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A POLLEN DIAGRAM OF THE PLEISTOCENE–HOLOCENE BOUNDARY OF LAKE VALENCIA, VENEZUELA

[redacted]

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ABSTRACT

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The deepest part of a core from Lake Valencia (403 m elevation) was studied. Radiocarbon dating shows that the section includes the Pleistocene–Holocene boundary. The pollen analysis indicates that the Pleistocene lake had desiccated, and from 13,400 to approx. 11,500 B.P. the site (today under 40 m water) was a swamp or intermittent lake. The region was covered by semi-arid vegetation. Shortly before 10,700 B.P. precipitation increased but evaporation was probably very high. Around 10,000 B.P. the lake started to form again. Dry or thorn forest and savannas occupied the region around the lake, and rain forest covered the mountain top. At that time the lake was smaller than today.

The Valencia dry phase at the end of the Pleistocene corresponds to the end of the Glaciation period in the northern Andes.

INTRODUCTION

Lake Valencia occupies a large graben between two mountain ridges: the Cordillera de la Costa (north) and the Serranía del Interior (south). The La Victoria fault zone separates the two ridges (Fig.1) and it appears to have been an active feature during the Late Quaternary and Holocene (Schubert and Laredo, in prep.). It is the largest natural fresh-water lake in Venezuela (360 km^2) and it seems to have formed at the end of the Tertiary or the beginning of the Quaternary (Peeters, 1968). Lake terraces above the present water level (Berry, in Schubert, 1979) indicate water-level fluctuations which reached a maximum between 425 and 427 m above sea level (present lake level is at 403 m), and at that time the lake probably drained towards the southwest into the Orinoco Basin. At present, it is an endorheic basin which is undergoing rapid desiccation, and it has not discharged any water for almost two centuries.

The study of lake terraces and of the deposited clay, led Peeters (1968, 1970, 1971) to describe three phases in the history of the lake: an initial humid phase at the end of the Tertiary or beginning of the Quaternary; a semi-arid phase at the end of the Pleistocene and the beginning of the Holocene; and a humid phase that extended to the present. During the last

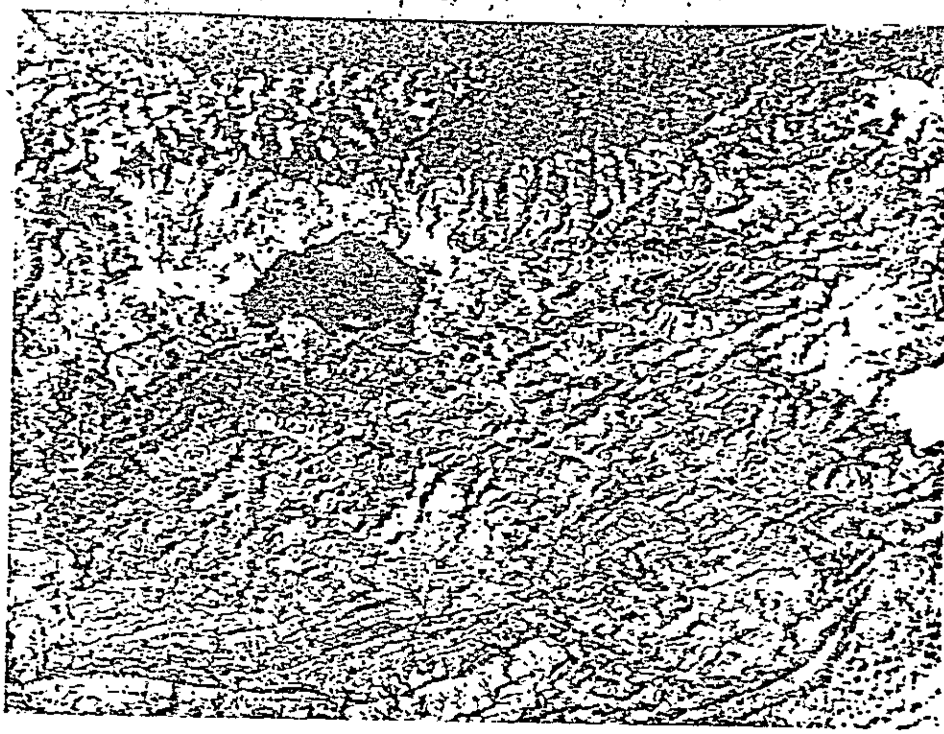

Fig.1. Lake Valencia, Satelite photograph NASA-ERTS, December 1975.

phase the lake was thought to have reached its maximum size, and it started to desiccate only during the last centuries.

An exhaustive and careful revision of previous studies concerning Lake Valencia was done by Schubert (1979), and he shows that between 1908 and 1960 the water volume was reduced by about 31%, and the lake area by about 20%. Several interpretations were attempted to explain this rapid desiccation, including capture of its streams by another basin (Cruxent and Rouse, 1958), climatic events (Peeters, 1968), extensive forest clearance and evaporation (Humboldt and others, see Schubert, 1979), and indiscriminate use of the ground water by industries and by the two adjacent cities of Valencia and Maracay. Radiocarbon dating of ground water within the Valencia basin (Tamers and Thielen, 1966) shows that this water takes five or six thousand years to flow from the basin edges to the lake. Tamers and Thielen suggested that the actual desiccation of the lake reflects hydrologic conditions which resulted from climatic events that took place about six thousand years ago.

Remains of Pleistocene hervibores have been found in the lake basin (Cruxent and Rouse, 1958). Old settlements and burial sites around the lake and on its islands show that the region has been inhabited by man for a long time. Human bones have been radiocarbon dated at 4200 ± 320 years B.P. (Peñalver, undated). The region has been intensively cultivated ever since the arrival of the Spaniards.

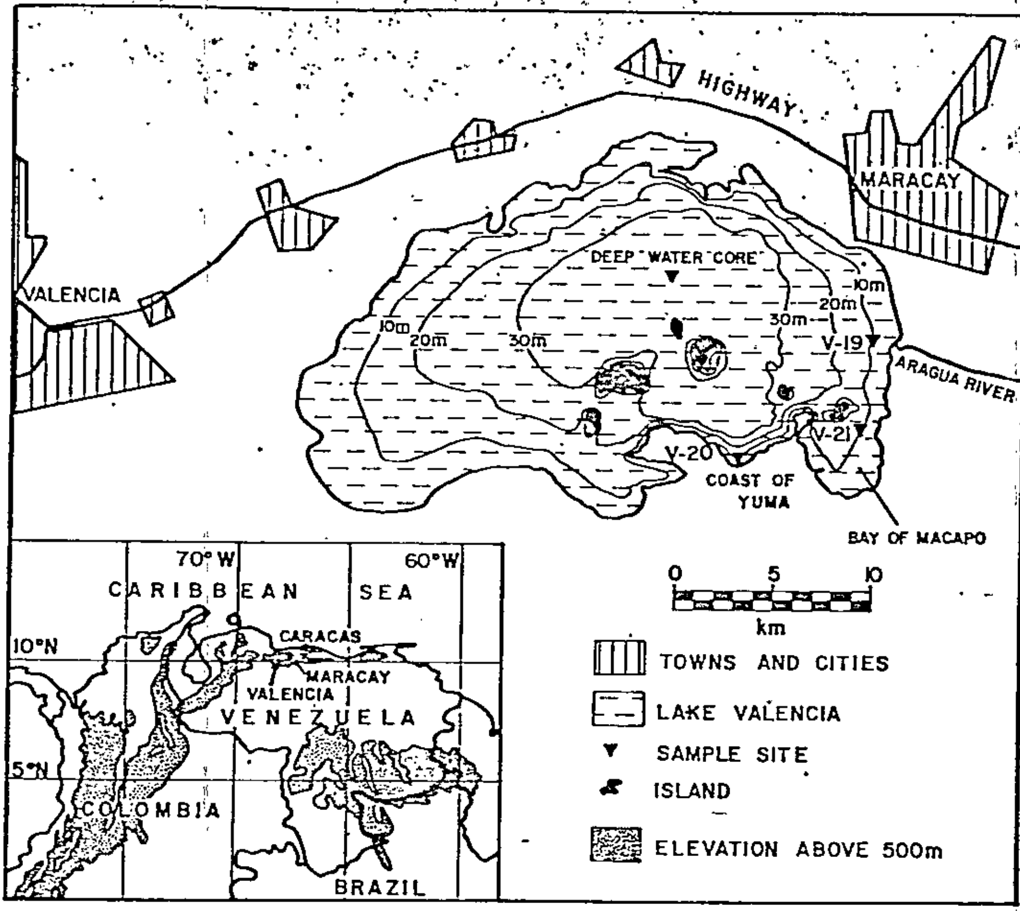

Fig.2. Map of Lake Valencia showing the location of the deep core and of the samples V-19 to V-21. Base map: Dirección de Cartografía Nacional, Venezuela 1968, sheet 6646. Inset: northern South America with location of the towns Caracas, Valencia and Maracay.

Geomorphological studies suggest that the lake sediments may be about 200—300 m thick (Peeters, 1973). A seismic survey with a resolution depth of ca. 80 m shows that sediments are present to that depth (Schubert and Laredo, 1978).

A joint Venezuelan—North American study of the ecosystem and the history of Lake Valencia was begun in the summer of 1976. Samples of several cores were divided among researchers for the study of pollen, diatoms, animal remains and paleolimnology. The author is particularly interested in the Pleistocene—Holocene boundary conditions, and for this reason this article will focus on the deeper part of the core. The more recent sediments and shallow-water cores are being studied by Leyden et al. (1978).

MATERIAL AND METHODS

Coring operation

A 7.43 m core was taken from the center of the lake at a water depth of 36.75 m. A coring platform floating on 50-gallon drums provided the base for coring. The sampler was a modified Livingstone type with 2-in. (0.05 m) diameter, stainless-steel rod piston corer. The sediment was drilled by hand. The coring stopped at 7.43 m depth below the bottom where a very compact silty layer prevented further penetration.

The core sections were extruded in the field and stored in sealed containers with nitrogen. They were subsampled in the laboratory on the basis of physical appearance without exposure to oxygen. Each sample was homogenized to provide all interested investigators with the same material, and divided among collaborators in the project. Fourteen samples from the core have been sent out for radiocarbon dating, but only nine gave results, due to the nature of the material (Table I).

Details on the coring operation and dating will be given elsewhere.

Description of the core

The sediment—water interface and the uppermost 0.15 m consist of a very dark organic-rich sediment with a very high water content. At ca. 0.15 m there is a transition to a more compact and light-colored sediment with a high organic and water content down to about 3.60 m. Between 3.70 and 4.70 m there are several thin layers of aragonite (Bradbury, 1978), about 1 mm thick each, alternating between brown organic layers of variable thickness (Fig. 4,

TABLE I

Radiocarbon determination from Lake Valencia

Laboratory No.	Depth (m)	Age (radiocarbon years B.P.)
W — 4146	0.22—0.25	700 ± 200
DIC — 959	1.02—1.05	1,820 ± 70
DIC — 960	1.91—1.95	5,210 ± 115
DIC — 961	2.30—2.34	6,730 ± 345
W — 4134	3.46—3.49	8,670 ± 250
W — 4143	4.58—4.62	10,340 ± 350
W — 4150	4.70—4.73	10,200 ± 350
W — 4140	4.88—4.92	9,840 ± 400
W — 4147	7.14—7.28	12,930 ± 500

W = U.S. Geological Survey Radiocarbon Laboratory, Reston, Va. (U.S.A.).
DIC = Dicarb Radioisotope Company, Chagrin Fall, Ohio (U.S.A.).

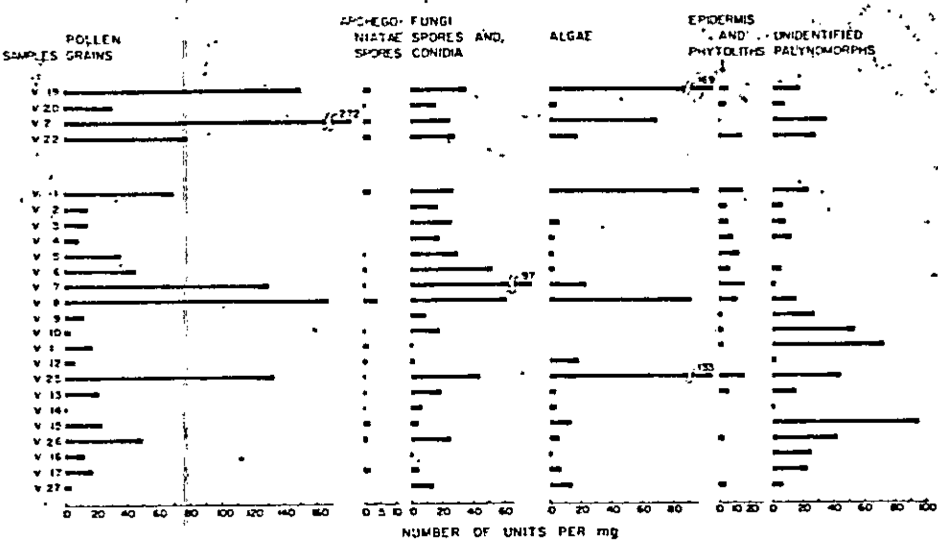

Fig.3. Abundance of pollen, spores, algae, and grass epiderms and phytoliths within Lake Valencia. Samples V-19 to V-22 are from the water—sediment interface. The other samples are from the deep-water core in stratigraphic order, older level at bottom.

left side). Just above 5 m depth there is an abrupt change to a very fine and compact clay that continues to the bottom of the core, at 7.43 m.

Method of preparation of samples for pollen analysis

Initially 17 samples for the interval 3.78—7.43 m were selected by the field team on the basis described above, and numbered from V-1 to V-17 (top to bottom). Most samples were 3 cm long, but sample V-17 was 14 cm long (7.14—7.28 m) because it had little organic material, and it was desirable that the ^{14}C dating would be possible. A preliminary note on the first 17 samples was given at the AsoVac Congress (Salgado-Labouriau, 1978). I later took three more samples at the intervals suggested by the results from the earlier samples. They were numbered from V-25 to V-27.

Four samples (V-19 to V-22) were taken from the water—sediment interface (Fig.2) in order to determine the modern pollen assemblage:

V-19 in front of the mouth of the river Aragua (10.00 m water)
V-20 coast of Yuña (9.15 m water)
V-21 bay of Macapo (12.90 m water)
V-22 deep-water core (36.75 m water), sample taken at 0.15 m below the water—sediment interface

Six grams of material were taken from each sample, and prepared by boiling in 10% KOH, sieved to remove shells, and acetolyzed. Next they were treated with 10% HCl followed by 40% HF (Salgado-Labouriau et al., 1977).

The number of grains per milligram was estimated by counting all grains mounted in at least two slides which contained over 2.5 mg of sediment (Salgado-Labouriau, 1973; Salgado-Labouriau and Schubert, 1976). Grain counts were continued in glycerine till no new type appeared among 60 consecutive grains (Salgado-Labouriau and Schubert, 1976; Salgado-Labouriau et al., 1977). The V-11 tube broke during preparation and the remaining sediment yielded only 220 grains, and did not reach saturation. Level V-16 had only 54 grains, and they were badly preserved.

The pollen sum was calculated using the total of pollen grains counted. Spores of Archegoniatae were recorded as percentage of the pollen sum. Other palynomorphs, such as spores of fungi, algae, and others are given as numbers per milligram.

Pollen types will be described elsewhere. Identification was based on reference slides of pollen from the modern regional flora, and on Salgado-Labouriau's (1973) description of savanna pollen types.

ANALYSIS OF THE DATA

Absolute number of palynomorphs per milligram (Figs.3, 4)

Abundance of palynomorphs is shown in Fig.3. Surface samples (V-19 to V-22) are dominated by pollen grains and have 30—272 grains per mg. Archegoniatae spores are scarce in all samples. Algae are abundant in V-19 and V-21. Fungi spores and conidia are 16.0—37.7 units per mg. Grass epidermis and phytoliths occur in low quantity.

The deep core sediment, in the interval 3.78—7.43 m, has as low a quantity of Archegoniatae spores as the surface samples (Fig.3). The abundance of pollen grains oscillates along the interval, and is very low in some levels. The most abundant levels are V-7 and V-8 with more than 100 grains per mg; and the less abundant are V-10, V-14 and V-27 with less than 5 grains per mg. Fungi spores and conidia are scarce at the bottom and increase towards the top with the maximum at V-7. Grass epidermis and phytoliths occur only in the upper part of this interval. Algae have three main maxima which occur at the same levels as the pollen maxima. These maxima are due to different algae. In the upper part most algae belong to *Pediastrum* (Fig.4), although a few other Chlorococcales and *Botryococcus* were found. Spores of Zygnemataceae are found only in the older sediments below 5.88 m. Other algae, such as diatoms, were probably destroyed by the pollen preparation techniques. The two main genera found in the surface samples (*Botryococcus* and *Coelastrum*) are mostly absent in the core (Fig.4).

The diagram of absolute number (Fig.4) includes the most abundant palynomorphs (over 2 units per mg). In the modern pollen assemblages grass pollen dominates the terrestrial herbs, whereas *Amaranthus* (two species) dominates the aquatic plants. *Botryococcus* and *Coelastrum* are the most frequent algae. In the old sediments grass pollen dominates the upper part (3.78—4.73 m) with a maximum at 3.93—4.06. *Bursera* has a maximum between 4.58 and 4.73 m, and Compositae between 4.32 and 4.73 m. The

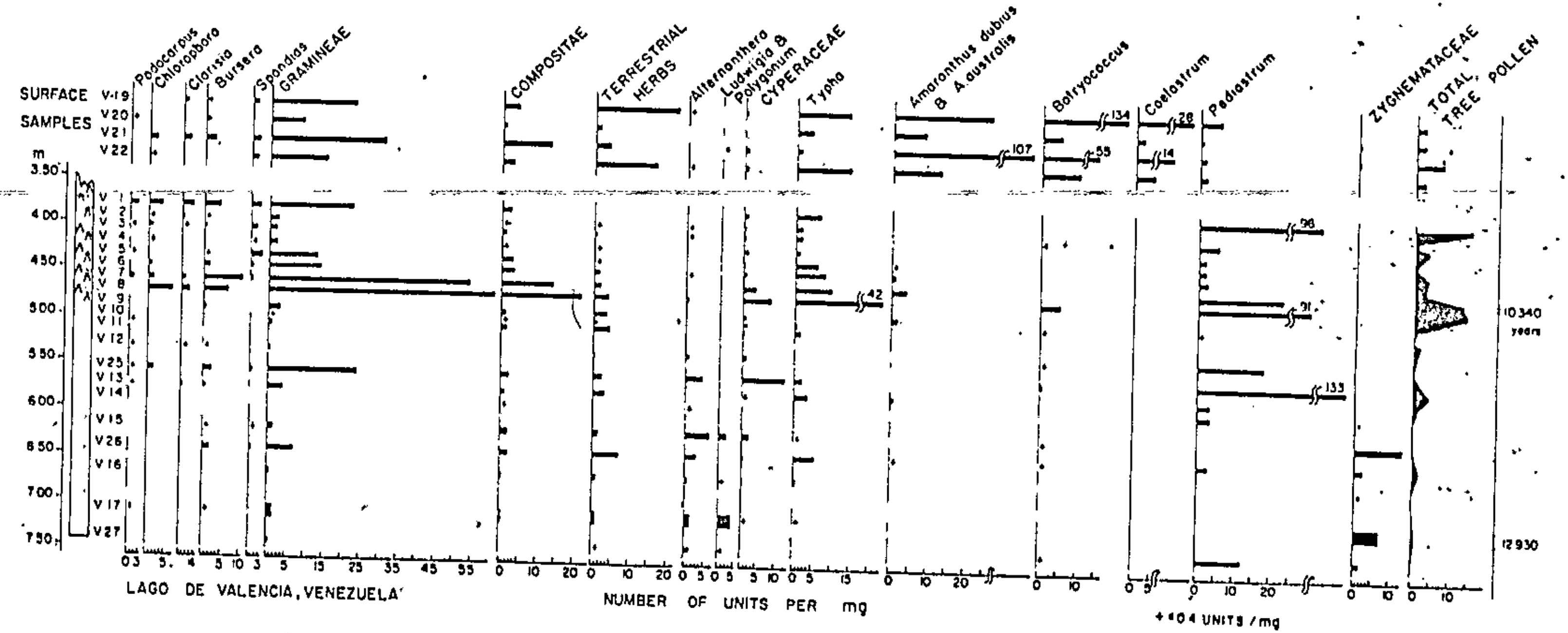

Fig.4. Histogram of the absolute values for pollen grains and algae from Lake Valencia deep-water core.

scarce assemblages of the lower part (6.17–7.43 m) contain pollen of swamp plants mainly; grass pollen is low, and tree pollen is mostly absent.

Relative pollen frequency (Figs. 5, 6, and Table II)

Although in many levels pollen grains are scarce, more than 300 grains were obtained per level (except V-11, V-14, V-16, V-17) which enables comparison of number of pollen types and of relative values of types among these and the more abundant levels.

The total number of pollen grains, trilete and monolete spores, and the total number of grain types counted are given in Table II. Diversity increases towards the top. Between 7.43 and 5.88 m the assemblages have 11 to 49 pollen types, and from 5.77 to 3.78 m they have 29 to 62 types. In the surface samples (V-19 to V-22) the number of types goes from 39 to 51 which falls into the range of the core upper part.

The pollen sum includes all the pollen grains; and is divided into five groups:

(1) Rain-forest trees: *Podocarpus*, *Chlorophora*, *Clarisia*, *Tapirira*, *Trema*, *Cecropia*, *Heliocarpus*.

Two types from the Andean montane forest are found in small quantities: *Alnus*, *Juglans*.

(2) Dry forest trees: *Bursera*, *Machaonia*, *Bravaisia* and *Macrolobium* (deciduous forest); *Acacia* and *Spondias* (thorn forest). The genus *Byrsonima* (savanna) is also included in this group.

(3) Other trees (genera and families that have species in different forest formations): Myrtaceae, Leguminosae (*Cassia* and *Andira* type); Mimosoideae

TABLE II

Total number of pollen grains, monolete and trilete spores counted in the deep-water core from Lake Valencia

Samples	Number of grains	Number of types	Samples	Number of grains	Number of types
V-1	690	54	V-13	751	62
V-2	311	33	V-14	148	21[a]
V-3	438	36	V-15	372	34
V-4	493	44	V-16	54	11[a]
V-5	533	29	V-17	285	35
V-6	519	36	V-19	678	39
V-7	663	39	V-20	563	51
V-8	1097	52	V-21	1234	45
V-9	434	41	V-22	755	44
V-10	410	36	V-25	1233	49
V-11	220	44[a]	V-26	478	41
V-12	520	41	V-27	233	16

[a]Counting has not reached saturation.

(other than *Acacia*), Bombacaceae, Anacardiaceae (other than groups 1 and 2), *Rapanea*, *Protium* and *Pera*.

(4) Terrestrial herbs and shrubs: Gramineae, Compositae, pantoporate grains (Chenopodiaceae, Amaranthaceae, Portulacaceae), Apocynaceae, Cucurbitaceae, *Sida*, *Ipomoea*, *Gomphrena*, *Tribulus* and *Peixotoa*. Although there are some aquatic and swamp grasses, as a first approach, all the grass pollen was put together in the terrestrial plant group.

(5) Aquatic and swamp plants: *Typha*, *Amaranthus australis*, *A. dubius*, *Ludwigia*, *Polygonum*, *Alternanthera* and Cyperaceae.

Other plants such as *Hyptis*, *Castella* type, Melastomataceae and Araliaceae, were placed separated in the end of the diagram because they occur in very small quantities (less than 0.4%, usually one grain).

The pollen diagram of relative values is shown in Figs.5 and 6. From the bottom of the core (7.43 m) up to 5.88 m grass pollen is low (13—17%) as well as other terrestrial herbs. Tree pollen is mostly absent, and does not include rain-forest types. *Alternanthera* dominates. This genus has about fifteen species in Venezuela occurring in different habitats. Most of the grains found in this interval are 20—21 μm in diameter which falls in the size of *A. sessilis*, a swamp plant. Although it is not yet possible to identify species in the old sediment, these pollen grains probably belong to a local swamp plant because they are associated with *Polygonum* and *Ludwigia* (Fig.6).

At levels V-13 and V-25 (5.77—5.59 m) there is an increase of grass and tree pollen that declines at the next level (V-12). The swamp elements are still present.

The interval between 5.08 and 4.88 m (V-11 to V-9) is characterized by a maximum of pantoporate grains (probably Chenopodiaceae), a drastic reduction of *Alternanthera* pollen, and the absence of the other swamp pollen.

From 4.73 to 3.78 m grass pollen dominates the assemblages, and reaches its maximum. *Bursera* dominates among the tree pollen (probably more than one species), followed by *Spondias* in the uppermost part. Rain-forest pollen increases in frequency and number of types, the same occurring with other trees. The swamp elements from the first two intervals are absent and are replaced by *Typha* and *Amaranthus dubius*.

In the surface samples (water—sediment interface V-19, V-20 and V-21) and at 0.15 m below the interface (V-22) the assemblages are dominated by grass pollen and the aquatic plants *Typha*, *Amaranthus dubius* and *A. australis*. Tree pollen is low and its relative value is lower than in the intervals 3.78—4.73 m and 5.59—5.77 m. In general the modern assemblages are similar to the interval 4.73—3.78 m, indicating that the modern plant formations were present since that time, although in the past there was more tree pollen than today.

CONCLUSIONS

Pollen analysis of the interval 7.43—3.78 m (approximately 13,000 to 9,000 B.P.) in the deep core from Lake Valencia suggests a division into four phases for the history of the lake during that time. From bottom to top:

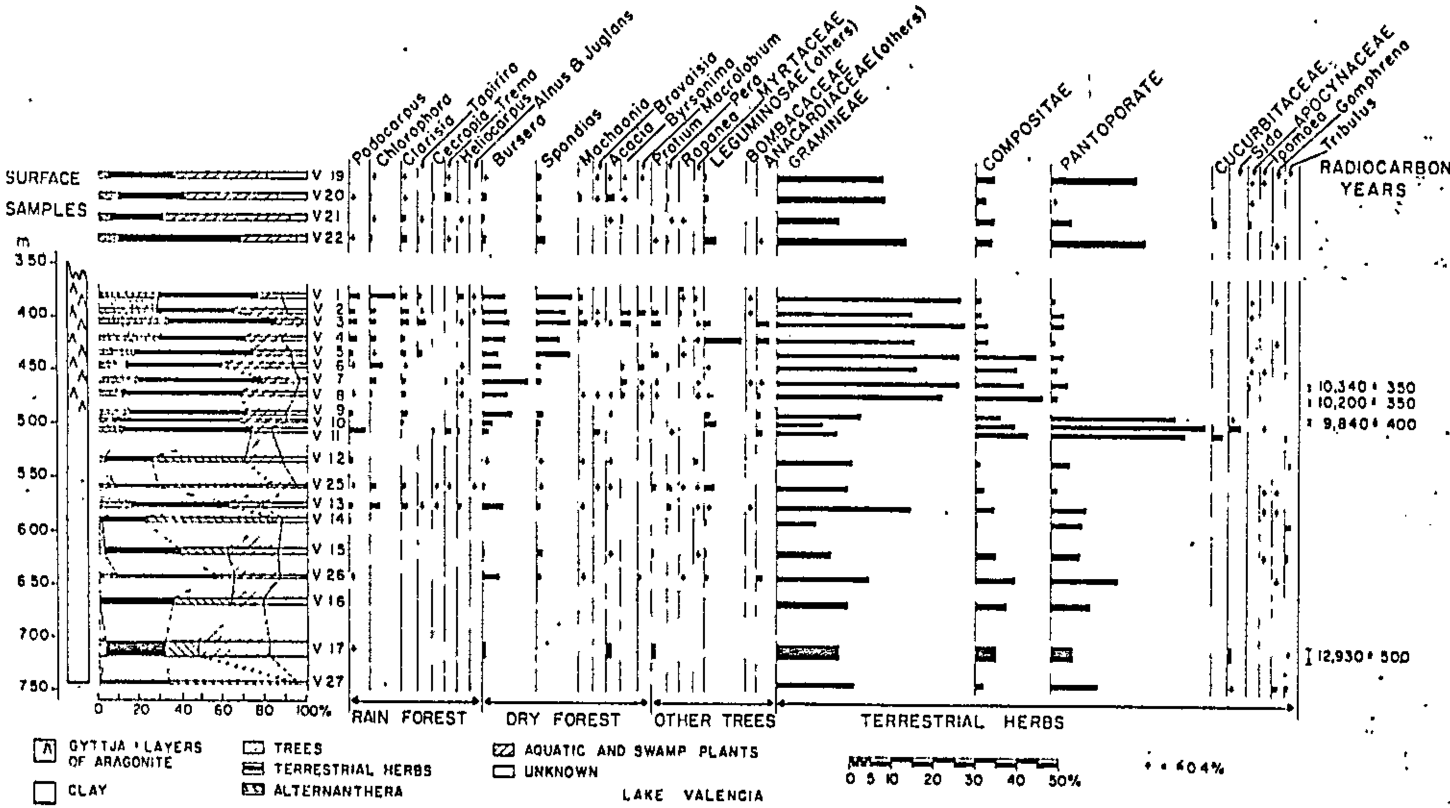

Fig.5. Pollen diagram from Lake Valencia deep water core with terrestrial elements.

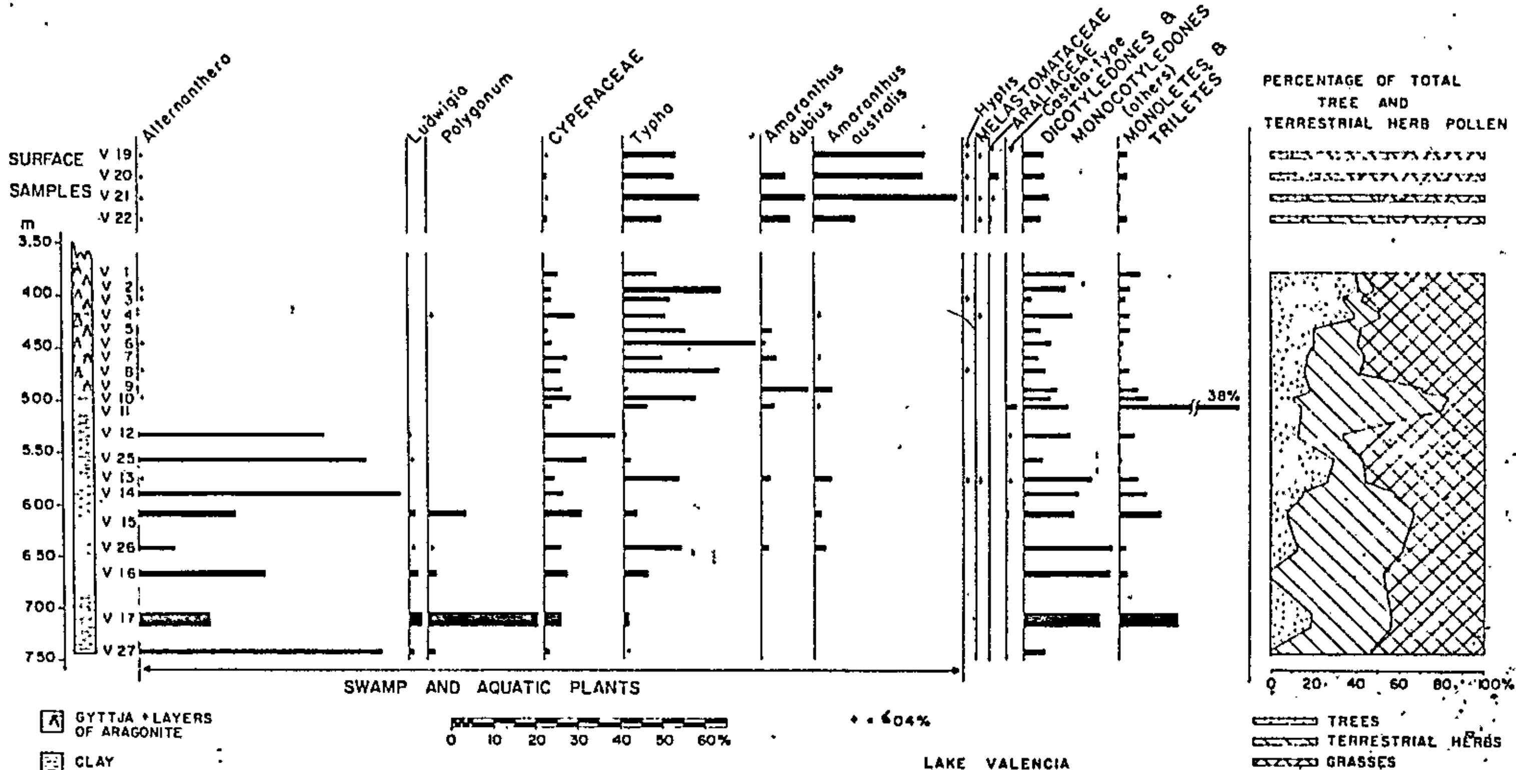

Fig.6. Pollen diagram from Lake Valencia deep-water core with swamp and aquatic elements, and pollen and spore types occurring in small frequency. At right representation of the pollen sum of total tree and terrestrial herb pollen (other elements excluded).

Phase IV (7.43—5.88 m; 7.14—7.28 m = 12,930 ± 500 B.P.). Clay sediment. Low quantity of pollen. Dominance of swamp pollen; minimum of grass, Compositae and tree pollen (absolute and relative values). Zygospores are found but the planktonic algae *Botryococcus* and *Coelastrum* are absent; *Pediastrum* is low or absent.

Zygnemataceae frequently lives in bare soil and swamps (Joly, 1963). Their occurrence together with the pollen of swamp plants indicates that a large lake did not exist at that time. The site (today the deepest part of the actual lake, Fig.2) was occupied by a marsh or intermittent lake. The low absolute and relative numbers of grass and tree pollen suggest that the region had mostly bare soil. The good preservation of the grains (except level V-16) indicates a very scarce vegetation with low input of pollen rather than destruction of the grains. Most of the grass pollen in this phase probably came from swamp grasses. The occurrence of *Bursera*, *Spondias*, *Acacia* and the herb *Tribulus*, all in low frequency, suggests the existence of thorn forest at some distance.

Since we know that sediments are found at least to a depth of 80 m (Schubert and Laredo, 1978), the existing lake had desiccated or at least was drastically reduced. In the Valencia Basin the climate was much dryer than today.

Phase III (5.77—5.36 m). Clay sediments. Increase of pollen types and of tree and grass pollen, nevertheless absolute numbers are still low (except grass at V-25). Rain-forest pollen starts, swamp plants continue. Zygospores are replaced by the planktonic *Pediastrum*.

This is probably a transition phase to a more humid climate.

Phase II (5.08—4.88 m; 4.88—4.92 m = 9,840 ± 400 B.P.). Shift from clay to gyttja. Absolute numbers still low. Drastic reduction of *Alternanthera*, and other swamp plants are not found. Grass and tree pollen are low. One type of *Chenopodium—Amaranthus* is the dominant pollen type. It probably belongs to a Chenopodiaceae which would indicate saline or subsaline soils (Wettstein, 1944; Stebbins, 1974).

The lake probably started to form at this phase. If the dominant type is a Chenopodiaceae, the evaporation rate in the forming lake was very high in a somewhat more humid climate.

Phase I (4.73—3.78 m; 4.70—4.73 m = 10,200 ± 350 B.P.; 4.58—4.62 m = 10,340 ± 350 B.P.). Gyttja with layers of aragonite. This interval starts with a great increase of pollen (type and number). Grass pollen is the dominant type. Tree pollen increases and the dry forest elements (*Bursera*, *Spondias*) are the most frequent. Rain-forest pollen reaches its maximum but its low quantity as well as that of the dry forest indicate long-distance transport. *Typha* pollen increases and is the dominant among the aquatic plants. *Pediastrum* is the main alga.

Grass phytoliths and epidermis are found in large amounts at this interval

(V-8 to V-1; Fig.3) indicating that grasses were growing near the edges of the forming lake. The great increase of grass pollen was probably not only due to the aquatic and swamp grasses, but must represent also terrestrial grasses covering at least partially the once bare soil of the earlier phases.

The abundance of pollen indicates that precipitation has increased in relation to phase IV, and the lake was probably rising.

During this phase, although the absolute number of pollen grains is high, it oscillates. The most plausible explanation for the decrease in pollen abundance at levels V-2, V-3 and V-6 is that the lake was still small and had strong fluctuations in its water level. Rivers in the desiccation phases would carry sediments closer to the core site, diluting the deposited pollen.

If the assemblages of phase I and II (10,700—9,000 B.P.) are compared with the modern deposition, the same types of pollen are found during ca. 10,700 years. Therefore, the actual types of vegetation existed during the whole of the Holocene in Lake Valencia: rain, dry and thorn forest and savanna (*Byrsonima* and grasses). These types of vegetation probably occupied the territory in the same pattern as at present, although their areas of distribution could have differed in size. The rain forest would occur at the top of the mountains followed by the dry forest and savanna at the lower belt. Nevertheless, the amount of trees was larger than at present, and the dominant forest association in the beginning of the Holocene was thorn forest (Espinar) which would have occupied the bottom of the graben, around the rising lake. At present this type of forest is mostly found along the coast of Venezuela, and it reaches the state of Lara about 200 km west of Lake Valencia.

The end of the Pleistocene (Phase IV) was characterized by a very scarce vegetation and a semi-arid climate. Phase III was probably the boundary between Pleistocene and Holocene where the climate shifted to more humid conditions, probably to a two-seasonal climate.

DISCUSSION

The end of the Pleistocene in Lake Valencia area was characterized by a dry phase. During this time the glaciation period in the Andean mountains was coming to its end (Van der Hammen, 1974; Schubert, 1974; Salgado-Labouriau et al., 1977). At the beginning of the Holocene the lake itself started to form. The rise of water level in lakes of tropical Africa (see Livingstone, 1975), in the Colombian Andes (Van Geel and Van der Hammen, 1973), and the formation of new lakes, in Valencia (this paper) and in the Galapagos Islands (Colinvaux and Schofield, 1976) indicate that the increase in precipitation at the Pleistocene—Holocene boundary took place in several parts of the Tropics. The study of marine sediments (Bonatti and Gartner, 1973) also indicates a dry phase for the Caribbean area. Nevertheless, it is still premature to conclude that the end of the Pleistocene was dry throughout the Tropics.

The Holocene Lake Valencia corresponds to Peeter's (1968) Lake Valencia III, and the dry period was probably between this and his Lake Valencia II.

Although the results from Lake Valencia show changes in humidity, they cannot yet be used to evaluate the temperature during the last 13,000 years. The dispersion power of pollen and the autoecological information on the species of *Bursera*, *Spondias* and others that occur in the region are largely unknown. Studies of isotope variations on deep-sea sediments indicate a decrease of approximately 5°C at the glacial maxima (Emiliani, 1966). If at Lake Valencia the decrease was about the same, the average temperature would have been about 19°C[1] at the low lands during this time. This would mean that the climate was warm (Griffiths, 1976). At 13,000 B.P. temperature probably was higher. In the highest part of the mountain facing the lake average temperature probably was lower, but it is not possible yet to estimate if it was as low as that of the northern Andes during the end of the Pleistocene.

In the deep-water core the five upper meters have diatoms and microfossil animal remains (Bindford and Frey, 1978; Bradbury, 1978). Brackish-water diatoms occur in the lower part of this interval (Bradbury, 1978), and the sediments are more saline than in the upper part (Lewis and Weibezahn, 1978). These occurrences support the interpretation of Chenopodiaceae dominance at 5 m, and indicates that although the lake had formed, evaporation was very high at the beginning of the Holocene.

The shift from clay to gyttja occurred at 5 m (a little before 10,700 B.P.), and it took place before the beginning of a richer vegetation. This shows an interval between the increase of precipitation and the colonization of the environment by new plants. The various pollen curves suggest that different species reacted at different times to the climatic changes. For example, *Bursera* increases before *Spondias* (both of the dry or thorn forest). It was not possible to date some of the old levels of the Lake Valencia deep core due to the nature of the material, and those that were dated had a very large standard deviation (Table I). Therefore, precise dating of the delay in the vegetational response was not possible. In order to time this, more careful sampling and more precise radiocarbon dating will be necessary. The delay of vegetational response and the independent reaction of each species to the climatic change remain as topics for further research.

The absence of rain-forest pollen at the bottom of the core indicates that between 13,400 B.P. and ca. 11,000 B.P. (and probably much before) this type of vegetation did not exist in the graben and on the mountains around it. Nevertheless, its presence from 10,700 B.P. on, followed by its rapid increase in type and number, suggests that it existed at a close distance so that it could reach the mountain top shortly after the climatic change. The obvious questions are: where was it? and how did it reach Lake Valencia afterwards?

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[1]Mean temperature at present is 24.6°C at Maracay and 24.1°C at Valencia.

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