in the Valley during prehistoric time. There is geological evidence, however, that water tables were once higher than they are today. Clearest demonstration of this comes, however, from the archaeological record at the well at the site of Balah Bisiye. This will be discussed presently by Mr. Orlandini. Perhaps more important is the lack of geological evidence indicative of any major climatic change in the Valley since Pleistocene or early Recent times. Nothing on the order of a change from glacial to non-glacial conditions, or tropical to arid ones, is evidenced geologically.

The botanical records are in essential agreement. Most of the plant macrofossils recovered are of genera presently occurring in the Valley or are fairly evident trade materials. The pollen record for the past 11,000 years is far from complete, but it also shows no clear major climatic fluctuations.

There are, however, fluctuations in the chronology of moisture variation (Fig. 2). The surface pollen samples allow us to recognize six units of moisture variation present in the Valley under today's climate. The floodplain of the Mitla area would today be classed in the second driest of these units. Pollen samples collected from the Mitla floodplain in association with datable ceramics, however, indicate the former existence of conditions drier than today and wetter than today in this part of the Valley. Going by the ceramic dates, the 15th century was wetter than it is now, as were most centuries from which we have available data. The periods about A.D. 800, 200 B.C., and about 900 B.C., however, were drier than today. The period ceramically dated between 1300 and 1400 A.D. indicates moisture values like those of today, as does the period about 800 B.C.

Though we as yet have only a very partial record of the moisture variations which occurred over the 3000 years since thebeginning of the Formative, it is clear that fluctuations in moisture values have taken place. Two initial questions occur: (1) how much of a fluctuation does this amount to, i.e., are these fluctuations of agricultural significance; and (2) what was the cause of these fluctuations? Because irrigation is now known in the area from an early Formative horizon, the moisture fluctuations may be reflections of technology rather than natural conditions.

I feel that the cause of most, if not all, of the recorded moisture fluctuations is environmental rather than technological. If they were technologically dependent, it does not seem likely that identical records of moisture variation would occur at two different sites on the same time horizon. Yet such identity can be illustrated. Two sites on the Mitla floodplain yielded pollen dating to A.D. 1300. The sites are separated by about a kilometer, but both indicate the same moisture index for that date, a moisture index two units higher than presently occurs. One site on the Mitla floodplain yields samples immediately below a horizon dated 700 B.C. This horizon indicates a moisture index like that presently occurring. A site on the Etla floodplain contains a sample dated 800 B.C. This sample also indicates a moisture index like that of the present. A site on the Mitla floodplain contains a sample dated to 900 A.D. that has a moisture index two units higher than occurs at present. A sample from a cave site dated 900 A.D. also indicates a moisture index two units higher than presently occurs. While more cases are needed to confirm the conclusion, all available records point to a non-cultural determinant for the moisture values recorded.

How much moisture fluctuation are we dealing with, then? The answer to this is provided by surface samples. The difference in moisture index represented by the maximum and minimum records of the past 3000 years is approximately equivalent to the difference recorded in surface pollen samples from the Etla floodplain and the most arid part of the valley floor. In agricultural terms, the difference is thus equal to the distinction between the worst dry farming land in the Valley today and the best dry farming land. It seems very likely, then, that the moisture fluctuations evidenced in this record are agriculturally meaningful. However, these fluctuations do <u>not</u> exceed the limits within which irrigation can make the difference between high and low crop productivity on the valley floor. In effect, none of the fluctuations necessarily had any agricultural significance during a period when irrigation was practised.

This, of course, dumps the problem of agricultural potential back in the lap of the archaeologist. If irrigation was <u>not</u> practised on a floodplain, periods as dry as today or drier would have resulted in agricultural stress. If it was practised, then there was no necessary stress during Formative and later times.

Our records from the Archaic Period are very spotty, and are difficult to deal with in any meaningful way. We have, in effect, only one pollen sample for a period which may easily cover a millenium of time. Somehow, we must try to compare such samples with those which represent only centuries of time.

The available data indicate that through much of the Archaic Period the valley floor was somewhat moister than today -- as was the case in Formative, Classic, and Post-Classic time. Occasionally it seems to have been as dry as it is today, and occasionally much more moist than during the succeeding periods. The very moist horizon occurs during the Coxcatlan Phase, definitely after 3200 B.C., but probably before 2000 B.C.

Two other archaeological questions may be raised: (1) does environmental fluctuation appear to play any role in the development of cultigens; and (2) does environmental fluctuation appear to play any role in the development of the Formative.

A pollen sample associated with Archaic material known to be older than 8000 B.C. indicates an environment one or two units moister than that occurring today. This sample does <u>not</u> contain pollen of possible cultigens, though it does contain pollen evidence of wild food collecting (<u>Agave</u>). The next highest level, which must be dated sometime in the 8th millenium B.C., contains macrofossils of squash and beans and pollen of teosinte or wild maize or both. The combination of beans, squash and teosinte, and possibly beans, squash and corn, must surely be indicative of incipient, if not full, cultivation. However, the environmental conditions are not different from those evidenced in the pollen sample preceding evidence of incipient cultivation. There is thus no evidence of an environmental fluctuation which may have acted as the stimulus for the beginnings of agriculture in the Valley of Oaxaca.

There is, as yet, no palynological record for the period just preceding the earliest Formative in the Valley, nor are there records from the earliest Formative horizon. In the late part of the San Jose Phase of the Formative, however, the pollen record indicates maximally dry conditions in the Valley of Oaxaca. The area which is now the best dry farming land in the Valley at that time had the agricultural potential of the districts which are now the worst dry farming land. If these conditions were typical, it is difficult to imagine an environmental stimulus for the beginning of the village farming communities. Indeed, an environmental determinist would have to acknowledge that the early Formative was probably the worst period for agriculture -- especially dry farming -- that has occurred in the Valley in the past 11,000 years.

Supplementary Report

Pollen of Cultigens

Pollen of cultigens in both surface and subsurface samples. In the surface samples, the only cultigen pollen was Zea. It was found in two samples from Hierve el Agua (1 grain each), the sample from Santa Ana Tlapocoyan (4 grains), a sample from Ajido land near Tanivé (1 grain), the sample from Roalo (3 grains), and the rocky slope flora sample collected above Cueva Blanca (2 grains).

Zea pollen was recovered from all of the sedimentary units analyzed at floodplain sites, with the exception of the culturally sterile unit 8A at Balah Bisiye. It was also recovered in unit A at Guila Naquitz. Individual samples range from 0 to 18 grains of Zea per 100-grain count. Because of the various fashions in which cultivated plants are handled, their pollen rains cannot be considered natural in any sense of the word. The quantity of cultigen pollen occurring in any given sample or sample series must be recognized as an irrelevant datum. Presence of cultigen pollen undeniably indicates occurrence of the plant at the horizon sampled, but absence does not indicate absence of the plant.

The following table shows the occurrence of other cultigen pollen. Pollen types marked with an asterisk represent plants that were possibly represented in the pollen rain because they were collected for some purpose.

Type	Common Name	Site & Unit	Date
Cucurbita moschata	squash	OS-68, unit 2	1 AD
" "	"	" unit 6	200-250 BC
" "	"	06-62, unit Bl	? 800 BC
" "	"	Guila Naquitz, unit B3	>6900 BC
Cucurbita pepo	pumpkin	Cueva Blanca, unit D	3300 BC
*Agave sp.	agave	06-68, unit 6	200-250 BC
"	"	06-67, unit 1	1300-1500 AD
"	"	Cueva Blanca, unit C	<3300 BC
"	"	unit D	<3300 BC
"	"	Guila Naquitz, unit A	900 AD
"	"	" ", unit Bl	<6900 BC
"	"	" ", unit B3	>6900 BC
"	"	" ", unit C	>6900 BC
"	"	" ", unit E	>7800 BC
*Platyopuntia	nopal	06-68, unit 6	200-250 BC
"	"	06-67, unit 7a	6-700 BC
"	"	", unit 7c	ca.7-800 BC
*Cactaceae	? Lemaireocereus	06-67, unit 6	4-500 BC

Type	Common Name	Site & Unit	Date
*Cactaceae	?Lemaireocereus	Guila Naquitz, unit A	900 AD
"	"	" " , unit B3	>6900 BC
*Tripsicum	Tripsicum	Cueva Blanca, unit C	<3300 BC
"	"	" " , unit D	<3300 BC
"	"	Guila Naquitz, unit B1	<6900 BC
"	"	" " , unit B2	6900 BC
"	"	" " , unit B3	>6900 BC
"	"	" " , unit C	>6900 BC
Euchleana or wild Zea	Teosinte or wild corn	Guila Naquitz, unit B2	6900 BC
"	"	" " , unit B3	>6900 BC
"	"	" " , unit C	>6900 BC
*Ericaceae	?edible heaths	Guila Naquitz, unit B1	<6900 BC
*Ribes	current	" " , unit B1	6900 BC

It may be relevant that *no Zea* or *Euchleana* pollen was observed in a 600-grain scan of unit C and a 450-grain scan of unit D at Cueva Blanca. The 100-grain count of Unit E at Guila Naquitz produced neither *Tripsicum*-type nor *Euchleana*-type pollen, but all others (except unit A) did yield these types.

An unknown pollen type (Type 12) which is evidently a member of the Malvaceae (mallow family) was found in Unit 6 at OS-67 and in Unit A at Guila Naquitz. Because of its large size I was suspicious of an identification to the genus *Gossypium* (cotton). Reference slides of these species in this genus, including *G. hirstutum*, were requested from the pollen herbarium of the University of Arizona for comparison with Type 12. Type 12 does not compare favorably with them; it has a far higher pore number than the reference specimens. However, there is great variability in pore number among the reference specimens. It is not impossible that the range of variation in *Gossipium* pollen does encompass Type 12.