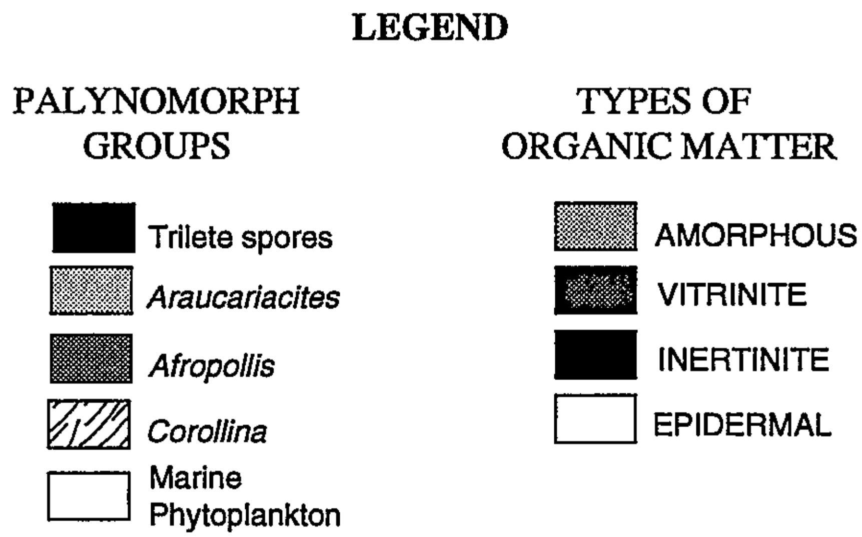
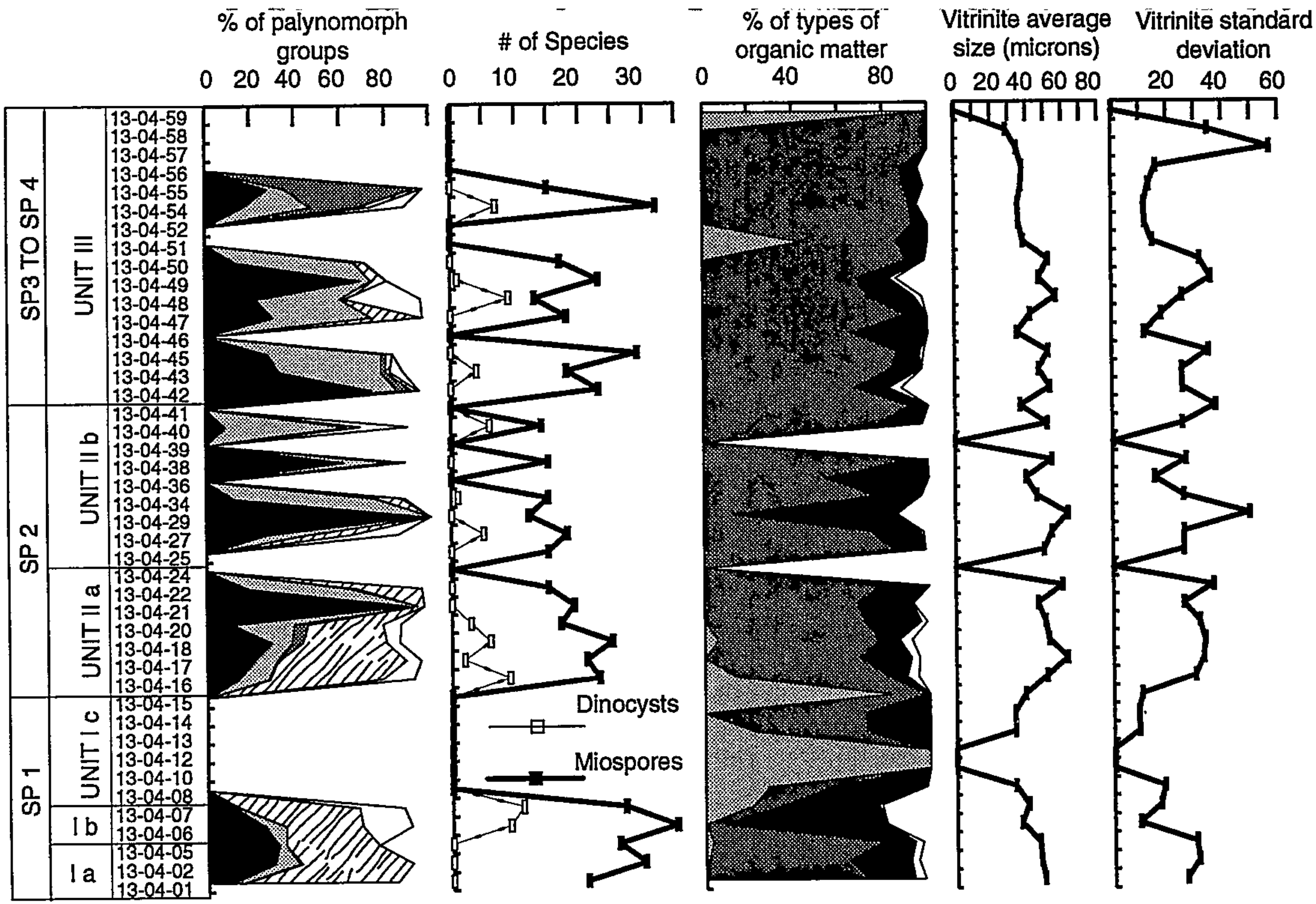
Figure 23. Palynological and palynofacies characteristics of the Zea-Panamericana outcrop section; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitriniteaverage size and its standard deviation. SP is referred to sedimentary phases (see discussion).





% of palynomorph groups
0 20 40 60 80
# of Species
0 10 20 30
% of types of organic matter
0 40 80
Vitrinite average size (microns)
0 20 40 60 80
Vitrinite standard deviation
20 40 60
SP3 TO SP 4
SP 2
SP 1
UNIT III
UNIT II b
UNIT II a
UNIT I c
I b
I a
13-04-59
13-04-58
13-04-57
13-04-56
13-04-55
13-04-54
13-04-52
13-04-51
13-04-50
13-04-49
13-04-48
13-04-47
13-04-46
13-04-45
13-04-43
13-04-42
13-04-41
13-04-40
13-04-39
13-04-38
13-04-36
13-04-34
13-04-29
13-04-27
13-04-25
13-04-24
13-04-22
13-04-21
13-04-20
13-04-18
13-04-17
13-04-16
13-04-15
13-04-14
13-04-13
13-04-12
13-04-10
13-04-08
13-04-07
13-04-06
13-04-05
13-04-02
13-04-01
Dinocysts
Miospores

- Unit I.

Unit I is located in the basal part of the outcrop and comprises the first 69.5 m of mainly clean to microconglomeratic sandstones, that are capped by an interval dominated by relatively massive gray to black shale with sandy and bituminous limestones at the top of this unit. The palynological asssemblages and the palynofacies observed in samples of this unit are characterized by the predominance of relatively well preserved terrestrial material. The number of miospore species averages near 30 (for samples 13-04-01 to 13-04-07), which is the highest number of species observed in the assemblages of this section. The palynological assemblages included in this unit correspond to those of biozone I (see discussion in the previous chapter).

The occurrence of dinocysts and amorphous organic matter, as well as changes in the preservation of the organic matter allows further subdivision of the Unit I in three main subunits.

- Unit Ia.

This unit includes the three most basal samples (13-04-01 to 13-04-05) examined in this section. They are characterized by:

a) Palynological assemblages: The main characteristic of the palynological assemblages is the occurrence of a relatively rich association of terrestrial miospore species, dominated by trilete spores. However, from the abundance (percentage of the total palynomorph count) point of view, the assemblages are dominated by pollen of *Corollina* (40 to 68% of the total) and trilete spores (11 to 32%). Marine phytoplankton (dinocysts, foram internal linings and acritarchs) is completely absent in these assemblages and only a few specimens of *Leiosphaeridia* sp. A are observed.

b) Palynofacies: The particulate organic matter of these three samples is dominated mainly by vitrinite (woody or degraded woody fragments), that predominantly shows some angularity and relatively large average size (about 50 µm on average). Visually, the vitrinite shows poor sorting (see Plate 18, figure 1). Values of the standard deviation of vitrinite phytoclasts for samples of this interval are the largest (near 40) in the interval.

Inertinite fragments are found in small percentages (14-27%) whereas epidermal fragments are rarely found (less than 5%).

- Unit Ib.

This unit comprises samples 13-04-06 and 13-04-07, collected in a massive shaly unit (6.5 m thick) that overlies unit Ia.

a) Palynological assemblages: As in unit Ia, the palynological association are still characterized by a relatively large number of miospores species (increasing to 40 in sample 13-04-06). Marine phytoplankton (almost exclusively dinocysts) have their first occurrence in these two samples. The dinocyst assemblages are characterized by percentages of about 20-22% and consist mainly of *Subtilisphaera senegalensis*, *Circulodinium distinctum* subsp. *distinctum*, *Kiokansium unituberculatum*, rare specimens of *Oligosphaeridium albertense* and foram internal linings. Pollen of *Corollina* and trilete spores are numerically the most abundant components of these assemblages.

b) Palynofacies: Changes in the composition and characteristics of the palynofacies are observed in samples 13-04-06 and 13-04-07. Inertinite becomes the dominant component of the palynofacies (40-70%), being relatively well sorted and with average sizes increasing towards the top of this unit (26 to 37 μm). Vitrinite percentages and the average size of the particles tend to decrease through this interval. Vitrinite phytoclasts are relatively well sorted and the standard deviation decreases upwards.

-Unit Ic.

This unit (samples 13-04-08 to 13-04-15) comprises a basal sandstone (with coaly nodules at the contact with Unit Ib), that is capped by an interval of arenaceous limestone, siltstone and bituminous limestone. A total of 6 samples were analyzed.

a) Palynological assemblages: Unlike units Ia and Ib, the palynological assemblages in unit Ic are either completely barren of palynomorphs or badly preserved and in very low numbers (less than 14 specimens per sample).

c) Palynofacies: Palynofacies of this interval are characterized by the dominance of amorphous organic material, with increasing proportions of vitrinite and inertinite towards the top of this unit. Vitrinite size tends to increase towards the top and is relatively well sorted. Values of standard deviation of the vitrinite size phytoclasts are relatively low for this interval.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Unit I.

Palynological assemblages and palynofacies of Unit I indicate a clear trend of increasing marine influence towards the top; at the base the assemblages are dominated by the abundance of pollen of *Corollina*, whereas dinoflagellate cysts are present in low percentages in samples 13-04-06 and 13-04-07. The dominance of pollen of *Corollina* seems to indicate that the paleoenvironments of deposition were located in low coastal areas (see Srivastava, 1976). A very likely sedimentary environment might be the fluvial dominated area of an estuary, where the influence of freshwater might be expected. The low percentages and number of species of dinoflagellates is related to this nearshore environment with predominantly continental influence in the depositional setting.

Unfortunately, the palynological assemblages towards the top of this unit are barren and preclude any possible inference regarding the paleoenvironments of deposition at the top of the unit. However, arenaceous and bituminous limestones at the top seem to indicate increasing marine conditions related to a trangressive pulse.

The onset of this transgressive pulse, inferred by the first occurrence of marine phytoplankton in unit Ib is also characterized by decreasing average size of the vitrinite phytoclasts and increasing degree of sorting, and by an abrupt increase of the inertinite percentage. The increasing degree of vitrinite sorting is related to coastal retreat towards inland areas, where the bulk of the large-sized phytoclasts would be deposited, leaving a finer fraction being transported basinwards. Both trends are evident in Figure 23, with average size of vitrinite and its standard deviation decreasing to the top of this unit.

The poor preservation of the assemblages might also be a consequence of the higher energy conditions and perhaps more oxidizing paleoenvironments of deposition near coastal areas.

- Unit II.

This unit includes the interval between by samples 13-04-16 and 13-04-41. The base of unit II is determined at the first level of sandstone overlying a covered interval (21 m). The palynological assemblages correspond to those described in biozone II and consist mainly of miospore species, with few species of dinoflagellates present throughout this interval. The palynofacies are dominated by terrestrial phytoclasts, mainly vitrinite.

- Unit IIa.

This unit comprises the first 25 m (samples 13-04-16 to13-04-24) of relatively clean sandstones, with some microconglomeratic levels and intercalations of dark gray to black massive shale.

a) Palynological assemblages: The assemblages of this unit are similar to those of units Ia and Ib; they are numerically dominated by pollen of *Corollina* and trilete spores. Characteristically, tetrads of *Corollina* occur in low percentages (less than 10%). Marine phytoplankton is present through most of this interval in low percentages (6 to 13%), composed mainly of specimens of *Subtilisphaera deformans*, *Circulodinium distinctum* subsp. *distinctum* and rare specimens of *Oligosphaeridium albertense*.

The number of species of miospores and dinoflagellates is higher at the base of this interval, with a clear trend to lower values at the top (25 to 15 species of miospores).

b) Palynofacies: The palynofacies of this unit are characterized by the dominance of poorly sorted vitrinite phytoclasts, with relatively large average size (up to almost 60 μm) (Plate I, figure 2). The values for the standard deviation of vitrinite size tends to increase towards the top of this unit.

- Unit IIb.

This unit (samples 13-04-25 to 13-04-41) comprises 34 m of mainly clean sandstone, with microconglomeratic levels, and intercalated with dark gray to black massive shale. In some cases, the contact of the sandstone and shales is more characteristic of fluvial channels.

a) Palynological assemblages: As in the previous units, the assemblages are dominated by terrestrial miospores. Pollen of *Corollina*; however, is only a minor constituent of the assemblages (at about 3-5%). In general the palynological assemblages consist of trilete spore-dominated assemblages, that alternate with *Araucariacites*-dominated assemblages. The latter are also characterized by the sporadic occurrence of marine phytoplankton, in general in very low proportions. The composition of the marine phytoplankton assemblages is more or less similar to that reported for units Ia, Ib and IIa, dominated mainly by *Subtilisphaera deformans*. The number of both miospores and dinocysts, tends to decrease towards the top of this unit.

b) Palynofacies: The palynofacies are dominated mainly by vitrinite phytoclasts. In general, the vitrinite phytoclasts exhibit relatively large average size (around 50 μm) and are poorly sorted. The values of the standard deviation of vitrinite size increase towards the top of this unit and in general show values of 20-30 units. The vitrinite assemblages in some cases are very dark in color (almost black) and are almost always associated with trilete spore-dominated assemblages.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Unit II.

The palynological assemblages and the palynofacies observed in unit II reflect a regressive event for most of the interval, with some trend to more marine influence towards the top. The palynological assemblages (dominated by pollen of *Corollina* and the low percentages of marine phytoplankton) of unit IIa seem to suggest paleoenvironments of deposition similar to those of units Ia and Ib, viz. low coastal plains located in the fluvial dominated estuary. The occurrence of tetrads of *Corollina* also suggests proximity to the sites where plants producing this pollen were growing. The transportation of pollen to the final site of deposition is in essence a physical process that has a definite effect on and relationship to the preservation of the palynomoprhs and the integrity of the particles being transported. Tetrads of miospores are expected to be preserved in larger numbers in sites near to the parent plants, since long distance transportation would tend to break them apart.

The trend to more continental assemblages in samples of unit IIb is more evident by the large decrease in the percentages of pollen of *Corollina* (indicative of coastal vegetation) and the occurrence of trilete-spore and *Araucariacites*-dominated assemblages. This palynological change occurs at the horizon where there is evidence of fluvial channels. Trilete spore-dominated assemblages might be related to swamp or restricted lagoonal environments (indicated by the lower number of species present per sample). The darkened vitrinite observed in some of these samples, might be the result of intensive sub-aerial oxidation due to variation of the water table within these swamps. *Araucariacites*-dominated assemblages, on the other hand, are characterized by the occurrence of marine phytoplankton and might be indicative of short trangressive pulses that caused the mixing of the palynological assemblages, that diluted the representation of trilete spores in these assemblages.

- Unit III.

This unit includes the top 75.80 m (samples 13-04-42 to 13-04-59) of the studied section in this locality. The interval consists of clean medium to fine-grained sandtsones, with intercalations of dark gray massive shales and limestone at the base.

a) Palynological assemblages: The assemblages are either dominated by trilete spores or *Araucariacites* and correspond to those described as part of biozone III. The trilete spore-dominated assemblages are characterized by relatively low diversities and predominance of specimens of *Dictyophyllidites harrisii* and *Deltoidospora australis*. On the other hand, the *Araucariacites*-dominated assemblages are characterized by high percentages of *Araucariacites australis* and relatively diverse assemblages. At the top of the section, one sample shows relatively large percentages of pollen of *Afropollis* (57%).

Miospore recovery was lower in this unit than in the underlying units I and II. Dinoflagellate cysts are not diverse and are dominated mainly by *Oligosphaeridium albertense*, *Circulodinium distinctum* subsp. *distinctum* and *Subtilisphaera deformans*. However, the number of miospores species is higher than that observed in Unit II.

b) Palynofacies: In general palynofacies are similar to those observed in samples of the underlying units I and II.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Unit III.

The distribution of the palynological assemblages and the palynofacies of this unit are characterized by the alternation of trilete spores and *Araucariacites* dominated assemblages, quite similar to that reported in Unit II. Ms. Xiomara Márquez and Selena Mederos (1992, personal communication), based on sedimentological evidence, have suggested that the basal interval of the herein defined Unit II correspond to fluvial deposits, whereas those of Unit III are more characteristic of distributary mouth bars. The increase in diversity of the species noticed for Unit III may be an effect of the mixing of inland and coastal palynological assemblages in this transitional paleoenvironments.

5.4.2 La Grita outcrop section.

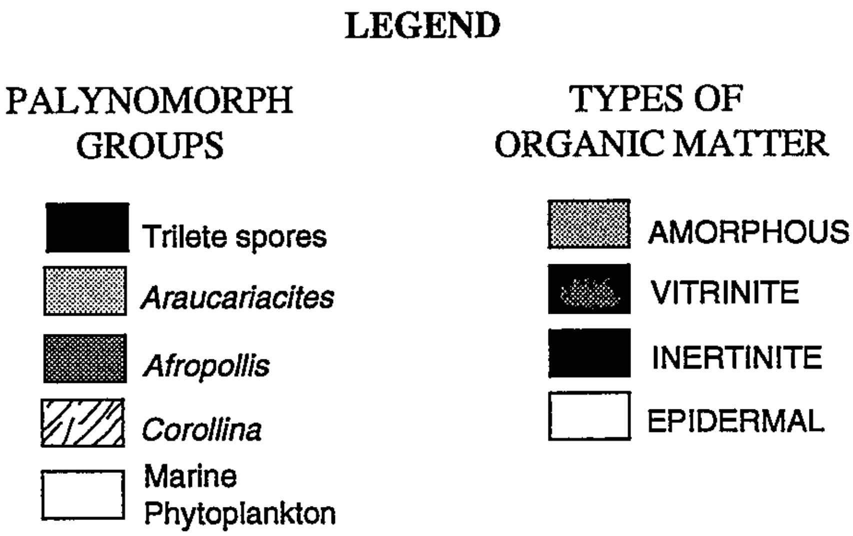
This outcrop section comprises nearly 49 m of predominantly clean, fine to medium-grained sandstone, with intercalations of massive dark gray to black shales, in some cases associated to gypsum veins and calcareous sands towards the top (see Appendix B-2). Ms. Xiomara Márquez and Selena Mederos kindly provided useful information on the sedimentology and lithology of this section of the Aguardiente Formation.

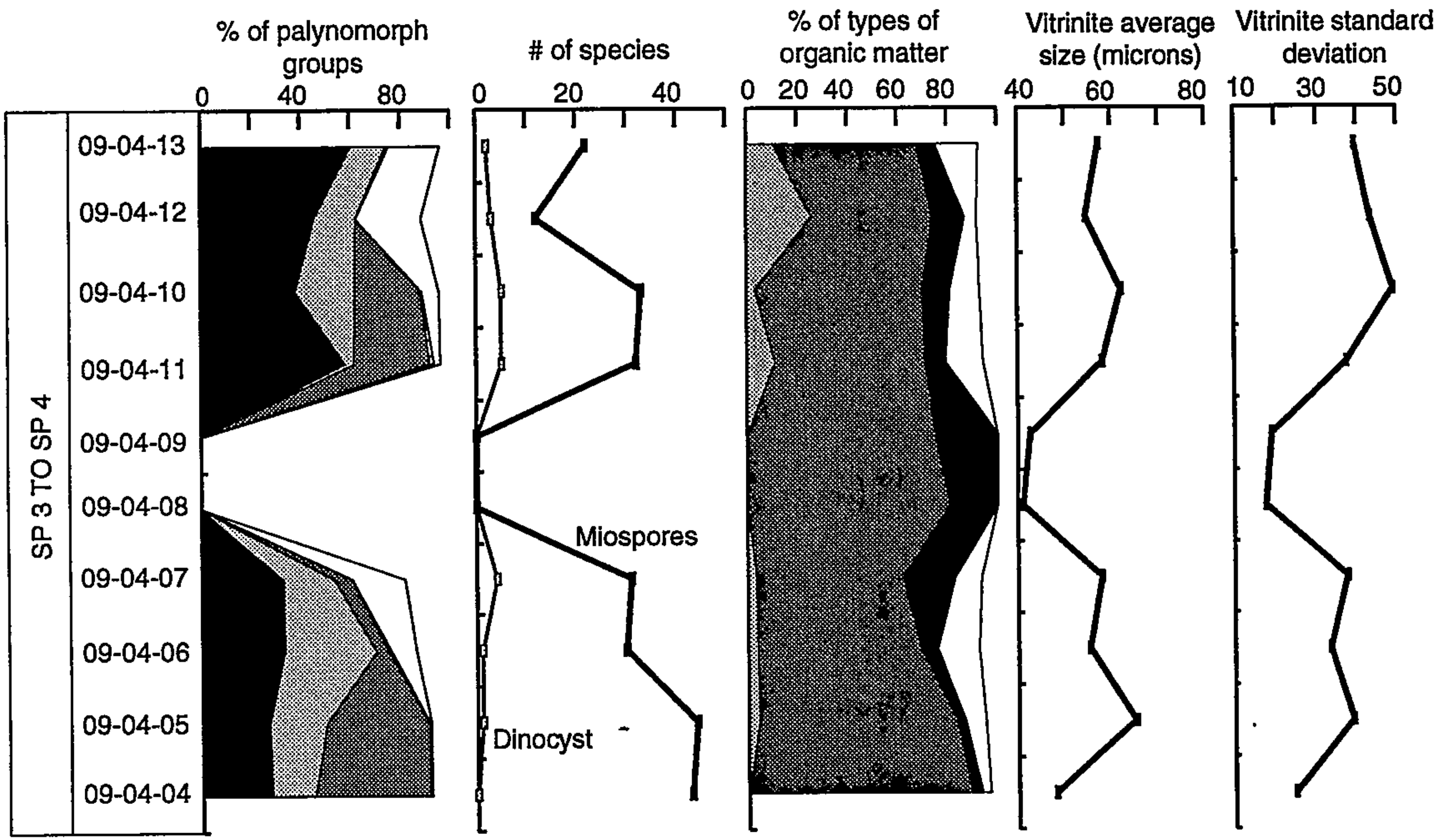
A total of 10 samples were analyzed for palynological and palynofacies studies (Figure 24).

Palynological-palynofacies description.

a) Palynological assemblages: The palynological assemblages observed in this unit correspond to those described in biozones III and IV. These assemblages are numerically dominated by the abundance of pollen of *Afropollis* sp. cf. *A. jardinus* and *Araucariacites australis*. The miospores constitute the major component of the assemblages, with marine phytoplankton being represented only by rare *Subtilisphaera senegalensis*, *Subtilisphaera deformans*, *S. zawaia*, *Oligosphaeridium albertense* and *Kiokansium unituberculatum*. Freshwater phytoplankton is also present; *Pediastrum* sp. A, *Chomotriletes minor* and *Tetraedron* sp. A.

Figure 24. Palynological and palynofacies characteristics of La Grita outcrop section; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitriniteaverage size and its standard deviation. SP is referred to sedimentary phases (see discussion).





% of palynomorph groups
0
40
80
# of species
0
20
40
% of types of organic matter
0
20
40
60
80
Vitrinite average size (microns)
40
60
80
Vitrinite standard deviation
10
30
50
SP 3 TO SP 4
09-04-13
09-04-12
09-04-10
09-04-11
09-04-09
09-04-08
09-04-07
09-04-06
09-04-05
09-04-04
Miospores
Dinocyst

Marine phytoplankton constitutes almost 20% of the assemblages, being mainly represented by common foraminiferal internal linings (especially at the top of the section). The percentages of *Corollina* are very low (less than 2%). The percentages of trilete spores tend to increase towards the top of the section, where foraminiferal internal linings are common. The number of species and the percentages of pollen of *Afropollis* per sample also decrease towards the top.

b) Palynofacies: The palynofacies are dominated mainly by vitrinite, that show average sizes relatively large (50-60 μm) with relatively poor sorting. Inertinite and epidermal phytoclasts occur in moderate to low percentages whereas amorphous organic matter is rare.

Two samples (09-04-08 and 09-04-09) are completely barren of palynomorphs, but show abundant particles of vitrinite, with low percentages of inertinite. Average size and standard deviation of vitrinite particles tend to decrease in these two samples.

- Paleoenvironmental significance of palynological assemblages and palynofacies of La Grita outcrop section.

The predominance of miospores and terrestrial phytoclasts and the low diversity of dinoflagellate cysts, suggest paleoenvironments of deposition greatly influenced by freshwater, with a transgressive pulse starting almost at the base of the section. Based on sedimentological evidence, Ms. Xiomara Márquez and Selena Mederos (1992, personal communication) that the paleoenvironments of deposition of this section considered a transition from more fluvial type of deposits at the base to more coastal or nearshore settings towards the top.

The occurrence of shales associated with veins of gypsum might be characteristic of lagoonal/estuarine paleoenvironments with restricted fresh and/or saline water input. The increase of trilete spore frequencies and the decrease of the percentages of pollen of *Afropollis* and *Araucariacites* as well as the number of species per sample in this interval, might be the result of restricted freshwater input into this paleoenvironmnents. The increasing restriction of water input and circulation, and perhaps the increasing degree of salinity might be also a factor related to the occurrence of foraminiferal internal linings in relatively moderate percentages (less than 20%). Stancliffe (1989) reported studies in the

Persian Gulf area, where foraminiferal internal linings are found in abundance in shallow water environments characterized by high salinity.

5.4.3 Well CR-5.

The cored section of well CR-5 can be divided lithologically into two main units: a basal limestone unit about 170' (51 m) thick, with some shale intercalations, overlain by a predominantly clastic unit of about 340' (103 m) of fine to medium-grained sandstone with intercalations of shales and limestones (see Appendix B-3). A total of 43 samples were processed, as shown in Figure 25.

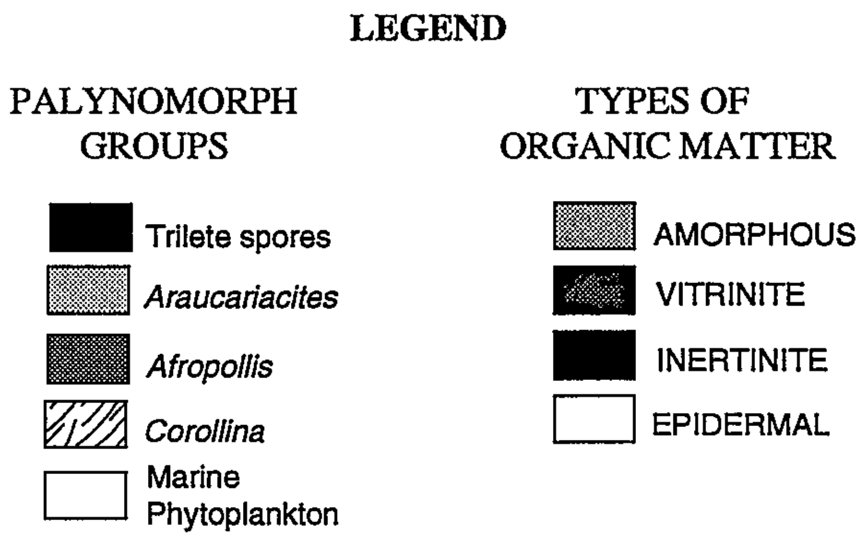
Palynological-palynofacies description.

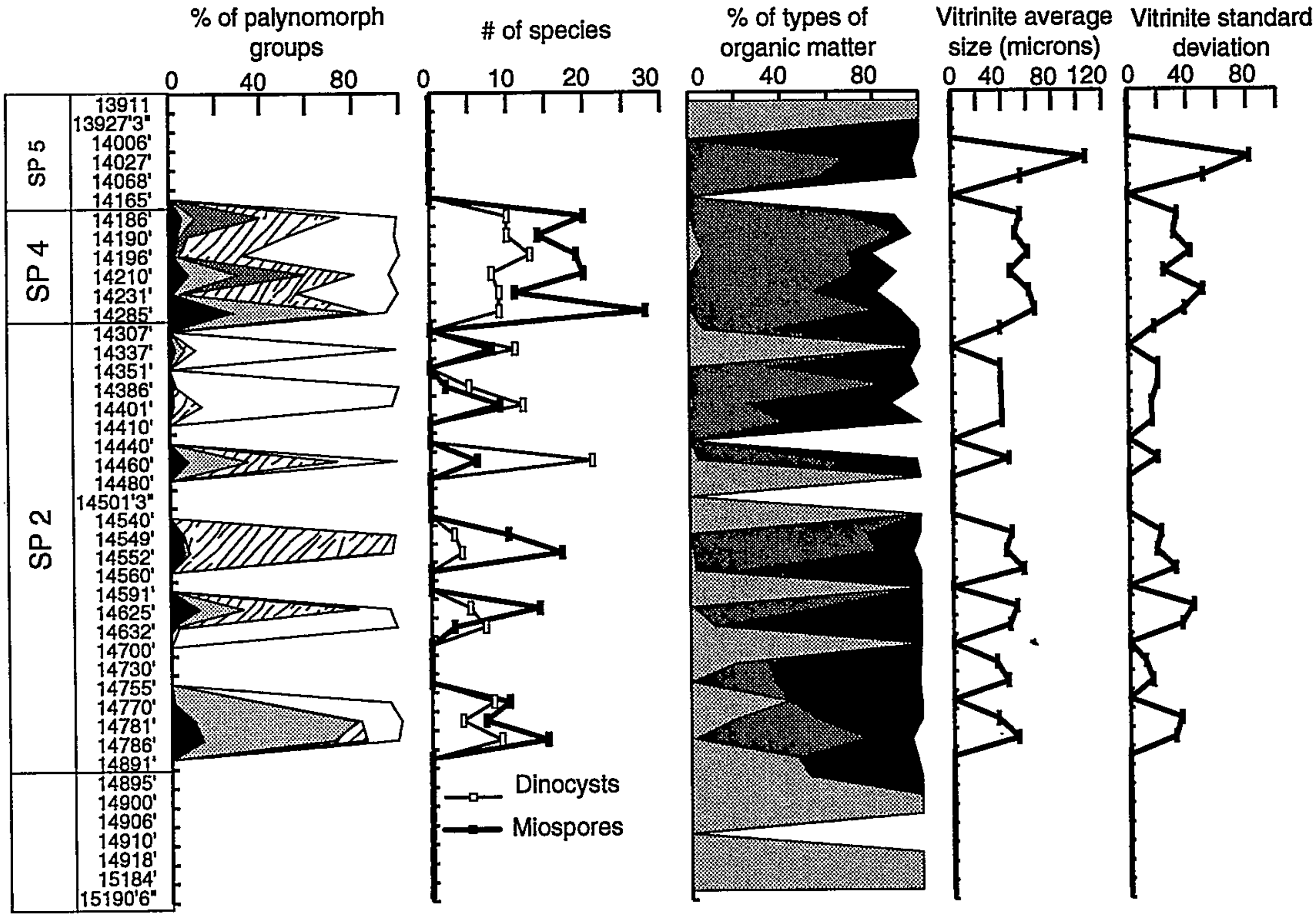
Unlike the two previously described sections, the palynological and palynofacies obtained in samples of well CR-5 show great variability in terms of recovery and composition. In general this variability might be related to several factors, among them the nature of the paleoenvironments of deposition and the lithologies of the processed samples. In the case of well CR-5, samples included carbonate facies (wackestone and packestone), calcareous sandstones, siltstones and shales. The best preservation and the more numerous assemblages were obtained from fine-grained sediments (shale).

a) Palynological assemblages: A relatively large number of samples yielded no palynological assemblages at all (barren) or only in very low numbers. They showed, with very few exceptions (see the following discussion), very poor preservation. However, some trends are evident in Figure 25.

Samples at the base of the studied interval (14895" to 15190' 6") yield very poor assemblages and for the most part they show extensive damage due to growth of pyrite crystals (Plate 18, figure 3). The assemblages show broken dinoflagellate cysts, making identification difficult. Among the species identified are *Oligosphaeridium albertense*, *Kiokansium unituberculatum* and *Circulodinium distinctum* subsp. *distinctum*. Miospores are badly preserved and are mainly pollen of *Araucariacites* and *Corollina*. These samples were sampled from a cored section including microconglomeratic sandstones of the Rio Negro Formation and wackestones of the Apón Formation (not described by Mederos, 1992).

Figure 25. Palynological and palynofacies characteristics of well CR-5; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitrinite average size and its standard deviation. SP is referred to sedimentary phases (see discussion).





% of palynomorph groups
# of species
% of types of organic matter
Vitrinite average size (microns)
Vitrinite standard deviation
SP 5
SP 4
SP 2
13911
13927'3"
14006'
14027'
14068'
14165'
14186'
14190'
14196'
14210'
14231'
14285'
14307'
14337'
14351'
14386'
14401'
14410'
14440'
14460'
14480'
14501'3"
14540'
14549'
14552'
14560'
14591'
14625'
14632'
14700'
14730'
14755'
14770'
14781'
14786'
14891'
14895'
14900'
14906'
14910'
14918'
15184'
15190'6"
Dinocysts
Miospores

A change in the preservation of the assemblages is noticed in the interval between 14770' and 14786', in three samples which yield relatively abundant assemblages that show dominance of *Araucariacites australis*, with subordinate amounts of *Corollina* and trilete spores (mainly of the genus *Deltoidospora*). At 14770', pollen of *Araucariacites* is still the most common miospore. However, the proportion of dinoflagellates cysts is about 50% of the total, but most of the cysts are poorly preserved and broken. *Oligosphaeridium albertense*, *Spiniferites twistringiensis* and *Circulodinium distinctum* subsp. *distinctum* are the most common. Unlike the previous interval, growth of pyrite crystal is not observed.

Very poor preservation and extensive pyrite crystal growth are common between 14632' and 14755', where the almost barren assemblages are characterized by broken dinoflagellates and poorly preserved cysts of *Oligosphaeridium albertense*, *Circulodinium distinctum* subsp. *distinctum* and rare *Kiokansium unituberculatum*. Sample 14625', however, yields a relatively better preserved assemblage, that is dominated mainly by *Corollina brasiliensis* and *Araucariacites australis*.

Samples 14549' and 14552' also yield relatively well preserved assemblages that are dominated by *Corollina*, with subordinate dinocysts. Sample 14460' also shows a well preserved assemblage dominated by *Araucariacites australis* and *Corollina*. Dinoflagellate cysts present in these samples are *Oligosphaeridium albertense*, *Circulodinium distinctum* subsp. *distinctum* and *Subtilisphaera deformans*, all in very low numbers. Up to this point in the sampled section, the number of species of dinocysts is less or equally to those of miospores.

In the interval between 14337' and 14460' the assemblages show also a very erratic trend in terms of recovery. When palynomorphs are abundant, however, the assemblages are numerically dominated by abundant dinocysts of *Odontochitina operculata*, *Oligosphaeridium albertense*, *Circulodinium distinctum* subsp. *distinctum*, *Florentinia* sp. cf. *F. verdieri*, *F. laciniata*, rare *Achomosphaera* sp. B and *Cribroperidinium orthoceras*, among others.

A significant change in the composition and preservation of the assemblages is observed in the interval between 14186' and 14285'. First, the number of species abruptly increases in comparison to the underlying interval, with the number of species of miospores being larger than those of dinocysts. For most of this interval *Corollina* *brasiliensis* (in general larger than 43 μm diameter), *Araucariacites australis* and in two samples, *Afropollis* sp. cf. *A. jardinus*, are the dominant elements. Trilete spores are also found in moderate percentages at the base, tending to decrease towards the top. Dinoflagellate cysts are present in relatively high percentages (from 7% at the base to 65% almost at the top). Species such as *Xiphorodinium* sp. A, *Subtilisphaera deformans*, *Oligosphaeridium albertense* and *Xenascus plotei* (in two samples; 14196' and 14190'), are the dominant elements of the phytoplankton assemblages, with subordinate amounts of *Spiniferites twistringiensis*, *Kiokansium unituberculatum*, *Circulodinium distinctum* subsp. *distinctum*, *Florentinia* sp. cf. *F. verdieri* and *F. laciniata*.

The top interval (13911' to 14165') is barren of palynomorphs.

b) Palynofacies: Most of the samples observed in this well yield enough amount of organic residue to allow the characterization of palynofacies.

Among the general trends observed in Figure 24, palynofacies of samples from well CR-5 are generally characterized by relatively larger percentages of inertinite phytoclasts, in comparison to most of the samples observed for the sections of Zea-Panamericana and La Grita-Seboruco. Furthermore, most samples are characterized by proportion of amorphous organic matter and poor preservation of the palynological residues. In some cases, the samples with a large proportion of amorphous organic matter are associated to extensive pyrite crystal growth (Plate 18, figure 3).

Inertinite phytoclasts are relatively abundant in the interval ranging from 14307' down to 14895'. The percentages of this type of phytoclast, on the other hand, tends to decrease in the interval of 14186' and 14285', where vitrinite is the dominant phytoclast. The average size of vitrinite particles in this interval is slightly larger than that observed in the underlying interval, in general showing poor sorting and much better preservation.

At the top, inertinite and amorphous organic matter are again the dominant phytoclasts, in an interval that shows no palynological assemblages at all. It is northworthy that the average size of the vitrinite particles increases at 14027'.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Well CR-5.

The common occurrence of dinoflagellate cysts throughout the studied interval suggests that the paleoenvironments of deposition in well CR-5 were more marine than those observed in the section of La Grita and Zea-Panamericana.

The alternation of samples enriched in amorphous organic matter and samples enriched in terrestrial phytoclasts and miospores suggest that this nearshore paleoenvironment had continuous but fluctuating input of terrestrial material. The amorphous organic intervals might not be necessarily related to biomass produced by the phytoplankton, but can also be product of extensive degradation of terrestrial material in high energy environments. The poor ultraviolet fluorescence shown by this fraction of the organic matter suggests a high degree of oxidation. The extensive development of pyrite crystals on the surface of palynomorphs and phytoclasts seems to be the consequence of sulfate-reducing bacteria, after burial of the organic material in marine environments (Davies et al., 1991). Vitrinite size did not show any significant trend, except at the top of the section (at 14027'), perhaps an indication of a progradational event during the deposition of the Aguardiente Formation.

- Interval 14307' to 14891'.

The occurrence of enriched inertinite palynofacies for most of this interval 14307' through 14891' suggests a regressive phase. Habib and Miller (1989) concluded that regressive palynofacies are characterized by enrichment of the more resistant and highly bouyant inertinite particles. The occurrence of relatively well preserved miospores and terrestrial palynofacies at few levels, as well as the predominance of terrestrial miospores, suggest periods of maximum inflow of terrestrial particles into these paleoenvironments, that perhaps enhanced the preservation of these assemblages. Dinocysts species begin to appear in larger numbers than miospores in the interval between 14336' and 14460'. The diversity of the dinocyst assemblages also increases in this interval, with species of *Florentinia*, *Achomosphaera* and *Cribroperidinium*. This change is observed to happen at the point at which there is a lithological change from the more calcareous lithologies of the Aguardiente Formation at the base of the cored section to more clastic deposits at the middle and top part of the section. Mederos (1992) also noticed that sedimentary styles changed from coarsening-upward (below this interval) to fining-upward sequences. These two events (the fining-upward and the increase in the number of species of dinoflagellates) suggest the onset of a transgressive pulse within the major regressive phase. The decreasing number of species of dinoflagellates and the occurrence of rounded and poorly preserved vitrinite phytoclasts and miospores at the top of this interval are indicators of the regressive phase.

- Interval 14186' to 14285'

The significant change in the preservation of the palynological assemblages and the palynofacies in this interval is characterized by a relatively well mixed and preserved assemblages of terrestrial organic material (miospores and vitrinite) and marine phytoplankton. The increase in the diversity of miospores and the slight increase of average vitrinite size, as well as the good preservation observed, suggest that these deposits were related to a significant progradational event. The assemblages of these samples correspond to biozones III and IV and indicate that this progradational phase took place during the Albian. It might be considered that proximal to estuarine paleoenvironments of deposition reflected the inflow of terrestrial miospores and phytoclasts, which is even further enhanced by the fine grained nature of the deposits that were sampled in this interval.

Unfortunately, samples at the top are unpalyniferous but the abundance of inertinite and the increase in average size of the vitrinite particles might indicate a regressive phase at the top of the cored section of the Aguardiente Formation in well CR-5.

5.4.4 Well ALT-19X.

The cored section of well ALT-19X consists of about 621' (189 m) of predominantly carbonate facies See Appendix B-4). Well developed clastic intervals are observed in the middle-upper part of the section. A total of 50 samples were processed for palynological and palynofacies analysis (Figure 26).

Palynological-palynofacies description.

As in the case of well CR-5, most of the samples that yield rich and well preserved palynomorph assemblages are fine-grained sediments (shale and siltstones).

Figure 26. Palynological and palynofacies characteristics of well ALT-19X; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitrinite average size and its standard deviation. SP is referred to sedimentary phases (see discussion).

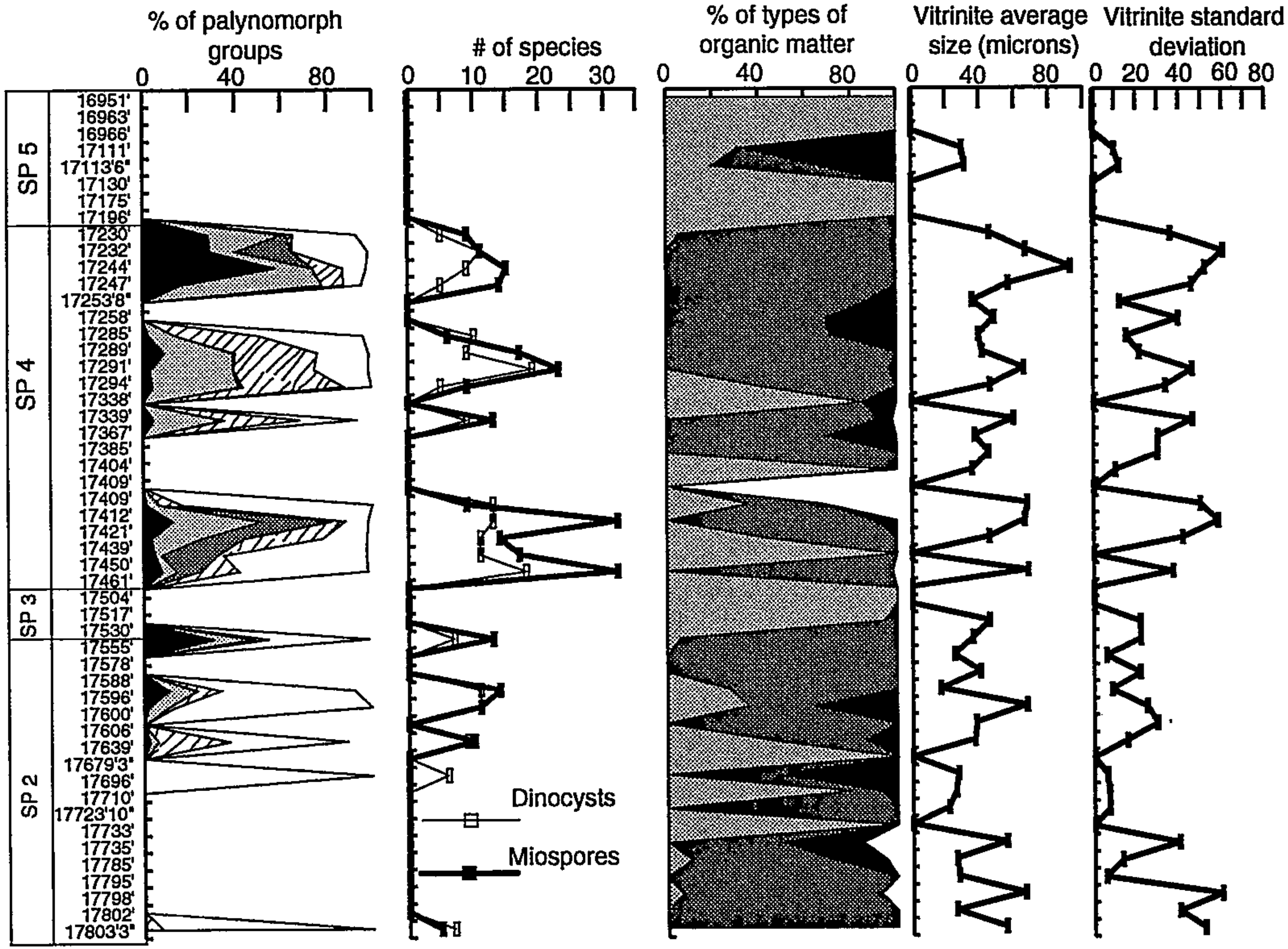
LEGEND

PALYNOMORPH GROUPS

- Trilete spores
- *Araucariacites*
- *Afropollis*
- *Corollina*
- Marine Phytoplankton

TYPES OF ORGANIC MATTER

- AMORPHOUS
- VITRINITE
- INERTINITE
- EPIDERMAL



% of palynomorph groups
0
40
80
# of species
0
10
20
30
% of types of organic matter
0
40
80
Vitrinite average size (microns)
0
40
80
Vitrinite standard deviation
0
20
40
60
80
SP 5
SP 4
SP 3
SP 2
16951'
16963'
16966'
17111'
17113'6"
17130'
17175'
17196'
17230'
17232'
17244'
17247'
17253'8"
17258'
17285'
17289'
17291'
17294'
17338'
17339'
17367'
17385'
17404'
17409'
17409'
17412'
17421'
17439'
17450'
17461'
17504'
17517'
17530'
17555'
17578'
17588'
17596'
17600'
17606'
17639'
17679'3"
17696'
17710'
17723'10"
17733'
17735'
17785'
17795'
17798'
17802'
17803'3"
Dinocysts
Miospores

a) Palynological assemblages: Dinocysts numerically dominate the observed assemblages in well ALT-19X. However the number of dinocysts species is lower than or equal to that of miospores throughout the studied sequence.

At the base of the studied sections, the assemblages are characterized by poor preservation, with most of the palynomorphs showing extensive damage by pyrite-crystal growth on the surface. In the interval between 17679'3" and 17803' 3", the diversity of the assemblages is very low and they are dominated by *Oligosphaeridium albertense, Oligosphaeridium complex, Circulodinium distinctum* subsp. *distinctum* and *Odontochitina operculata.* Rare specimens of *Subtilisphaera deformans, Microdinium opacum, Spiniferites twistringiensis* and *Cribroperidinium orthoceras* occur. Miospores are observed in very low numbers.

Some of the samples located in the interval of 17504' and 17639' yield palynological assemblages that are better preserved with miospore assemblages in moderate good numbers. In general the miospore assemblages are dominated by *Corollina* or *Araucariacites*, with increasing proportion of trilete spores at 17555'. However, the dinocysts are numerically dominant. The assemblages are characterized by the common occurrences of *Oligosphaeridium albertense, Kiokansium unituberculatum, Coronifera oceanica, Circulodinium distinctum* subsp. *distinctum, Florentinia* sp. cf. *F. verdieri, F. laciniata* and rare specimens of *Achomosphaera, Cribroperidinium* and *Spiniferites*.

As observed in well CR-5, a significant change in the composition and the diversity of the assemblages is observed, in this case in the interval located between 17230' and 17461'. The assemblages of miospores become quite diverse, mainly dominated by *Corollina brasiliensis* (larger than 43 µm) and *Araucariacites australis. Afropollis* and *Elaterosporites klaszi* also occur throughout this interval. Trilete spores are present in low percentages, with *Deltoidospora* and *Dictyophyllidtes* being dominant. Dinoflagellate assemblages also show a significant increase in the diversity. Species such as *Xiphophoridium* sp. A, *Xenascus plotei, Kiokansium unituberculatum, Cribroperidinium orthoceras, Florentinia* sp. cf. *F. verdieri, F. laciniata, Achomosphaera* sp. A, *Achomosphaera* sp. B, *Circulodinium distinctum, Subtilisphaera deformans, Subtilisphaera senegalensis* and *Oligosphaeridium albertense* occur in relatively moderate to large numbers in the assemblages, whereas *Chichoadinium boydii* shows its first occurrences at the base of this interval. The diversity and the preservation of the assemblages in this interval tend to decrease to the top, where trilete spores appear in moderate percentages.

Samples located at the top of the studied interval are completely barren of palynomorphs.

b) Palynofacies.

As in the case of well CR-5, the palynofacies are characterized by the alternation of samples with enriched terrestrial material with those comprising amorphous organic matter as the main constituents.

At the base of the studied section (17785' to 17803'3"), poorly preserved vitrinite, relatively rounded and very fragmented, predominante. Amorphous organic matter is a common component at 17735' and it is present in fluctuating proportions throughout the interval between 17504' and 17735'. In most of these samples, marcasite-pyrite crystals are abundant. In the vitrinite-dominated palynofacies occurring in this interval, vitrinite is observed to be mainly highly degraded and fragmented (smaller average size than in the previous interval). The interval is capped by the occurrence of abundant amorphous organic matter at 17517' and 17504'.

Palynofacies also show a significant change in the preservation of the palynofacies and phytoclasts (Plate 19, figure 1). The interval is characterized by increasing amounts of terrestrial material (vitrinite and and inertinite), with very good preservation at the base of the interval. At the interval between 17412' and 17461', vitrinite fragments are angular and relatively large in size, showing very poor sorting. The size of vitrinite phytoclasts (in average) tend to decrease between 17253'8" and 17294' with an increase in size and decreasing degree of sorting between 17230' and 17247'. The average size of vitrinite phytoclast and its standard deviation are relatively larger in this interval than those observed between 17555' and 17735'.

Amorphous organic matter is the dominant constituent of the palynofacies at the top of the studied section.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Well ALT-19X.

The lithology and the common occurrence of dinoflagellate cysts throughout the studied interval suggest that the paleoenvironments of deposition in well ALT-19X were located at increasing distance from shore, in comparison to the previously considered sections. Pinto Auso and Moldovanyi (1987) characterized the paleoenvironments of deposition within the litoral and upper neritic zone, in general at shallow depths (25-30 m).

- Interval 17555' to 17803'3"

The first interval is characterized by the poorly-preserved assemblages of palynomorphs and palynofacies (17555' to 17803'3"). The occurrence of very rounded and poorly preserved vitrinite phytoclasts is characteristic of this interval. Increasing proportions of miospores and terrestrial material at the top of this interval indicate maximum periods of input of terrestrial matter in the paleoenvironments of deposition. Unlike the palynofacies of well CR-5, the amount of inertinite found in the studied samples is very low. However, the roundness and the degradation shown by the vitrinite phytoclasts, indicates that the deposition of this interval took place during a regressive phase in marine environments. The roundness and degradation of vitrinite can be the consequence of the transportation from continental areas and the level of energy of the paleoenvironments. The diversification of dinoflagellate cysts in the interval 17555' to 17639' might be a reflection of a minor transgressive pulse, also inferred in well CR-5 during this major regressive pulse. It is noteworthy that diversity of the dinocyst assemblages decreases at 17555', perhaps as a result of the regressive cycle. The palynological assemblages of this regressive phase are those reported in biozone III (Late Aptian).

- Interval 17504' to 17530'

The previous interval is capped by palynofacies rich in amorphous organic matter of marine origin. These palynofacies were recovered from carbonate facies that perhaps were deposited during early stages of a transgressive pulse. The palynological assemblage are poor and species of dinoflagellates are the only elements indicative of this transgressive phase.

- Interval 17230' to 17461'

As was also discussed for well CR-5, a major progradational event was inferred in the interval between 17230' and 17461'. It is characterized by the occurrence of of well preserved and diversified palynological and palynofacies. The increasing proportion of miospores and terrestrial material towards the top of this interval might be related to increasing progradation of estuarine environments. As in the case of well CR-5, the assemblage of this interval are determined to be Albian.

The interval at 17230' and 17247' is characterized by decreasing diversity of the assemblages, as well as by generally increasing amounts of trilete spores and miospores. Vitrinite found in this interval shows increasing roundness and degradation, in comparison to the underlying interval already described.

Unfortunately, assemblages of palynomorphs and palynofacies at the top are of little use because of the significant degradation and poor preservation.

Moldovanyi and Pinto Auso (1987) reported the occurrence of three sedimentary phases, based on sedimentological and micropaleontological evidence, for the deposition of the cored sequence of well ALT-19X.

The first comprises the interval between 17540' to 17806' and is characterized by increasing levels of energy towards the top of the sequence. In general this interval corresponds to the first interval described here, based on the palynological and palynofacies (17555' to 17803'6") and it may correspond to the suggested regressive cycle. Moldovanyi and Pinto Auso (1987) also reported the occurrence of intercalated shale beds that might represent pulses of clastic material input into the paleoenvironments.

The second sedimentary cycle of these authors extends from 17200' to 17540'. The base of the of this interval shows the occurrences of planktonic foraminifera, indicative of open marine conditions. This would correlate to the inferred onset of the transgressive pulse that was placed in samples 17517'3", 17504' and 17530' based on the occurrence of amorphous organic matter of marine origin. This phase of more marine conditions was perhaps related to the deposition of a package of packstone/wackestones

(17468' to 17542') and it is followed by a period of clastic and terrestrial input, that correspond to the progradational event characterized by the occurrence of well preserved palynological and palynomorph assemblages (17253'8" to 17460'). Towards the top of the interval, Moldovanyi and Pinto Auso (1987) inferred an increase in the conditions of energy of the paleoenvironments which is related to the regressive pulse (17230' to 17347') that was determined based on the palynological and palynofacies analyses (characterized mainly by increasing proportions of terrestrial assemblages and poorly and relatively rounded vitrinite, with increasing average size at the top). This regressive phase at the top of the studied sequence is related to the occurrence of the deposition of assemblages that were described in sub-biozone IV-1, dominated mainly by miospores.

The third cycle reported by Moldovanyi and Pinto Auso (1987) (17110' to 17200') corresponds to increasing marine conditions. This interval corresponds to samples with a high content of amorphous organic matter, which is poorly preserved and showing some degree of thermal alteration. However, because of the limited assemblages, it was not possible to further characterize this interval.

5.4.5 Well ALP-6.

The cored section of well ALP-6 consists of about 1250' (380 m) of predominantly carbonate facies (see Appendix B-5). Well developed clastic intervals are observed in the middle part of the section. A total of 56 samples were processed for palynological and palynofacies analysis (Figure 27). Dr. Bruno Murat, of the sedimentology section of the Exploration Division of Maraven, S.A., kindly provided sedimentological and lithological information of the cored section of well ALP-6.

Palynological-palynofacies description.

A large number of samples (41) yield very low counts of palynomorphs (either barren or less than 50 specimens per sample). Samples that produced large counts are mainly fine-grained sediments (shales).

a) Palynological assemblages: Samples located in the interval 16780' and 16881' 8" show relatively numerous assemblages with abundant *Corollina*, *Araucariacites*, and in one case of *Afropollis* (Figure 27). Dinocysts and foraminiferal internal linings are present in

Figure 27. Palynological and palynofacies characteristics of well ALP-6; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitrinite average size and its standard deviation. SP is referred to sedimentary phases (see discussion).

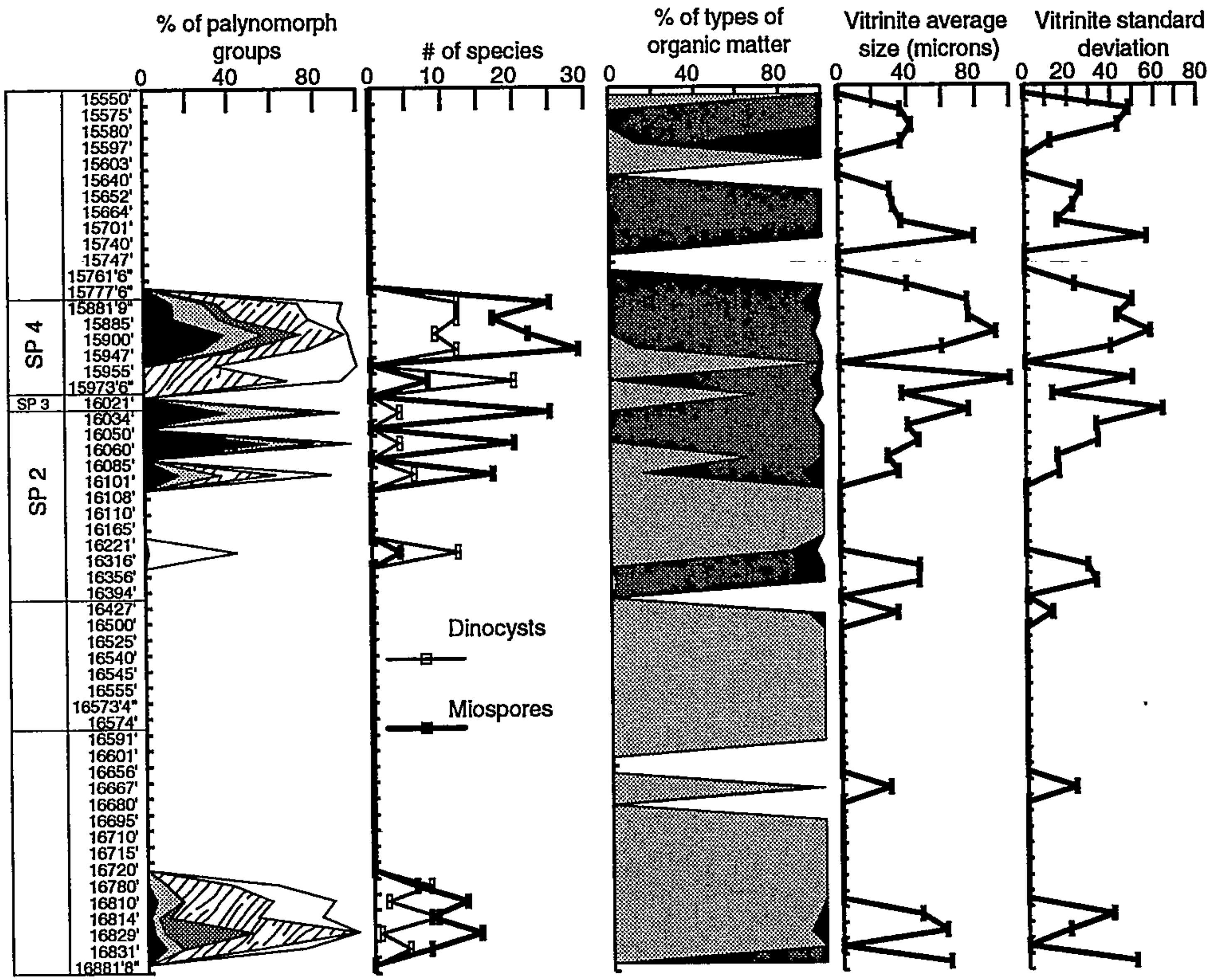
LEGEND

PALYNOMORPH GROUPS

- Trilete spores
- *Araucariacites*
- *Afropollis*
- *Corollina*
- Marine Phytoplankton

TYPES OF ORGANIC MATTER

- AMORPHOUS
- VITRINITE
- INERTINITE
- EPIDERMAL



% of palynomorph groups
# of species
% of types of organic matter
Vitrinite average size (microns)
Vitrinite standard deviation
SP 4
SP 3
SP 2
Dinocysts
Miospores
15550'
15575'
15580'
15597'
15603'
15640'
15652'
15664'
15701'
15740'
15747'
15761'6"
15777'6"
15881'9"
15885'
15900'
15947'
15955'
15973'6"
16021'
16034'
16050'
16060'
16085'
16101'
16108'
16110'
16165'
16221'
16316'
16356'
16394'
16427'
16500'
16525'
16540'
16545'
16555'
16573'4"
16574'
16591'
16601'
16656'
16667'
16680'
16695'
16710'
16715'
16720'
16780'
16810'
16814'
16829'
16831'
16881'8"

significant percentages (up to 20%), except at sample 16829', that yield an assemblage dominated by miospores. The dinocysts assemblages are dominated mainly by specimens of *Subtilisphaera deformans* and *Oligosphaerdium albertense,* with the accesory occurrences of *Spiniferites twistringiensis, Cribroperidinium orthoceras* and *Pterospermella australiensis.*

The palynological assemblages in the interval between 16108' and 16720' show very poor recovery and preservation. Specimens of dinocysts are mainly broken and damaged by extensive marcasite-pyrite crystal growth. Dinocysts such as *Kiokansium unituberculatum, Cribroperidinium orthoceras, Oligosphaeridium albertense* and *Subtilisphaera deformans* are the most common specimens observed throughout this interval, with very rare occurrences of *Circulodinium distinctum* subsp. *distinctum, Microdinium opacum* and *Florentinia laciniata.* Foraminiferal internal linings are observed to be almost 50% of the total assemblage at sample 16316'.

The assemblages show a significant change of composition and preservation in the interval between 16021' and 16101'. The assemblages begin are dominated by miospores, especially trilete spores (mainly of the genera *Deltoidospora, Concavisporites* and *Dictyophyllidites*) and pollen of *Araucariacites* and *Corollina.* The number of miospore species increases in comparison to the previous interval. The number of species and occurrences of dinoflagellates is very limited, with specimens of *Oligosphaeridium albertense* and *Odontochitina operculata* as the most common.

Sample 15973' 6" shows a significant change in the preservation and composition of the assemblages. Miospores become numerically dominant, mainly by the increased abundances of *Corollina brasiliensis* (larger than 43 µm). Specimens of *Spiniferites, Achomosphaera, Kiokansium unituberculatum, Oligosphaeridum albertense, Circulodinium distinctum* subsp. *distinctum, Florentinia laciniata* and *Subtilisphaera cheit* are observed in moderate percentages. The assemblages are very well preserved. Samples located in the interval 15881' 9" and 15947" show relatively good preservation, with more diverse assemblages of miospores, still dominated by *Corollina, Araucariacites* and *Afropollis* sp. cf. *A. jardinus* and trilete spores. Dynocyst assemblages are characterized by *Oligosphaeridium albertense, Xiphophoridium* sp. A, species of *Spiniferites, Subtilisphaera, Circulodinium, Florentinia* and *Microdinium* being common. The palynological assemblages of this interval correspond to those described for biozone IV (Albian).

Samples located at the top of the cored section yielded no assemblages.

b) Palynofaciess: Samples located in the basal part of the cored section of well ALP-6 show a predominance of amorphous organic matter in the interval 16108' to 16831'6". The few samples that contained terrestrial phytoclasts show poorly preserved and well rounded fragments of vitrinite (16356') or in some cases very degraded (16394'). It is noteworthy that in one interval (16500' to 16574'), the dominant organic component is dark brown amorphous organic matter forming dense aggregates. This interval has been included withing the Machiques Member of the Apón Formation by Dr. Bruno Murat (1992, personal communication).

Vitrinite phytoclasts increase in abundance in the interval between 15652' and 16101'. Rounded vitrinite phytoclasts occur in the interval between 16021' and 16101', with some trend to increasing average size towards the top. An abrupt increase in the average size of vitrinite phytoclasts was observed at 15973' 6". In this sample, and for the interval 15881' 9" and 15947', vitrinite phytoclasts show poor sorting and angular forms. At the top of the interval (15652' and 15776'), vitrinite phytoclasts are more rounded with tendency to smaller sizes.

Samples located between 15550' and 15597' yield only amorphous organic matter or thermally altered vitrinite.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Well ALP-6.

The large number of barren samples or those producing impoverished assemblages is an indication of more adverse conditions for the preservation of organic material in the studied interval. The predominantly carbonate section indicates marine conditions. Unlike the cases of wells CR-5 and ALP-6, clastic input was very restricted, except in the middle part of the cored section.

- Interval 16500' to 16574'

The organic matter forms dark brown spongy clusters of organic matter and is rather abundant (Plate 19, figure 2). These characteristics might suggest paleoenvironments with enhanced conditions for the preservation of organic matter. Dr. Bruno Murat (1992, personal communication) suggested that this level of black shales can be related to a maximum flooding surface during a transgressive system tract. It is difficult to further characterize this interval due to the lack of palynological information and the absence of this horizon in other wells included in this study.

- Interval 16034' to 16394'

The characteristics of the composition and preservation of the particulate organic matter changes in this interval, with increasing proportions of terrestrial palynomorphs and phytoclasts towards the top. The badly preserved and rounded fragments of vitrinite indicate some similarities with the regressive phase that has been suggested for intervals in wells CR-5 and ALT-19X. As already described for these two wells, towards the top of this regressive phase, palynological assemblages dominated by miospores with rounded vitrinite fragments are present.

- Interval 15974' to 16034'

In well ALT-19X, the regressive and progradational phases are separated by a 74' (28 m) thick carbonate interval containing planktonic foraminifera indicative of open marine conditions (Moldovanyi and Pinto Auso, 1987). In well ALP-6, a 60' (23 m) thick wackestone facies is also present in the cored section and might be an indication of marine conditions produced by a transgressive pulse that capped the overall regressive phase.

Interval 15881' 9" to 15973' 6"

A significant change in the composition of the palynological and palynofacies occurs in the interval between 15881'9" and 15973'6", in which well preserved angular fragments of vitrinite, with a clear trend of increasing the average size, are observed along with well preserved palynological assemblages, dominated by miospores. As already discussed for the cases of well ALT-19X and CR-5, these characteristics seems to be related to the organic matter deposited during a major progradational event.

The predominance of terrestrial phytoclasts (mainly vitrinite) seems to indicate that the progradational event was still taking place during the deposition of the sediments located in the interval between 15652' to 15777', in which vitrinite average size tend to decrease to the top. The occurrence of inertine fragments in moderate percentages at 15597' might be an indicator of the onset of a regressive phase at the top of the studied sections, as is inferred in wells CR-5 and ALT-19X. However, the poor preservation of the phytoclasts precludes a more definite characterization.

5.4.6. Catatumbo outcrop section.

The outcrop section at Catatumbo outcrop that was sampled consists of 19 m of predominantly dolomitic shales, with some levels of calcareous sandstone (see Appendix B-6). It overlies a carbonate layer rich in nodules with well preserved and abundant ammonites and fish remains.

Palynological-palynofacies description.

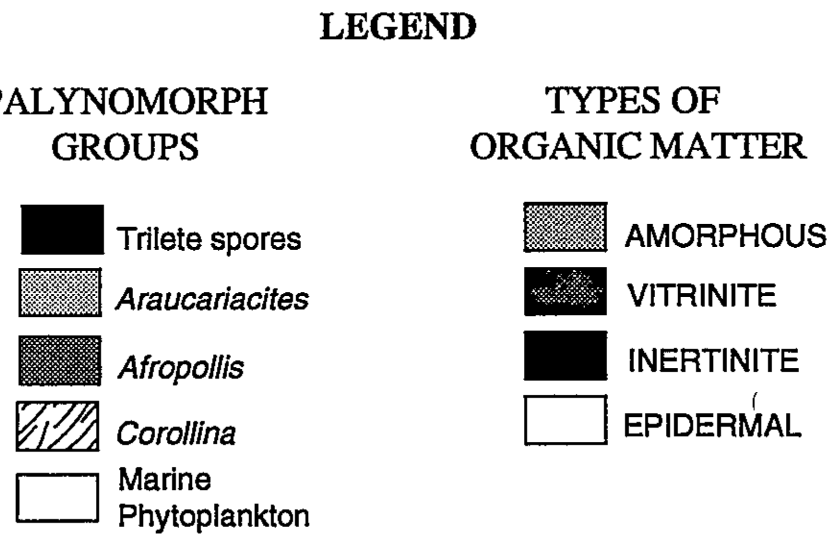
Only two out of a total of 9 samples from the Catatumbo outcrop scetion yield rich palynomorph assemblages (Figure 28).

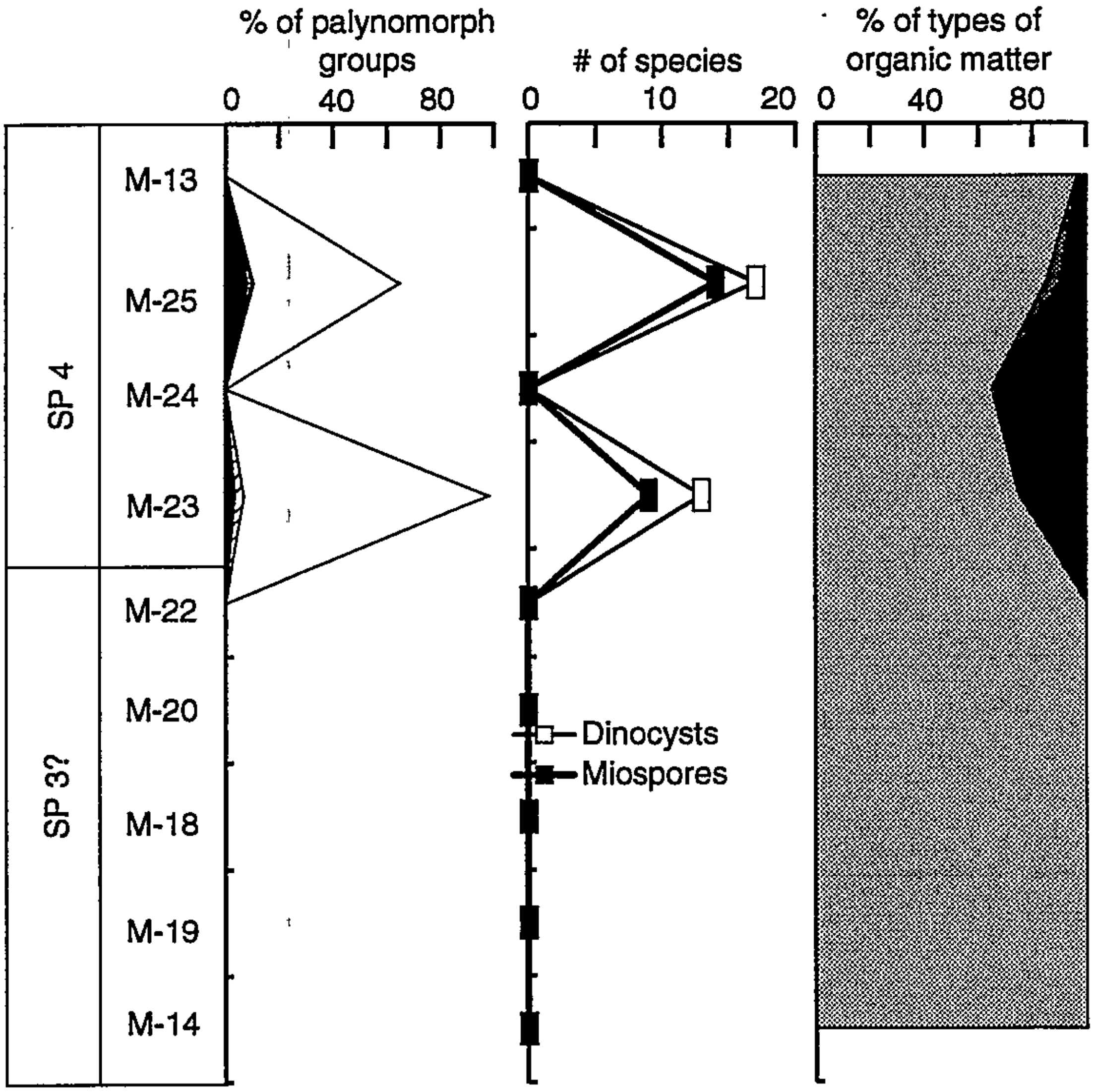
a) Palynological assemblages: Samples located in the basal and middle part of the section (M-22 through M-14) yield very poor assemblages, if any, with badly preserved specimens of *Oligosphaeridium albertense*, *Microdinium*? sp. B and *M. opacum*.

Only samples M-23 and M-25 produce rich palynological assemblages. These assemblages are dominated by dinocysts such as *Microdinium opacum*, *Xiphophoridium* sp. A, *Oligosphaeridium albertense* and *Incertae sedis* A. Foraminiferal internal linings are observed to occur in large numbers. Miospores are present and consist mainly of poorly preserved specimens of trilete spores. Samples M-24 and M-13 yield less numerous assemblages (less than 100 specimens) with miospore species being numerous in M-13.

b) Palynofacies: Samples are dominated by amorphous organic material. In all cases, the preservation is poor and the almost traslucent aspect of the palynomorphs seems to indicate that extensive weathering of the outcrop might have played and effect in the preservation of the isolated residues.

Figure 28. Palynological and palynofacies characteristics of the Catatumbo outcrop section; percentages of the palynomorph groups, number of species miospores and dinoflagellates, percentages of different types of organic matter, vitrinite average size and its standard deviation. SP is referred to sedimentary phases (see discussion).





% of palynomorph groups
0
40
80
# of species
0
10
20
% of types of organic matter
0
40
80
SP 4
SP 3?
M-13
M-25
M-24
M-23
M-22
M-20
M-18
M-19
M-14
Dinocysts
Miospores

At the base of the section (M-22 through M-14), only amorphous organic material is present. At the top of the section, well sorted inertinite fragments occur in samples M-25, M-24 and M-23 (Plate 19, figure 3).

- Paleoenvironmental significance of palynological assemblages and palynofacies of the Catatumbo outcrop section.

When this section was sampled in June 1991, it was thought to be part of the Machiques Member of the Apón Formation, because of the dolomitic dark gray to black shales. However, the observations of the palynological and palynofacies seems to indicate a different intepretation, as discussed below.

- Interval M-22 to M-14.

In general, the section outcropping and sampled in the Catatumbo Quarry showed extreme structural complexity, that complicated the stratigraphical interpretation. The shale interval that was sampled overlies a characteristic carbonate horizon, composed of well preserved fish and ammonite remains, present in large numbers. The contact with the overlying shaly unit is abrupt. The recovery of palynomorphs is poor to none at the base of the section (M-19 and M-18). The occurrence of abundant amorphous organic material, of marine origin, seems to indicate marine paleoenvironments. The abundace of well preserved fossil remains at the top of the underlying level seems to indicate the onset of anoxic conditions. The abundance of amorphous organic matter is perhaps an indication of anaerobic or dysaerobic conditions, which enhanced the preservation of the organic matter and that of the fossil remains. These conditions seemed to change upwards in the section. The occurrence of badly preserved dinocysts in samples M-20 and M-22, along with poorly preserved organic matter, not as abundant as in the underlying interval, suggest more oxidizing conditions.

- Interval M-25 to M-23.

The occurrence of inertinite phytoclasts, as well as miospore assemblages towards the top of the section, seems to indicate increasing input of terrestrial material, in low amounts. The occurrences of *Xiphophoridium* sp. A and *Xenascus plotei* are indicative of assemblages that were described in biozone IV (Albian).

5.4.7. Rosarito outcrop section.

Only one sample was processed for the Rosarito Quarry section. It consists of a lens of bituminous shale, obtained a few centimeters below the contact between the Maraca and La Luna Formation.

Palynological-palynofacies description.

a) Palynological assemblages: The palynological assemblage of this sample is dominated by *Oligosphaeridium albertense* and foraminiferal internal linings, with subordinate occurrences of *Microdinium opacum*, *Microdinium*? sp. B and *Kiokansium unituberculatum.* Only two genera of miospores, *Dictyophyllidites* and *Deltoidospora,* are observed in this sample.

b) Palynofaciess: The palynofacies is composed almost totally of badly preserved amorphous organic matter, with an accessory amount of inertinite.

5.4.8 Well P-201.

The cored section of well P-201 consists of about 506' (154 m) of predominantly carbonate facies, with some shale horizons (see Appendix B-7). A total of 37 samples were studied for palynological and palynofacies.

Palynological-palynofacies description.

a) Palynological assemblages: As discussed in well ALP-6, most of the samples processed for well P-201 produced poorly preserved and impoverished palynological assemblages (Figure 29).

At the base, sample 11570' yield a relatively diverse assemblage dominated mainly by dinoflagellate cysts (*Subtilisphaera senegalensis* and *Kiokansium unituberculatum*) and foraminiferal internal linings (almost 27% of the total assemblage). Miospores are dominated by *Corollina.*

Figure 29. Palynological and palynofacies characteristics of well P-201; percentages of the palynomorph groups, number of species of miospores and dinoflagellates, percentages of different types of organic matter, vitrinite average size and its standard deviation. SP is referred to sedimentary phases (see discussion).

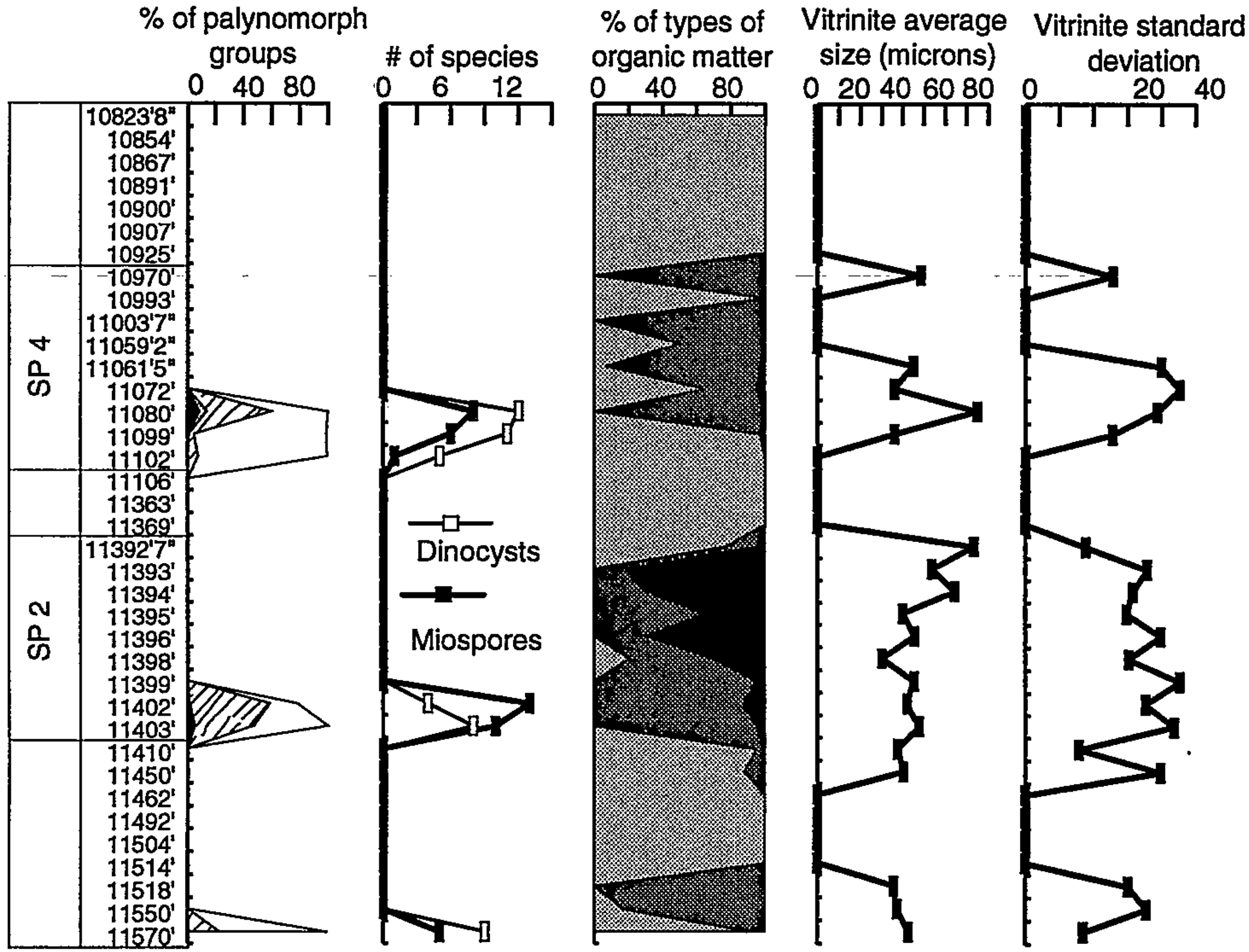
LEGEND

PALYNOMORPH GROUPS

- Trilete spores
- *Araucariacites*
- *Afropollis*
- *Corollina*
- Marine Phytoplankton

TYPES OF ORGANIC MATTER

- AMORPHOUS
- VITRINITE
- INERTINITE
- EPIDERMAL



% of palynomorph groups
0 40 80
# of species
0 6 12
% of types of organic matter
0 40 80
Vitrinite average size (microns)
0 20 40 60 80
Vitrinite standard deviation
0 20 40
10823'8"
10854'
10867'
10891'
10900'
10907'
10925'
10970'
10993'
11003'7"
11059'2"
11061'5"
11072'
11080'
11099'
11102'
11106'
11363'
11369'
11392'7"
11393'
11394'
11395'
11396'
11398'
11399'
11402'
11403'
11410'
11450'
11462'
11492'
11504'
11514'
11518'
11550'
11570'
SP 4
SP 2
Dinocysts
Miospores

Samples located in the interval 11410' and 11550' are completely barren of palynomorphs and show extensive evidence of pyrite-marcasite crystal growth.

Samples 11402' and 11403' yield relatively well preserved assemblages, numerically dominated by dinocysts. Two species of dinoflagellates are dominant; *Oligosphaeridium albertense* and *Subtilisphaera senegalensis* cooccurring with rare *Microdinium opacum, Florentinia laciniata* and *Circulodinium distinctum* subsp. *distinctum. Corollina brasiliensis* is the dominant miospore. Foraminiferal internal linings are present in very low percentages. Unlike the assemblage of sample 11570', the number of miospore species is larger than that of dinoflagellate cysts.

Samples located between 11363' and 11399' show very poor assemblages, with dinocysts of *Cribroperidinium orthoceras, Oligosphaeridium albertense, Odontochitina operculata* and *Circulodinium distinctum,* and pollen of *Corollina.* The organic residues show extensive evidence of pyrite-marcasite crystal growth.

Samples located in the interval 11080' and 11102' yield relatively well preserved assemblages of dinocysts and miospores. Dinoflagellate cysts, along with foraminiferal internal linings (in percentages up to 84% of the total) are dominant in these assemblages. *Kiokansium unituberculatum, Coronifera oceanica* and *Subtilisphaera senegalensis* are the most common species. Miospore assemblages are dominated mainly by *Corollina brasiliensis*. In the assemblage of sample 11072', specimens of *Xenascus plotei* and *Xiphophoridium*sp. A are observed.

The remaining palynological assemblages are very poorly preserved and completely lack palynomorphs towards the top of the cored section.

b) Palynofaciess: The basal interval of the cored section (11410' down to 11570') is dominated by poorly preserved amorphous organic matter and in some cases associated with rounded and poorly preserved vitrinite fragments.

A change in the composition of the assemblages is noticed in the interval from 11392' 7" to 11403'. The palynofacies are mainly dominated by abundant vitrinite fragments, with increasing proportions of inertinite fragments at the top. Vitrinite fragments are relatively well preserved, with a clear trend of increasing average-size towards the top of the interval.

Increasing amounts of vitrinite phytoclasts are also observed in the interval between 10925' and 11080'. In general the vitrinite phytoclasts are badly preserved and rounded, showing a clear trend of decreasing size towards the top.

- Paleoenvironmental significance of palynological assemblages and palynofacies of Well P-201.

Chacartegui (1984) pointed out that the paleoenvironments of deposition for the Cogollo Group section studied in well P-201 were mainly oolitic marine bars (grainstones and packstones), lagoons (wackstones, mudstones and shales) and pelecypod biostromes (grainstones and packstones).

- Interval 11392'7" to 11403'.

Samples located in this interval show palynofacies rich in vitrinite and inertinite phytoclasts. A few of these samples (11402' and 11403') yield palynomorph assemblages dominated miospores, even though dinocysts are numerically important. As discussed in the previous cases, this interval seems to be associated with a major regressive phase to judge from the miospore dominated assemblages and the facies enriched in inertinite, especially at the top. However, the impoverished assemblages of palynomorphs precludes a more detailed characterization and correlation with other studied sections. Another point of uncertainty is that cores were not obtained for the interval between 11009' and 11360'.

- Interval 10970' to 11072'.

The second interval is characterized by a few samples rich in vitrinite phytoclasts at the base that yield abundant foraminiferal linings and dinocysts. The assemblages of these samples show some similarities to samples reported for the major progradational phase in wells CR-5, ALT-19 and ALP-6. The occurrence of *Xiphophoridium* sp. A and *Xenascus plotei* in sample 11072' enhances these similarities, since these two dinocysts species are observed only in this progradational phase.

5.4.9 Well VLB-704

A total of 44 samples were processed from the cored section of well VLB-704. Due to the poor recovery and the thermal alteration of the organic material, not further attempt was made to characterize the palynomorph or the palynofacies. Gallango et al. (1984) have reported that organic matter of Lower Cretaceous sections in wells located in the northern and eastern part of the Maracaibo Basin are thermally mature.The absence of palynomorphs might have been related to high energy paleoenvironments of deposition. Only one sample (14222' 5") yielded a limited assemblage with badly preserved and blackened trilete spores (mainly of the genera *Dictyophyllidites* and *Deltoidospora*).

5.5 Discussion.

Despite the fact that preservation of palynological and palynofacies was far from ideal for a high resolution study, the palynofacies evaluation in this study has produced a consistent overall framework for the sedimentary evolution of the basin during the Early Cretaceous.

5.5.1 Sedimentary evolution.

Based on the palynological and palynofacies information, a total of five sedimentary phases are proposed. These sedimentary phases include sediments deposited during inferred regressive-transgressive pulses.

- Sedimentary phase 1 (SP 1).

This phase is only observed at the base of the Zea-Panamericana section (unit I) and it is characterized by a transgressive pulse occurring during the Early Aptian (biozone I).

Because of the poor preservation of the palynological assemblages in wells located in the central and northern areas of the basin, it was not possible to correlate this unit in these areas. However, some sections of wells CR-5 (14891' to 14196'), ALT-19X (at 17696') and ALP-6 (16500' to 16574' corresponding to the Machiques Member) are rich in organic matter that might be an indication of more marine conditions. However, further characterization of these intervals is needed to establish a possible correlation.

- Sedimentary phase 2 (SP 2).

Unit II was defined in the Zea-Panamericana section as a regressive unit, with a clear trend to more fluvial paleoenvironments of deposition towards the top. Clear evidence for a regressive pulse is also observed for all the subsurface section in the central and northern areas of the basin. Therefore, it is proposed that the second major sedimentary phase observed in this study is generally regressive in nature and comprises most of the intervals considered as Lower to Middle Aptian (biozones II and and part of biozone III).

An interval in well CR-5 (14307' 14460') was observed to show relatively diverse assemblages of dinoflagellates (especially at sample 14460'). However, the number of miospore species tend to increase to the top whereas dinoflagellate species number drastically decreased, an indication of the regressive nature of this interval. Therefore all the section between 14307' to 14786' is included as part of this regressive phase. Similar characteristics for the palynological/palynofacies suggest that the regressive phase is also present in wells ALT-19X (17555' to 17803' 3"), ALP-6 (16034' to 16394') and P-201 (11392' 7" to 11403')

Azpiritxaga (1991) proposed that sea-level fell during most of the Aptian in the Maracaibo Basin. The occurrence of the regressive phase here proposed supports this putative sea-level fall.

- Sedimentary phase 3 (SP 3).

This sedimentary phase is characterized as a transgressive pulse. This unit is defined in intervals of wells, ALT-19X (the wackestone-packstone facies with foraminifera indicative of open marine environments in the interval between 17468' and 17542'; Moldovanyi and Pinto Auso, 1987), ALP-6 (wackestone/packstone facies in the interval between 15974'-16034') and the basal 12 m of the Catatumbo Quarry section. There is no major palynological information on samples coming from these intervals, except that they are enriched in marine amorphous organic matter and show few specimens of dinoflagellates. Because of their stratigraphic position, these intervals are considered as Upper Aptian.

This transgressive pulse might also be related to the transition from fluvial deposits of the Zea-Panamericana (unit II) to mouth bar deposits (Unit III). A similar transition was proposed for the section of La Grita-Seboruco (Márquez and Mederos, personal communication) and it is characterized by an increase in marine phytoplankton towards the top of this section.

- Sedimentary phase 4 (SP 4).

This unit is interpreted as a progradational phase, characterized by very diverse palynological assemblages, with predominance of miospores and terrestrial phytoclasts. Dinocysts are also abundant and diverse. The excellent preservation of the phytoclasts and their poor sorting indicate that following the transgressive pulse, continental facies prograded into the basin, causing the input of massive amounts of clastics and terrestrial organic material into marine environments. The good preservation of the assemblages might be related to increasing sedimentary rates. It is considered that this phase is related to the sea-level high proposed by Azpiritxaga (1991) for the Albian in the central area of the Maracaibo Basin. The progradation might have ben the result of decreasing rates of relative sea-level rise and increasing input of siliciclastics into the basin area. The palynological assemblages of this sedimentary phase correspond to those of biozone IV (Albian).

This sedimentary phase includes the top part of Unit III of the Zea-Panamericana and La Grita-Seboruco sections, as well as intervals of wells CR-5 (14186' to 14285'), ALT-19X (17230' to 17461'), ALP-6 (15881' 9"-15973' 6"), P-201 (10970' to 11072') and the top of the sampled section of the Catatumbo Quarry.

The first significant occurrence of siliciclastics, as well as the occurrence of glauconite, have been used as the typical criteria for determining the formational contact between the Lisure Formation and the underlying carbonate unit of the Apón Formation. González de Juana et al. (1980) pointed out that the basal part of the Lisure Formation is characterized by a shale sequence, with an intercalated limestone horizon dividing this basal shaly interval. In the case of well ALP-6, it is noteworthy to mention that Dr. Bruno Murat (personal communication) determined the top of the Lisure Formation at the base of a shaly sequence at 16108'. Results of this palynofacies study suggest that this shaly sequence (16034' to 16108') is part of sedimentary phase 2. Overlying this unit, there is a wackestone/packstone layer (sedimentary phase 3) and then the inferred interval belonging to the major progradational phase. A similar situation is seen in well ALT-19X, where a shaly sequence (17548' to 17641') located within the sedimentary phase 2 is separated from the shaly intervals of the prograding phase 4 by wackestone/packstone facies. Therefore, the sediments of the Lisure Formation were deposited during three sedimentary phases (upper part of SP 2, SP 3 and SP 4), as discussed by Méndez (1989).

- Sedimentary phase 5 (SP 5).

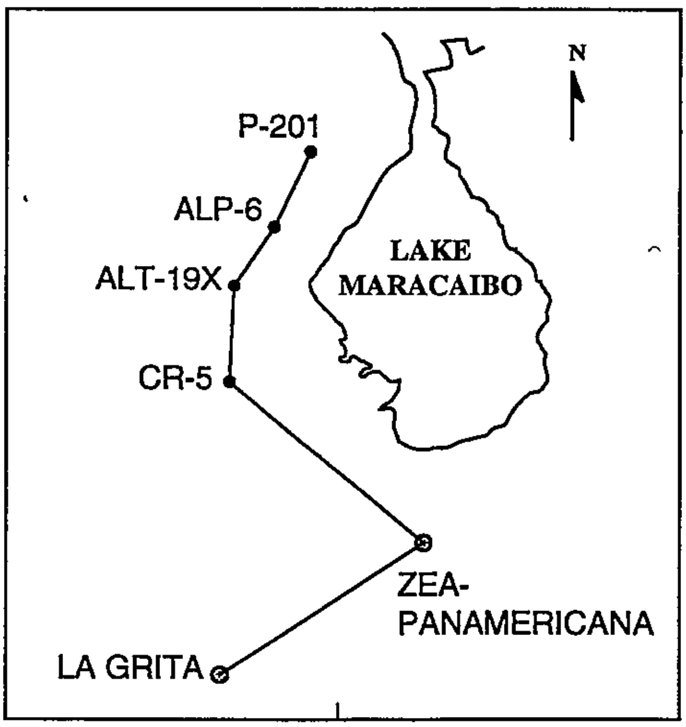
This unit occurs towards the top of the cored sections in wells CR-5 (14006' to 14068') and ALT-19X (17111' and 17113'6"). Palynological assemblages are either barren of palynomorphs or show very poor preservation, with increasing proportion and average size of the vitrinite fragments. Azpiritxaga (1991) proposed a drop of sea level in the Upper Albian, which might be related to the onset of the regressive phase at the top of the Cogollo Group as deduced from the palynofacies analyses.

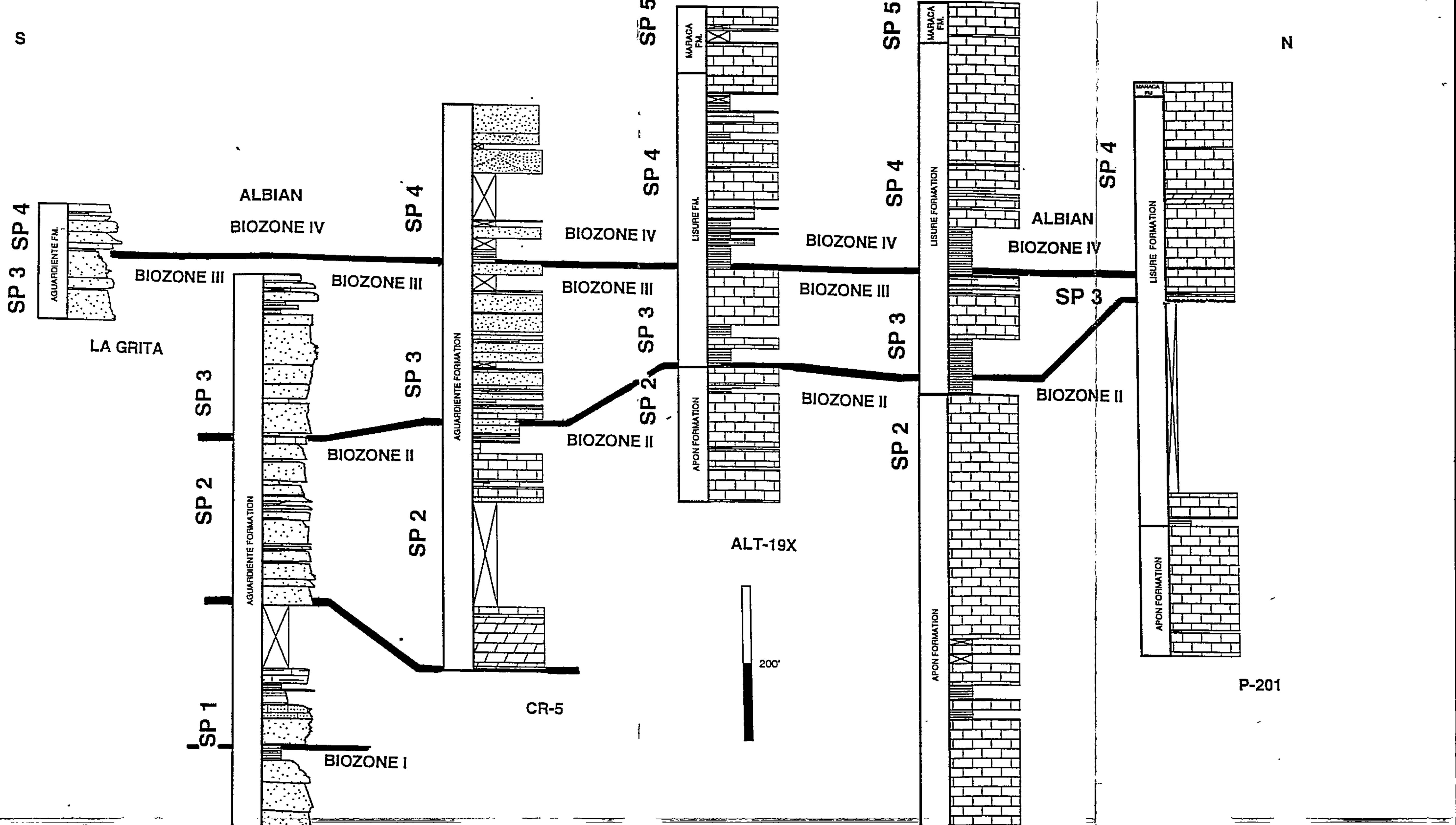
Figure 30 shows the palynostratigraphic correlation, using the base of biozone IV as the datum plane. Preservation of miospores and dinoflagellate cysts associated with SP 2 decreases in sections to the north. The change in preservation is related to the oxidizing conditions of the shallow water carbonate platform in the northern area of the Maracaibo Basin. Phytoplankton species frequencies also increases to the north, away from the siliciclastic influx in the south, where miospores and terrestrial phytoclasts are the dominant elements of the palynofloras. At the top of the intervals included within SP 2, a clear trend of increasing the frequencies of the different miospores is observed in wells ALT-19X and ALP-6, and it is related to regressive nature of this sedimentary phase. SP 3 is considered to be related to a relative sea-level rise. The base of this sedimentary phase consists of a shaley to silty interval in wells ALT-19X and ALP-6. This interval is overlain by a limestone section that is a clear indication that carbonate production in more marine conditions as the result of this relative sea-level rise. In the southernmost sections, evidence of this transgresive pulse is observed by slight increases of the proportion of dinoflagellate cysts and coincides with the transition from the inferred fluvial paleoenvironments of SP 2 to transitional deltaic to nearshore paleoenvironments at the top of La Grita and Zea-Panamericana sections (see previous discussion).

Figure 30. Regional correlation of six of the studied sections and the different sedimentary phases inferred in this study. Base of Biozone IV is the datum. SP refers to the different sedimentary phases. No horizontal scale.

LEGEND

SANDSTONE
CALCAREOUS SANDSTONE
CROSS-BEDDED SANDSTONE
SILTSTONE
SHALE
SANDY LIMESTONE
WACKESTONE
DOLOMITE




S
N
LA GRITA
CR-5
ALT-19X
P-201
ALBIAN
BIOZONE IV
BIOZONE III
BIOZONE II
BIOZONE I
SP 1
SP 2
SP 3
SP 4
SP 5
AGUARDIENTE FM.
AGUARDIENTE FORMATION
LISURE FM.
LISURE FORMATION
APON FORMATION
MARACA FM.
200'

SP 4 assemblages are well preserved, especially at the basal intervals, where shale or silty-shales are the predominant lithology. These fine-grained sediments represent part the clastic influx of this progradational phase into the carbonate platform. Palynomorph particles behave as silt-sized particles and are concentrated in silty-shaley lithologies (Traverse and Ginsburg, 1966; Cross et al., 1966; Dale, 1976; Tyson, 1987). The preservation of miospores, dinocysts and phytoclasts tends to decrease to the top of the section of the Cogollo Group and to the north (well P-201), where carbonates are the dominant lithology and therefore, more oxidant conditions were present.

5.5.2.Palynological assemblages and palynofacies distribution.

The previously described data elucidated some basic patterns of distribution of some of the main palynomorph groups and phytoclasts that were observed in this study.

5.5.2.1 Miospore assemblages.

Samples from sections located to the south of the studied area, show assemblages that are dominated mainly by miospores, especially *Corollina, Araucariacites, Afropollis* and trilete spores. Other miospores, such as pollen of *Equisetosporites, Callialasporites,* elater-bearing palynomorphs and tricolpate angiosperm pollen occur only in very low numbers and are not diagnostic of any specific area or paleoenvironmental pattern.

Pollen of *Corollina* is observed to be abundant in some of the intervals of the Zea-Panamericana section. Hughes and Moody-Stuart (1967), Hughes (1976), Srivastava (1976), Batten (1982) and Lister and Batten (1988) have related large percentages of pollen of *Corollina* to transgressive phases, suggesting that parent plants grew in coastal swamps. The association of assemblages dominated by pollen of *Corollina* with dinocysts and intervals showing evidence of increasing marine influence is consistent with the inferences made by these authors. Another interesting pattern shown by *Corollina* is the abundant occurrence of *Corollina brasilensis* in sediments of the prograding phase. In general pollen of *Corollina brasiliensis* is characterized by sizes larger than 43 µm. Herngreen (1973 and 1975b) reported that pollen of *Corollina* larger than 30 µm is quite common in Upper Albian sediments in Brazil and considered it an evolutionary event. This study indicates that *Corollina brasiliensis* occurs in low abundances during most of the Aptian; its increase observed in number and average size in the Albian is related mainly to the onset of a major progradation of continental material into the basin. Therefore, the increase in the average size of grains of this species is not considered an evolutionary event and must not be used for correlation or biostratigraphic purposes.

Another abundant component is *Araucariacites australis*. In general species of the Araucariaceae seem to be diagnostic of low to middle latitudes zones with summer-dry climate (Krassilov. 1978). Doyle et al. (1982) have suggested that increasing representation of pollen of *Araucariacites* in the Aptian–Albian of Senegal, Liberia, Ghana and Chad might be the result of increasingly arid conditions. Large proportions of *Araucariacites* occur in sections located to the south (La Grita-Seboruco, Zea Panamericana, CR-5 and ALT-19X). In the Aguardiente Formation, *Araucariacites* is more or less abundant in samples that show relatively high diversity, the presence of dinoflagellate cysts and very low proportions of *Corollina*. This pattern seems to indicate that the plants producing *Araucariacites* might have been present inland, in zones away from the coastal communities dominated by *Corollina*-producing cheirolepidiacean plants (producing pollen of *Corollina*). Large percentages of *Araucariacites* might result from the mixing of terrestrial and coastal assemblages in nearshore areas.

Afropollis is also observed in large percentages in some samples of the Zea-Panamericana, La Grita-Seboruco and in sections of wells CR-5, ALT-19X and ALP-6. Herngreen and Chlonova (1981) and Doyle et al. (1982) showed that pollen of *Afropollis* is characteristic in Aptian–Albian floras of northern Gondwana and noticed that percentages of *Afropollis* is very low in intervals with brackish water or increasing salinity whereas it occurs in high percentages in samples from nearshore paleoenvironments. These authors concluded that the parent plants might have been quite abundant in coastal areas. In sediments of the La Grita-Seboruco section, the percentages of pollen of *Afropollis* are high in the basal interval (Figure 23), concommitant with limited dinoflagellate cysts; more fluvial conditions of deposition are thus inferred. As evidence of increasing marine or brackish water influence begin to appear indicated by the occurrence of dinocysts and foraminiferal linings, the percentages of *Afropollis* decrease significantly, disappearing at the top where restricted paleoenvironments are inferred. Its occurrence in relatively large percentages in the clastic sections of the wells located in the central area of the basin (CR-5 and ALT-19X) is the product of mixing of the coastal, inland and marine assemblages in marine paleoenvironments during a major progradational event.

Trilete spores were also observed to be abundant in the clastic sections of the Aguardiente Formation (La Grita-Seboruco and Zea-Panamericana). The trilete spores include mainly species of the genera *Dictyophyllidites*, *Deltoidospora*, *Concavissimisporites*, *Concavisporites* and *Leptolepidites*, and in lesser numbers, *Cicatricosisporites*, *Ischyosporites* and *Osmundancites*. Their abundances in some intervals may be related to conditions of deposition in swamp or flood-plain areas, where the parent plants were growing (unit II a in Zea-Panamericana). Burger (1980) was able to infer species of miospores related to marginal coastal and backland plant paleocommunities in the Surat Basin of Australia based on their frequency fluctuations. The dominance of mainly two genera, whose affinities is difficult to determine (*Deltoidopora* and *Dictyophyllidites*) in most of the assemblages of this study does not provide a clear clue to determine patterns of distribution of trilete spores in continental areas.

5.5.2.2 Phytoplankton assemblages.

Unlike the miospore assemblages, phytoplankton assemblages can be considered mostly as autochthonous or parautochthonous, and are more diagnostic of given paleoenvironmental or paleoecological conditions. Overall, the phytoplankton assemblages are dominated by dinocysts and foraminiferal linings, with acritarchs and prasinophyte algae cysts being present in very low counts in very few samples. Dinoflagellate cyst occur in large numbers in sections in the central and northern areas of the basin, perhaps an indication of increasing distance from the coastal or continental areas.

Sarjeant et al. (1987) indicated that there is a relationship between dinoflagellate cyst morphology and the environments in which they occur. Spines and processes appear to be developed as buoyancy controls or to slow dlow down the sinking of the cyst. Therefore, dinoflagellate cysts with elaborate spines and processes should be more common in open marine conditions (Scott and Kidson, 1977). These authors noted that assemblages dominated by species with relatively long processes were related to quieter waters, whereas those proximate-proximochorate dinocysts and acritarchs were related to higher energy conditions. Harker et al. (1990) described several dinoflagellate associations that reflect similar environments of deposition in the Campanian of North America. Assemblages dominated by peridinioid species are related to nearshore conditions with low salinities and also to regressive pulses due to a relative sea-level fall.

On the other hand, dinoflagellate associations dominated by gonyaulacoid species (with proximate, cavate, proximochorate and chorate forms) are more characteristic of open marine conditions and are related to transgressive pulses.

The distribution patterns of dinoflagellate cysts emerging from the results of the present study seem to be a rather complex and strongly related to the paleoenvironmental and paleoecological conditions that existed on the carbonate platform. Some dinoflagellate cyst species seem to have widespread occurrences in all the sections. For example, *Oligosphaeridium albertense, Circulodinium distinctum* subsp. *distinctum, Kiokansium unituberculatum, Spiniferites twistringiensis* and *Subtilisphaera deformans* are the most common in all the sections. *Circulodinium distinctum* subsp. *distinctum* is considered, along with other species of this genus and of *Cyclonephelium*, to be characteristic of stressed nearshore shallow environments in the Upper Cretaceous (Eshet et al., 1992).

Subtilisphaera deformans dominates the impoverished dinocyst assemblages of Zea-Panamericana and La Grita-Seboruco section and is also present in sediments of sections located in the central and northern areas of the basin. The other species are present in very low numbers in the more nearshore facies whereas their percentages are much higher in the sections sampled in the central and northern areas. These species seems to have been characteristic of nearshore areas and during the regressive period that was inferred for the sections of wells CR-5, ALT-19X and to a lesser degree in well ALP-6.

Circulodinium distinctum subsp. *distinctum, Kiokansium unituberculatum, Oligosphaeridium albertense, Subtilisphaera deformans* and *Spiniferites twistringiensis* are also associated with *Odontochitina operculata* in some samples from wells located in the south and central areas of the basin (CR-5 and ALT-19X) in assemblages whose diversity and preservation were rather poor. In some horizons of these two wells, where transgressive pulses are inferred, these species are also associated with *Coronifera oceanica, Florentinia laciniata, Florentinia* sp. cf. *F. verdieri* and species of *Spiniferites* and *Achomosphaera*, with rare specimens of *Cribroperidinium orthoceras*. Apparently the onset of this transgressive pulse, causing the flooding of areas of the platform and more open marine conditions, allowed more marine species to migrate into the interior of the platform.

The overall pattern of diversity and abundance of dinoflagellate cysts exhibited a significant change during the onset of the major progradational phase. Most importantly, the abundance of species such as *Oligosphaeridium albertense*, *Kiokansium unituberculamm* and *Subtilisphaera deformans* increase significantly. Other species of *Subtilisphaera*, such as *Subtilisphaera senegalensis*, *Subtilisphaera cheit* and *Subtilisphaera zawia* occur more frequently and in some cases, they dominate. Furthermore, species of the genera *Achomosphaera* (*Achomosphaera triangulata*, *Achomosphaera* sp. A and *Achomosphaera* sp. B) and *Spiniferites* are observed in low numbers.

Xenascus plotei is also a associated with this major progradational phase. Uwins and Batten (1988) observed the first occurrence of this species in the Albian of Lybia, in facies of the middle shelf during a regressive event. Characteristically, the abundance of *X. plotei* decreases to the north of the basin.

Another species that was observed to be associated with the onset of the progradational phase is *Xiphophoridium* sp. A. This species is common in sections of wells CR-5, ALT-19X and Catatumbo Quarry, but it is virtually absent in wells ALP-6 and P-201. The occurrence of this species in sediments of the Catatumbo Quarry section is concomitant with the occurrence of inertinite phytoclasts.

Microdinium opacum is common in sediments the Catatumbo outcrop section but less abundant in the central and southernmost sections. *Incertae sedis* A also occurs in significant abundances in sediments of the Catatumbo and Rosarito quarries along the Perija Ranges, but is absent in other sections.

Thus, from the previous discussion it is obvious that the ratios of chorate to proximate or gonyaulacoid to peridinioid cysts do not fully explain the variation of the dinocysts assemblages. Species of *Subtilisphaera* and *Circulodinium*, as well as *Kiokansium unituberculatum* and *Oligosphaeridium albertense*, seem to represent opportunistic species that were adapted to relatively unstable conditions. Habib and Miller (1989) described nearshore dinoflagellate assemblages from the Upper Cretaceous of the Atlantic Coastal Plain in the United States. These assemblages are characterized by the low number of dinocyst species and the dominance a few species (two or three). These authors attributed this pattern of changes to the unstable conditions caused by the discharge of deltaic waters near the shoreline.

Diversification of the dinoflagellate cyst assemblages started during the onset of transgressive pulses and reaches a maximum during the major progradational phase to judge from most of the subsurface section in the carbonate platform. Perhaps this the result of relatively more open marine conditions during the Albian. The flooding of the platform may have opened new ecological niches for other species. The influx of terrestrial material during the progradational phase may also have had an effect that allowed the diversification of dinoflagellates because the input of nutrients and because of unstable hydrographic conditions. The relatively good preservation of the assemblages of the progradational phase SP 4 indicates paleoenvironments of deposition with relatively low energy levels. Preservation might also be enhanced by higher sedimentary rates. A point of discussion in the recent palynological literature has been the relation of dinoflagellate diversity to transgressive and highstand system tract. Gorin and Steffen (1991), Helenes et al. (1993) and Blondel et al. (1993) have proposed that dinocyst diversity reaches a maximum during the transgressive system tract and tends to decrease during the shallowing-up parasequences of the highstand. The data from this study indicates that maximum diversity of dinoflagellate cysts is observed during the sedimentary phase SP 4, characterized by a progradational event during the Albian in the shallow water carbonate platform of the Maracaibo Basin.

Foraminiferal linings are another important component of the phytoplankton assemblages. They are present in all the sections but are especially abundant in the northernmost section of well P-201 and in well ALP-6. They are also abundant in sediments at the top of the La Grita-Seboruco section. To judge from the sedimentological evidence, foraminiferal linings appear to be present in lagoonal sediments, away from areas of major clastic influence (P-201 and at the top of La Grita-Seboruco section, where restricted circulation was inferred). Stancliffe (1989) concluded that foraminiferal linings have been commonly observed in shallow water environments with high salinity. Melia (1984) observed that the absolute abundance of foraminiferal internal linings decreases with increasing water depth.

Figure 31 shows diagramatically the approximate lateral distribution of the main palynomorphs groups and species based on the information produced in this study.

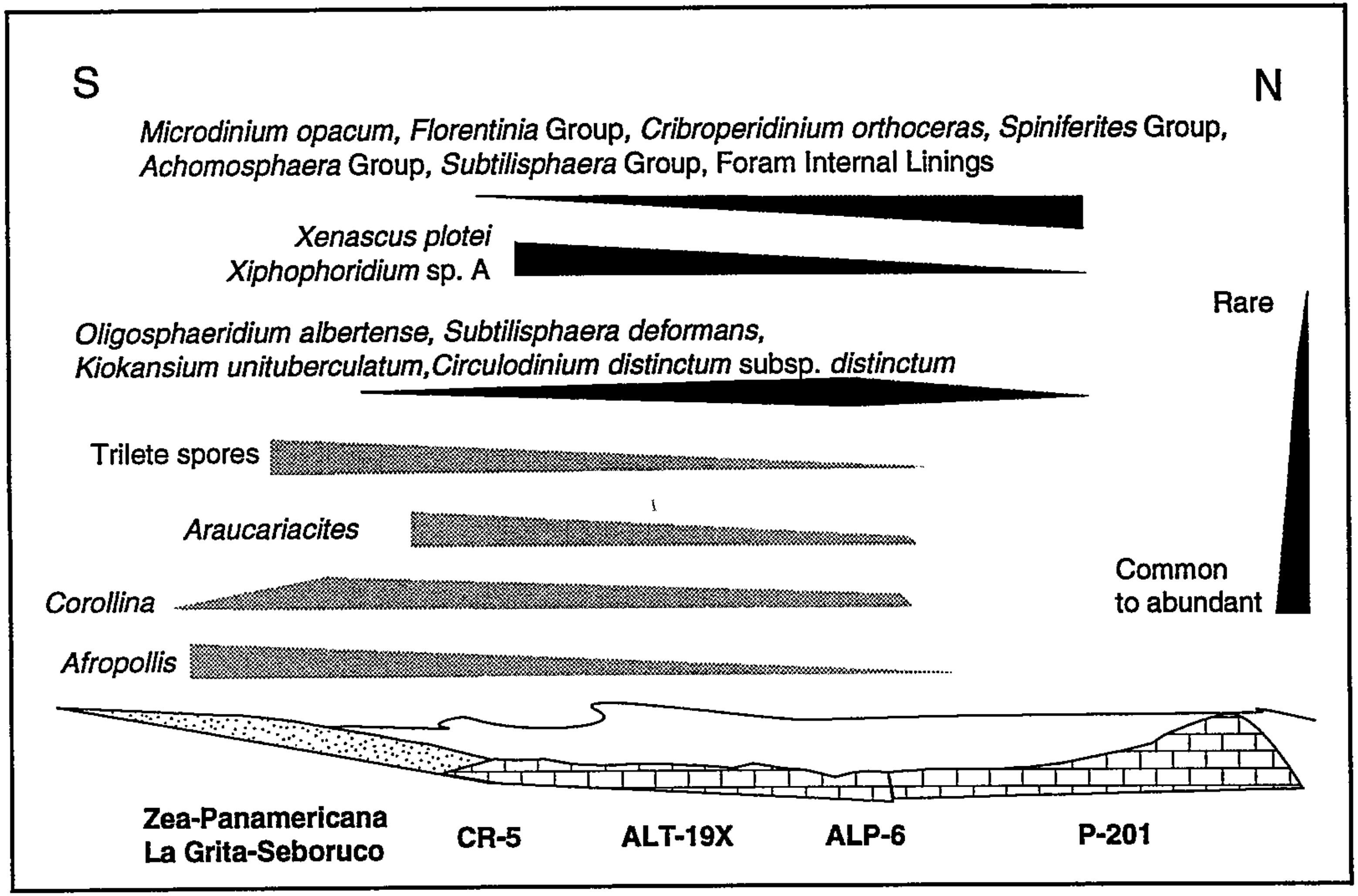


Figure 31. General lateral distribution of the main palynofloral elements observed in this study
Thickness of the distribution bars indicates approximate abundance. Approximate location
of the studied sections is provided for reference (not to scale)

5.5.2.3 Palynofacies.

Palynofacies studies in carbonate platforms are rare and difficult to undertake due to the oxidizing depositional conditions and the lower sedimentary rates (Gorin and Steffen, 1991). To date only open marine carbonate palynofacies have been analyzed (Steffen and Gorin, 1993a)

The results of this study show that, as in the case of miospore assemblages, the abundance and the preservation of terrestrial phytoclasts decrease to the north. Large phytoclasts of vitrinite, exhibiting angularity and poor sorting, occur only the southernmost sections (La Grita-Seboruco and Zea-Panamericana) or are associated with the phase of major progradation in wells CR-5, ALT-19X and ALP-6 in the central area.

In the more continental facies of the Aguadiente Formation sampled in the two southernmost sections, palynofacies revealed changes in composition and characteristics inferred in the interpretation for each of the sections. Decreasing vitrinite size and abundance and increasing sorting is related to transgressive pulses at the base of the Zea-Panamericana outcrop (unit Ib) and in the middle part of the La Grita-Seboruco outcrop section. The average size of the vitrinite phytoclasts remains more or less constant throughout the sampled section.

Habib and Miller (1989) noted that regressive intervals are characterized by the abundance of the more resistant phytoclasts of inertinite. Inertinite is observed in moderate to abundant percentages only in samples of well CR-5, especially a the base of the inferred regressive cycle (SP 2) and towards the top of the cored section (SP 5), when a second regressive phase was inferred. Vitrinite phytoclasts tends to be rounded and poorly preserved with average sizes similar to those of the more continental facies of the Aguardiente Formation in La Grita-Seboruco and Zea-Panamericana section. A slight increase in the size and preservation of vitrinite is observed in the interval included within the major progradational phase. Similar trends for vitrinite phytoclasts occur in wells ALT-19X and ALP-6. However, the amount of inertinite phytoclasts present in samples of these two wells is very low, even during the inferred regressive cycles. Therefore the enrichment of vitrinite phytoclasts in samples of these wells might be related to differential transportation into the shallow carbonate platform. González de Juana et al. (1980) pointed out that the influence of clastics in the Lower Cretaceous Maracaibo Basin was more evident in areas to the south and in the Alturitas Field.

Some of the samples from the Catatumbo outcrop section show inertinite fragments as the only terrestrial phytoclast type. As discussed earlier, the deposits sampled in the Catatumbo Quarry might be basinal facies, that were rich in amorphous organic matter during the transgressive pulse and began to receive inertinite phytoclasts during the onset of the major progradational phase. Therefore, the occurrence of inertinite in this more distal deposits might be further evidence of differential transportation of this highly resistant phytoclast during the period of major progradation.

Amorphous organic matter, of marine origin, is more abundant in sections located in the central and northern parts of the basin (wells ALP-6 and P-201 and Catatumbo and Rosarito Quarry sections). Two main types of amorphous organic matter occur. In samples located at the base of the studied interval in the Catatumbo outcrop section, the amorphous organic matter forms dense dark brown clusters. This type of organic matter contrasts with the more granulate and weakly fluorescent amorphous organic matter that occur in the rest of the samples. This marked contrast might be the result of more anoxic conditions at the base of the section Catatumbo outcrop section, which enhanced the preservation of the organic matter. The abundance of well preserved fish and ammonite remains at the top of the underlying carbonate bed in the Catatumbo section accords with this possible anoxic event. A similar assemblage of enriched amorphous organic matter was observed in the Machiques Member in the section of well ALP-6, and might have also been related to a transgressive pulse within the the Machiques Graben, since there was no evidence of this event in the other studied sections.

The quantitative characterization of phytoclasts proved to be useful in determining some trends in the more continental facies of the Aguardiente Formation. Variations of the average size of the phytoclasts and its standard deviation correlate with transgressive and regressive events. In the northern sections, the variation in size and sorting was observed only at the level of the sedimentary phase characterized by a major progradational event (SP 4). It is considered that terrestrial phytoclasts are sorted in the nearshore environments (significant accumulation of large-sized phytoclasts observed by Cross et al., 1966) and therefore the variation in size and sorting of these phytoclasts must be considered with special care in their study in shallow water nearshore sedimentary environments. Unlike those situations in the deep-water environments (Steffen and Gorin, 1993a; Pasley et al., 1993), the abundance, size and sorting of these phytoclasts in nearshore paleoenvironments is of limited use.

5.6 Conclusions.

Palynological and palynofacies analyses allow a consistent framework to be established for the sedimentary evolution of the Maracaibo Basin during the Early Cretaceous. The five defined sedimentary phases are related to the regressive-transgressive nature of the intervals considered. The general framework suggests that these phases are consistent with and maybe related to relative changes in sea level, as suggested by Azpiritxaga (1991). These relative sea-level changes appear to have had a definite effect on the characteristics of the palynomorph and palynofacies observed in this study.

The first of the sedimentary phases (SP 1) is observed only in assemblages of samples of the Aguardiente Formation from unit I of the Zea-Panamericana section and involves increasing marine influence to the top of the unit. The more continental-coastal assemblages dominated by pollen of *Corollina* are associated with dinocysts and amorphous organic matter at the base of this interval. Because of the poor recovery of palynological assemblages, it was not possible to correlate this unit to intervals in other sections. Some evidence of rising sea-level and even anoxic conditions occur in the Machiques Member in well ALP-6 (16500' to 16574'), but evidence of these two intervals lack convincing correlation.

The second sedimentary phase (SP 2) is characterized in the Aguardiente Formation in the Zea-Panamericana outcrop section by a clear trend from coastal deposits (dominated by pollen of *Corollina*) to more fluvial deposits at the top of unit II. In the other subsurface sections, the palynological assemblages are characterized by dominance of miospores, with vitrinite that show evident signs of degradation and transportation (rounding of the phytoclasts). The final expression of this regressive phase is related to a shale sequence, rich in miospore assemblages, at the base of the Lisure Formation, that seems to indicate influx of clastics into the basin during the period of Aptian sea-level fall proposed by Azpirtitxaga (1991) in the Maracaibo Basin.

A transgressive pulse seems to be associated with the sedimentary phase SP 3. Palynological and palynofacies of samples included within this phase are poor, but micropaleontological evidence in well ALT-19X (Moldovanyi and Pinto Auso, 1987), seems to indicate more open marine conditions above SP 2. An inferred level with wackestone/packstone facies overlying the regressive shales in well ALP-6 was correlated to this level of SP 3 of well ALT-19X. This transgressive pulse was also inferred in sediments of the Zea-Panamericana and La Grita-Seboruco sections based on the transition from fluvial sediments to marine-deltaic intervals. This phase might be associated with putative rise in sea level during the Late Aptian–Albian (Azpiritxaga, 1991).

The more diverse and better preserved palynological and palynofacies occur in the sedimentological phase SP 4. In general, miospores species are dominant, but dinoflagellate assemblages also occur in large numbers and species richness increases. The diversification of the dinoflagellate assemblages seems to be the result of rising sea-level during the preceeding SP 3 and the onset of this progradational phase, that allowed more marine species to establish in the shallow water platform. Wall et al. (1977) proposed that cyst production might be triggered by unstable hydrographic conditions, perhaps the kind of conditions expected during a major progradational event with abundant continental runoff. The assemblages of this major progradational sedimentary phase were those of biozone IV (Albian).

The last of the sedimentary phases (SP 5) defined on basis of palynological and palynofacies seems to be regressive. The palynological assemblages are poor but palynofacies exhibit increasing amounts of vitrinite phytoclasts with relatively large fragments. This phase was probably related to a drop of sea-level proposed by Azpiritxaga (1991) for the Upper Albian of the Maracaibo Basin.

Lateral distribution of dinocysts is related to paleoecology. Species such as *Oligosphaeridium albertense*, *Circulodinium distinctum* subsp. *distinctum*, *Kiokansium unituberculatum* and *Subtlisphaera deformans* occur widely in most of the sections, regardless of the sedimentary phases here defined and are considered to be generalists. Their abundances increase in the more marine sections in the north and especially during the onset of the progradational phase SP 4 concommitantly with other species. For example, *Florentinia* sp. cf. *F. verdieri*, *Florentinia oceanica*, *Coronifera oceanica*, *Cribroperidinium orthoceras*, *Xiphophoridium* sp. A, *Microdinium opacum*, some species of *Spiniferites* and *Achomosphaera*, *Subtilisphaera senegalensis*, *Subtilisphaera cheit* and *Xenascus plotei* occur abundantly in intervals deposited under more marine conditions in sections in the north and central areas of the basin, especially during the progradational phase SP 4. The criteria of ratios of gonyaulacoid to peridinoid and skolochorate to proximate dinocysts does not fully explain the distribution of the dinoflagellate assemblages along the nearshore-offshore gradient. Distribution of miospores is less diagnostic for paleoecology of the land plant paleocommunities. Plant producing pollen of *Corollina* appear to have been related to coastal swamps. In contrast, the parent plants of *Afropollis* occupied coastal environments with much less saline or brackish water influence.

Vitrinite and inertinite phytoclasts dominate the southernmost and central sections. To the north, intervals with abundant amorphous organic matter seems to indicate minor terrestrial influence in the marine environments of the shallow carbonate platform. The poor preservation of palynological assemblages to the north can be related to oxidizing conditions of these paleoenvironments and to small sedimentary rates in the shallow carbonate platform. Characters such as size and sorting (estimated indirectly by the standard deviation of the size) of vitrinite particles proved to be useful parameters to characterize transgressive and regressive pulses, especially in coastal paleoenvironments such as those of the Zea-Panamericana and La Grita-Seboruco sections. Increase in average size and preservation are also useful determining the progradational (SP 4) and regressive (SP 5) events at the top of the cored sections of the Cogollo Group.

However, palynofacies could not be used alone as a reliable indicator of sedimentary phases. A multidisciplinary approach, including the analyses of the palynological assemblages, was necessary to determine a reliable framework for the correlation and characterization of the sedimentary evolution of the basin.

PLATE 18

Figure 1. Palynofacies Unit Ia. Zea-Panamericana Outcrop section. Sample 13-04-01 S1. Phytoclasts mainly of vitrinite or degrade woody tissues, poorly sorted, relatively angular.

Figure 2. Palynofacies Unit IIa. Zea-Panamericana Outcrop section. Sample 13-04-16 S1. Phytoclasts dominated by degraded woody tissue, relatively poor sorting, with tracheid fragments and miospores.

Figure 3. Palynofacies Sedimentary Phase 2 (SP 2). Well CR-5, 14401'. Mix of amorphous and very degraded and poorly sorted-rouded vitrinite fragments.

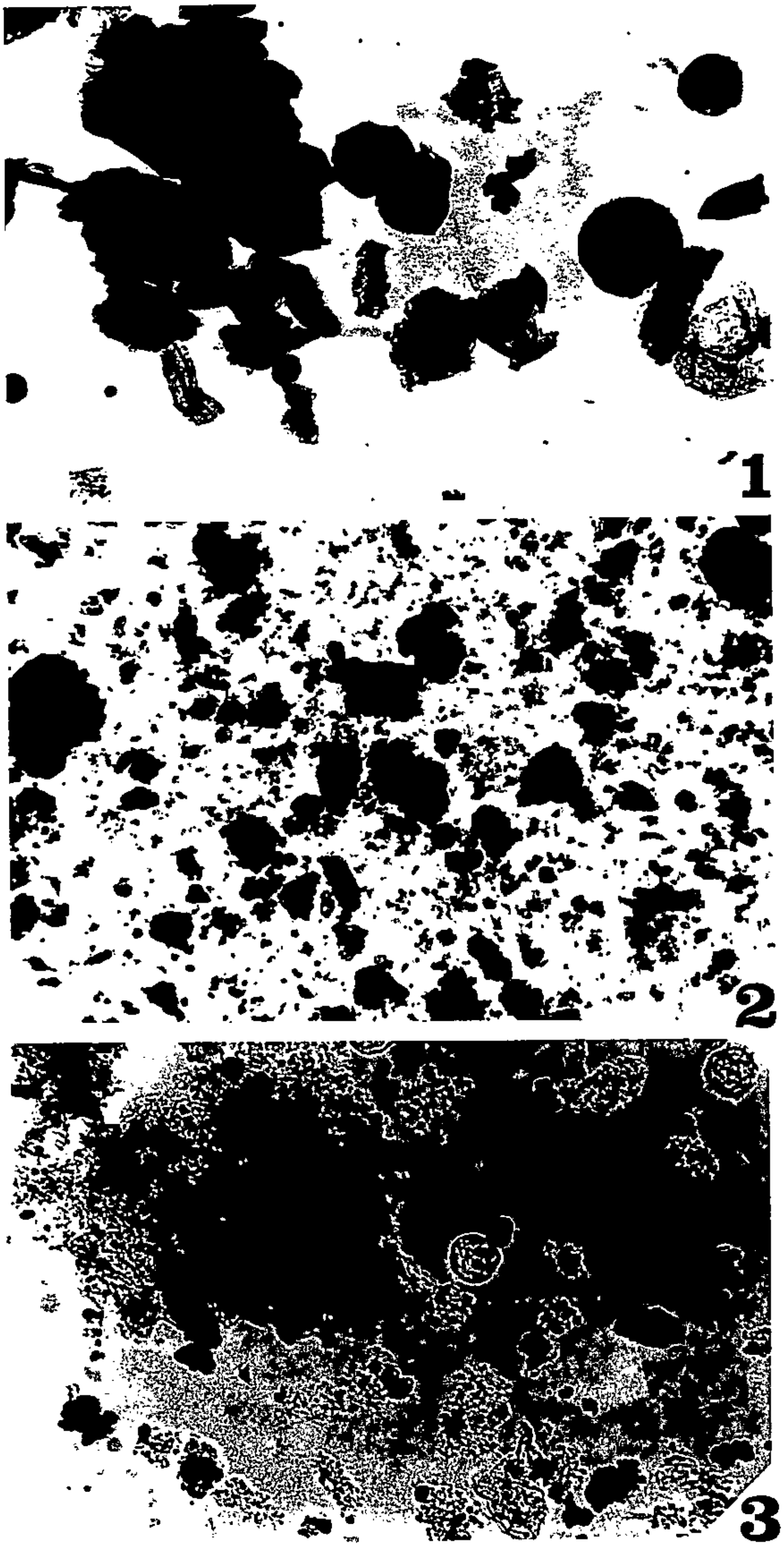

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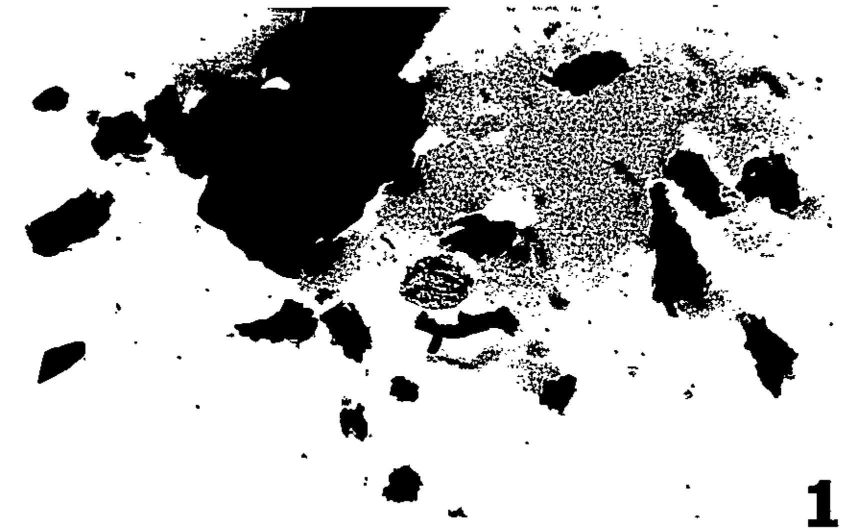
PLATE 19

Figure 1. Palynofacies Sedimentary Phase 4 (SP 4). Well ALT-19X, 14421'. Palynofacies with very good preservation dominated by vitrinite fragments with structure and miospores.

Figure 2. Palynofacies Machiques Member; Apón Formation. Well ALP-6, 16565'. Palynofacies dominated by abundant amorphous organic matter forming dense clusters.

Figure 3. Palynofacies Sedimentary Phase 4 (SP 4). Catatumbo Outcrop section, sample M-23. Palynofacies dominated by amorphous organic matter with well sorted and relatively rounded inertinite phytoclasts.



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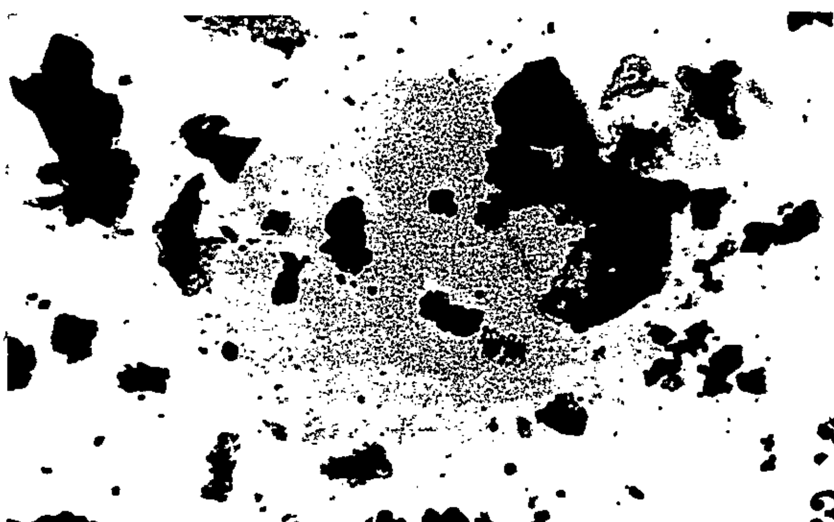

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6. CONCLUSIONS.

The study of the taxonomy and distribution of palynological assemblages and associated palynofacies in the Lower Cretaceous sediments of the Maracaibo Basin has provided information on the palynostratigraphy and the paleoenvironments of deposition of the Aguardiente Formation and the Cogollo Group (the Apón, Lisure and Maraca formations).

The assemblage consists of a total of 97 species of miospores (pollen and spores), 48 species of dinoflagellates and 12 species of green algae and acritarchs. All these species are described and illustrated. A total of seven new species of miospores are described: *Apiculatisporis rotundus, Leptolepidites zeaensis, Uvaesporites inferus, Concavissimisporites miniverrucatus, Rotverrusporites convexus, Dictyophyllidites grandis* and *Tricolpites gritaensis*. The following new combinations are proposed: *Corollina brasiliensis, Corollina kieseri, Corollina torosa, Concavisporites mesozoicus, Deltoidospora punctata* and *Cibotiumspora sinuata*. The description of *Exesipollenites crassimarginatus*, a species of pollen recorded for the first time in the Lower Cretaceous of South America in this study, is emended to incorporate more adequate description of the morphology.

Corollina, Araucariacites and *Afropollis* are the most common elements of the miospore assemblages. Their presence, as well as the occurrence of *Reyrea polymorpha, Elaterosporites klaszi, E. verrucatus* and *Sofrepites legouxiae* indicate close resemblance to coeval assemblages of Brazil and Africa. Other miospore species are present in very low abundance in general and their overall composition is similar to that reported for Lower Cretaceous assemblages of the African and South American province (Herngreen and Chlonova, 1981). Trilete spores belong to genera with widespread distribution in the Lower Cretaceous and are dominated by species of *Deltoidospora, Dictyophyllidites* and *Concavisporites*.

Dinoflagellate assemblages include several species that have been reported from the Lower Cretaceous of Europe, North America and Australia. Quantitative comparison of the assemblages reported from the Maracaibo Basin with coeval assemblages from other localities show low percentages of similarity. The differences are considered to be related not only to climatic-latitudinal factors, but also to differences of the associated paleoenvironments of deposition. However, the occurrences of species such as *Xenascus* *plotei*, *Subtilisphaera cheit*, *Subtilisphaera zawia*, *Subtilisphaera senegalensis*, *Achomosphaera triangulata* and *Kiokansium unituberculatum*, which are common in or restricted to northern Africa and southern United States, indicate that the Venezuelan dinoflagellate assemblages exhibit provincialism consistant with Aptian–Albian patterns elsewhere (Williams et al., 1990). The widespread occurrence of species of *Subtilisphaera* in low latitude assemblages seems to indicate that provincialism of peridiniacean dinocysts was initiated as early as in the Aptian–Albian.

The vertical and lateral distribution of palynomorphs in different sections of the Aguardiente Formation and the Cogollo Group allows the definition of four biozones. Biozones I (Lower Aptian) and II (Lower to Middle Aptian) are only observed in the Aguardiente Formation and are characterized by the dominance of terrestrial material, with dinoflagellate assemblages as a secondary component. Biozone III (Upper Aptian) is characterized by the first occurrence of tricolpate angiosperm pollen in northern South America, as well as the lower range of *Afropollis* sp. cf. *A. jardinus*.

Biozone IV (Albian) is characterized by the first occurrence of elater-bearing palynomorphs: *Elaterosporites klaszi* and *Sofrepites legouxiae*, a biovent that can be correlated not only in South America, but also in Africa. The age of the first occurrence of this type of palynomorph has been discussed in the literarature and placed in sediments of the Middle to Upper Albian (Herngreen and Dueñas Jiménez, 1990), but normally has been placed in the Lower Albian (Muller et al., 1987; Regali et al., 1974a). The co-occurrence of the elater-bearing palynomorphs with the dinoflagellate species *Xenascus plotei*, reported from the Albian of northern Africa and southern United States, seems to restrict the base of this biozone to the Lower Albian. Other species, such as *Xiphophoridium* sp. A and *Cibotiumspora sinuata* are also restricted to this biozone IV. The latter species has been reported from the Jurassic to the Cretaceous, but in western Venezuela is only observed in the Albian.

The age of the different lithostratigraphic units is determined based on the palynostratigraphic framework developed in this study: Lower Aptian to Albian for the Aguardiente Formation, Aptian for the Apón Formation, Upper Aptian to Albian for the Lisure Formation and Albian for the Maraca Formation.

Future studies on the biostratigraphy of the Maracaibo Basin must pursue the calibration of the palynostratigraphy proposed in this study with nannoplankton and foraminifera zonations. Dr. Robert Scott (1992, personal communication) has been completing high-resolution biostratigraphic studies in Lower to lower Upper Cretaceous sections of Texas, Mexico and Central America. Because of similarities of the dinoflagellate assemblages of southern United States and the Maracaibo Basin, a possible correlation between these areas might be possible and provide a more reliable chrono- and biostratigraphic framework for the Lower Cretaceous of the Caribbean area.

The palynofacies in combination with the results of the palynological analyses indicate that the paleoenvironments of deposition of the Aguardiente Formation are continental to transitional (estuarine-deltaic). The palynofacies are characterized by the dominance of vitrinite phytoclasts and the palynomorph assemblages are dominated mainly by miospores (trilete spores, *Corollina, Afropollis* and *Araucariacites*). Decrease of the average size and the standard deviation (an estimator of the degree of sorting) of vitrinite and increase of the percentages of inertinite are related to transgressive pulses in the coastal to nearshore environments.

Palynological assemblages and palynofacies of the Cogollo Group are characterized by very variable preservation. Poorly preserved assemblages are related to the shallow water paleoenvironments and oxidizing conditions of the carbonate platform, as well to diagenetic processes (for example pyrite crystal growth and extensive thermal alteration observed in samples of well VLB-704). Palynological assemblages are largely dominated by miospores (dominated by *Corollina* and *Araucariacites*) together with dinocysts (dominated by *Oligosphaeridium albertense,* species of *Circulodinium, Subtilisphaera* and *Kiokansium unituberculatum*). Palynofacies are dominated by terrestrial material (vitrinite and inertinite). Abundant amorphous organic matter is observed only in some intervals (corresponding mainly to the Machiques Member of the Apón Formation in well ALP-6 and in the Catatumbo outcrop section) and is associated with anoxic conditions that enhanced the preservation of the organic matter. Well preserved palynological assemblages (largely of miospores but associated with diverse dinoflagellate assemblages) and palynofacies (mainly consisting of poorly sorted and well preserved vitrinite fragments) are observed in sediments of the Aguardiente and Lisure formations (well CR-5, and wells ALT-19X and ALP-6 respectively). The difference in the preservation is related to increasing sedimentary rates that enhanced the preservation of the organic matter during a progradational pulse in the Albian.

A total of five sedimentary phases are defined based on the palynological and palynofacies characterization. The different sedimentary phases are related to transgressive and regressive pulses and roughly coincide with the relative sea-level curve proposed by Azpiritxaga (1991) for the eastern and central areas of the Maracaibo Basin. Figure 32 shows a synthesis of the the main characteristics of these different sedimentary phases.

The miospore assemblages of this study are inferred to be representative of coastal plant communities. Parent plants of *Corollina* were the dominant element of this coastal settings, whereas plants producing *Afropollis* were to coastal restricted to areas with lesser salinity or brackish water influence. Other components of the miospore assemblages seem to be produced further inland and are only observed in high abundance in nearshore settings, where the mixing of the inland and coastal palynological assemblages is expected to occur. The distribution of dinocysts is related to ecological preferences of the species. The well known parameters for estimating nearshore-offshore distances (ratios of gonyaulacoid to perdiniacean cysts or skolochorate to proximate cysts) do not seem to fully characterize the distribution of the dinoflagellate assemblages. Most assemblages are dominated by a few species of dinocysts that are considered paleoecologically generalists.

As part of the exploratory efforts of Maraven, S.A., recent research has been done on the sequence stratigraphy of the Lower Cretaceous carbonate platform of western Venezuela (Dr. Bruno Murat and Ms. Izaskun Azpirtitxaga, personal communication). Integration of the combined approach used in this study with the results of the sequence stratigraphic interpretations might prove useful for establishing a more detailed framework for the sedimentary evolution of the carbonate platform of the Maraciabo Basin during the Early Cretaceous.

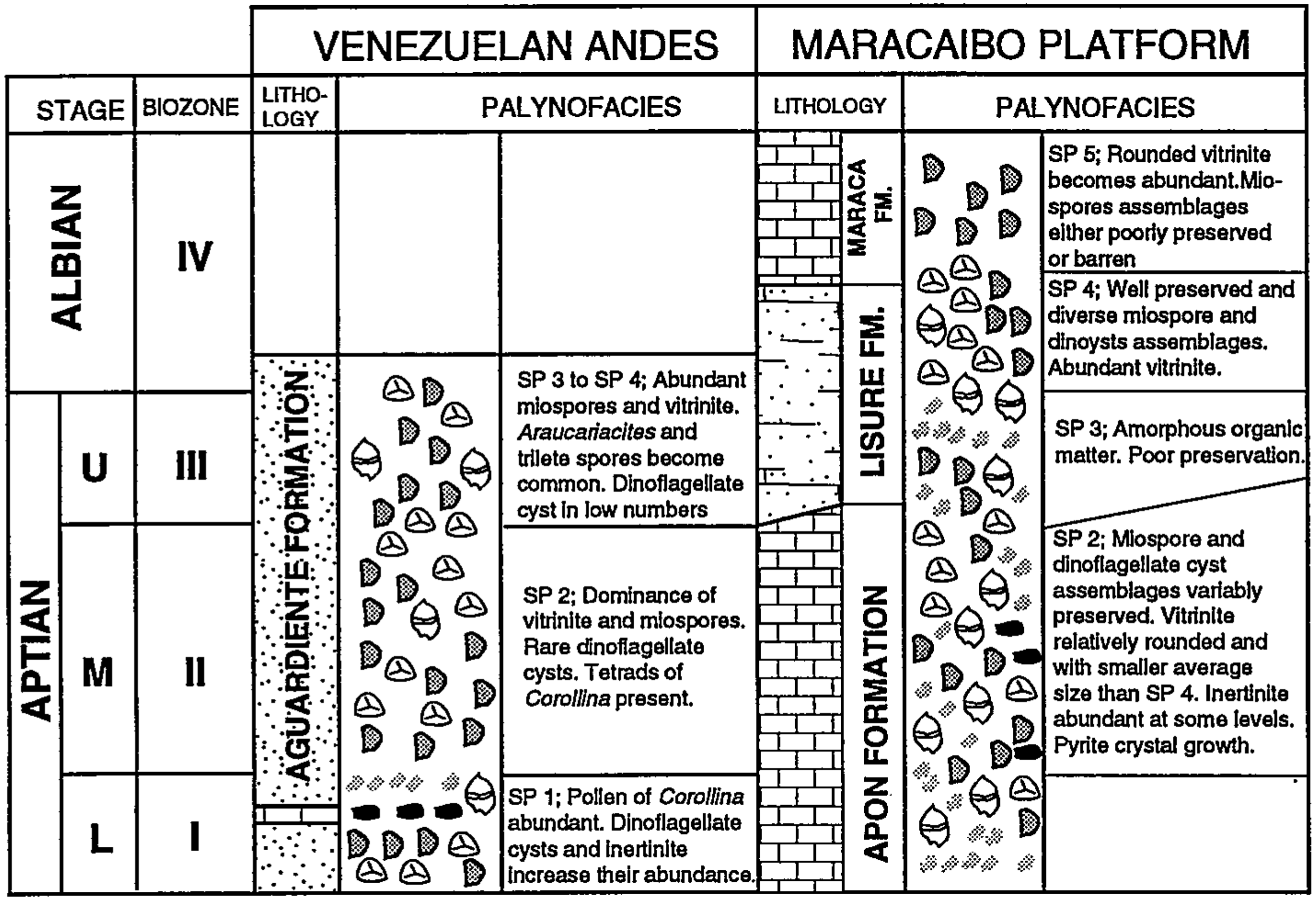

Figure 32. Palynofacies and palynological characteristics of the main sedimentary phases inferred in this study. = Miospores; = Dinoflagellate cysts; = Vitrinite; = Inertinite and = Amorphous Organic matter

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