PLATE 1

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Aequitriradites verrucosus* (Cookson & Dettmann) Cookson & Dettmann. Zea-Panamericana 13-04-27 S2; 49.4 x 102.3. Polar view.
2. *Triporoletes* sp. A. La Grita 09-04-04 S3; 24.6 x 106.2. Undetermined orientation.
3. *Apiculatisporis rotundus* sp. nov. Holotype; La Grita-09-04-06 S2; 13.0 x 99.6. Polar view.

4 & 6. *Echinatisporis varispinosus* (Pocock) Srivastava. (4) La Grita 09-04-06 S1; 8.2 x 107.0.; 4a: Lower focus on proximal face, 4b: Upper focus on distal face (6) SEM; proximal face (3000X), La Grita 09-04-07 SEM S1.

5. *Camarozonosporites* sp. cf. *C. insignis* Norris. CR-5 14210' S1; 11.9 x 95.9. Polar view.
7. *Leptolepidites* sp. cf. *L. psarosus* Norris. CR-5 14285' S1; 25.6 x 95.7. Oblique equatorial view.
8. *Leptolepidites* sp. A. ALT-19X 17639' S1; 10.7 x 95.3. Polar view.
9. *Leptolepidites zeaensis* sp. nov. Holotype; Zea-Panamericana 13-04-02 S1; 35.3 x 98.5. ?Polar view.
10. *Leptolepidites* sp. B. ALT-19X 17421' S1; 33.3 x 96.1. 10a: Lower focus on proximal face, 10b: Upper focus on distal face.

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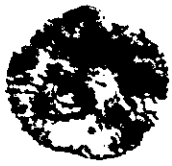

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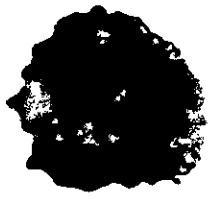

4a

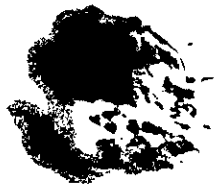

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PLATE 2

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Neoraistrickia* sp. A. La Grita 09-04-07 S2; 22.0 x 100.8. Polar view.
2. *Uvaesporites inferus* sp. nov. Holotype; La Grita 09-04-05 S1; 32.3 x 95.1. Polar view.
3. *Concavissimisporites exquisitus* (Singh) Fensome. Zea-Panamericana 13-04-16 S2; 41.8 x 94.4. 3a: Upper focus on distal face, 3b: Lower focus on distal face.
4. *Concavissimisporites miniverrucatus* sp. nov. Holotype; La Grita 09-04-04 S1; 45.0 x 94.8. Oblique polar view,
5. *Concavissimisporites* sp. A. La Grita 09-04-05 S2; 25.0 x 100.2. Polar view.
6. *Concavissimisporites* sp. B. La Grita 09-04-12 S1; 37.3 x 100.2. Polar view.
7. *Concavissimisporites* sp. F. La Grita 09-04-04 S1; 39.0 x 99.5. Polar view.
8. *Concavissimisporites* sp. C. La Grita 09-04-04 S1; 21.1 x 97.0. Polar view.
9. *Concavissimisporites* sp. E. La Grita 09-04-13 S2; 42.0 x 106.4. Polar view.
10. *Concavissimisporites* sp. D. La Grita 09-04-04 S1; 7.8 x 102.6. Polar view.
11. *Concavissimisporites* sp. G. Zea-Panamericana 13-04-02 S1; 23.2 x 92.8. Polar view.
12. *Matonisporites* sp. A. La Grita 09-04-11 S1; 14.3 x 102.8. Polar view.

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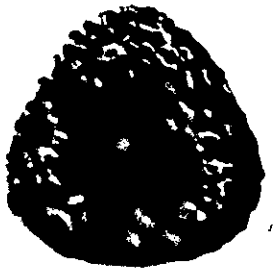
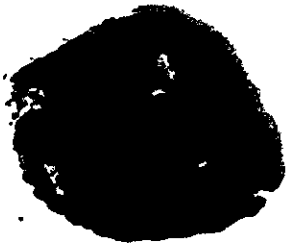
3a



3b



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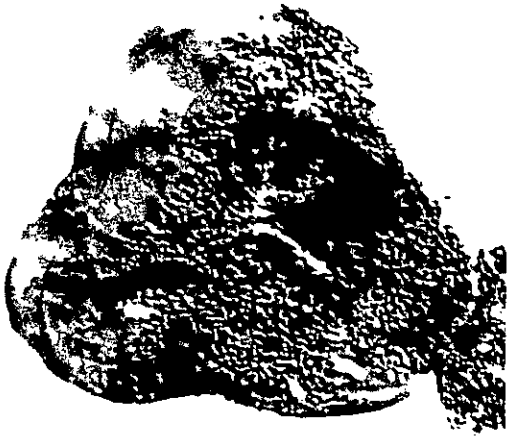

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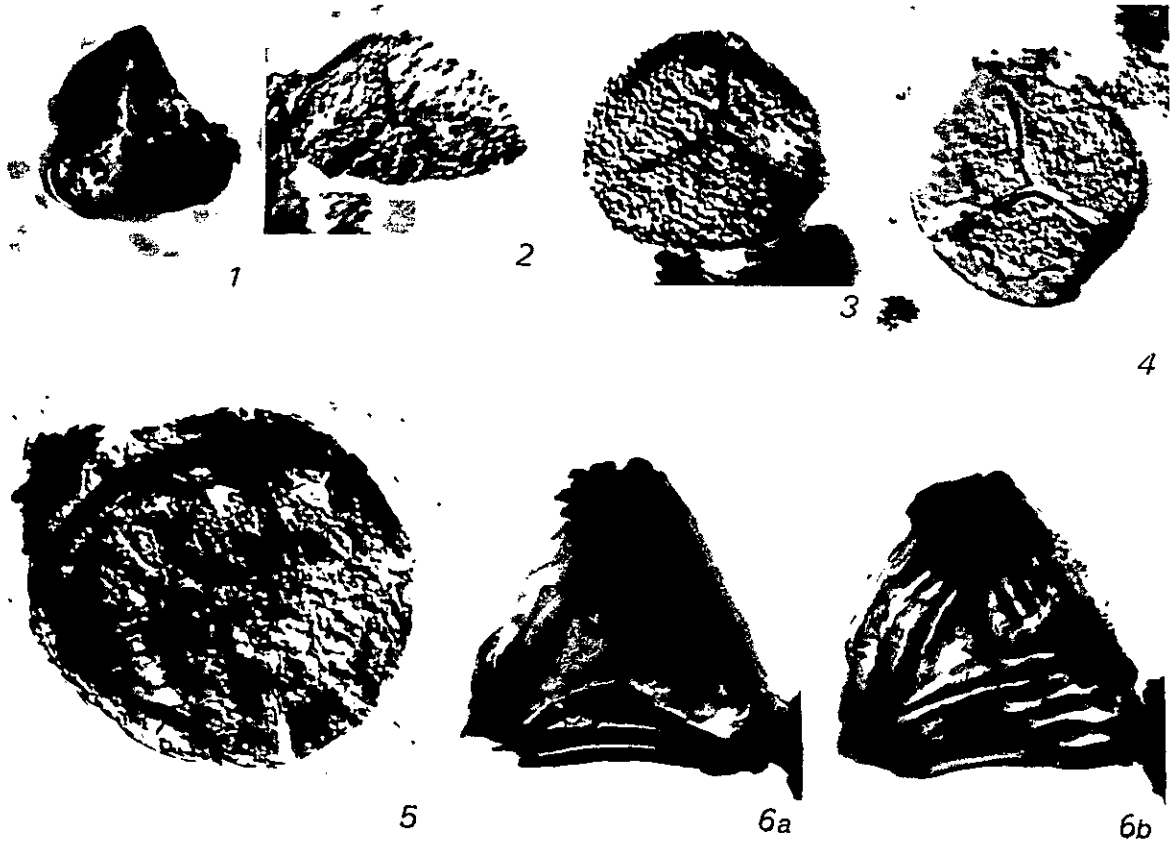
PLATE 3

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Matonisporites* sp. B. La Grita 09-04-05 S1; 43.2 x 97.0. Polar view.
2. *Baculatisporites* sp. cf. *C. comaumensis* (Cookson) Potonié. La Grita 09-04-05 S2; 41.2 x 106.7. Polar view of folded specimen.
3. *Osmundacidites wellmanii* Couper. Zea-Panamericana 13-04-16 S1; 9.1 x 96.0.Polar view.
4. *Osmundacidites* sp. A. Zea-Panamericana 13-04-07 S1; 23.9 x 98.2. Polar view.
5. *Todisporites* sp. A. Zea-Panamericana 13-04-05 S2; 27.9 x 96.0.Polar view (700X).
6. *Cicatricosisporites abacus* Burger emend. Fensome. La Grita 09-04-11 S1; 39.6 x 107.0. 6a: Lower focus on proximal face?, 6b: Upper focus on distal face.
7. *Cicatricosisporites australiensis* (Cookson) Potonié. ALT-19X 17421' S1'; 38.1 x 102.0. 7a: Lower focus on proximal face, 7b: Upper focus in distal face.
8. *Cicatricosisporites* sp. cf. *C. proxiradiatus* Kemp. La Grita 09-04-05 S1; 36.5 x 98.5. Polar view.
9. *Cicatricosisporites* sp. A. Zea-Panamericana 13-04-01 S2; 5.3 x 93.5. Polar view of folded specimen.
10. *Cicatricosisporites* sp. B. La Grita 09-04-06 S1; 34.0 x 97.6. Undetermined orientation.
11. *Cicatricosisporites* sp. C. La Grita 09-04-06 S2; 16.3 x 105.3. Undetermined orientation.
12. *Cicatricosisporites* sp. D. Zea-Panamericana 13-04-02 S1; 6.0 x 103.5. Undetermined orientation.
13. *Cicatricosisporites hallei* Delcourt & Sprumont. Zea-Panamericana 13-04-01 S2; 5.4 x 106.3. Polar view.



1 2 3 4

5 6a 6b

7a 7b 8 9

10 11 12 13

PLATE 4

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Cicatricosisporites* sp. E. Zea-Panamericana 13-04-01 S2; 33.3 x 96.6. Polar view (600X).
2. *Cicatricosisporites* sp. F. Zea-Panamericana 13-04-02 S1; 17.3 x 98.7. ?Polar view.
3. *Cicatricosisporites* sp. G. Zea-Panamericana 13-04-45 S1; 40.7 x 93.2. Oblique polar view.
4. *Cicatricosisporites* sp. H. Zea-Panamericana 13-04-47 S2; 23.8 x 94.0. 4a: Lower focus on proximal face, 4b: Upper focus on distal face.
5. *Cicatricosisporites* sp. I. CR-5 14549' S1; 8.0 x 105.2. 5a: Upper focus on proximal face, 5b: Lower focus on distal face.
6. *Crassitudisporites problematicus* (Couper) Hiltmann emend. Fensome. La Grita 09-04-04 S1; 26.1 x 97.2. 6a: Upper focus on proximal face, 6b: Lower focus on distal face.
7. *Contignisporites* sp. cf. *C. cooksonae* (Balme) Dettmann. CR-5 14460' S1; 44.1 x 97.1. Polar view.
8. *Costatoperforosporites* sp. A. La Grita 09-04-13 S2; 38.2 x 103.8. Undetermined orientation.
9. *Distaltriangulisporites* sp. A. La Grita 09-04-05 S1; 18.4 x 95.0. Polar view.

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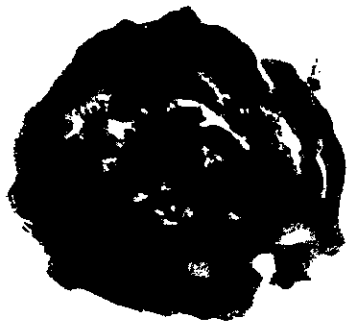
4a

4b

5a

5b

6a



6b

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PLATE 5

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Ischyosporites variegatus* (Couper) Schulz. La Grita 09-04-04 S1; 11.3 x 109.4. Oblique equatorial view.3a: Upper focus, 3b: Lowe focus.
2. *Ischyosporites pseudoreticulatus* (Couper) Döring. ALT-19X 17421' S1; 31.1 x 102.3. ?Oblique polar view.
3. *Plicatella potomacensis* (Brenner) Davies. ALT-19X 17439' S1; 23.9 x 104.0. Polar view.
4. *Rotverrusporites convexus* sp. nov. Holotype; Zea-Panamericana 13-04-05 S2; 40.7 x 95.1. Polar view.
5. *Rotverrusporites* sp. A. ALT-19X 17461' S1; 20.2 x 92.3. 5a: Upper focus on proximal face, 5b: Lower focus on distal face.

6 & 7. *Biretisporites potoniaei* Delcourt & Sprumont emend. Delcourt et al. (6) La Grita 09-04-04 S2; 24.3 x 102.8. Polar view. (7) SEM; proximal face (2000X). La Grita 09-04-07 SEM S2.

8 & 9. *Cibotiumspora sinuata* (Couper) comb. nov. (8) La Grita 09-04-13 S1. 49.6 x 101.6. Polar view. (9) ALT-19X 17253' S1; 19.0 x 102.0. 9a: Upper focus on proximal face, 9b: Lower focus on distal face.

1a

1b

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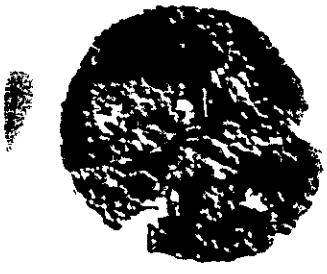
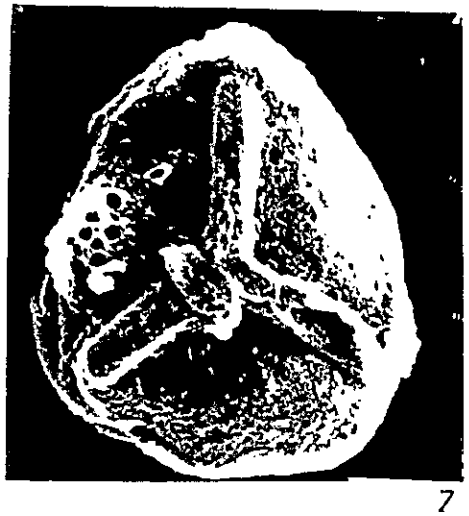


5a

5b

6



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9a

9b

PLATE 6

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Concavisporites mesozoicus* (Döring) comb. nov. La Grita 09-04-11 S3; 19.4 x 103.1. 1a: Upper focus on proximal face, 1b: Lower focus on distal face.
2. *Concavisporites* sp. cf. *C. toralis* (Leschik) Nilsson. La Grita 09-04-04 S1; 37.2 x 94.6. Polar view.
3. *Deltoidospora australis* (Couper) Pocock. La Grita 09-04-05 S2; 31.8 x 100.5. Polar view.
4. *Dictyophyllidites harrisii* Couper. La Grita 09-04-04 S1; 20.2 x 94.0. Polar view.
5. *Dictyophyllidites grandis* sp. nov. Holotype; Zea-Panamericana 13-04-06 S1; 11.4 x 94.1. Polar view.
6. *Deltoidospora punctata* (Delcourt & Sprumont) Delcourt et al. Zea-Panamericana 13-04-49 S3; 14.3 x 94.4. Polar view.
7. *Foveotriletes* sp. A. Zea-Panamericana 13-04-18 S1; 44.3 x 100.1. Polar view.
8. *Retitriletes* sp. A. Zea-Panamericana 13-04-49 S3; 22.0 x 98.6. Polar view of folded specimen.

1a

1b

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8a

8b

PLATE 7

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Retitriletes* sp. B. ALT-19X 17291' S1; 33.0 x 98.0. Broken specimen showing both proximal (finely reticulate) and distal (coarsely reticulate) faces.
2. *Foveosporites* sp. cf. *F. subtriangularis* (Brenner) Döring. ALT-19X 17439' S1; 28.9 x 106.0. 2a: Upper focus on proximal face, 2b: Lower focus on distal face.
3. *Undulatisporites* sp. A. Zea-Panamericana 13-04-06 S1; 18.7 x 100.9. Polar view, 5a: Upper focus, 5b: Lower focus.
4. *Undulatisporites undulapolus* Brenner. La Grita 09-04-07 S2; 49.0 x 104.1. Polar view.
5. Reworked spore A. Zea-Panamericana 13-04-47 S2; 30.3 x 106.9. 6a; Lower focus, 6b: Upper focus.
6. *Araucariacites australis* Cookson *ex* Couper emend. Couper. La Grita 09-04-04 S1; 19.9 x 93.7.
7. *Callialasporites dampieri* (Balme) Dev. Zea-Panamericana 13-04-27 S1; 26.0 x 100.0. Polar view.

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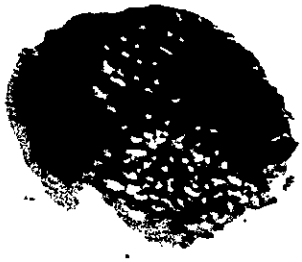
2a

3a



2b

3b

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5a

5b

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PLATE 8

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Callialasporites turbatus* (Balme) Schulz, ALT-19X 17461' S1; 31.0 x 95.9. Polar view.
2. *Callialasporites trilobatus* (Balme) Dev. ALT-19X 17421' S1; 49.9 x 102.2. Polar view.
3. *Callialasporites*? sp. A. Zea-Panamericana 13-04-06 S2; 16.0 x 99.7. Polar view.
4. *Corollina brasiliensis* (Herngreen) comb. nov. Zea-Panamericana 13-04-01 S2; 10.0 x 97.4. Oblique polar view.
5. *Corollina torosus* (Reissinger) Klaus emend. Cornet & Traverse. La Grita 09-04-04 S1; 43.9 x 99.1. Polar view.

6 & 7. *Corollina kieseri* (Reyre) comb. nov. (6) SEM, polar view (2500X). La Grita 09-04-07 SEM S1. (7) ALT-19X 17639' S1; 10.3 x 102.1. Polar view.

8 & 9. *Exesipollenites crassimarginatus* Jain & Sah emend. nov. (8) La Grita 09-04-05 S2; 33.3 x 94.9. Polar View of folded specimen. (9) SEM, polar view (3000X). La Grita 09-04-07 SEM S1.

10. *Cycadopites carpentieri* (Delcourt & Sprumont) Singh. Zea-Panamericana 13-04-01 S3; 13.9 x 105.5. Equatorial view.
11. *Cycadopites* sp. cf. *C. nitidus* (Balme) Norris. La Grita 09-04-04 S3; 18.8 x 105.9. Equatorial view.
12. *Equisetosporites* sp. A. La Grita 09-04-07 S1; 35.6 x 94.6. Equatorial view.
13. *Equisetosporites* sp. cf. *C. dudarensis* (Deák) Lima. La Grita 09-04-04 S1; 16.4 x 104.5. Equatorial view.
14. *Equisetosporites concinnus* Singh 1964. La Grita 09-04-04 S1; 28.5 x 111.1. Equatorial view.

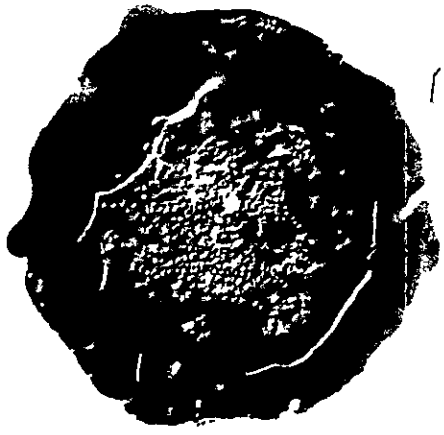

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PLATE 9

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Equisetosporites multicostatus* (Brenner) Norris. La Grita 09-04-05 S1; 34.7 x 96.0. Equatorial view.
2. *Equisetosporites* sp. cf. *E. amabilis* Srivastava. La Grita 09-04-07 S2; 12.0 x 100.5. Equatorial view.
3. *Tricolpites* sp. B. ALT-19X 17421' S1; 27.5 x 93.5. Polar view, 3a: Upper focus, 3b: Lower focus.
4. *Tricolpites* sp. A. La Grita 09-04-05 S1; 26.4 x 98.0. Equatorial view.
5. *Tricolpites gritaensis* sp. nov. Holotype; La Grita 09-04-05 S1; 12.8 x 93.4. Equatorial view.
6. *Rousea brenneri* Singh . La Grita 09-04-04 S1; 16.3 x 99.5. Polar view.
7. *Striatopollis* sp. cf. *S. paraneus* (Norris) Singh. La Grita 09-04-04 S2; 21.4 x 100.3. Equatorial view.
8. *Verrutricolpites* sp. A. Zea-Panamericana 13-04-54 S2; 7.3 x 103.0. Polar view.
9. *Afropollis zonatus* Doyle et al. 1982. Zea-Panamericana 13-04-18 S1; 8.2 x 97.0. Undetermined orientation.
10 & 12 *Afropollis* sp. cf. *A. jardinus* (Brenner) Doyle et al.. 10: La Grita 09-04-04 S1; 39.8 x 93.3. Undetermined orientation. 12a: SEM undetermined orientation (2500X), 12b: Detail of the supractectal ornamentation of the muri (10000X).
11. *Afropollis* sp. B *sensu* Doyle et al. Zea-Panamericana 13-04-16 S1; 17.1 x 93.2. Undetermined orientation.

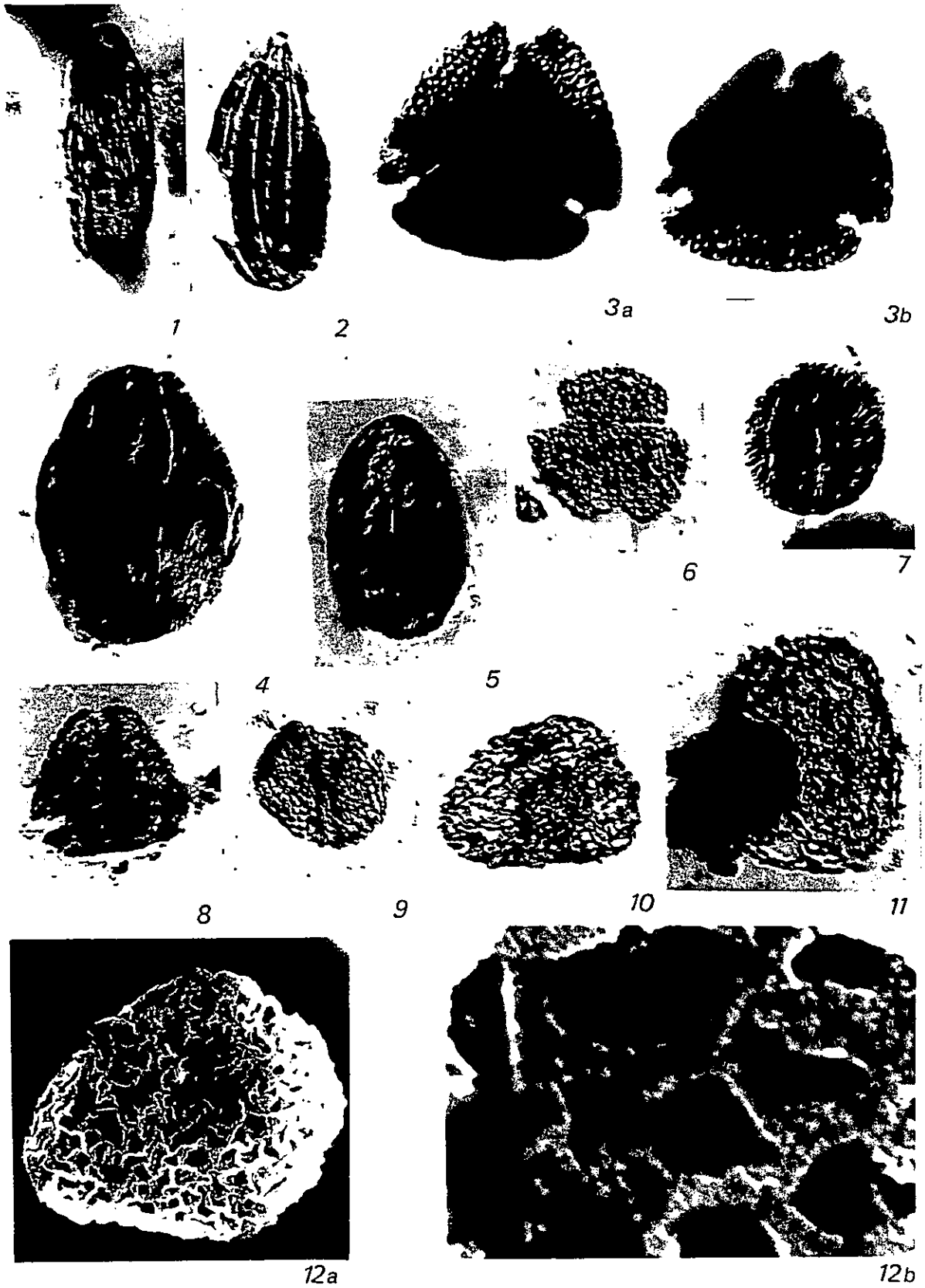
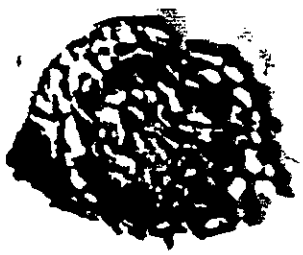


PLATE 10

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Afropollis* sp. C. La Grita 09-04-07 S3; 40.4 x 94.6. Undetermined orientation. 1a: Upper focus, 1b: Lower focus.
2. *Afropollis* sp. D. Zea-Panamericana 13-04-16 S1; 29.0 x 96.0. Undetermined orientation.
3. *Afropollis* sp. E. ALT-19X 17461' S1; 17.4 x 94.9. Undetermined orientation.
4. *Afropollis* sp. F. Catatumbo M-13 SS1; 20.9 x 97.0. 4a: broken specimen, 4b: Detail of the echinate supratectal ornamentation of the muri.
5. *Afropollis* sp. G. Catatumbo M-25 S1, 42.5 x 102.1. 5a: Upper focus, 5b: Lower focus.
6. *Elaterosporites klazi* (Jardiné & Magloire) Jardiné. ALT-19X 17450' S1; 38.9 x 106.1. Equatorial view.
7. *Elaterosporites verrucatus* (Jardiné & Magloire) Jardiné. ALT-19X 17291' S1; 15.2 x 95.9. Undetermined orientation.
8. *Sofrepites legouxiae* Jardiné emend. Boltenhagen. La Grita 09-04-10 S1; 43.5 x 98.5. Undetermined orientation, 8a: Lower focus, 8b: Upper focus.
9. *Reyrea polymorpha* Herngreen. Zea-Panamericana 13-04-06 S1; 39.7 x 92.0. Undetermined orientation.



1a

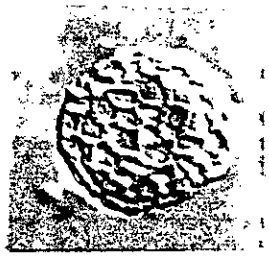
1b

2

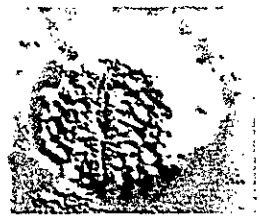
3

4a

4b



5a



5b

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8a

8b

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PLATE 11

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Microdinium opacum* Brideaux. ALT-19X 17450' S1; 4.0 x 100.1. Dorsal view.
2. *Lithosphaeridium* sp. A. ALT-19X 17421' S1; 14.0 x 101.2. ?Apical view.
3. *Pareodinia* sp. A. Zea-Panamericana 13-04-48 S1; 37.6 x 108.1. Right lateral view.
4. *Microdinium* sp. A. Rosarito S2A S1; 9.1 x 101.2. Dorsal view.
5. *Microdinium*? sp. B. Rosarito S2A S1; 30.3 x 96.2. Lateral view.

6 & 7. *Oligosphaeridium albertense* (Pocock) Davey & Williams. (6) ALT-19X 17439' S1; 8.8 x 102.0. ?Left lateral view. (7) SEM right lateral view (1000X). CR-5 14196' SEM S1.

8. *Oligosphaeridium complex* (White) Davey & Williams. ALT-19X 17803'3" S1; 41.8 x 98.2.
9. *Oligosphaeridium* sp. cf. *O. pulcherrimum* (Deflandre and Cookson) Davey & Williams. ALT-19X 17339' S1; 18.8 x 99.7. Undetermined orientation.

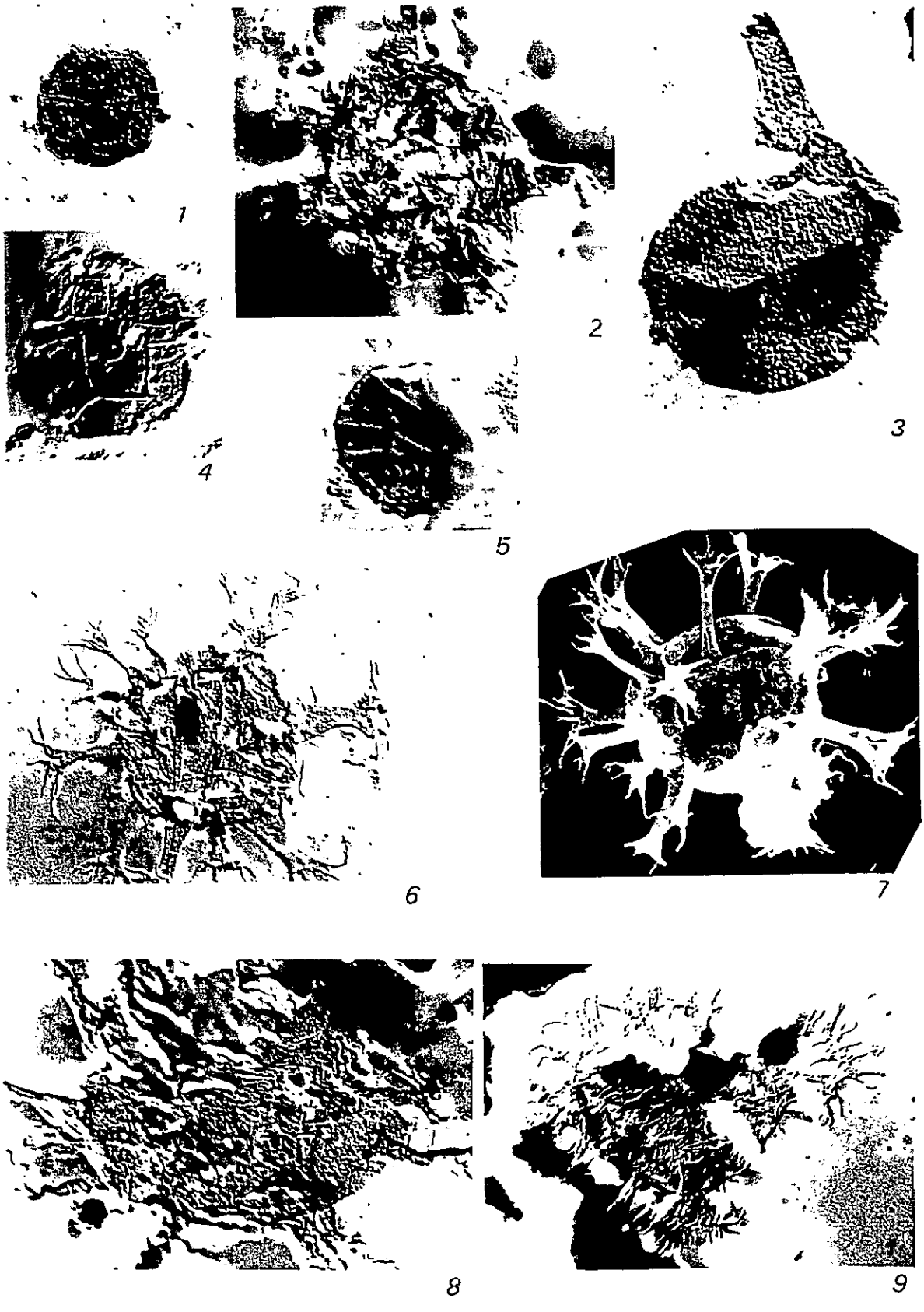

PLATE 12

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Cribroperidinium orthoceras* (Eisenack) Davey emend. Sarjeant. ALT-19X 17461' S2; 7.3 x 94.4. 1a: Ventral view, 1b: Dorsal view.
2. *Florentinia laciniata* Davey & Verdier. ALT-19X 17461' S2; 17.7 x 105.4. ?Dorsal view?
3 & 4. *Florentinia* sp. cf. *F. verdieri* Singh. (3) ALT-19X 17461' S1; 22.5 x 102.4. ?Lateral view. (4) SEM lateral view (750X). Catatumbo M-25 SEM S1.
5. *Protoellipsodinium* sp. A. La Grita 09-04-07 S1; 10.7 x 97.8. ?Oblique left lateral view.
6. *Achomosphaera* sp. A. ALT-19X 17461' S1; 6.9 x 98.7. Undetermined orientation.
7. *Achomosphaera* sp. B. ALT-19X 17600' S1; 38.6 x 99.8. Undetermined orientation.

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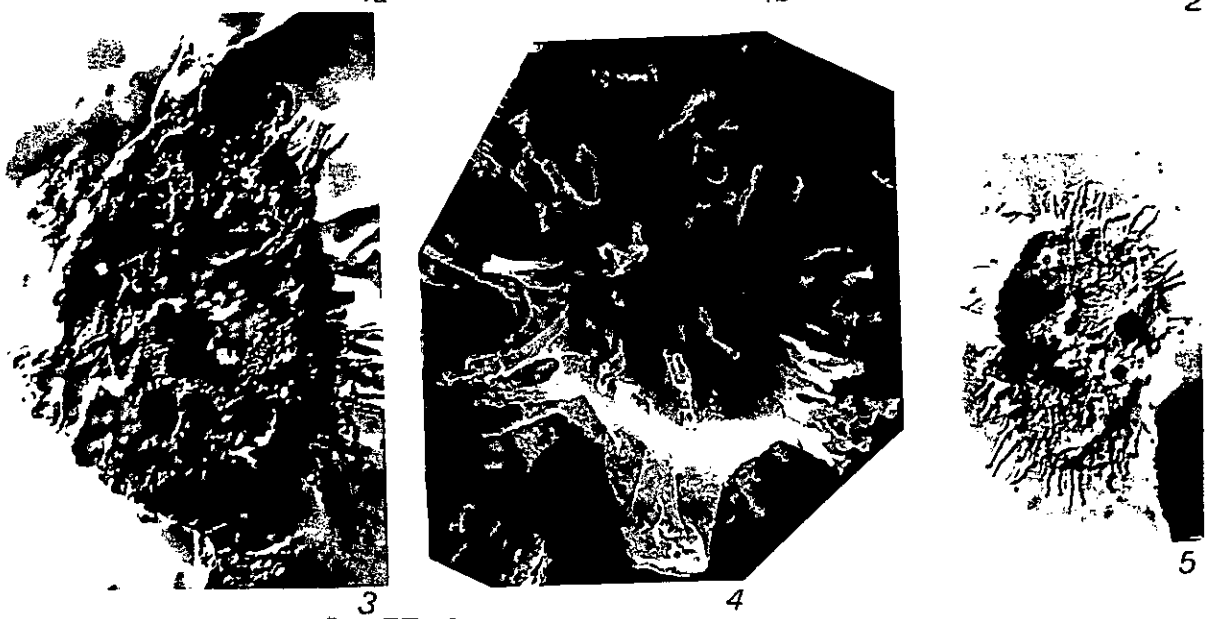

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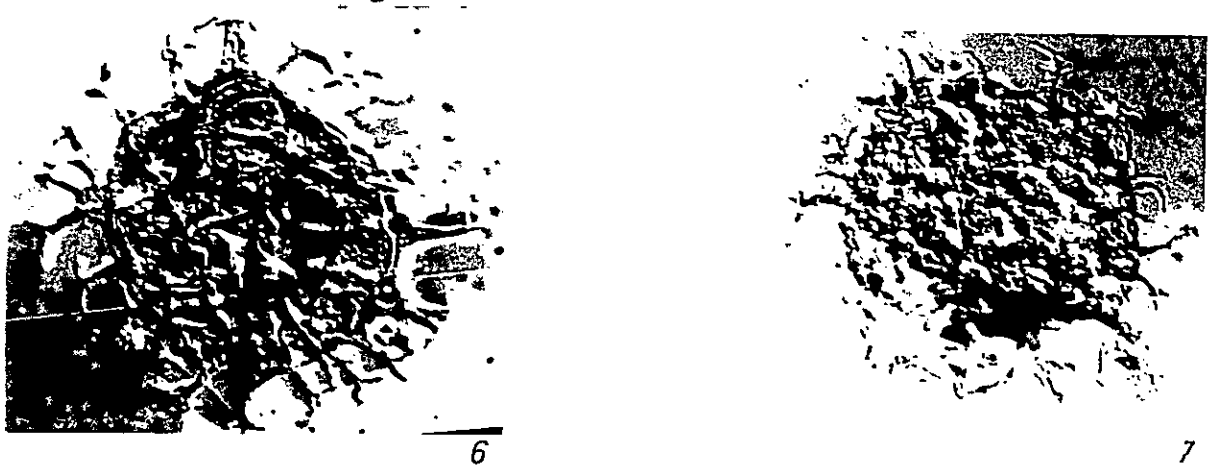

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PLATE 13

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Achomosphaera triangulata* (Gerlach) Davey & Williams. ALT-19X 17461' S1; 40.9 x 97.1. Dorsal view.
2. *Spiniferites twistringiensis* (Maier) Fensome et al.. Zea-Panamericana 13-04-06 S1; 24.8 x 102.8. Undetermined orientation.
3. *Spiniferites* sp. A. ALT-19X 17412' S1; 30.2 x 96.1. Undetermined orientation.
4. *Coronifera oceanica* Cookson & Eisenack emend. May. ALT-19X 17461' S1; 48.0 x 98.2. Right lateral view.
5. *Spiniferites* sp. B. ALT-19X 17291' S1; 36.9 x 100.0. Undetermined orientation.
6. *Kiokansium*? sp. B. ALT-19X 17461' S1; 21.5 x 93.2. Oblique dorsal view.
7. *Kiokansium*? sp. A. Catatumbo M-25 S1; 41.7 x 93.2. Undetermined orientation.
8. *Kiokansium unituberculatum* (Tasch in Tasch et al.) Stover & Evitt. ALT-19X 17421' S1; 34.8 x 95.8. Oblique dorsal view.
9. *Hystrichodinium pulchrum* Deflandre. ALT-19X 17291' S1; 14.7 x 94.8. Undetermined orientation.
10. *Circulodinium colliveri* (Cookson & Eisenack) Helby. CR-5 14231' S1; 19.5 x 95.0. ?Dorsal view.

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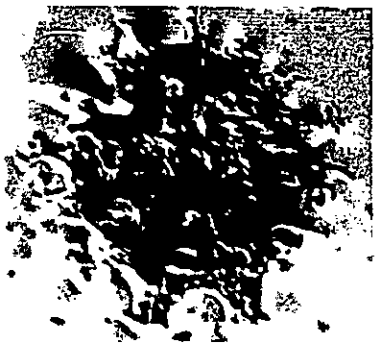

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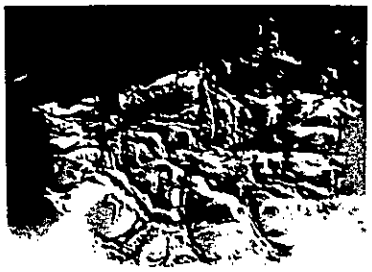

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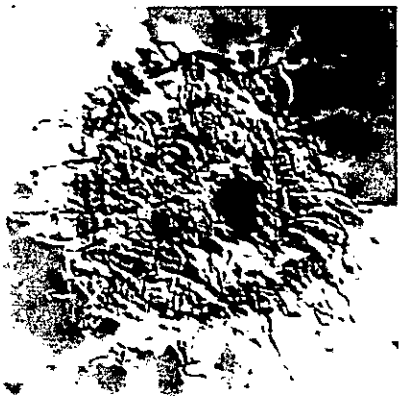

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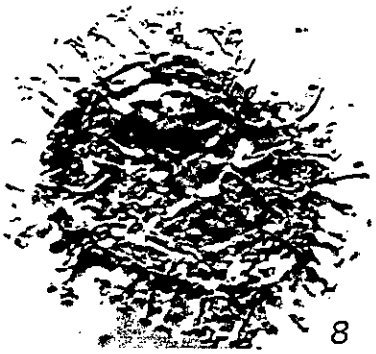

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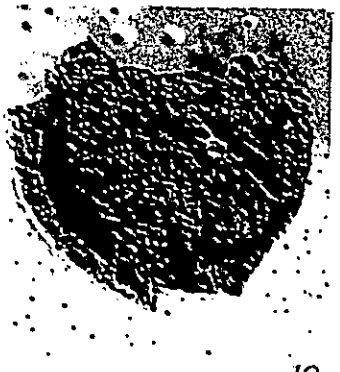

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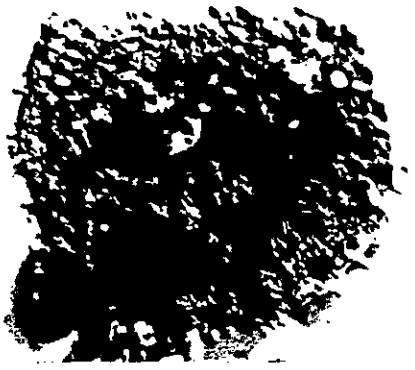
PLATE 14

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Circulodinium distinctum* subsp. *distinctum.* La Grita 09-04-10 S1; 45.6 x 103.2. ?Dorsal view.
2. *Circulodinium* sp. A. Zea-Panamericana 13-04-18 S1; 48.9 x 96.1. Dorsal orientation.
3. *Circulodinium* sp. B. Zea-Panamericana 13-04-27 S1; 9.2 x 98.5. Ventral view.
4. *Circulodinium distinctum* subsp. *longispinatum* (Davey) Lentin & Williams. ALT-19X 17461' S2; 44.8 x 105.7. ?Lateral orientation.
5. *Pseudoceratium* sp. A. ALT-19X 17439' S1; 14.9 x 103.1. Undetermined lateral orientation.

6 & 7. *Cyclonephelium vannophorum* Davey. (6) ALT-19X 17421' S1; 24.0 x 94.2. Ventral view. (7) SEM left lateral view (800X). Catatumbo M-25 SEM S1.

8. *Odontochitina operculata* (Wetzel) Deflandre & Cookson. ALT-19X 17600' S1; 43.3 x 107.7. Oblique dorsal view (500X).
9. *Xenascus plotei* Below. ALT-19X 17461' S1; 9.4 x 98.9. Undetermined lateral view.



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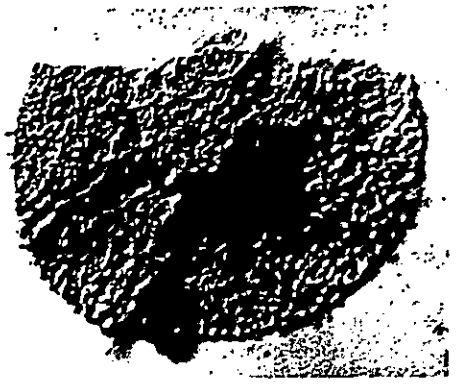

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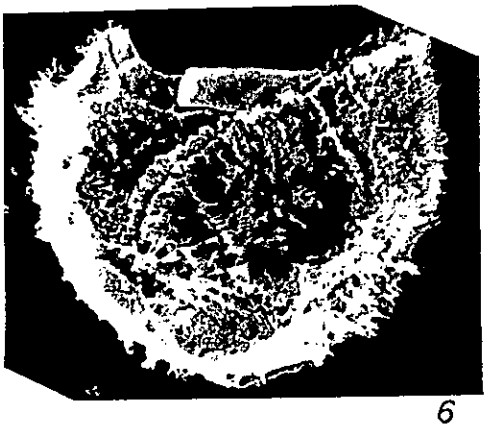

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PLATE 15

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Dapsilidinium* sp. A. LGRT-09-04-10 S2; 27.6 x 94.4. Undetermined lateral orientation.
2. *Dapsilidinium* sp. B. CR-5 14196' S1; 44.0 x 96.0. Undetermined lateral view.
3. *Dapsilidinium* sp. C. ALT-19X 17461' S1; 35.8 x 93.3. Undetermined lateral view.
4. *Xiphophoridium* sp. A. ALT-19X 17461' S1; 4.6 x 95.1. Left lateral view, 4a: Upper focus, 4b: Lower focus.
5. *Dyoxia* sp. A. ALT-19X 17639' S3; 31.1 x 101.7. Undetermined lateral view.
6. *Chichaouadinium boydii* (Morgan) Bujak & Davies. ALT-19X 17421' S1; 17.4 x 95.5. Dorsal view.
7. *Chlamydophorella nyei* Cookson & Eisenack. ALT-19X 17461' S1; 31.9 x 99.0. Undetermined orientation.
8. *Exochosphaeridium phragmites* Davey et al. ALT-19X 17421' S1; 27.3 x 99.0. Oblique dorsal view.

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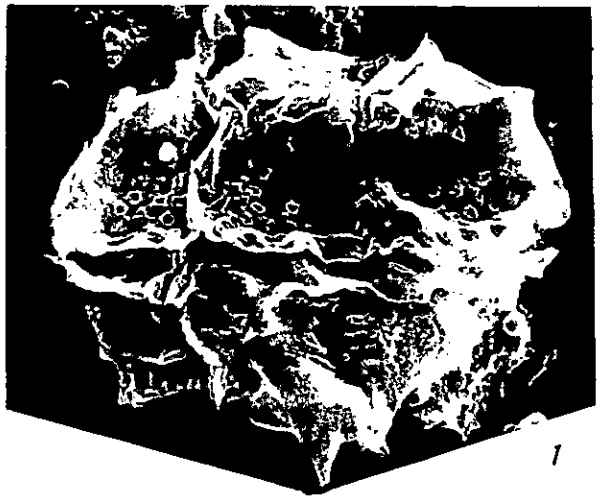
PLATE 16

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Xiphophoridium* sp. A. SEM undetermined lateral view (1200X). Catatumbo M-25, SEM S2.
2. *Ginginodinium*? sp. A. La Grita 09-04-07 S1; 32.2 x 102.5. Undetermined operation.
3. *Subtilisphaera cheit* Below. ALT-19X 17291' S1; 37.0 x 99.0. Dorsal view.
4. *Subtilisphaera deformans* (Davey & Verdier) Stover & Evitt. Zea-Panamericana 13-04-06 S1; 40.3 x 111.0. Left lateral view.
5. *Subtilisphaera senegalensis* Jain & Millepied. ALT-19X 17450' S1; 42.7 x 95.8. Undetermined lateral orientation.
6. *Subtilisphaera zawia* Below. La Grita 09-04-06 S2; 24.6 x 103.2. Dorsal view.
7. *Incertae Sedis* B. ALT-19X 17461' S1; 22.0 x 103.1. Undetermined orientation.
8. *Prolixosphaeridium* sp. A. Zea-Panamericana 13-04-06 S1; 20.7 x 97.8. Undetermined lateral orientation.
9. *Incertae Sedis* A. Catatumbo M-25 S1; 26.0 x 93.5. ?Apical/Antapical view.



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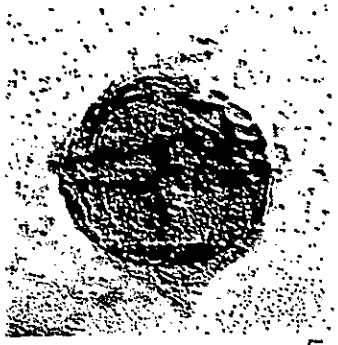

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PLATE 17

All photomicrographs in transmitted light with interference contrast optics (IC), x1000 (unless otherwise indicated). Referenced slides of the palynological collection of INTEVEP, S.A; well or outcrop section name followed by sample number and slide number. Specimen coordinates measured on a Wild Leitz Microscope rectangular stage.

1. *Tetraedron* sp. A. La Grita 09-04-10 S2; 16.3 x 102.6.
2. *Incertae sedis* C. ALT-19X 17421' S1; 15.7 x 102.1.
4. *Pterospermella australiensis* (Deflandre & Cookson) Eisenack & Cramer. La Grita 09-04-11 S2. 25.7 x 95.0.
3. *Pediastrum* sp. A. La Grita 09-04-12 S2; 30.7 x 107.1.
5. *Pterospermella* sp. A. Zea-Panamericana 13-04-06 S1; 6.8 x 108.2.
6. *Pterospermella* sp. B. La Grita 09-04-10 S2; 43.3 x 103.0.
7. *Leiosphaeridia* sp. A. Zea-Panamericana 13-04-06 S1; 21.7 x 98.5.
8. *Chomotriletes minor* (Kedves) Pocock. La Grita 09-04-05 S2; 18.6 x 103.1.
9. *Goniosphaeridium polygonale* (Eisenack) Eisenack. La Grita 09-04-11 S2; 24.1 x 107.2. Undetermined orientation.
10. *Micrhystridium* sp. A. La Grita 09-04-10 S1; 19.7 x 95.0. Undetermined orientation.
11. *Incertae sedis* D. Zea-Panamericana 13-04-54 S1; 46.0 x 106.0.

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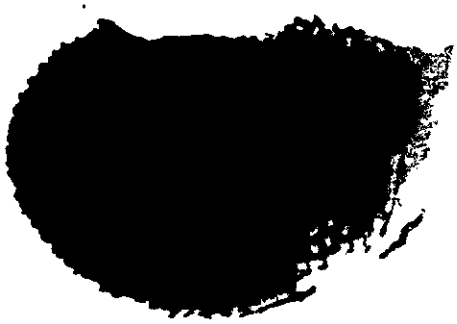

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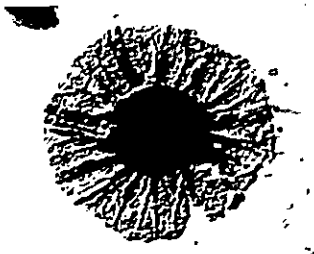

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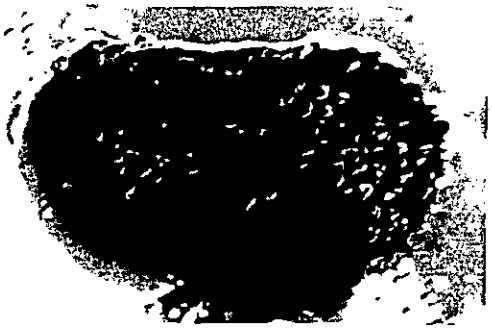

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HUGGIERO FELAY

## 4. BIOSTRATIGRAPHY: INTRODUCTION.

A large amount of information has been published regarding Lower Cretaceous palynofloras on a worldwide basis. However, several factors limit the use of this information for biostratigraphic purposes. In the case of miospores, well differentiated floral provinces existed during the Early Cretaceous (Brenner, 1976; Srivastava, 1978; Herngreen and Chlonova, 1981). The differentiation between the floras of the different provinces precludes precise worldwide correlations. Most of the palynological studies of Lower Cretaceous floras have been rather local and despite the number of studies that have been published, taxonomy and detailed characterizations of the floras of Africa and South America are still poorly understood. The main emphasis of these studies has been on the remarkable similarities existing in floras of eastern Brazil and western Africa, but there is little information on how these palynofloras correlate with assemblages of other regions. Since most of the palynological studies in Brazil and Africa have been done on continental sediments, these studies also lack correlation with ammonite zonations, defined in the stratotype sections of the Lower Cretaceous, especially those of the Aptian and Albian of Europe (Hancock, 1991).

Dinoflagellates, on the other hand, might be a better instrument to achieve correlations on a worldwide basis. Williams et al. (1990) reported that during the Early Cretaceous, the distribution of dinoflagellates was also affected by patterns of provincialism. However, these authors noticed similarities of the assemblages from offshore eastern Canada and those reported in the Aptian stratotype section and others in Europe (Davey and Verdier, 1974; Duxbury, 1983). Williams et al. (1990) also reported some similarities to tropical and subtropical dinoflagellate assemblages of Africa (Below, 1981 and 1982) and eastern United States (Habib, 1977). Bujak and Williams (1978) reported that despite the similarities, there are differences mainly related to paleoenvironmental factors (see discussion below). The similarities are also observed in Albian assemblages, characterized by the more widespread occurrences of tropical to subtropical dinoflagellate species in eastern offshore Canada. These authors concluded that these patterns arose from more uniform climatic conditions during the Albian or to more active ocean currents moving northwards during the Albian in the Atlantic region.

Unfortunately there are very few studies published on dinoflagellate cyst assemblages in the South American and Caribbean areas for the Lower Cretaceous. Riley and Fenton (1984) reported 14 species from the Aptian of the southeastern Gulf of

Mexico. Most of these species have been also reported from the European sections. Habib (1972) reported 5 dinoflagellate species in Albian sediments north of Surinam (northern South America). These species have also been described by Habib (1978 and 1979), as well as in the European sections; *Spinidinium echinoideum* , *Druggidium deflandrei, Chlamydophorella nyei, Coronifera oceanica* and *Palaeohystrichophora infusorioides.* In the Maracaibo Basin, Paredes de Ramos and Fasola (in Moldovanyi and Pinto Ausó, 1987) reported 27 species of dinoflagellates in an interval dated as Hauterivian?-Cenomanian in well ALT-19X. Species such as *Oligosphaeridium complex, Odontochitina costata, Exochospheridium bifidum, Aptea polymorpha, Coronifera oceanica, Florentinia mantelli* and *Dinopterygium tuberculatum* have been described from Lower Cretaceous sections of Europe. Arai and Coimbra (1990) and Arai (1992) have reported dinoflagellate assemblages associated with the rifting stages of the southern Atlantic ocean in Brazilian basins. In general, there is not major biostratigraphical information and the species that were reported in these studies are either long ranging or show geographically widespread distribution during the Early Cretaceous. Prössl (1992) recently presented preliminary results of dinoflagellate assemblages from the Middle Albian of Colombia, reporting assemblages that might be of Middle Aptian to Turonian–Coniacian, but did not present detailed evidence on the distribution of the assemblages.

### 4.1 Miospore biostratigraphy: South America and Africa.

Very relevant to this the study is the zonation proposed by Muller et al. (1987) for northern South America. A total of three superzones and four palynological zones were defined for the Aptian and Albian of this area by these authors (Figure 9). Superzones II through IV encompass the Aptian–Cenomanian. Superzone II includes the *Tucanopollis crisopolensis-Afropollis* zone which has not been reported in northern South America yet and their age assignment (Early to Middle Aptian) is based mainly on the information outlined by Regali et al. (1974a). The Aptian *Tucanopollis crisopolensis-Afropollis* concurrent-range zone, is defined by the first stratigraphic occurrence of pollen of *Afropollis* at the base and the co-occurrence of pollen of this genus with pollen of *Reyrea polymorpha* and *Tucanipollis crisopolensis.* The latter species became extinct at the top of the zone.

Superzone III encompasses the Middle Aptian–Lower Albian of northern South America and includes the "*Tricolpites*"-*Exesipollenites tumulus* and the *Elateropollenites*

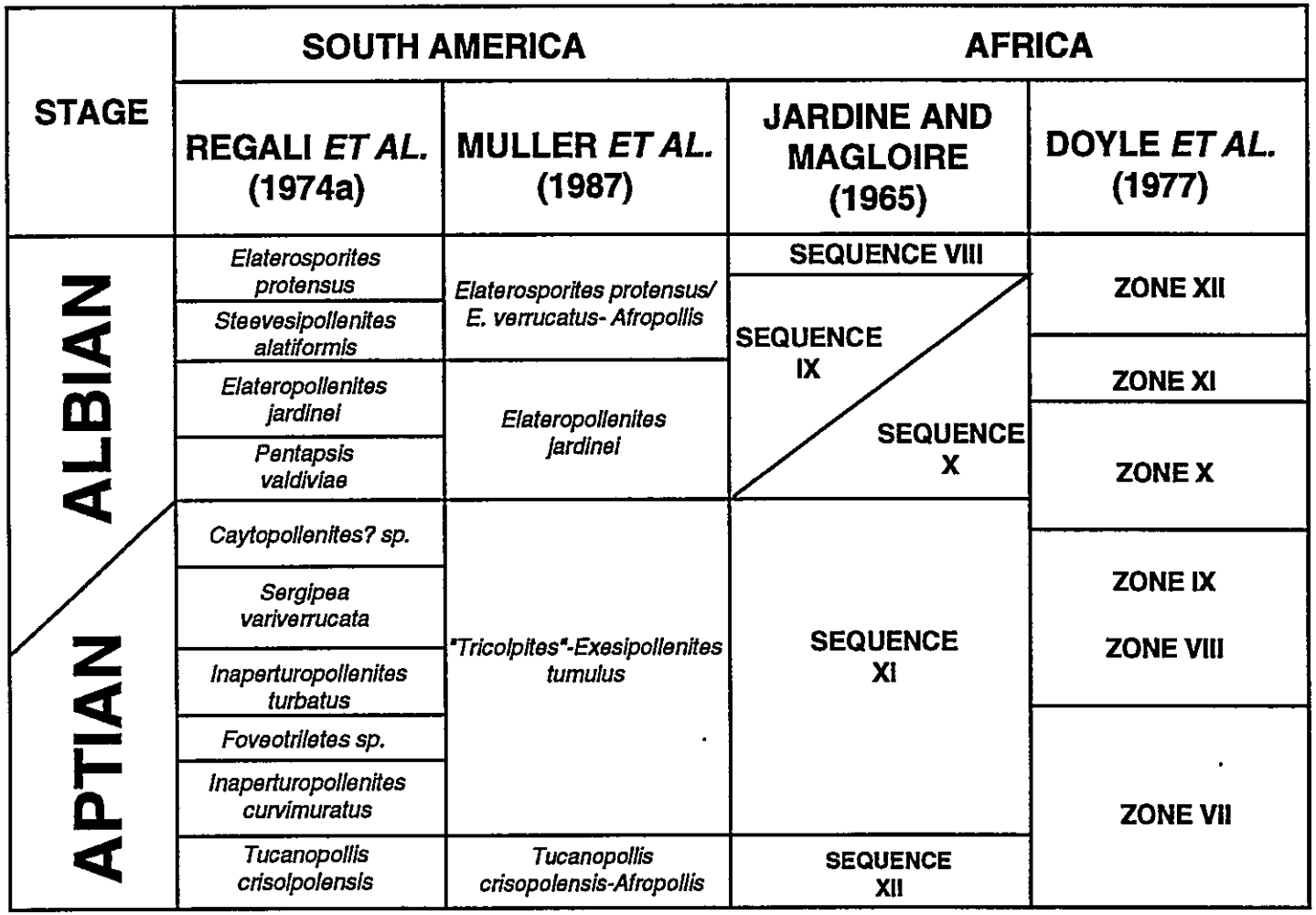



Figure 9. Aptian–Albian miospore zonations for Brazil (Regali et al., 1974a) and northern South America (Muller et al., 1987). Correlation with palynological zonations proposed for Africa (Jardiné and Magloire, 1965 and Doyle et al, 1977) as proposed by Muller et al. (1987) (see text for discussion).

*jardinei* zones. The former is defined as a concurrent-range zone, characterized by the first occurrence of tricolpate angiosperm pollen at the base and by the first occurrence of elater-bearing palynomorphs and the last stratigraphic occurrence of *Exesipollenites tumulus* at the top. Unlike the first of previous zones, the "*Tricolpites*"-*Exesipollenites tumulus zone* has been reported from eastern Venezuela and Guyana (Belsky et al., 1974). Pollen of the genus *Equisetosporites* and a diverse angiosperm pollen suite were reported in this zone by Belsky et al. (1974). Based on the absence of the elater-bearing palynomorphs, the zone is considered to be Middle Aptian to Upper Aptian–Lower Albian. On the other hand, the *Elateropollenites jardinei* concurrent-range zone is characterized by the abundance and diversification of elater-bearing palynomorphs of the genera *Elaterosporites, Elateropollenites* and *Elateroplicites*, along with *Pentapsis valdiviae*, and angiosperm pollen of *Cretacaeiporites* and *Striopollenites dubius*. At the top of the zone, several species became extinct, such as *Reyrea polymorpha, Pentapsis valdiviae*, and *Triporoletes reticulatus*. Fern spores and pollen of *Equisetosporites* are reported to be present in abundance in assemblages included in this zone, that is considered to be Albian. Hedberg (1976, p. 56) pointed out that a concurrent-range zone must be named "from two or more of the taxons which characterize the zone by their concurrence". Therefore the zone might be redefined as a range zone, named after *Elateropollenites jardinei,* a species restricted to this zone, or be renamed including other species whose cooccurrences characterize this zone (*Pentapsis valdiviae* and *Elateropollenites jardinei*).

Superzone IV encompass the top of the Albian and the Cenomanian. The *Elaterosporites protensus/E. verrucatus-Afropollis* concurrent range zone (Albian to lower Cenomanian) is characterized by the co-occurrences of the nominative species, common presence of pollen of *Equisetosporites*, diversification of elater-bearing palynomorphs along with the first occurrence of triporate and tricolporate angiosperm pollen (of the genus *Psilatricolporites*) at the base and the last stratigraphic occurrence of pollen of *Afropollis* at the top. This zone has been reported, according to Muller et al. (1987), in Guyana (Belsky et al., 1974) and northeastern Brazil (pollen zone II of Herngreen, 1975b).

Regali et al. (1974a) defined a total of 3 palynological superzones and 11 palynological zones (based on miospore occurrences) in sediments of the "Alagoas" (Aptian–Lower Albian) and the Albian of Brazil (Figure 9). Seven interval zones were defined by Regali et al. (1974a) for the Aptian: *Tucanopollis crisopolensis, I.*

*curvimuratus, Foveotriletes* sp., *Inaperturopollenites turbatus, Segipea variverrucata* and *Caytonipollenites*? sp. 1. These interval zones are defined by the last occurrence of the nominative species of the underlying zone at the base and the last occurrence of the nominative species of the zone at the top. The microfloras are characterized by the presence of a diverse suite of fern and other pteridophyte spores and abundant pollen of the genus *Inaperturopollenites,* and of *Afropollis*. The paleoenvironment ranged from terrestrial at the base to the first evidences of marine incursions towards the top (*Caytonipollenites*? sp. 1 zone).

A total of four interval zones (defined as previously discussed) were defined within this superzone; the *Pentapsis valdiviae, Elateropollenites jardinei, Steevesipollenites alatiformis* and *Elaterosporites protensus* zones. The first occurrences of the elater-bearing palynomorphs are reported within the *Elateropollenites jardinei* zone in the Lower Albian. In general, assemblages are still dominated by fern and pteridophyte spores, with occurrences of pollen of *Afropollis, Corollina* and *Elaterosporites*. The paleoenvironments of deposition were in general marine to transitional.

The uppermost part of the Upper Albian is included within the *Elaterosporites protensus* interval zone. The miospore floras are characterized by the diversification of pollen of *Equisetosporites* and of elater-bearing species belonging to the genera *Elaterosporites, Elaterocolpites, Elateroplicites, Sofrepites* and *Galeacornea*. Pollen of *Corollina* and other gymnosperms are the dominant elements, whereas those of angiosperms (for example of the genus *Hexaporotricolpites*) are rare. The diversification of angiosperm pollen is recorded during the Cenomanian–Turonian. The paleoenvironments of deposition were rather similar to those reported for the Aptian–Lower Albian. A more recent zonation for northeastern Brazil was proposed by Regali in 1989. According to Schrank (1992), the first occurrence of *Tucanopollis crisopolensis* is reported in the Upper Barremian to Lower Aptian from Brazil, along with the first occurrence of pollen of *Afropollis*, tricolporate and other monocolpate angiosperm pollen of the genera *Brenneripollis* and *Stellatopollis*.

Herngreen (1975b) defined two palynological zones for the Albian–lower Cenomanian of northeastern Brazil. The *Reyrea polymorphus* (zone I) local range zone was considered to be Lower to Middle Albian by Herngreen (1975b) and is defined on the basis of occurrence of the nominative species (restricted to this interval in this area).

Assemblages of this zone are characterized by the abundant occurrence of fern spores, pollen of *Corollina* (less than 30 µm diameter) and pollen of angiosperms (*Afropollis*, *Cretacaeiporites* and tricolpates). Herngreen (1975b) further subdivided this zone into the *Elaterosporites protensus-Ephedripites irregularis* and *Elaterosporites protensus-E. verrucatus* assemblage subzones, based on the co-occurrences of the eponymous species. Herngreen (1975b) defined the *Elaterocolpites-Elateroplicites-Sofrepites* assemblage zone (zone II) by the co-occurrences of *Elaterocolpites castelaini*, *Elateroplicites africaensis* and *Sofrepites legouxiae*, along with pollen of *Corollina* (exclusively species larger than 30 µm diameter). The main characteristic of this zone is the significant diversification of the elater-bearing palynomorphs and porate angiosperm pollen, that according to Herngreen (1975) took place during the Late Albian to early Cenomanian. Herngreen (1975) subdivided this zone into the *Corollina spinosus* range subzone (characterized by the occurrence of this species and the replacement of pollen of *Corollina* with diameter less than 30 µm by larger species) and the *Corollina brasiliensis* assemblage subzone (characterized by the predominance of the nominative species and other elater-bearing palynomorphs).

Jardiné and Magloire (1965) proposed a total of five "sequences" for the Aptian–Barremian to Albian–Cenomanian. These sequences were defined on the relative frequencies of different species or groups of species, as well as different bioevents (first and last occurrence of taxa). These authors also pointed out that limits of these sequences were very imprecise and rarely coincided with stratigraphic boundaries defined based on lithostratigraphic or biostratigraphic criteria. The definitions of their zones or sequences, in view of the criteria outlined by Hedberg (1976) are rather loose. For example, their "Sequence" XII, a biozone that might be considered as acme zone since it is characterized by significant abundances of pollen of the genus *Araucariacites* and relatively lower frequencies of pollen of *Corollina*, encompasses the Barremian–Aptian. The Upper Aptian–Lower Albian ("Sequence" XI) is characterized by high abundance of pollen of *Corollina* (30-60%) and *Equisetosporites* (5-20%) and persistent occurrences of spores of the genus *Cicatricosisporites*.

"Sequence" X of the Upper Albian is characterized by the increase of pollen of *Corollina* and the first occurrence of *Striopollenites dubius*, as well as by a diverse suite of pteridophyte spores with verrucate-tuberculate ornamentation. However, there is no information on at what level *Striopollenites dubius* occurs for the first time or to what percentages of pollen of *Corollina* are present. "Sequence" IX (also of the Upper Albian)

is characterized by a drastic decrease in abudance of pollen of *Corollina*, increasing representation of trilete spores and tricolporate angiosperm pollen, and the first occurrence of pollen of *Galeacornea*. "Sequence" VIII (Upper Albian to Cenomanian) is characterized by the first occurrence of triporate angiosperm pollen, as well as of several species of the elater-bearing palynomorphs.

The zonal scheme proposed by Doyle et al. (1977) for Gabon has also been widely used for inter-regional correlation between Africa and South America. The first occurrences of angiosperm pollen (tricolpates, monocolpates and *Afropollis*) are reported from zone C VII (Lower Aptian). This has been subsequently revised by Penny (1988) to be as early as Upper Barremian. Doyle et al. (1982) reported that only operculate and zonosulcate species of *Afropollis* occur in zone C VII. The first stratigraphic appearance of elater bearing species is placed within the Lower Albian (zones C X and C XI) and, according to Doyle et al. (1982), coinciding with peaks of abundance of pollen of *Afropollis jardinus* in Africa and Brazil.

Muller et al. (1987) correlated their zonal scheme with the other miospore zonations referred to above. Their correlation is shown in Figure 9. It is evident that the key point of correlation of these zonal schemes seems to be centered around the first stratigraphic occurrence of the elater-bearing palynomorphs, which all the authors placed close to the Aptian–Albian boundary. However Herngreen and Dueñas Jiménez (1990) concluded that the elater-bearing palynomorphs appeared during the Middle to Late Albian of the Africa-South America Province.

The zonation proposed by Herngreen (1975b) for eastern Brazil lacked age assignment constrained by foraminifera or ammonites. The complete replacement of species of *Corollina* smaller than 30 µm by larger forms might also be a taphonomic artifact related to paleoenvironmental and depositional factors. However, the observed diversification of elater-bearing spores and angiosperm porate pollen is well documented.

Correlation with the so-called "sequences" of Jardiné and Magloire (1965) is considered here be very tentative and speculative, since these sequences are loosely defined and there are no key index species. Percentages of taxa might be the result of paleoecological, depositional and/or taphonomic factors, which are unlikely to be the same in widely separated regions. In their definition of the sequences, Jardiné and Magloire (1965) referred to the occurrence of the species of planktonic foraminifera

*Hedbergella washitensis*, which they considered to be indicative of the Middle to Upper Albian in Senegal. However, Regali et al. (1974a) found that this species is characteristic of the Albian–Cenomanian of Brazil. As discussed by Penny (1988), age assignment of the zones C VII and C VIII of Doyle et al. (1977) needs further revision in light of the new evidence of the evolution of angiosperm pollen during the Early Cretaceous.

Correlation between the zonational schemes proposed by Regali et al. (1974a) and Muller et al. (1987) seems to be more solid. However, the *Tucanopollis crisopolensis-Afropollis* concurrent-range zone of Muller et al. (1987) of the Lower to Middle Aptian is yet to be reported in northern South America. *Inaperturopollenites* is not observed in the present assemblages. Its absence presents a limitation on using these zonal schemes for the assemblages of the Maracaibo Basin. The zonation proposed by Muller et al. (1987) only has been correlated to pelagic foraminifera for the Cenozoic section, whereas its correlation for the Cretaceous has yet to be defined. Regali et al. (1974a) presented a correlation of their palynological zones to the planktonic foraminifera zonation of Brazil. However, most of the "Alagoas" (Aptian and part of the Albian) has not been correlated and the Albian zones have been correlated to the zone of *Hedbergella washitensis* (Albian–Cenomanian).

**4.2 Lower Cretaceous dinoflagellate cyst biostratigraphy.**

No Lower Cretaceous dinoflagellate cyst zonation has been proposed for the the Caribbean area or for northern South America. Figure 10 shows the different zonations that include the Aptian and Albian and that have been proposed for eastern offshore Canada and the northwestern Atlantic Tethyan. The similarities of European dinoflagellate assemblages and those reported in eastern offshore Canada (Williams, 1975; Bujak and Williams, 1978) and in the northwestern Atlantic (Habib, 1977; Habib and Drugg, 1987) are considered of particular interest for this study.

Williams (1975) and Bujak and Williams (1978) defined a total of five palynomorph zones (involving miospores and dinoflagellate cysts) for the Lower Cretaceous of offshore eastern Canada. The *Phoberocysta neocomica* assemblage zone (Berriasian to Valanginian) is characterized by rare occurrences of dinoflagellates. The species *Phoberocysta neocomica* and *Biorbifera johnewingi* are used to define this interval. These authors reported that dinoflagellates became widespread in the Lower Cretaceous *Ctenidodinium elegantulum* assemblage zone (Hauterivian), that is defined by

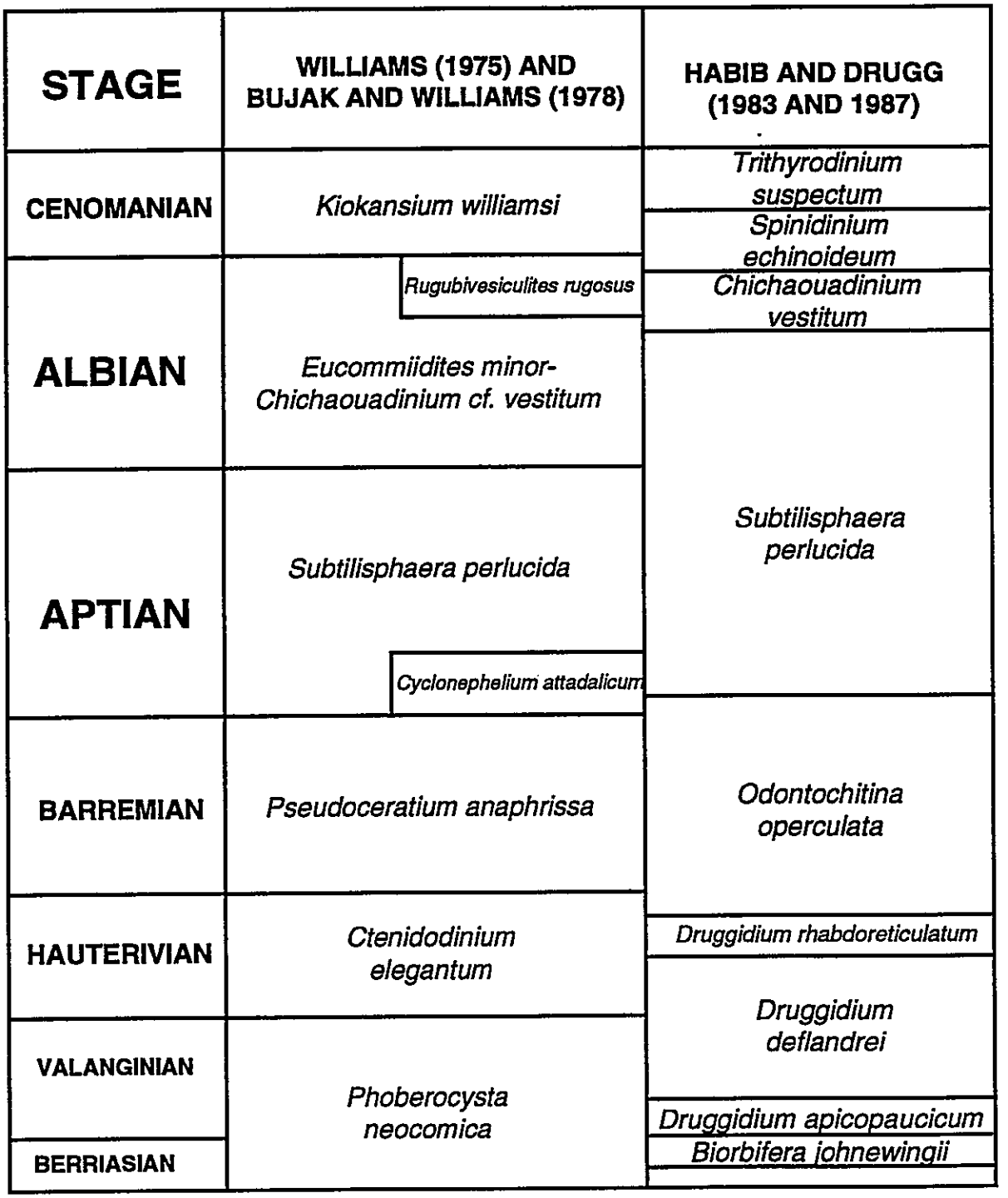



Figure 10. Lower Cretaceous dinoflagellate zonations for eastern offshore Canada (Williams, 1975 and Bujak and Williams, 1978) and for the northwestern Atlantic Ocean (Habib and Drugg, 1983 and 1987).

the occurrence of the nominative species and the first stratigraphic appearance of *Gardodinium trabeculosum, Kleithriasphaeridium fasciatum* and *Subtilisphaera pirnaensis*. The *Pseudoceratium anaphrissa* peak zone (Barremian) is also characterized by the association of *Muderongia perforata, M. simplex, Odontochitina operculata* and *Pseudoceratium pelliferum.*

The dinoflagellate diversity of the *Subtilisphaera perlucida* assemblage zone (Aptian) is lower than in the *Ctenidodinium elegantulum* and *Pseudoceratium anaphrissa* zones. As Bujak and Williams (1978) pointed out, there are similarities of the assemblages of this zone offshore eastern Canada and the assemblages reported in the European sections (23 common species). However, genera such as *Gonyaulacysta* and *Lithodinia,* that are common in the European sections, are rarely observed in eastern Canada where the assemblages are dominated by species of *Circulodinium* and *Oligosphaeridium*. These differences reported by Bujak and Davies (1978) might be related to paleoenvironments. The sporadic development of the *Circulodinium attadalicum* peak subzone (Lower? Aptian) verifies the paleo-environmental influence in the distribution of the assemblages in the area.

The *Eucommiidites minor-Chichaouadinium* sp. cf. *C. vestitum* assemblage zone (Albian) is the most widespread of all the Lower Cretaceous zones and shows the more diverse dinoflagellate assemblages, as well as the occurrences of pollen of *Eucommiidites minor*. Species such as *Litosphaeridium siphoniphorum, Chichaouadinium* sp. cf. *C. vestitum, Paleohystrichophora infusorioides* and *Xenascus ceratioides* are common. Below (1984) used the first stratigraphic appearance of *Xenascus ceratioides* as the base of the Cenomanian for assemblages offshore northwest Africa but Williams and Bujak (1985) reported that the range of this species begins in the Middle Albian.

Habib (1977) and Habib and Drugg (1983 and 1987) defined eight palynological zones for the Lower Cretaceous in offshore sections in the western north Atlantic, with age determinations based on magnetostratigraphy. These authors also correlated the assemblages of these biozones to the ammonite zonation of the Lower Cretaceous stratotypes. The Upper Berriasian *Biorbifera johnewingii* interval zone is defined by the top of the nominative species at the base and the first occurrence of *Druggidium apicopaucicum* at the top. The *Druggidium apicopaucicum* interval zone (Lower to Middle Valanginian) is defined based on the lower range of the nominative species at the base and the first stratigraphic appearance of *Druggidium deflandrei* at the top. The

*Druggidium deflandrei* lineage zone (Upper Valanginian to Upper? Hauterivian) is characterized by the the first occurrence of the nominative species at the base and by the first appearance of *Druggidium rhabdoreticulatum* at the top. The *Druggidium rhabdoreticulatum* interval zone (Hauterivian to Barremian) is characterized by the lower range of nominative species at the base and the first appearance of *Odontochitina operculata* at the top.

The Upper Hauterivian to Lower Aptian assemblages are included within the *Odontochitina operculata* interval zone. The base of the zone is defined by the first appearance of the nominative species at the base and the first occurrence of *Phoberocysta neocomica* at the top. As previously discussed, Williams (1975) reported that the last occurrence of *Phoberocysta neocomica* in offshore eastern Canada is located within the Hauterivian. Habib and Drugg (1988) pointed out that the last occurrence of *Druggidium apicopaucicum* is a reliable indicator of the Hauterivian–Barremian boundary, at which *Coronifera oceanica* is observed for the first time in the western North Atlantic.

The *Subtilisphaera perlucida* interval zone (Aptian to Middle Albian) is defined at the base by the lower range of the nominative species at the base and the first occurrence of *Chichaouadinium vestitum* at the top. The last occurrence of *Druggidium deflandrei* is placed at the Aptian–Albian boundary. The *Chichaouadinium vestitum* zone (Middle to Upper Albian) was defined as an interval zone by Habib and Drugg (1987). The *Spinidinium echinoideum* interval zone encompasses the uppermost Albian (Vraconian) to Cenomanian and it is defined by the lower range of the nominative species at the base and the first occurrence of *Trithyrodinium suspectum.* The *Trithyrodinium suspectum* interval zone (Cenomanian) is defined at the base by the first occurrence of the nominative species at the base and the last appearance of *Litosphaeridium siphoniphorum glabrum.*

Williams (1978) noticed some discrepancies between the inferred ranges of dinoflagellates in eastern Canada and those reported for the European sections. For example, *Phoberocysta neocomica* has been reported to range from the Berriasian into the Aptian in Europe, whereas in eastern Canada this species terminates in the Hauterivian (local range). Habib (1977) and Habib and Drugg (1987) pointed out that the range of *P. neocomica* in the Blake Bahamas Plateau extends into the Lower Aptian, unlike the case reported by Williams for eastern Canada. Duxbury (1983) pointed out that this species range also terminates in the Lower Aptian of Europe. Riley and Fenton

(1984) reported the occurrence of this species in Aptian sediments in the southeastern area of the Gulf of Mexico. Differences in the range of this species can be the result of paleoenvironmental controls. As noted by Williams and Bujak (1985), the assemblages reported by Habib (1977) and Habib and Drugg (1983 and 1987) are related to deep-water environments whereas, as already noted, the conditions of deposition in eastern Canada were shallower. Duxbury (1983) noted that the distribution of *P. neocomica* in Europe is limited by paleoenvironmental factors. Williams et al. (1993) synthesized the range of this species between the Lower Valanginian to the Lower Aptian. On the other hand, Helby et al. (1987) observed that this species is present in sediments of the Valanginian to Hauterivian-Barremian of Australia.

These paleoenvironmental differences that affect the composition of the assemblages of the Aptian–Albian of eastern Canada, in comparison to those reported from the European sections, should also be considered of importance for the purposes of this study. The shallow carbonate platform developed in the Maracaibo Basin obviously represents different conditions of deposition to those prevailing in the more open ocean basins of France. A preliminary comparison of the assemblages observed in this study, reveal that, as reported for offshore eastern Canada, common European species of the genus *Gonyaulacysta* are absent from the assemblages of the Maracaibo Basin. Bujak and Williams (1978) reported the common occurrence and predominance of several species of *Circulodinium/Cyclonephelium* and *Oligosphaeridium* (e.g. *Circulodinium distinctum* subsp. *distinctum* and *Oligosphaeridium albertense*) that also occur in the Maracaibo Basin. Bujak and Williams (1978) reported a total of 70 species in the Albian *Eucommiidites minor-Chichaouadinium* sp. cf. *C. vestitum* zone. This is significantly more than the total of dinoflagellate cysts species richness reported in this study (50), a clear indication of the more restricted and perhaps stressed paleoenvironmental conditions in the Maracaibo Basin (see discussion in the following chapter). The zonation proposed by Habib (1977) and Habib and Drugg (1983 and 1987) are based on assemblages of deep-water or more open oceanic settings, which differ in many respects from those of the shallow water carbonate platform of the Maracaibo Basin during the Lower Cretaceous.

Helby et al. (1987) proposed a miospore/dinoflagellate zonation for the Mesozoic of Australia A total of three superzones and 20 zones based on dinoflagellates were defined by these authors. This very detailed zonation will not be discussed in this study. These authors pointed out that variations in the diversity and characteristics of the

assemblages in different areas of Australia were related to paleoenvironmental factors in the intracratonic basins and to the onset of sea-floor spreading in the Albian. A preliminary comparison of the dinoflagellate assemblages observed in this study (see previous chapter on Systematic Palynology) and those reported from Australia (Helby et al., 1987) shows few similarities.

## 4.3 Results.

This study encompasses the Aptian–Albian Cogollo Group (Apón, Lisure and Maraca formations) and the Aguardiente Formation, which outcrops in the southeastern margin of the Basin, along the Venezuelan Andes. Figure 11 shows the stratigraphic nomenclature and the location of the studied sections in the Maracaibo Basin.

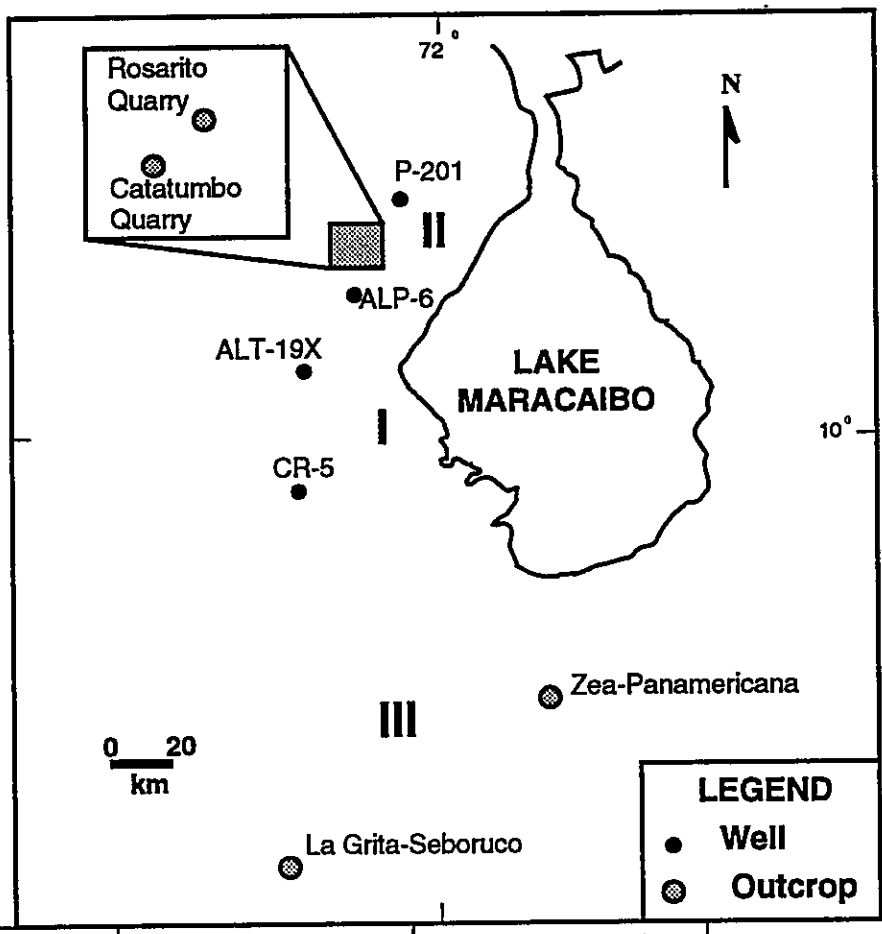
Figures 12 through 18 show the occurrence and distribution of miospores and phytoplankton species in the sections investigated in this study. The biozonal scheme will be discussed in detail after outlining the main results found in each of the sections.

### 4.3.1 Zea-Panamericana outcrop section

A total of 35 samples collected from an outcrop of the Aguardiente Formation yielded palynomorphs. These are mainly dominated by terrestrial miospores. Figure 12 shows the distribution chart of the identified palynomorphs in this outcrop section.

Several miospore species show widespread occurrences throughout the sampled interval; *Deltoidospora australis, Deltoidospora punctata, Dictyophyllidites grandis, Dictyophyllistes harrisii, Araucariacites australis, Corollina brasiliensis, Corollina torosa, Corollina kieseri, Cicatricosisporites hallei, Cicatricosisporites australiensis, Equisetosporites multicostatus, Concavissimisporites miniverrucatus, Ischyosporites variegatus, Cycadopites carpentieri, Callialasporites dampieri, Afropollis zonatus* and *Exesipollenites crassimarginatus. Reyrea polymorpha* has been reported in the Aptian–Albian of northern South America and *Afropollis zonatus* has been reported from the Lower–Middle Aptian of Africa (zone C VII) by Doyle et al. (1982).

Dinoflagellate cyst species occur throughout the sampled interval as well, in




| STAGE | MARACAIBO PLATFORM (I) | | | MACHIQUES TROUGH (II) | | | SOUTHWEST ANDES (III) | |
|---|---|---|---|---|---|---|---|---|
| ALBIAN | COGOLLO | MARACA | | COGOLLO | MARACA | | MARACA | |
| | | LISURE | | | LISURE | | AGUARDIENTE | |
| APTIAN | | APON | PICHE | | APON | PICHE | | |
| | | | GUAIMAROS | | | MACHIQUES | APON | GUAIMAROS |
| | | | TIBU | | | TIBU | | TIBU |

Figure 11. Stratigraphic nomenclature of the Aptian–Albian of the Maracaibo Basin and location of the studied sections.

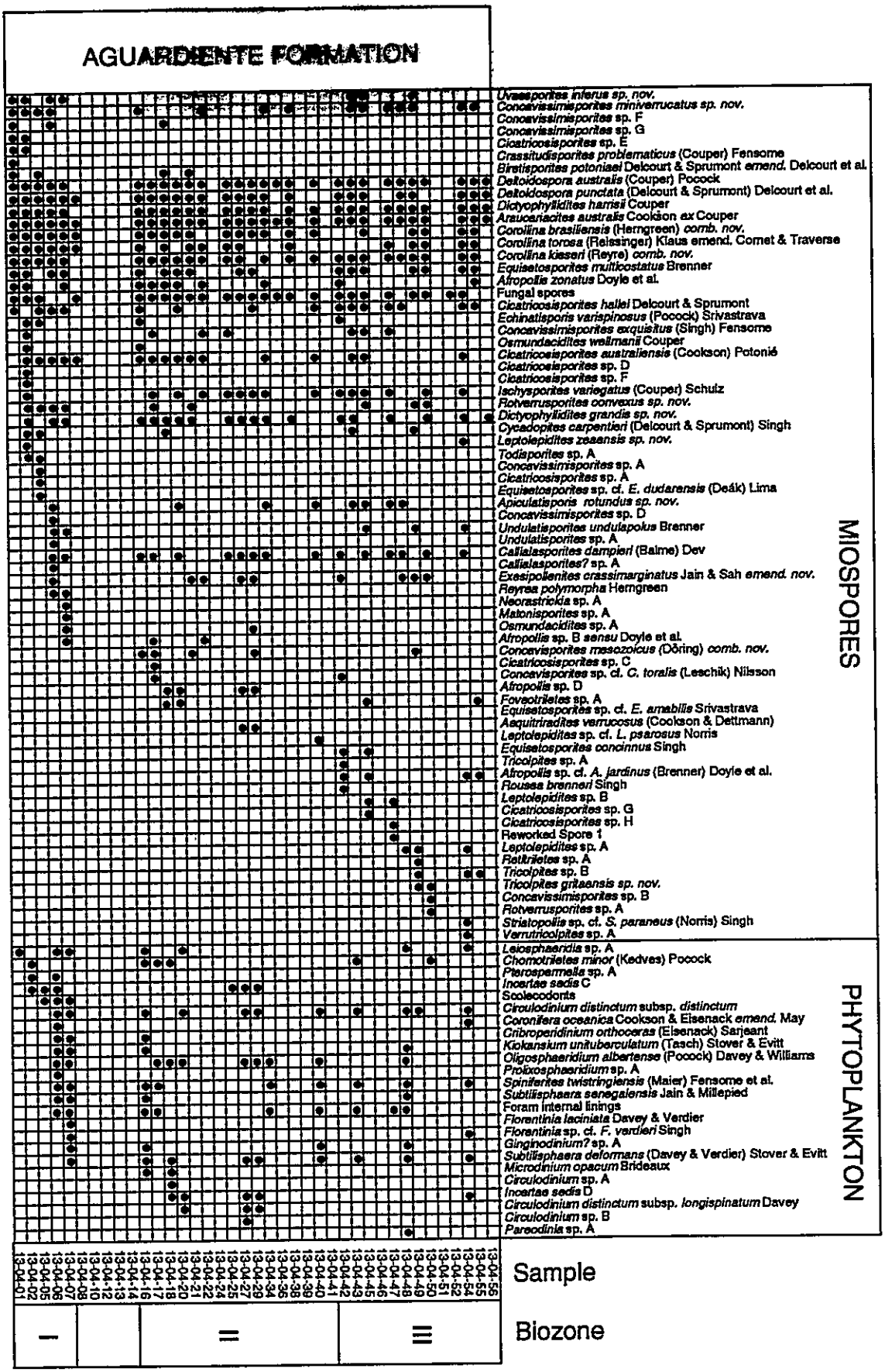



Figure 12. Distribution chart of miospores and phytoplankton observed in the Zea-Panamericana oucrop section.

lower abundances. Species that are relatively consistent in the sampled interval in the Zea-Panamericana section; *Circulodinium distinctum*, *Oligosphaeridium albertense*, *Spiniferites twistringiensis* and *Subtilisphaera deformans*.

Some miospore species show restricted occurrences in the sampled interval and have their occurrences within interval including samples 13-04-07 to 13-04-01. *Reyrea polymorpha*, *Concavissimisporites* sp. A, *Concavissimisporites* sp. D, *Concavissimisporites* sp. F, *Concavissimisporites* sp. G, *Cicatricosisporites* sp. A, *Cicatricosisporites* sp. B, *Cicatricosisporites* sp. D, *Cicatricosisporites* sp. E, *Cicatricosisporites* sp. F, *Crassitudisporites problematicus*, *Equisetosporites* sp. cf. *E. dudaresis*, *Todisporites* sp. A, *Undulatisporites* sp. A, *Callialasporites*? sp. A, *Neorastrickia* sp. A and *Osmundacidites* sp. A. The assemblage of this interval is characterized by the dominance of pollen of *Corollina* and *Araucariacites*, as well as trilete fern spores. Marine phytoplankton is rare at the base of this interval, but becomes relatively abundant in samples 13-04-06 and 13-04-07. Very few dinoflagellate species are restricted to this interval; *Prolixosphaeridium* sp. A and *Florentinia laciniata*. *Pterospermella australiensis* is only observed in this interval.

The interval including samples 13-04-14 to 13-04-08 is almost completely devoid of palynomorph. However, the interval including samples 13-04-41 to 13-04-16 is characterized by assemblages dominated by miospores, with conspicuous occurrences of dinoflagellate species. Miospore species restricted to this interval are *Aequitriradites verrucosus*, *Cicatricosisporites* sp. C, *Afropollis* sp. D, *Leptolepidites* sp. cf. *L. psarosus* and *Equisetosporites* sp. cf. *E. amabilis*. *Circulodinium* sp. A, *Circulodinium* sp. B and *Circulodinium distinctum* subsp. *longispinatum* are the only dinoflagellate species restricted to this interval. *Biretisporites potoniaei* is restricted to the basal interval (13-04-07 to 13-04-01) and to this interval.

An important change in the composition of the miospore assemblages is noticed in the interval including samples 13-04-56 to 13-04-42. Tricolpate angiosperm pollen is restricted to this interval; *Rousea brenneri*, *Striatopollis* sp. cf. *S. paraneus*, *Tricolpites gritaensis*, *Tricolpites* sp. A, *Tricolpites* sp. B and *Verrutricolpites* sp. A. Muller et al. (1987) pointed out that the first occurrence of tricolpate pollen in northern South America is localized within the "*Tricolpites*"-*Exesipollenites tumulus* zone (Aptian to Lower Albian?). *Afropollis* sp. cf. *A. jardinus* also has its first occurrence in sample 13-04-42. *A. jardinus* has been reported from the Upper Aptian–Albian of Africa by Doyle et al.

(1982). Other species restricted to this interval are *Equisetosporites concinnus*, *Leptolepidites zeaensis*, *Leptolepidites* sp. A, *Leptolepidites* sp. B, *Cicatricosisporites* sp. G, *Cicatricosisporites* sp. H, *Foveotriletes* sp. A, *Concavissimisporites* sp. B and *Rotverrusporites* sp. A. The only dinoflagellate cyst restricted to this interval is *Pareodinia* sp. A. Species such as *Uvaesporites inferus* shows occurrences only in the basal and top intervals, perhaps an indication of paleoenvironmental controls, that will the subject of discussion in the following chapter.

### 4.3.2 La Grita outcrop section.

Figure 13 shows the distribution of miospore and phytoplankton assemblages in 10 samples collected from the outcrop section of the Aguardiente Formation nearby the city of La Grita in the Venezuelan Andes.

The assemblages observed in this section are rather similar to those reported in the top interval of the Zea-Panamericana outcrop section. Assemblages of the interval including samples 09-04-07 to 09-04-04 are characterized by the occurrence of tricolpate angiosperm pollen (the same species reported for Zea-Panamericana outcrop section, except for *Verrutricolpites* sp. A) along with pollen of *Afropollis* sp. cf. *A. jardinus*. Other species restricted to this interval are *Concavissimisporites* sp. A, *Concavissimisporites* sp. B, *Concavissimisporites* sp. F, *Baculatisporistes* sp. cf. *B. comaumensis*, *Cicatricosisporites* sp. A, *Cicatricosisporites* sp. C, *Cicatricosisporites australiensis*, *Crassitudisporites problematicus* (also observed in the basal interval of Zea-Panamericana outcrop section), *Distaltriangulisporites* sp. A, *Rotverrusporites convexus*, *Equisetosporites conccinus*, *Equisetosporites* sp. cf. *E. amabilis*, *Equisetosporites* sp. cf. *E. dudarensis*, *Afropollis zonatus* and *Reyrea polymorpha*. Other miospore species with widespread and common occurrences in the Zea-Panamericana assemblages are also observed in this section. Microplankton species that are associated with these miospore assemblages became more abundant towards the top of the interval and include *Subtilisphaera zawia* and *Protoellipsodinium* sp. A, as well as other species of dinoflagellates that show widespread occurrences in the other studied sections; *Odontochitina operculata* , *Spiniferites twistringiensis*, *Cribroperidinium orthoceras*, *Ginginodinium*? sp. A, *Oligosphaeridium albertense* and *Subtilisphaera senegalensis* .

At the top of the section, separated from this basal interval by a barren section

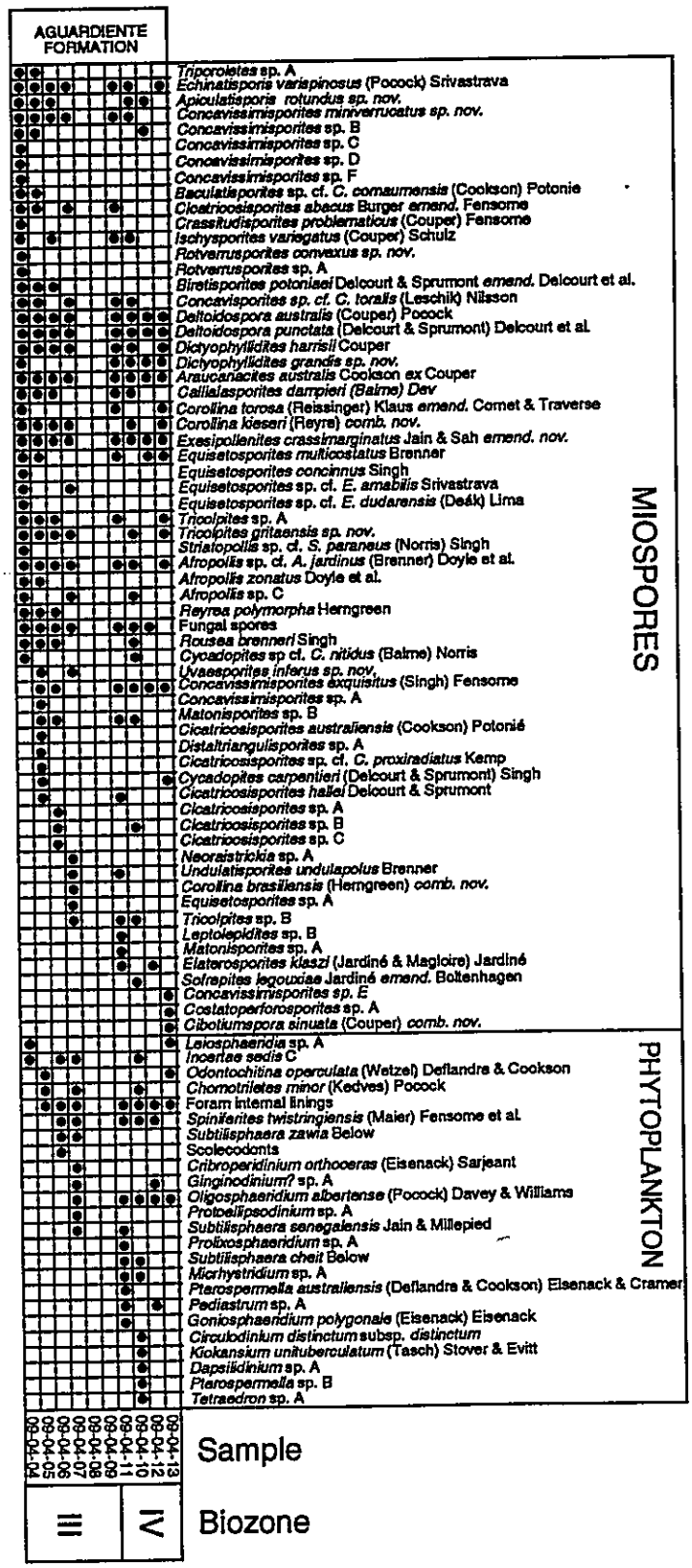



Figure 13. Distribution chart of miospores and phytoplankton observed in La Grita oucrop section.

(samples 09-04-09 and 09-04-08), a second microfloral association is observed in the interval including samples 09-04-13 to 09-04-11. This association is characterized by the occurrence of elater-bearing palynomorphs; *Elaterosporites klaszi* and *Sofrepites legouxiae*. Regali et al. (1974a) and Muller et al. (1987) have reported the first stratigraphic occurrences of these palynomorphs in the *Elateropollenites jardinei* zone (Albian of Brazil and northern South America). Other miospore species also restricted to this interval include *Leptolepidites* sp. B, *Matonisporites* sp. A (also observed in the basal interval of the Zea-Panamericana outcrop section), *Concavissimisporites* sp. D, *Concavissimisporites* sp. E, *Costatoperforosporites* sp. A and *Cibotiumspora sinuata* (Couper). The dinoflagellate species restricted to this interval include *Prolixosphaeridium* sp. A (also observed in the basal interval of the Zea-Panamericana outcrop section), *Subtilisphaera cheit* and *Polysphaeridium* sp. A, along with other species such as *Circulodinium distinctum, Kiokansium unituberculatum.* Acritarch species such as *Goniosphaeridium polygonale, Michrystridium* sp. A and *Pterospermella australiensis* are also present.

**4.3.3 Well CR-5 subsurface section.**

A total of 32 samples of the Aguardiente Formation yielded palynological assemblages. Figure 14 shows the distribution of the identified palynomorphs in the studied samples.

A basal interval (14891' to 14918") is distinguished by poorly preserved assemblages consisting mainly of dinoflagellate species such as *Oligosphaeridium albertense, Microdinium opacum, Oligosphaeridium complex, Coronifera oceanica, Kiokansium unituberculatum, Spiniferites twistringiensis* and *Circulodinium distinctum.* Miospores such as *Araucariacites australis, Afropollis zonatus* and *Corollina kieseri* are also present.

The overlying interval (14410' to 14786') is characterized by an increasing number of miospore species. Species such as *Contignisporites* sp. cf. *C. cooksonae, Concavissimisporites* sp. A, *Cicatricosisporites* sp. A, *Cicatricosisporites hallei, Cicatricosisporites* sp. I and *Cycadopites carpentieri* are restricted to this interval. A few dinoflagellate species are also restricted to this interval; *Dapsilidinium* sp. A and *Ginginodinium*? sp. A. The fresh water alga *Chomotriletes minor* is also observed to this interval.

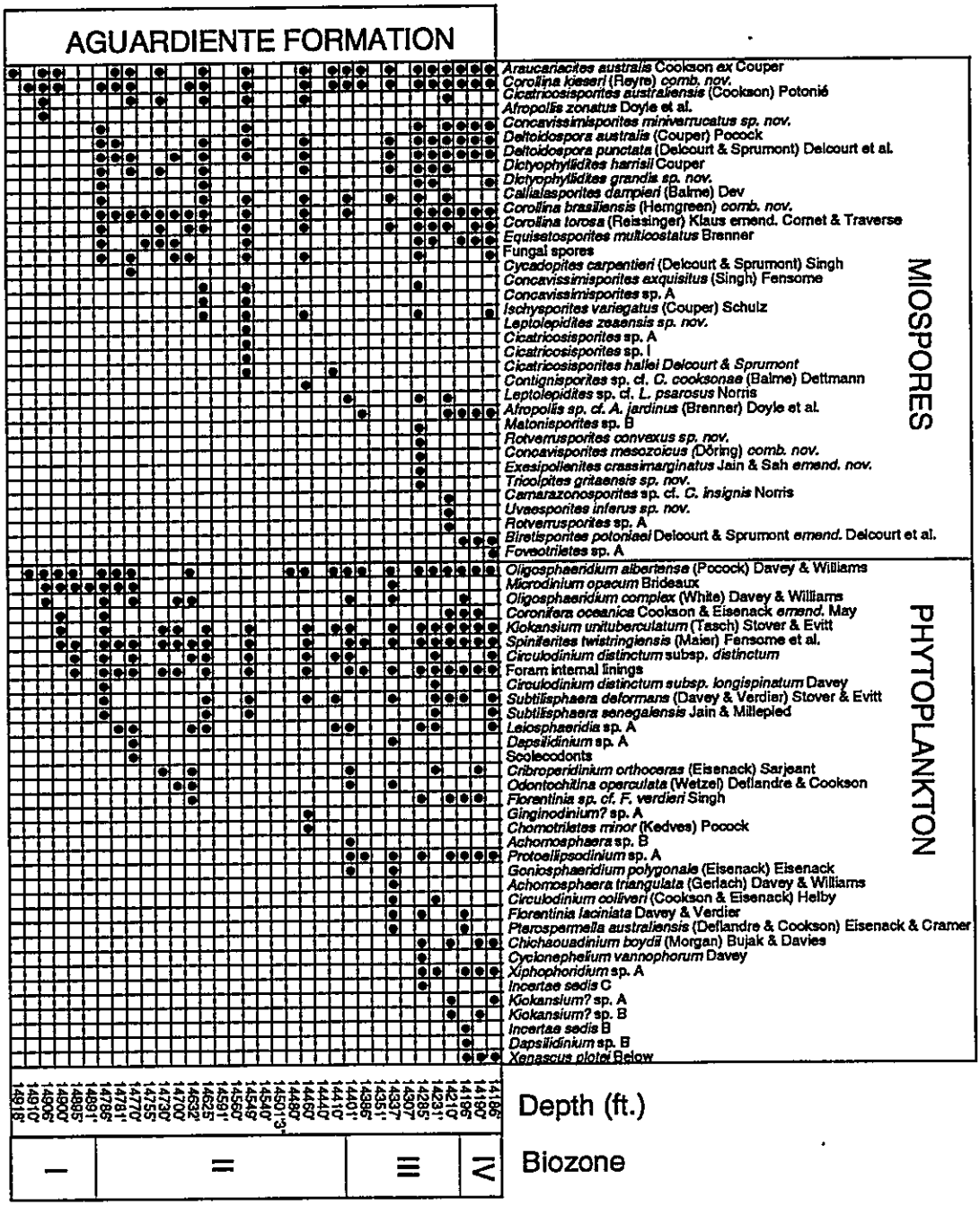



Figure 14. Distribution chart of miospores and phytoplankton observed in well CR-5.

A third microfloral association occurs in the interval 14307' and 14401' and is characterized by the occurrences of *Afropollis* sp. cf. *A. jardinus, Achomosphaera* sp. B, *Protoellipsodinium* sp. A, *Goniosphaeridium polygonale, Leptolepidites* sp. cf. *L. psarosus, Achomosphaera triangulata, Circulodinium colliveri, Florentinia laciniata* and *Pterospermella australiensis*, along with other species commonly occuring throughout the studied sections.

A fourth microfloral association is present at the top of the sampled section (14186' to 14285') and is characterized by the restricted occurrences of *Chichaouadinium boydii, Cyclonephelium vannophorum, Xiphophoridium* sp. A, *Matonisporites* sp. B, *Rotverrusporites convexus, Tricolpites gritaensis, Kiokansium*? sp. A, *Kiokansium*? sp. B, *Camarazonosporites* sp. cf. *C. insignis, Polysphaeridium* sp. B and *Xenascus plotei. Chichaouadinium boydii* (Morgan) has been reported from the Aptian to Cenomanian in Australia and Germany. *Xenascus plotei* has been reported from Upper Aptian–Albian to Cenomanian of northern Africa and North America (see chapter on Systematic Palynology).

### 4.3.4 Well ALT-19X subsurface section

Figure 15 shows the distribution of the identified palynomorphs in the 36 palyniferous samples in the cored section of well ALT-19X, that included sections of the Apón (17578' to 17803'3"), Lisure (17230' to 17555') and Maraca (17111' to 17196') formations. Samples of the latter are completely devoid of palynomorphs.

As in the case of well CR-5, the basal interval (17679' 3" to 17802') is characterized by poorly preserved palynological assemblages that consist mainly of species of dinoflagellate cysts such as *Circulodinium distinctum* subsp. *distinctum, Circulodinium distinctum* subsp. *longispinatum, Cribroberidinium orthoceras, Odontochitina operculata, Oligosphaeridium complex, Protoellipsodinium* sp. A, *Spiniferites twistriengensis, Incertae sedis* B, *Oligosphaeridium albertense* and *Microdinium opacum, Leiosphaerdia* sp. A and *Pterospermella australiensis.* A few miospore species are observed such as *Araucariacites australis, Corollina brasiliensis, Corollina torosa, Corollina kieseri* and *Cicatricosisporites hallei.* All of these species have been observed quite commonly in other studied sections in this study.

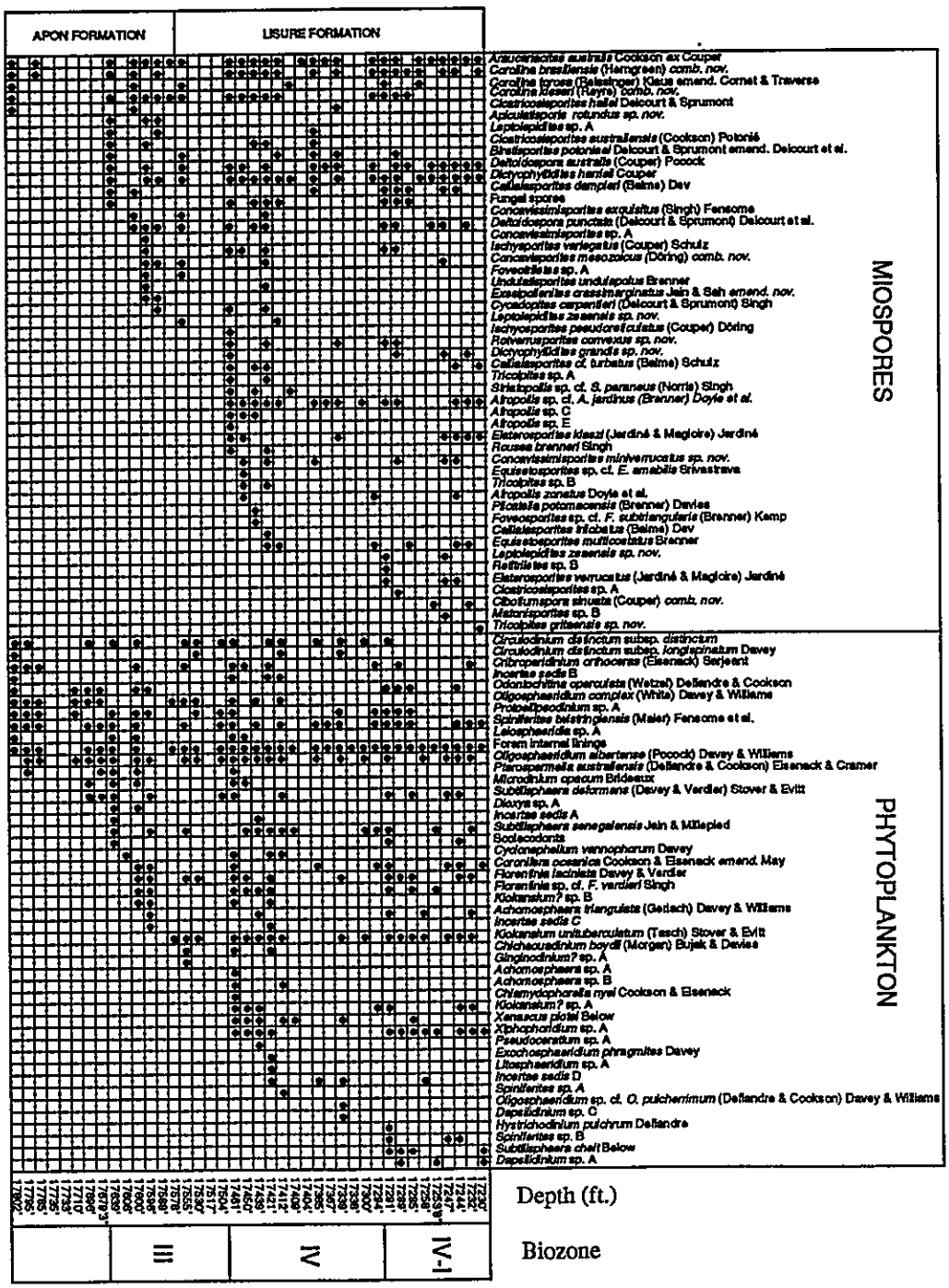



Figure 15. Distribution chart of miospores and phytoplankton observed in well ALT-19X

A second microfloral assemblage occurs in the interval between 17504' to 17639' (basal part of the Lisure Formation- 17504' to 17555' and Apón Formation -17578' to 17639'). The assemblages are characterized by the same dinoflagellate species as the basal interval, as well as by the occurrences of *Dioxya* sp. A, *Incertae sedis* A, *Subtilisphaera senegalensis, Cyclonephelium vannophorum, Coronifera oceanica, Florentinia laciniata, Florentinia* sp. cf. *F. verdieri, Kiokansium?* sp. B, *K. unituberculatum, Achomosphaera triangulata, Chichaouadinium boydii* and *Giniginodinium*? sp. A. Miospore species characteristic of this interval are *Apiculatisporis rotundus, Leptolepidites* sp. A, *Leptolepidites* sp. B, *Cicatricosisporites autraliensis, Biretisporites potoniaei, Concavissisporites exquisitus, Ischyosporites variegatus, Concavisporites mesozoicus, Foveotriletes* sp. A and *Cycadopites carpentieri.*

A third assemblage between 17294' and 17461' from samples the Lisure Formation is characterized by the occurrences of *Xenascus plotei, Xiphophoridium* sp. A, *Achomosphaera* sp. A, *Achomosphaera* sp. B, *Chlamydophorella nyei, Kiokansium*? sp. A, *Pseudoceratium* sp. A, *Exochosphaeridium phragmites, Spiniferites* sp. A, *Polysphaeridium* sp. C and *Oligosphaeridium pulcherrimum.* Among the miospore species, *Elaterosporites klaszi, Afropollis* sp. cf. *A. jardinus* and several tricolpate angioperm pollen such as *Tricolpites* sp. A, *Tricolpites* sp. B, *Striatopollis* sp. cf. *S. paraneus* and *Rousea brenneri* are characteristic. Other miospore species such as *Ischyosporites pseudoreticulatus, Callialasporites turbatus, Afropollis* sp. C, *Afropollis* sp. E, *Equisetosporites* sp. cf. *E. amabilis, Plicatella potomacensis* and *Callialasporites trilobatus* are observed only in this interval. Preservation of the assemblages of this interval tends to be poor towards the middle and the top.

A fifth microfloral association is recognized at the top of the investigated cored section (17230' to 17291') that corresponds to samples of the top of the Maraca Formation). The occurrences of *Spiniferites* sp. B, *Subtilisphaera cheit,* and *Polysphaeridium* sp. A, as well as the occurrences of *Leptolepidites zeaensis, Retitriletes* sp. B, *Elaterosporites verrucatus, Cicatricosisporites* sp. A, *Matonisporites* sp. A, *Tricolpites gritaensis* and *Cibotiumspora sinuata.* It is important to notice that the occurrences of *Equisetosporites multicostatus,* a common species in other of the sections already discussed, is restricted in the section of well ALT-19X to the interval between samples 17232' to 17421'. This fact clearly indicates the role of paleoenvironmental controls on the distribution of the palynomorphs. These controls will be discussed in the next chapter.

### 4.3.5 Well ALP-6 subsurface section.

Figure 16 shows the distribution of identified palynomorphs in 35 palyniferous samples in well ALP-6, including samples from the Apón (16110' to 16831'), Lisure (15652' to 16108') and Maraca (15597' to 15640') formations.

Palynological assemblages in the basal interval of the cored section of well ALP-6 (16601' to 16831'), all corresponding to the Tibú Member of the Apón Formation, are characterized by the poor preservation and the occurrence of vey few palynomorph species. *Circulodinium distinctum* subsp. *distinctum*, *Circulodinium distinctum* subsp. *longispinatum*, *Cribroperidinium orthoceras*, *Microdinium opacum*, *Subtilisphaera deformans*, *Subtilisphaera senegalensis*, *Ginginodinium*? sp. A, *Kiokansium unituberculatum*, *Oligosphaeridium albertense* and *Florentinia laciniata* are dinoflagellate present in this interval. *Uvaesporites inferus*, *Concavissimisporites miniverrucatus*, *Deltoidospora australis*, *Dictyophyllidites harrisii*, *Araucariacites australis*, *Corollina brasiliensis*, *Corollina kieseri*, *Corollina torosa*, *Reyrea polymorpha*, *Callialasporites dampieri*, *Equisetosporites multicostatus* and *Afropollis zonatus* are miospore species present throughout this interval.

The interval between 16108' to 16591' shows impoverished poorly preserved palynological assemblages. The interval 16525' to 16573'4" corresponds to the Machiques Member of the Apón Formation, comprising mainly bituminuous shales in which amorphous organic matter is observed to be very abundant, with few palynomorphs present. The paleoenvironmental analysis of the Machiques Member will be discussed in the following chapter. Samples between 16108' to 16500' correspond to the Piche Member, the topmost unit of the Apón Formation. These samples showed poor palynological assemblages, caused mainly by adverse paleoenvironmental conditions for the preservation of organic matter.

A change in the preservation and diversity of the assemblages is observed in the interval 15973'6" to 16101', representing the cored section of the Lisure Formation. The palynological assemblages are characterized by the occurrences of almost the same species that were reported for the basal interval of this well, along with *Florentinia* sp. cf. *F. verdieri*, *Cyclonephelium vannophorum*, *Achomosphaera* sp. B, *Achomosphaera*

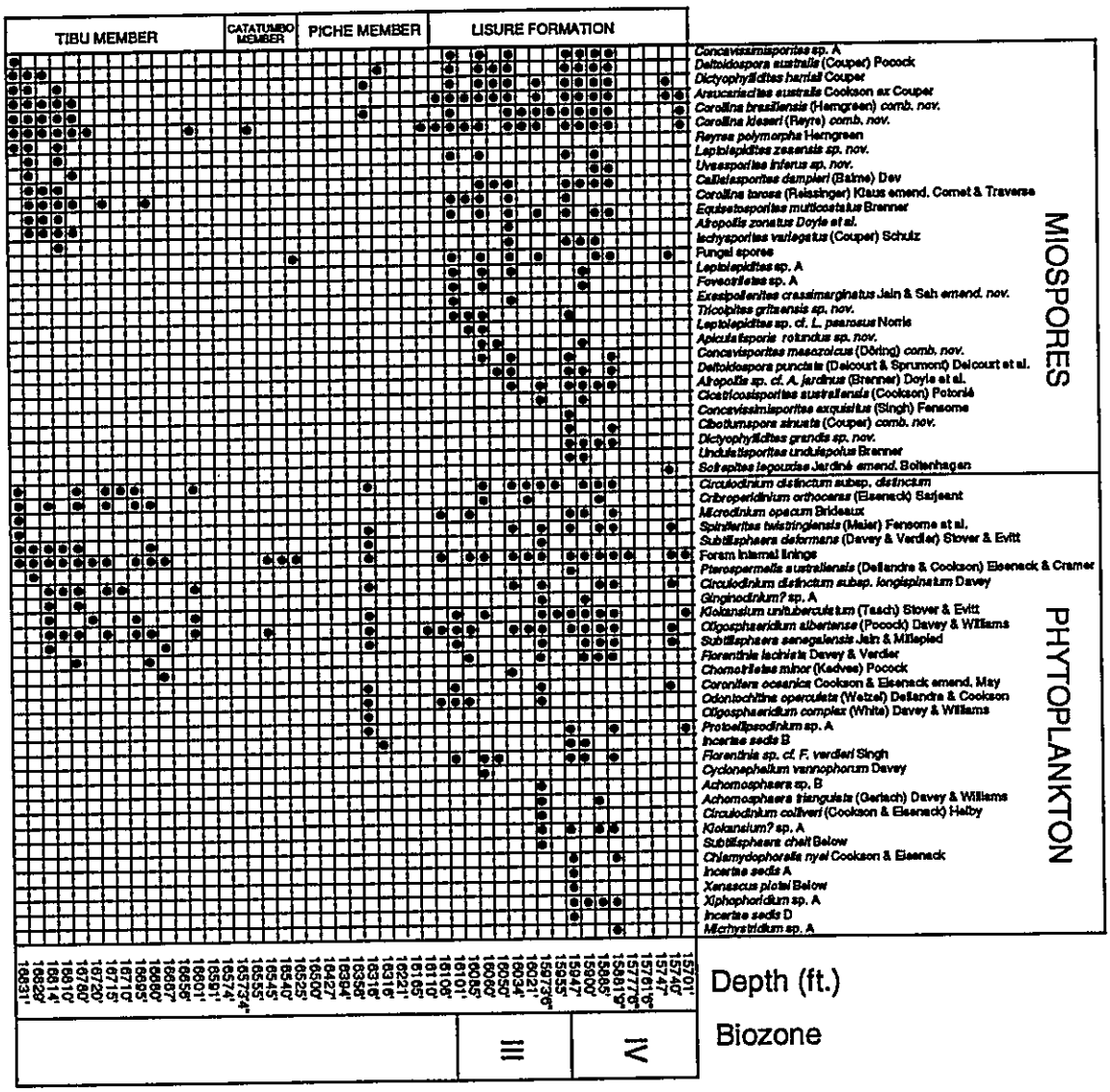



Figure 16. Distribution chart of miospores and phytoplankton observed in well ALP-6

*triangulata, Circulodinium colliveri, Kiokansium*? sp. A, *Subtilisphaera cheit, Leptolepidites* sp. A, *Leptolepidites* sp cf. *L. psarosus, Foveotriletes*, sp. A, *Exesipollenites crassimarginatus, Tricolpites gritaensis, Apiculatisporis rotundus, Concavisporites mesozoicus, Deltoidospora punctata, Cicatricosisporites australiensis* and *Afropollis* sp. cf. *A. jardinus*.

At the top of the cored section, 15701' to 15947' (Lisure Formation), the palynological assemblages are characterized by the occurrences of most of the previously mentioned species along with *Xenascus plotei, Xiphophoridium* sp. A, *Chlamydophorella nyei, Incertae sedis* A, *Concavissimisporites exquisitus, Cibotiumspora sinuata, Dictyophyllidites grandis, Undulatisporites undulapolus* and *Sofrepites legouxiae*.

Samples collected at the top of the cored section of the Lisure Formation (15652' to 15664') and Maraca Formation (15597' to 15640') are devoid of palynomorphs.

**4.3.6 Catatumbo outcrop section.**

Figure 17 shows the distribution of identified palynomorphs in seven samples of of the Machiques Member (Apón Formation) collected in the Catatumbo outcrop section.

The palynological assemblages located at the base of the sampled interval (M-24 to M-13) show assemblages with very few species such as *Araucariacites australis, Florentinia laciniata, Microdinium opacum, Microdinium*? sp. B, *Oligosphaeridium albertense* and *Circulodinium distinctum*.

The interval including samples M-18 to M-23 shows palynological assemblages characterized by the occurrences of *Xenascus plotei, Xiphophoridium* sp. A, *Achomosphaera* sp. B, *Achomosphaera triangulata, Kiokansium*? sp. A, *Kiokansium*? sp. B, *Kiokansium unituberculatum, Protoellipsodinium* sp. A, *Afropollis* sp. F, *Afropollis* sp. G and *Cibotiumspora sinuata*.

**4.3.7 Rosarito outcrop section.**

A total of 13 species are observed in sample S2A of the Rosarito outcrop section.

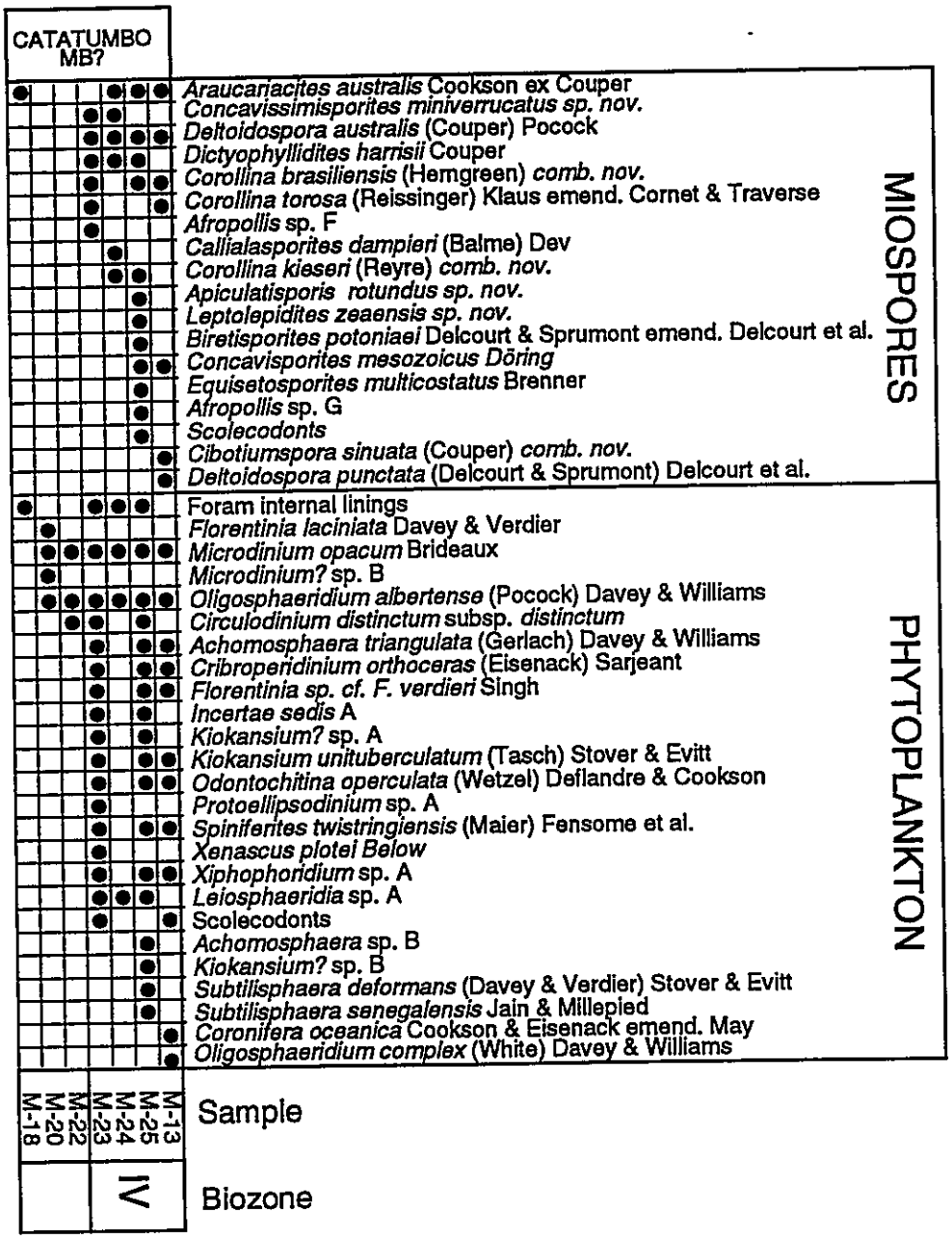



Figure 17. Distribution chart of miospores and phytoplankton observed in the Catatumbo outcrop section.

This sample was collected just below the contact of the La Luna and the underlying Maraca formations, in a bituminuous shale lense. The phytoplankton species recovered from this sample are *Xenascus plotei, Achomosphaera triangulata, Microdinium* sp. A, *Microdinium*? sp. B, *Subtilisphaera cheit, Circulodinium distinctum, Kiokansium unituberculatum, Microdinium opacum, Odontochitina operculata, Oligosphaeridium albertense, Spiniferites twistringiensis* and *Leiosphaeridia* sp. A. Only two species of miospores are present in this sample; *Deltoidospora punctata* and *Dictyophyllidites harrisii.*

### 4.3.8 Well P-201 subsurface section

Figure 18 shows the distribution of palynomorphs identified in 19 samples from well P-201. The sampled interval included samples of the Apón (11410' to 11570'), Lisure (10854' to 11403') and Maraca (10823'9") formations. Only samples of the Lisure Formation yielded palynomorph assemblages, characterized by few species and poor preservation. In the interval located at the base of the productive samples (11363' to 11402'), the palynological assemblages are characterized by the occurrences of *Circulodinium distinctum* subsp. *distinctum, Microdinium opacum, Oligosphaerdium albertense, Oligosphaeridium complex, Subtilisphaera senegalensis, Kiokansium unituberculatum, Cribroperidinium orthoceras, Odontochitina operculata, Protoellipsodinium* sp. A, and *Pterospermella australiensis. Leptolepidites* sp. A, *Leptolepidites zeaensis, Concavissimisporites exquisitus, Deltoidospora australis, Corollina brasiliensis, Corollina torosa, Corollina kiesieri, Callialasporites dampieri, Dictyophyllidites harrisii* and *Araucariacites australis.*

A second microfloral association is observed in the interval 11080' to 11102'. This association is characterized by the occurrence of most of the previously mentioned species of the basal interval, along with *Coronifera oceanica, Kiokansium*? sp. A, *Leiosphaeridia* sp.A, *Circulodinium distinctum* subsp. *longispinatum, Florentinia laciniata, F.* sp. cf. *F. verdieri, Concavissimisporites miniverrucatus, Afropollis* sp. cf. *A. jardinus, Achomosphaera triangulata, Concavissimisporites mesozoicus* and *Deltoidospora punctata.*

A third microfloral association is observed at the top of the studied interval

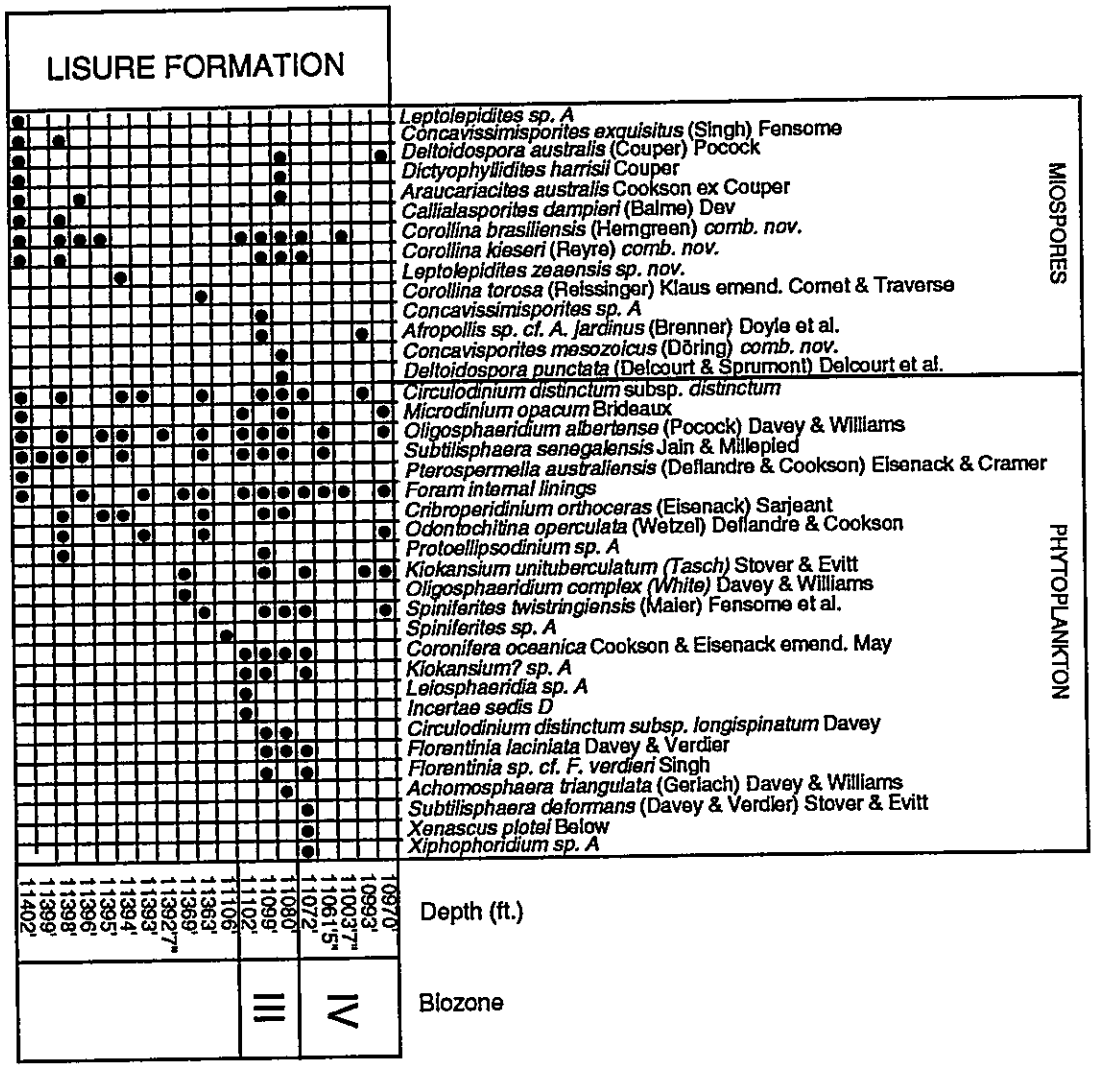



Figure 18. Distribution chart of miospores and phytoplankton observed in well P-201

(10970' to 11072'), characterized by relatively poor assemblages. At the base of this interval (11072'), the species *Xenascus plotei, Xiphophoridium* sp. A and *Subtilisphaera deformans* have their first occurrences.

### 4.3.9 Biozonation

Figure 19 shows the local stratigraphic range of some of the palynomorph species observed in this study. A total of five microfloral associations are recognized in the studied sections. These represent four palynological zones and a subzone, that from older to younger are here defined:

- **BIOZONE I**: *Uvaesporites inferus-Subtilisphaera deformans* zone.

**Type of zone**: Assemblage zone.

**Definition**: The palynological assemblage of this biozone is characterized by the occurrence of a relatively diverse suite of miospores, some of which are only observed in the Zea-Panamericana section: *Concavissimisporites* sp. A, *Concavissimisporites* sp. D, *Concavissimisporites* sp. G, *Cicatricosisporites* sp. D, *Cicatricosisporites* sp. F, *Todisporites* sp. A, *Undulatisporites* sp. A, *Osmundacidites* sp. A, *Callialasporites*? sp. A., *Deltoidospora australis, Dyctyophyllidites harrisii, Araucariacites australis* and *Afropollis zonatus*. Most of these species occur only as single specimens and are probably not useful indices, but their co-occurrences in intervals of this zone indicates a natural association or assemblage. Phytoplankton species are also present in the Zea-Panamericana outcrop section, in very low abundances at the base (13-04-01 to 13-04-05) and consist only of *Leiosphaeridia* sp. A and *Pterospermella* sp. A. However at the top of the biozone, dinoflagellate cyst are observed. Species such as *Circulodinium distinctum* subsp. *distinctum, Oligosphaeridium albertense, Coronifera oceanica, Spiniferites twistringiensis, Kiokansium unituberculatum, Subtilisphaera deformans* and *Subtilisphaera senegalensis* are present. The latter is the most commonly occurring species of dinoflagellate observed in this interval.

Pollen of *Corollina torosa, Corollina brasiliensis, Corollina keisieri* and *Uvaesporites inferus* are also abundant. The latter species is not restricted to this interval,

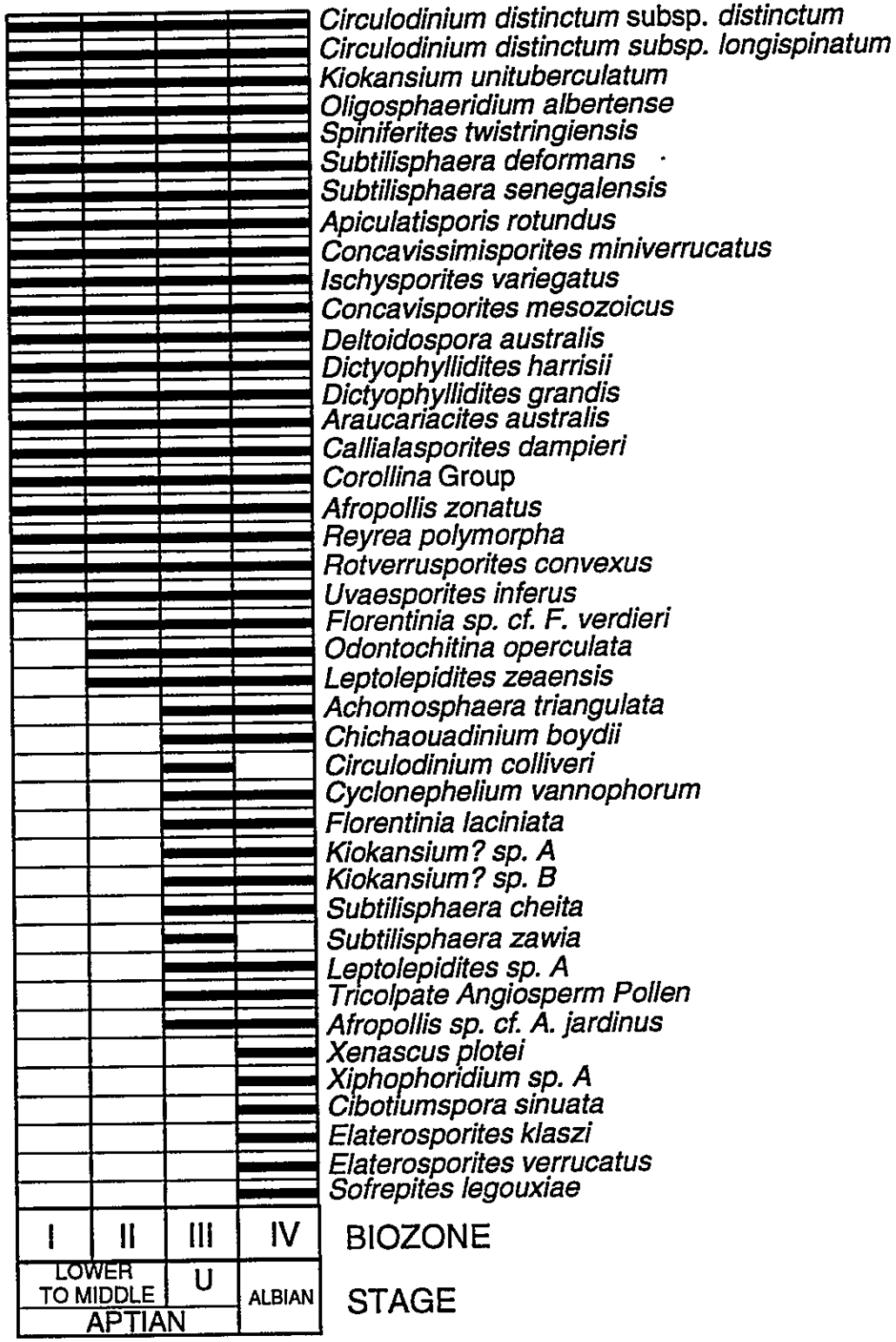



Figure 19 . Local ranges of selected palynomorphs observed in this study

but is present in percentages up to the 15% of the assemblages in the Zea-Panamericana section.

**General remarks**: This biozone is also inferred in the basal interval of well CR-5, where the poorly preserved and impoverished assemblages are dominated mainly by most of the species of dinoflagellates reported in the Zea-Panamericana outcrop section, with *Araucariacites australis* and *Corollina keisieri* as the only miospores present.

The lower limit this zone remains unknown, since the base of this zone is defined by the lowest horizon available of the Aguardiente Formation in the Zea-Panamericana outcrop section and in the cored section of well CR-5. The top of the zone is defined by a change in the composition of the assemblages in the overlying biozone II (see discussion below).

**Age**: The occurrences of *Afropollis zonatus* and *Reyrea polymorpha* are considered of significance for the determination of age of this biozone. The former has been reported from C VII (Lower Aptian) of Africa by Doyle et al. (1982) and the latter has been reported from the Aptian–Albian of northern South America (Muller et al., 1987). Therefore, based on this information and the absence of *Dicheiropollis etruscus*, a species whose stratigraphic top has been observed up to the Barremian of Africa and South America (Jardiné et al., 1974; Regali et al., 1974a), the *Uvaesporites inferus-Subtilisphaera deformans* zone is believed to be Early Aptian. A note of caution is needed. As mentioned in the introductory remarks, new evidence reported by Penny (1988 and 1992) indicates that zone C VII of Doyle et al. (1977) might be as old as Barremian. However, until this evidence becomes more rigorously evaluated, the age of this zone is considered to be Early Aptian.

## - **BIOZONE II**: *Leptolepidites* sp. cf. *L. psarosus-Circulodinum distinctum* subsp. *longispinatum* zone.

**Type of zone**: Assemblage zone.

**Definition**: The palynological assemblages of this biozone are characterized by the occurrence of the most common miospore and dinoflagellate species observed in this study (see results of the Zea-Panamericana section). A few species are restricted to

this biozone: *Cicatricosisporites* sp. C, *Afropollis* sp. B *sensu* Doyle et al., *Afropollis* sp. D, *Equisetosporites* sp. cf. *E. amabilis*, *Aequitriradites verrucosus*, *Contignisporites* sp. cf. *C. cooksonae*, *Circulodinium distinctum* subsp. *longispinatus*, *Circulodinium* sp. A and *Circulodinium* sp. B. Other species that occur in this biozone for the first time, and in overlying biozones, but are absent from the underlying Biozone I include *Leptolepidites zeaensis*, *Leptolepidites* sp. cf. *L. psarosus*, *Odontochitina operculata*, *Florentinia* sp. cf. *F. verdieri*, *Oligosphaeridium complex* .

Assemblages of the Aguardiente Formation of the Zea-Panamericana outcrop section are characterized by the abundance of *Corollina torosa* and *Corollina keisieri*. In samples at the base of the Biozone II in the Zea-Panamericana section (13-04-27 to 13-04-16), tetrads of these species make up 10% of the total count of palynomorphs. The paleoenvironmental significance of these findings will be discussed in the next chapter.

**General remarks**: This biozone is identified in the Zea-Panamericana outcrop section (13-04-41 to 13-04-16) and the core section of well CR-5 (in the interval 14410' to 14786'). In both sections, the intervals correspond to the Aguardiente Formation. The basal intervals of well ALT-19X (17679'3" to 17802'), ALP-6 (16108' to 16831') and P-201 (11106' to 11402') show poorly preserved assemblages that could not be related to this biozone or the underlying biozone I.

The lower limit of this zone is placed at the level where pollen of *Corollina* and dinoflagellate cysts of the genus *Circulodinium* co-occur as the dominant elements of the miospores and phytoplankton. The top of the zone is defined just below the first occurrence of the palynomorph species characteristic of biozone III (see discussion below).

**Age**: Unlike the underlying and overlying biozones, the assemblages of this biozone lack age diagnostic palynomorphs. Its stratigraphic position in between intervals considered Early Aptian (Biozone I) and Late Aptian (biozone III) indicates that this biozone must be considered Early to Middle Aptian.

### - **BIOZONE III**: *Afropollis* sp. cf. *A. jardinus*-Tricolpate pollen zone.

**Type of zone**: Oppel zone.

**Definition**: The palynological assemblages of this biozone are characterized by the earliest occurrences of *Afropollis* sp. cf. *A. jardinus*, tricolpate angiosperm pollen grains such as *Rousea brenneri, Tricolpites gritaensis, Tricolpites* sp. A, *Tricolpites* sp. B, *Verrutricolpites* sp. A and *Striatopollis* sp. cf. *S. paraneus, Achomosphaera triangulata* and *Chichaouadinium boydii.*

Other species that occur only in this biozone are *Leptolepidites* sp. A, *Distaltriangulisporites* sp. A, *Equisetosporites concinnus, Subtilisphaera zawia, Achomosphaera* sp. B, *Pareodinia* sp. A and *Dioxya* sp. A. Other species appear in assemblages of this and the overlying biozones, but are absent from the underlying biozones: *Circulodinium colliveri, Florentinia laciniata, Cyclonephelium vannophorum, Kiokansium*? sp. A, *Kiokansium*? sp. B, *Subtilisphaera cheit, Microdinium*? sp. B and *Foveotriletes* sp. A.

**General remarks**: This biozone is identified in the Zea-Panamericana (13-04-56 to 13-04-42) and La Grita (09-04-07 to 09-04-04) outcrop sections, wells CR-5 (14307' to 14401') (all these intervals of the Aguardiente Formation), ALT-19X (17504' to 17639'; Lisure and Apón formations), ALP-6 (15955' to 16101'; Lisure Formation) and P-201 (11080' to 11102'; Lisure Formation).

The lower limit of this biozone is defined at the earliest occurrence of *Afropollis* sp. cf. *A. jardinus*, tricolpate angiosperm pollen grains, *Achomosphaera triangulata* and *Chichaouadinium boydii*. The top of the zone is defined just below the lowest range of diganostic species of Biozone IV (see discussion below).

**Age**: *Afropollis jardinus* has been reported from the Late Aptian of Africa and Brazil (see discussion in the previous Systematic Palynology chapter). The occurrence of *Afropollis* sp. cf. *A. jardinus*, which differs from *A. jardinus* only in the supratectal ornamentation, might also be indicative of the Late Aptian-Early Albian (see discussion below). Tricolpate pollen was reported by Muller et al. (1987) to have its earliest occurrence in the "*Tricolpites*"-*Exesipollenites tumulus* zone, considered by these authors as Aptian to Early Albian. This biozone is restricted to the Late Aptian, based on the first reported occurrences of *Afropollis jardinus* and tricolpate angiosperm pollen grains at the base and the age of the overlying biozone (discussion below).

## - **BIOZONE IV**: *Xenascus plotei-Elaterosporites klaszi* zone.

**Type of zone:** Concurrent range zone.

**Definition:** The palynological association of this biozone is characterized by the earliest occurrences of *Elaterosporites klaszi, Sofrepites legouxiae, Xenascus plotei* and *Xiphophoridium sp. A.* Other species that are observed only in assemblages of this zone are *Cibotiumspora sinuata, Leptolepidites* sp. B, *Concavissimisporites* sp. E, *Costatoperforosporites* sp. A, *Foveosporites* sp. cf. *F. subtriangularis, Ischyosporites pseudoreticulatus, Plicatella potomacensis, Callialasporites turbatus, Callialasporites trilobatus, Afropollis* sp. F, *Afropollis* sp. G, *Achomosphaera* sp. A, *Chlamydophorella nyei, Pseudoceratium* sp. A, *Spiniferites* sp. A, *Exochosphaeridium phragmites, Litosphaeridium* sp. A, *Oligosphaerdium* sp. cf. *O. pulcherrimum* and *Dapsilidinium* sp. C.

**General remarks:** This biozone is identified in the outcrop sections of La Grita (09-04-11 to 09-04-13; Aguardiente Formation) Catatumbo (M-13 to M-24; Machiques Member?) and Rosarito (Sample S2A Maraca Formation) outcrop sections, wells CR-5 (14186' to 14285'; Aguardiente Formation), ALT-19X (17230' to 17461'; Lisure Formation), ALP-6 (15701 to 115947'; Lisure Formation) and P-201 (10970' to 11072'; Lisure Formation).

The lower limit of this biozone is identified at the level where any of the diagnostic species mentioned in the previous paragraph have their earliest occurrences. The top of the zone is undetermined, since samples located at the top of the cored sections are completely barren.

**Age:** *Elaterosporites klaszi* and *Sofrepites legouxiae*, have been reported from the Albian of Africa, Brazil and northern South America (see the Systematic Palynology chapter). *Xenascus plotei* has been reported mainly from the Albian in northern Africa and in south-central United States (see Systematic Palynology chapter). The co-occurrences of these species indicate that biozone IV must be considered Albian. The lack of diversification of angiosperm pollen and elater-bearing palynomorphs in the assemblages under study was observed for the Middle to Late Albian by Herngreen (1975) and Herngreen and Chlonova (1981). Thus biozone IV appears to be restricted to the Early Albian.

In essence, this zone might be considered equivalent to the *Elateropollenites jardinei* zone proposed by Regali et al. (1974a) and Muller et al. (1987).

### - SUB-BIOZONE IV-I: *Elaterosporites verrucatus* subzone.

**Type of zone:** Assemblage zone.

**General remarks:** This sub-biozone is identified only in well ALT-19X (17230' to 17291'; Lisure Formation).

**Definition:** The palynological assemblages of this sub-biozone are characterized the occurrences of *Elaterosporites verrucatus*, *Hystrichodinium pulchrum* and *Spiniferites* sp. B. The assemblage is composed mainly of miospores.

**General remarks:** The lower limit of this biozone is identified at the level where any of the diagnostic species mentioned in the previous paragraph had their first occurrences. The top of the zone is undetermined, since most of the top intervals of the studied subsurface section in well ALT-19X proved to be completely barren.

**Age:** The similarity of the assemblages observed in this interval and those observed in biozone IV, indicate that sub-biozone IV-I is Lower Albian. The predominance of miospore species might be an indication of progradational events taking place at the time of deposition.

### 4.4 Discussion.

The results obtained in this study allow the definition of a total of four zones and a sub-subzone. Some of these biostratigraphic units, like biozones III and IV, are identified in six of the studied sections in the Maracaibo Basin, showing their potential as correlation tools sequences across the basin. Figure 20 shows the zonation proposed in this study, that proposed by Muller et al. (1987) for the Aptian and Albian of northern South America and the lithological units.

Biozones I and II are assemblage zones and some of the components of their

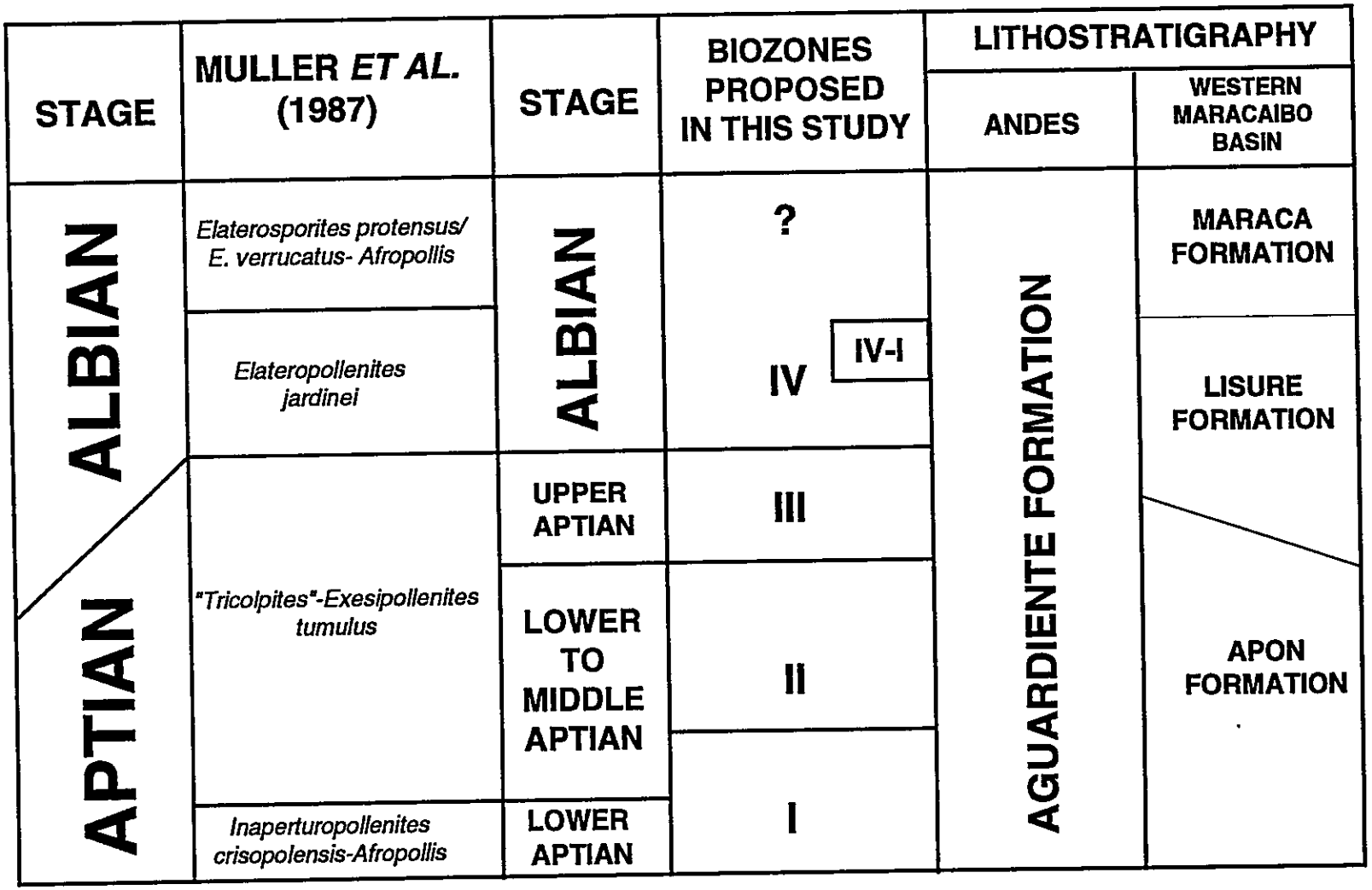



Figure 20. Comparison of the palynological zonation proposed by Muller et al. (1987) and the biozonation proposed in this study. Muller et al. (1987) did not determine their palynological zones in the lithological units of Lower Cretaceous of the Maracaibo Basin and the age assignment for these units is based on the results of this study.

assemblages are present in very limited numbers or individual occurrences, a situation that imposes a limit on the possibilities of assessing their potential use value. Most of the species of the assemblages of these biozones are commonly observed in other biozones and sampled sections. Their irregular occurrence is considered due to indicators paleoenvironmental control. Biozones I and II are limited to the Zea-Panamericana outcrop section and well CR-5. Essentially, these two biozones are only observed in samples collected from the Aguardiente Formation, thus supporting the argument that their assemblages are paleoenvironmentally controled.

The inferred age of bizone I (Early Aptian) based on the occurrence of *Afropollis zonatus* must be considered with caution. Doyle (1992) discussed the possible correlation of the Potomac Group (USA) and the sedimentary sequence of Gabon for the Barremian and Aptian. He illustrated several discrepancies in regard to the the dating of the first angiosperm occurrences and proposed that zone C VII (reported as Aptian by Doyle et al., 1977 and 1982) might be as old as the Late Barremian. However, the data cited by Doyle (1992) is not considered conclusive. The angiosperm radiation seems to hace occurred at different times in different regions during the Early Cretaceous. Brenner (1976) proposed that evolution of angiosperms took place early in low latitude regions, during the Barremian and Aptian, spreading poleward during the Albian and Cenomanian. This model seems to be supported by the evidence proposed by Norris et al. (1975) which showed progressive replacement of gymnospermous pollen by angiosperm pollen during the Middle Albian in Canada, at least at the local level. However, the pattern of diversification and dispersion of angiosperms seems to be more complex. Penny (1988) pointed out that tricolpate angiosperm pollen might have originated earlier in the eastern regions of Gondwana (Israel). Schrank (1992) reported that striate pollen is observed in the Barremian of Egypt and Israel, but is absent from the Barremian of Sudan. Therefore, it is plausible to assume that appearances of angiosperm pollen might show significant diachronism in low and high latitudes, as well as in different regions within the same floristic province (in the African-South American Province). In view of the lack of definite evidence, the age of biozone I is considered to be Early Aptian, pending future studies that might provide a conclusive dating for these associations.

An important bioevent was observed in biozone III; the first occurrences of tricolpate pollen grains, along with *Afropollis* sp. cf. *A. jardinus*. Muller et al. (1987) proposed that the first appereance of angiosperm tricolpate pollen occurred in the Aptian of northern South America. Doyle et al. (1982) reported *A. jardinus* from the Upper

Aptian–Lower Albian of Brazil and Africa. *Afropollis* sp. cf. *A. jardinus* differs from the species described by Doyle et al. (1982) in the supractetal ornamentation, but the overall morphology and the cryptoaperturate nature of the grain is identical to *Afropollis jardinus*. Penny (1989) reported species of *Afropollis* from the Barremian of Egypt and England, describing morphological features that in part contradicted the phylogenetic pattern proposed by Doyle et al. (1982) for species of this genus. Some of the species found by Penny (1989) in the Barremian are cryptoaperturate. Doyle et al. (1982) considered that cryptoaperturate species of *Afropollis* are derived from more primitive forms with zonosulcate and operculate apertures, which were present in the Lower Aptian. Therefore, the assessment of the age determination based on the occurrence of this species alone is not considered definite.

The first occurrence of tricolpate pollen grains has also been discussed in the palynological literature. Doyle (1992) concluded that angiosperm plants producing tricolpate pollen appeared during the Barremian and Early Aptian, in both high and low latitudinal assemblages. Schrank (1992) analyzed the main trends exhibited by terrestrially-derived palynofloras, determining that they compare well throughout the African-South America Province. Among the trends, he pointed out that the first occurrence of tricolpate pollen in Africa is in the Late Aptian. The evidence derived from this study supports Schrank's (1992) conclusion that the first occurrences of tricolpate pollen are Late Aptian. Penny (1992) mentioned that the absence of tricolpate pollen in older intervals than the Albian in England is related to the rarity of this pollen and to the marine nature of the deposits of the Aptian of England. However, samples of biozones I through III were collected in continental facies of the Aguardiente Formation outcropping in the Venezuelan Andes. Therefore, the first occurrences of this type of angiosperm pollen must be considered as reliable indicator of the Upper Aptian of the Maracaibo Basin.

Biozone IV is considered to be equivalent to the *Elateropollenites jardinei* zones of Regali et al. (1974a) and Muller et al. (1987) for Brazil and Venezuela. As discussed in the introduction, the first occurrence of elater-bearing palynomorphs is a bioevent that can be used for correlation in different continents and also within South America (pantropical and intracontinental zones, as defined by Germeraad et al, 1968 for the Cenozoic of tropical regions). The first occurrences of species with elators have been considered to be Early Albian. However, Herngreen and Dueñas Jiménez (1990) concluded that the elater plexus is restricted to Middle Albian to Cenomanian. The

evidence obtained in this study does not support the conclusion reached by Herngreen and Dueñas Jiménez (1990). As mentioned in the definition of the biozone IV, the assemblages of this biozone lack the diversification of not only of other genera and species of the elater plexus, but also the porate and colporate angiosperm pollen. Jardiné and Magloire (1965), Regali et al. (1974a), Herngreen (1975) and Muller et al. (1987) reported that the diversification of angiosperm pollen and elater-bearing palynomorphs occurred during the Middle to Late Albian.

A second fact that might help to restrict the age of the base of biozone IV is the first occurrence of *Xenascus plotei*. This species was described from the Upper Aptian to Lower Albian of Morocco by Below (1981). Other occurrences of this species have been placed in the Albian and Cenomanian of northern Africa, the north Atlantic and south-central United States (see Systematic Palynology). Therefore the earliest co-occurrences of *Xenascus plotei* with elater-bearing palynomorphs must be considered a definite indication that the base of biozone IV is Lower Albian.

The ages of the lithostratigraphic units are also determined on the basis of the results of palynology. There are some differences in relation to previous studies. As shown in Figure 11, the Aguardiente Formation is considered to be Late Aptian to Albian. However, palynological analyses of samples of the Aguardiente Formation collected in the Zea-Panamericana and La Grita outcrop section, as well as from well CR-5, indicates that this formation is Early Aptian–Albian. Results obtained from the western part of the basin show that the Lisure Formation is Late Aptian–Albian. The present results indicate that the Apón Formation is restricted to the Aptian. The age of the different members of this formation could not be determined because of the lack of well preserved assemblages that might have allowed their correlation to the biozones I and II, which so far have only been observed in the Aguardiente Formation.

### 4.4.1 Comparison of miospore assemblages.

*Araucariacites, Corollina* and *Afropollis* have been commonly reported in Africa and South America. Jardiné and Magloire (1965) characterized their "sequence" XII (Barremian to Aptian) by the abundance of *Araucariacites australis*. This species is found to be quite common throughout the studied sections in the Maracaibo Basin. On the other hand, pollen of the genus *Callialasporites* is not as abundant and consistently present as *Araucariacites australis*. Plants producing pollen of *Callialasporites* might

have been growing in areas further inland or were present in lower density than those producing *Araucariacites*.

*Corollina* has also been extensively documented in the Lower Cretaceous, but is especially common in low latitude areas of the African-South America Province of Herngreen and Chlonova (1981). All the species of this genus are observed to show consistent and common occurrences throughout most of the sequences under study. In particular, a reference has to be made to *Corollina brasiliensis*, a species that had been reported only in Upper Albian sediments of western and northern Africa (Jardiné and Magloire, 1965, Lawal and Moullade, 1986 and Aboul Ela and Mahrous, 1992) and Brazil (Pollen zone II of Herngreen, 1975b). This species is observed in assemblages of biozones I through IV (Aptian to Albian) of the Maracaibo Basin. The occurrence of this species in sediments older than Late Albian extens its stratigraphic range to the Aptian, when this species was found in very low abundances. The abundance of this species increases dramatically near the Aptian–Albian boundary, specimens above the boundary being normally larger than 35 µm. The occurrence of large specimens of *Corollina brasiliensis* in the Albian may have been related to the onset of a major progradational phase, as will be discussed in the next chapter.

*Afropollis* is sporadically found in the Aptian, when zonosulcate pollen were the dominant forms of this genus. Doyle et al. (1982) reported that zonosulcate and operculate forms of *Afropollis* are the only types present in the Aptian of Africa and Brazil. *Afropollis* sp. cf. *A. jardinus* occurs only in the Late Aptian and Albian, when it became the dominant species of this genus in the Maracaibo Basin.

Another group of characteristic palynomorphs of the African-South America province observed in this study is the so-called elater-bearing palynomorphs of the genera *Elaterosporites* and *Sofrepites*. As already discussed, species of these genera have been reported from the Albian-Cenomanian of Africa, South America, Asia and the Pacific area (see Herngreen and Dueñas Jiménez, 1990), becoming more diverse and abundant in the Upper Albian. Their sporadic and inconsistent distribution in this study indicates paleoenvironmental controls. For example, *Elaterosporites klaszi* and *Sofrepites legouxiae* are observed in two samples of La Grita outcrop section, but are absent from samples of the Zea-Panamericana. These species are present in wells ALT-19X and ALP-6, but absent in well CR-5, perhaps related to differential deposition of finer grained sediments further offshore in the central areas of the basin. *Elaterosporites verrucatus*,

whose local stratigraphic range in northern South America has been reported to coincide with that of *E. klaszi*, is observed only in samples of sub-biozone IV-I in well ALT-19X. Assemblages of this sub-zone are dominated mainly by miospores mixed with dinoflagellate cysts and have been related to progradational events taking place during the Albian (see discussion in the next chapter).

*Exesipollenites crassimarginatus* is abundant in a few samples of the Zea-Panamericana and La Grita outcrop section and rare in the central and northern areas of the Maracaibo basin. This species has been reported only from the Lower Cretaceous of Ceylon and is reported here for the first time in South America. Regali et al. (1974a) and Muller et al. (1987) reported several species of this genus as a base for their zonations of Brazil and northern South America.

*Equisetosporites* is another component of the miospore assemblages of the Lower Cretaceous in the Maracaibo Basin. In general, pollen of this genus is observed in low abundances and except for *E. multicostatus*, the other species show limited occurrences. *E. concinnus* is observed only in samples of the Late Aptian and Albian, which might be related to sedimentary phases, as will be discussed in the next chapter. Herngreen and Chlonova (1981) reported a significant increase and diversification of pollen related to the *Ephedra* complex during the Late Albian-Cenomanian of the ASA province. Schrank (1992) reported that ephedroid pollen has a maximum during the Aptian in Sudan. Their limited occurrences in the Maracaibo Basin during the Aptian–Albian might be related to climatic differences between areas located in eastern Brazil and western and northern Africa.

Another factor that suggest some similarity to the assemblages of the ASA province of Herngreen and Chlonova (1981) is the complete absence of saccate pollen; these palynomorphs were more common in northern and southern latitudes during the Early Cretaceous.

Trilete spores of the ASA province are not diverse. Assemblages from the Maracaibo Basin are dominated by species *Deltoidospora, Dictyophyllidites, Concavisporites* with *Biretisporites* as a sub-dominant; these species are widespread and consistently present throughout most of the studied sections.

Schizaeacean and lygodiacean spores were a rapidly evolving group during the Early Cretaceous (Fensome, 1983). In the assemblages of the Aptian–Albian of the Maracaibo Basin, this group is represented by several species of the genera *Cicatricosisporites, Ischyosporites* and *Concavissimisporites.* However, species of this genera are present in very low abundances and only species such as *Cicatricosisporites australiensis, Cicatricosisporites hallei* and *Concavissimisporites miniverrucatus* are observed consistently throughout the studied sections. Several species of *Cicatricosisporites* showed single individual occurrences, sometimes with very poor preservation, possibly suggesting reworking or significant transportation to the final site of deposition. Large-sized species such as *Concavissimisporites* sp. D and *Cicatricosisporites* sp. E are only observed in samples of the more continental facies of the Aguardiente Formation in the Zea-Panamericana and La Grita outcrop sections south of the Maracaibo Basin.

**4.4.2 Comparison of dinoflagellate cyst assemblages.**

Table 1 shows the percentages of phytoplankton species common to each of several Lower Cretaceous localities and the Maracaibo Basin. In general the percentages fluctuate in the range of 10 to 13%. These percentages are considered to be low and indicative of differences in the composition of the assemblages related mainly to different types of paleoenvironments.

Dinoflagellate cyst assemblages observed in the Maracaibo show some common species with assemblages of the European Aptian–Albian stratotypes and to the Aptian and Albian of Europe. Davey and Verdier (1974) described the assemblages from the Aptian of France. Species of the Maracaibo Basin and the French Aptian stratotype include *Circulodinium colliveri, Circulodinium distinctum, Exochosphaeridium phragmites, Florentinia laciniata, Hystrichodinium pulchrum, Odontochitina operculata, Oligosphaeridium complex, Chlamydophorella nyei* and *Coronifera oceanica.* The percentages of common species reported in Table 1 are considered to be very low (13%). My personal observations of some samples collected by Prof. Geoffrey Norris from the Aptian stratotype showed that assemblages from there lack major terrestrial influence. Species of *Gonyaulacysta* are common, along with species of *Achomosphaera* and *Spiniferites.* In contrast, species of *Gonyaulacysta* are

| LOCALITY | STAGE | $N_1$ | $N_2$ | $\%_1$ | $\%_2$ |
|---|---|---|---|---|---|
| **APTIAN STRATOTYPE, FRANCE** (Davey and Verdier, 1974) | APTIAN | 67 | 9 | 13.43 | 13.24 |
| **ALBIAN STRATOTYPE, FRANCE** (Davey and Verdier 1971 and 1973) | ALBIAN | 93 | 9 | 9.68 | 13.24 |
| **BAY OF BISCAY, NW EUROPE** (Davey, 1979a) | APTIAN | 70 | 7 | 10.00 | 10.29 |
| | ALBIAN | 80 | 7 | 8.75 | 10.29 |
| **OFFSHORE EASTERN CANADA** (Bujak and Williams, 1978) | APTIAN | 44 | 8 | 18.18 | 11.76 |
| | ALBIAN | 68 | 9 | 13.24 | 13.24 |
| **ALBERTA, CANADA** (Singh, 1971) | M. ALBIAN | 114 | 8 | 7.02 | 11.76 |
| **NORTHWESTERN TERRITORIES, CANADA** (Brideaux and McIntyre, 1975) | APTIAN | 23 | 4 | 17.39 | 5.88 |
| | ALBIAN | 17 | 5 | 29.41 | 7.35 |
| **OKLAHOMA, UNITED STATES** (Hedlund and Norris, 1986) | M. ALBIAN | 29 | 8 | 27.59 | 11.76 |
| **OFFSHORE NORTHWEST MOROCCO** (Below, 1984) | APTIAN | 137 | 15 | 10.95 | 22.06 |
| | U. ALBIAN | 45 | 8 | 17.78 | 11.76 |
| **MOROCCO** (Below, 1981 and 1982) | APTIAN | 91 | 15 | 16.48 | 22.06 |
| | ALBIAN | 79 | 14 | 17.72 | 20.59 |
| **GULF OF MEXICO, CARIBBEAN SEA** (Riley and Fenton, 1984) | APTIAN | 29 | 3 | 10.34 | 4.41 |
| **ANGOLA BASIN, OFFSHORE SOUTHWESTERN AFRICA** (Morgan, 1978) | APTIAN | 9 | 1 | 11.11 | 1.47 |
| | ALBIAN | 40 | 2 | 5.00 | 2.94 |
| **OFFSHORE SOUTHWESTERN AFRICA** (Davey, 1978) | APTIAN | 46 | 7 | 15.22 | 10.29 |
| **SURAT BASIN, AUSTRALIA** (Burger, 1980) | APTIAN | 69 | 7 | 10.14 | 10.29 |
| | ALBIAN | 70 | 7 | 10.00 | 10.29 |
| **AUSTRALIA** (Morgan, 1980) | APTIAN | 101 | 11 | 10.89 | 16.18 |
| | ALBIAN | 140 | 12 | 8.57 | 17.65 |

Table 1. Percentages of phytoplankton species in common between compared localities and the Maracaibo Basin for the Aptian and Albian. $N_1$: Total number of phytoplankton species reported for the compared locality. $N_2$: Number species in common between the compared locality and the Maracaibo Basin. $\%_1$: Percentage of species in common calculated by ($N_2$ x 100)/$N_1$. $\%_2$: Percentage of species in common calculated by ($N_2$ x100)/68, where 68 is the total number of phytoplankton species reported in this Study for the Maracaibo Basin.

absent from the samples of the Maracaibo Basin and species of *Spiniferites* and *Achomosphaera* are present in limited number and abundance compared to those of the Aptian stratotype.

Davey and Verdier (1971 and 1973) and Fauconnier (1977) reported assemblages from the Albian stratotype in France. The only common species between those reported by these authors and those observed in this study are *Circulodinium colliveri, Circulodinium distinctum, Coronifera oceanica, Cyclonephelium vannophorum, Hystrichodinium pulchrum, Exochosphaeridum phragmites, Florentinia laciniata, Odontochitina operculata, Oligosphaeridium complex Spiniferites twintrigiensis* and *Subtilisphaera deformans*. As in the case of the Aptian stratotype (Davey and Verdier, 1971), percentages of species in common with the Venezuelan material are low. My personal observations of samples of the Albian of France and England, provided by Prof. Geoffrey Norris, also revealed that assemblages are dominated mainly by dinoflagellate cysts of *Spiniferites/Achomosphaera, Gonyaulacysta, Oligosphaeridium complex* and species of the genus *Litosphaeridium*. As mentioned above, species of *Gonyaulacysta* from the present material are absent and very limited numbers of specimens of the other taxa occur. The lack of terrestrial material and the very diverse assemblage of dinoflagellates are indicative of open marine conditions.

Costa and Davey (1992) reported stratigraphic ranges of dinoflagellate cysts from the Cretaceous of northwestern Europe. *Oligosphaeridium albertense, Oligosphaeridium complex, Coronifera oceanica, Exochosphaerdium phragmites, Hystrichodinium pulchrum* and *Odontochitina operculata* are listed by Costa and Davey (1992) and occur in the Maracaibo Basin. Duxbury (1983) reported assemblages from the lower Greensand of England (Aptian) and only species such as *Odontochitina operculata, Chlamydophorella nyei, Coronifera oceanica, Oligosphaerdium pulcherrimum* and *Oligosphaeridium complex* are common to the assemblages of the Maracaibo Basin. Davey (1970) reported assemblages from England, France and Canada. Species such as *Cribroperidinium orthoceras, Oligosphaeridum complex, Coronifera oceanica, Exochosphaeridum phragmites, Cyclonephelium vannophorum, Circulodinium distinctum, Spiniferites twistringiensis* and *Chlamydophorella nyei* are common with the assemblages of the Maracaibo Basin.

Davey (1979a) and Fauconnier (1984) reported assemblages from the Bay of Biscay area. Species such as *Circulodinium distinctum, Circulodinium distinctum* subsp.

*longispinatum, Hystrichodinium pulchrum, Chlamydophorella nyei, Spiniferites twistringiensis, Coronifera oceanica, Exochosphaerdium phragmites, Odontochitina operculata Oligosphaeridium pulcherrimum* and *Oligosphaeridium complex* are in common with those of the Maracaibo Basin. Fechner and Gruber (1991) reported dinoflagellate assemblages of the Lower Cretaceous (Aptian) Ereño Limestone of Spain. Of these, only *Circulodinium colliveri, Chlamydophorella nyei, Coronifera oceanica* and *Exochosphaeridium phragmites* are also observed in the Maracaibo Basin.

Similarities with coeval dinoflagellate assemblages of Canada seems more limited at the genus and species level. Bujak and Williams (1978) reported dinoflagellate assemblages from eastern offshore Canada. Species such as *Circulodinium colliveri, Circulodinium distinctum, Coronifera oceanica, Oligosphaeridium complex, Cribroperidinium orthoceras, Hystrichodinium pulchrum, Odontochitina operculata, Cyclonephelium vannophorum and Subtilisphaera deformans* are common to the Maracaibo Basin. Among the species whose local stratigraphic range for the northern hemisphere are reported by Williams et al. (1993), only *Circulodinium distinctum, Odontochitina operculata* and *Coronifera oceanica* are also observed in the assemblages of the Maracaibo Basin. Singh (1964 and 1971), Brideaux and McIntyre (1975) and Brideaux (1977) have described assemblages from western and northwestern Canada. Of these, species such as *Chlamydophorella nyei, Circulodinium colliveri, Circulodinium distinctum, Cribroperidinium orthoceras, Microdinium opacum, Odontochitina operculata, Oligosphaeridum albertense, Oligosphaeridium complex* and *Oligosphaeridium pulcherrimum* are also observed in western Venezuela. The percentages of species in common between these localities and the Maracaibo Basin are low, except for the percentage of species in common between the Albian of Arctic Canada (Brideaux and McIntyre, 1975). However, the limited number of species reported by these authors for the Albian (17 species) must be considered before assuming any strong similarity of the assemblages.

Habib and Drugg (1987) reported dinoflagellate assemblages of the northwestern Atlantic Ocean. Only *Circulodinium distinctum, Chlamydophorella nyei, Coronifera oceanica* and *Odontochitina operculata* are present in this area and in the Maracaibo Basin during the Aptian-Albian. Albian assemblages of southern United States, reported by Hedlund and Norris (1986) contained species such as *Circulodinium colliveri, Kiokansium unituberculatum, Microdinium opacum, Odontochitina operculata, Oligosphaeridium albertense, Oligosphaeridium complex, Spiniferites twistringiensis* and

*Xenascus plotei* that are also observed in assemblages of the Maracaibo Basin. *Xenascus plotei* was also reported by Bint (1986) in the Albian of Texas. Aptian assemblages of the Gulf of Mexico were described by Riley and Fenton (1984). *Circulodinium distinctum, Coronifera oceanica, Florentinia laciniata, Hystrichodinium pulchrum, Oligosphaeridium complex, Oligosphaeridium pulcherrimum* and *Spiniferites twistringiensis* are common to the Maracaibo Basin. The percentage of common species ($\%_1$) calculated by the number of species reported by Hedlund and Norris (1986) is relatively high (27.59%), whereas it is rather low for the the assemblages of Riley and Fenton (1984) from the Gulf of Mexico.

Assemblages from Senegal (Jain and Millepied, 1975) show that *Circulodinium distinctum, Coronifera oceanica, Cribroperdinium orthoceras, Odontochitina operculata* and *Oligosphaerdium complex* are in common with western Venezuela. Morgan (1978) reported assemblages of the Albian-Senonian offshore west Africa (Angola Basin). Among the species he reported, only *Coronifera oceanica, Exochosphaeridium phragmites* and *Oligosphaeridium complex* are also observed in the assemblages from the Maracaibo Basin. The percentages of species in common between offshore south Africa and and the Maracaibo Basin are the lowest reported in Table 1. Davey (1978) reported assemblages offshore southwest Africa and only *Circulodinium colliveri, Coronifera oceanica, Exochosphaeridium phragmites, Hystrichodinium pulchrum, Odontochitina operculata, Oligosphaeridium complex* and *Spiniferites twistringiensis* are common to the Maracaibo Basin. Hedlund and Beju (1976) studied palynological assemblages from the Falkland Plateau and only *Circulodinium distinctum, Cribroperidinium orthoceras, Odontochitina operculata* and *Oligosphaeridium complex* are common to both areas.

Comparisons of the assemblages reported here from western Venezuela to coeval assemblages of Australia (Burger, 1980; Morgan, 1980; Helby et al., 1987) is restricted to very few species such as *Circulodinium colliveri, Circulodinium distinctum, Chichaouadinium boydii, Chlamydophorella nyei, Coronifera oceanica, Exochosphaeridum phragmites, Florentinia laciniata, Hystrichodinium pulchrum, Odontochitina operculata, Oligosphaerdium complex* and *Spiniferites twistringiensis*. The percentages of common species are relatively low (8 to 16%) between the assemblages reported by Burger (1980), Morgan (1980) and those reported in this study from the Maracaibo Basin.

Dinoflagellate assemblages from northern Africa (Below, 1981 and 1982; Thusu et al., 1988; Uwins and Batten, 1988) and offshore northwest Africa (Williams, 1978; Below, 1984) show similarities with the assemblages of the Maracaibo Basin. Common species between these two areas are *Achomosphaera triangulata, Circulodinium distinctum, Cribroperidinium orthoceras, Coronifera oceanica, Cyclonephelium vannophorum, Exochosphaeridium phragmites, Florentinia laciniata, Hystrichodinium pulchrum, Microdinium opacum, Odontochitina operculata, Oligosphaeridium albertense, Oligosphaeridium complex, Oligosphaeridium pulcherrimum, Spiniferites twistringiensis, Subtilisphaera cheit, Subtilisphaera senegalensis, Subtilisphaera zawia* and *Xenascus plotei*. The percentages of common species with the assemblages reported by Below (1981 and 1982 for Morocco; 1984 for offshore NW Morocco) are among the highest reported in Table 1 (up to 22%).

Species such as *Xenascus plotei, Subtilisphaera cheit* and *Subtilisphaera zawia* have only been reported in northern Africa or southern United States, as well as in western Venezuela. This restricted distribution is interesting paleographically. Regardless of the paleoenvironmental differences, these species seem to be restricted to low paleolatitude areas (northern Africa and South America and southern United States). Kauffman (1973) pointed out that tropical and subtropical biotas of the Mesozoic are classically related to the Tethyan Realm, which includes the Mediterranean and west Pacific areas as well as western Central America, the Caribbean and southern Asia. The occurrence of dinoflagellate cyst species restricted to these areas located at low latitude during the Aptian and Albian is an indication of differentiation of the assemblages, in comparison to high northern and southern latitudes. Williams et al. (1990) pointed out that Aptian dinoflagellate assemblages show pronounced provincialism and can be differentiated in Boreal, North Temperate-Boreal, North Temperate, Tropical-Subtropical and South Temperate regions. According to these authors, dinoflagellate provincialism is also evident during the Albian, with four provinces; tropical-subtropical, north temperate, south temperate and boreal). The present study seems to indicate that elements from northern assemblages (reported from European sections) are also present in low latitude assemblages, perhaps an indication of relatively uniform paleoclimatic conditions or dinoflagellate species adapted to a broad spectrum of paleoenvironmental-paleoecological conditions. Other species, especially some of the genus *Subtilisphaera,* seem to be restricted to or are more common in, low latitudinal areas. Lentin and Williams (1980) pointed out the existence of different peridiniacean dinoflagellate suites during the Campanian, as a consequence of provincialism. It seems to be that species of the genus

*Subtilisphaera* had quite persistent and diversified occurrences in the assemblages of northern Africa (see Below, 1981) and western Africa (Jain and Millepied, 1973). On the other hand, northern assemblages seems to be represented mainly by species of *Deflandrea, Luxadinium* and *Paleoperidinium* (Davey, 1970; Brideaux and McIntyre, 1974). Therefore, differentiation of peridiniacean dinoflagellates may have been initiated during the Aptian–Albian.

As discussed by Williams et al. (1990) some of the tropical to subtropical elements, such as *Kiokansium unituberculatum*, are present in northern assemblages as a product of the Protogulf Current moving northward. Lister and Batten (1988) considered the species *Microdinium opacum* as an indicator of boreal influence in assemblages from the Lower Cretaceous of England. However, the occurrence of this species in assemblages from Africa and northern South America, might be an indication that this species is characteristic of low latitude assemblages. Its occurrence in England might be the result of migration aided by the protogulf current, as discussed by Williams et al. (1990). The occurrence of this species in northwestern Canada, along with *Oligosphaerdium albertense*, might also be the result of warm water incursions in the North America Western Interior Seaway from the protogulf area during the Aptian-Albian.

**4.5 Conclusions.**

A total of four biozones have been defined for the Maracaibo Basin. These biozones are characterized by assemblages of miospores and dinoflagellate cysts. Assemblage biozones I and II are observed onlyt in facies of the Aguardiente Formation and are considered to be largely controlled by paleoenvironmental factors. The variable distribution of occurrences of common species throughout the basin indicates significant paleoenvironmental controls on the distribution of palynomorphs.

The age of biozone I is determined to be Early Aptian. This age assignment is contingent upon further evidence regarding the early evolution of angiosperm pollen in low latitude areas. The sporadic occurrences of angiosperm pollen in the Africa-South America floral province precludes any definite correlation with palynological assemblages of other regions that have been correlated to other fossil group zonations of the Early Cretaceous. It is important to mention that most of the biozonations that have been proposed for Africa and South America have not been correlated to marine

organism such ammonites or foraminifera. As previously discussed, the occurrences of key ammonite and foraminifera taxa are very localized. The presence of *Orbitolina texana* (indicative of the Late Aptian-Albian) in sediments of the Aguardiente Formation (González de Juana et al., 1981) might be used in further studies in order to establish a possible correlation with the palynological assemblages.

The age determination for biozone III indicates that diversification of angiosperm tricolpate pollen grains took place during the Late Aptian. In comparison to the information provided by Muller et al. (1987), it is possible to restrict the time at which this biovent occurred in northern South America.

Another important result of this study is the age determination for assemblages of biozone IV which is constrained by the occurrence of the dinoflagellate species *Xenascus plotei*, that first occurs in the Lower Albian of Morocco (Below, 1981). This information dates the first occurrence of the elater-bearing palynomorphs as Lower Albian in the Africa-South American Province; this event might be synchronous across continents in the Africa-South America Province. In general, miospore assemblages show striking similarities to microfloras that have been reported in the African-South America Early Cretaceous Province (see general discussion in Herngreen and Chlonova, 1981).

The age of the Aguardiente Formation is Aptian–Albian, a result that differs from previous information available in the area, based on scarce paleontological and biostratigraphical data. The age of the Lisure Formation is determined to be Late Aptian to Albian, whereas that of the Apón Formation is restricted to the Aptian.

Dinoflagellate assemblages are not only used for restricting age determinations, but also to assess provincialism for this group during the Aptian–Albian. From the quantitative point of view, the percentages of common species between several localities and the Maracaibo Basin are low and might reflect not only paleoenvironmental differences, but also climatic effects on the distribution of dinoflagellates. Percentages of common species are relatively high for localities of northern Africa (Below, 1981; 1982 and 1984) and southern United States (Hedlund and Norris, 1986). From the qualitative point of view, some species seem to be restricted to northern Africa, South America and southern United States, areas considered by Kauffman (1973) to be part of the Tethyan Realm. The occurrence of these characteristic species support the inferences made by Williams et al. (1990) regarding the existence of provincialism of dinoflagellates during

the Aptian and Albian. The occurrence of species of the genus *Subtilisphaera* in these low latitude assemblages seems to indicate that this group of dinoflagellates had pronounced provincialism during the Aptian and Albian, since peridinacean assemblages at high latitudes were dominated by other genera. Thus, the pattern of provincialism inferred by Lentin and Williams (1980) for the Campanian peridiniaceans might also have existed in the Lower Cretaceous (AptianAlbian).

# 5. ORGANIC SEDIMENTOLOGY AND PALYNOFACIES: INTRODUCTION.

This chapter presents the results and the interpretation of the quantitative and qualitative study of palynofacies and palynomorphs. The main objective is to discriminate and analyze the lateral and vertical distribution of the main palynofloral elements and the main components of the particulate organic matter. The integration of these data is expected to generate a preliminary framework for the sedimentary evolution and correlation of the Maracaibo Basin for the Lower Cretaceous and contribute to the evaluation of the hydrocarbon potential of the basin.

## 5.1 Palynofacies and their applications.

The term palynofacies was introduced by Combaz (1964) to describe the total assemblage of particulate organic matter that is left after maceration with non-oxidizing acids. As recognized by authors such as Denison and Fowler (1980), Batten (1982) and Lorente (1986), palynofacies studies have been used as an aid to sedimentological studies (recognition of paleoenvironments of deposition) and to the characterization of source rocks, both aspects relating to the evaluation of the hydrocarbon potential at the regional level. As Lister and Batten (1988) and Steffen (1993) recognized, palynofacies are characterized by autochthonous and allochthonous organic matter. The former, as the name implies, is the organic matter that is produced in situ; for marine rocks the autochthonous component consists of organic matter produced by marine phytoplankton and for non-marine rocks it comprises organic matter produced mainly by fresh water algae. Allochthonous organic matter, on the other hand, is derived from different sedimentary sources. Terrestrial palynomorphs and phytoclasts (tracheids, vitrinite, inertinite and cuticles-epidermal tissues) behave like sedimentary particles; therefore, the distribution and abundance of the allochthonous component is affected by the nature of the sedimentary environments as well as the texture and characteristics of the sediments. Tyson (1987) pointed out that organic matter is concentrated in fine-grained sediments. Cross et al. (1966) noticed that large concentrations of terrestrial palynomorphs are detected in silty clays at delta mouths whereas low concentrations along the shore are related to winnowing from coarse sediments. Traverse and Ginsburg (1966) also reported that bisaccate pollen are found to be abundant in the silty-sized fraction and concluded that the reported amount of pollen per gram of carbonate mud is one or two orders of magnitude less than in silty-shaly sediments. The proportion of terrestrial palynomorphs and phytoclasts tends to decrease with the distance from the coast line (Muller, 1959;

Cross et al., 1966). These authors noted that the abundance of some species of pollen diminish with the distance from shore, whereas others, such as mangrove pollen, increase their relative frequency offshore. The use of the ratio of terrestrially derived spores and pollen to marine phytoplankton has been used as a method for approximating the distance from the coast (Upshaw, 1964; Zaitzeff and Cross, 1970; Manun, 1976). Muller (1959), Cross et al. (1966) and Farr (1989) noticed that the proportion of phytoclasts is high near the shoreline and delta mouths. van der Zwan (1990) and Steffen and Gorin (1993b) have proposed that more bouyant particles, like degraded woody tissue or vitrinite and blade-shape inertinite, are the more likely phytoclasts to be transported further into the basin, away from the source areas. The composition of these particles makes them highly refractory, increasing their likehood of survival and distribution (Tyson, 1987).

The ultimate fate of palynomorphs and particulate organic matter not only depends on transportation to the final site of deposition, but also to the physical and chemical conditions of the paleoenvironments. Tyson (1987) pointed out that the distribution of marine source rocks is controlled by several factors. He considered that the type of sediment (related to the degree of energy of the environmnent), water depth, primary productivity, rate of deposition of allochthonous organic matter (mainly terrestrial) and level of oxygen at the water-sediment interface largely controlled the accumulation of source rocks. He pointed out that water depth and level of oxygen at the site of deposition are essential for the enrichment of organic matter, generally in fine-grained sediments, because these two factors are highly related to the possibilities of preserving the organic matter during its deposition. Rates of primary productivity also have an effect but, as discussed by Tyson (1987), without the conditions under which this matter can be preserved, there is not significant accumulation. Rates of deposition might enhance the preservation of the organic matter, but high rates of deposition also dilute the organic matter being accumulated. However, this parameter is important for studies like the one proposed here, in the sense that changes in the preservation of the palynomorph assemblages and particulate organic matter might be related to changing sedimentary conditions.

A more recent application of palynofacies has been developed in relation to sequence stratigraphy. Vail et al. (1977), Posamentier et al. (1988) and Vail et al. (1991) have proposed that sedimentary processes are controlled by a complex interaction of several factors (subsidence, tectonics, sediment supply and eustasy) being eustasy the driving force that controls the generation of accomodation space. Based on the concepts

elaborated by these authors, recent work on visual and geochemical characterization of palynofacies and kerogen have been conducted to determine the variation of particulate organic matter within the framework of sequence stratigraphy. Recent contributions have dealt extensively with concepts and methodology of how palynofacies change during different parts of the eustatic cycle. In general these studies have been done mainly in deep water settings and have focused their attention on source rocks (for example, Tribovillard and Gorin, 1991; Pasley et al., 1993; Steffen and Gorin, 1993a-b). In essence these authors have characterized the allochthonous fraction (the one that is transported to this deep water settings) from the quantitative (percentage of a given maceral or phytoclasts) and qualitative (aspect, preservation and sorting) points of view. The lowstand system tract deposits (formed during sea-level fall) are characterized by the predominance of terrestrial organic matter (vitrinite and inertinite, see discussion below on classification of organic matter) which is poorly sorted and of large average size. Autochthonous organic matter is absent or in very low abundance, diluted by the abundance of terrestrial material that in being transported into the distal parts of the basin. As sea-level begins to rise, palynofacies associated with the transgressive systems tract are characterized by the abundance of inertinite material, along with vitrinite. The average size of these phytoclasts is often smaller compared with the lowstand system tract palynofacies. Autochthonous organic matter (produced by phytoplankton) tends to increase towards the top of the transgressive system tract, as the distal paleoenvironments become more marine. The abundance of marine phytoplankton and autochthonous organic matter reaches a peak at the maximum flooding surface (Blondell et al., 1993; Helenes et al., 1993; Steffen and Gorin, 1993b). However, the latter trend regarding the diversity of the phytoplankton assemblages, is a point still discussed and controversial. Habib et al. (1992) recorded the abundance peaks for dinoflagellate in sediments of the transgressive system tract. These authors reported that the number of species of dinocysts decreased towards the top, in the condensed section (maximum flooding surface) and highstand system tract sediments. The highstand system tract palynofacies shows a reverse trend to that observed for the transgressive system tract; increasing amount of terrestrial (allocthonous) material towards the top.

Studies of palynofacies in shallow water environments or paleoenvironments are not common in the literature. Blondel et al. (1993) pointed out that biostratigraphic framework is in general poor in coastal settings, since most of the fossil assemblage show greater lateral variability. Gorin and Steffen (1991) mentioned that open marine

carbonates are usually less favourable for the preservation of organic matter because of their oxidizing conditions and lower sedimentary rates.

**5.2 Dinoflagellate assemblages: Paleoecology.**

Miospore and dinoflagellate assemblages are routinely observed during palynofacies studies. Miospores are essentially considered allochthonous material in marine settings and their distribution is controlled by the same factors as terrestrial organic phytoclasts.

Dinoflagellate assemblage distributions reflect to some degree the complex interaction of several factors such as latitude, temperature, salinity and paleoenvironments (Dale, 1976; Morzadec-Kerfourn, 1976; Wall et al., 1977; Edwards and Andrle, 1992). Norris (1975) noted that the distribution of dinoflagellates can also be affected by photoperiod. Reid and Harland (1977) noted that cyst thanatocoenoses is controlled by 4 main factors:

a) Latitude; amount of solar radiation, photoperiod, temperature and climate
b) Water depth; as onshore-offshore gradients
c) Water mass; convergence, upwelling, bathymetry
d) Sedimentary factors; selective concentration of a given taxa.

Wall et al. (1977) noted that diversity and occurrence of given taxa in the Recent are functions of the salinity, currents, turbidity, temperature and distance from coastal areas. They compared different paleoenvironments of deposition, located at different latitudes, and concluded that the distribution of dinoflagellates is partially controlled by two major paleoenvironmental gradients; latitudinal and inshore-offshore. The diversity increases with distance from the coastal areas in the continental shelf. The gradient inshore-offshore is also characterized by different association of dinoflagellate assemblages that were related to conditions of salinity, turbidity and the occurrence of open marine environments. Wrenn and Kokinos (1986) also recognized latitudinal (arctic, temperate and tropical elements) and inshore-offshore (inner neritic, outer neritic and oceanic assemblages) gradients. They noted the occurrence of in situ late Cenozoic inner-neritic and oceanic assemblages, as well as displaced or mixed assemblages as a result of upwelling (displacing oceanic or outer neritic assemblages into inner neritic environments) or density flows (displacing inner neritic species into the slope in outer

neritic and oceanic environments). Edwards and Andrle (1992) recognized that the distribution of dinoflagellate cyst in modern sediments reveals a clear trend of ecologic preferences and tolerances of several species of dinoflagellate cyst, mainly related to the water temperature and depth. Morzadec-Kerfourn (1988) distinguished different dinocyst assemblages in the Recent of the Nile Delta. These assemblages were related to climatic variations during glacial and interglacial periods. de Vernal et al. (1992) reported that mid-latitude dinoflagellate cyst stratigraphy differs from that at high latitudes during the Quaternary. The differences in composition and abundance of the different dinoflagellate cyst species clearly reflects the local climate and paleoceanography. These authors also reported that low latitude dinocyst assemblages show small changes during the Quaternary, compared with the appearance, acme and disappearance of several taxa at high latitude areas during different climatic cycles.

Sarjeant et al. (1987) indicated that there is a relationship between dinoflagellate cyst morphology and the environments where they occur. Spines and processes appear to be developed as buoyancy controls or structures that might be related to increasing resistance to the sinking of the cysts. Therefore, dinocysts with elaborate spines and processes should be more common in open marine conditions. Scott and Kidson (1977) reported the existence of characteristically high- and low-energy dinoflagellate assemblages in Lower and lower Upper Cretaceous carbonate deposits in Texas. Harker et al. (1990) described several dinoflagellate associations from the Upper Cretaceous (Campanian) of the western interior of North America. Assemblages dominated by peridinioid species (in general characterized by the lack of processes or spines) were in general related to nearshore conditions with low salinities. These perinidioid-dominated assemblages were also related to regressive pulses due to a relative sea-level fall. The occurrence of terrestrial palynomorphs and phytoclasts in these associations seems to validate the interpretation. Davey (1979a) also noted that peridiniacean cyst abundance is greater in nearshore environments. On the other hand, dinoflagellate associations dominated by gonyaulacoid species (with proximate, cavate, proximochorate and chorate forms) were more characteristic of open marine conditions and were related to transgressive pulses. Changes in the composition and diversity of dinoflagellate assemblages has also been used to infer sea-level changes (Morzadec-Kerfourn, 1976; Habib and Miller, 1989; Habib et al., 1992; Eshet et al., 1992).

Little information is available on the nature of Lower Cretaceous dinocyst assemblages in low latitudes, especially on shallow water carbonate platforms. Scott and

Kidson (1977) reported dinoflagellate assemblages from the Lower to lower Upper Cretaceous carbonate deposits in Texas, but the publication did not present details about regional distribution of these assemblages. Uwins and Batten (1988) described different miospore and dinoflagellate assemblages from the Lower Cretaceous of Libya, but without detailed remarks on the distribution and variation of these assemblages as a function of inferred distance from shore or lithology with which the assemblages were associated.

### 5.3 Procedure.

The basic procedure for the chemical maceration of samples and the isolation of palynological residues was summarized in the third chapter (Figure 8, p. 35). In this study, samples were not oxidized as is normally done for palynomorph extraction, because preservation of the assemblages did not require it. Furthermore, it was considered necessary to reduce the chemical alteration of the final residue to the minimum possible.

#### 5.3.1 Palynomorph counts.

Description and counting of the different palynomorphs groups and classes of particulate organic matter were done mainly in a transmitted-light microscope (Wild Leitz Ortholux Microscope), using bright field and interference contrast (IC). Scanning of the slides during counting was done using a 40X objective, whereas detailed descriptions and observation were done using a 100X objective.

Due to the variable preservation of the assemblages, a two-fold procedure for the counting of palynomorphs was used:

a) For samples with very low counts of palynomorphs (less than 350 palynomorphs), the counting was done using the three slides that were prepared for each sample. The number of palynomorphs reported correspond to those observed in the three slides.

b) For samples with very rich palynomorph assemblages, counting was done taking into consideration the appearance of new species or types as the counting proceeded. Counts were done up to 350 specimens per slide. Then, 50 additional specimens were counted and if no new species or types were observed, the counting was stopped. Otherwise,

counting proceeded until the previous criterion was fulfilled. Only samples with 100 or more specimens were considered for the quantitative analysis presented in this study.

### 5.3.2 Phytoclast identification and count.

The methodology for the study of particulate organic matter was designed to cover, firstly, the identification of the main types of phytoclasts and secondly, their quantitative and qualitative characterization.

Several schemes for the classification of particulate organic matter have been proposed in the literature. Initially, nomenclature of organic matter was developed almost exclusively by coal petrologists (see Stach et al., 1975). Most of the classifications schemes proposed for particulate organic matter recognize two basic types: structured and non-structured phytoclasts. Structured material shows morphological features that allow its classification according to biological origin. In general, as Combaz (1980) discussed, the classifications are based on the separation of different phytoclasts according to their botanical origin; terrestrial plants (including macrophyte tissues-woody, herbaceous, epidermal, pollen and spores), phytoplankton (dinoflagellates, algae, protists and acritarchs) and animal (foraminiferal linings, graptolites, scolecodonts). Unstructured material, on the other hand, is considered polygenetic, since it might be the result of chemical, physical and biochemical degradation and/or organic aggregates or fecal pellets of planktonic organisms (Combaz, 1980 and Hart, 1986).

Whittaker (1984) and Steffen (1993) have proposed a classification for particulate organic matter that is the basis for the classification adopted in this study (Figure 21). These authors divided the organic matter into continental (allochthonous) organic matter and marine (mostly autochthonous). The so-called palynomacerals PM1 and PM2 of Whittaker (1984) were incorporated in this study as one category, that of vitrinite (see Plate 18, figures 1-3 and Plate 19, figure 1). Vitrinite phytoclasts are recognized by the light to dark brown chunky appearance (resembling wood) and that in most cases in this study, lacked of any structure. PM 3 palynomacerals (cuticles) of Whittaker were also observed in this study and are considered to be epidermal tissues. Epidermal tissues are characterized by fragments with clear cellular structure. The lack of stoma in these macerals is the main reason to consider them as epidermal tissues in general and not cuticles, which are specifically to leaf epidermal tissues. The PM 4 palynomaceral

<table>
<tr><th>COAL MACERALS (STACH ET AL., 1975)</th><th>WHITTAKER (1984)</th><th colspan="2">STEFFEN (1992)</th><th>THIS STUDY</th><th>ORIGIN</th></tr>
<tr><td rowspan="2">VITRINITE</td><td>PM 1<br>PM 2</td><td colspan="2">PM 1<br>PM 2</td><td rowspan="2">VITRINITE</td><td rowspan="7">CONTINENTAL</td></tr>
<tr><td>PM 3 (CUTICLES)</td><td colspan="2">PM 3 (CUTICLES)</td><td>EPIDERMAL</td></tr>
<tr><td>INERTINITE</td><td>PM 4</td><td>PM 4</td><td>EQUI.<br>BLADE</td><td>INERTINITE</td></tr>
<tr><td rowspan="2">EXINITE OR LIPTINITE</td><td>SPOROMORPHS (SACCATES)</td><td colspan="2">BISACCATES</td><td>MIOSPORES</td></tr>
<tr><td>SPOROMORPHS (NON-SACCATES)</td><td colspan="2">NON-SACCATES</td><td>FRESHWATER ALGAE</td></tr>
<tr><td></td><td>AMORPHOUS ORGANIC MATTER</td><td colspan="2">NON-FLUORSC. AMORPHOUS<br>FLUORESCENT AMORPHOUS</td><td>AMORPHOUS ORGANIC MATTER</td><td rowspan="5">MARINE</td></tr>
<tr><td rowspan="2">EXINITE OR LIPTINITE</td><td>ACRITARCHS</td><td colspan="2">ACRITARCHS</td><td>ACRITARCHS</td></tr>
<tr><td>DINOCYSTS</td><td>DINO-CYSTS</td><td>PROX.<br>CHORA.</td><td>DINOCYSTS</td></tr>
<tr><td></td><td>FORAM. LININGS</td><td colspan="2">FORAM. LININGS</td><td>FORAM. LININGS</td></tr>
<tr><td>ALGINITE</td><td>ALGAE</td><td colspan="2">ALGAE</td><td>ALGAE</td></tr>
</table>

Figure 21. Particulate organic matter classification proposed by Whittaker (1984), Steffen (1992) and in this study (Equi. and blade refer to shape of inertinite (PM 4) fragments. Prox.= proximate dinocyst, Chora.= chorate dinocyst).

category of Whittaker's classification was also observed in this study and is characterized by black color and unstructured appearance. It is considered here as inertinite (see Plate 19, figure 3). Under interference contrast, the inertinite fragments show some luster and in some cases it was possible to see parting, which is characteristic of coals (Stach et al., 1975). Other phytoclasts of continental origin are miospores, extensively described in the Systematic Chapter.

The allochthonous fraction of the organic matter for the purposes of this study was divided into three categories: dinoflagellate cysts, other algae and acritarchs (see chapter on Systematic Palynology); foraminiferal linings and scolecodonts (see discussion in this chapter); and amorphous organic matter. The amorphous organic matter observed in this study is characterized by the lack of any morphological features and resembles organic aggregates or organic clusters (see Plate19, figures 2 and 3). Observations done under ultraviolet light did not show significant fluorescence, perhaps related to oxidizing conditions and thermal alteration of the organic matter after deposition.

A total of 240 particles per sample were identified and counted per sample. In order to avoid bias due to any differences in the preparation of slides, three sets of 80 particles each were counted in different areas of each slide.

In the case of vitrinite, epidermal and inertinite phytoclasts, miospores and for the marine dinoflagellate cysts and foraminiferal linings, the length of the longest axis was measured. No dimensions were determined for the the spongy aggregates of amorphous organic matter, since it was considered that size of the aggregates could have been significantly modified by the preparation, sieving of the residues and by the mounting of the slide.

The average and standard deviation particle size were then calculated for each of the categories of organic matter. Most of the studies using particulate organic matter have quantified their abundance (in general as a percentage of the total count of phytoclasts). Steffen and Gorin (1993b) and Pasley et al. (1993) have proposed that palynofacies show different degrees of sorting depending on the systems tracts and the associated sedimentary processes. However, evaluation of the degree of sorting from the quantitative point of view has been absent from these studies. It is noteworthy that in a palynological slide, despite the efforts to prepare a homogeneous residue, the distribution

of palynomorphs and particulate organic matter is seldom completely homogeneous. Therefore, there is a degree of subjectivity to this type of evaluation. The use of the standard deviation, as an indirect measure of the degree of sorting, can be useful in order to determine variational trends in this type of studies.

## 5.4 Results.

One of the main factors limiting the interpretation of the information produced from palynological and palynofacies analyses of this study is the preservation of the different assemblages. As seen in Figure 22, the number of samples with numerous specimens (more than 300 palynomorphs) is low. Samples obtained from the most southern sections (La Grita-Seboruco, Zea-Panamericana and to a lesser degree, CR-5) show more samples with more than 300 palynomorphs than the sections located in the central and northern areas of the basin. In part, lithologies sampled in the sections of La Grita-Seboruco and Zea-Panamericana are mainly fine-grained sediments (shales) whereas the lithologies that were collected in the subsurface sections are more diverse and included carbonate facies. In these sections, the more productive samples are also mainly shale and siltstone samples. A more detailed decription of the results for each of the sections follows.

### 5.4.1 Zea-Panamericana outcrop section.

The Zea-Panamericana outcrop section consists of about 230 m of fine to medium grained sandstones with microconglomeratic horizons at some levels, alternations of gray to black massive to finely laminated shales, and development of localized arenaceous and bituminous limestones (see Appendix B-1). Ms. Xiomara Márquez and Selena Mederos did a preliminary sedimentological study of this section as part of the exploratory efforts of Maraven, S.A. and kindly provided information on the sedimentology and lithology of this section. A total of 43 samples were included in the palynological and palynofacies analysis.

#### Palynological-palynofacies description.

The palynological assemblages and palynofacies are dominated by terrestrial miospores and macerals (Figure 23). Changes of their composition and characteristics allows the recognition of three main sedimentological-palynological units.

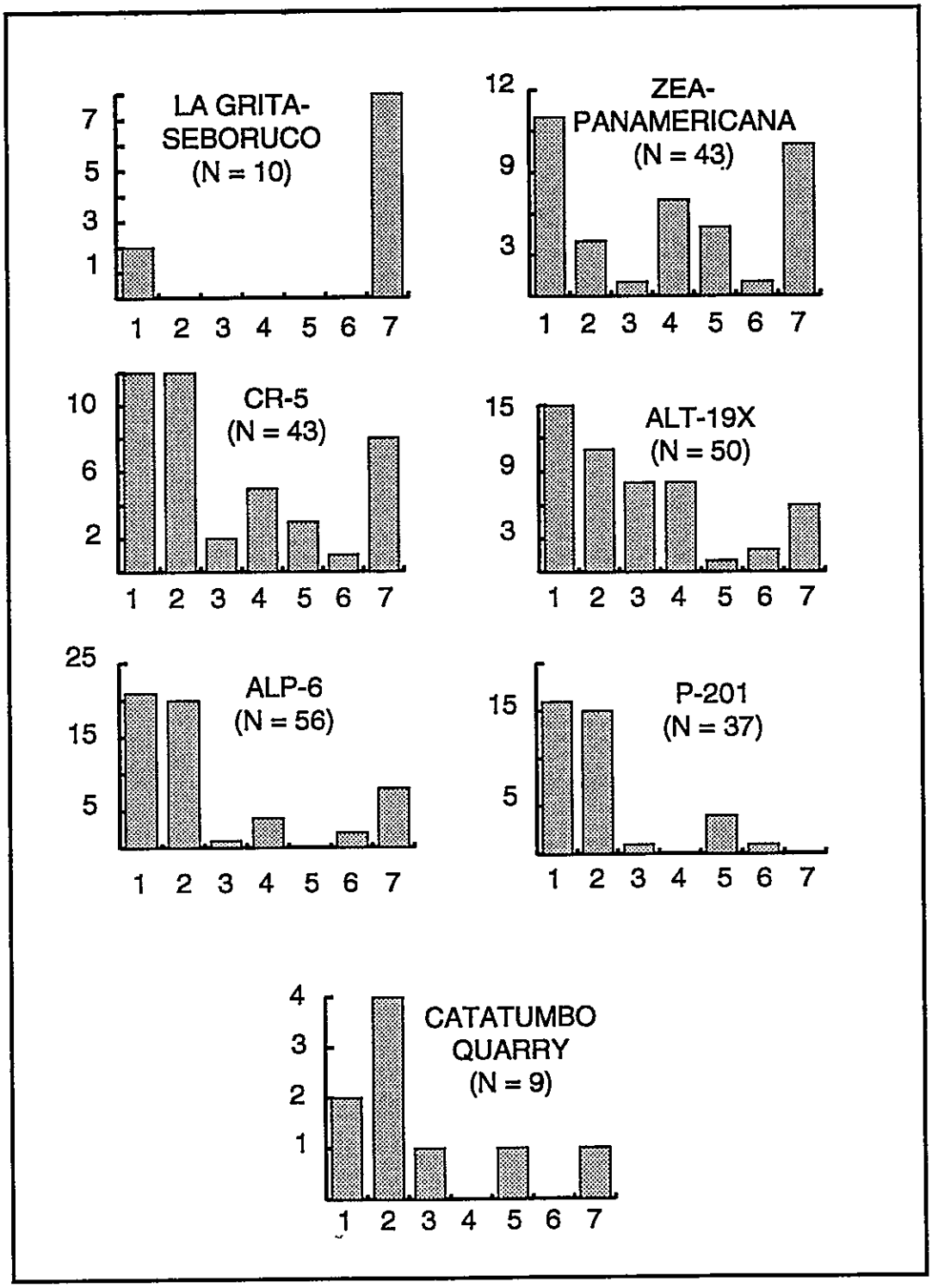



Figure 22. Number of samples per studied section with a given yield of palynomorphs; **1**= barren, **2** = 1 to 50 specimens counted; **3** = 51 to 100 specimens; **4** = 101 to 200 specimens; **5** = 201 to 300 specimens; **6** = 301 to 350 specimens and **7** = 351 or more specimens.