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BIOSTRATIGRAPHIC STUDY OF CALPIONELLIDS AND NANNOFOSSILS IN THE TETHYAN REALM (SPAIN, SICILY, SE FRANCE) IN LATE JURASSIC AND BERRIASIAN TIME: A CORRELATION WITH MAGNETOSTRATIGRAPHIC RESULTS

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The examination of three sections in the Tethyan realm in Late Jurassic and earliest Cretaceous time is re-grouped. One of them has been selected in Alicante Province, Spain. Another section was studied in Sécani Mts. in Sicily. The third section is that of the stratotype of the Berriasian in Ardèche (SE France), on the Cévennes border.

The biostratigraphic analysis is based on an exhaustive study of the ammonites, the calpionellids the nannofossils and the radiolarians.

The magnetostratigraphic results concern only the profile of the stratotype at Berrias, France.

Keywords: Jurassic/Cretaceous boundary, lithostratigraphy, biostratigraphy, calpionellid zonation, nannofossil zonation, magnetostratigraphy, stratotype of Berriasian stage

Biostratigraphic Study of the Nannoplankton from the Profile of Foncalent (Alicante, Spain)

The Sierra of Foncalent is situated at a distance of a dozen kilometres west of Alicante, near the national highway Madrid-Alicante. The section under consideration belongs to the pre-Betic zone (Fig. 1).

The study of nannoplankton from the profile of Foncalent included the observation of 30 samples, the mainly carbonate facies of which had yielded coccolith and Nannoconus assemblages suitable for defining biozones comparable to the ones described from the Tethyan realm or the Atlantic.

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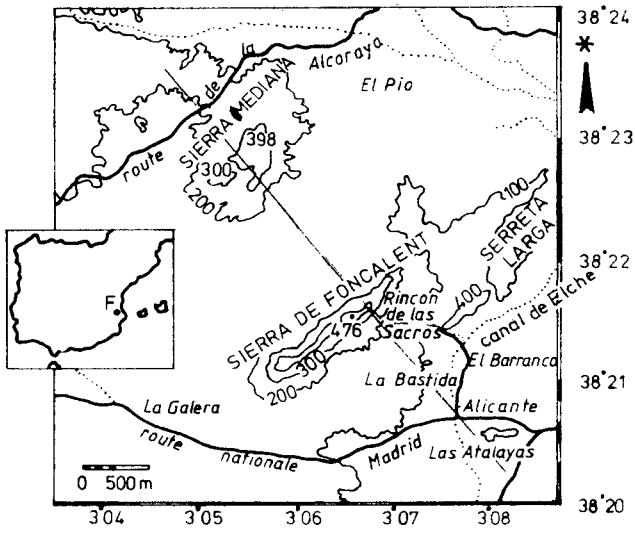

Fig. 1. **Location of the profile of Foncalent (Spain)**

Biostratigraphy

Historical review

Several biozonations were proposed in the last decade for the Lower Cretaceous in the Tethyan realm by Thierstein (1973), Manivit (1979), Deres and Acheriteguy (1980) and, for England, by Taylor (1978).

Observations and biozones were presented for the Jurassic-Cretaceous boundary by Thierstein (1975) and, in the oceanic domain, by Wind (1978), Cepek (1978) and quite recently by Roth (1983).

For the Upper Jurassic, three biozones were proposed for the boreal realm by Barnard and Hay (1975), Hamilton (1982) and Medd (1982). Correlation schemes and a new detailed biozonation developed for the oceanic domain and comparable to the Tethyan realm were published by Roth (1983) on Site 534 in the NW Atlantic.

Kimmeridgian to Valanginian nannofossil biozonation

As shown by the optical analyses of samples from the Foncalent profile, the main index species utilized for the zonation proposed here are recognizable.

The biozone boundaries and the major appearances and disappearances are indicated on the detailed geological log of the profile (Fig. 2).

The biozones are defined with precision and comparisons and discussions with the works of preceding authors are introduced (cf. Table I).

Table I

Correlation of calcareous nannofossil zonations by Medd *(1982),* Roth *(1983) and the new zonation proposed in this study*

<table>
<tr><th>Stage</th><th>Medd (1982)</th><th colspan="2">Roth (1983)</th><th>This study</th></tr>
<tr><td>Berriasian</td><td rowspan="3">*P. embergeri*</td><td colspan="2">*Nannoconus colomii*</td><td>*Nannoconus colomii*</td></tr>
<tr><td rowspan="2">Tithonian</td><td rowspan="2">*Conusphaera mexicana*</td><td>*Polycostella beckmannii*</td><td rowspan="2">*Conusphaera mexicana*</td></tr>
<tr><td>*Hexapodar cuvillieri*</td></tr>
<tr><td rowspan="3">Kimmeridgian</td><td>*Polypodorhabdus mandingleyensis*</td><td colspan="2" rowspan="3">*Vagalapilla stradneri*</td><td rowspan="3">*Vagalapilla stradneri*</td></tr>
<tr><td>*S. tortuosus*</td></tr>
<tr><td>*E. britannica*</td></tr>
</table>

1. *Vagalapilla stradneri* Zone, Barnard and Hay, emend Roth (1983). The *Vagalapillas stradneri* Zone spans the interval between the appearance of *Vagalapilla stradneri* and the appearance of *Conusphaera mexicana.*

In the profile of Fontcalent, *Vagalapilla stradneri* appears much later and more rarely than it is the case with England or the N Atlantic. Consequently, the length of my zone is more reduced than that of the same name proposed by Barnard and Hay (1975) or Roth (1983). As identifiable in the samples studied, (827 – 818 – 787), it corresponds nearly to the *Polypodorhabdus mandingleyensis* Zone of Medd (1982) or to the top of Roth's *Vagalapilla stradneri* Zone, i.e. to the Upper Kimmeridgian.

In samples 818 and 787, *P. mandingleyensis* is absent and so are the forms liable to being lost to dissolution. Only resistant species that existed already in Middle to Late Jurassic times, such as *Cyclagelosphaera margereli*, *Diazomatholithus lehmanii*, *Watznaueria communis* and *Watznaueria barnesae* are present.

2. *Conusphaera mexicana* Zone, Thierstein (1975), modified in this paper. The *Conusphaera mexicana* Zone spans the interval between the first appearance of *Conusphaera mexicana* and the first appearance of true *Nannoconus colomi* specimens.

At Foncalent there is no possibility for subdividing this biozone, unlike could be done by Roth (1983), for the index species *Hexapodorhabdus cuvillieri* and *Stephanolithion bigoti* have not been recognized.

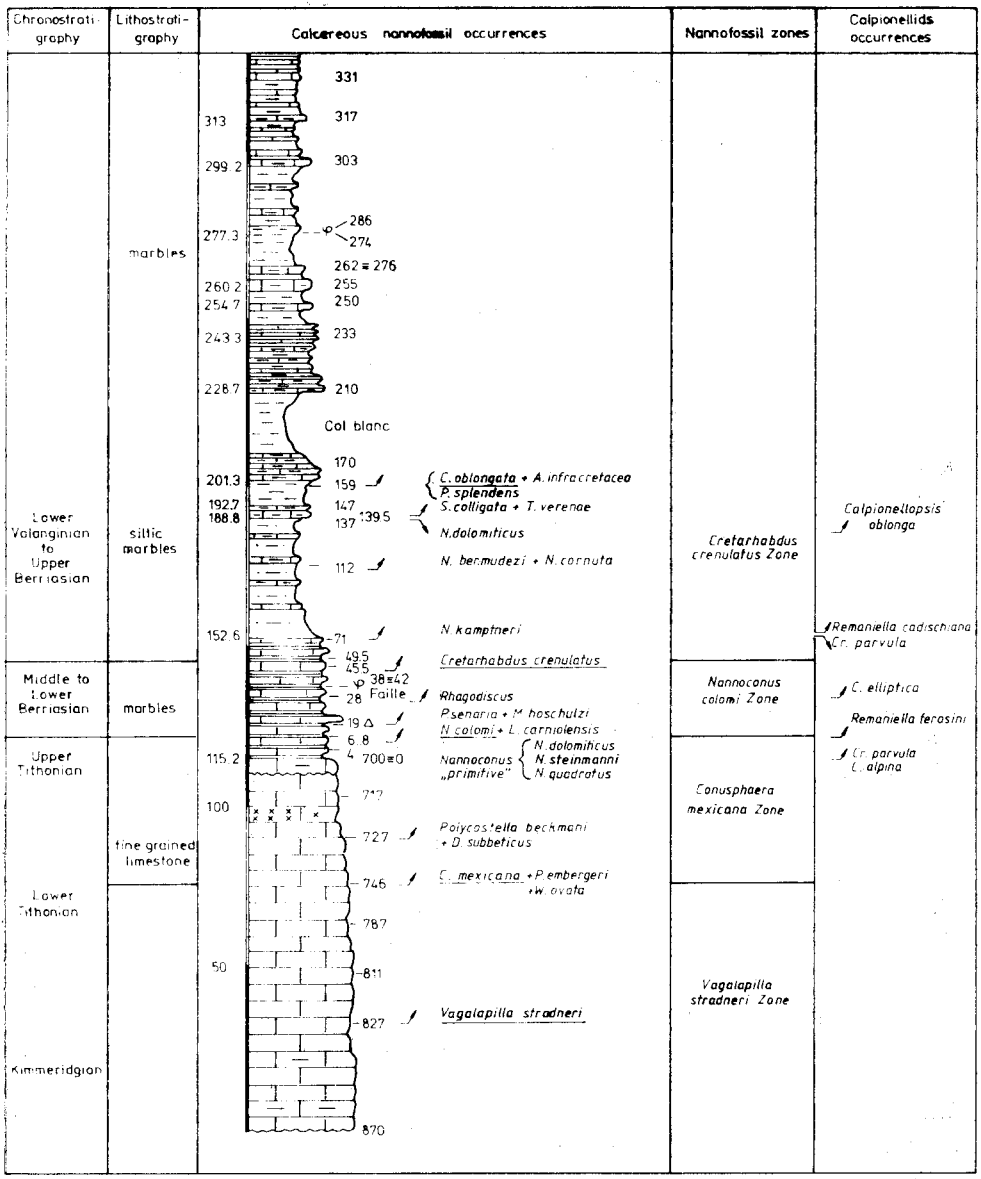

Fig. 2. Upper Jurassic and Lower Cretaceous chronostratigraphy of Foncalent (Spain)

Simultaneously with the appearance, from 746 onwards, of *Conusphaera mexicana*, there appear the first, small (7 to 9 μ long) representatives of *Parhabdolithus embergeri* (the Berriasian ones being larger).

In addition to the Jurassic species already presented in the former zone, there appear, from 727 onwards, *Polycostella beckmannii* and *Diazomatholithus subbeticus; Watznaueria ovata* appears at 746.

Age: Identified in the Tethyan and the oceanic domains, the *Conusphaera mexicana* Zone seems to correspond to the Lower and Upper Tithonian. At the top of this zone, from Sample 700 onwards, the first small nannoconids less than 8 μm long which are not yet the true *Nannoconus colomi* are observed to appear quite distinctly. Deres and Acheriteguy (1980) described and figured these "primitive" Nannoconus occurring rather frequently in the terminal beds of the Tithonian. They are well represented at Foncalent, including *Nannoconus dolomiticus*, *Nannoconus quadratus* and *Nannoconus steinmanni* minor.

The profile of Foncalent has permitted us to confirm that the first appearance of *Conusphaera mexicana* marks the base of the Tithonian and that the first Nannoconus of small size are indicative of the top of the Tithonian.

Thus the first basal Cretaceous beds can be defined only by the appearance and the abundance of *Nannoconus colomi* s. str. The first appearance of the genus *Nannoconus* does not mark the Jurassic-Cretaceous boundary as defined by Thierstein in 1975.

3. *Nannoconus colomi* Zone. The *Nannoconus colomi* Zone spans the interval between the first appearance of *Nannoconus colomi* s. str. and the appearance of *Cretarhabdus crenulatus* Bramlette et Martini (synonym of *Retecapsa neocomiana* zone's). Author: Worsley (1971), modified by Thierstein (1975).

At Foncalent the base of this zone is observed at Sample 12.8, where scarce *Lithrapidites carniolensis* and *Crucielliepsis cuvillieri* appear. The first true *Nannoconus colomi* (more than 8 μ long) as well as *Nannoconus bronnimanii* and *N. globulus* make their appearance, too. At 19.5, *Polycostella senaria* and *Micrantholithus obstusus* appear. At 28, *Rhagodiscus asper* and *Stephanolithion laffittei* are accompanied by the Upper Jurassic coccolith assemblage of *W. barnesae*, *W. communis*, *Cyclagelosphaera deflandrei*, *Diazomatholithus subbeticus*, *Conusphaera mexicana* and *Parhabdolithus embergeri*. *Polycostella beckmanii* seems to disappear at 40.5, at the top of the *Nannoconus colomi* Zone which virtually represents the Lower Berriasian.

4. *Cretarhabdus crenulatus* Zone. The *Cretarhabdus crenulatus* Zone defined by Thierstein (1971) spans the interval between the first appearance of *Cretarhabdus crenulatus* and the appearance of *Calcicalathina oblongata*. In this zone, the representatives of *Rucinolithus wisei* and, from Bed 139.4 onwards, *Tubodiscus verenae*, a species that is refringent owing to its central tube, also appear, together with *Speetonia colligata* and *Reinhardites fenestratus*. As far as the nannoconids are concerned, *Nannoconus kamptneri* appears at 71, *Nannoconus cornuta* with *N. bermudezi* appearing at 112.

Remark: In the *Cretarhabdus crenulatus* Zone there is a great diversity of coccoliths and *Nannoconus* which I encountered also at Berrias and which Thierstein (1973) had observed in SE France, too. Grün and Allemann (1975)

described, at Caravaca, Spain, a list of species almost completely analogous with that of Fontcalent, except for *Lithraphidites carniolensis Rucinolithus wisei* and *Reinhardites fenestratus*. *Tubodiscus verenae* seems to appear a little bit earlier in Spain, a little before the appearance of *Calcicalathina oblongata*, while in the Atlantic these two species have synchronous appearances.

Age: The *Cretarhabdus crenulatus* Biozone seems to correspond to the Upper Berriasian-Lower Valanginian, the Berriasian-Valanginian boundary being impossible to trace by the aid of the nannoplankton.

Preservation and distribution

If a good number of useful markers or guide-fossils could be recognized for the definition of biozones, it must be admitted that not all samples have supplied a well-preserved and homogeneous nannoflora. The fact is that recrystallization and dissolution have often weakened the specific diversity of the fossils.

The different development of the nannofossils and the extremely variable proportion of coccoliths as compared to Nannoconus was controlled by the abundance of the influx of detrital material, the carbonate to clay ratio and the diagenetic factors.

In Tithonian-Berriasian time, the Watznaueria group as well as the genera *Conusphaera*, *Polycostella*, *Cyclagelosphaera* and *Micrantholithus* are predominant. Smaller Nannoconus, often quite abundant, also contribute to the proportion of the assemblage of "robust" coccoliths. Delicate forms such as *Corollithion*, *Stradnerlithus*, *Stephanolithion* and *Diadorhombus* are almost totally absent in Spain, while they are very diversified in the Late Jurassic epicontinental sea deposits of England (Barnard and Hay, 1975; Medd, 1982) and in France (Noel, 1973); hence the loss of relevant information for the establishment of subzones. Nevertheless, the diversity and abundance of *Nannoconus* at Foncalent and throughout the Tethys (and their quasi-absence in England) provide a parallel scale, complementary to that based on coccoliths and comparable to that recorded by Deres and Acheriteguy (1980) in Aquitaine and N Africa.

In the profile of Foncalent, the preservation and the abundance of nannofossils are observed to vary with the facies, the coccoliths being more abundant in the marls, while the limestones are dominated by *Nannoconus* and resistant forms.

Paleobiogeography

The nannoflora observed in the section of Foncalent is constituted, for a considerable part, by cosmopolitan species, resistant to diagenesis, and by a few typical Mediterranean species, i.e. by ones absent in the boreal realm — England and Germany — such as:

Diadorhombus rectus
Tubodiscus verenae
Speetonia colligata
Polycostella beckmanii
Diazomatolithus subbeticus
Hexalithus noelae.

This last-quoted assemblage was found by Thierstein in southern France, by Grün and Allemann (1975) in Spain and, quite frequently, in the Atlantic Ocean by Thierstein (1975), Cepek (1978), Wind (1978) and Roth (1983).

The resemblance of the nannoflora of southern France and Spain to that described recently by Roth (1983) from Site 534 in the Atlantic suggests that the degree of aeration of the water rather than the biostratigraphic factors of preservation of the nannoflora is responsible for the difference between some nannofossils of England and those of the Tethys, having much in common with their North Atlantic counterparts.

Profile of Santa Anna (Sicily)

Situated south of Caltabellota, Sicani Mts., Sicily, this profile was the subject of a number of earlier studies by Mascle (1979), Riedel and Sanfilippo (1974) and Baumgartner et al. (1980) (Fig. 3).

The ages determined for the three quite typical formations vary from author to author. These are radiolarites at the base, followed next by the Ammonitico Rosso facies and, at the top, by the Calpionella Limestone, the

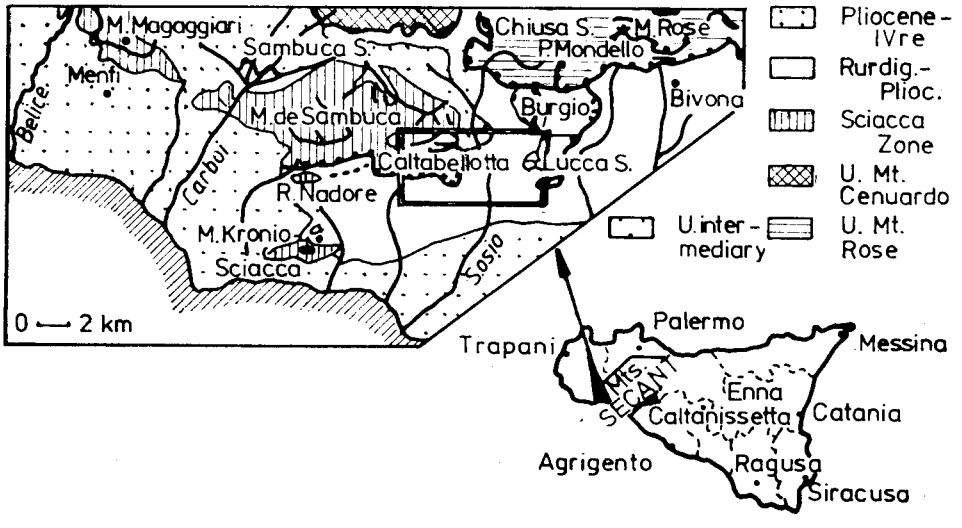

Fig. 3. Location of the profile of Santa Anna (Sicily)

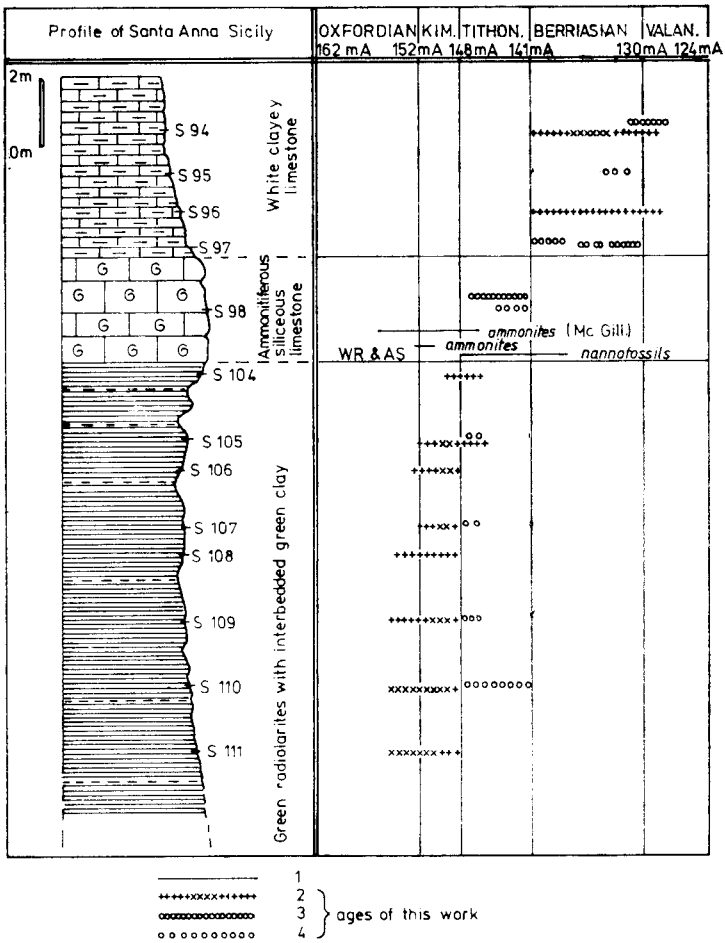

Fig. 4. Synthesis of data obtained from Santa Anna, Sicily, based on *Radiolaria* (left column of the lithostratigraphic column) and the ages of all samples after different fossils (on the right). The age of all samples in the lithostratigraphic column are shown according to different fossils. 1. Previous data; 2. radiolarite data; 3. calpionellid data; 4. nannofossil data. WR AS = Reidel and Sanfilippo

dating having been based both on ammonites and nannofossils. The rather closely spaced sampling by P. De Wever has permitted to add further precision to the biozonation due to the presence of Calpionellids, *Radiolaria* and Nannofossils. Figure 4 illustrates the distribution of the different types of microfossils. A comprehensive synthesis have been worked out (De Wever et al. 1986).

The nannofossils are rather well represented in the radiolarites, while the calpionellids are absent. The coccolith assemblage is constituted by Jurassic forms plus *Conusphaera mexicana* and *Polycostella beckmanii* with the first

primitive *Nannoconus* as: *N. dolomiticus* and *N. steinmanni* minor. This assemblage characterizes the *C. mexicana* Zone of the Upper Kimmeridgian to Lower Tithonian.

The Ammonitico Rosso facies has yielded resistant *Tithonian* s.l. *coccoliths*, the age having been confirmed by the presence of *Crassicollaria intermedia* and *C. gr. massutiniana.*

The Calpionella Limestone has furnished a rather rich and well-preserved nannoflora composed of coccoliths and *Nannoconus* belonging to the basal Berriasian and, from Sample 95 onwards, to the Upper Berriasian. The NC1 and NC2 Zones of Roth are successively recognizable. The presence of *Calpionellopsis simplex* and *C. oblonga* speaks in favour of a Middle to Upper Berriasian age.

The Stratotype of the Berriasian

Lithostratigraphy

A 25 m thick section has been exposed north of Berrias, in the bed of a small brook, the Graveyron. Vast structure surfaces, tilted 8° to the SE, have permitted a precise sampling. The outcrops are continuous from the Tithonian onwards. The section is constituted by a sequence of bedded grey limestones with beds several decimetres thick separated by thin marly limestone interlayers. Consistent throughout the section, the facies is calpionellid-bearing micrite, except for the top of the sequence which is more marly and laminated (Fig 5 and 6).

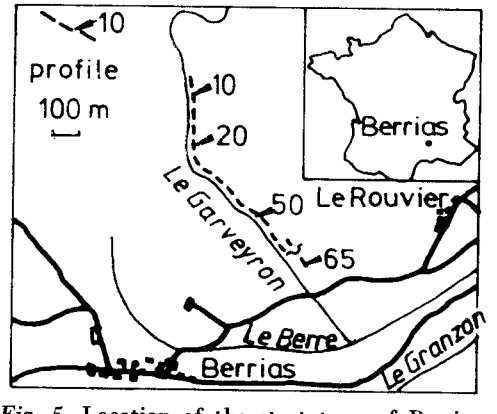

Fig. 5. Location of the stratotype of Berrias

Biostratigraphy

Based on ammonites and calpionellids, a subdivision of the stage into zones and subzones was proposed by Le Hégarat and Remane (1968–1973). The Berriasian at Berrias comprises three ammonite zones. It begins with the upper half of the Calpionella Zone, encompasses the Tintinnopsella Zone and

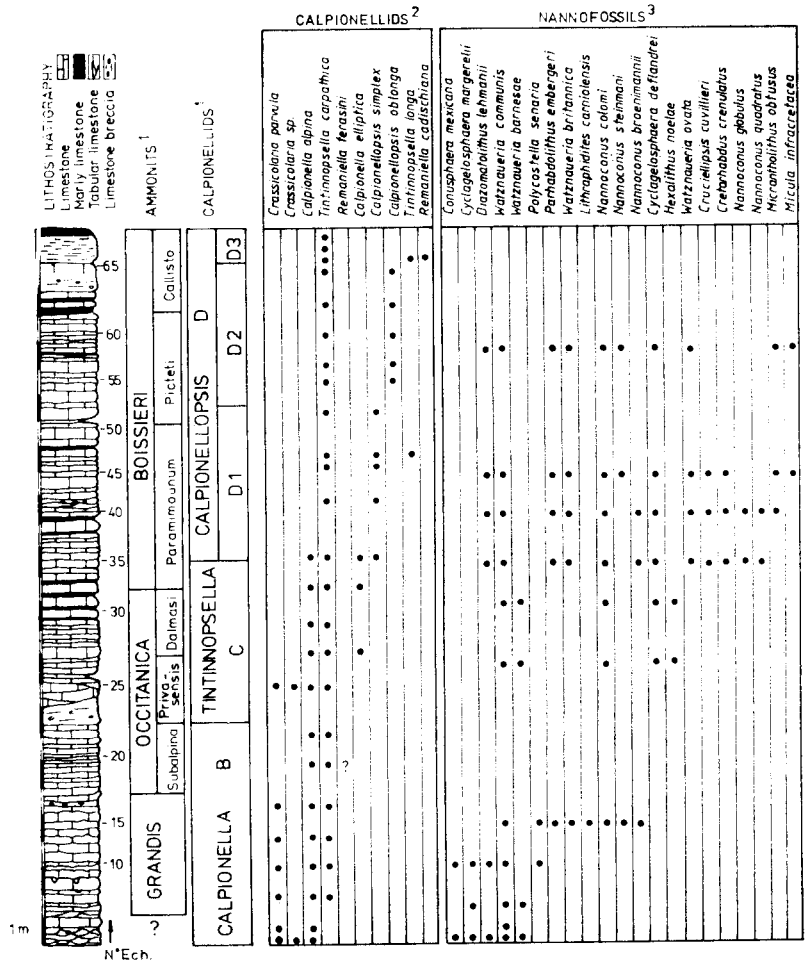

Fig. 6. Lithostratigraphy, biostratigraphy of the Berrias profile.
1. Le Hégarat-Remane, 1968; Le Hégarat, 1973, 1980; 2. Determinations of J. Azéma; 3. Déterminations of H. Manivit

ends towards the top of the Calpionellopsis Zone. The lower stage boundary, however, is difficult to draw at the locality of Berrias, owing to the absence of guide-fossils in the beds underlying the Grandis Zone.

Twenty-five horizons sampled by B. Galbrun (1984) have permitted a new study of the calpionellids by J. Azéma (cf. Fig. 6 showing the distribution of the calpionellids and the results of complementary studies on nannofossils). Because of the limestone nature of the samples, the nannoflora is poorly diversified and the biozonation is less precise than it is the case with the calpionellids. Nevertheless, Thierstein's associations and Roth's NC1 and NC2 Zones are recognizable. The appearance of *Nannoconus colomi* and *N. steinmanni* takes places in the Calpionella B Zone.

Magnetostratigraphy

Historical review

Magnetic polarity sets established for land sections are still rather scarse. The first study of this kind ever made was done by OG6 (1981) on the pelagic limestones of the Maiolica Formation and the Ammonitico Rosso facies from a number of sections checked biostratigraphically. A more recent study of the profile of Bosso, Italy, at the Jurassic-Cretaceous boundary was carried out by Lowrie and Channel (1984). The sequence is well-calibrated owing to a biozonation based on calpionellids. Finally, a good magnetostratigraphy was established for the Upper Berriasian by Ogg (1983) at Site 534, where the polarity sequence is readily dated by calpionellid, nannofossil and dinoflagellate forms.

The present-day inventory of magnetostratigraphic data concerning the Jurassic to Lower Cretaceous gives reliable evidence of the difficulties involved in correlating between magnetic polarity sequences in absence of a reference section perfectly calibrated in terms of biozones. The profile at Berrias has enabled B. Galbrun to porpose a reference polarity sequence extending from the top of Zone A up to Subzone D3 based on calpionellids (cf. Fig. 7).

Results

As shown by detailed studies of the magnetic mineralogy and the remanent magnetization of Berrias by classic techniques (A. R. I. curves, thermal demagnetization and in alternative magnetic fields), the natural remanent magnetization of the limestones of Berrias is constituted essentially by a stable detrital component, thus lending high fidelity to the proposed sequence. The isolated stable magnetization directions measured on 163 specimens are re-grouped according to the two opposed polarities. The paleodirections allow to propose a magnetic polarity sequence, the polarity of a specimen being defined by the paleo-declination and paleo-inclination or the relative latitude of the virtual magnetic pole (V. M. P.) calculated by the method of Lowrie et al. (1980) taking these two parameters into account. All the polarity zones have been named according to I. U. G. S. recommendations.

Accordingly, five inverse-polarity zones and four normal-polarity zones as well as two normal subzones have been qualified (cf. Fig. 7). Because of their low range, these are referred to as subzones.

Contribution to Upper Jurassic Lower Cretaceous polarity sequence

The comparisons proposed between the stratotype section's polarity sequence and the polarity sequences established earlier for the land sections of Foza and Bosso in Italy have enabled the establishment of correlations

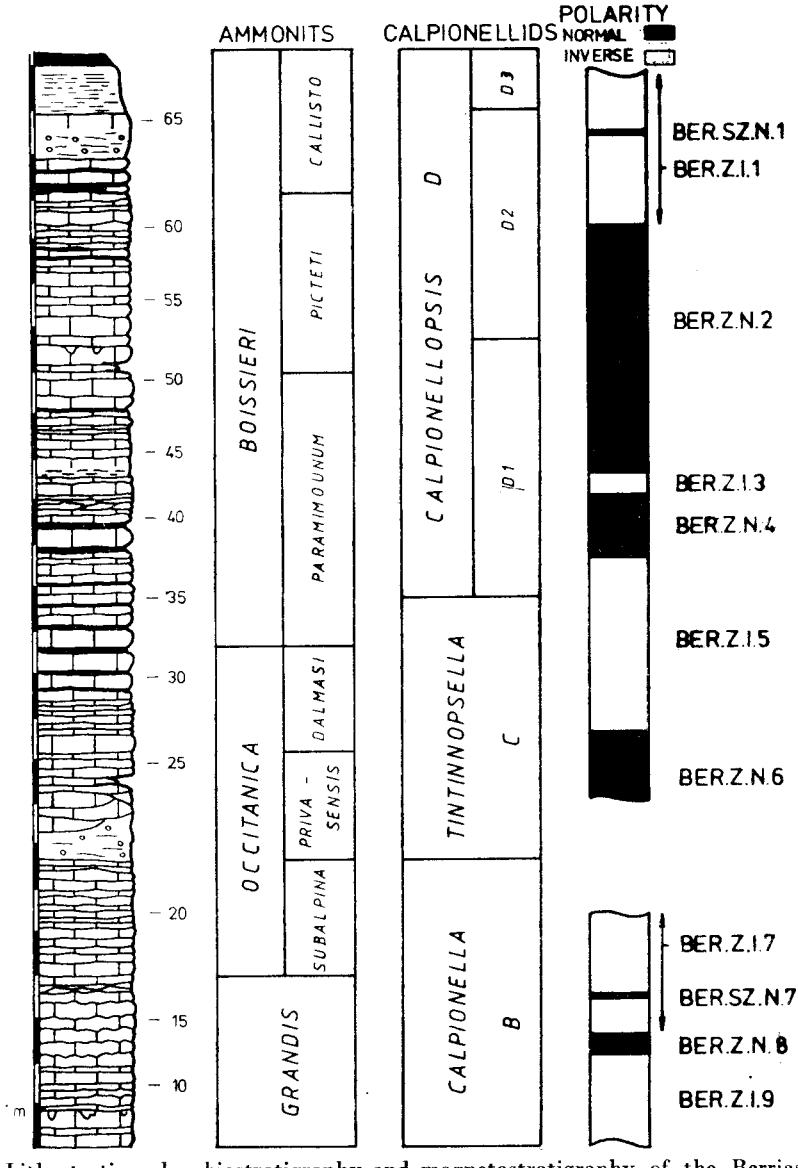

Fig. 7. Lithostratigraphy, biostratigraphy and magnetostratigraphy of the Berrias profile

between these localities (in press), being now extended to the oceanic domain (North Atlantic), Site 534, at which the Tithonian-Berriasian boundary is located with high precision.

This study has also permitted to assign the oceanic magnetic anomalies of Sequence M an age, the precision of which is of the order of an ammonite subzone (Fig. 7) which means remarkable progress as compared to the scheme hitherto adopted (Ogg, 1983).

The Berriasian extends from the base of Anomaly M18 up to the top of Anomaly M15.

The Tithonian-Berriasian boundary is situated close to the base of Anomaly M18.

The Berriasian-Valanginian boundary is located near the top of Anomaly M15.

Thus magnetostratigraphy appears to be an efficient correlation tool for, this method can help in carrying out a direct correlation of biostratigraphic scales established on organisms deriving from different environments or distant sedimentary basins.

Table II

List of nannofossils observed in this study

Braarudosphaera africana	*Cyclagelosphaera margereli*
Loxolithus armilla	*Conusphaera mexicana*
Rhagodiscus asper	*Micrantholithus obtusus*
Watznaueria barnesae	*Calcicalathina oblongata*
Polycostella beckmannii	*Watznaueria ovata*
Nannoconus bermudezi	*Manivitella pemmatoidea*
Watznaueria biporta	*Diadorhombus rectus*
Braarudosphaera bigelowi	*Nannoconus quadratus*
Discorhabdus biradiatus	*Polycostella senaria*
Watznaueria britannica	*Parhabdolithus splendens*
Nannoconus bronnimanni	*Vagalapilla stradneri*
Lithraphidites carniolensis	*Cretarhabdus surirellus*
Cruciellipsis chiasta	*Nannoconus steinmanni*
Markalius circumradiatus	*Nannoconus steinmanni minor*
Speetonia colligata	*Diazomatolithus subbeticus*
Nannoconus colomi	*Tubodiscus verenae*
Nannoconus cornuta	*Rucinolithus wisei*
Watznaueria communis	
Cretarhabdus conicus	
Biscutum constans	
Crucielliepsis cuvillieri	
Podorhabdus dietzmanni	
Podorhabdus decorus	
Zygodiscus diplogrammus	
Nannoconus dolomiticus	
Zygodiscus elegans	
Parhabdolithus embergeri	
Reinhardites fenestratus	
Zygodiscus erectus	
Nannoconus globulus	
Lithastrinus floralis	
Micrantholithus hoschulzi	
Assipetra infracretacea	
Rucinolithus irregularis	
Stephanolithion laffittei	
Nannoconus kamptneri	
Diazomatolithus lehmani	

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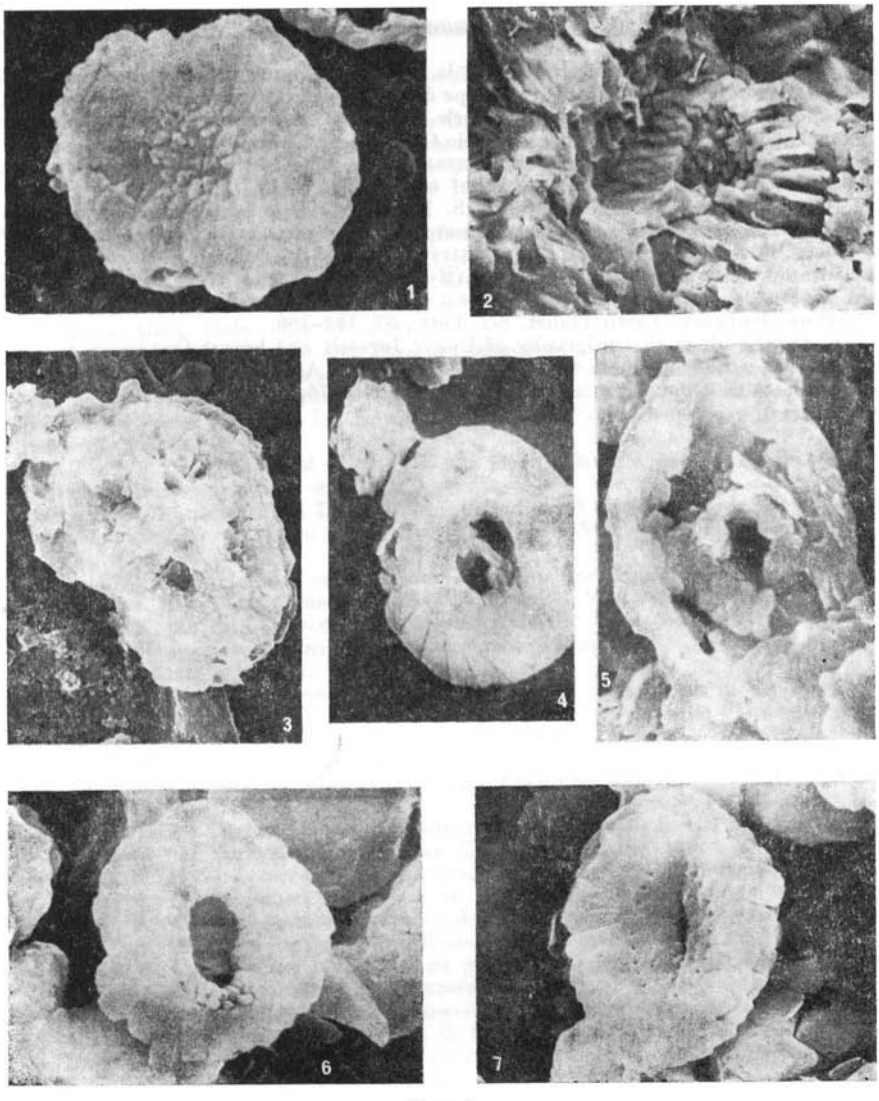

Plate I

Foncalent (Nannofossils)

1. *Biscutum ellipticum* (GORKA) GRÜN et ALLEMANN, 1975 Proximal view sample 112×25 000 Lower Valanginian
2. *Nannoconus cf. bronnimanni* BRONNIMANN, 1955 Nannofacies sample 45.5×3900 Middle Berriasian
3. *Podorhabdus dietzmanni* REINHARDT, 1967 Distal view sample 45.5×7000 Middle Berriasian
4. *Watznaueria britannica* (STRADNER) PERCH NIELSEN, 1968 Distal view sample 211.9×12 000 Upper Valanginian
5. *Parhabdolithus asper* (STRADNER) STRADNER, 1968 Distal view sample 112×15 000 Lower Valanginian
6. *Watznaueria oblonga* BUKRY Distal view sample 119×10 000 Lower Valanginian
7. *Watznaueria martelae* (NOEL) BURKY, 1969 Proximal view sample 139.5×12 000 Lower Valanginian

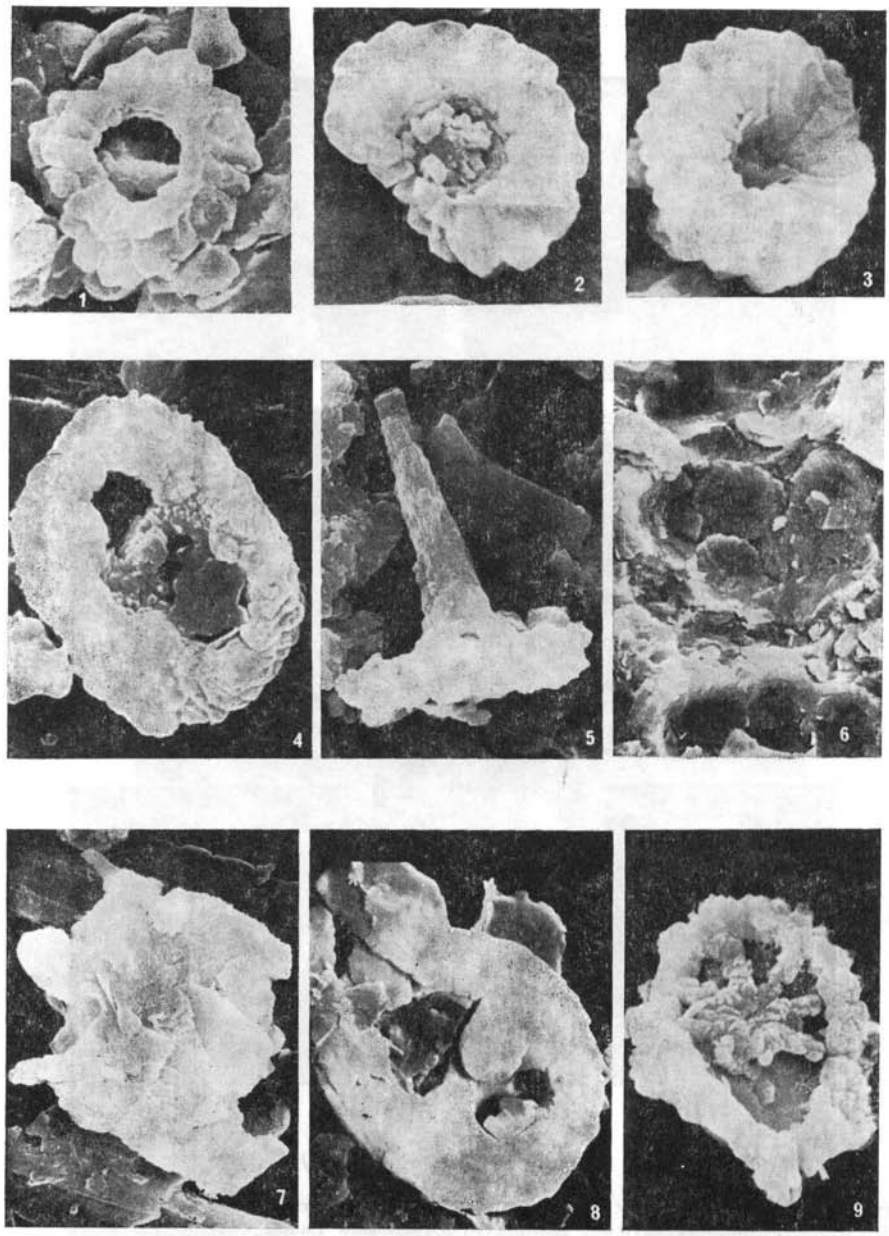

Plate II

Foncalent (Nannofossils)

1. *Diazomatolithus subbeticus* GRÜN et ALLEMANN, 1975 Distal view sample 56.5 × 10 000 Upper Berriasian
2. *Discorhabdus ignotus* (GORKA) PERCH NIELSEN, 1968 Distal view sample 45.5 × 10 000 Middle Berriasian
3. *Cyclagelosphaera margereli* NOEL, 1965 Profil view sample 112 × 9000 Lower Valanginian
4. *Parhabdolithus embergeri* (NOEL) STRADNER, 1968 Distal view sample 45.5 × 12 000 Middle Berriasian
5. *Podorhabdus dietzmanni* REINHARDT, 1967 Distal view sample 45.5 × 12 000 Middle Berriasian
6. Coccosphère de *Watznaueria cf. barnesae* Nannofaciès sample 112 × 2000 Lower Valanginian
7. *Polycostella beckmannii* THIERSTEIN, 1971 sample 45.5 × 5500 Middle Berriasian
8. *Speetonica colligata* BLACK, 1971 Proximal view sample 112 × 6000 Lower Valanginian
9. *Stephanolithion laffittei* NOEL, 1956 Distal view sample 45.5 × 10 000 Middle Berriasian

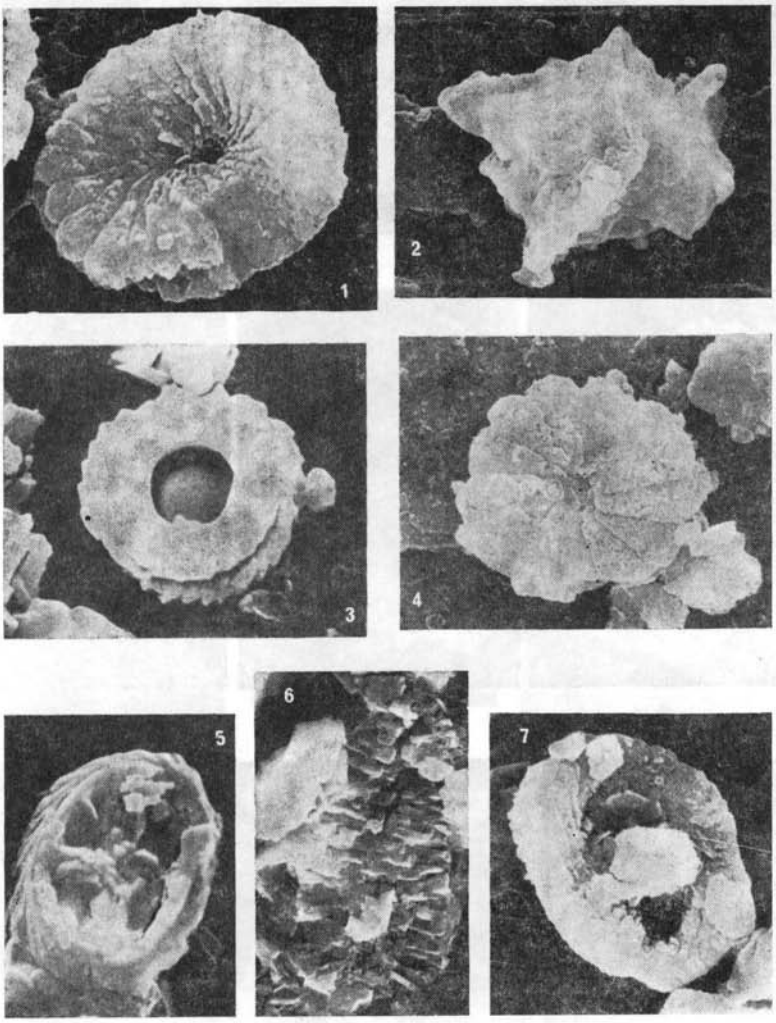

Plate III

Santa Anna (Nannofossils)

1. *Cyclagelosphaera margereli* ×10 000 sample 94 Upper Berriasian
2. *Polycostella beckmanni* ×10 000 sample 97 Distal side Lower Berriasian
3. *Diazmatolithus lehmani* ×8000 sample 97 Distal side
4. *Discorhabdus ignotus* ×8000 sample 94 Proximal side
5. *Vagalapilla stradneri* ×7000 sample 94 Proximal side
6. *Nannoconus steinmani* ×3000 sample 97 Nannofacies
7. *Zygodiscus erectus* ×8000 sample 94 Distal side — Upper Berriasian

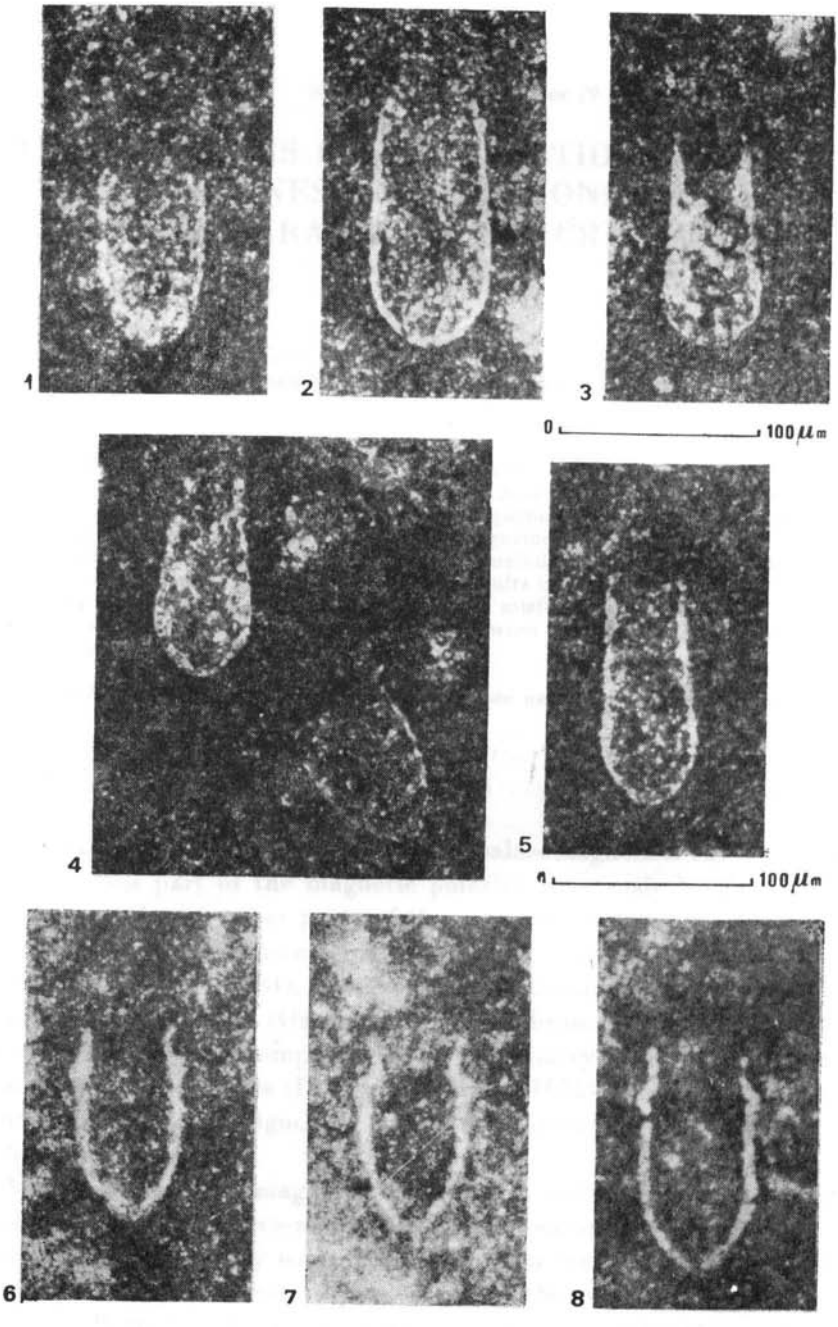

Plate IV

Santa Anna (Calpionellids)

1. *Calpionellites cf. darderi* (Colom) Upper Berriasian sample S. 94
2. *Calpionellopsis simplex* (Colom) Middle-Upper Berriasian sample S. 97
3. *Calpionellopsis oblonga* (Cadisch) Middle-Upper Berriasian sample S. 97
4. *Calpionellopsis oblonga* (Cadisch) and *Tintinnopsella carpathica* (Murg. et Fil.) sample S. 97
5. *Calpionellopsis oblonga* (Cadisch) sample S. 97
6—7. *Crassicollaria intermedia* (Durand Delga) Upper Tithonian sample AR. 2
8. *Crassicollaria gr. massutiniana* (Colom) Upper Tithonian sample AR. 2