CLIMATIC PERIODICITY AND EVOLUTION OF SOUTH AMERICAN MAESTRICHTIAN AND TERTIARY FLORAS

(A STUDY BASED ON POLLEN ANALYSIS IN COLOMBIA)

(with 1 plate and 9 figures)

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ABSTRACT

The present article deals (chapter 1) with pollen-analytical data from Colombia (South America) and includes a complete pollen-diagram running from the base of the Maestrichtian until the beginning of the Miocene. Special principles were used in its construction. The diagram shows periodical changes in the numeric composition of the flora, which are associated with the entrance of new species and the extinction of other ones. 2 and 6 million-year cycles may be distinguished the latter corresponding to *epochs* or *ages* (Paleocene, Lower Eocene, etc.). The problem of evolution and migration is treated in the light of these and other pollen-analytical data.

In chapter 2 a further interpretation of the pollen-analytical data is given, taking into consideration causes of the vegetational changes (changes of temperature) and of evolution. The relationship between these changes and tectonic-orogenetic movements and transgressions is treated too, and it is known that these movements may partly have a periodicity comparable to vegetation-changes and evolution, but that in these cases they are always somewhat delayed. The registration of the periodic temperature-changes by means of pollen-statistics is proposed as a possible new stratigraphical criterion, being independent of index-fossils, migrations of species, etc.

INTRODUCTION

In the course of pollen-analytical and stratigraphical investigations carried out in the last five year in Colombia (South America), on the Upper Cretaceous and Tertiary series of sediments, some interesting data has come to light, which, in our opinion, is of not only local importance, but may have a world-wide significance, and may finally lead us to frame a theory of periodicity. In order to separate clearly the precise palynological data from the theory, we will first treat the actual results and afterwards the partly theoretical interpretation.

I am very grateful to the many friends and colleagues who have helped me, by discussing the different problems expounded in this paper and making suggestions. Amongst them I would like to mention in the first place doctor Enrique Hubach, former director of the National Geological Institute of Colombia, who stimulated my work throughout its course with his continual personal interest and who helped me with his unparalleled knowledge of the Geology of Colombia. I would also like to thank Dr. Hans Bürgl, Prof. Dr. F. Florschütz and Dr. Johs Iversen for their valuable advice and assistance.

The Colombian Petroleum Company put at my disposal their extensive collection of bore-hole samples in the Barco Concession (Catatumbo region), on which an important part of the pollen diagram is based. At this point I would like to express my sincere gratitude to the manager of that Company and the geologists of the Barco field.

The constant collaboration of all the personnel of the paleobotanical section of the National Geological Institute was of the utmost importance to the realization of this study: Miss Cecilia García Barriga and Mr. Enrique González as scientific assistants; Miss Irma Cortés, who did all the drawings; and Mr. Juan Perico, who prepared all the samples in the laboratory and was my assistant during the field work in different parts of the country.

CHAPTER I

POLLEN - ANALYTICAL DATA

a) *Correlation on the basis of vegetational and climatic changes*

Most statistical pollen-analytical work up to now has been done on the vegetational changes of the Pleistocene and Holocene, which are originated by climatic variations, while evolution of species is of little importance. Nevertheless it is relevant to our subject to give a short introductory review on some of the problems.

In great regions of Europe and North America forest vegetation, during the Quaternary period receded and returned owing to the influence of succesive cold and mild periods. Hence, immigration and emigration of existing species, with a general North-South and South-North direction, was an important factor. However, migration of a certain tree-species takes time, and the species will, in the case of an improving climate, arrive earlier or later, according to the latitude of the site. Thus the first appearance of a species in pollen-diagrams from various sites at different latitudes will not be synchronous. This problem has been treated before (VAN DER HAMMEN, 1951), and the opinion advanced that exact time-limits in these cases can only be drawn on the basis of frequency changes of species already present.

The "conditio sine qua non" for this type of correlation is that the climatic changes, in which the vegetational changes originate, are exactly simultaneous over large regions or over the whole world. Until recently this was only a matter of supposition. But since C_{14}-datings proved that the late-glacial Alleröd-interstadial was contemporaneous all over Europe and North America, and also that the last important ice advance following this interstadial was contemporaneous not only in the Northern hemisphere, but probably also in the Southern, we can consider it as fact that the great climatic changes of the Quaternary were simultaneous all over the earth, and were not caused by polar movements, but by influences coming directly from outside the earth.

Turning now to the Tertiary, we find that one of the few known and generally recognized features is that the climate in the course of this period gradually became colder simultaneously all over the Northern hemisphere. Of great interest in this connection is an article of GERTH (1941) as it shows, on the basis of the distribution of fossil *Nothofagus*-floras in South America, that the climate in the Southern part of the Western hemisphere grew colder during the Tertiary, just as in the Northern hemisphere. This general tendency to climatic decline, resulted in the clear separation of the climatic-vegetational latitudinal belts that we know today.

A shifting of the vegetation in the latitudinal belts also took place all over the earth in the Upper Paleozoic, in part accompanied by glaciation. From this evidence we can conclude that certain factors, simultaneously at work all over the earth, caused synchronous changes in the vegetation, whatever the specific composition of this vegetation may have been.

If we could register these changes in the vegetation in a detailed way, they would be an excellent basis for exact world-wide time correlations. For several reasons pollen-analysis seems to be the science best-equipped to solve the problem of registration. It works with a material present everywhere and found in abundance in many sediments, terrestrial and marine, and hence statistical investigations can usually be carried out. Moreover, Palynology has already demonstrated its value in the correlation of the Pleistocene ice-ages.

Now, it is a fact that evolution plays a great role in pre-quaternary floral history. Since during the Tertiary period the vegetation of the earth was separated into different floral regions, a profound difference is found between the pollen-species of, for instance, the South American Eocene and the European Eocene. Furthermore, as we will see later, a new species may, even within one floral area, need a considerable interim period to migrate from its place of origin to other regions. Nevertheless associations of pollen are fairly constant within quite extensive parts of a floral area.

From these facts we may drow the following conclusions:

1. Correlations within quite large sectors of a floral area may be carried out on the basis of type-pollen associations, but never on the basis of single "index-pollen".

2. Correlations within entire floral areas, and probably world-wide correlations may be carried out on the basis of quantitative pollen investigations, registering important vegetational changes (and excluding local phenomena). The basis of these correlations is the concept, that whatever may be the specific content of the flora, these profound vegetational changes, registered statistically, are the response to great and world-wide climatic changes.

On the basis of these considerations, we have tried to adapt the method of pollen statistics to fit the recording of the important vegetational changes just mentioned. This working-method is treated in the next paragraph.

b) *Working-methods*

First of all we want to point out that our pollen-analytical working-methods are somewhat different from those generally used. The basic principles of our working method were published some time ago (VAN DER HAMMEN, 1953), in a study on the development of the Maestrichtian flora and vegetation, but we have extended it in some respects to fit the Tertiary pollen-floras (VAN DER HAMMEN, 1957). Thus the diagrams (see plate I) are worked out in the following way.

1. From each coal or lignite layer a series of samples is analysed and the average percentage for each species or group is calculated from the sum of these analyses; or one analysis is made of one mixed sample of the same whole series.

2. Some 200 or 300 pollen-grains are counted in each sample, and the percentages are calculated on the basis of the sum of all the pollen grains and spores of pteridophytes.

3. The composite spectra of one series of sediments are demonstrated in a diagram, the horizontal axis representing the percentages of the different pollen and spore-groups, added one on top of the other, while the vertical axis represents the separation of the spectra in the stratigraphical column. Best results were obtained in our case with a 1:2.000 scale for the stratigraphical column and 10 centimeters for the 100% of the pollen and spore sum, but the scale may be changed according to the relative thickness of the sediments.

4. The pollen- and spore-groups (the species mentioned are described in VAN DER HAMMEN, 1954 a and 1956 b) are placed one on top of the other, and arranged in the following way (see plate I, and figs. 1 and 2):

    a) From the left the percentages of the different groups of palm-pollen (fig. 1), in the order:

Monocolpites medius group (including *M. minutus, medius, huertasi, grandis* and nearly-related forms, all related to some recent genera of palms).

Monocolpites franciscoi group (including all the pollen grains of Mauritiaceae).

Proxapertites operculatus group (including all the varieties of this species, and nearly-related forms, all closely related to the recent species *Astrocaryum acaule*).

    b) From the right the percentages of the different groups of spores (fig. 2), in the order:

Psilatriletes group (including all trilete spores, mainly psilate, except the *Striatriletes susannae*-group).

Striatriletes susannae group (including this species and related spore forms, belonging (or closely related to), partly to the recent genus *Aneimia*).

Verrumonoletes usmensis group (including the monolete-verrucate spores *V. usmensis* and *V. usmensoides,* and nearly-related forms, probably belonging mainly to the Polypodiaceae).

Psilamonoletes tibui group (including all monolete-psilate spores: in part of this group occur species in which no clear aperture is found, and which, accordingly would have to be classified rather as "alete", but since they are otherwise identical with monolete species, they are here relegated to this group).

    c) In the middle, between palm-pollen groups on the left and spore groups on the right, are the percentages of the sum

Monocolpites medius-group

Monocolpites franciscoi-group

Proxapertites operculatus-group

1000 x.

Fig. 1

ALGUNOS REPRESENTANTES DE LOS DISTINTOS GRUPOS DE POLEN DE PALMAS USADOS EN LOS DIAGRAMAS

SOME REPRESENTATIVES OF THE DIFFERENT PALM-POLLEN GROUPS USED IN THE DIAGRAMS

Psilatriletes - group

Striatriletes susannae - group

Verrumonoletes usmensis - group

Psilamonoletes tibui - group

1000 x.

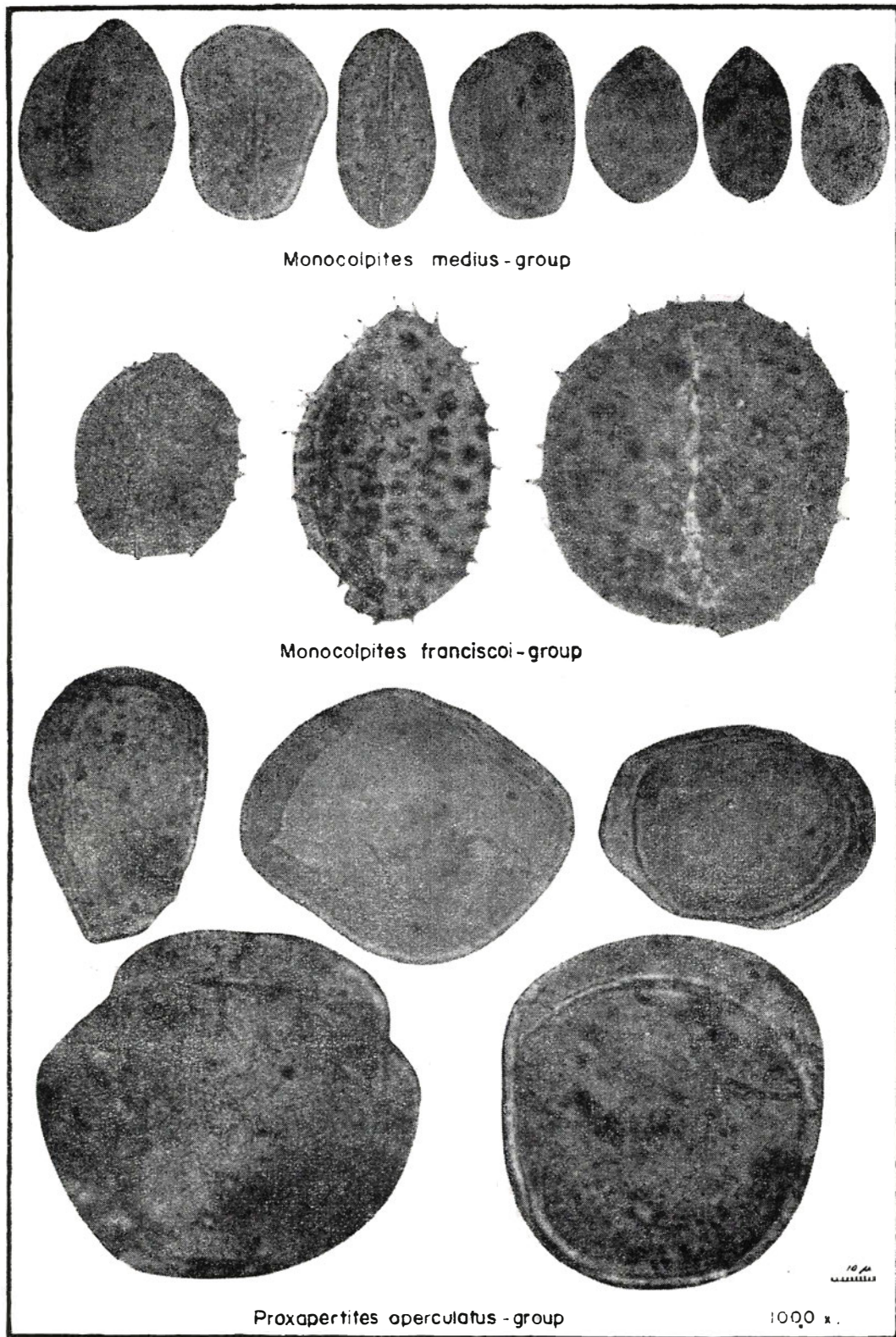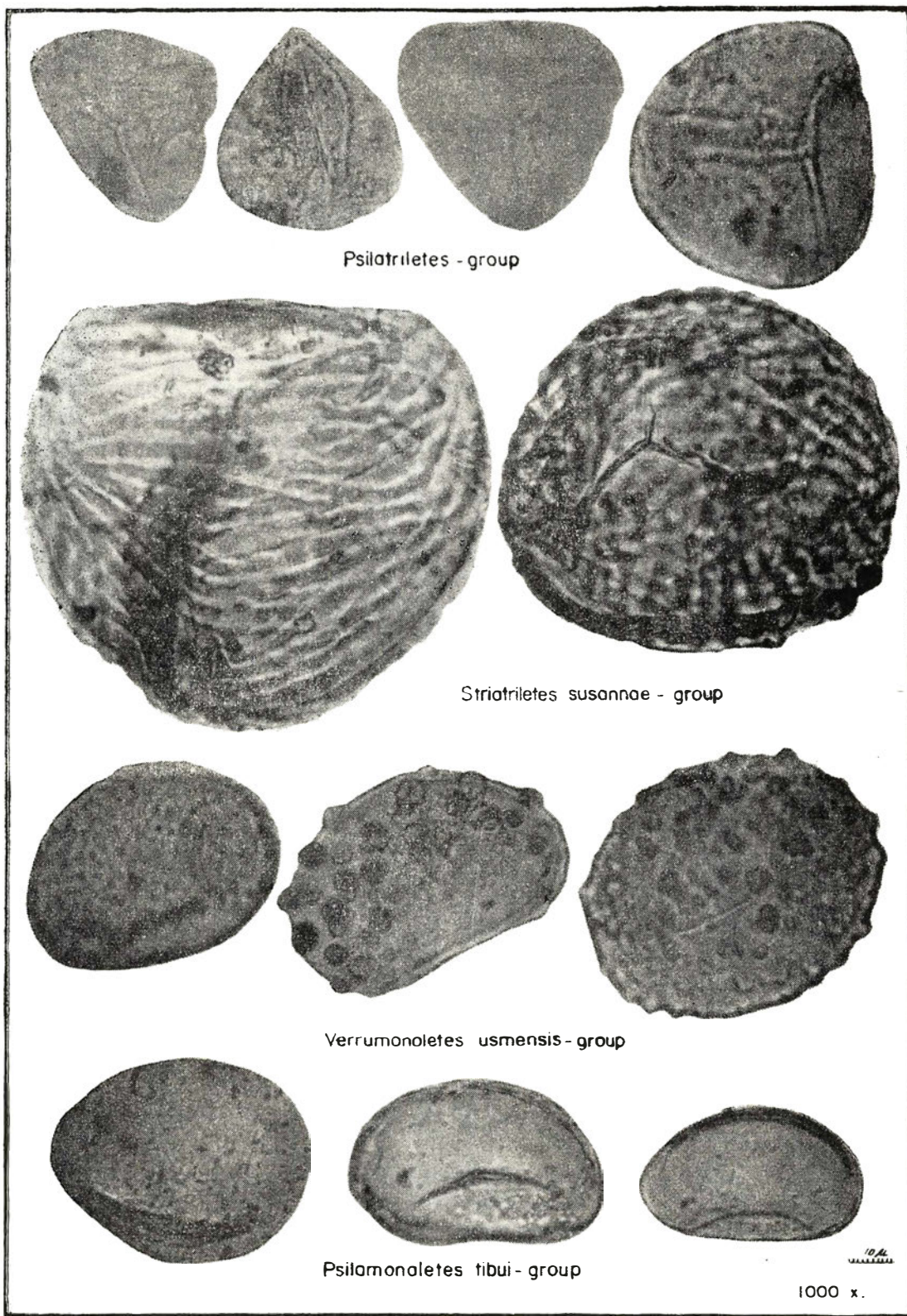**Fig. 2**

ALGUNOS REPRESENTANTES DE LOS DISTINTOS GRUPOS DE ESPORAS USADOS EN LOS DIAGRAMAS

SOME REPRESENTATIVES OF THE DIFFERENT SPORE-GROUPS USED IN THE DIAGRAMS

of all those pollen grains of Angiosperms (mainly Dicotyledons) which are not included in the palm-pollen groups. We will call this group simply "Angiosperm-group".

This type of diagram will be referred to as PAF-diagram (Palms-Angiosperms-Ferns). Naturally these groups are appropriate to tropical South America, and would have to be changed for other floral areas.

In addition to this main diagram, curves for the separate species of Angiosperms, etc., and of the groups mentioned may be drawn in the usual way.

This type of spectra and diagram has been chosen after many experiments with other types, as it better than those reflects the important numeric changes of the total (pollen) flora, excluding minor changes which may be of local origin and also changes in local vegetational successions. Such successions, shown by diagrams based on a series of separate samples from one coal-layer, may be of importance for the correlation of coal-layers in one mining region, but are of little importance for stratigraphical correlations over greater areas.

Although only coal-layers were used for the spectra which make up our diagram, we want to stress that comparable results were obtained in analysing shale-samples, in which each composite spectrum was based on several analyses from samples taken at relatively short vertical distances from each other.

c)   *Description of the pollen-diagram*
      (Maestrichtian-Lower Miocene)

The Maestrichtian part of the diagram (plate I) is composed of two combined sections from the Sabana de Bogotá (VAN DER HAMMEN, 1957), the Paleocene of combined Tibú-(Catatumbo) and Lebrija-sections (VAN DER HAMMEN, 1957), the Lower and Middle Eocene of combined Tibú-sections, the Upper Eocene, Lower Oligocene and Middle Oligocene of combined Tibú and Timba-(Valle del Cauca) sections, and the Upper Oligocene and lowermost Miocene of combined Timba and Antioquia-sections. The combination of the different sections and the corresponding parts of the diagram was carried out very carefully and was done only if the following conditions were all fulfilled:

1.   There had to be an overlap of the diagrams of at least two pollen zones.
2.   The overlapping parts of the diagrams had to correspond completely in the course of their respective curves or in the relative percentages of separate spectra and in their specific content.
3.   The stratigraphical succession of the different sections had to correspond one with another.

Differences in relative thickness of different sections, if present, were eliminated by proportional reduction or amplification. As a basis for reduction we took a 1:2.000 scale of the Tibú, Timba and Antioquia-sections, having the same thickness in their corresponding parts. As stated

already, all the "composite spectra" are derived from coal-layers, although we obtained comparable results, not included here, with series of shale-samples. Those parts of the diagram which were reduced on the above-mentioned basis are mentioned on plate I.

As all the spectra were obtained from fairly thick coal-layers, we can be sure that they all represent tropical low-land vegetation, when comparing different spectra.

We shall now begin the description of the diagram, beginning with the lowermost part (see plate I).

Maestrichtian

The lowermost part of the diagram is of Maestrichtian age, and is also published in this number together with more details (VAN DER HAMMEN, 1957). The Maestrichtian can be subdivided on a palynological basis into three zones. These zones A, B and C are identical with those described earlier (VAN DER HAMMEN, 1954 a), the only exception being that we now prefer to put the boundary between the B and C zones somewhat higher, at the beginning of the Monocolpites medius-group maximum next to the one at the base of the B zone. Age-determination can be said to be proved by the following data: 1º Maestrichtian foraminifera and ammonites are found at the very bottom of zone A; 2º Maestrichtian foraminifera are still found in zone C in the Catatumbo area.

The Maestrichtian part of the diagram is only composed of three groups: the *Monocolpites medius*-group, the Angiosperm-group and the *Psilatriletes*-group (mainly *Psilatriletes guaduensis*). As the lowermost part of the Maestrichtian is marine everywhere in Colombia, no coal-samples were obtained from that relatively thin interval, but the coal-layers immediately above it show relatively high percentages of the *Monocolpites medius*-group, and low percentages of the *Psilatriletes*-group. Than the curve of the former goes down while the latter rises. A second top in the *Monocolpites medius*-group comes next, flanked by two *Psilatriletes*-maxima. After another drop the *Monocolpites medius*-group reaches a third maximum, again flanked by relative maxima of the *Psilatriletes*-group.

Immediately after each one of the last two tops of the *Monocolpites medius*-group a relatively large number of new species appear (for this phenomenon just after the second top see the diagram of plate II and III in VAN DER HAMMEN, 1954 a). The maximum of the first *Monocolpites medius*-group top must lie still somewhat lower than the first spectrum of the diagram, probably somewhat below the Upper Guadalupe sand-stone, or in the hiatus which may exist between this sandstone and the Guaduas formation.

The three zones are approximately of the same thickness, only the C zone was in some cases found to be somewhat thinner. The three zones could be distinguished on the basis of the *Monocolpites medius*-group and *Psilatriletes*-group maxima (and on the basis of type-associations of the other Angiosperms) in all the diagrams we made from the Maestrichtian, at sites up to 1.500 kilometers apart (North-South distance in the Eastern Cordillera).

Paleocene

The Paleocene begins with a very high top of the *Monocolpites medius*-group, the highest of the whole diagram. Immediately after this top the specific (and quantitative) composition of the pollen flora changes profoundly. *Proxapertites operculatus* forms an important part of the total, from beginning to end of the Paleocene. The *Monocolpites franciscoi*-group (Mauritiaceae) appears for the first time at the base of the Paleocene, and also many new types like the *Tricolporites annae* (Bombacaceae), etc.

A second top in the *Monocolpites medius*-group, and third one (small, but combined with a top of the *Monocolpites franciscoi*-group) at nearly equal intervals, bring some change in the quantitative composition of the flora, and a few new species come in after each of them, but the general picture does not greatly change, untll after the next, very high, top of the *Monocolpites medius*-group, the vegetation once again alters profoundly (beginning of the Eocene).

The Paleocene age of this part of the diagram is proved in the following way. The typical association of pollen in this diagram-section we found also in the Cerrejón area in the Hato Nuevo formation, which lies on top of fossiliferous Maestrichtian and below the Eocene coal-formation. In the Hato Nuevo formation equivalent on the Venezuelan side of the frontier a Paleocene age can be proved by means of foraminifera.

Lower Eocene

The Lower Eocene begins with a high top of the *Monocolpites medius*-group, and a high *Monocolpites franciscoi*-group top lies a little below it. At the same time the *Proxapertites operculatus*-curve drops to zero. Immediately afterwards two new groups enter, the *Verrumonoletes usmensis*-group and the *Psilamonoletes tibui*-group. A number of new species of dicotyledons appear after the *Monocolpites medius* top. Two much lower tops of the *Monocolpites medius*-group follow, each combined with a top the *Monocolpites franciscoi*- and *Psilamonoletes tibui*-groups, in the following order: *Monocolpites franciscoi*-top, *Psilamonoletes tibui*-top, *Monocolpites medius*-top. It is to be noted that these tops in the somewhat thicker B-zone are also more widespread. The *Monocolpites medius*-curve, not taking into account the tops mentioned, is very low throughout the greater part of the Lower Eocene, showing only one or a few percent.

The next top is again a rather high one, and with this top begins the Middle Eocene.

The age of the diagram-section here described was established as Lower Eocene by means of the pollen correlation of the uppermost part of the Los Cuervos formation and of the main part of the Mirador sandstone, on which this diagram-section is based, with formations containing foraminifera in Venezuela (KUYL c. s., 1955).

Middle Eocene

The Middle Eocene begins with a high top of the *Monocolpites medius*-group, again combined with tops of other groups, in the order *Monocolpites franciscoi*-group, *Psilamonoletes tibui*-group, *Monocolpites medius*-group. Immediately after this top a few new species come in. Two lower tops follow, at short distances, combined with tops of the *Psilamonoletes tibui*-group. Both *Monocolpites medius*-group and *Psilamonoletes tibui*-group are relatively high during most of the Middle Eocene, but the *Monocolpites franciscoi*-group is low.

With the next top, this time combined with tops of both *Psilamonoletes tibui*-group and *Monocolpites franciscoi*-group, the rather different vegetation of the Upper Eocene begins while the palm- and spore-groups fall steeply. The Middle Eocene is relatively thin, probably due to orogenetic movements, almost everywhere in Colombia.

The age of the diagram-section described was established as Middle Eocene by means of pollen correlation of the uppermost part of the Mirador-sandstone, on which this diagram-section is based, with formations containing foraminifera in Venezuela (KUYL c. s., 1955). Moreover lithologically this part can be correlated with a conglomerate and limestone series in Bolívar (Colombia), containing Middle Eocene foraminifera (BÜRGL, verbal information), above wich an Upper Eocene pollen-flora was found.

Upper Eocene

The Upper Eocene begins with a *Monocolpites medius*-group top, preceded by important tops of the *Monocolpites franciscoi*-group and the *Psilamonoletes tibui*-group. Then the vegetation changes considerably, and new species come in. A second and a third top of the *Monocolpites medius*-group follow, at almost equal distances. During the whole Upper Eocene the palm- and spore-groups are very low, the Angiosperms-group dominating completely. With a relatively high top of the *Monocolpites medius*-group and a profound change in the quantitative composition of the flora, the Lower Oligocene begins. From the base of the Upper Eocene onwards we have diagrams from both the East and West Andine Geosyncline, which agree perfectly even in details.

The Upper Eocene age of this diagram-section could be established by means of pollen-correlation with the middle part of the Concentración-formation of the Paz del Río area, where two fossil-horizons occur. These fossils were studied by ROYO Y GÓMEZ (internal report Servicio Geológico Nacional). The lowermost horizon was of Middle-Upper Eocene age, the higher one of Upper Eocene-Lower Oligocene age. Moreover in other places (Catatumbo, Valle, etc.), these pollen-zones are found on top of the Middle Eocene and below a formation with fossils of probably Lower Oligocene age. Palynologically these pollen-zones correspond to the major part of the Esmeraldas formation, which contains a fossiliferous horizon of Upper Eocene age.

In the Catatumbo area they correspond to the lower part of the Carboneras-formation, which was correlated palynologically with formations containing Upper Eocene foraminifera in Western Venezuela (KUYL c. s., 1955).

Lower Oligocene

As we have seen before, the Lower Oligocene begins with a relatively high top of the *Monocolpites medius*-group, and immediately above this top the quantitative composition of the pollen-flora changes profoundly. The spore-groups all show relatively high values, and also the *Monocolpites franciscoi*-group; the Angiosperm-group is very low in the first part. An important fact is also the presence of the first, small top of the *Striatriletes susannae*-group, near the base of the Lower Oligocene.

The A-zone of the Lower Oligocene is thicker than the B- and C- zones, and corresponds to a time of widely distributed ingressions of the sea, and probably of greater subsidence and sedimentation.

Two *Monocolpites medius*-group tops, somewhat lower than the first one, follow. They are preceded by or combined with tops of several other groups. It should be especially noted that the Angiosperm-group shows high percentages just before the *Monocolpites medius*-group tops. The *Monocolpites medius*-group top at the base of the B-zone is combined with a top of the *Proxapertites operculatus*-group, the first appreciable top presented by this group since the end of the Paleocene; this top is present in the East as in the West-Andine Geosyncline.

A high top of the *Monocolpites medius*-group indicates the beginning of the Middle Oligocene.

The Lower Oligocene age of this part of the diagram could be established in the following way. Fossiliferous horizons of approximately this age are present in various sections (Catatumbo, Valle, etc.), which could be correlated palynologically with this part of the diagram. Moreover the age of the Upper part of the Carboneras-formation (Catatumbo), from which this part of the diagram is derived, could be established by palynological correlations with formations containing foraminifera in Western Venezuela (KUYL c. s., 1955).

Middle Oligocene

The Middle Oligocene starts with a rather high top of the *Monocolpites medius*-group, preceded by an Angiosperm-group maximum, a *Monocolpites franciscoi*-group maximum and a relatively high top of the *Striatriletes susannae*-group; shortly afterwards a certain number of new Angiosperms species enter. Two smaller tops at almost equal distances follow. The next top is again a higher one, with which the Upper Oligocene begins.

The Middle Oligocene age of this part of the diagram could only be established indirectly. This age is very probable because of its stratigraphical position immediately on top of the Lower Oligocene, without hiatus in the stratigraphical succession. Moreover the stratigraphical succession

from the interior can be compared with the marine succession at the coast, where the comparable strata contain, according to BÜRGL (verbal information) Middle Oligocene fossils. The corresponding flora was also found in the Usme-syncline, and BÜRGL (1955) found a foraminifer of upper Middle-Oligocene to lower Upper-Oligocene age at a somewhat higher stratigraphical niveau in a sample from a boring in Bogotá (Andina), in the same geosyncline.

The major part of the Leon-shales (Catatumbo-area), to which this part of the diagram corresponds palynologically, was correlated palynologically with formations containing Middle Oligocene foraminifera in Western Venezuela (KUYL c. s., 1955).

Upper Oligocene

The Upper Oligocene begins with a relatively high top of the *Monocolpites medius*-group. A little higher the *Striatriletes susannae*-group reveals its highest top in the whole diagram. Two lower tops of the *Monocolpites medius*-group follow, at equal distances. After the third top, that is from the base of the C-zone onwards, begins a very rapid subsidence and sedimentation, which continues throughout the whole Miocene. This part of the diagram (from the base of the C-zone onwards) is represented at half the original scale, that is to say at 1:4.000 instead of 1:2.000 of the Catatumbo and Valle-Antioquia sections [1]. With a relatively high top of the *Monocolpites medius*-group the Lower Miocene starts. The age of this part of the diagram could be established by means of pollen-analytical correlation with the lower part of the La Cira-formation near La Dorada (Magdalena-Valley), which is, according to the contents of fossil vertebrates, of Late Oligocene age (STIRTON, 1953). The La Cira formation is also considered to be of Upper Oligocene age on the basis of other fossiliferous horizons. This diagram-section can also be correlated by pollen analysis with the lower part of the Guayabo-formation (Catatumbo-area), which could be correlated palynologically with formations containing foraminifera in Western Venezuela (KUYL c. s., 1955).

Lower Miocene

The Lower Miocene begins with a relatively high top of the *Monocolpites medius*-group. A second top is present in our diagram, but the rest of the Miocene has not yet been analysed to date.

The Miocene age of the pollen-flora characteristic for this part of the diagram could be established by means of correlation with the Honda-formation (Magdalena-Valley). The Honda-formation contains Vertebrate-fossils of Miocene age (STIRTON, 1953), and in its upper part also foraminifera (BÜRGL, verbal information) of upper Miocene age.

Conclusions

Considering now the diagram as a whole, we see that changes in the quantitative composition of the pollen-flora occur at intervals, particularly indicated by the tops of the *Monocolpites medius*-group, at the beginn-

[1] Posterior reduction of the diagram for reproduction is not taken in account here.

ing of *epochs* or *ages* [1] (Paleocene, Lower Eocene, etc.), followed by two tops which are lower. There is no exception to this rule, and it is surprising that the tops in the diagram as a whole are so regular. The *Monocolpites medius*-group tops are often accompanied or preceded by tops of other groups, especially of the *Monocolpites franciscoi*-group and of different spore-groups, and frequently show a certain constant order.

d) *Evolution and migration of species*

As we saw in the foregoing paragraph, each *epoch* or *age* (e. g. Paleocene, Lower Eocene, etc.) begins with a strong change in the quantitative composition of the vegetation, clearly marked by a top in the curve of the *Monocolpites medius*-group. With this change, a number of species present in the foregoing period disappears, and immediately or not long afterwards other new ones appear. The same, but to a much smaller degree, is the case with the secondary vegetational changes within each *age* (or *epoch*).

There can be no doubt that a great percentage of these new species (which may represent new natural genera, etc., as well) are formed by a strong evolution-process taking place at the same time as the quantitative vegetation-changes.

Nevertheless we have to bear in mind the time-factor of migration. Immigration of forest-trees into a tree-less area at the end of glacial or stadial period took place relatively very quickly; but we cannot compare this with the spread of new species in a densely-forested tropical area representing what would have been called today a climax-vegetation.

If we see that, notwithstanding this fact, many species appear in the diagram of a region almost at once immediately after the great quantitative change in the vegetation, we can attribute it to one or more of the following factors:

1. We have to keep in mind that the distance of the spectra at the critical points in the diagrams represents a considerable lapse of time and can easily be in the order of one hundred thousand years.
2. The distribution may have been facilitated by the disturbance or disequilibration of the original climax-vegetation.
3. The species had their origin in a relatively nearby region, or in the region itself.

Without any doubt, the first point is the most important one. **Nevertheless** there are many cases where migration of species evidently took place extremely slowly.

An example of this is a representative of the palm-genus *Astrocaryum*, the pollen-species *Proxapertites operculatus* (see fig. 3). This species had its greatest distribution in the Paleocene and high percentages

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[1] When we use these terms in the restricted sense of the American Commission on stratigraphic nomenclature, they are written in italics. We consider as *epochs*: Paleocene, Eocene, etc., and as *ages*: Lower Eocene, Middle Eocene, etc. However it will be clear from the following that the Paleocene, the Lower Eocene, the Middle Eocene, the Pliocene, etc., are units of equal time length.
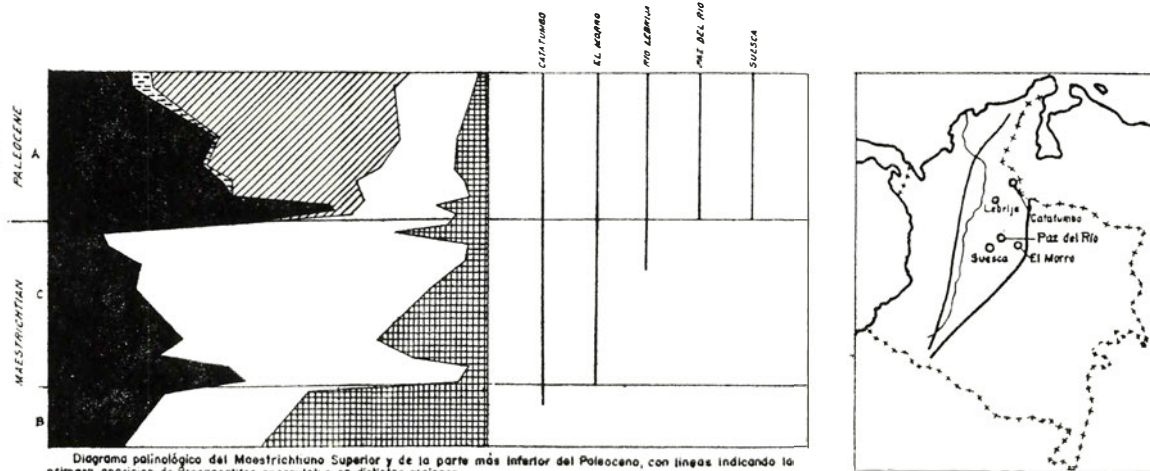
Diagrama palinológico del Maestrichtiano Superior y de la parte más inferior del Paleoceno, con líneas indicando la
primera aparición de *Proxapertites operculatus* en distintas regiones

Pollen-diagram of the Upper Maestrichtian and the lowermost Paleocene, with lines indicating the first appearance
of *Proxapertites operculatus* in different regions.

LEYENDA - LEGEND

- ■ Monocolpites medius group
- ▨ Monocolpites franciscoi - group
- ▨ Proxapertites operculatus group
- ▨ Psilatrileles group

Granos de polen recientes de *Astrocaryum acaule*
Recent pollengrains of *Astrocaryum acaule*

Mapa areal del género *Astrocaryum* con líneas
conectando sitios con un igual número de especies

Areal map of the genus *Astrocaryum*, with lines
connecting places with an equal number of species
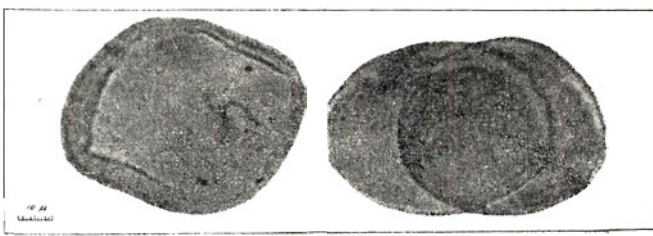
Granos de polen fósil de *Proxapertites operculatus*
Fossil pollengrains of *Proxapertites operculatus*

Fig: 3   ORIGEN Y MIGRACION DEL GENERO DE PALMAS ASTROCARYUM
ORIGIN AND MIGRATION OF THE PALM - GENUS ASTROCARYUM

Dib: Irma Cortés Cediel

of it are to a certain extent characteristic of this epoch, although it continues to exist in later ages (in one case we found up to 10% in the Oligocene), and the recent *Astrocaryum acaule* has a very similar pollen-type.

In the Catatumbo region this species already appears at the limit of zones B and C of the Maestrichtian, though in the Lebrija area in zone C, and in the Suesca and Lenguazaque areas not until the beginning of the Paleocene. Also, in the El Morro region (eastern foot-hills of the Eastern Cordillera) *Proxapertites operculatus* appears at the limit of Maestrichtian B and C, but in the Paz del Río region much later. Thus we can draw the conclusion that the migration of the *Proxapertites operculatus* took place from east to west, and that its migration from the present western margin of the Eastern Planes to the inner part of the present Eastern Cordillera took the time of almost the whole C zone of the Maestrichtian, that is about two million years (see the second chapter of the present article).

If we now take a look at the map of the distribution area and frequency of species of the genus *Astrocaryum* (fig. 3), we see that this genus had its theoretical centre of origin and distribution on the Guiana-shield and radiated from a theoretical point in the geological centre of this shield, near the border of French Guiana and Brazil. These theoretical data thus agree quite well with the data on the direction of migration we obtained from palynology.

Now there are several important genera which we know had their theoretical centre of origin and radiation in the same region, and even close to the same spot.

One example is the two more important genera of the Mauritiaceae: *Mauritea* and *Lepidocaryum* (see fig. 4) (the third genus, *Raphia,* is represented with one species only in South America). Pollen grains of Mauritiaceae appear in Colombia for the first time at the base of the Paleocene.

Therefore, we can draw the conclusion that, in so far as our still poor knowledge of the distribution of South American tropical plants can provide us with data, several (and probably many) important genera had their origin on, and radiated from, the old nucleus of the continent.

As we have seen from the foregoing, palynological data agree with this conclusion, and confirm it.

While finishing this manuscript, we became acquainted with the work of CROIZAT (1952); one of his "gates of Angiospermy" is the Roraima centre, which corresponds with what we have called the geological centre of the Guiana Shield. Thus his point of view agrees in this respect perfectly with ours. The fact that this Roraima centre forms also the geological centre of the, probably Mesozoic, Roraima formation (GANSER, 1954), and the fact that on the erosion-remnants ("mesas") of this formation in the Colombian Amazonia (VAN DER HAMMEN, 1954) a very primitive flora has been found (R. E. SCHULTES, verbal information), make the whole question extremely interesting from the point of view of evolution and distribution (see also paragraph g).

Fig: 4

MAPAS AREALES DE LOS GENEROS DE PALMAS: MAURITIA Y LEPIDOCARYUM (MAURITIACEAE), CON LINEAS CONECTANDO SITIOS CON UN IGUAL NUMERO DE ESPECIES

AREAL MAPS OF THE PALM-GENERA MAURITIA AND LEPIDOCARYUM (MAURITIACEAE), WITH LINES CONNECTING PLACES WITH AN EQUAL NUMBER OF SPECIES

CHAPTER II

FURTHER INTERPRETATION
OF THE POLLEN - ANALYTICAL DATA

e) *Periodicity of the vegetational changes*

In the preceding chapter we have seen that each *age* or *epoch* begins with a strong, in general temporary, change in the quantitative composition of the vegetation, followed by two more changes of the same character but generally less strong. These three changes divide each of these periods into three zones, which we have called A, B and C.

In those cases where subsidence and sedimentation went on at an equal rate during a whole *epoch* or *age*, the three zones are of approximately the same thickness (see Maestrichtian, Paleocene, Upper Eocene and Middle Oligocene), and therefore the corresponding time is presumably of the same length. In other cases the thickness of the zones varies to some extent but nevertheless there are always three zones in each *age* (or *epoch*). We may assume that the zones are still all of the same time-length, but that irregular subsidence and sedimentation has caused the differences in thickness. As proof that this is correct, we give the following data:

1. Where one zone is thicker than the others, the three tops (*Monocolpites franciscoi*-group, spore-groups and *Monocolpites medius*-group, and sometimes the Angiosperm-group) which indicate the vegetational change are more widespread in the thick zone than in the thin zones, in proportion to the thickness (see especially the B-zone of the Lower Eocene).
2. Thin zones are nearly always accompanied by indications of tectonic movements.
3. In one case (zone A of the Lower Oligocene) a very thick zone is contemporaneous with a strong subsidence and a marine transgression all over the country.
4. In one case three very thin zones, of the Middle Eocene, correspond to an epoch of strong tectonic movements (and inconformities) over great parts of South America.
5. Thin zones are often provided with many more coal-layers than the thick ones, indicating that minerogene sedimentation and subsidence were slower.
6. Every investigated *epoch* or equivalent *age* has three zones.
7. In one case a very thick zone (zone C of the Upper Oligocene) shows all the lithological characteristics of a very rapid, monotonous sedimentation, and the same is true for the thick Miocene zones.

Curva de cambios de vegetacion y de temperatura

Curve showing changes in vegetation and temperature

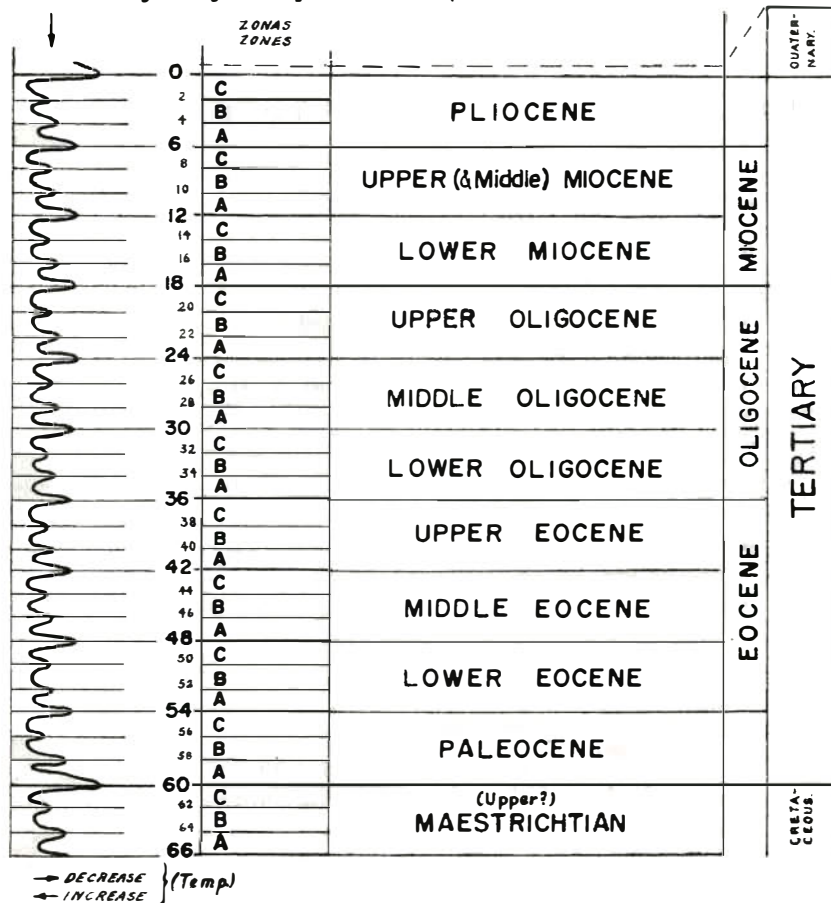| ZONAS / ZONES		
C	PLIOCENE	
B		
A		
C	UPPER (& Middle) MIOCENE	MIOCENE
B		
A		
C	LOWER MIOCENE	
B		
A		
C	UPPER OLIGOCENE	OLIGOCENE
B		
A		
C	MIDDLE OLIGOCENE	
B		
A		
C	LOWER OLIGOCENE	
B		
A		
C	UPPER EOCENE	EOCENE
B		
A		
C	MIDDLE EOCENE	
B		
A		
C	LOWER EOCENE	
B		
A		
C	PALEOCENE	
B		
A		
C	(Upper?) MAESTRICHTIAN	CRETACEOUS
B		
A		

→ DECREASE
← INCREASE } (Temp)

Fig: 5

SUBDIVISION DEL MAESTRICHTIANO Y DEL TERCIARIO BASADO SOBRE PERIODOS DE 6 Y 2 MILLONES DE AÑOS

SUBDIVISION OF THE MAESTRICHTIAN AND THE TERTIARY ON THE BASIS OF 6-AND 2- MILLION YEAR PERIODS

Dib. Irma Cortés Ledicl

We can therefore draw the conclusion that from the base of the Maestrichtian until the beginning of the Miocene a periodism of temporal changes in the quantitative composition of the vegetation has been established, subdividing each of the following units into three zones of apparently equal time-length: (Upper?) Maestrichtian, Paleocene, Lower Eocene, Middle Eocene, Upper Eocene, Lower Oligocene, Middle Oligocene, and Upper Oligocene. The change in the quantitative composition of the vegetation is stronger at the base of each of these units, the other two being less strong.

On the basis of the known intermediate values of the radium-lead, etc., age-determinations we may now calculate the approximate duration of the time corresponding to each zone (fig. 5).

From the base of the Tertiary to the base of the Miocene we have $3 + 9 + 9 = 21$ zones. If we put the age of the base of the Tertiary at 60 million years and the base of the Miocene at 18 million years, the duration of the same lapse of time was $60 - 18 = 42$ million years [2].

Thus the duration of each zone was approximately $42 : 21 = 2$ million years, and of each unit of three zones $3 \times 2 = 6$ million years.

As the Miocene had a duration of 12 million years, we can calculate that theoretically this epoch has 2 units of three zones each. We have still not worked out a complete diagram of the Miocene, but palynological data, as so far available, seems to verify this conclusion.

In the same way the Pliocene, with a duration of 6 million years, will have one unit of three zones.

Although no age determinations for the Maestrichtian are available, we may now assume, on the basis of its three zones present in the part analysed, that it lasted 6 million years at least.

Similarly we can calculate that the Paleocene had a duration of 6 million years, the Eocene 18 million years and the Oligocene 18 million years. These numbers agree fairly well with the available datings.

The conclusion we can draw from all the foregoing is that by means of pollen-diagrams of the uppermost Cretaceous and the Tertiary of Colombia, a periodism seems to appear in the quantitative changes of the vegetation, with minor phases of 2 million years, and major phases of 6 million years (fig. 5). Although corrections of the radium, etc., age of the Tertiary may appear afterwards, the ciphers given for the phases will scarcely change to any significant extent.

We will end this paragraph by expressing the probability that the influences exercised on the vegetation are world-wide and contemporaneous all over the earth. It is true that similar data is not yet available from other continents, but pre-quaternary palynology is a very young science, and comparable results may be obtained in the future through the use of similar working-methods.

However we can consider the following facts as being strong evidence that this phenomenon is world-wide.

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[2] According to HOLMES' B-scale, the age of the base of the Miocene is 26 million years, and according to the paleontological interpretation of several authors, our Upper Oligocene may be Lower Miocene (see the postscript and fig. 9).

1. The periodicity continues over the whole investigated lapse of time (about 50 million years).

2. The major phases of the periodicity, of 6 million years, correspond, in all those cases where it could be checked, with the international *epochs* or *ages,* which can be recognized all over the earth on the basis of paleontology.

3. The periodicity is intimately related with evolution, a process showing intermittent accelerations which are contemporaneous all over the world.

f)   *Nature and causes of the periodic vegetational changes*

As we saw in paragraph c, the periodic vegetational changes are indicated by tops of different pollen and spore-groups, with a certain order and configuration, which becomes more complex as the changes become more recent.

The group which is most constant and indicates this most clearly is the *Monocolpites medius* palm-group; it existed already in the Upper Cretaceous and continues throughout the whole Tertiary until recent times. The specific content of this group remains evtraordinarily constant. Consequently we have to conclude that it is a very resistant group, whose species are little affected by influences from outside and, perhaps for the same reason, show very little evolution.

In the light of these facts we are now able to explain why this group shows such regular, well-marked and often high tops at periodic intervals.

Some influence must have worked periodically on the vegetation, against which many plants could not offer any resistance. Some of them died out, others developed new characters by evolution which enabled them to resist. Meanwhile, the resistant group (or groups) which did not suffer from the influence, had an advantage over the less resistant: while optimal living conditions for the former persisted (or may even have improved), living condition were less favorable for the latter. Accordingly, the resistant species began to dominate in the vegetation or at least increased considerably, a situation which persisted until normal conditions were restored, or until new and more resistant species from other groups were formed.

The same must hold true for the other groups which show periodical tops concurrent with the tops of the *Monocolpites medius*-group. These other groups are also among the most constant ones, e. g. the *Monocolpites franciscoi*-group (Mauritiaceae), the *Psilamonoletes tibui*-group, etc.; all these are groups which after their first appearance, have persisted without, or only with very few, specific changes until recently.

When sufficiently spread, a certain order can be noted in the tops of the different groups. In our diagram this is the case, for instance, with the top indicating the quantitative vegetational change at the base of the Middle Eocene. While here the curve for the *Monocolpites medius*-group is already rising, the *Monocolpites franciscoi*-group reaches a maximum and shortly afterwards the same applies to the *Psilamonoletes tibui*-group; the rising curve of the *Monocolpites medius*-group now reaches its maximum immediately after the latter. This configuration we can find

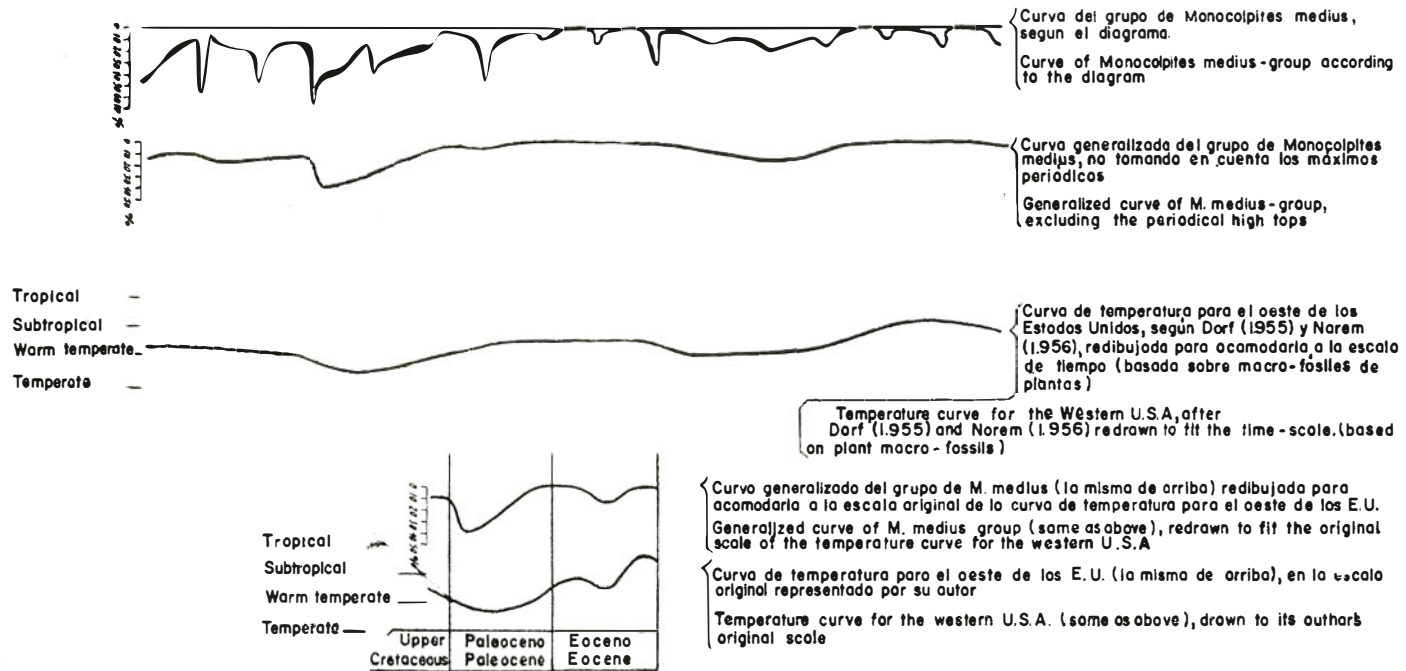| MAESTRICHTIANO MAESTRICHTIAN			PALEOCENO PALEOCENE			EOCENO EOCENE								
						Inferior Lower			Medio Middle			Superior Upper		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C

Curva del grupo de Monocolpites medius, segun el diagrama.

Curve of Monocolpites medius - group according to the diagram

Curva generalizada del grupo de Monocolpites medius, no tomando en cuenta los máximos periodicos

Generalized curve of M. medius - group, excluding the periodical high tops

Tropical —
Subtropical —
Warm temperate
Temperate —

Curva de temperatura para el oeste de los Estados Unidos, según Dorf (1955) y Norem (1.956), redibujada para acomodarla a la escala de tiempo (basada sobre macro-fósiles de plantas)

Temperature curve for the Western U.S.A, after Dorf (1.955) and Norem (1.956) redrawn to fit the time-scale.(based on plant macro - fossils)

Tropical
Subtropical
Warm temperate
Temperate

Upper Cretaceous | Paleoceno Paleocene | Eoceno Eocene

Curva generalizado del grupo de M. medius (la misma de arriba) redibujada para acomodarla a la escala original de la curva de temperatura para el oeste de los E.U.

Generalized curve of M. medius group (same as above), redrawn to fit the original scale of the temperature curve for the western U.S.A

Curva de temperatura para el oeste de los E.U. (la misma de arriba), en la escala original representada por su autor

Temperature curve for the western U.S.A. (same as above), drawn to its author's original scale

Fig 6

CURVA DE TEMPERATURA, PARA EL OESTE DE LOS ESTADOS UNIDOS, BASADA SOBRE MACRO-FOSILES DE PLANTAS, COMPARADA CON UNA CURVA PARA COLOMBIA (SUR AMERICA) BASADA SOBRE LA FRECUENCIA DEL GRUPO DE MONOCOLPITES MEDIUS

TEMPERATURE CURVE FOR THE WESTERN U S, BASED ON PLANT MACRO-FOSSILS, COMPARED WITH A CURVE BASED ON THE FREQUENCY OF THE MONOCOLPITES MEDIUS -GROUP IN COLOMBIA (SOUTH AMERICA) MAINLY BASED ON A POLLEN DIAGRAM FROM TIBU, CATATUMBO.-

Dib. Irma Cortés Ledier.

repeated at several places in the diagram (plate I), more widespread or less.

It is possible to find in this configuration the relative resistance of these groups against the growing influence from outside, the third top (of the *Monocolpites medius*-group) being the most resistant and constant one. However it is also quite possible, that secondary climatic effects of the growing influence (changes in rainfall, etc.) were the cause of one or more of the other tops.

Sometimes a repetition of one or more of these tops may be present above the maximum of the *Monocolpites medius*-group, which may indicate a reverse process of decrease of the influence from outside. This is clearly visible at the base of both B and C zones of the Maestrichtian; here the top of the *Monocolpites medius*-group is flanked in both cases by tops of the *Psilatriletes*-group, immediately below and above it.

Nevertheless these tops (those above the maximum of the *Monocolpites medius*-group) are much less frequent, which seems to indicate that the increase of the outside influence was slower than its decrease, or that the influence did not decrease to the same extent as it increased, i. e. that the influence was more or less step-like.

We may also deduce that the top of the most resistant group will be higher or lower according to the strength of the influence. In general we may say that a stronger influence was exercised at the base of each unit of three zones. The strongest influence (corresponding with the highest top of the diagram) was exercised at the base of the Paleocene, but the one at the base of the Eocene was also considerable. We may now summarize as follows:

Some periodic influence worked on the vegetation; with the increase of this influence, different resistant groups reached a maximum, possibly according to their degree of resistibility or partly because of secondary climatic effects; the most resistant group reached higher maxima when the influence was stronger.

If we now turn to the causes of the periodic influence exercised on the vegetation, it seems at first that very little can be said about it with any certainty. Theoretically, we have to consider several possibilities: the influence may have come from outside or from inside the earth; moreover, the influence may have worked directly on the vegetation or indirectly. But it is even feasible that a combination of all these possibilities was realized, although one of them must have been the primary cause. We will leave the principal discussion on this problem for later, but we would like to put forward here some aspects which are of importance to this paragraph.

As we will see in paragraph h, neither tectonic-orogenetic movements nor transgressions, etc., can be the cause (directly or indirectly) of the vegetation changes; thus the possibility that the primary influence came from inside the earth has been reduced almost to nil. If the primary cause lies outside the earth, then it seems most probable that the influence was directly climatic.

As a matter of fact we think it very probable that the periodic influence caused temporal (or partly step-like?) climatic changes by a lowering of the temperature. There are several reasons which favour strongly this possibility, and altogether seem to us to be conclusive.

1. According to UMBGROVE (1942), we should accept a lowering of temperature at the very beginning of each *period* (Tertiary, Cretaceous, etc.), of which the result was the formation of mountain-glaciers. Now, as we have seen before, the strongest influence we found was that exercised at the beginning of the Tertiary (Paleocene).

2. Recent pollen analytical investigations we have carried out on Quaternary sediments of the tropical Lower Magdalena Valley show that the same groups which indicate the vegetational changes in our pre-quaternary diagrams, play an important role in the indication of the quaternary climatic changes, which were due primarly to changes in temperature.

3. There is a striking similarity between the temperature-curve based on plant-macrofossils in the United States (DORF, 1955 and NOREM, 1956), and a curve based on the frequency of the *Monocolpites medius*-group in Colombia (fig. 6), which only can be explained if the *Monocolpites medius*-group fluctuations also depend on temperature.

4. Isotopic temperature-curves for surface ocean-water determined by EMILIANI (1956) from Oligocene and Miocene sections of Atlantic deep-sea cores show that, although temperature changes like those of the Pleistocene do not occur, several interesting decreases of temperature are present at more or less regular intervals. We can make the following interesting observations. A core of Lower-Middle Miocene age (depth 410-730 cm) shows the following minima, starting from a temperature of $\pm$ 25°-26°C: 22.75°C at 440 cm depth and 22.5° at 550 cm; a very little pronounced minimum of 24.25° is present at 640 cm, and an equal one at 720 cm. A core of Middle Oligocene age (depth 50-250 cm), shows the following minima starting from a temperature of 29°-29.5°C: 28°C at 105 cm depth and 28°C at 205 cm. Another core of Lower-Middle Miocene age (depth 700-1.500 cm) shows the following minima, starting from a temperature of $\pm$ 23°-25°C : 21°C at 702 cm depth (and 765 cm), 21°C at 860 cm, 21.5°C at 1.022 cm, 22° at 1.202-1.235 cm, 21.75° at 1.462 cm. The isotopic temperature curves thus show minima at an interval of $\pm$ 100 cm in the first two cores, and an interval of $\pm$ 150-200 cm in the third core. Maximal temperature differences of the ocean-water are 3° for both Lower-Middle Miocene cores, and 1.5° for the small Middle Oligocene core.

Now the question arises whether anything is known directly about the oecological conditions of the species forming the different resistant groups, which indicate by their maxima the periodic influences, and if they, from this point of view, really could be more resistant against a decreasing temperature than the majority of the other species (which are mainly Dicotyledons).

Although there are certainly other climatic factors which must have altered with a fall in temperature, such as amount of rainfall, and which had a certain influence on the vegetation, we will first consider here the question of temperature which seems to be the principal and constant factor.

We have to realize first of all, that so long as we do not know the exact position in the natural system of the majority of the fossil dicotyledons, very little can be said about their optimum and minimum living conditions. Moreover our knowledge of the oecology of South American tropical plants is still very poor, and the families recognized up till now

among the fossil dicotyledons (Bombacaceae, Malvaceae, Malpighiaceae, Moraceae, Acanthaceae, etc.) contain recent genera and species with rather different oecological conditions and distribution. Nevertheless we can say that many recent tropical dicotyledons are fairly restricted in their latitudinal distribution.

If we turn now to the palms of the *Monocolpites medius*-group, we see that various genera of recent palms have pollen grains closely related to it. As a matter of fact it seems that those palms have, taken as a whole, quite a wide latitudinal distribution. Examples are, for instance:

Geonoma	from	20° lat. N. to 25° lat. S.
Sabal	"	35° lat. N. " 2° lat. N.
Attalea	"	20° lat. N. " 35° lat. S.
Acromia	"	25° lat. N. " 25° lat. S.

Thus it seems not unlikely, also from this point of view, that the palms of the *Monocolpites medius*-group were relatively more resistant to a decreasing temperature than the majority of the dicotyledons.

The latitudinal distribution of the Mauritiaceae (15° lat. N. to 20° lat. S.) is more restricted than that of the former group. This may agree with the supposed relative resistance of the different groups, but particularly in the case of the Mauritiaceae there seems to be some reason to suppose that an increase in rainfall, as a secondary effect of the decreasing temperature, might have been the cause of the tops of the *Monocolpites franciscoi*-group.

We may summarize:

There are important reasons for assuming that the periodic vegetational changes were caused by periodic decreases in temperature, possibly accompanied by secondary climatic effects, such as increase of annual precipitation.

One important question is left: whether it is possible to estimate the degree of decrease in temperature during the periodic vegetational changes. We will try to do so in the following indirect way:

As we saw in point 4 of the reasons stated hitherto in favour of a periodic temperature-decrease coinciding with our vegetational changes, EMILIANI (1956) worked out isotopic temperature curves for surface ocean-water from Atlantic equatorial and subtropical deep-sea cores. The three curves published by him represent parts of the Middle Oligocene and the Lower-Middle Miocene. As we stated above, temperature-falls of 1.5°-3° are present in these curves, at more or less regular intervals of 100-200 cm.

The same author (EMILIANI, 1955) published, in another very important paper, curves of the same type from the same regions for the Pleistocene. Temperature-fluctuations with a period of 41.000 years, a period not present in the tertiary curves, were found, with an amplitude of about 6°C. The temperature of the surface ocean-water at the beginning of the rise of the temperature-curve near the end of the last glaciation was 6°-10°C (average 8°C) lower than today. Thus the minima, below the general temperature during that time, of the Oligocene-Miocene fluctuations of the surface ocean-water were $1/_5$ - $3/_8$ of the average of this last ice-age minimum below present temperatures. The average tempera-

ture in NW. Europe at the beginning of the retreat of the ice near the end of the last glaciation was probably some 10° lower than today, and according to recent but still unpublished pollen-analytical investigations of late-glacial and glacial lake-sediments in Colombia (4 $^1/_2$° lat. N. from the equator at an altitude of 2.600 m), the decrease of temperature was almost the same near the equator. Thus, when near the equator a surface ocean-water temperature of 8° lower than today corresponds to an average temperature of approximately 10° lower than today on the equatorial South-American continent, and assuming that both change proportionally, then the Middle Oligocene temperature lowering would have had minima below the general temperature of that time of about $^1/_5 \times 10° = 2°C$ on the continent, and the Miocene $^3/_8 \times 10° = 3 \, ^3/_4°C$. As the temperature minimum at the base of the Tertiary (Paleocene), must have been considerably lower, a multiple of these ciphers may possibly be accepted for that time.

According to the temperature-curve published by NOREM (1956), the Miocene temperatures in the western United States were more or less the same as at the present-day. If this is right, and valid also for the whole Western hemisphere, then the periodic Miocene relative temperature-falls could be directly interpreted as more or less absolute values. But it seems premature to do this, as we do not know if NOREM's curve can be applied directly to South America. Nevertheless it seems possible that the deeper temperature minima were lower than the present-day average temperatures, and the minimum at the base of the Tertiary may even have been considerably lower.

g) *Relationship between the periodic vegetational changes and evolution.*

As stated above, immediately after each periodic change of the vegetation, new species (which may represent natural genera and families as well) appeared; on the other hand some species died out a little earlier. This "evolution-process" is stronger at the beginning of the "6 million year periods" than at the beginning of the rest of the "2 million year periods", that is to say more new "species" come in at the base of the international subdivisions. This "evolution process" is apparently of the character of SCHINDEWOLF's "typogenesis" (SCHINDEWOLF, 1950), and we will use this useful term in the following pages.

Thus we have to conclude that the typogenesis is intimately related with the periodic changes in the quantitative composition of the flora, that it shows the same periodicity and that therefore it must depend on the same primary causes of this periodicity.

Now the question arises as to whether the evolution process depends directly on the same cause as the vegetation changes, or whether other more primary or more secondary factors of this cause are responsible. We are here entering a purely theoretical field, and shall therefore discuss this matter in another publication. But we want to indicate here already that we consider it possible that both lowering of temperature and simultaneous increase in cosmic radiation, both originated by long

range solar cycles, are responsible for the periodic acceleration of the evolution-process.

As mentioned before, we have found that various important genera, and possibly many, had and have their center of origin and radiation on the stable continental precambrian nucleus (the Guiana shield) and not in the labile marginal zone (the geosyncline of the Andes).

This suggests that the orogenetic movements, transgressions and regressions may not be the primary causes of the typogenesis.

This agrees again with the fact mentioned before that this process depends directly on a periodic influence exercised on the earth, and that the orogenetic movements, are not, as we will see in the next paragraph, contemporaneous with this periodic influence but come afterwards. Of course, evolution of species took place in the labile marginal regions too, but it seems that here the factor of adaptation and specialization also play-ed a role. So we find for instance many representatives of tropical families and genera in the subandine and high andine vegetation. An example is the tropical Melastomataceae family, which has many shrub-like species in the subandine woods and shrub-vegetations, and even a herbaceous re-presentative in the high andine "Paramo". Without any doubt species evolved here during and after the uplift of the Andes, by a process of change of characteristics through adaptation to the new special circums-tances. But even in these cases the periodic influences may have "helped".

If the reasons given above are correct, then we may distinguish two different evolution-processes:

1. Typogenesis, taking place periodically all over the earth, depend-ing directly on periodic influences from outside. The process went forward on the nuclei just as in the marginal zones of the continents, but may have been more intensive on the nuclei in tropical regions. Direct influences may have been: decrease of temperature and (or) increase of cosmic ra-diation (both dependent on long range solar cycles).

2. A secondary evolution process taking place in the labile marginal areas of the continents, depending on specialization and adaptation to changed local circumstances. Direct influences may have been: uplift of mountains, giving new soils and new local climates; transgressions and regressions, changing local climatic conditions, groundwater-level, alka-linity, etc.

A definition of the evolution-process could be:

The ability to evolve is inherent in the species, but the evolution process is periodically accelerated (Typogenesis, SCHINDEWOLF, 1950) by a periodic influence from outside. As a secondary evolution-process, spe-cialization and adaptation to newly-formed local circumstances takes place (Typostasis, SCHINDEWOLF).

We also agree with SCHINDEWOLF in rejecting the influence of oro-genetic cycles, etc., on typogenesis; however it will be clear from the foregoing that some connection between periodic typogenesis and tempe-rature-fluctuations and (or) fluctuations of cosmic radiation (long range solar cycles) seems most probable.

h) *Relationship between the periodic vegetational changes, transgressions and tectonic movements*

Within the geosynclines of the Colombian Andes tectonic and minor orogenetic movements took place throughout the Upper Cretaceous and Tertiary. There are only few big inconformities, although smaller inconformities may be present at many levels, and the sedimentation in this respect was partly synorogenetic. However orogenetic movements and the principal upheaval took place during Miocene and especially Pliocene times.

Nevertheless, all the tectonic movements taking place partly within the geosyncline and combined partly with movements in the old Central Cordillera (which formed the Upper Cretaceous and Tertiary separation of the East-andine and West-andine geosynclines; inf. HUBACH), seem to be well registered in the stratigraphical succession of fluviatile and lacustrine sediments, as the presence of coarse sandstone and conglomerate horizons demonstrate. Thus constant sandstone or conglomerate horizons, and sometimes smaller or greater inconformities, are present almost everywhere in the andean geosynclines: near the base of the Maestrichtian ("arenisca tierna"), near the base of the Paleocene (Cacho sandstone, Barco sands, Socha sands), in the Lower Eocene and in the Middle Eocene (Mirador sst, La Paz sst, Usme sst, Hoyon conglomerates and Lower Gualanday conglomerates, etc.), near the base of the Lower Oligocene, near the base of the Middle Oligocene, near the base of the Upper Oligocene (Upper Gualanday conglomerate, Suárez conglomerates), and near the base of the Lower Miocene and of the Upper Miocene.

We must now consider whether there is some relation between tectonic movements and periodic influences in the area of fluviatile and lacustrine sedimentation.

The first thing that can be established is that they are never contemporaneous. Nevertheless, the more important tectonic movements always fall within the A-zone of the 6-million year periods, although in general a considerable time after the climatic change at the base. Sometimes these movements fall in the lower half of the A-zone, sometimes in the upper half, and we may estimate the time-interval between the climatic change and the beginning of the tectonic-orogenetic movements, according to the relative thicknesses, ranging from some hundreds of thousands of years to almost 2 million years. There seems to be very little connection between tectonic movements and the climatic changes at the base of the B and C zones.

We may deduce, that climatic changes by no means depend on tectonic-orogenetic movements. The same is true for transgressions, which, in those cases where we could check, come, in the interior of the geosyncline, some time after the vegetation-changes at the base of the A-zones. Nevertheless it is a curious fact that the tectonic and minor orogenetic movements always fall in the A-zone, showing in this way a, less pronounced, periodicity of about 6-million years; but the strength of the movements is very irregular, being now very feeble, now very strong.

Thus there seems to exist some relationship between climatic changes and tectonic and minor orogenetic movements, but it is rather feeble and irregular, and climatic changes at any rate do not depend on the latter.

The nature of this relationship is completely unknown. Although HUNTINGTON & VISHER (1932) tried to correlate sunspot- and temperature-changes with crustal movements, it still remains doubtful if it really exists. We think it most probable that crustal movements depend primarily on internal processes of the earth, but it may be that influences from outside have some secondary stimulating influence; this at least is suggested by the relationship established above, feeble though it may be.

One might suppose that, if this influence did not originate in solar cycles, there may have been some primary cosmic cause which affected both sun and earth, the effect being delayed in the stiff earths' crust, but according to a communication by letter from H. SHAPLEY (Director of the Harvard College Observatory), this is very unlikely according to our present knowledge of Astronomy.

Although highly theoretical, we would like to indicate another possibility here, which can explain various facts.

During the periodical decreases of temperature an ice-cap may have formed at the poles, disappearing (or diminishing) again when normal temperatures were restored. An increase of polar (land-)ice naturally lowers the sea-level all over the world, and a decrease of polar (land-)ice will raise the sea-level.

Thus it is possible that regressions established at the end of *periods, epochs* and *ages,* and transgressions coming a little afterwards at the beginning of the next *period (epoch* or *age),* depend partly on temperature-changes, and only partly on movements of the land. In that case the relatively slowly falling temperatures reflected by the relatively slowly rising top of the *Monocolpites medius*-group in our diagrams could correspond with regressions, and the rapidly rising temperature reflected by the relatively rapid fall of the *Monocolpites medius*-group after its top, with transgressions. This agrees with the fact that transgressions were found above the climatic changes in those cases which could be established.

Strong evidence that this postulate may be correct, can be found in the investigations of BÜRGL c. s. (1955), carried out in the Miocene of the Dept. of Atlántico (Colombia, S. A.).

As stated before (paragraph e), the Miocene, on the base of its duration of 12 million years, theoretically should have two 6-million year periods, each of three 2-million year periods. This was calculated on the basis of a total duration of 12 million years for the Miocene, on the assumption that the climatic fluctuations during the Miocene have the same periodism as the Maestrichtian, Paleocene, Eocene and Oligocene ones, completely independent of the results of BÜRGL c. s.

BÜRGL, in the above-mentioned publication, correlated the Miocene deposits from Atlántico with the european stages, and found a transgression at the base of each of them (fig. 7; the presence of the transgression at the base of the Tortonian is postulated in the later studies of BÜRGL, not yet published). The curve indicating the relative strength of these transgressions is in form remarkably like the *Monocolpites medius*-group curve for two 6-million year periods wherever in the Tertiary and uppermost Cretaceous. A relatively strong transgression is present at the base
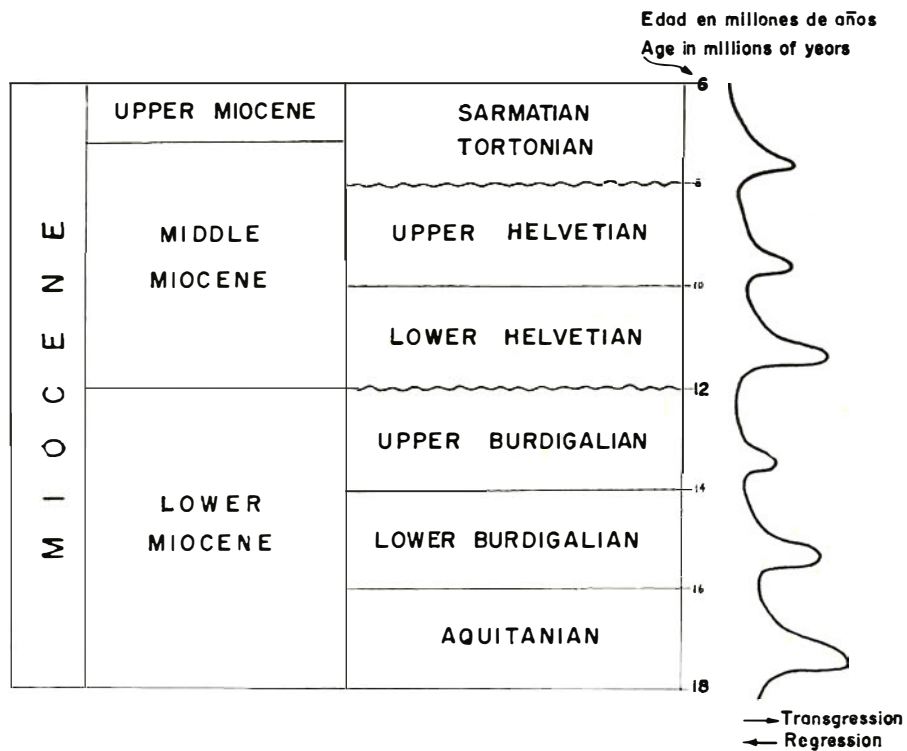
Fig: 7

SUBDIVISION DEL MIOCENO BASADO SOBRE INVESTIGACIONES PALEONTOLOGICAS Y ESTRATIGRAFICAS REALIZAS POR BÜRGL c.s (1.955) EN EL DEPARTAMENTO DE ATLANTICO (COLOMBIA, SUR AMERICA), CORRELACIONADA CON LOS CICLOS DE 6 Y 2 MILLONES DE AÑOS

SUBDIVISION OF THE MIOCENE ON THE BASIS OF PALEONTOLOGICAL STRATIGRAPHICAL INVESTIGATIONS CARRIED OUT BY BÜRGL c.s. (1.955) IN THE DEPT. OF ATLANTICO (COLOMBIA, SOUTH AMERICA), CORRELATED WITH THE 6 - AND 2 - MILLION YEAR CYCLES

Dib: Irma Cortés Cediel.

of the Aquitanian, followed by two minor ones at the bases of the Lower and Upper Burdigalian; another relatively strong transgression is found at the base of the Lower Helvetian, again followed by two minor ones, at the bases of the Upper Helvetian and the Tortonian.

If we bear in mind that, in the cases where we found indications of transgressions in our analysed sections, they always lay above the *Monocolpites medius*-group tops, then we find that this data yields further evidence for the assumption that the transgressions and regressions in the Upper Cretaceous and Tertiary may have been partly climatically determined.

This does not imply that we think this is the only explanation of transgressions and regressions. Doubtless there are many which depend on movements of the land, but these will not show a well-defined connection with the climatic periodicity.

There remains the problem of tectonic movements. Practically nothing can be said with any degree of probability about the nature of the relationship between climatic changes and these movements. The treatment of this problem, being more of a geophysical nature, is beyond our competence. Nevertheless we would like finally to ask the question whether it not might be a possibility that relatively small crustal disturbances of equilibrium, the result of regressions and transgressions, brought into movement tensions already present and caused by internal processes. This could explain both the relationship which seems to exist between the periodical climatic changes and the irregular intensity of the movements, which are primarily of internal origin.

i)   *A new stratigraphical criterion*

As a matter of fact stratigraphy is based on marine index-fossils. Now the question arises in which way the marine animals react on the periodic influences.

As we saw above, the 6-million year periods correspond very well to the international *epochs* or *ages,* established on the basis of marine fossils. The conclusion must be that the evolution of marine animals is parallel to that of land-plants. The reason for this fact may be that the same periodic decreases of temperature (and increases of cosmic radiation?) which seemed to have influenced the evolution process of land-plants, influenced the marine faunas by means of the formation and disappearance (or increase and decrease) of polar ice-caps, which may have exercised a very great influence on the temperature of the ocean water all over the earth (see above).

Just as with the land-plants, the factor of migration plays a role with marine animals, and in many cases, the finer correlation of widely separated places on earth is difficult or has to date been impossible; faunal differences due to climatical or facies-reasons must also be taken into account here.

The same problem exists, and is even greater, with correlations based on plant-species, which are impossible (or almost impossible) between widely separated continents such as South-America and Europe.
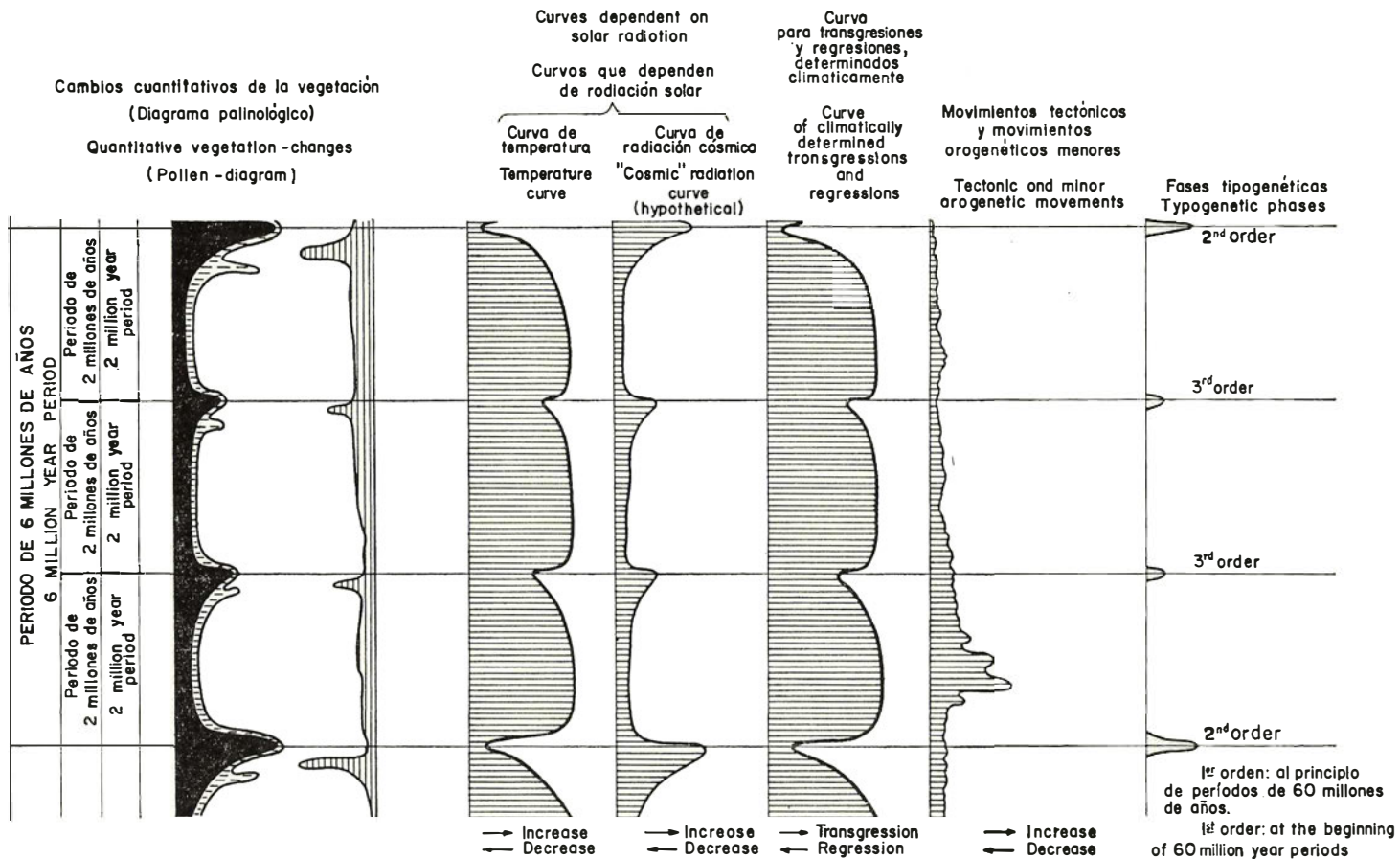
Fig: 8 ESQUEMA DE LA SUPUESTA CORRELACION DE LOS CAMBIOS CUANTITATIVOS DE LA VEGETACION, DE FLUCTUACIONES DE TEMPERATURA Y DE RADIACION COSMICA, CLIMATICAMENTE DETERMINADAS TRANSGRESIONES Y REGRESIONES, MOVIMIENTOS TECTONICOS Y TIPOGENESIS.
PLAN OF THE SUPPOSED CORRELATION OF THE QUANTITATIVE VEGETATION-CHANGES, FLUCTUATIONS OF TEMPERATURE AND COSMIC RADIATION, CLIMATICALLY DETERMINED TRANSGRESSIONS AND REGRESSIONS, TECTONIC MOVEMENTS AND TYPOGENESIS

But now the fact that a vegetation reacts immediately to an alteration in the climatic conditions by changes in its quantitative composition, whatever the specific content of this vegetation may be, and that these changes can be established by means of pollen (and spore) statistics, gives us a possible new criterion in stratigraphy. It is not quite impossible that similar investigations can be carried out on the abundant marine fossils, e. g. foraminifera. This possibility will of course have to be submitted to a detailed study of the problems which may arise and special working-methods will have to be established carefully as here changes of facies by means of transgressions and regressions may have a very great influence on the quantitative composition of the communities.

We may therefore conclude, that the registration of universal periodic influences (climatic changes) by means of pollen (and spore) statistics (and eventually by statistical paleontological methods), may bring a new criterion for time-correlations in stratigraphy, as this method is less dependent on the specific composition of local flora (or fauna) and is independent of migration-problems.

Conclusions. (See fig. 8).

1. Periodical changes of the quantitative composition of the terrestrial vegetation could be established on the basis of pollen analysis in the NW. part of South America, with a minor period of 2- and a major period of 6-million years. A very strong change could be recognized at the base of the Tertiary (60-million year period).

2. Typogenesis takes place during all these periodical changes, but especially during the major ones, those with a 6-million year period. Specially strong typogenesis took place at the base of the Tertiary (60-million year period).

3. There are important reasons for assuming that the causes of these periodical vegetation-changes and typogenesis are periodical decreases of temperature and (or) combined periodical increase of cosmic radiation.

4. Both periodical decreases of temperature and increase of cosmic radiation can be explained by periodical variations of solar radiation (long range solar cycles), with periods of about 60, 6 and 2 million years.

5. Transgressions and regressions which show this periodicity may have partly the same climatic cause, by means of the increase and decrease (or formation and disappearance) of polar (land-)ice-caps. In general they will have a relatively small extension.

6. Transgressions and regressions which depend on crustal movements will show little or no connection with periodism.

7. In the interior of the Colombian Andes (with principally fluviatile, lacustrine and lagunar sedimentation) a certain relationship seems to exist between tectonic movements and the 6-million year periods. These movements begin during the time of the deposition of the A-zons, but always a fairly considerable time after the periodical

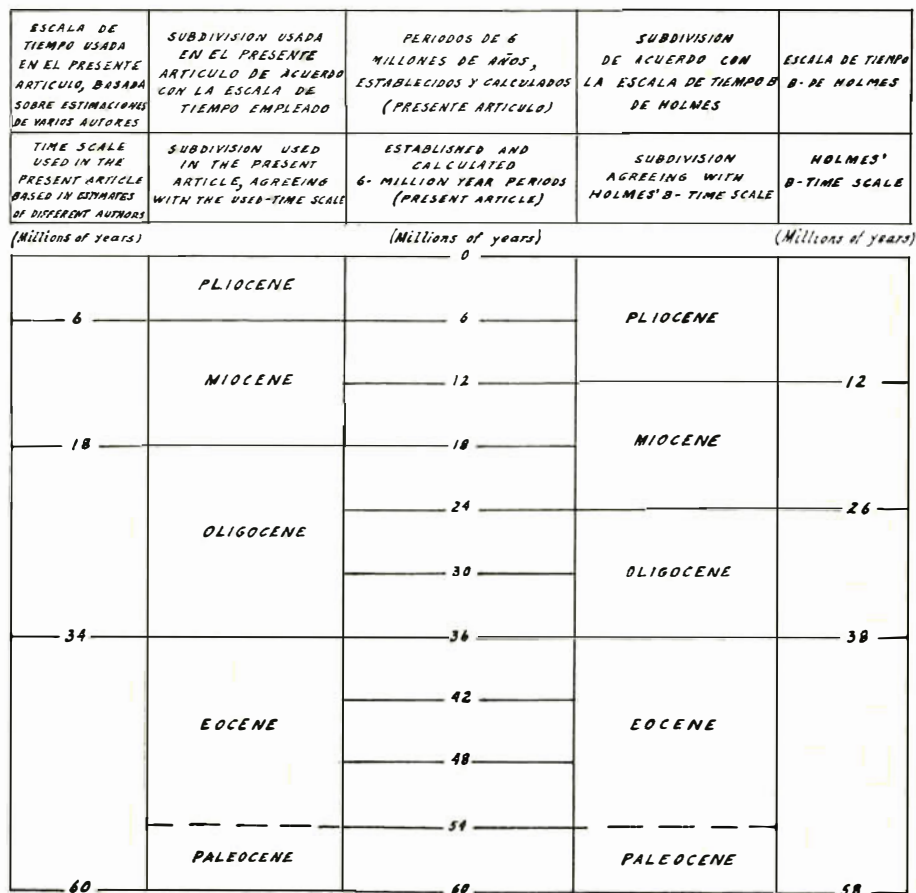| ESCALA DE TIEMPO USADA EN EL PRESENTE ARTICULO, BASADA SOBRE ESTIMACIONES DE VARIOS AUTORES	SUBDIVISION USADA EN EL PRESENTE ARTICULO DE ACUERDO CON LA ESCALA DE TIEMPO EMPLEADO	PERIODOS DE 6 MILLONES DE AÑOS, ESTABLECIDOS Y CALCULADOS (PRESENTE ARTICULO)	SUBDIVISION DE ACUERDO CON LA ESCALA DE TIEMPO B DE HOLMES	ESCALA DE TIEMPO B- DE HOLMES
TIME SCALE USED IN THE PRESENT ARTICLE BASED IN ESTIMATES OF DIFFERENT AUTHORS	SUBDIVISION USED IN THE PRESENT ARTICLE, AGREEING WITH THE USED-TIME SCALE	ESTABLISHED AND CALCULATED 6-MILLION YEAR PERIODS (PRESENT ARTICLE)	SUBDIVISION AGREEING WITH HOLMES' B-TIME SCALE	HOLMES' B-TIME SCALE
(Millions of years)		(Millions of years)		(Millions of years)

FIG: 9 OLIGOCENE - MIOCENE AND MIOCENE - PLIOCENE BOUNDARIES IN CONNECTION WITH THE 6-MILLION YEAR PERIODS AND DIFFERENT "ABSOLUTE" TIME-SCALES

LOS LIMITES DEL OLIGOCENO MIOCENO Y MIOCENO -PLIOCENO EN RELA- CION CON LOS PERIODOS DE 6 MILLONES DE AÑOS Y DISTINTAS ESCALAS DE TIEMPO "ABSOLUTO"

Dib. Irma Cortés Cediel.

vegetation-changes at the beginning of the deposition of these zones. The irregular strength of these tectonic movements show nevertheless that their primary cause probably lies inside the earth.

8. The temperature of the ocean-water must have shown periodical changes contemporary with the temperature oscillations on the continents.

9. Temperatures during the periodic decreases of temperature during the Tertiary, both of surface ocean water and on the continent, may have been somewhat lower than those of the present day in the same latitude, and the temperature at the beginning of the Paleocene may even have been considerably lower.

10. The registration of universal periodical influences (climatic changes) by means of pollen (and spore) statistics, and eventually statistical paleozoölogical methods, may bring a new criterion for time-correlations in stratigraphy. This method of correlation, being based on the same periodism as shown by the typogenesis, gives essentially the same international units and limits but with much better possibilities of exact world-wide correlation as it is in the main independent of the specific composition of local flora or fauna and of migration-problems.

Postscript

There exists a controversy on the correlation of the American (Caribbean) Oligocene-Miocene with the European. One group of students (EAMES, 1953; DROOGER, 1956) puts the boundary Oligocene-Miocene lower than others (STAINFORTH, 1948; BÜRGL c. s., 1955). We followed in this study STAINFORTH and BÜRGL, and what we called Upper Oligocene, should be lower Miocene according to EAMES and DROOGER.

We used an "absolute" time scale based on estimations by various authors. If using the B-scale of HOLMES (1947) our time-scale fits also perfectly, if we take the Oligocene-Miocene limit and the Miocene-Pliocene limit each one 6-million year period lower (see fig. 9).

Thus it seems that the differences in the time-scales of HOLMES and the one used by us depend only on where the Oligocene-Miocene and Miocene-Pliocene boundaries are placed and that our division on the basis of 6-million year periods may agree with both scales.

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MINISTERIO DE MINAS Y PETROLEOS
INSTITUTO GEOLOGICO NACIONAL
SECCI. DE PALEONTOLOGIA

DIAGRAMA PALINOLOGICO COMPUESTO
MAESTRICHTIANO - MIOCENO INFERIOR
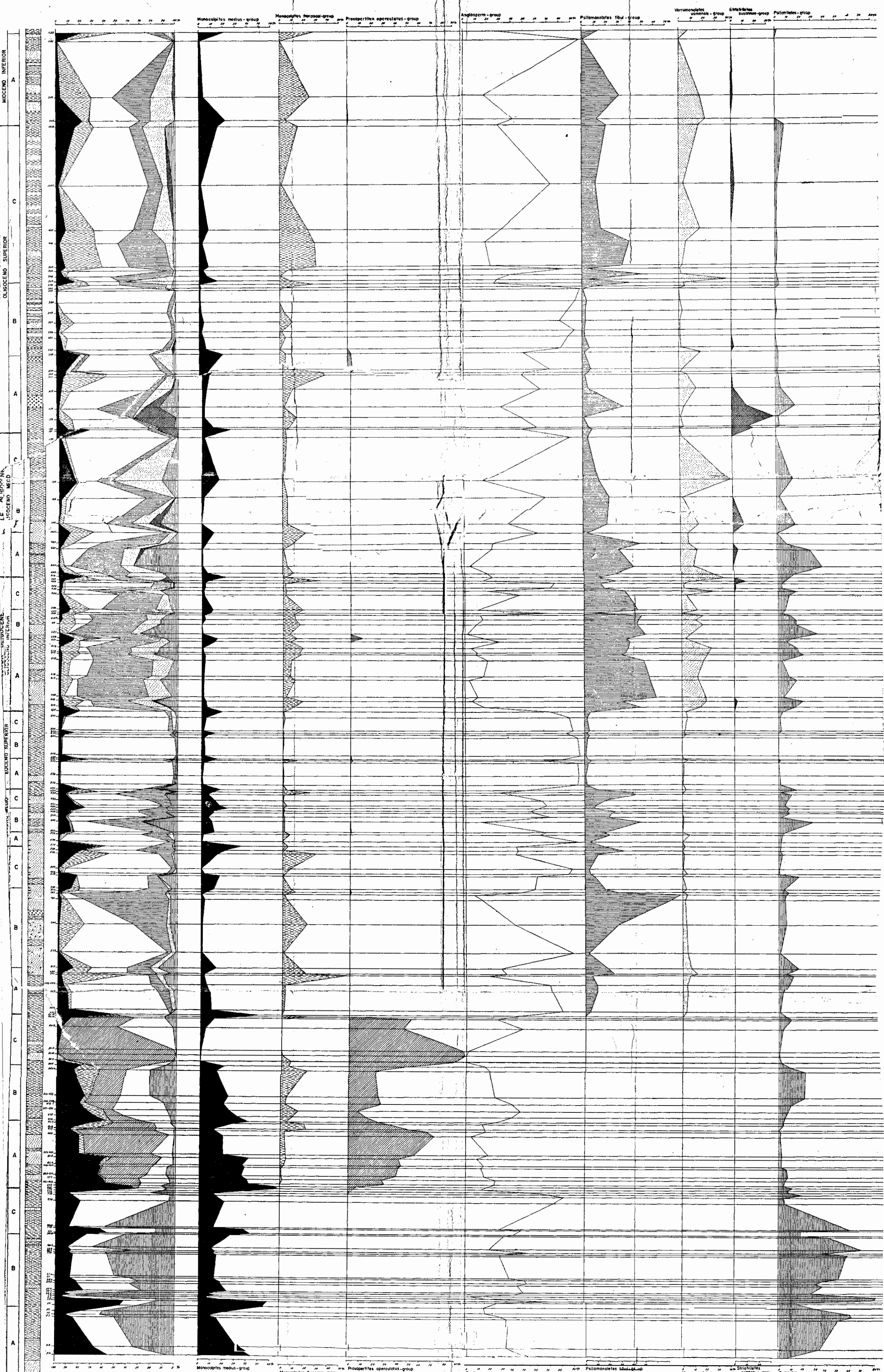### COLOMBIA (SUR AMERICA)
BASADO SOBRE ANALISIS PALINOLOGICOS DE SECCIONES DE LA
SABANA DE BOGOTA, DE TIBU (CATATUMBO),
TIMBA (VALLE DEL CAUCA) Y ANTIOQUIA

COMPOSITE PALYNOLOGICAL DIAGRAM
MAESTRICHTIAN – LOWER MIOCENE
COLOMBIA (SOUTH AMERICA)
BASED ON PALYNOLOGICAL ANALYSIS OF SECTIONS FROM
THE SABANA DE BOGOTA, FROM TIBU (CATATUMBO),
TIMBA (VALLE DEL CAUCA) AND ANTIOQUIA

Anal.
THOMAS VAN DER HAMMEN
PALEOBOTANICO JEFE

Drawing:
IRMA CORTES CEDIEL
DIBUJANTE

Monocolpites medius-group
Monocolpites franciscoi-group
Proxapertites operculatus-group
Angiosperm-group
Psilamonoletes tibu-group
Verrumonoletes usmensis-group
Striatriletes susannae-group
Psilatriletes-group

LEYENDA (Columna estratigrafica)-LEGEND (Stratigraphical column)

ARCILLAS ESQUISTOSAS, GREDAS ETC.
SHALES, CLAYS ETC.

ARENISCAS
SANDSTONES

CONGLOMERADOS
CONGLOMERATES

SITIO DE LOS MANTOS DE CARBON ANALIZADOS
EN LA COLUMNA ESTRATIGRAFICA
PLACE OF ANALYSED COAL-SEAMS IN THE STRATIGRAPHICAL COLUMN

LEYENDA DIAGRAMA - LEGEND (DIAGRAM)

MONOCOLPITES MEDIUS-GROUP
MONOCOLPITES FRANCISCOI-GROUP
PROXAPERTITES OPERCULATUS GROUP
ANGIOSPERM - GROUP (EXCEPT THOSE PALMS INCLUDED IN THE FORMER GROUPS)
(EXCEPTUANDO LAS PALMAS INCLUIDAS EN LOS GRUPOS ANTERIORES)

PSILAMONOLETES TIBU- GROUP
VERRUMONOLETES USMENSIS-GROUP
STRIATRILETES SUSANNAE- GROUP
PSILATRILETES - GROUP

LOS ESPESORES ESTAN BASADOS SOBRE OBSERVACIONES EN LAS AREAS DE TIBU, TIMBA Y ANTIOQUIA.
DOS PARTES DE LAS CUALES NO SE PODIAN OBTENER BUENAS MUESTRAS EN ESAS REGIONES, FUERON COMPLETADAS CON COLECCIONES EN OTRAS AREAS USANDO LOS ESPESORES OBSERVADOS EN LA SECCION DE TIBU (LA PARTE MAESTRICHTIANA DEL DIAGRAMA FUE TOMADO DE LA SECCION DE LA SUESCA - SANTA ROSITA, Y LA ZONA C DEL PALEOCENO DE LA SECCION DE LEBRIJA).
EXCEPCION: ZONA C DEL OLIGOCENO SUPERIOR Y LA ZONA A DEL MIOCENO INFERIOR TIENEN UN ESPESOR REAL VECES MAS GRANDE QUE LA REPRESENTADA, PARA FACILITAR LA REPRESENTACION DE ESTAS ZONAS.

THICKNESSES ARE BASED ON OBSERVATIONS IN THE TIBU-, TIMBA- AND ANTIOQUA AREAS.
TWO PORTIONS OF WHICH IN THESE REGIONS NO GOOD SAMPLES COULD BE OBTAINED, WERE COMPLETED BY COLLECTIONS IN OTHER AREAS, USING THE OBSERVED THICKNESSES IN THE TIBU- SECTION (THE MAESTRICHTIAN PART OF THE DIAGRAM WAS TAKEN FROM THE SUESCA - SANTA ROSITA SECTION, AND ZONE C OF THE PALEOCENE FROM THE LEBRIJA - SECTION)
EXCEPTION: ZONE C OF THE UPPER OLIGOCENE AND ZONE A OF THE LOWER MIOCENE ARE TWICE AS THICK AS REPRESENTED, TO MAKE THE REPRESENTATION OF THESE VENT THICK ZONES - EASIER.

EACH SPECTRUM CORRESPONDS TO A COAL-SEAM, AND IS THE AVERAGE OF A SERIES OF SAMPLES TAKEN FROM TOP TO BOTTOM FROM THAT SEAM.
CADA ESPECTRO CORRESPONDE A UN MANTO DE CARBON, Y ES EL PROMEDIO DE UNA SERIE DE MUESTRAS TOMADAS (DE ARRIBA HACIA ABAJO) DE ESTE MANTO.

ESCALA VERTICAL - VERTICAL SCALE
0 10 20 30 40 50 60 70 80 90 100
METROS - METRES