

# A TENTATIVE INTEGRATED STRATIGRAPHY IN THE TURONIAN OF CENTRAL TUNISIA : FORMATIONS, ZONES AND SEQUENTIAL STRATIGRAPHY IN THE KALAAT SENAN AREA

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Turonian deposits were analysed in the Kalaat Senan area in Central Tunisia where they reach a thickness of 810 metres.

An attempt was made to provide a sequence stratigraphic interpretation on the strength of the results obtained from the analysis of macro- and microfossils, the microfacies, chemical analysis, clay mineralogy and field observations. Three complete and two partial sequences are proposed. The stratigraphic subdivisions and sequence interpretation are supported by detailed analytical considerations and the contributions from Ammonite, Planktonic Foraminifera and Calcareous Nannofossil analysis.

The sequence stratigraphic interpretation shows promising agreements between the Turonian of Central Tunisia and the Early and Middle Turonian of the type areas (Touraine, Saumur) in France. The Late Turonian is particularly well developed in the Kalaat Senan area, and much better than in the type areas in France. As a result an additional sequence was recognized at 89.2 Ma in the latest Turonian. This sequence is merged with the 90 Ma sequence in the incomplete Turonian of the type areas.

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6. — THE PLANKTONIC FORAMINIFERA (J.M.G.D. & D.L.)	281	Towards the end of this period, BUROLLET <i>et al.</i> (1954) proposed a lithological nomenclature for formations and members in the Upper Cretaceous of Central Tunisia, along the lines of the methodology proposed in the United States (HEBERG, 1948). This nomenclature was again used by BUROLLET (1956), completed by FOURNIÉ (1978) and used for the new 1:500'000 geological map of Tunisia (BEN HAJ ALI <i>et al.</i> , 1985). The latter served as a model during the preparation of the 1:50'000 geological map of "Kalaat Es Senan" (LEHOSKY <i>et al.</i> , 1978) and for the present study as well.	
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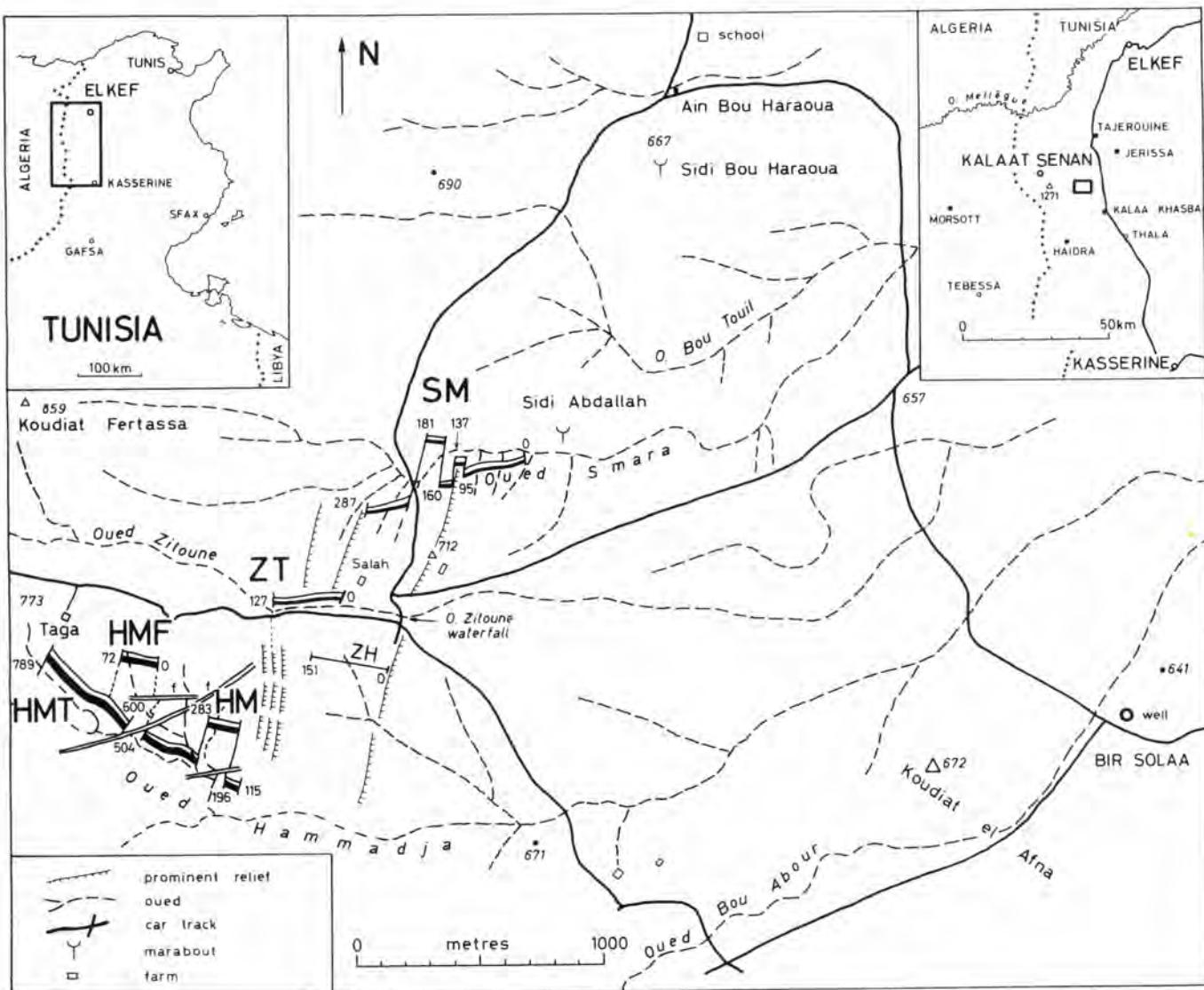


FIGURE 1  
Geographic location of the five studied sections.

Tunisian border is, in part, applicable to the Kalaat Senan area.

More recently, a sedimentological approach in areas further south (Jbel Bireno, Mhrila, Semmana) integrates the formations and members with a series of regressive filling sequences (BISMUTH *et al.*, 1981; BOLTHAGEN, 1985). MARIE *et al.* (1984) attempts to correlate basin-fill cycles with biostratigraphic zones.

Simultaneous with the lithostratigraphic studies, micropalaeontologists developed zonations for Planktonic Foraminifera and Ostracoda recovered from strata exposed either in Tunisia or in Algeria. The principal contributions were made by SIGAL (1949, 1952, 1956, 1967, 1977 and 1987), DALBIEZ (1955), GLINTBOECKEL & MAGNÉ (1959), FLEURY (1969), SALAJ (1980, 1987), BISMUTH *et al.* (1981) and BELLIER (1983).

## 1.2. OBJECTIVES

To complement the study of the Turonian undertaken in the type area (ROBASZYNSKI *et al.*, 1982), in the boreal domain (ROBASZYNSKI, AMEDRO *et al.*, 1980) and in the western Tethys (DEVALQUE *et al.*, 1983), it appeared that Tunisia could offer an excellent area to represent the southern Tethys.

On the suggestion of Elf-Aquitaine, a project outline was devised and subsequently funded. SEREPT provided substantial logistic assistance. EXXON Production Research partly funded fieldwork, carried out selected analysis and assisted in the sequence stratigraphy interpretation.

One of the objectives was to acquire a continuous section in the Upper Cretaceous permitting a correlation between the Tethys and the Boreal domain. To accomplish this goal, it was

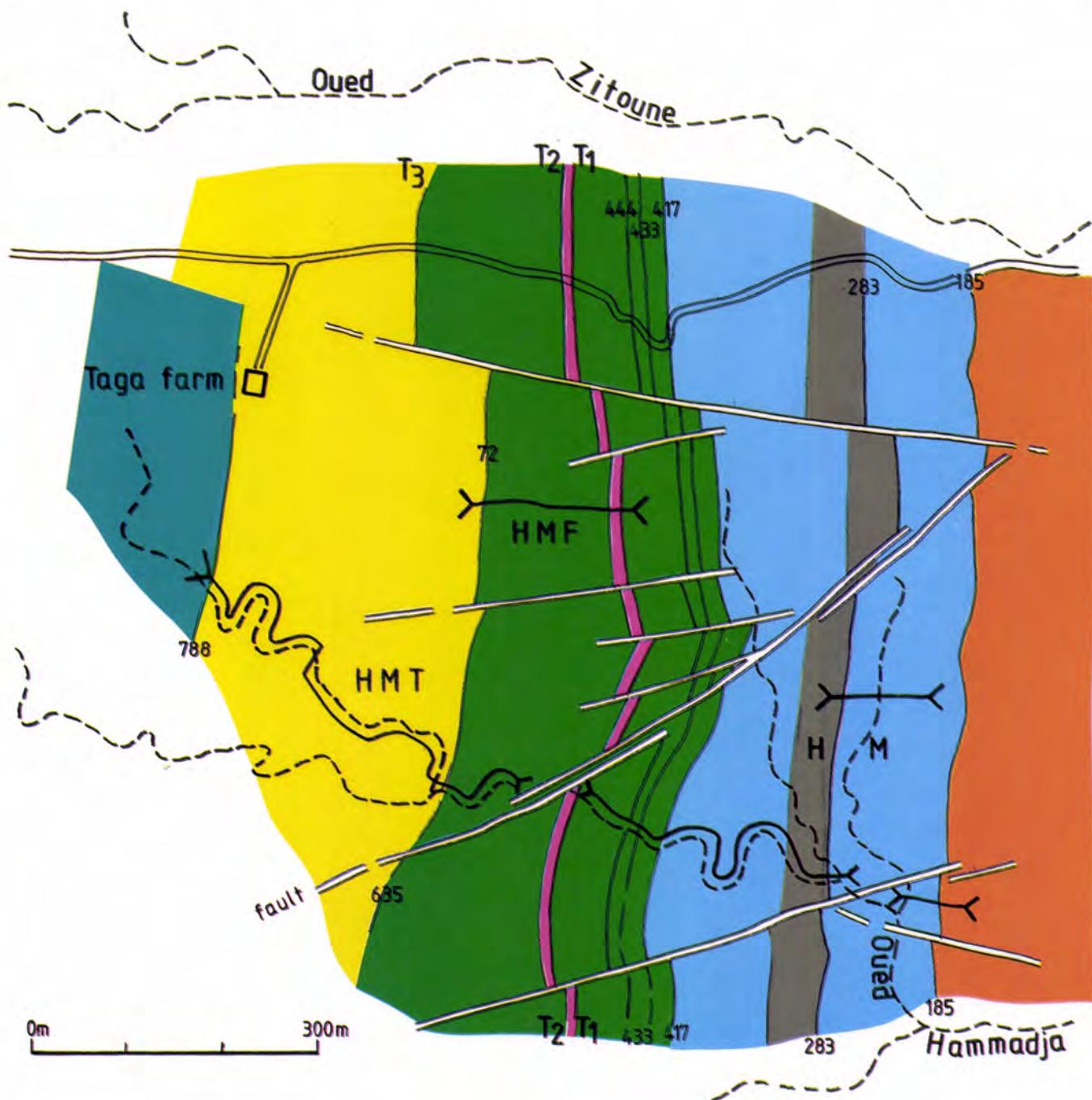


FIGURE 2  
Detailed location of sections in the Oued Hammadja area.

essential that the same biostratigraphic tools could be applied in either area, in particular Ammonites and Planktonic Foraminifera. For this purpose, the area of Kalaat Senan seemed suitable because of its location between the platform (Jbel Bireno and Semmama) and the basin (El Kef), where sediments should have an excellent chance of containing either fossil group. The present study aims at the establishment of a lithostratigraphical and biostratigraphical frame-

work for the Turonian that is sufficiently detailed to permit a sequence stratigraphic interpretation of the deposits that can serve as a model for future comparison with other areas in the Tethyan, as well as Boreal, domains.

**Remark :** The transliteration "Kalaat Senan" used in this paper follows the actual tradition in the village, as is witnessed by the bilingual Arab/French postal stamp. Howe-

ver, today as in the past, other transliterations are and were employed. Old road signs in the area include transliterations such as Kalaat Es Senam, Kalaat Es Snam, Kalaat Es Sinan or Kalaat Essenam, while more recent signs read Kalaat Senan or Kalaat Sinan(e). PERVINQUIÈRE (1903) used Kalaat Es Snam, BUROLLET (1956, Fig. 24) Kalaat es Senam or Kalaat es Snam. The 1:50'000 (1926/1956) topographic map carries Kalaat es Senam, while the geological map sheet shows Kalaat es Senan (LEHOTSKY *et al.*, 1978).

#### Note:

The samples which were the source for the analytical laboratory studies as stored at the "lithothèques" of the SEREPT in Tunis (Tunisia), of the SNEA(P) in Pau (France) and of the EXXON company in Houston (USA).

## MAIN LITHO-BIOSTRATIGRAPHIC RESULTS

### 2 — LITHOFACIES, BIOSTRATIGRAPHIC MARKERS, MICROFACIES AND DEPOSITIONAL ENVIRONMENTS (F. ROBASZYNSKI & M. CARON)

#### 2.1. COMPOSITE SECTION, FAULTS, LITHOFACIES AND MICROFACIES

The strata studied here crop out as ridges in the landscape and along three dry streambeds, or "Oueds", Smara, Zitoune and Hammada. All three "Oueds" are indicated on the 1:50 000 "Kalaat Es Senam" (1926/1956) topographic map but only the Oued Hammada is named. The two other names were provided by the farmers living nearby. However, distinctive marker beds permitted the measuring of a composite section (Fig. 3) from a number of partial sections (Fig. 4-8). The composite section is complete from the Middle Cenomanian to the base of the Coniacian (Fig. 9). Measuring the sections in the field, as well as the sampling and palaeontological collection, was carried out by the first three authors. Measuring the true thickness of the section was assured by the use of an Abney level.

Limestones and marls were each qualitatively subdivided into three groups. The type 1 beds are true limestones, cemented, competent and resistant. They contain fossil fragments and often show indications of surface winnowing. They are weathered out in the field and can easily be followed. In contrast the type 3 limestones which are, in reality, marly limestones, do not stand out in the field and have transitional upper and lower boundaries. The type 2 limestones are intermediate, better defined than type 3 but not as well as type 1 limestones.

Type 1 marls have the highest clay content and break down readily in water. The  $\text{CaCO}_3$  content is lower and varies between 10-30 %. Microfossils are well preserved in type 1 marls. In contrast, type 3 marls are very calcareous. They grade into type 3 limestones and are quite similar in appearance, but do not form relief in the outcrop as do type 3 limestones. Type 2 marls are calcareous marls, intermediate between friable type 1 marls and hard type 3 marls.

The study of microfacies (M.C.) is based on more than 250 thin sections and "peels" sampled all along the succession.

Most of the thin sections have been made with the Elf-Aquitaine technical assistance and R. DELOFFRE took the first set of photographs.

Information on the rock texture (DUNHAM, 1962), the mineral or skeletal nature of the components, the proportion of these components and their distribution within the matrix is preserved in the thin section. Thus, the microfacies provides a link between field observation at the bed scale and marl washings which destroy all sedimentary structures. Microfacies is an essential tool for the analysis of the mode of transport and depositional environment of the sediments. The following microfacies components have been identified :

- rock texture : mudstone (M), wackestone (W), packstone (P), grainstone (G);
- minerals : glauconite and phosphate;
- macrofossil bioclasts : Echinoderms, Inoceramids, Bivalves, Ostreids, Gastropods and Serpulids;
- microfossils :
  - calcareous Benthic Foraminifera (small Buliminids, Lenticulinids);
  - agglutinated Benthic Foraminifera (small Textulariids, large *Dorothyia*);
  - planktonic Foraminifera, grouped by genera : biserial, globular : *Heterohelix*; trochospiral, globular : *Hedbergella*, *Whiteinella*; trochospiral, single keeled : *Rotalipora*; trochospiral, double keeled : *Discarinella*, *Marginotruncana*; trochospiral, plano-convex : *H. helvetica* (zone marker);
  - calciphores : Algae or Dinoflagellate cysts, unicellular, planktonic ?
  - "filaments" : minute Bivalves of the Jurassic planktonic *Pisidonia* type.

For each formation, several microfacies have been described and selected to illustrate the main depositional types. The brief discussion which follows the description takes into account the macroscopic criteria (depositional features at the scale of the outcrop, bioturbation, and so on) so as to retain the most probable hypothesis. Thus, the depositional environment is interpreted in order to obtain a consistent model. The latter is then used for the analysis of the sequence stratigraphy which finally considers the subtle relations between the main sedimentary components : terrigenous muds, detrital carbonates and pelagic carbonates.

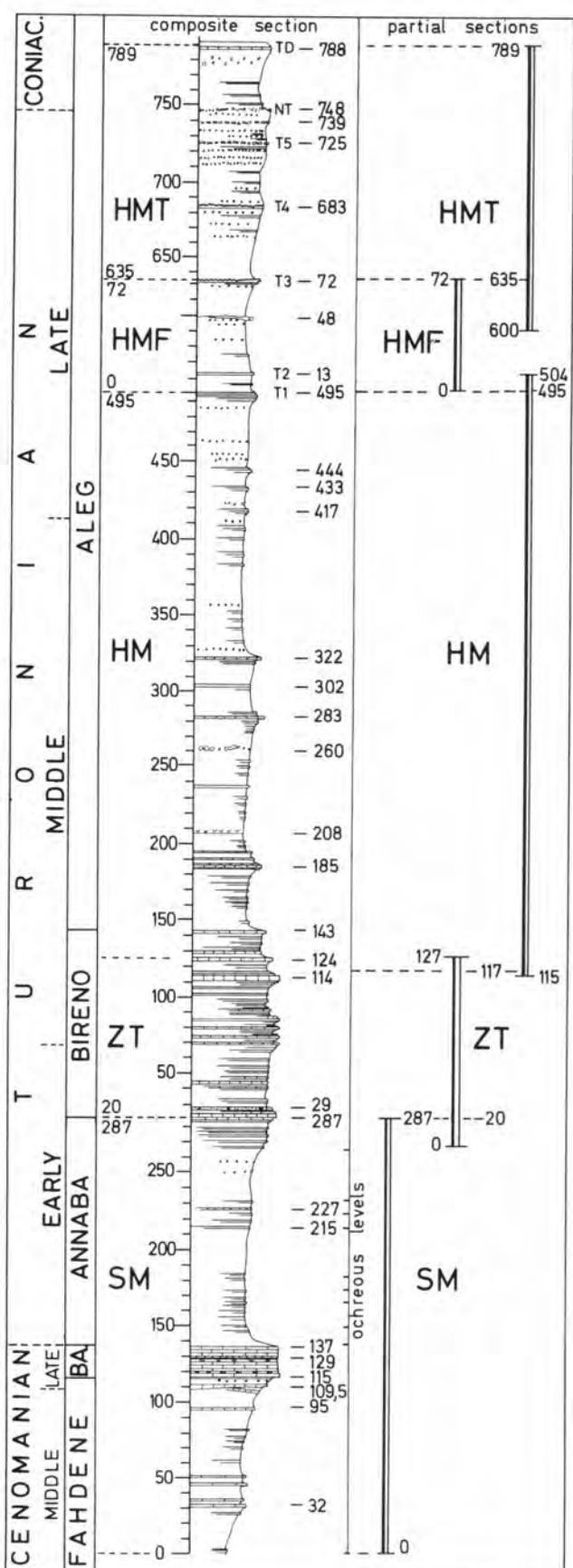
Figure 10 shows the vertical distribution of main microfacies textures and limestone components.

#### 2.2. MAIN LITHOLOGICAL SUBDIVISIONS (Pl. 1 to 13)

Definitions of formations and members based on the criteria proposed by BUROLLET *et al.* (1954), BUROLLET (1956) and FOURNIE (1978) are described as follows :

**Fahdène Formation** : "très puissante série d'argiles et de marnes grises ou noires, marines, présentant un certain nombre de bancs de calcaire ou de calcaire marneux dont certains ont la valeur stratigraphique de bancs repères" (BUROLLET, 1956, p. 67; modified from BUROLLET *et al.*, 1954; FOURNIE, 1978).

**Bahloul Formation** : "Calcaires finement lités et généralement feuilletés ou cartonnés, marneux en de nombreux lits, alternant parfois avec quelques marnes. Ils sont bruns, gris foncé ou noirs, devenant blancs en surface à l'altération; lorsqu'ils sont cassés au marteau, ils dégagent une forte



odeur bitumineuse. Les surfaces de stratification présentent de fréquentes empreintes aplatis d'Ammonites et très rarement des restes de Poissons (...). Cette unité n'est pas très résistante, mais elle forme généralement un ressaut dans la topographie entre les deux larges ensembles argilo-marneux qui l'entourent" (BUROLLET, 1956, p. 81; modified from BUROLLET *et al.*, 1954).

**Aleg Formation sensu lato**: "Epaisse séquence d'argiles et de marnes avec des intercalations plus ou moins nombreuses et épaisses de calcaires et de calcaires marneux. La Formation Aleg repose (...) sur les calcaires feuilletés du Bahloul. Elle est recouverte par les calcaires de l'Abiod." (BUROLLET, 1956, p. 101; modified from BUROLLET *et al.*, 1954; FOURNIÉ, 1978). Two members, Annaba and Bireno, were recognized in the lower part:

- Annaba Member: "Entre le calcaire du Bireno et les couches feuilletées" (du Bahloul), "une séquence d'argiles et de marnes grises, présentant souvent une faune assez riche du Turonien, a été nommée Annaba..." (BUROLLET, 1956, p. 92).
- Bireno Member: "... calcaire massif ayant en moyenne 50 m d'épaisseur... Plus au Nord, le calcaire du Bireno perd beaucoup d'importance et n'est souvent formé que de quelques alternances de calcaires et de marnes." (BUROLLET, 1956, p. 92).

On a bigger scale, these definitions are sufficient to discern the major facies packages in the field, but in close-up, the boundaries between formations and members are sometimes harder to recognize. For example, the base of the Bireno Member was identified at SM 287 (= ZT 20) but the first calcareous marls and marly limestones appear at SM 265 (= ZT 5) and gradually acquire the "Bireno facies".

The beginning of the Aleg Formation *sensu stricto* is not easy to place. After limestones clearly belonging to the Bireno facies, a succession of marls from HM 143 to HM 184 (over 40 m), would make HM 143 a strong possibility. But from HM 185 to HM 195, limestones reappear bearing a Bireno type facies. This difficulty in accurately defining the limits between the formations and members explains the discrepancies in thicknesses between those measured in this work and those published by BUROLLET (1956, p. 111). In his work, levels b + c, which correspond to the Annaba Member, measure 176 m (150 m in this paper) and levels d, equivalent to the Bireno Member, measure 67 m (123 m in this paper). It is even more difficult to establish a valid correspondence for the Aleg Formation *s.s.*. Indeed, we measured close to 1200 m thickness for this formation with 537 m belonging to the Turonian, whereas all levels from e to j (Turonian to Campanian) cover only 732 m. Bearing in mind that the Aleg Formation is distorted by faults, it is probable that the thicknesses given by BUROLLET are underestimated values. The same is true for the unpublished surveys by BERTHE (1954) and the information provided by PERVINQUIÈRE (1903, p. 101, p. 127) for the Kalaat Senan area. The latter always presents surprisingly underestimated thicknesses: 140 m for "all the Turonian" to which several dozen metres of "Senonian" (*sensu* PERVINQUIÈRE) marls, which are in fact Turonian, must be added, as opposed to over 800 m for the Turonian measured in this paper.

FIGURE 3  
Composite section established from five partial sections.

### 2.3. FAHDÈNE FORMATION (top part), 24 metres; marls and limestones (Fig. 4)

#### 2.3.1. From SM 90 to SM 109.5 (19.5 m)

**Lithology**: marls interbedded with few limestone beds. Marls are of type 2, grey to greenish. Limestones beds are of type 2 and not very thick : several dm in SM 107 and SM 109 to half-metre in SM 95. Moreover, SM 107 is lenticular.

**Palaeontology**: marls at SM 91 gave one Rudist. The top of the limestone bed SM 95 is covered with small black Ostreids, irregular Echinids and their spines, Bivalves as *Janira* and *Pecten*, and the Ammonite *Acanthoceras jukes-brownei*. Marls at SM 108 gave one *Eucalycceras* sp. Microfossils are abundant with Benthic Foraminifera such as *Lenticulina*, *Rheophax*, *Gavelinella* and Planktonic Foraminifera such as *Rotalipora cushmani*, *R. greenhornensis*, *Dicarinella* gr. *hagni/imbricata/algeriana* and genera *Hedbergella/Whiteinella*.

**Age**: the presence of *A. jukesbrownei* indicates a Middle Cenomanian age till SM 108 where the first *Eucalycceras* appear marking the base of Late Cenomanian.

#### 2.3.2. From SM 109.5 to SM 114 (4.5 m)

**Lithology**: marls with limestone beds. Marls are of type 2, grey to greenish. The limestone bed beginning at SM 109.5 is slightly unconformable on the underlying layers and its thickness is laterally variable. Bed SM 111.5 is thin and of type 3. At SM 113, marls include a row of carbonate nodules of one to three dm in diameter.

**Palaeontology**: several Ammonites of the genera *Eucalycceras* and *Pseudocalycoceras* were collected and Planktonic Foraminifera of the *Rotalipora cushmani* group were found in the marls.

**Age**: Late Cenomanian according to Ammonite content.

**Microfacies** (Fig. 10) : from SM 90 to SM 114m the few limestone beds occur under a micritic Calcisphere-rich microfacies. The texture ranges from a wackestone to a packstone. It is characterized by the abundance of Calcispheres. Planktonic Foraminifera are rare but diversified with *Rotalipora* (Pl. 7, fig. 1). Benthic Foraminifera are mainly agglutinated forms; they too are rare and are scattered in the micrite along with some Echinoderm debris. The bioturbation is of the *Chondrites* type and appears as dark patches in the thin section.

**Discussion**: the predominance of Calcispheres (DALI-RESSOT, 1987) mixed with Echinoderm debris suggests that there was displacement of the material involved from the external margin of the platform into the basin. Planktonic Foraminifera and Calcareous Nannoplankton are the only autochthonous calcareous components. The rare Benthic Foraminifera could also be displaced, but the occurrence of bioturbation (Pl. 7, fig. 2) indicates that the water/sediment interface was normally oxygenated and therefore propitious to benthos. The appearance of phosphate grains in SM 109.5 points to a modification in the depositional conditions, probably an increase in the current energy.

#### 2.3.3. Depositional environment of the Fahdène Formation (top part)

Located at the foot of a slightly dipping slope.

### 2.4. BAHLOUL FORMATION

23 metres; black laminated limestones making a waterfall in Oued Smara, as in Oued Zitoune (Fig. 4 and Pl. 1).

#### 2.4.1. From SM 114 to SM 119 (5m)

**Lithology**: in the basal 5 m of the Bahloul Formation, there is a succession of black laminites interbedded with grey limestones arranged as follows. From SM 114 to 114.55: layered black limestones, laminated, with bioturbation imprints on the laminite surface; from 114.55 to 114.60: greenish marls; from 114.60 to 116.20: thick, grey, micritic limestone bed with slumped features at 115.90 and pyritic nodules at 116; from 116.20 to 117.10: black laminites alternating with grey limestones; from 117.10 to 119: black laminites, thinly layered, with a slumped level from 117.90 to 118 composed of a rough biotrital material with pyritic nodules of 1 to 3 cm in diameter.

**Palaeontology**: several Ammonites were found of the genus *Pseudocalycoceras*. At the base, grey limestones contain the last *Rotalipora* gr. *cushmani*. Above the level SM 114.8, *Rotalipora* will be always absent.

**Age**: Late Cenomanian according to Ammonite content.

**Microfacies**: the microfacies analysis has been focused on the two types of lithofacies most frequently represented in the basal 5 metres of the Bahloul Formation : grey limestones and black laminites.

Grey Limestones

(SM 114.6-116.2; SM 116.4-116.5; SM 116.9-117 and SM 117.9-118).

They are wackestone to packstone biomicrites with abundant Calcispheres. At the base of the first bed, phosphate grains and well-sorted Echinoderm bioclasts mingle with a diversified population of Planktonic Foraminifera (*Heterohelix*, *Hedbergella*, *Whiteinella*, *Rotalipora*). The bed is bioturbated by *Chondrites*. In its middle part (around SM 115.9), micro-slumps deform the Calcisphere-rich micrite. The same microfacies occurs in two decimetric beds standing out against the black laminites at about SM 116.5 and SM 117. Higher up (SM 117.9-SM 118) a micro-slump is intercalated in the black laminites where it forms a distinct grey band. In the latter, centimetre-thick layers of a Calcisphere packstone alternate with millimetre-thick laminae of a packstone made up of well sorted and graded Echinoderm bioclasts (Pl. 7, fig. 4). Micro-slumps deform this alternation at the scale of the thin section (Pl. 7, fig. 6). The last *Rotaliporas* (*R. cushmani*) occur in SM 114.8. They are not found above this level.

**Discussion**: the graded nature of the Echinoderm bioclasts as well as the abundant Calcispheres suggests that they have been displaced by a current. The micro-slumps point to a ductile deformation of the Calcisphere-mud on a gentle slope. The presence of Planktonic Foraminifera, well diversified in the first 20 cm, documents the minor proportion of autochthonous pelagic carbonate components. Here the last *Rotaliporas* are clearly associated with the last bioturbated beds. This disappearance is regionally correlated with the deposition of black laminites which record the installation of a dysaerobic environment. This important biological event has already been reported in numerous regions: Vocontian Basin (CRUMIERE, 1989), Chalk "Sea" (JARVIS *et al.*, 1988), Atlantic Ocean and Tethys (KUHN *et al.*, 1986).

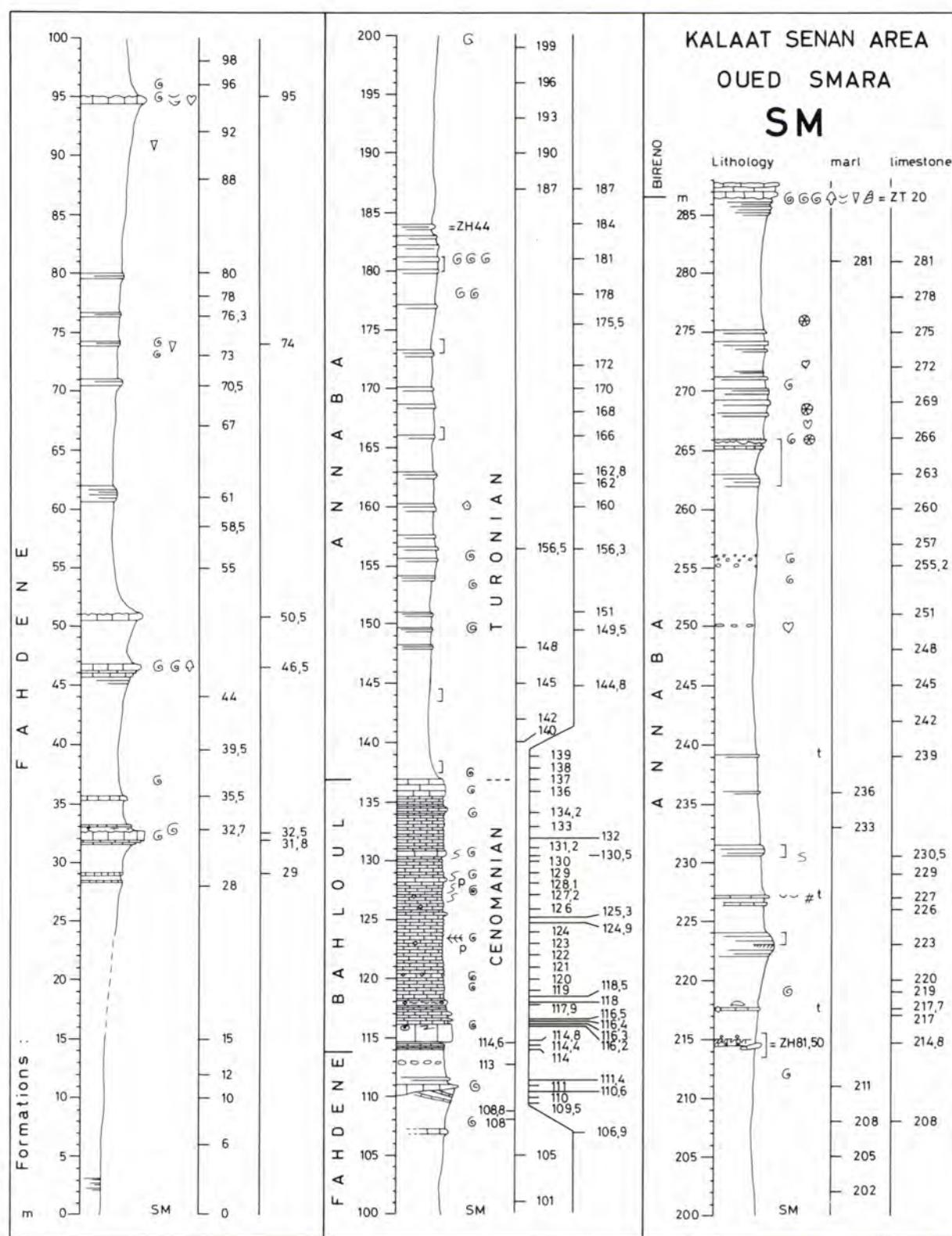


FIGURE 4  
Lithologic succession in the SM section at Oued Smara; Middle Cenomanian to Early Turonian.

**Black Laminites**  
(SM 114-114.55; SM 116.2-116.4; SM 116.5-116.9; SM 117-117.9).

They are inframillimetric alternations made up of dark laminae which are very rich in organic matter, and light-coloured laminae, where carbonate components, exclusively made up of shells of Planktonic Foraminifera (packstone) predominate. The microfauna is poorly diversified but prolific. Numerous, small *Heterohelix* dominate (Pl. 7, fig. 5). The trochospiral forms, attributed to the *Hedbergella/Whiteinella* group, are larger but less abundant (Pl. 7, fig. 3). The Calcispheres occur sporadically and are difficult to spot amidst the mass of foraminiferal shells. There are no Benthic Foraminifera nor phosphate grains. Bioturbations which are extremely thin and spread out at the top of the light-coloured laminae, are only visible in the outcrop. Grey limestones, thinning-upwards, made up of a dense Calcisphere-mud, are intercalated in this type of laminite.

**Discussion:** the Foraminifera are exclusively globular forms with thin, biserial or trochospiral shells. They belong to the most primitive morphotypes which lived in the uppermost layer of the ocean (ca. 0-50 m). Their diversity is low (3 genera, each represented by a maximum of 2 species), but their productivity is very high. These populations, called "colonizer", are the first to invade the environment as soon as life conditions are restored. The millimetric alternation of light-coloured laminae with dark organic-rich ones clearly indicates that the environment was periodically depleted in oxygen. The rare, thin, and horizontal bioturbations corroborate a dysaerobic setting at the water/sediment interface (THOMPSON *et al.*, 1985). Periodically, the surface waters must have provided a new supply of oxygen and nutrients, probably by hypersaline floods coming from the continent (cf. KAUFFMAN, 1986). The regularity of this alternation could be seasonal. This type of environment must have existed for a long period of time.

#### 2.4.2. From SM 119 to SM 137 (18 m)

**Lithology:** black laminated limestones with superficial bioturbations. It is the most important part of the Bahloul Formation in the Kalaat Senan area. Layered in thin sheets, it forms laminated limestones of type 1. Several levels contain pyritic nodules of some centimetres in diameter, especially at SM 120.2, 123, 124, 126.2 and 127. Some beds are grey as at SM 125.3, 128.3, 130.5, 134.2 and from 135.5 to 137. When weathering clears the surface of laminites, it is easy to see, from SM 119 onwards, the whole succession, superficial and branched bioturbations, of 1 to 2 cm width, filled with glauconite and phosphate grains or Echinoderm remains. The last bed of the Bahloul Formation, from SM 135.5 to 137, is more resistant and forms a small topographic rise after a depression consisting of more marly black laminites at SM 131-135.5.

**Palaeontology:** Ammonites are not rare in the Bahloul Formation but often crushed and flattened. Flank and ventral side imprints attributed to *Eucalyoceras* and *Pseudocalyoceras* were found in the whole succession. The species *Euomphaloceras cf. septemseriatum* was collected towards SM 134-135 and several small *Vascoceras?* between SM 135-137. At about 200 m towards the south, black laminites near SM 125 delivered phosphatic fish remains.

**Age:** the three Ammonite genera mentioned above are characteristic of the Late Cenomanian.

**Microfacies:** the microfacies analysis has been focused on this third lithofacies, here summarized as bioturbated black laminites.

**Bioturbated black Laminites**  
(SM 119-SM 137)

They consist of inframillimetric alternations of dark organic-rich laminae and light-coloured ones where Planktonic Foraminifera prevail (Pl. 7, fig. 7). The laminae are stacked into 1 to 5 cm thick beds on top of which occur bioturbations which are larger (1-2 cm) and deeper (a few mm) than those observed in the "black laminites". These traces are filled (from SM 119 to SM 129) with Echinoderm debris, a few phosphate grains and (from SM 123) rare and minute glauconite elements.

In the beds containing a great number of phosphate grains (SM 126-SM 128.5), abundant "filaments" appear. They are minute nektonplanktonic Bivalves belonging to the *Posidonia* group (JEFFERIES & MILTON, 1965). They persist until SM 137 and even up to the top of the Bireno Member. The bed SM 130.5-131, greyer and more compact at the outcrop than the surrounding beds, contains abundant "filaments" (Pl. 8, fig. 1). The remainder of the microfauna consists of *Heterohelix* and large *Whiteinella* (Pl. 8, fig. 3).

As with the black laminites, the Planktonic Foraminifera occurring in the bioturbated black laminites have a simple morphology (globular shells), a low diversity and a high level of productivity. They belong to the *Heterohelix* genus and the *Hedbergella/Whiteinella* genera undifferentiated until SM 126. As from this level, the *Whiteinella* are recognizable in thin section by their large size, their thicker wall and sometimes by the pinched profile of their last chamber (*W. archaeoecretacea*, Pl. 8, fig. 7). Calcispheres are very rare and Echinoderm debris are confined to bioturbations.

The millimetre scale alternation of organic matter, "filaments" and Planktonic Foraminifera results in a varved deposit.

The "filaments" and the large *Whiteinella* first appear in beds where the concentration of phosphate grains is highest (see for example SM 128.1, on Plate 8, fig. 2)

**Discussion:** the carbonate elements are mainly derived from pelagic production. Planktonic Foraminifera and "filaments" are the sole components of this autochthonous microfauna. Information on the evolution of the environment may be gained from their presence. In addition to the occurrence of *Heterohelix* and *Hedbergella/Whiteinella*, the appearance of minute Bivalves similar to the Jurassic *Posidonia* confirms the "colonization" of the uppermost water layer. This colonization, which is recorded in the laminated sediments as a sudden, short, but prolific event, could reasonably be linked to the renewal of the uppermost water layer: the latter was, at times, rich in nutrients, certainly more oxygenated than the intermediate waters, and probably inclined to hypersalinity. The hypothesis outlined previously for the black laminites, concerning the recurrent floods issued from the continent, applies here as well.

According to BE & TOLDERLUND (1971), the Planktonic Foraminifera, especially the keeled, open-sea morphotypes, are mainly stenohaline. The *Heterohelix* and *Hedbergella* certainly tolerate a larger variation in salinity since they are regularly found in sediments from the external shelf as well

as from the basin. On the other hand, their adaptation to a hypoxic environment is not fully known. According to LECKIE (1989), these globular morphotypes would be "eurytopic", i.e. demanding little, and therefore expanding in "blooms" as soon as nutrients are available.

This would explain both the high productivity and the low diversity of the globular-shelled Planktonic Foraminifera during the entire episode, as well as the absence of more complex keeled forms.

If the surface waters were oxygenated enough to sustain periodically a rich planktonic microfauna, the intermediate and bottom waters must have been dysaerobic, or even entirely anoxic, given the high proportion of organic matter preserved and the absence of microbenthos. On occasions, the water stratification must have been disturbed by some ventilation which brought enough oxygen to the water/sediment interface to allow the development of burrowing organisms. In the sub-horizontal bioturbations, which are the only record left by these organisms, Echinoderm debris, phosphate and glauconite grains are concentrated, thus corroborating an increase in energy.

#### 2.4.3. Interpretation and depositional model of the Bahoul Formation

The entire formation is characterized by a high organic matter content. Its alternation of sub-horizontal laminites with sheets consisting of shells of planktonic, calcareous micro-organisms points to a quiet depositional environment, like a gently inclined slope located far from the shelf edge. Three episodes in the succession of microfacies may be distinguished.

First episode (SM 114-119) : during a period of lowstand where the grey limestones are built up from material derived from the external shelf. The latter progrades by flows of Calcisphere-rich mud on a shelf edge — wedge where organic — and rich laminites accumulate. In this regressive context, the lowest point of sea-level is represented by the Calcisphere and Echinoderm flow of SM 114.6-116 which temporarily ventilates the environment and gives the last Rotaliporas a short reprieve.

Second episode (SM 119-123) : beginning of the transgressive interval. The Calcispheres and Echinoderm debris disappear, phosphate grains appear and globular Planktonic Foraminifera predominate. The transgression inundates the shelf and exposes it to the intermediate water-layer, which is lacking in oxygen. This is the period of maximum bottom anoxia, which corresponds to the most rapid speed at which the sea-level rises.

Third episode (SM 123-137) : recorded by the occurrence of bioturbations filled with phosphate and glauconite grains, it represents the return of an oxygenated period. It ends with a rich association of small Bivalves (= "filaments") and globular Planktonic Foraminifera indicating a maximum thickness of the water layer.

#### 2.5. ANNABA MEMBER

150 metres; bluey-grey calcareous marls (Fig. 4 and Pl. 2)

#### 2.5.1. From SM 137 to SM 287 (150)

**Lithology** : in the whole succession, Annaba blue marls always have a high carbonate content and thus are of type 3, dry and harsh. Marly limestones of type 3 are interbedded in these marls, but never are there true limestone beds. In the upper half of the member, several small levels make good local lithologic markers.

- At SM 215 there is an irregular bed, 1 dm thick, slightly dolomitic, perforated, with ferruginous crust. It is followed by an irregular bed of pyrite nodules.
- At SM 217.7 there is a thin calcareous and laminated horizon which, in places, supports carbonate domes several decimetres high, scattered with pyrite.
- SM 227 is a thin laminated, carbonate horizon (5 cm) interpreted as a distal tempestite. The losangic, cracked aspect of its surface makes this horizon easy to locate, as with SM 239 which is thinner (2-3 cm).
- At SM 250 and SM 255-256 there are cylindroid contorted calcareous nodules of diagenetic origin.
- SM 266 is a thin calcareous level (5 cm) of which the upper part consists of a bio-arenite made with Echinoderm fragments.

Above SM 266 till SM 276 (= ZT 0 to ZT 12 in the Oued Zitoune section), calcareous levels become more numerous and form grey limestone beds of type 3, then type 2. From SM 276 to SM 285 follow hard calcareous marls of type 2, then type 3 which become marly limestones from SM 285 to SM 286.5.

Furthermore, ochreous marls are distributed all along the succession (SM 137.5-138.5, 2148.4-149.4, 165.9-166.8, 173-174, 180-181, 213.7-215.5, 223-224, 230.5-231.5 and SM 262-266). They stand out against blue marls by their colouration and their slightly greater resistance to erosion. They make levels easy to follow on the field as in the ZH section located between Oueds Zitoune and Hammada.

**Palaeontology** : macro- and microfossils are badly preserved and generally flattened in Annaba "marls". Nevertheless, systematic cutting up of the marls produced some Ammonites and rare Bivalves. At the surface of bed SM 137, that is at the very base of Annaba Member, the imprint of a large Ammonite (40 cm in diameter) attributed to *Pseudaspidoceeras flexuosum* was found. The marls immediately above SM 137 (and their equivalent in ZH section : between ZH 0.5 = SM 137.5 and ZH 3.5 = SM 140.5) delivered Planktonic Foraminifera such as *Dicarinella* gr. *imbricata*, *Whiteinella praehelvetica* and primitive forms of *Helvetoglobotruncana helvetica* (and the nannofossil *Gartnerago obliquum*). At SM 150 and SM 180, there are a lot of small Ammonites such as *Thomasites* and *Choffaticeras*. Higher, until we reach SM 250, macrofossils become very rare. They are small, flattened or pyritized and thus difficult to determine. A single specimen of *Choffaticeras* sp. was collected at SM 219. Above SM 250, macrofossils become less rare : irregular Echinids, small Corals and Ammonites occur as pyritized nuclei. This is especially true for *Mammites nodosoides* detected from SM 254. The top of Annaba Member is better exposed in Oued Zitoune (ZT 0-20) where it produced numerous irregular Echinids, Inoceramids and some Nautilids. Everywhere Foraminifera are difficult to remove from the marls, these being too calcareous. Only some *Whiteinella* and *Dicarinella* gr. *imbricata* were extracted.

**Age**: The Ammonite *Pseudaspisdoceras flexuosum* marks the base of the Turonian. The presence of *Thomasites* sp., *Choffaticeras* sp. and *Mammites nodosoides* is also characteristic of Early Turonian.

**Microfacies**: the microfacies analysis has been focused on the three lithofacies described below: bluey-grey marls, ochreous marls and thin marly limestones.

#### Bluey-grey Marls

They have a mudstone texture with few microfossils. Only the "filaments" occur regularly, although in small quantities. Until SM 200, Planktonic Foraminifera are very rare and small. They are globular morphotypes belonging to the genera *Heterohelix* and *Hedbergella*. Usually, in the first metres of this facies, in SM 138 (and in ZH 3.5, equivalent to SM 140.5 in a nearby section), the Planktonic Foraminifera are larger and more diversified, but very scarce. Large *Whiteinella archaeocretacea*, *W. praehelvetica*, *Helvetoglobotruncan helvetica* and *Dicarinella* gr. *imbricata* have been identified. From SM 208, Calcispheres reappear in small numbers and "filaments" still occur, whereas Planktonic Foraminifera disappear almost completely (Pl. 9, fig. 1).

**Discussion**: the predominant, relatively dark grey colour of these marls and the absence of benthos indicate a tendency towards anaerobic conditions on the sea floor. The abundance of fine mud characterizes these deposits. It may be of neritic origin, but transported over a long distance. The only micro-organisms present are small nektonoplanktonic Bivalves, few in number but constant, which are "opportunist" like the rare Planktonic Foraminifera occurring until around SM 200. They are then replaced by Calcispheres. This suggests that the surface waters were relatively well oxygenated, as opposed to the bottom waters.

#### Ochreous Marls

They have a mudstone texture containing very abundant microcrystals (10-30 micro-m) which would be dolomitic. The microfossil content is hard to estimate because the bioclasts are so micritized that they are unidentifiable (Pl. 9, fig. 4). Only the Calcispheres withstand the micritization to some extent (cf. SM 263).

**Discussion**: the fine rhombohedric crystals of dolomite, often surrounded by an iron halo, give the sediments their ochreous colouration. According to MCHARGUE & PRICE (1982), these microcrystals appear during the early diagenesis (post-compaction) of a magnesium-rich mud made of marine carbonates associated with detrital clays. Another origin of the dolomitic microcrystals could be the leaching of evaporitic deposits from the southern shelf. Whether it be diagenetic or detrital, the dolomite seems to contribute greatly to the obliteration of the carbonate bioclasts contained in these marls.

#### Marly Limestones

Thinly bedded marly limestones occur mostly near the base and top of the Annaba Marls. At the base of the member, the marly limestones are mudstones containing "filaments" and rare, small and globular Planktonic Foraminifera. Here, their microfacies is similar to that of the bluey-grey marls. In the middle of the Annaba Member, thin beds of marly limestone (2-5 cm) indicate on the outcrop an oblique to sub-horizontal stratification (SM 217, SM 226, SM 227). An acetate peel made from bed SM 227 displays some criteria belonging to a distal carbonate tempestite (GUILLOCHEAU, 1983; AIGNER, 1985): hummocky cross-bedding,

low-angle laminae, wide distribution of the inclination directions, decreasing grain size and even an escape structure typical of a sudden high rate of sedimentation. The infra-millimetric laminae are made up of an alternation of pellets, "filaments", Calcispheres and minute Buliminids. Towards the top of the member, the marly limestones are enriched in Echinoderm bioclasts (Pl. 9, fig. 8), agglutinated Foraminifera and Calcispheres.

On the thin marly limestone bed SM 217, small carbonate domes develop locally. Their width ranges from 10 to 20 cm and their height up to 5 cm. Their microfacies exhibit a fine structureless micrite, totally azoic and containing "stromatotaxis"-like cavities filled with sparry calcite. These domes could be very small mud-mounds (MONTY, 1984).

**Discussion**: the microfacies of the marly limestones is lacking in microfossils and remains of larger organisms. Bed SM 266, which is the only one having a bioturbated surface, shows a sudden increase in bioclasts derived from the shelf. The depositional environment was therefore very distal at the base of the member; it suffered a period of stagnation around SM 217 (mud-mounds); it then recorded the first signs of shelf supply as is witnessed by distal carbonate tempestites (SM 227) and finally by concentrated bioclasts (SM 266).

#### 2.5.2. Interpretation and depositional model of the Annaba Member

The basal part of the Annaba blue marls records the maximum flooding related to a sea-level rise which started during the deposition of the bioturbated black laminites of the Bahloul Formation. It corresponds to a sequence of the third order according to HAO *et al.* (1987). The maximum flooding of the sequence of the second order (HAO *et al.*, 1987) occurs between SM 150 and SM 200. The conjunction of these maxima causes a wide flooding of the shelf during a period of fine detrital supply. A large proportion of very fine calcareous mud, poor in macro- and microfossils, accumulates during the period of highstand. A period of stagnation leads to the development of small "mud-mound" domes on SM 217. As progradation begins, the muddy deposits are interrupted by very distal, thin, calcareous tempestites which document the onset of regression of the shoreline to the south. As progradation continues, marly limestones become more frequent and contain more bioclasts towards the top of the sequence.

#### 2.6. BIRENO MEMBER

123 metres; fossiliferous, marly limestones and limestones (Fig. 5 and Pl. 3-4)

##### 2.6.1. From ZT 20 (= SM 287) to ZT 85 (65 m)

**Lithology**: this interval consists mainly of a succession of more or less marly limestones and calcarenites. Three units may be distinguished on the field

ZT 20 to ZT 29 : Unit forming a prominent ridge in the landscape, crossed as a waterfall by Oued Zitoune. It is composed of thick beds of type 1 limestones with thin intercalations of calcareous marls from ZT 24.5. Bioturbations are present everywhere but are irregularly distributed except at ZT 28.5 where there is a bed completely riddled with

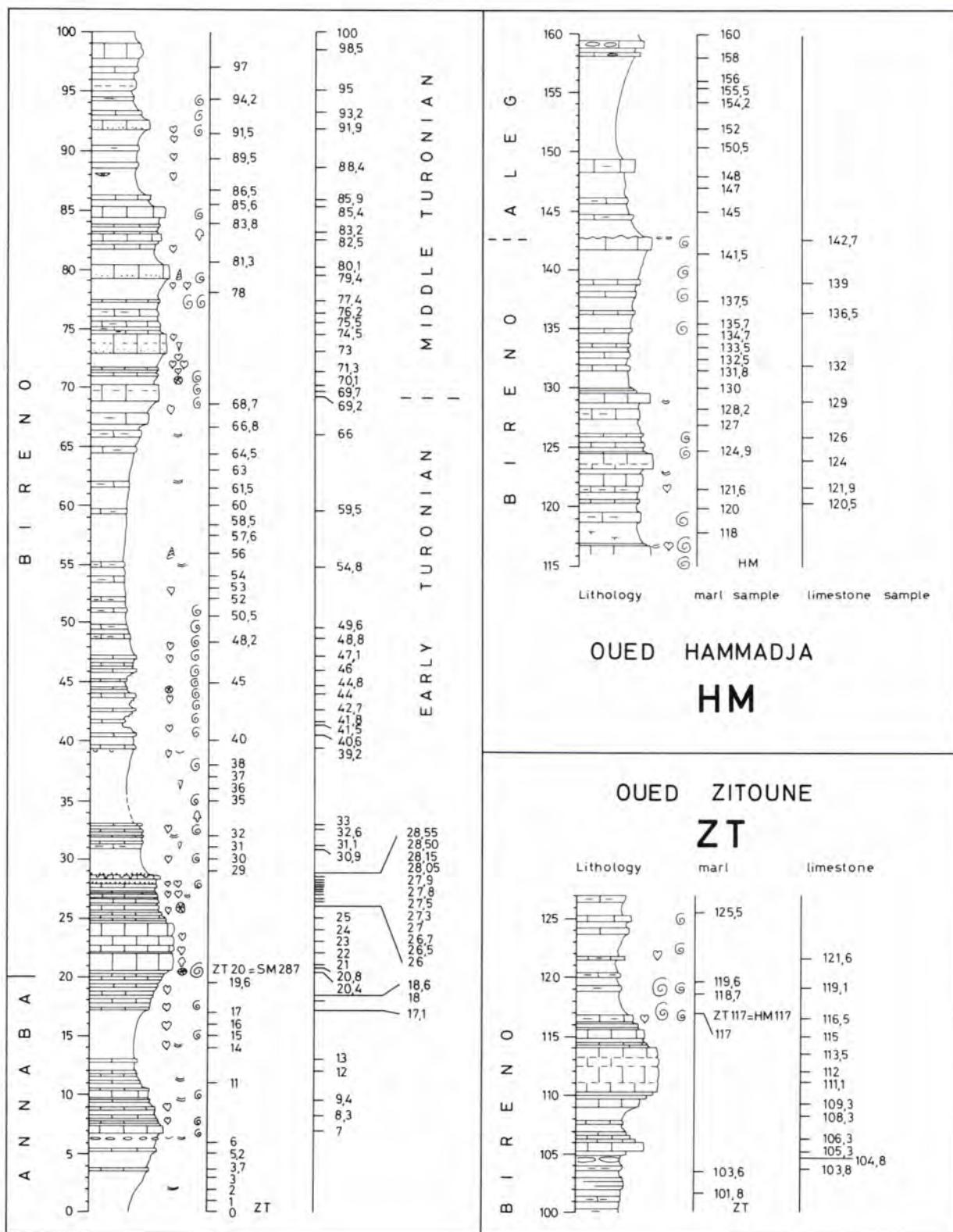


FIGURE 5

Lithologic succession in the ZT section (Oued Zitoune) and base of the HM section (Oued Hammadja); Early and Middle Turonian.

burrows filled in with coarse biotitic calcarenite. This feature is also well illustrated in the neighbouring section ZH.

ZT 29 to ZT 69 : Unit appearing like a slight depression. It is an irregular alternating succession of type 2-3 calcareous marls and type 2-3 limestone beds (about half-metre thick).

ZT 69 to ZT 85 : Unit forming a relief in the middle of Bireno Member. It is marked by four prominent limestone beds, of 1.5 m to 2 m thick, at ZT 70, 74, 80 and 85.

**Palaeontology :** macrofossils are frequent and numerous groups are represented as Ammonites : *Fagesia*, *Thomasites*, *Choffaticeras*, *Lewesiceras*, *Neptychites*, *Paramammites*, *Mammites* and *Kamerunoceras*. Nautilids, irregular and regular Echinids, isolated and branchy Corals, Ostreids, diverse Bivalves (*Lima*, *Pinna*), Rudists and Gastropods (especially *Tylostoma*). Just at the base, at SM 287 = ZH 20.5, globulous Vascoceratids 10 to 30 cm in diameter (*Fagesia superstes*) form a regional widespread level, very useful for lateral correlations. With regard to *Mammites nodosoides*, it is notable that this species was not found above ZT 69.

Calcareous marls are very difficult to wash and Foraminifera seem not to be numerous; some Benthic forms are present as *Dorothia*, *Rheophax*, *Haplophragmium* with Planktonic forms present as *Whiteinella*, *Dicarinella*, *Heterohelix*. All are generally associated with starfish and ophiurid ossicles as with echinid spines. At ZT 83, the limestones on the field gave good sections of *H. helvetica*.

**Age :** Below ZT 69, the presence of *Mammites nodosoides*, *Thomasites* and *Choffaticeras* is indicative of Early Turonian. Above this level, the coexistence of *Kamerunoceras turonense* and *Neptychites cephalotus* is strong evidence for a Middle Turonian age.

**Microfacies :** the microfacies analysis has been focused on the two main lithofacies : marly limestones with Calcispheres and "filaments", and calcarenites with bioclasts of benthic macrofossils (fig. 10).

#### Marly Limestones with "filaments"

These are the dominant lithological type in the Bireno up to ZT 85-100. Their texture ranges from mudstone to wackestone. They are mostly biomicrites containing Calcispheres, small Bivalves of the "filament" type (Pl. 10, fig. 4), and rare, globular Planktonic Foraminifera (Pl. 10, fig. 6). Thick-walled, agglutinated Benthic Foraminifera occur regularly : with a fine agglutination (Pl. 11, fig. 2) or a coarse one consisting of Calcispheres (Pl. 11, fig. 3). Echinoderm bioclasts may be mixed in with them, carried by burrowing organisms in bioturbations, or by currents (Pl. 10, fig. 2). Phosphate grains are scattered throughout these bioclastic beds. At different horizons, the marly limestones enclose whole shells of macrofauna :

- isolated Corals : ZT 20.5; ZT 20.8; ZT 27 (Pl. 10, fig. 7);
- Urchins in nests : ZT 20.4; ZT 27.9 and ZT 88.4;
- Oysters : ZT 20.8 (Pl. 11, fig. 1); ZT 39.2 and ZT 41.5;
- Serpulids : ZT 46; ZT 66; ZT 76.2 and ZT 77.4 (Pl. 10, fig. 8);
- Gastropods : ZT 70.1 (Pl. 11, fig. 6); ZT 79.3; ZT 79.8.

A special colonization of Gastropods and Serpulids developed between ZT 41 and 82, reaching a maximum between ZT 66 and 80.

**Discussion :** in general, the state of preservation of these shells does not imply a long and rough transport : the Urchins' fragile shell has hardly collapsed under the sediment compaction; the Serpulids are still grouped together and the Gastropods are buried in a fine Calcisphere-rich mud. Only

the small Corals and the Oysters, whose shells are more widely scattered, could have travelled from the southern shelf, just like the isolated Rudists which are found in the field.

A varied and abundant macrofauna lived therefore on the sea floor, despite the large amount of detrital sediments.

#### Calcareites

Packstones are much more frequent than grainstones. They are bioclastic accumulations, either in bulk or well sorted. Phosphate grains and Calcispheres are rare. In general, the beds are compact when the matrix is homogeneous (Pl. 10, fig. 3), as is the case in ZT 28.15; ZT 28.5; ZT 47.1; ZT 69.2; ZT 71.3; ZT 80.1 and ZT 91.9. When the elements are coarse, they form poorly consolidated coquinas (for example in ZT 28.05; ZT 28.55). The calcarenites regularly overlie beds of Urchins, Serpulids, Gastropods and Bivalves which were thus choked in their life environment.

**Discussion :** the sharp contact, sometimes erosive (cf. ZT 28.05 which reworks the top of the bed ZT 27.9), between the calcarenites and the underlying marly limestones indicates a sudden supply of detrital material. The elements of this detrital material consist mainly of debris from Echinoderm and Bivalve shells. The latter were broken, mixed together and rapidly deposited (cf. ZT 70.71; ZT 73-73.8). The material is derived from the southern platform, but only a relatively short distance away since the components are similar to the local fauna.

#### 2.6.2. From ZT 85 to HM 143 (58 m)

**Lithology :** it is a succession of marly limestones and Calcisphere limestones. The abundance of Calcispheres is very characteristic. Three units compose the succession.

ZT 85 to ZT 110 : as most of the beds are type 2 marly limestones, this unit makes a slight depression although beds ZT 92, 98 and 106 are thick type 1-2 limestones.

ZT 110 to ZT 117 : thick, hard and prominent type 1 limestones which can be easily followed on the field to correlate the sections in Oueds Zitoune (ZT) and Hammadja (HM). The level ZT 117 = HM 117 applies to both sections and numbering of the beds is continuous from the one to the other.

ZT 117 to HM 143 : type 2-3 marly limestones alternating with calcareous marls and Calcisphere limestones of type 1 at HM 124, HM 129 and HM 143.

**Palaeontology :** apart from some scattered *Lewisiceras* and a single *Collignoniceras woollgari* found at the top of the succession, the Ammonites collected belong to two species: *Kamerunoceras turonense* and *Romaniceras kallesi*, the second evolving from the first about the level ZT 120. Other macrofossils are quite rare and only some Echinids and Bivalves were noticed. On the other hand, marls containing Planktonic Foraminifera of the *Whiteinella* and *Dicarinella* groups, for example, evolved *Dicarinella hagni* with umbilical side of *Marginotruncana*. Moreover, in this interval there appear nannofossils such as *Lithastrinus moratus* and *Lucianorhabdus quadrifidus*, accompanying *Gartnerago obliquum*.

**Age :** the Ammonites *R. kallesi* and *C. woollgari* are indicative of a Middle Turonian age.

**Microfacies :** the microfacies analysis has been focused on the main lithofacies limestones characterized by exceptional amounts of Calcispheres.

### Calcisphere Limestones

They are compact beds with a packstone texture, very rich in Calcispheres. They are particularly abundant in ZT 114 and 116.5 (Pl. 10, fig. 5). Planktonic Foraminifera are rare but diversified, especially in ZT 114-117 (Pl. 11, fig. 7). Echinoderm debris (Pl. 11, fig. 4) and phosphate grains occur in greater amounts at the same level.

**Discussion :** the pelagic microfauna dominates again with the presence of a very large number of Calcispheres. The diversification of the Planktonic Foraminifera with the consistent occurrence of *H. helvetica* (Pl. 11, fig. 7 and Pl. 12, fig. 1) from ZT 114 and the decrease of detrital material in this interval suggests a renewed drowning.

### 2.6.3. Interpretation and depositional model of the Bireno Member

The basal alternations of marly limestones with calcarenites, rich in Benthic macrofauna, document a large detrital supply from the external shelf. They are overlain by neritic deposits prograding in the basin; the neritic organisms are firstly, Echinoderms and small isolated Corals until ZT 30; then, from ZT 30.9 onwards, they are Serpulids, Gastropods and Bivalves, which are typical of more proximal environments. Up until ZT 80.1, these deposits record a prograding shelf margin wedge during sea-level lowstand (cf. BOLTENHAGEN, 1981). From ZT 83, Calcispheres reappear in great numbers, suggesting a slowing down of the progradation. The proportion of marly limestones decreases and that of Calcisphere-rich limestones increases until ZT 114-117. This last bed, which contains numerous shells of pelagic organisms and phosphate grains, marks a transgressive surface. From this bed until the end of the Bireno, the limestones which are rich in Calcispheres and Planktonic Foraminifera represent the beginning of a transgressive interval.

The rapid rise in sea-level confined the detrital supply to the internal shelf. It promoted a bioclast concentration on the external shelf and allowed open-sea Planktonic Foraminifera to return.

### 2.7. ALEG FORMATION *sensu stricto* pars

537 metres for the Turonian part and 40 metres for the basal Coniacian part; clayey marls with limestone beds, calcareous marls and nodule rows (Fig. 6, 7, 8 and Pl. 5-6).

#### 2.7.1. From HM 143 to HM 417 (274 m)

**Lithology :** marls predominate over limestone beds. Three distinct units were differentiated.

HM 143 to HM 208 (65 m) : marls develop from HM 143 to HM 184. They are type 2 calcareous marls alternating with type 2 marly limestones. Between HM 184 and HM 195 there are three thick limestone beds of type 1 making a topographic ridge. Then come several marly limestone beds of types 2 and 3. The last, at HM 208, supports a coquina of numerous, small, black ostreids of 2 to 4 cm in length. In some marly limestone beds, as in HM 159 and HM 179, calcareous nodules of 5 to 10 cm in diameter develop and exhibit septaria structure.

HM 208 to HM 283 (75 m) : type 2 grey marls with about twenty half-metre thick marly limestones of types 2 or 3. Only

the bed HM 283 is clearly a type 1 limestone being 0.3 to 0.4 m thick. As it is more resistant, it forms a ridge line which can be followed easily on the field. Nodules showing septaria structure appear at HM 219 and HM 229 and are well developed between HM 260 and HM 264 where they form whitish, cylindroid, contorted rolls of more than 1 metre in length. Some of these nodulous features fill chambers of large Ammonites such as *Lewesiceras* at HM 261 (cf. Pl. 5).

HM 283 to HM 417 (134 m) : marly facies dominate with clayey marls of types 2 and 1, including about twenty marly limestone beds of type 2 and 5 nodule beds (at HM 327, 355, 410, 412 and 413). The marls contain 20 to 30 % CaCO<sub>3</sub> as opposed to 50 to 60 % in Annaba and Bireno Members. They are generally grey coloured except between HM 285 and HM 320 where they take a dark to black colouration. The Total Organic Carbon curve displays a carbon amount of 1 % which suggests a sedimentation in dysaerobic conditions. Another band of several metres also shows a dark facies near HM 380.

Limestone beds can be separated into two sets : those belonging to type 1, resistant to the weathering, with a reddish alteration of the surface as at HM 283, HM 285 and HM 322, and the other of type 2 to 3, bluey-grey in colour, with a surface rounded by weathering exfoliation.

**Palaeontology :** generally, macrofossils are less frequent than in the Bireno Member. However, each lithological unit was carefully investigated and produced the following throughout the succession : irregular Echinids, Ostreids, Pectinid fragments, Rudist fragments and large chambers of *Lewesiceras*. Ammonites are rare. *Romaniceras kallesi* disappears near HM 225 and *Coilopoceras* emerges. The first *Prionocyclus* was detected from HM 407 and *Romaniceras deverianum* was collected between HM 411 and 414.

As it becomes easier to process marls by washing, they produced a lot of material, especially planktonic forms : *Whiteinella* and *Dicarinella* continue, *H. helvetica* develops but totally disappears about HM 308. Now appear and develop numerous species of *Marginotruncana* such as *M. schneegansi*, *M. pseudolineana*, *M. coronata*, *M. tarfayaensis*, *M. renzi* and species of *Sigalitruncana* such as *S. sigali* and *S. undulata*. It is worth noting that the very peculiar genus *Falsotruncana* is restricted to the interval HM 283-302. Moreover, the nannofossil *Eiffellithus eximus* appears just above HM 283.

**Age :** the appearance of *Romaniceras deverianum* at HM 411 marks the base of Late Turonian (*sensu gallico*, see the chapter relative to Ammonites). In other words, most of the marls of the unit described are Middle Turonian in age, providing that this marker Ammonite is not found lower in the succession.

**Microfacies :** in the HM 143-HM 417 interval, the microfacies analysis has been focused on the three main types of lithofacies, having distinct characteristics : calcisphere-rich limestones, marly limestones with varied microfauna and marly limestones with scarce microfauna.

Moreover, in the whole Aleg Formation, marls contain calcareous nodules of diagenetic origin which display septaria structure when broken. These nodules are spherical or cylindroidal and more or less contorted. They increase in number towards the top of the Hammadja section where they are arranged in rows underlining stratification. In thin section, they have a recrystallized texture and bioelements such as Echinoderm debris or Foraminifera tests are generally obliterated by micritization.

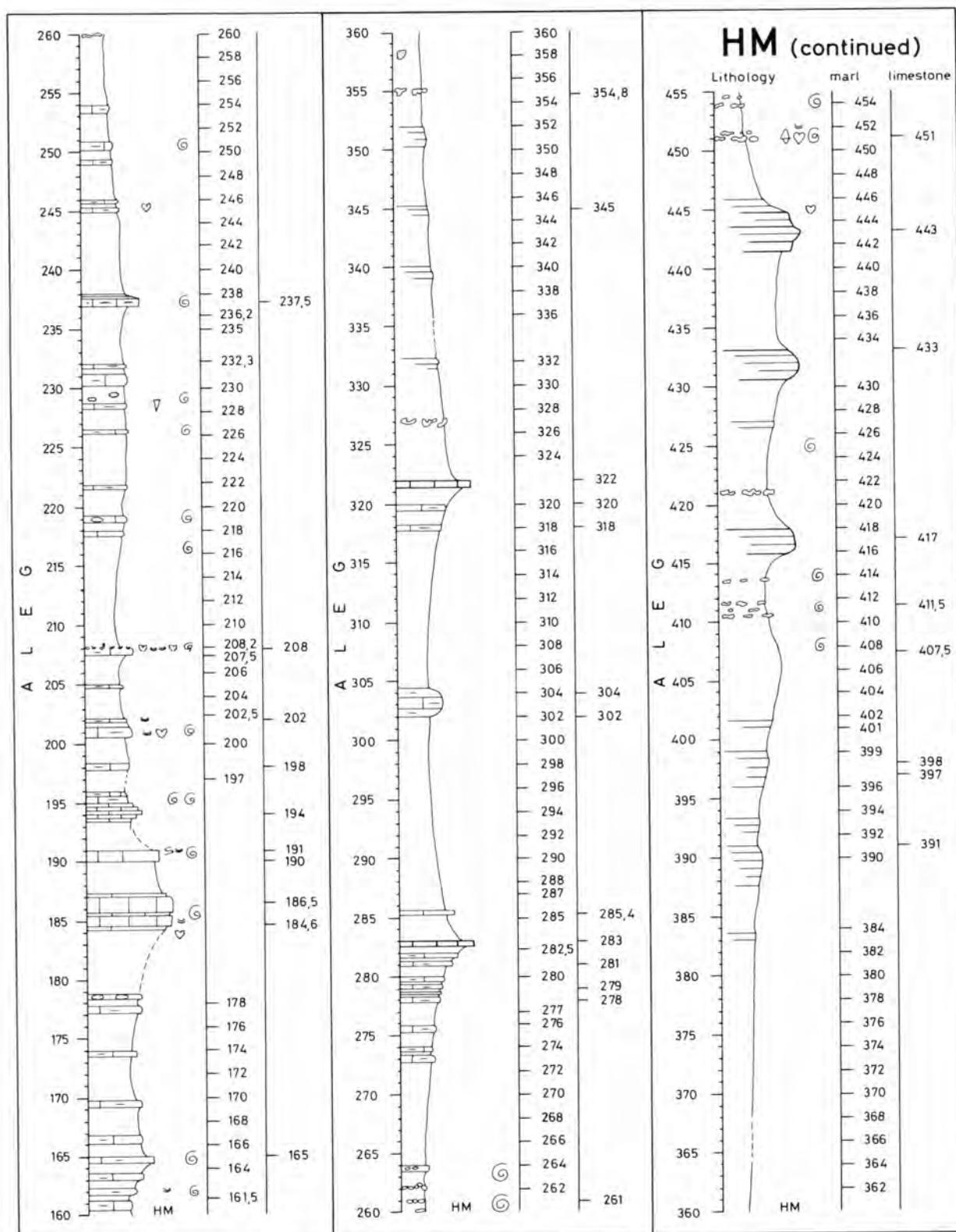


FIGURE 6  
Lithologic succession in the HM section (continued) at Oued Hammadjah; Middle and Late Turonian.

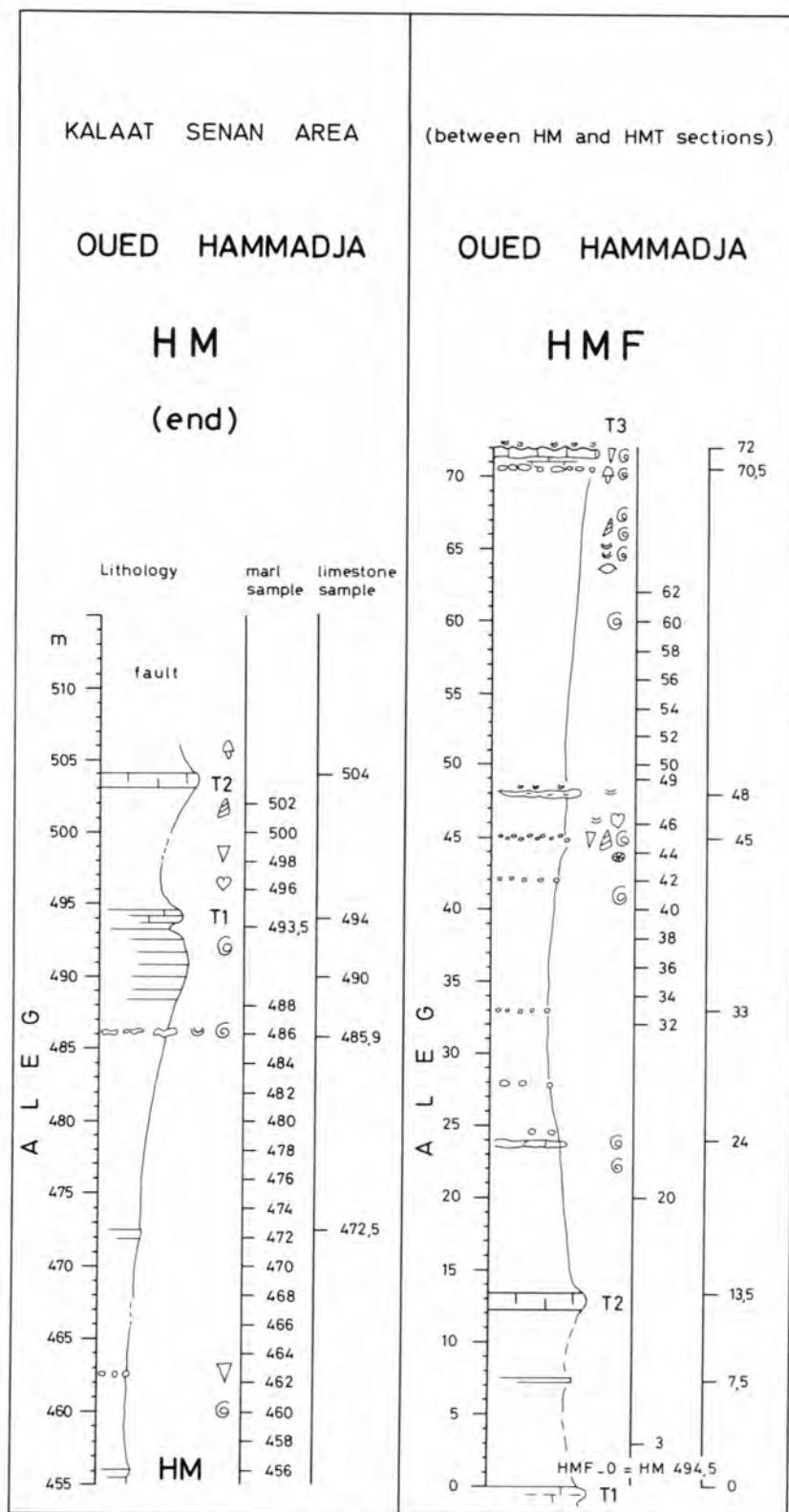


FIGURE 7  
Lithologic succession in the HM section (end) and HMF section at Oued Hammadja: Late Turonian.

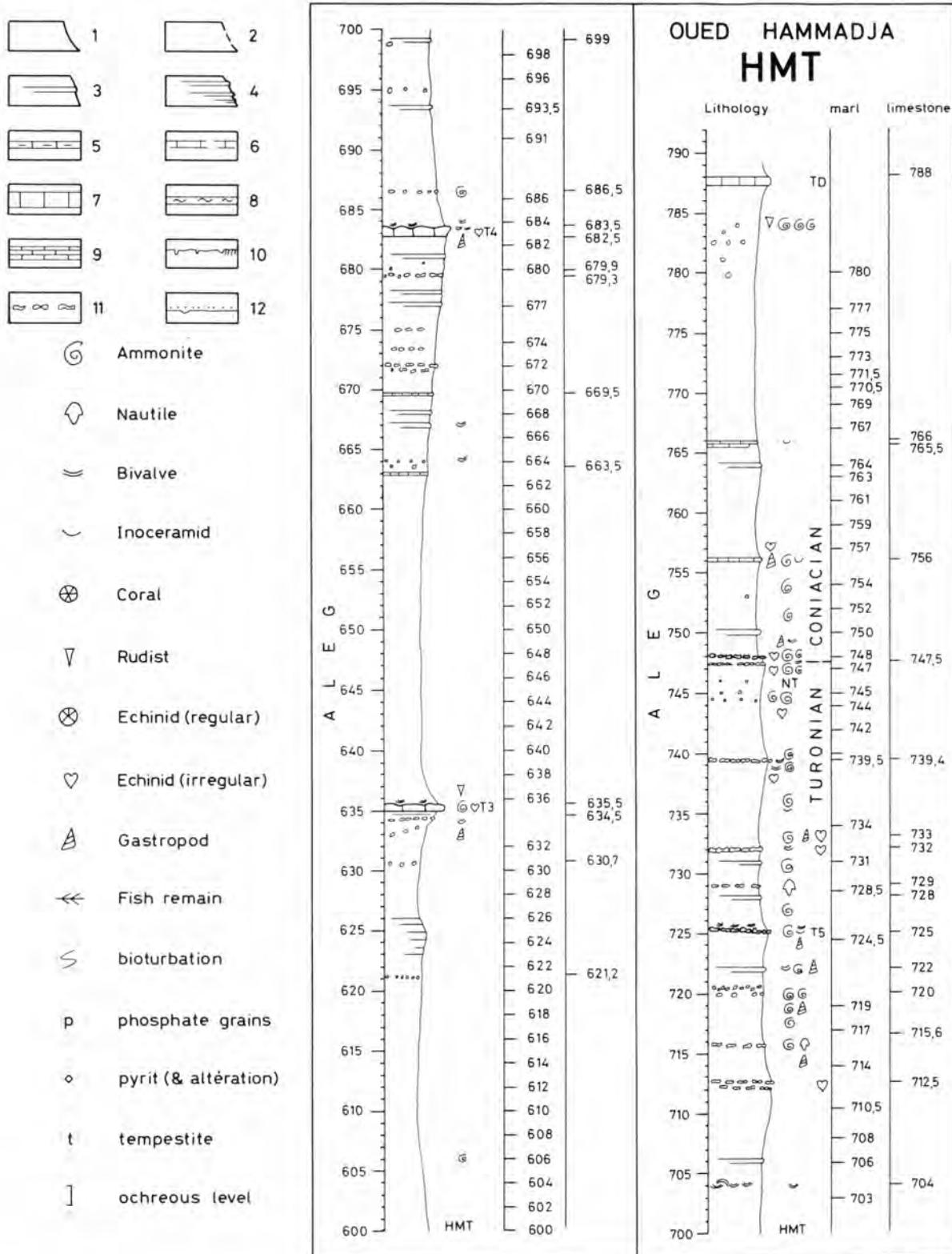


FIGURE 8

Lithologic succession in the HMT section at Oued Hammadja; Late Turonian and basal Coniacian.  
Legend for Fig. 4 to 8.

## Calcisphere-rich Limestones

Well demonstrated in HM 185, 190, 278, 283, 285, 322. This type of limestone is also found higher in the succession as in HM 504 = T2 = HMF 13.

In general, they have a packstone, but also much less commonly a grainstone texture, where Calcispheres prevail (Pl. 12, fig. 1). Planktonic Foraminifera (Pl. 12, fig. 10, 11, 12, 13) are well diversified (*Heterohelix* sp., *Hedbergella* sp., *Whiteinella* sp., *H. helvetica* (until HM 285), *Marginotruncana* sp. and *Dicarinella* sp.), as are the Benthic Foraminifera. Phosphate grains occur, in especially large numbers in HM 283-285. The absence of bioclasts of benthic organisms is remarkable.

Between HM 300 and HM 304, there is a surprising increase in T.O.C. (1%), Calcispheres disappear, small Buliminids become abundant (Pl. 12, fig. 2) and a single specimen of *H. helvetica* occurs.

**Discussion :** the limestones are mainly made up of shells from pelagic organisms among which Planktonic Foraminifera and Calcispheres dominate. They document periods where shelf carbonates no longer reached the basin. The darker beds between HM 300 and HM 308 reflect the return of a low-oxygen water layer which may have precipitated the extinction of *H. helvetica* forms at HM 302 in thin section, at HM 308 in pickings.

Marly Limestones with varied microfauna  
(HM 165, 194, 198, 202, 208)

Wackestones characterized by a high diversity in Planktonic and Benthic Foraminifera (Pl. 12, fig. 6), and by a large number of Calcispheres. Echinoderm debris occurs (Pl. 12, fig. 4), but there are no phosphate grains. A coquina of small Oysters covers the upper surface of HM 208.

**Discussion :** the marly limestones are more numerous than the Calcisphere-rich limestones with which they alternate. They show episodically an enrichment in bioclasts derived from the external shelf. The diversity of Planktonic Foraminifera is consistent with the predominant influence of the open-sea (Pl. 12, fig. 8-9).

Marly Limestones with scarce microfauna  
(HM 237, 261, 407, 417)

They have a mudstone texture with rare microfauna and bioclasts. Planktonic Foraminifera are poorly diversified (*Heterohelix* and *Hedbergella*). Benthic Foraminifera are represented only by minute and numerous Buliminids and Calcispheres are small and rare. There are no phosphate grains.

**Discussion :** the scarcity of microfauna could be linked to an increased terrigenous sediment supply.

## 2.7.2. From HM 417 to HMT 789 (304 m)

**Lithology :** the presence of faults in the Oued Hammada area made it difficult to sort out the bed succession in this marly interval. However, the definition of distinct lithological characteristics of some beds in the HM, HMF and HMT sections made it possible to demonstrate a complete succession where marls predominate over calcareous beds and nodule bands. Three units are distinguished.

HM 417 to HMF 13 = HM 504 (91 m). Grey marls of type 1-2 including four heavy marly limestone beds of type 2-3, rounded by weathering. In succession, HM 417 is grey, HM 433 purple-grey, HM 444 is grey and double, HM 495 is grey, double and thick. This last bed can be followed easily on the field and was named T1 (T for beds near the Taga farm) similarly HM 504 = HMF 13, grey and less thick, was named T2. In this manner, the distinction of the three-bed set HM 417-433-444 and of the twin-bed set HM 495-504 = T1-T2 is very convenient for following the succession through tectonic blocks (Fig. 2). Furthermore, the interval contains only five small nodule bands.

HMF 13 to HMT 683 (107 m). Grey marls of type 1 with two half-metre limestone beds of type 1, some marly limestone beds and about ten nodule beds. The limestone beds are HMF 72 = HMT 635 = T3 and HMT 683 = T4. Their surface is covered with fossil fragments. Moreover, HMF 48 is a level with large lenticles of biocalcitrudites full of fossil fragments.

HMT 683 to HMT 789 (106 m). Marls of type 1, grey to brownish, containing about ten small marly limestone beds of type 3-2 and about twenty nodule bands where nodules are abundant and sometimes close, as in HMT 725 = T5 and HMT 747.5-748 = NT ("Niveau de Taga"). Generally, these nodule beds are covered with thin horizons full of Bivalves or Echinids debris

**Palaeontology :** as nodular facies develops, the quantity and diversity of macrofossils increase. Most of the nodule bands give an abundant macrofauna which consists of Ostreids and other Bivalves, Echinids, Gastropods (*Tylostoma*), Rudist fragments and Ammonites. Amongst the latter, *Coilopoceras* is rather rare but present till HMF 72 (T3), whereas *Prionocyclus* is represented by numerous specimens from HMT 720 to HMT 747.5, the level where it disappears and is replaced by abundant *Forresteria*.

About Planktonic Foraminifera, species which appeared in the first part of the Aleg Formation develop and evolve. It is worth noting that specimens of *Dicarinella concavata* were detected from HM 424 and, although rare and scattered, were found all along the second part of the Aleg Formation. In this interval the two species of nannofossils *Marthasterites furcatus* and *Lithastrinus septenarius*, also appear.

**Age :** The first appearance of *Forresteria* in HMT 748 marks the base of the Coniacian stage. Consequently most of this second part of the Aleg Formation is Late Turonian in age. In this way, it becomes obvious that the first appearance of *Dicarinella concavata* — which was considered generally as marking the basal Coniacian — occurs, in fact, in the Late Turonian.

**Microfacies :** Apart from the calcareous nodules which are the same as below, two lithofacies, specific to this part of Aleg, are analysed here: bioclastic marly limestones and marly limestones in ill-defined beds.

## Bioclastic Limestones

(HMF 48; HMF 72 = T3; HMT 683.5 = T4, HMT 725 = T5; HMT 739.5)

They are marly limestones containing abundant bioclasts (Pl. 13, fig. 6) which are, in general, fine and sorted. They overlie rows of whole benthic macrofauna (Pl. 13, fig. 7). Their upper surface is often topped by a coquina made of small Bivalve shells.

Their texture is that of a dense packstone, rich in Gastropods, and Bivalve and Echinoderm bioclasts. Calcispheres, phosphate grains and a few, rare but diversified Planktonic Foraminifera (Pl. 13, fig. 9) may also be found (*Heterohelix* sp., *Whiteinella* sp., *Marginotruncana* sp., *Dicarinella* sp.).

**Discussion :** sedimentation obviously occurred very rapidly; whole macrofauna were buried under a sudden outpour of bioclasts derived from a nearby source which had been exposed to stronger hydrodynamical conditions. The sedimentary episode ends with the accumulation of small, flat Bivalve shells on top of the bed. At HMT 747, 747.5, 748, a

row of nodules, consisting of an accumulation of Ammonite shells, are found; the upper part of the "parasequence" is missing, maybe eroded by a later erosive event.

## Marly Limestones in ill-defined beds (HMT 756, 766, 788)

They have a wackestone texture characterized by the small size of their bioclasts. The quantity of phosphate grains and small, globular Planktonic Foraminifera is remarkable (Pl. 13, fig. 4). Inoceramid prisms, seen for the first time in HMF 48, are abundant.

**Discussion :** The fine bioclasts redistributed in these marly limestones indicate a decrease in the supply of shelf-derived material. The abundance of Planktonic Foraminifera, glauconite and phosphate grains points to the recurrence of a well marked open-sea influence.

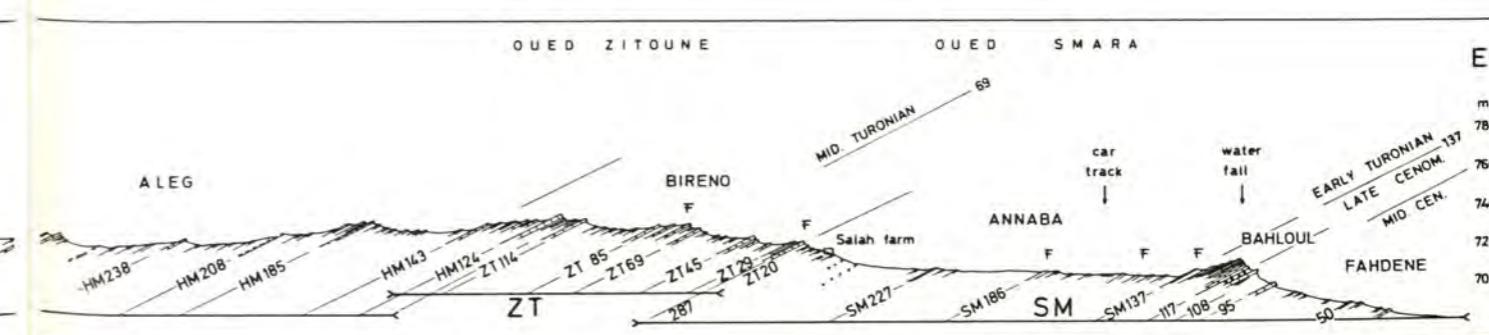
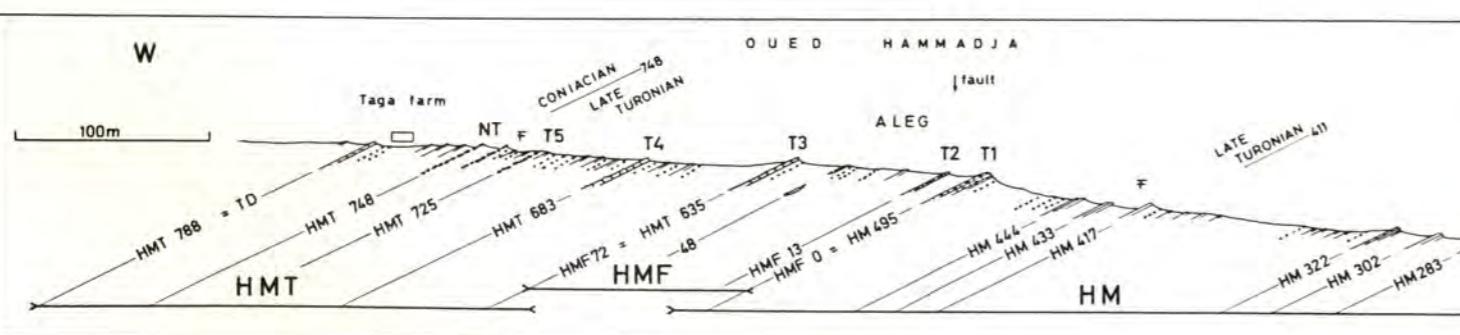
## 2.7.3. Interpretation and depositional model of the base of the Aleg Formation s.s.

After the Bireno fossiliferous limestones, the basal Aleg marls mark the end of the transgressive interval. The event is documented by a wealth of Planktonic Foraminifera and Calcispheres. The bed HM 208 records the maximum flooding. The overlying marly limestones, poor in microfauna, build up the highstand deposits until HM 283: the end of the first complete Turonian sequence.

The second sequence begins at HM 283 with a bed rich in Calcispheres, Planktonic and Benthic Foraminifera, and phosphate grains. This bed overlies both a sequence boundary and a transgressive surface. The transgressive interval, extending from HM 283 to HM 370, is characterized by the diversity of Planktonic Foraminifera and the scarcity of bioclasts. Worth noting is a short period between HM 300 and HM 304, where the environment was dysaerobic as a result of the expansion of the oxygen-minimum layer, brought about by the transgression. This event coincides with the disappearance of the taxon *H. helvetica*. The highstand deposits of this second sequence (from HM 370 to HM 417) contain few Calcispheres and Planktonic Foraminifera.

The third sequence begins at HM 417 with transgressive deposits. From HM 417 = T2, the upper part of the transgressive interval is rich in Planktonic Foraminifera and benthic macrofauna shells. The highstand deposits contain bioclasts and organisms derived from more proximal environments, and accumulated by progradation. Planktonic Foraminifera are very rare.

The final sequence begins at HMT 683 (= T4) with



1  
PLATE  
BAHLOUL FORMATION

Fig. 1. — Panorama from East to West (left to right) in the high part of the Oued Smara. The upper part of the Fahdène Formation is characterized by thick marls and two limestone levels at SM 95 and SM 109.5-111.

The black limestone of the Bahloul Formation forms a slightly prominent bar in the landscape where Oued Smara crosses a small waterfall. Since it is mainly formed of calcareous marls, the Annaba Member appears as a depression between the Bahloul and Bireno limestones.

SB : sequence boundary — S : Salah farm.

From the base of the section up to SM 109.5 the highstand deposits of the preceding sequence are to be found. From SM 109.5 to SM 119 there is an outcrop of the lowstand slope prograding limestones of the shelf-margin wedge. Between SM 119 and SM 200 the transgressive systems tracts develop and are followed by the highstand systems tracts up to SM 287 which forms the sequence boundary with the next sequence. The systems tracts boundaries are fixed after studies on macro- and microfaunal content, lithology, sedimentological features, microfacies and calcium carbonate amount... (see text).

2. — The SM 109.5 sequence boundary. This level presents a slight unconformity with the preceding ones. At SM 108 the first Ammonites indicative of the Late Cenomanian were found.
3. — The Oued Smara waterfall at SM 114 well exposes the limit between the Fahdène and Bahloul Formations. The latter begins when laminated carbon-rich limestones appear, which eliminate the Planktonic Foraminiferal genus *Rotalipora* at SM 114.8.
4. — From SM 119, phosphatic and glauconitic grains become frequent between the limestone laminae of the Bahloul Formation. Generally, grains fill in bioturbations, as can be seen at the surface of the SM 127.5 level. This would suggest a transgressive systems tract (scale with hammer point).
5. — Small slumping features sometimes appear in the shelf-margin wedge of lowstand deposits, as for example at the SM 117.9 level (scale with hammer).

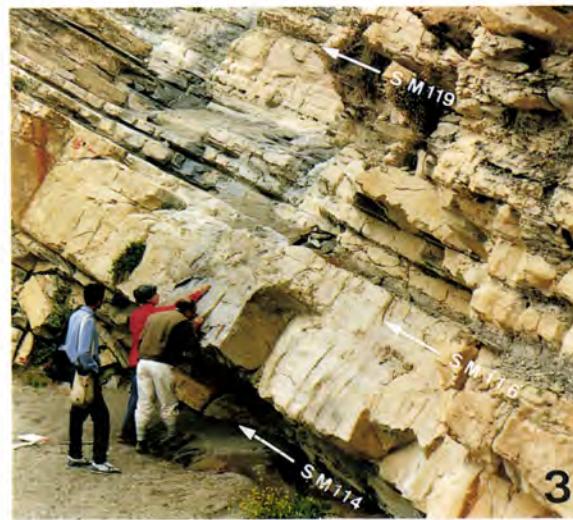
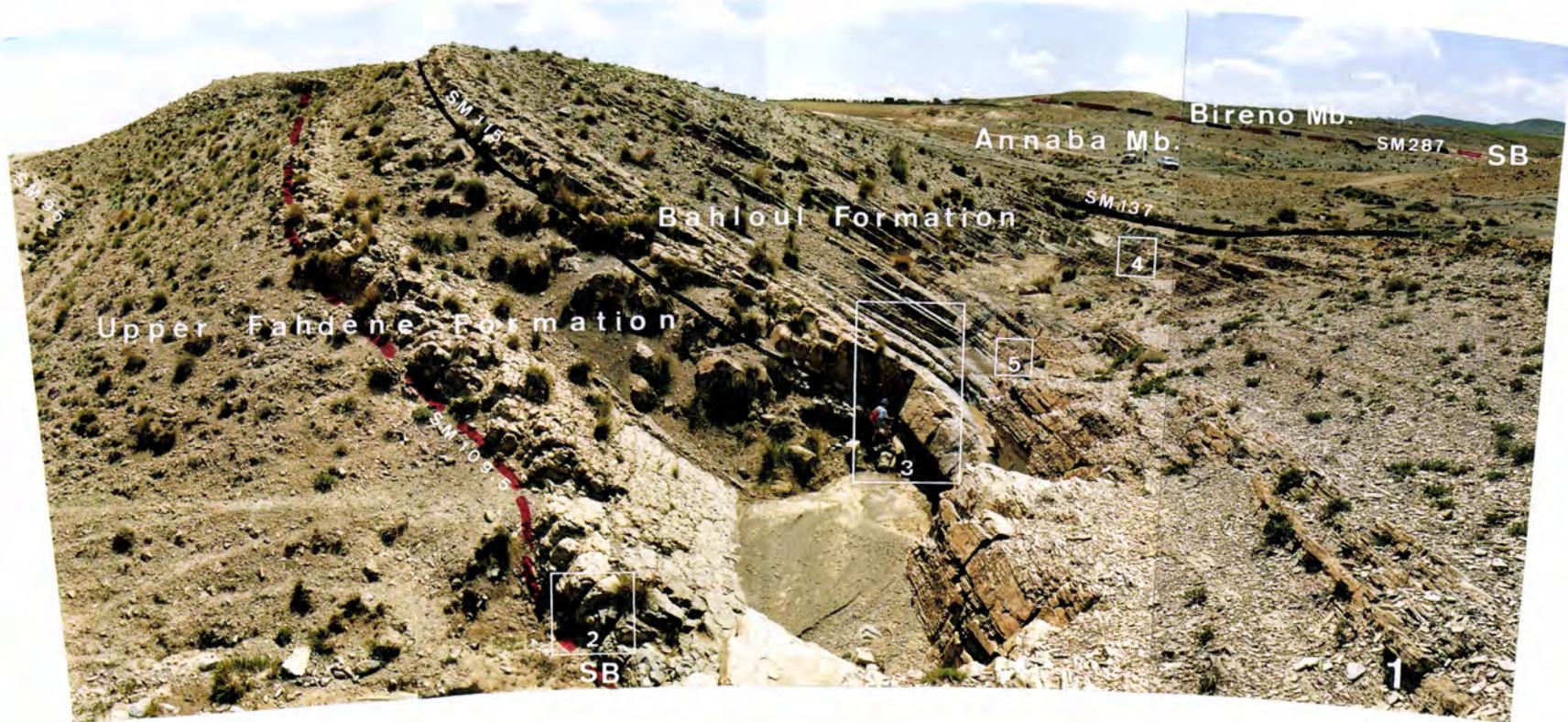


PLATE 2  
ANNABA MEMBER

Fig. 1. — Panorama from East to West (left to right) in the higher part of the Oued Smara showing the marly Annaba Member forming a depressed band between black limestones of Bahloul Formation and fossiliferous limestones of Bireno Member. The Annaba Member is completely comprised between SM 137 and SM 287 and is Early Turonian in age as the basal third part of the Bireno.  
(S : Salah farm)

2. — The base of the marly Annaba Member lies on the calcareous laminated level SM 137 which is the top of the Bahloul Formation. At SM 149 there is a 1.20 metre band of calcareous marl which owes its ochreous colour to a very large number of microscopic dolomitic crystals.
3. — Higher in Annaba Member, the thick calcareous blue marls comprise thin light grey horizons of limestones interpreted as calcareous tempestites at SM 227.
4. — The rest of Annaba Member consists of calcareous blue marls only marked by a thick ochreous level between SM 262 and SM 266, above which small pyritized fossils as such Corals, Echinids and Ammonites especially *Mammites nodosoides* are found. The first appearance of the latter in this section is at SM 254.

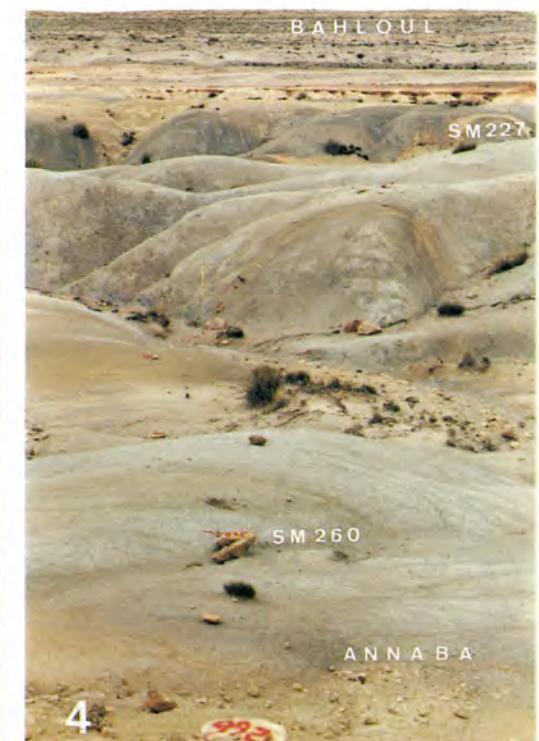
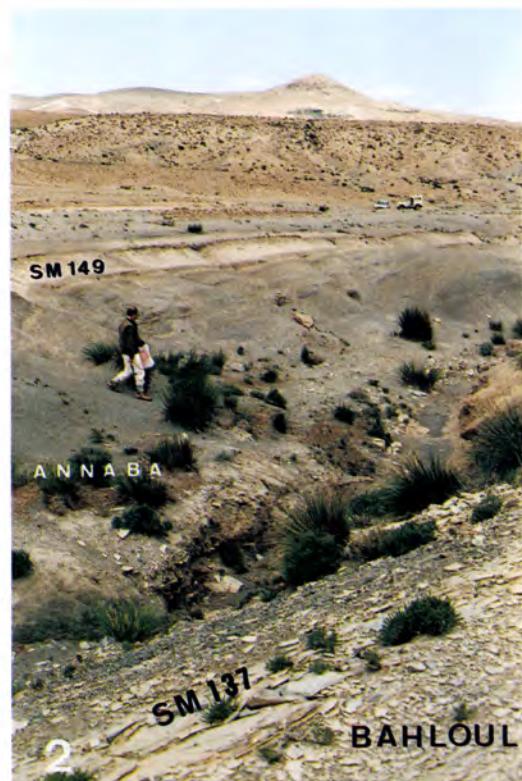
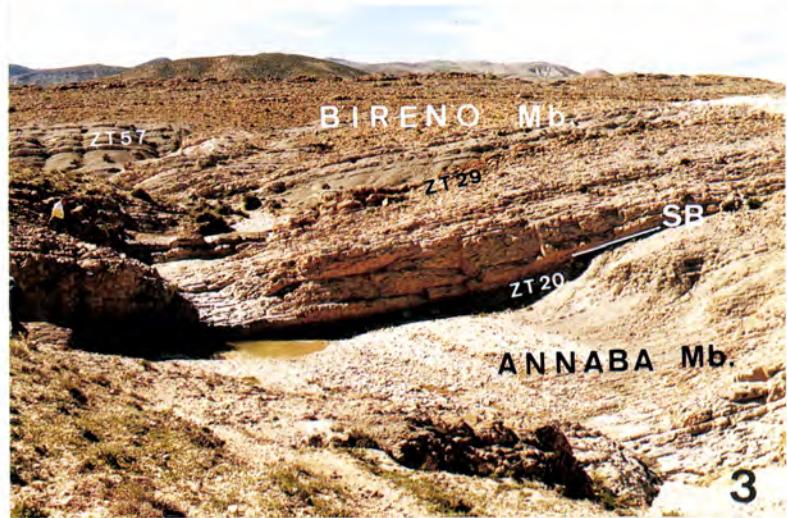


PLATE      **3**  
BIRENO MEMBER

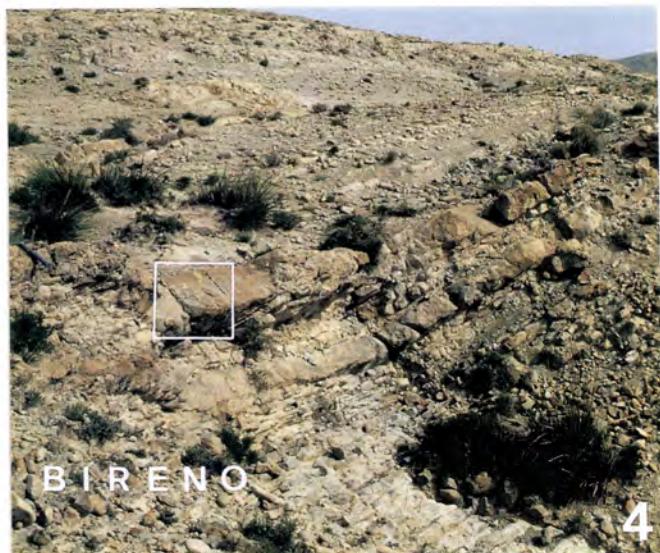
- Fig. 1-2. — Panorama of the Bireno Member exposed on the left side of the Oued Zitoune from East to West (left to right). It is a succession of bioclastic limestones and calcareous marls, very fossiliferous, building a Shelf-Margin Wedge from ZT 20 (= SM 287) to ZT 114. With the latter level which is a transgressive surface (TS) begins a transgressive systems tract marked by a grainstone texture and numerous phosphatic grains.
3. — Because the base of the limestone Bireno Member is harder than the marly Annaba Member, it makes a small waterfall, here in the Oued Zitoune. The level ZT 20 is a lithologic limit and a sequence boundary (SB). It often produces the Ammonite *Fagesia superstes*.
  4. — Between ZT 28.5 and 29, a limestone level which is deeply burrowed and bioturbated forms an outcrop. Its fractured surface is easily recognizable in the Oued Zitoune.
  5. — The result of one hour collecting Ammonites at the base of the Bireno Member between Oueds Zitoune and Smara, in the vicinity of the Salah farm; a : *Fagesia superstes* group; b : mixed forms with *Choffaticeras* on the right; c : *Neptychites cephalotus* and *Thomasites*; d : *Neptychites* and *Lewesiceras*; e : *Mammites nodosoides* and *Morrowites*; f : *Kamerunoceras turonense*.
  6. — A specimen of the Ammonite *Fagesia superstes* (Early Turonian) was found in ZT 20, at the Oued Zitoune waterfall.
  7. — An Ammonite in the Bireno limestone at ZT 117 (*Thomasites* sp.).



## PLATE 4

ANNABA & BIRENO MEMBERS, ALEG FORMATION *s.s.* (lower part)

- Fig. 1. — Contact between Bahloul Formation and Annaba Member at about 200 m south of the Oued Smara waterfall. Bed SM 137 is the very base of Annaba; SM 138 and SM 149 are the two first ochreous levels of the Member. At about 800 m south of the Oued Smara waterfall (ZH section), several samples from a bed equivalent to the interval SM 137-SM 138 produced specimens of Planktonic Foraminifera from the *W. praehelvetica* — *H. helvetica* group.
2. — In the vicinity of the site presented in fig. 1, at the boundary of Bahloul-Annaba (SM 137) we found the large Ammonite *Pseudaspidoceras flexuosum*, marker of basal Early Turonian.
3. — The higher part of Annaba Member is underlined by a thick ochreous level. Here, in ZH section, it is an equivalent of SM 262-266.
4. — Base of the Bireno Member at ZH section; frame bed is an equivalent of ZT 28.5-29.
5. — Framed part of fig. 4 showing large bioturbations filled with biocalcicrudites.
6. — At the base of Aleg Formation *s.s.* are blue marls followed by several calcareous beds as from HM 184 to HM 195. They are covered by more than 1000 m of marl, more or less calcareous, with limestone and nodule beds, from Middle Turonian to Early Campanian.



## PLATE 5

ALEG FORMATION *s.s.* (lower part)

- Fig. 1. — Marls and limestones from the transgressive systems tracts up to HM 208. The surface of the bed is covered with small black ostracids and is interpreted as a downlap surface.
2. — From the downlap surface at HM 208 to the bed HM283 a succession of marls and marly limestones with very rare macrofossils is exposed. The interval represents a high stand systems tract.
3. — A westward view showing the extent of Aleg Formation up to A (= white limestones of Abiod Formation). T = Taga farm.
4. — A typical aspect of Aleg Formation : grey-blue marls and marly limestones.
- 5-6. — The level HM 260-262 is the first bed in the Aleg Formation with septaria nodules (6). Some of them can fill in chambers of large Ammonites (A) as *Lewesiceras sp.* at HM 260.
7. — The Ammonite at HM 260 forming a septaria nodule; s : chambers with suture lines; b : body chamber.

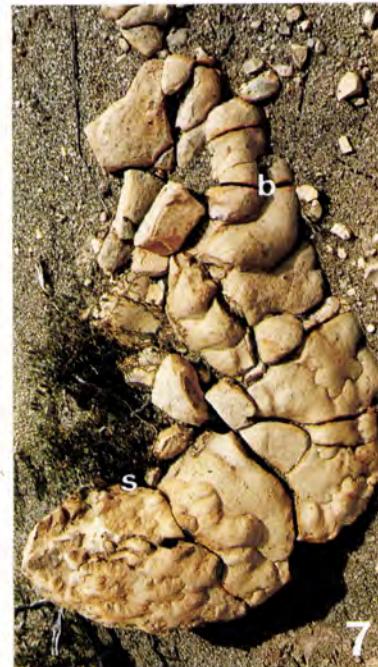
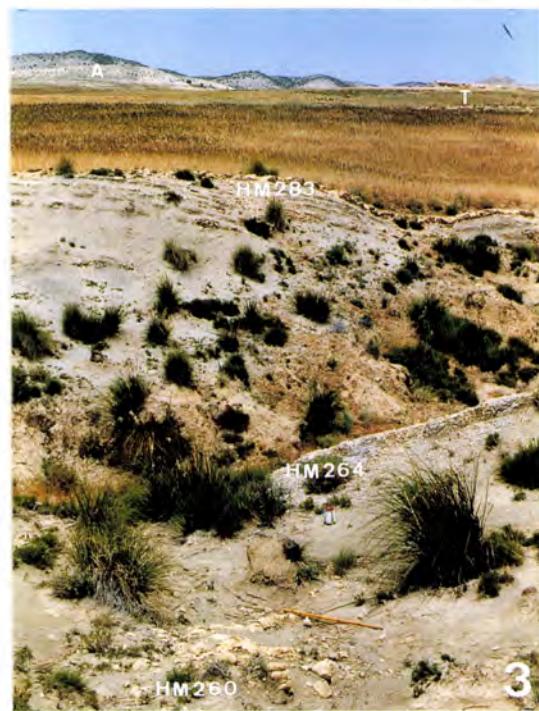


PLATE **6**  
ALEG FORMATION *s.s.*

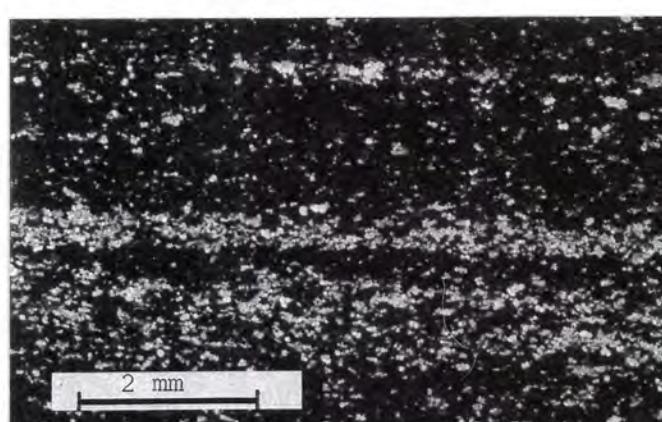
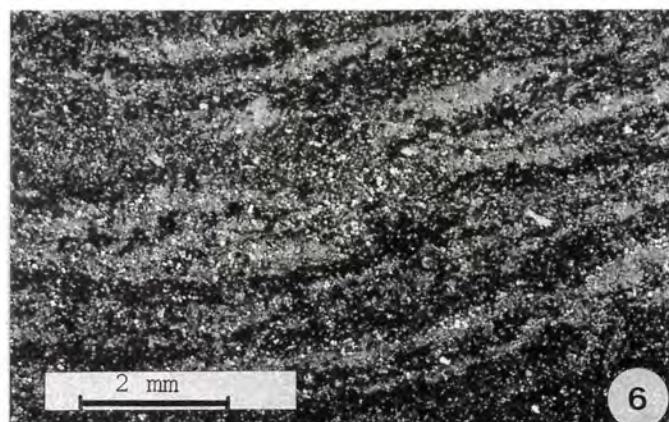
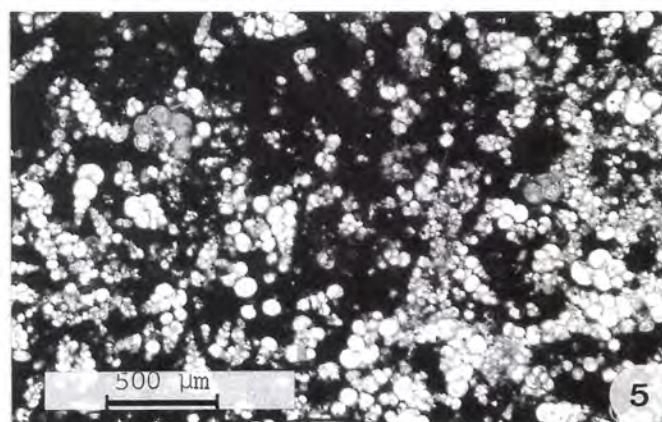
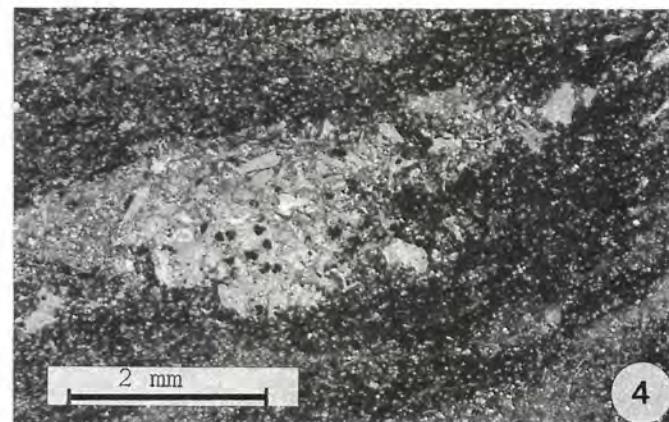
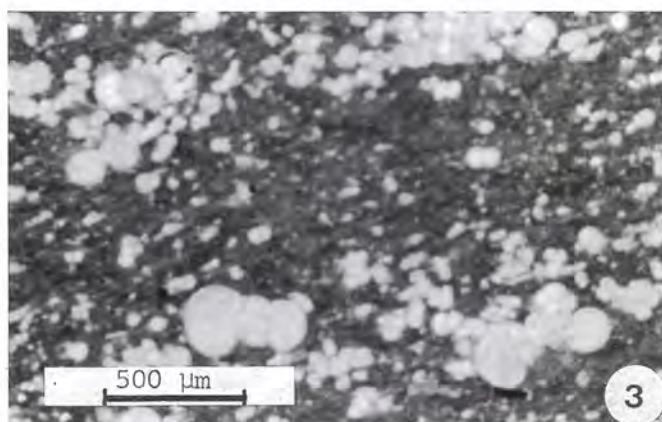
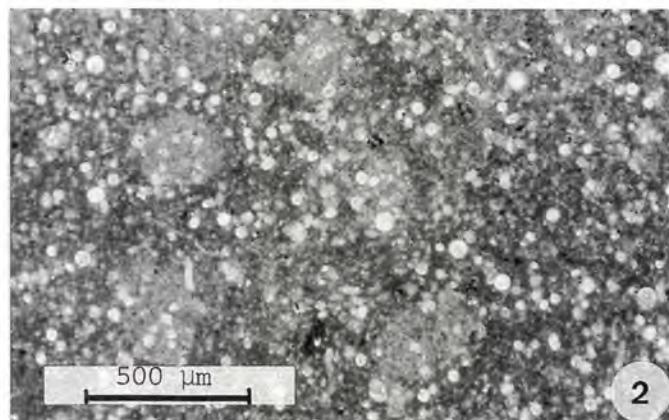
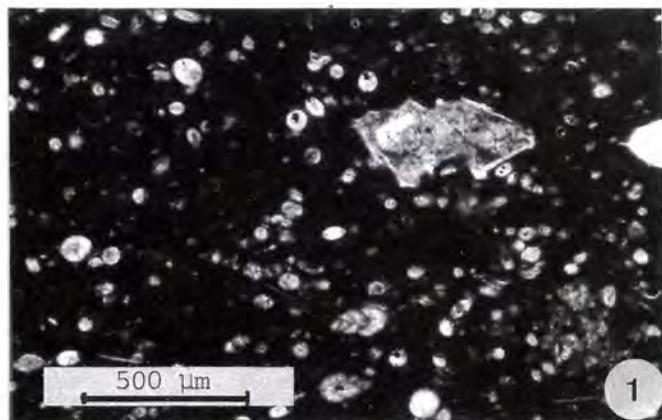
- Fig. 1. — View to the East along Oued Hammadja showing black Aleg marls between HM 283 and HM 322. These dysaerobic black marls cause the Planktonic Foraminifera *H. helvetica* to become extinct. T = Taga farm.
2. — In the vicinity of Taga farm (T), marls of Aleg Formation are well exposed in the Oued Hammadja. They contain rare limestone beds as in HMT 635 (or T3 bed) and HMT 683 (or T4 bed) which are a downlap surface and a sequence boundary respectively.  
Above T3 and T4, marls are interbedded with numerous nodule levels generally rich in macrofauna (Ammonites, Bivalves, Echinids...) which indicate a succession of flooding surfaces in transgressive systems tracts.  
The Turonian-Coniacian boundary lies between HMT 683 and HMT 788 at the level HMT 748.5 where the Ammonite *Forresteria* appears and replaces *Prionocyclus*. This level is still a flooding surface.  
Above HMT 788 up to A (Abiod Formation), there are more than 500 m of Aleg marls. Coniacian, Santonian and Early Campanian in age.



## PLATE 7

## Microfacies of the Fahdène and Bahloul Formations

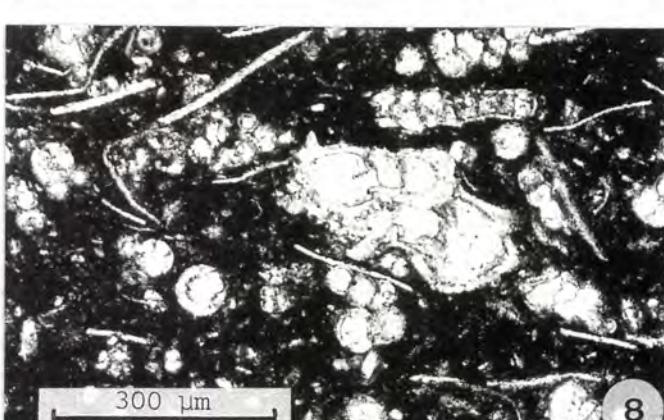
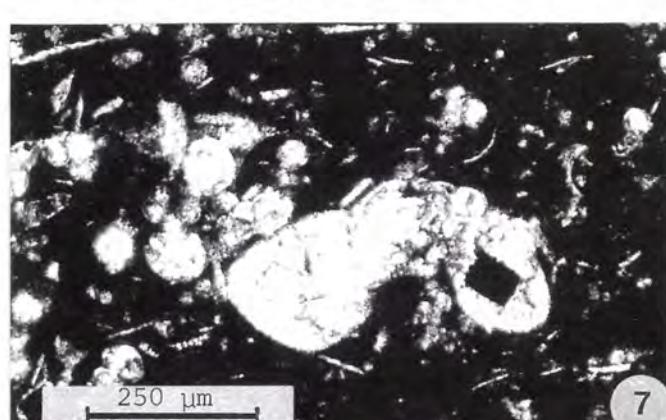
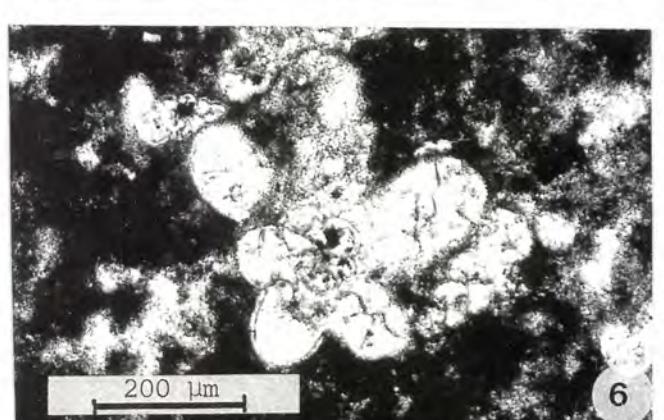
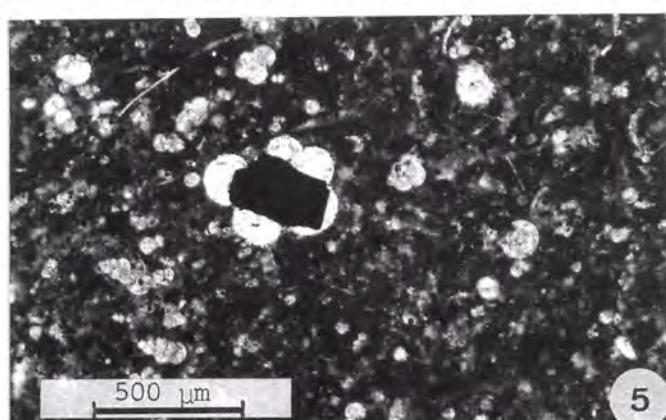
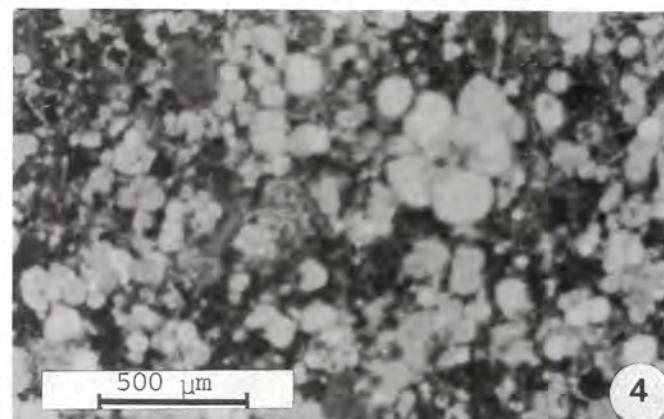
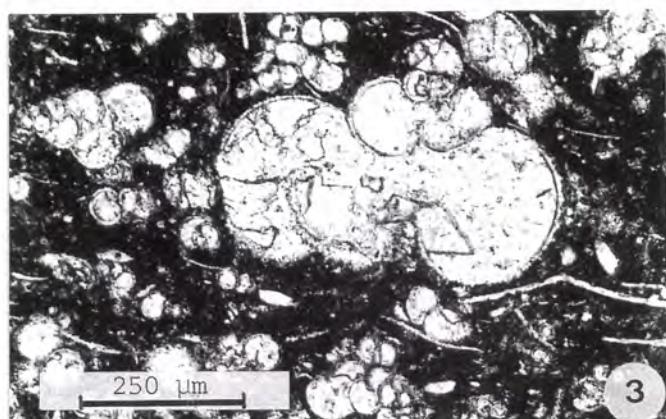
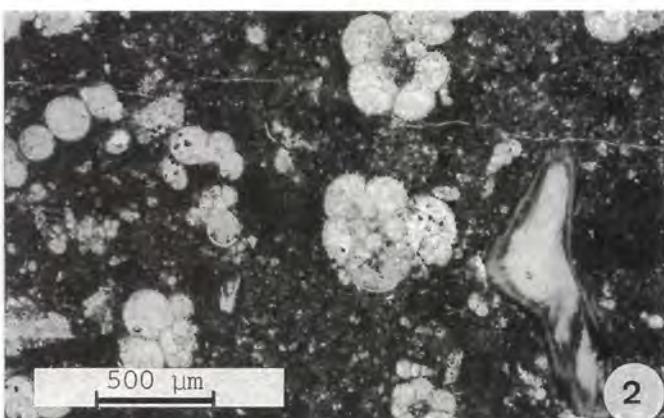
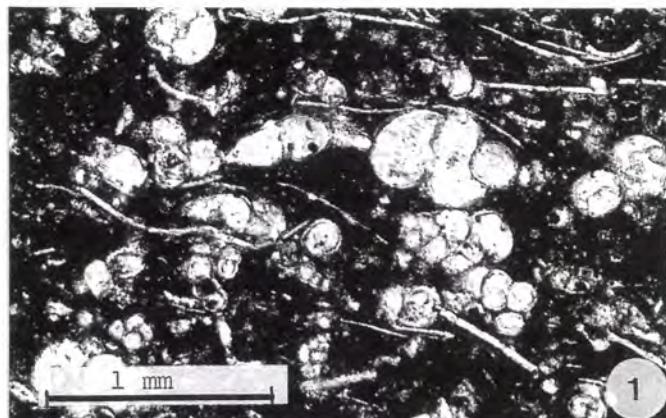
- Fig. 1. — Calcisphere wackestone with sparse *Rotalipora*.  
Fahdène Formation, sample SM 95.
2. — Bioturbated Calcisphere packstone.  
Fahdène Formation, sample SM 111.
3. — Millimetric alternation of light, heterohelicid and whiteinellid-rich, laminae, and dark, organic matter-rich, laminae.  
Bahloul Formation, sample SM 125.30.
4. — Detail of a lamina in the level with minislumps : graded deposit of Echinoderm debris continues laterally in a light, Calcisphere-rich, lamina.  
Bahloul Formation, sample SM 118.
5. — Plane-parallel view of a heterohelicid-rich lamina.  
Bahloul Formation, sample SM 121.
6. — Laminations disturbed by minislumps. General view of the same sample as fig. 4. Light laminae are Calcisphere packstone.  
Bahloul Formation, sample SM 118.
7. — Typical millimetric laminations in the Bahloul Formation. The light laminae are rich in Heterohelicids and Whiteinellids and dark laminae are rich in organic matter.  
Bahloul Formation, sample SM 125.30.



## PLATE 8

## Microfacies of the Bahloul Formation

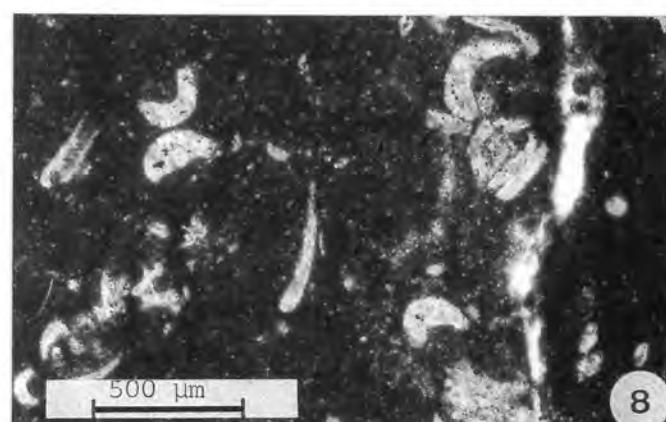
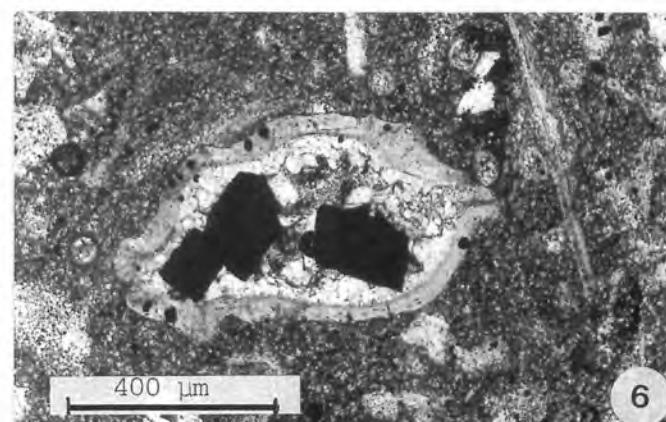
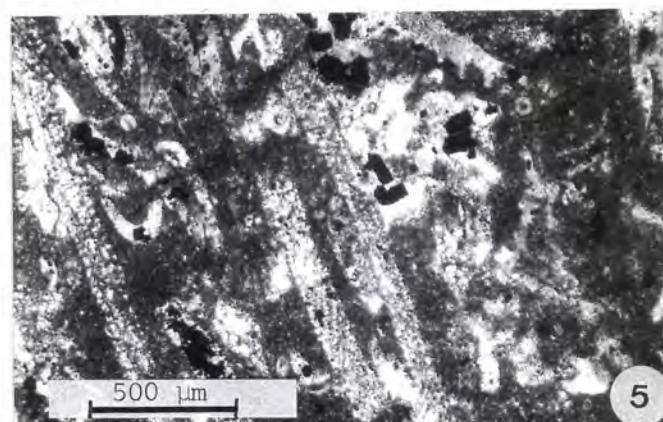
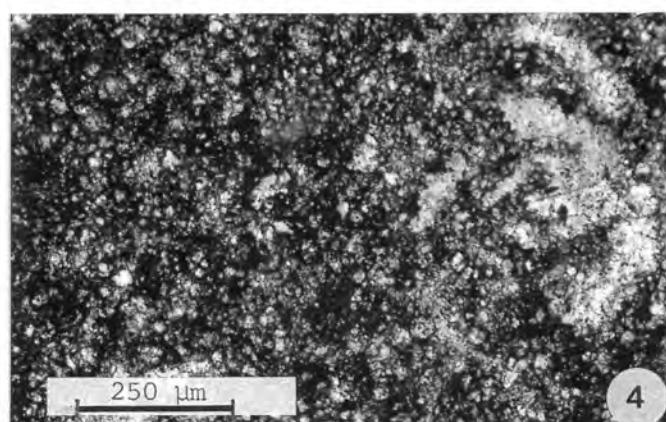
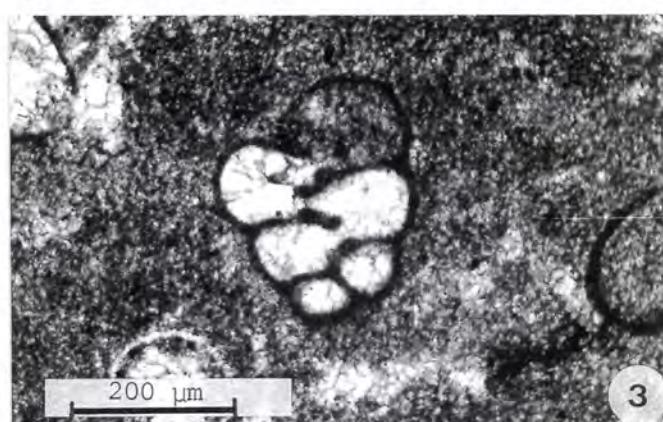
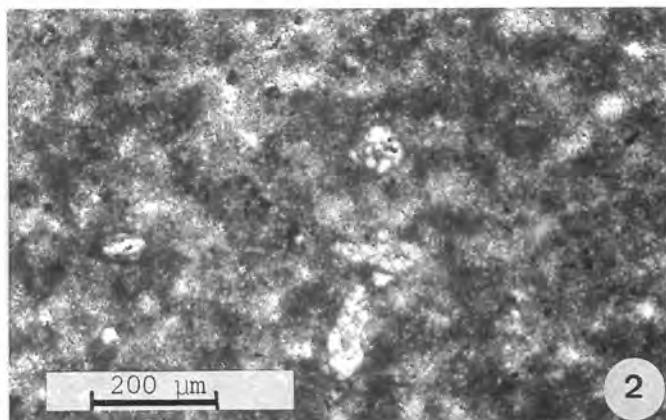
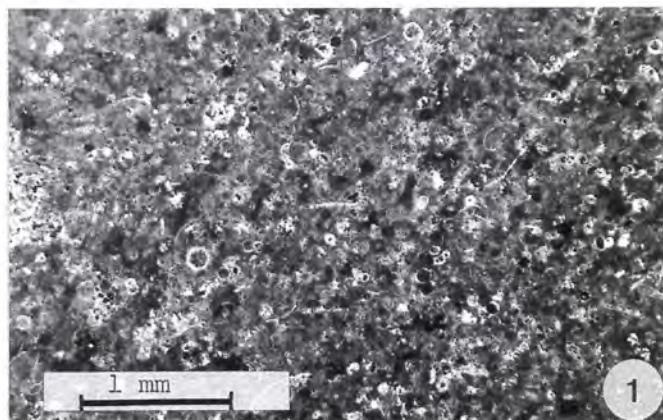
- Fig. 1. — Heterohelicid and "filaments" packstone. Whiteinellids are sparse, but large in size. Bahloul Formation, sample SM 130.5.
2. — Whiteinellid wackestone-packstone. Sparse phosphate bioclasts (here, teeth). Absence of "filaments". Bahloul Formation, sample SM 127.2.
3. — Same association as fig. 1. Here large *Whiteinella*. Bahloul Formation, sample SM 130.50.
4. — Heterohelicids, Whiteinellids, small-sized phosphate grains, and "filaments" in packstone-grainstone. Bahloul Formation, sample SM 128.10.
5. — Pyrite crystal developed inside a Whiteinellid test. Bahloul Formation, sample SM 137.
6. — *Hedbergella simplex* in an organic matter-rich lamina. Absence of "filaments". Bahloul Formation, sample SM 134.2.
7. — *Whiteinella archaeocretacea*, in heterohelicid, whiteinellid and "filaments" wackestone-packstone. Bahloul Formation, sample SM 133.
8. — *Dicarinella hagni*, occurring exceptionally in a lamina with "filaments". Heterohelicids and Whiteinellids. Bahloul Formation, sample SM 130.5.



## PLATE 9

## Microfacies of the Annaba Member

- Fig. 1. — Calcisphere argillaceous mudstone.  
Annaba Member, sample SM 217.7.
2. — Small Buliminids in argillaceous mudstone.  
Annaba Member, sample SM 239.
3. — Agglutinated Foraminifera (*Dorothia*?) in mudstone.  
Annaba Member, sample SM 255.2.
4. — Bioclasts (Echinoderms ?) partially eroded by micritisation.  
Annaba Member, sample SM 263.
5. — Calcarenite with abundant Echinid bioclasts.  
Annaba Member, sample SM 266.
6. — Same sample. Here Ostracods with test filled by pyrite and sparocalcrite.
7. — Same sample. Foraminifera fixed on a large fragment of Bivalve.
8. — Ophiure ossicles in wackestone.  
Annaba Member, sample SM 269.



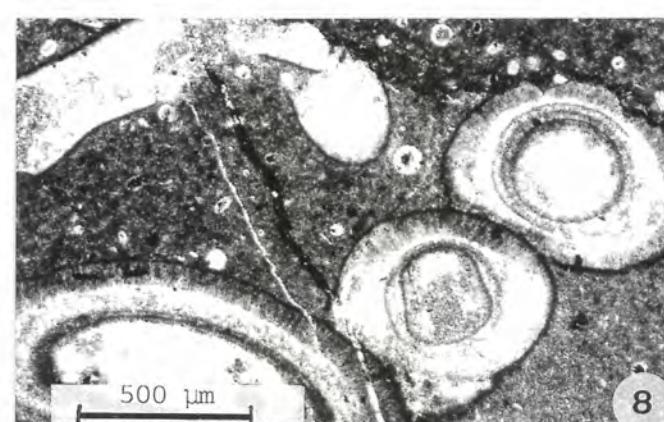
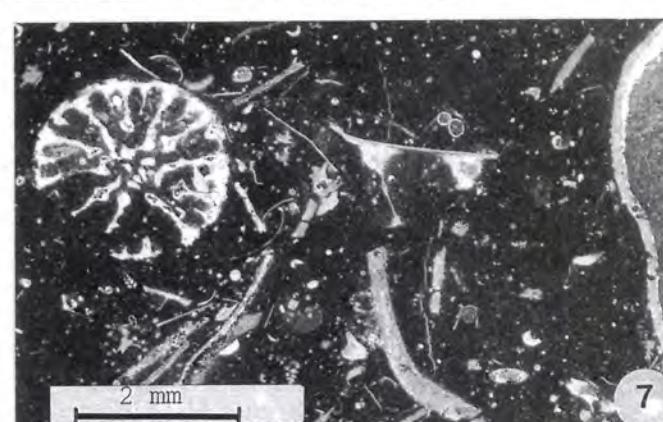
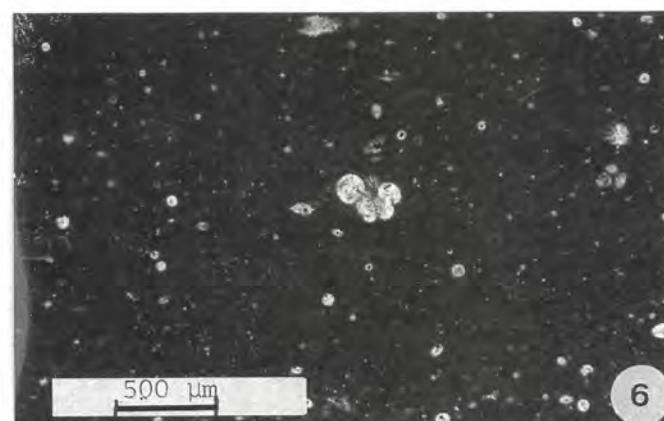
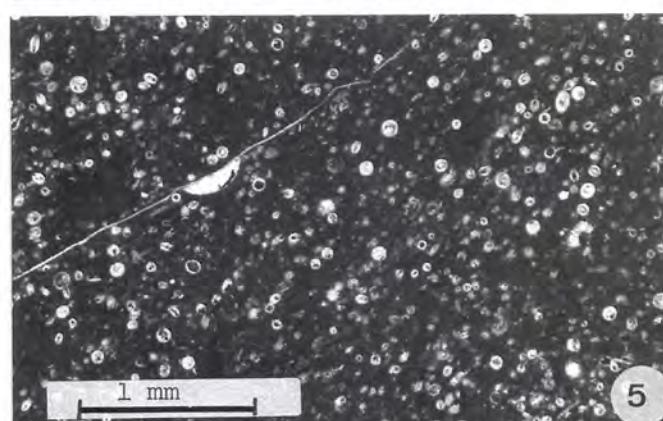
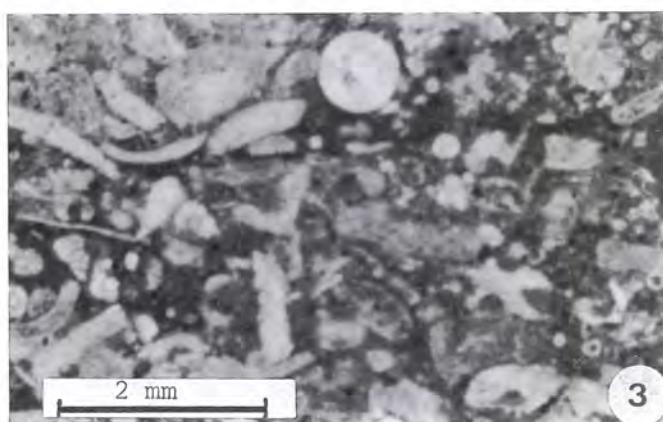
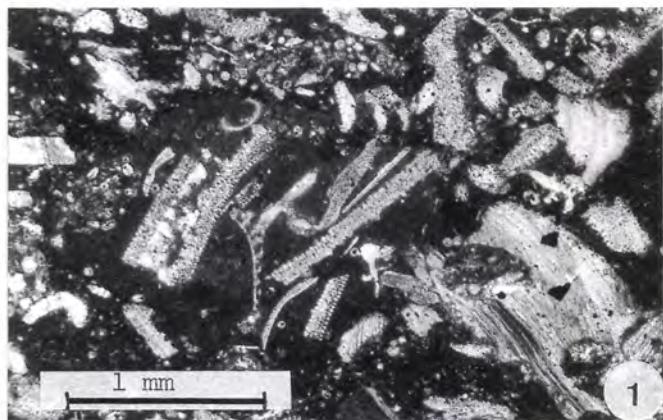
## PLATE 10

## Microfacies of the Bireno Member

- Fig. 1. — Echinid packstone. Very rare Calcispheres.  
Bireno Member, sample ZT 28.05.
2. — Echinoderm wackestone-packstone.  
Bireno Member, sample ZT 27.90.
3. — Echinoderm packstone-grainstone.  
Bireno Member, sample ZT 28.15.
4. — Wackestone with "filaments", Echinids, Calcispheres and rare Planktonic Foraminifera.  
Bireno Member, sample ZT 30.9.
5. — Calcisphere wackestone-packstone.  
Bireno Member, sample ZT 121.6.
6. — Calcisphere and rare Hedbergellid mudstone.  
Bireno Member, sample ZT 49.6.

## Fossils of Bireno Member

7. — Isolated Coral in Echinoderm wackestone-packstone.  
Bireno Member, sample ZT 27.
8. — Serpulids in Calcisphere wackestone.  
Bireno Member, sample ZT 76.2.

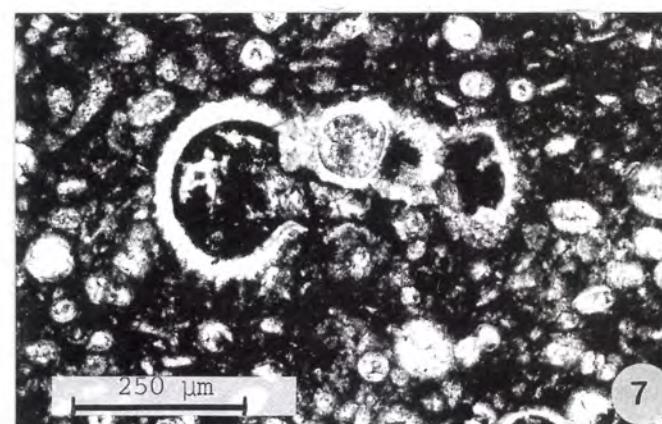
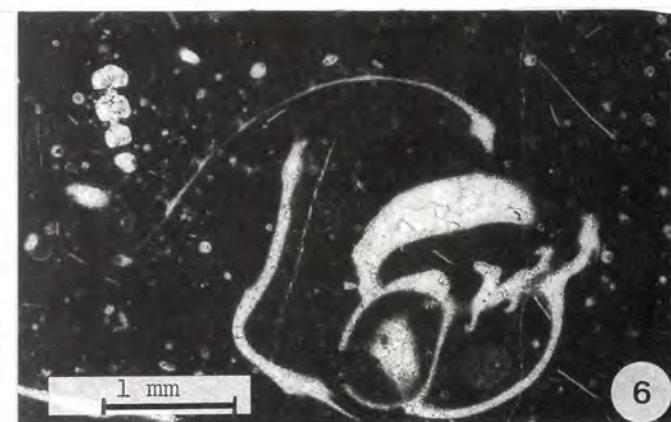
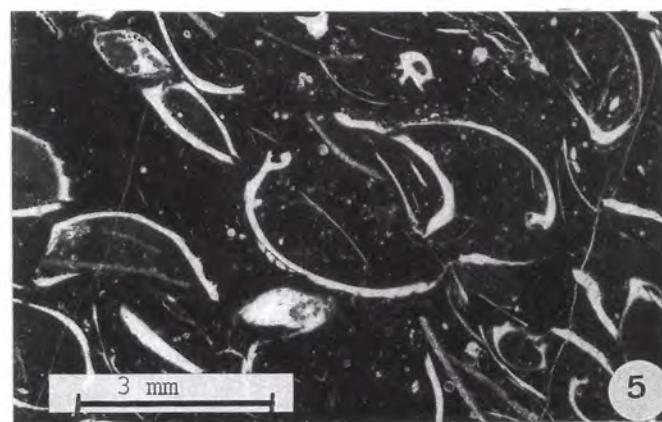
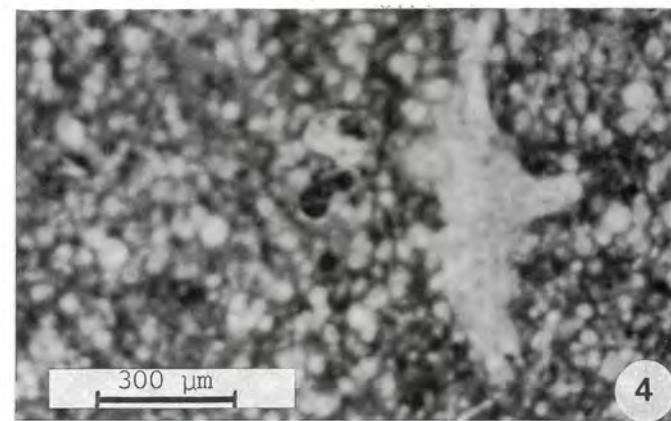
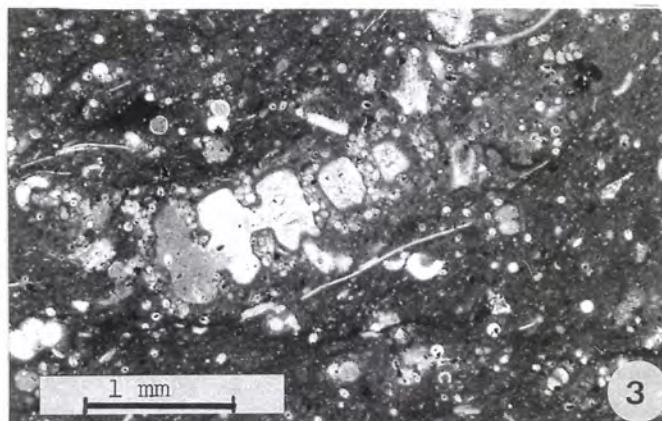
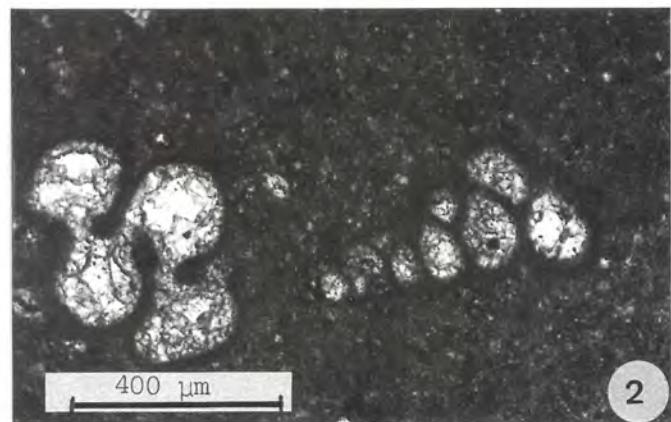
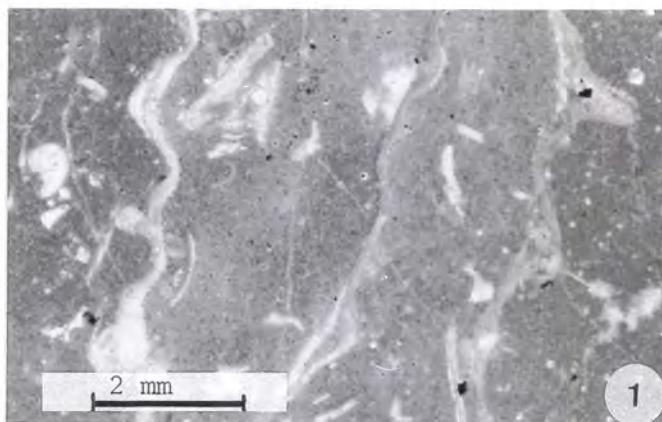


## 11

## PLATE

## Fossils of the Bireno Member

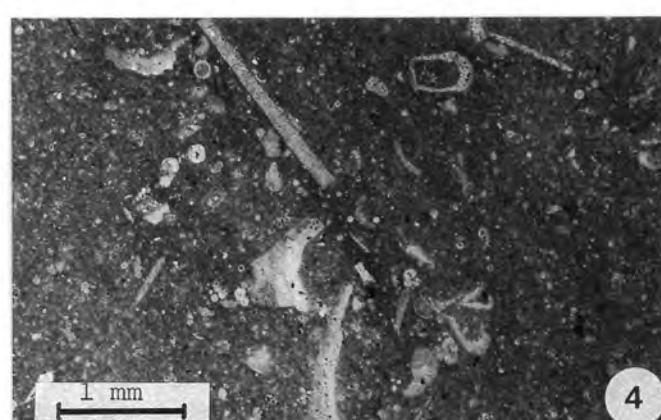
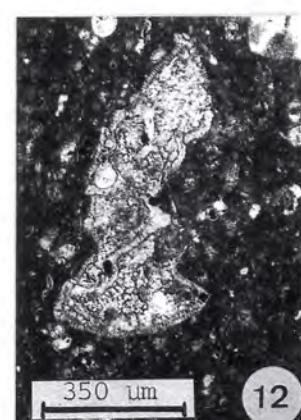
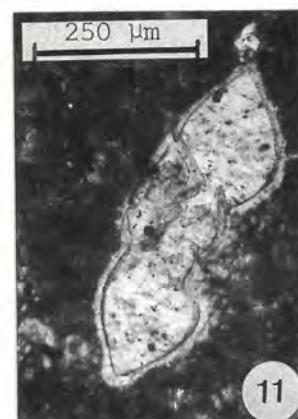
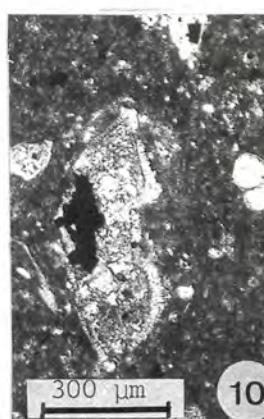
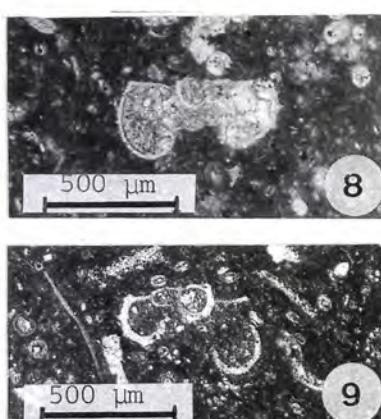
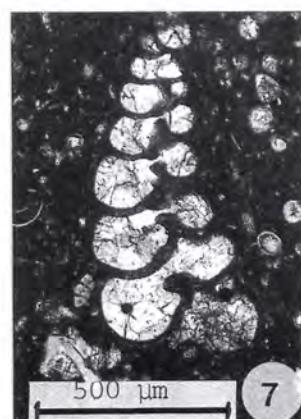
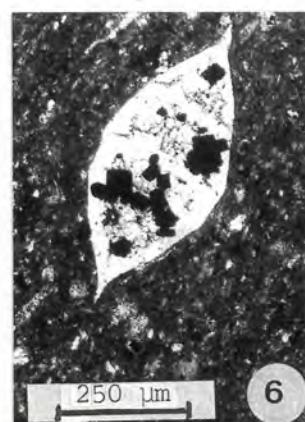
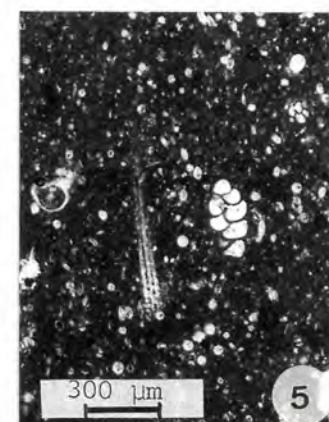
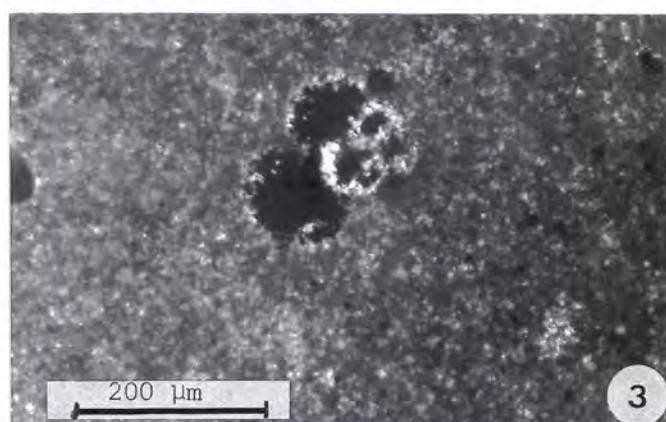
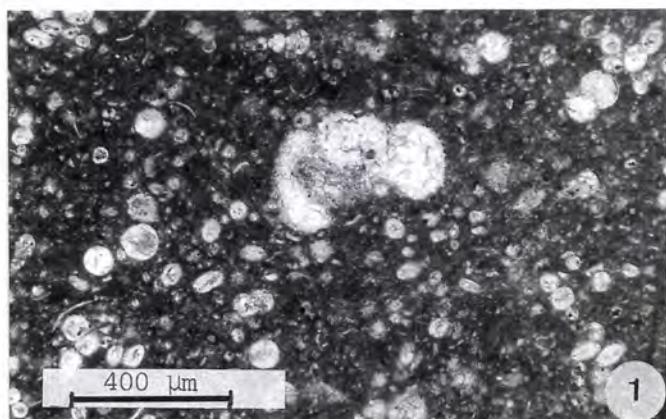
- Fig. 1. — Ostreid in Echinoderm wackestone.  
Bireno Member, sample ZT 20.8.
2. — Agglutinated Foraminifera (*Gaudryina* ?) in mudstone.  
Bireno Member, sample ZT 20.4.
3. — Foraminifera with test agglutinating Calcispheres.  
Bireno Member, sample ZT 46.
4. — *Saccocoma* sp. and *Hedbergella* sp. in Calcisphere packstone.  
Bireno Member, sample ZT 116.5.
5. — Bivalves in mudstone.  
Bireno Member, sample ZT 70.1.
6. — Same sample as fig. 5. Axial section of Gastropod in mudstone.  
Bireno Member, sample ZT 70.1.
7. — *Whiteinella praehelvetica* in Calcisphere packstone.  
Bireno Member, sample ZT 116.50.
8. — *Dicarinella* cf. *imbricata* in Calcisphere and Echinoderm packstone.  
Bireno Member, sample ZT 80.1.



## PLATE 12

## Microfacies and microfauna of the Aleg Formation

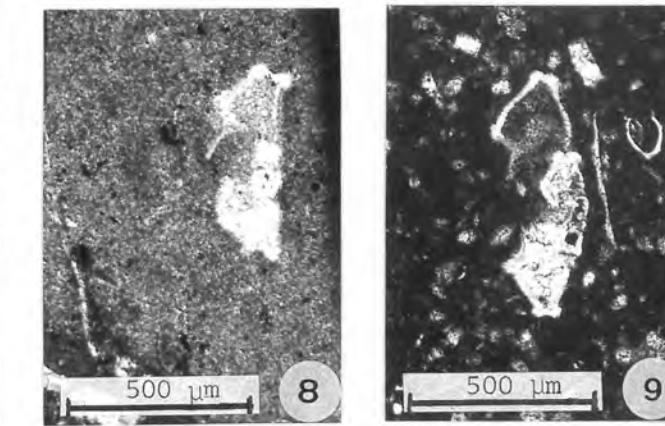
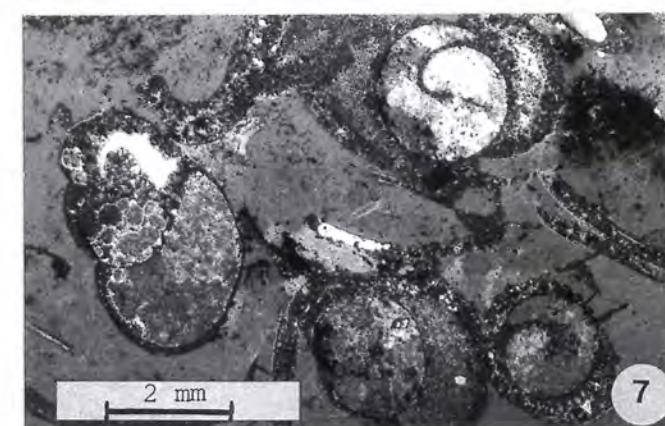
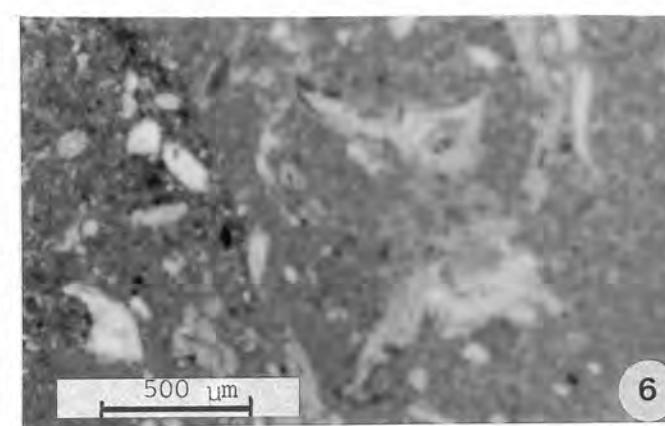
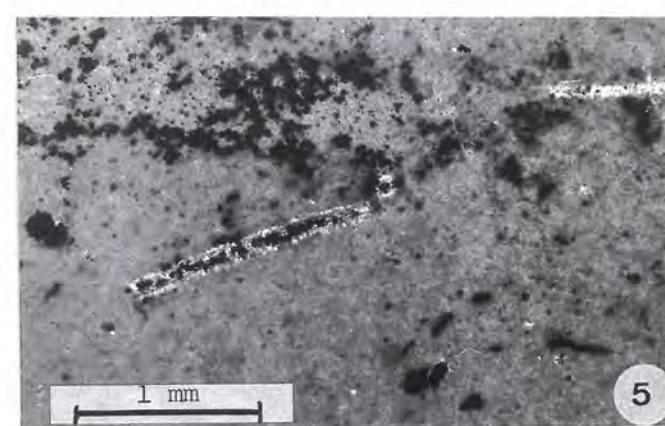
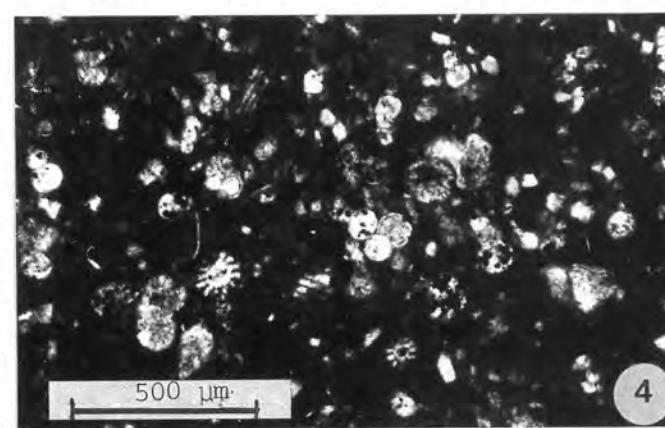
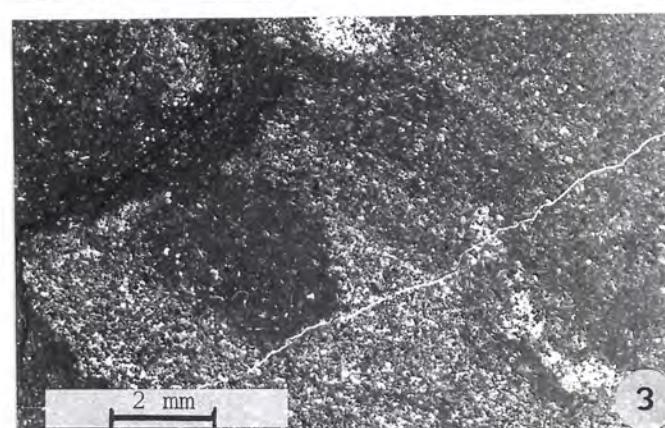
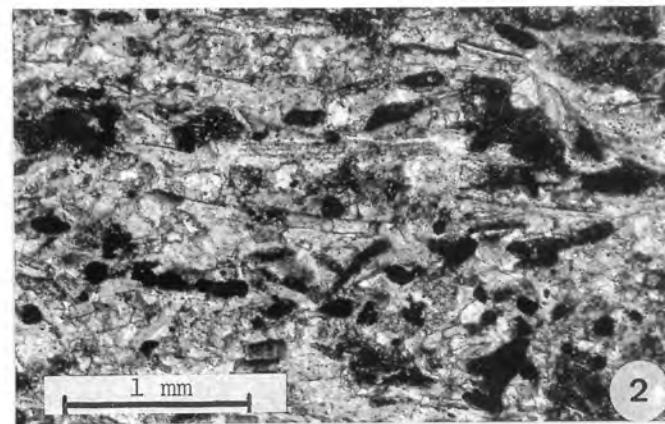
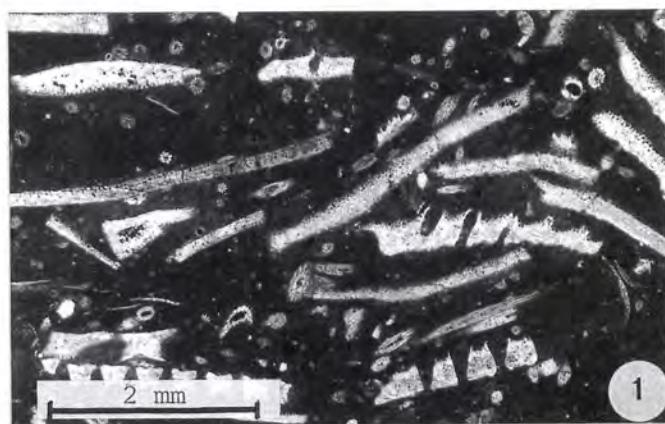
- Fig. 1. — *Whiteinella praehelvetica* in Calcisphere and Foraminiferal packstone. Microfacies of the upper part of Bireno Member, identical to that of the lower part of Aleg Formation.  
Aleg Formation, sample HM 129.
2. — Buliminids in mudstone.  
Aleg Formation, sample HM 304.
3. — Trochospiral Planktonic Foraminifera (*Hedbergella*? or *Whiteinella*?) partially dissolved in a recrystallized calcareous nodule.  
Aleg Formation, sample HM 451.
4. — Echinoderm and Bivalve bioclasts in a Calcisphere wackestone-packstone.  
Aleg Formation, sample HM 208.
5. — Echinid bristle in Calcisphere wackestone-packstone.  
Aleg Formation, sample HM 186.5.
6. — Pyrite and sparcalcite inside the test of *Lenticulina*.  
Aleg Formation, sample HM 202.
7. — Finely agglutinated Foraminifera (*Dorothia*?) in Calcisphere wackestone.  
Aleg Formation, sample HM 184.6.
8. — *Helvetoglobotruncana helvetica* in a Calcisphere wackestone.  
Aleg Formation, sample HM 194.
9. — *H. helvetica* in a Calcisphere wackestone.  
Aleg Formation, sample HM 208.
10. — *Marginotruncana sigali* in a packstone of benthic and planktonic Foraminifera, phosphate grains and Calcispheres.  
Aleg Formation, sample HM 285.4.
11. — Intermediate form between *Whiteinella inornata* and *Marginotruncana schneegansi*, in a mudstone.  
Aleg Formation, sample HM 278.
12. — *Marginotruncana mariannosi* in a packstone of benthic and planktonic Foraminifera, Calcispheres and phosphate grains.  
Aleg Formation, sample HM 283.
13. — Same sample as fig. 12. Here, *Marginotruncana* cf. *coronata*.

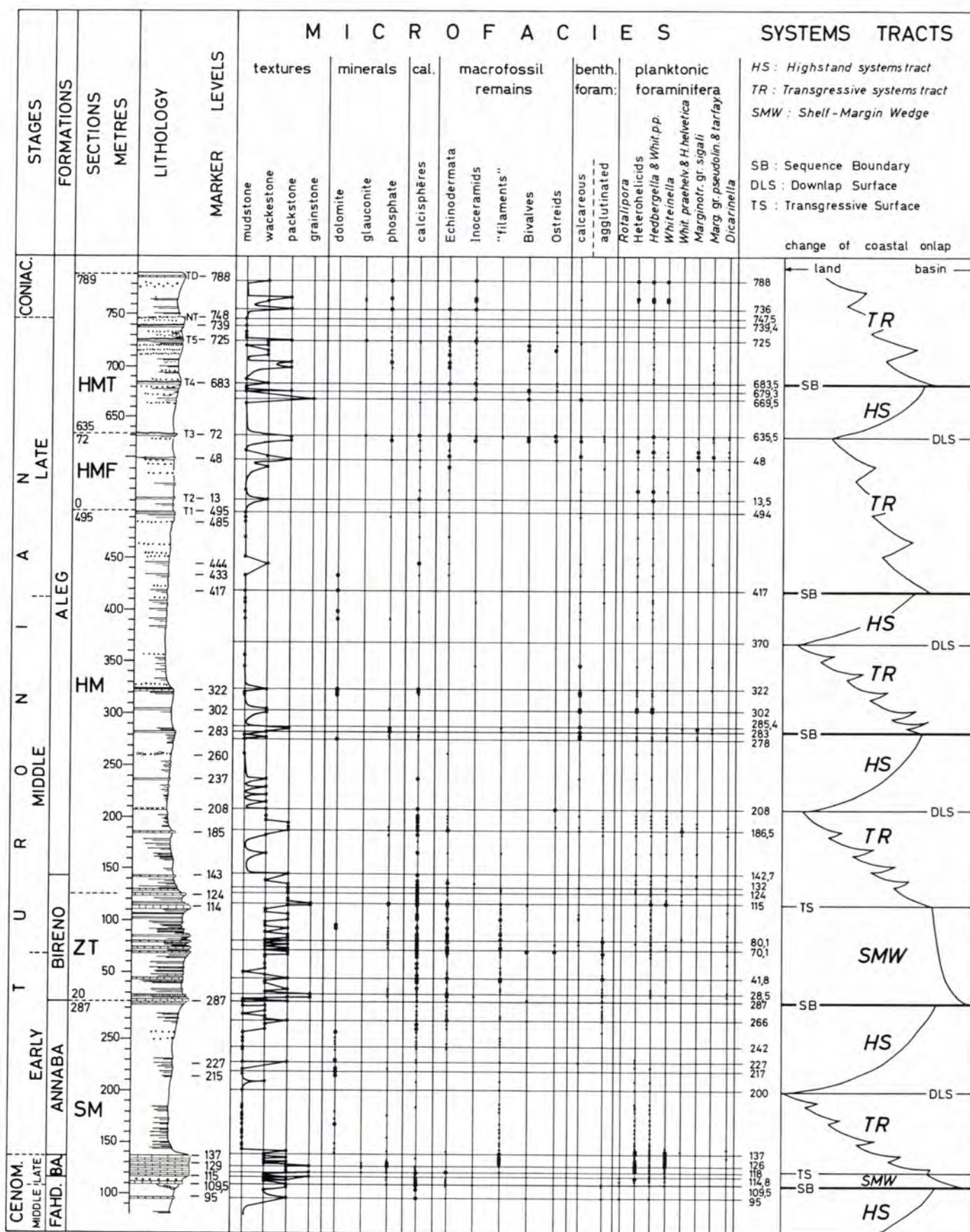


## PLATE 13

## Microfacies of the Aleg Formation

- Fig. 1. — Echinid bioclasts and phosphate grains in a calcarenite.  
Aleg Formation, sample HMT 699.
2. — Echinoderms, Bivalves and pellets in a grainstone.  
Aleg Formation, sample HMT 669.5.
3. — Bioturbations in Calcisphere packstone.  
Aleg Formation, sample HMT 634.5
4. — Calcisphere, Inoceramid and Echinid bioclasts, and Planktonic Foraminifera in wackestone.  
Aleg Formation, sample HMT 766.
5. — Echinid bioclast hardly corroded by dissolution in a pseudomicrite (recrystallized ?).  
Aleg Formation, sample HMT 663.5.
6. — Phosphate grains in an Inoceramid-Echinoderm packstone.  
Aleg Formation, sample HMT 725.
7. — Gastropods partially dissolved in a mudstone. Tests are filled initially by pelletoidal remains and secondly by sparocalcite.  
Aleg Formation, sample HMT 679.9.
8. — *Dicarinella primitiva* unusually present in Gastropod mudstone.  
Aleg Formation, sample HMT 679.3.
9. — *Marginotruncana* gr. *tarfayaensis* in Calcisphere and Planktonic Foraminifera packstone.  
Aleg Formation, sample HMT 635.5.





transgressive deposits. Shelf supplies are however still abundant, and benthic communities become more diversified on the muddy basin floor. The parasequences T4, T5 and NT record the burial of such populations during storms, a fine, bioclastic, calcareous mud accumulates, topped by a coquina of small Oysters. The last event is not entirely recorded (HMT 748 = NT). It is overlain by an ill-defined alternation of marls and marly limestones where Planktonic Foraminifera occur in great number. It is at this level (HMT 748) that the Ammonite fauna changes considerably, thus marking the Turonian-Coniacian boundary.

### 3. — ABOUT TURONIAN STAGE BOUNDARIES (F. ROBASZYNSKI)

When PERVINQUIERE (1903, p. 101 and pl. 1, fig. 10) transposed his observations on Jbel Mhrila to the Kalaat Senan area, he selected three lithological markers to define the Turonian of Kalaat Senan. He characterized the base of the Turonian with a unit of shaly marls ("marne schisteuse" = the present Bahloul Formation) and the top with marls and limestones without fossils ("marnes et calcaires sans fossiles") which can equate his level with "*Ostrea boucheroni*" at Jbel Mhrila (1903, p. 96). In the middle, he pointed out limestones with numerous fossils, typically Turonian such as *Mammites nodosoides*. That is the present Bireno Member.

Most geologists then followed this interpretation such as BERTHE (1949), SCHIJFSMA (1955) and BUROLLET (1956). For SCHIJFSMA, the Turonian begins with a first limestone body ("première masse calcaire" or "calcaire en plaquettes" = the present Bahloul Formation) and ends with a second limestone body ("seconde masse calcaire" = the present Bireno Member). As "*Globotruncana helvetica*" was found in the Aleg marls just above a Bireno facies, considered as forming the top Turonian, he concluded that this marker species of Planktonic Foraminifera was typical for the Coniacian. Nevertheless, his opinion was not followed by most micropaleontologists who used this species as a Turonian marker (DALBIEZ, 1956, and see the closely argued discussion in KLAUS, 1960).

In fact, if we refer to the recommendations expressed by the International Subcommission for Cretaceous Stratigraphy (BIRKELUND *et al.*, 1984), the Turonian stage begins with the *Pseudaspidoceras flexuosum* Ammonite-Zone and ends with the first appearance of the Ammonite genus *Forresteria*. In the Kalaat Senan area, *P. flexuosum* was found at the boundary between Bahloul Formation and Annaba Member, at SM 137, and this level is considered to represent the base of the Turonian. Besides, numerous specimens of the genus *Forresteria* were collected from HMT 748 onwards, after about 500 metres of Aleg marls, above the limestones of the Bireno Member.

That clearly shows that the vertical distribution of *H. helvetica* is only Turonian and more precisely Early to Middle Turonian if we take into account that in SM and ZH sections,

*W. praehelvetica* and primitive *H. helvetica* were found immediately above the base of the Turonian marked by the Ammonite *P. flexuosum*.

Following these remarks and taking into account the recommendations of the Subcommission, it becomes difficult to support the proposal of SALAJ (1986) who would prefer to begin the Turonian with the "*Metaicoceras geslinianum* Zone" (which is in fact in the Late Cenomanian) and to begin the Coniacian with the first appearance of *Dicarinella concavata* (as this taxon was found in the Late Turonian).

In the present work, for all interpretations and on all figures, the stage boundaries used for the Turonian agree with the recommendations of the Subcommission and as expressed in BIRKELUND *et al.*, 1984.

With regard to the substage boundaries of the Turonian used here, we followed the proposals given in the conclusions of the Colloquium on the Turonian (ROBASZYNSKI, coord., 1983, p. 213), namely: top of Early Turonian is marked by the extinction of *Mammites nodosoides*, base of Late Turonian is defined by the appearance of *Romaniceras deverianum*.

## PALAEONTOLOGICAL EVIDENCES

### 4. — THE AMMONITES (F. AMÉDRO)

#### 4.1. THE FOSSILIFEROUS LEVELS

The systematic research of macrofauna, undertaken in the Kalaat Senan area while conducting the lithological survey, has led to the collecting of important ammonitological material. This collection contains some 300 specimens attributed to the Turonian which have been taken from sections of Oueds Smara, Zitoune and Hammada. The findings cover more or less the whole succession, but as shown in Fig. 11, their abundance varies noticeably from one level to the next. On a lithological succession some 800 m thick, three units totalling 130 m provided most of the material. These are from bottom to top:

— The base of the Annaba Member (SM 137 to SM 185) with some 40 specimens. The Ammonites are preserved in calcareous marls as pyritic nuclei, which are often very oxidized or appear as imprints on the surface of limestone beds.

— The Bireno Member and its lower part in particular (ZT 20 to ZT 94) with 120 specimens. These are usually internal moulds which are more or less altered on their exposed sides, whereas the shells appear as imprints. The extraction of specimens was not always possible in the latter case, so photographs were systematically taken in the field. The

FIGURE 10

Main microfacies data of thin-sections in limestone samples. Interpretation in terms of coastal onlap.

Bireno Member is the source of most of the Turonian Ammonites described by PERVINQUIERE (1903, 1907) in his geological and paleontological studies of Central Tunisia.

— The calcareous nodular beds called T5 within the « Niveaux de la ferme Taga », situated in the lower third of the Aleg Formation (HMT 720 to 725). These have delivered about one hundred Ammonites preserved in calcareous nodules (septaria) enclosed in marls. The fossiliferous horizon « de la ferme Taga » is described for the first time. Its reduced thickness is probably the reason why it had remained undiscovered until now. It is made up of two limestone beds of 0.30 m intercalated in several hundred metres of clayey marl.

#### 4.2. DESCRIPTION OF THE MATERIAL

Some of the material is still being studied. This is why a certain number of determinations have only been made at a generic level. Future findings may modify some of the classifications and clarify the vertical distribution of the species. The position of the specimens in the lithological sequence is presented in Fig. 11.

Order : AMMONOIDEA ZITTEL, 1884

Suborder : AMMONITINA HYATT, 1889

Superfamily : Desmocerataceae ZITTEL, 1895

Family : Pachydiscidae SPATH, 1922

#### Genus *Lewesiceras* SPATH 1939, p. 296

Type species : *Ammonites peramplus* MANTELL, 1822, by original designation.

#### *Lewesiceras* sp.

Pl. 14, fig. 1 a-b.

#### Material

15 specimens distributed as follows : 1 from Oued Smara at level SM 287 at the base of the Bireno Member; 7 from Oued Zitoune above level ZT 23 in the Bireno Member; 7 from Oued Hammadja between levels HM 115 and HMT 715 (the upper part of the Bireno Member and the lower half of the Aleg Formation).

#### Description

The material consists of several strongly crushed imprints and internal moulds. The Ammonites, with a diameter varying from 8 cm to some 30 cm, are moderately involute. The ventral side must have been rounded before crushing linked to diagenesis of the sediment. On average 4 umbilical bullae per half whorl are present at the diameter of 9 cm. Each gives birth to a primary rib, concave towards the front. 3 to 4 secondary ribs develop between the primary ribs.

#### Discussion

Despite their poor preservation, these specimens are close to *Lewesiceras* from the Anglo-Paris basin described by AMÉDRO (1980), WRIGHT & KENNEDY (1981), even though an accurate determination remains difficult. The presence of several intercalated ribs distinguishes them particularly well from *Pachydesmoceras* SPATH, 1922, whereas *Puzosia* BAYLE, 1878 have finer ribs.

#### Vertical distribution

The genus *Lewesiceras* is known throughout the Cenomanian to Late Turonian. Its distribution spreads from the summit of Early Turonian to the Turonian-Coniacian boundary in the Kalaat Senan area.

Superfamily : Hoplitaceae DOUVILLE, 1890

Family : Placenticeratidae HYATT, 1900

Genus : *Placenticeras* MEEK, 1876

Type species : *Ammonites placenta* DEKAY, 1828, by subsequent designation by MEEK, 1876.

Subgenus *Karamaites* SOKOLOV in CASEY, 1965

Type species : *Placenticeras grossouvrei* SEMENOV, 1899, by original designation.

#### *Placenticeras (Karamaites) stantoni* HYATT, 1903

Pl. 14, fig. 2 a-b.

1903 *Placenticeras stantoni* HYATT, p. 214.

1903 *Placenticeras stantoni* var. *bolli* HYATT, p. 214, pl. 40, fig. 3-7; pl. 41, fig. 1-7; pl. 42, fig. 1-2; pl. 43, fig. 1-2.

#### Material

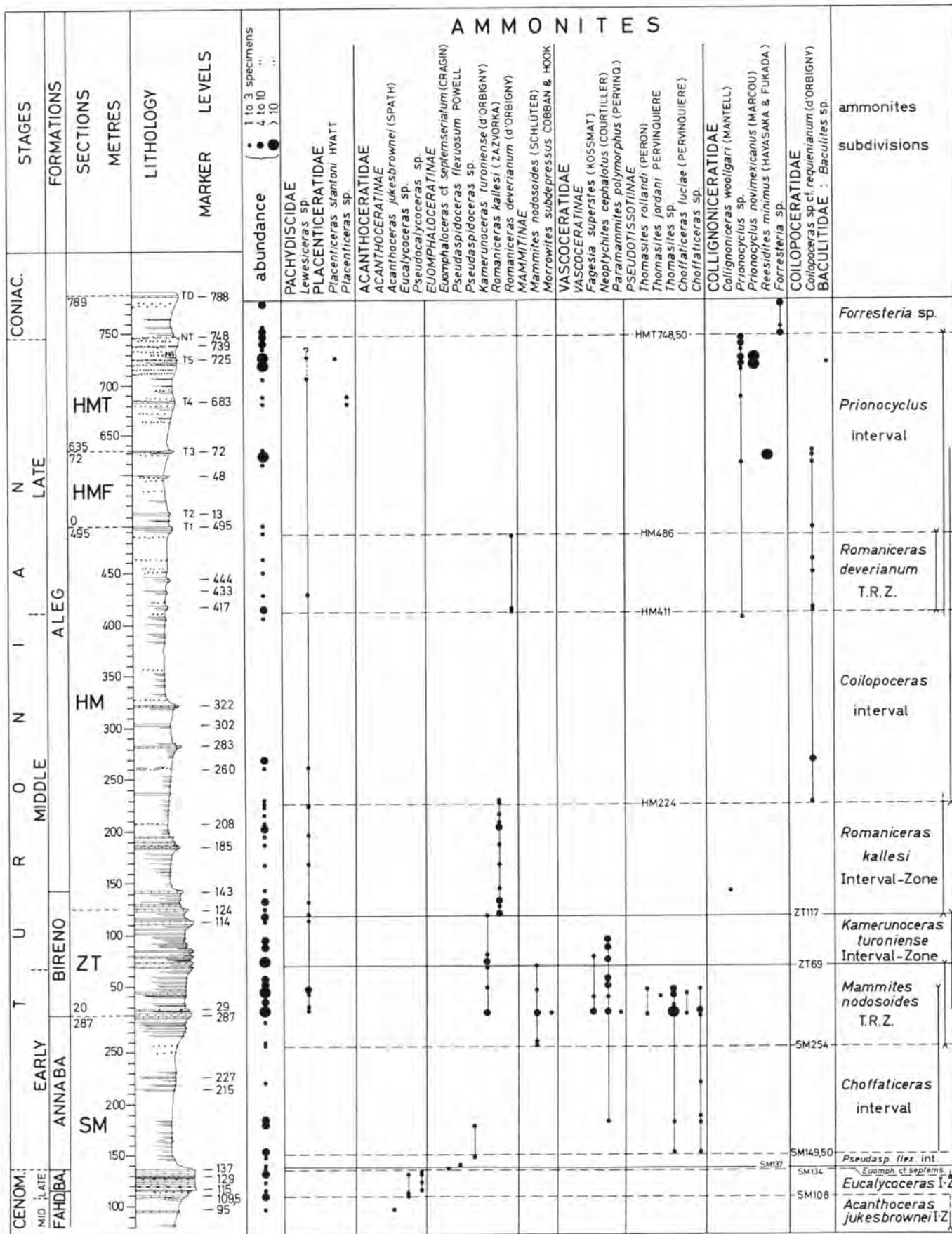
One specimen (numbered T6) from Oued Hammadja, at level HMT 725, from the middle part of the Aleg Formation.

#### Discussion

The classification of this Ammonite is the work of Dr. W.A. COBBAN. It is an internal mould with a diameter of 112 mm, exposing a portion of phragmocone and a body chamber. The shell is involute and compressed ( $H/E = 1.74$ ), with slightly convex flanks on the internal two thirds, oblique on the external one third, and a flat, narrow central region. The ornamentation is weak. It is, on the one hand, composed of umbilical tubercles obliquely pinched forwards, numbering 5 to 6 per half-whorl, and on the other hand, of flexuous ribs ending on ventrolateral clavi disposed alternately on the ventral region. According to Dr. COBBAN (*in litteris*) « specimen T6 is an early *Placenticeras*. The first auxiliary lobe (next to the lateral lobe) is a little smaller than the next auxiliary lobe which is a character of *Karamaites* SOKOLOV. I would regard *Karamaites* as a subgenus of *Placenticeras*. The Tunisian specimen may well be *P. (Karamaites) stantoni* HYATT ».

FIGURE 11

Vertical distribution of Ammonites in the Late Cenomanian-Turonian basal-Coniacian succession of Kalaat Senan area.



### Vertical distribution

The species has an extension from upper Early Turonian to Middle Turonian in the Western Interior of the USA. The Tunisian specimen extends this distribution to the upper part of the Turonian.

### *Placenticeras* sp.

Pl. 14, fig. 3 a-b.

### Material

Two specimens from Oued Hammadja, at levels HMT 679.30 and HMT 686.50 in the lower third of the Aleg Formation.

### Discussion

These are two large fragments of *Placenticeras* (15 to 20 cm in diameter), the first being a phragmocone and the second a crushed body chamber. The umbilical tubercles are situated very low on the flank which suggests it could also be *P. (Karamaites)*. Compared to the specimen described in the previous paragraph as *P. (K.) stantoni* HYATT, the section of the whorl is thicker (H/E = 1.48 for the sample from level HMT 686.50), but this difference is perhaps not very significant as the works of COBBAN & HOOK (1979), KENNEDY & WRIGHT (1983) have shown large intraspecific variations from compressed forms to thick forms. The material at our disposal is insufficient to make a reliable comparison. A more accurate determination will no doubt be possible in the future.

### Vertical distribution

Upper part of the Turonian in the Kalaat Senan area.

Superfamily : Acanthocerataceae de GROSSOUIRE, 1894

Family : Acanthoceratidae de GROSSOUIRE, 1894

Subfamily : Euomphaloceratinae COOPER, 1978

### Genus *Euomphaloceras* SPATH, 1923, p. 143

Type species : *Ammonites euomphalus* SHARPE, 1855, by monotypy.

### *Euomphaloceras* cf. *septemseriatum* (CRAGIN, 1893)

Pl. 15, fig. 5.

### Material

One specimen collected from the last bed of the Bahoul Formation from the locality « ferme de la cascade de l'Oued Zitoune » – (probably equivalent to level SM 134-135).

### Description

The sample is a portion of external mould. Only the ventral region is visible. The ornament is composed of three rows of tubercles disposed in chevron. The irregularly developed siphonal tubercles are rounded, whereas the external ventrolateral bullae tend to be oblique towards the front.

### Discussion

This specimen displays the same kind of ornamentation as the Euomphaloceratinae, characterised among other things by a line of siphonal tubercles and irregular ornaments. The ventral morphology in chevron and the robustness of the siphonal tubercles distinguish this fragment from both *Euomphaloceras euomphalum* and *Kamerunoceras*. On

the other hand, these same features resemble *E. septemseriatum*, of which a series of well preserved specimens from the USA and Great Britain is illustrated by COBBAN & SCOTT (1972) and WRIGHT & KENNEDY (1981) (note especially the ventral view illustrated by WRIGHT & KENNEDY, 1981, pl. 13, fig. 6b). Considering the incomplete nature of our imprint, the comparison is not very reliable, hence the determination as *Euomphaloceras* cf. *septemseriatum*.

### Vertical distribution

In the USA, as in Europe or Israel, *E. septemseriatum* is associated with *Metoicoceras geslinianum* (d'ORBIGNY, 1850) in Late, but not uppermost, Cenomanian.

### *Euomphaloceratinae* gen. and sp. undetermined

Pl. 15, fig. 4.

### Material

Two specimens : the first comes from Oued Smara at level SM 149.50, the second between Oueds Zitoune and Hammadja at level ZH 51 (lateral equivalent of level SM 190). Both are situated in the lower part of the Annaba Member.

### Description

One of these Ammonites is a pyritized internal mould (ZH 21), the other, an external imprint of a ventral area (SM 149.50). Despite the crushing, sample ZH 21 shows the main characteristics of ornamentation. It is characterised by the presence of ribs curved forwards, forming a ventral chevron. The simple, primary ribs carry 7 rows of tubercles : umbilical, inner ventrolateral, outer ventrolateral, and siphonal, the last being pinched in the direction of coiling. Only one, less protruding secondary rib is visible on the conserved portion of the whorl.

### Discussion and vertical distribution

Morphologically these Ammonites are quite close to *Euomphaloceras septemseriatum*. The ribbing of *E. septemseriatum* is however finer and the ventral tubercles are much more abundant than the umbilical tubercles, which is not the case here. On the other hand, the *Kamerunoceras* show a significant increase in ribbing with respect to tuberculation. These Ammonites have still not been classified but their description is nevertheless necessary since the collection level is situated in lowermost Turonian.

### Genus *Kamerunoceras* REYMENT, 1954, p. 250

Type species : *Acanthoceras eschii* SOLGER, 1904, by original designation.

### *Kamerunoceras turoniense* (d'ORBIGNY, 1850)

Pl. 15, fig. 1, 2 a-b.

1850 *Ammonites turoniensis* d'ORBIGNY, p. 190.

1867 *Ammonites salmuriensis* COURTILLER, p. 6, pl. 6, fig. 1-4.

1907 *Mammites (Pseudaspidooceras) salmuriensis* (COURTILLER), PERVINQUIERE, p. 314, pl. 19, fig. 1 a-b, text-fig. 120.

1907 *Mammites (Pseudaspidooceras) armatus* PERVINQUIERE, p. 317, pl. 19, fig. 2, 3, 4 a-b, fig. 121, 317.

1979 *Kamerunoceras turoniense* (COURTILLER) (sic), KENNEDY & WRIGHT, p. 1170, pl. 2, fig. 1-11; pl. 3, fig. 1-2, pl. 4, fig. 1-3; text-fig. 2-3 (with synonymy).

- 1981 *Kamerunoceras turoniense* (d'ORBIGNY); WRIGHT & KENNEDY, p. 57, pl. 14, fig. 1, 2, 10.
- 1982 *Kamerunoceras turoniense* (d'ORBIGNY); AMEDRO & BADILLET pl. 3, fig. 2 a-b.
- 1983 *Kamerunoceras turoniense* (d'ORBIGNY); COBBAN & HOOK, p. 13, pl. 8, fig. 1-5, 9-11, text-fig. 8.

### Material

13 specimens: 7 from Oued Smara at level SM 287 at the base of the Bireno Member, and 6 from Oued Zitoune between levels ZT 47 and ZT 117 in the Bireno Member.

### Description

Relatively evolute shell. The more or less compressed whorl section is oval to polygonal. The ornamentation is composed of single, well spaced, straight or slightly flexuous ribs, each bearing an umbilical tubercle fairly high on the flank, an inner ventrolateral tubercle, an outer ventrolateral tubercle and a siphonal tubercle. The siphonal tubercle is usually set back with respect to the outer ventrolateral tubercles. With diameters of 100 to 150 mm there are on average 25 to 28 ribs per whorl.

### Discussion

The *Kamerunoceras* of the Kalaat Senan area are identical to the specimens from Central Tunisia described by PERVINQUIÈRE (1907) as *Mammites (Pseudaspidocephalus) salmuriensis* (COURTIILLER), *M. (P.) salmuriensis* var. *byzacenica* PERVINQUIÈRE, *M. (P.) salmuriensis* var. *zerhalmensis* PERVINQUIÈRE and *M. (P.) armatus* PERVINQUIÈRE. They also correspond to the lectotype of d'ORBIGNY (1850) collected in the lower part of *Tuffeau de Saumur* in Tourtenay, France. This Ammonite is illustrated by KENNEDY & WRIGHT (1979) pl. 3, fig. 1-2 with a revision of the species.

### Vertical distribution

In the type-Turonian, *K. turoniensis* is only present in the *K. turoniense* Zone defined by AMEDRO & BADILLET (1982), equivalent to the lower third of the *Collignonoceras woollgari* Zone of WRIGHT (1957), in the lower part of Middle Turonian. According to COBBAN (1984), the species is limited in the USA to the *Mammites nodosoides* Zone at the summit of Early Turonian. It seems that these differences in vertical distribution reflect a phenomenon of faunistic provincialism. In the Kalaat Senan area, as in Israel (FREUD & RAAB, 1969), *K. turoniense* appears in Early Turonian and continues until Middle Turonian.

### Genus and subgenus *Romaniceras* SPATH, 1923, p. 144

**Type species:** *Ammonites deverianus* d'ORBIGNY, 1841, by original designation.

### *Romaniceras (Romaniceras) kallesi* (ZAZVORKA, 1958)

- 1958 *Acanthoceras kallesi* ZAZVORKA, p. 39, pl. 1, fig. 1-2.
- 1969 *Romaniceras inerme* (?) (de GROSSEAUVE); FREUND & RAAB, pl. 1, figs. 1-2 (only).
- 1980 *Romaniceras (Romaniceras) kallesi* (ZAZVORKA); KENNEDY, WRIGHT & HANCOCK, p. 342, pl. 44, fig. 1-3, pl. 45, fig. 2-7, pl. 46, fig. 1-4, pl. 47, fig. 1-4, text-fig. 6 (with synonymy).
- 1982 *Romaniceras (Romaniceras) kallesi* (ZAZVORKA); AMEDRO & BADILLET, pl. 6, fig. 1 a-b.

### Material

22 specimens: 9 from Oued Zitoune above level ZT 117 at the top of the Bireno Member, and 13 from Oued Hammadja between levels HM 124 and HM 230 in the upper part of the Bireno Member and the base of the Aleg Formation.

### Description

Moderately evolute shell with a whorl section higher than it is wide and parallel flanks. The ornamentation consists of 30 to 40 more or less sinuous fine ribs per whorl. Most of them are primary ribs. A small number of them are secondary and occur at variable heights on the flank. On the internal whorls, the primary ribs carry 9 rows of tubercles: umbilical radially pinched, lateral, inner ventrolateral, outer ventrolateral and siphonal. At maturity, the lateral and inner ventrolateral tubercles almost entirely disappear and the ventral region now carries only 3 rows of tubercles. At this stage, the ribs also become clearly convex towards the front.

### Discussion

The very fine ribbing, the convexity of the ribs towards the front in the adult stage, and the disappearance of the lateral and inner ventrolateral tubercles allow *R. (R.) kallesi* to be easily distinguished from the other *Romaniceras* species and *Romaniceras (R.) deverianum* in particular. To our knowledge, *R. (R.) kallesi* is now determined for the first time in North Africa. It is, however, likely that the Ammonites described by PERVINQUIÈRE (1903-1907) from Djebel Fékirine as *Acanthoceras cf. ornatum* (STOLICZKA) (PERVINQUIÈRE, 1903), then as *A. cf. deverianum* (PERVINQUIÈRE, 1907), but not illustrated, belong to that species.

### Vertical distribution

In the type-Turonian, *R. (R.) kallesi* is strictly limited to the middle part of Middle Turonian where it is the type species of the *R. (R.) kallesi* Zone, bounded by the *Kamerunoceras turoniense* and *Romaniceras (Y.) ornatum* Zones below and above respectively. In the Kalaat Senan area, the species occupies an identical position.

### *Romaniceras (Romaniceras) deverianum* (d'ORBIGNY, 1841)

PI. 16, fig. 1 a-b, 2 a-b, 3, 4

- 1841 *Ammonites deverianus* d'ORBIGNY, p. 356, pl. 110, figs. 1, 2.
- 1907 *Tunesites choffati* PERVINQUIÈRE, p. 257, pl. 12, figs. 7 a-b, 8 a-b; text-fig. 102.
- 1910 *Acanthoceras aff. newboldi* KOSSMAT, PERVINQUIÈRE, p. 45, pl. 4, fig. 37.
- 1981 *Romaniceras (Romaniceras) deverianum* (d'ORBIGNY); WRIGHT & KENNEDY, p. 58, pl. 15, figs. 3, 5; pl. 43, figs. 1-3, text-fig. 19 f. (with complete synonymy).
- 1982 *Romaniceras (Romaniceras) deverianum* (d'ORBIGNY); AMEDRO, COLLETE, PIETRESSON DE SAINT-AUBIN & ROBASZYNSKI, p. 30, pl. 1, fig. 1.

### Material

6 specimens from Oued Hammadja at levels HM 411 (3 specimens), HM 414 and HM 486 (2 specimens), in the lower half of the Aleg Formation.

### Discussion

*Romaniceras (Romaniceras) deverianum* belongs to the *Romaniceras* group with 9 tubercles per rib as with *R. (R.) kallesi*. The distinction of the two species is based on several

characteristics, the main ones being the polygonal section of *R. (R.) deverianum*, the involute whorl of the shell with a more or less spaced and always well marked costulation, and the vigour of tuberculation which remains apparent even on the outer whorls of big shells. The umbilical and lateral tubercles are always prominent and do not attenuate with age as in the case of *R. (R.) kalleesi*. The intraspecific morphological variations of *R. (R.) deverianum* are described in detail by KENNEDY, WRIGHT & HANCOCK, 1980.

The specimens from Oued Hammadja are typical of the species. They all show robust ribs and well developed tubercles numbering 9 per rib. The whorlwise extension of the siphonal and ventral tubercles links several fragments (such as those illustrated in Pl. 16, fig. 1,2) of specimens from the Massif d'Uchaux in France named by COLLIGNON, 1939, *Romaniceras uchauxiense* but considered by KENNEDY *et al.* (1980) as being variants and synonyms of *R. (R.) deverianum*.

#### Vertical distribution

In the type-Turonian and especially in the Vaucluse in France, *R. (R.) deverianum* is only present in a horizon situated between the beds with *R. (Y.) ornatissimum* and the levels with *Subprionocyclus neptuni* (DEVALQUE *et al.*, 1983). The material collected in the Kalaat Senan area seems to occupy a similar position according to the correlation suggested in paragraph 4.5. It should be noted that the stratigraphic attribution of *R. (R.) deverianum* is interpreted differently in France (basal Late Turonian) and in Great Britain (top of Middle Turonian) (see the discussion of this topic in the Conclusions of the Colloquium on the Turonian, ROBASZYNSKI *coord.*, 1983).

#### Genus *Pseudaspidooceras* HYATT, 1903

Type species: *Ammonites footeanus* STOLICZKA, 1864, by original designation.

#### *Pseudaspidooceras flexuosum* POWELL, 1963

Pl. 17, fig. 1; Pl. 18, fig. 1.

1902 *Mammites footeanus* STOLICZKA; PETRASCHECK, p. 144, pl. 9, fig. 1.

1963 *Pseudaspidooceras flexuosum* POWELL, p. 318, pl. 32, figs. 1-10; text-fig. 2 a-c, f, g.

1987 *Pseudaspidooceras flexuosum* POWELL; KENNEDY, WRIGHT & HANCOCK, p. 34, pl. 2, figs. 1-4, 8-13, 16-17; text-figs. 3 A-C, 5, 6 C, D, 7 A-C (with synonymy)

#### Material

A portion of internal mould from level ZH 0 (= SM 137), and an imprint from level SM 137 in Oued Smara. The two specimens come from the last limestone bed of the Bahoul Formation. The extraction of the specimen from level SM 137 was not possible due to fissuration, but a latex mould was made instead.

#### Description

The specimen from level ZH 0 is a ventrally crushed fragment. The shell with a diameter close to 5-6 cm must originally have had a subrectangular whorl section. The visible portion of the whorl bears fine ribs, irregularly developed, and strongly arched towards the aperture on the ventre. The mould made on the bed surface SM 137 represents the inner imprint of a laterally positioned macroconch shell with a diameter of 35 cm. Only part of the last whorl is preserved,

probably corresponding to the body chamber. The visible ornamentation shows umbilical bullae from which single, very attenuated ribs arise, first inclined slightly forward, then inflected backwards at mid-flank. The first ribs of the body chamber also bear a weak tubercle on the ventrolateral shoulder. Finally, stria, which could correspond to very attenuated secondary ribs free of tuberculation, intercalate between the primary ribs.

#### Discussion

The recent works of COBBAN & SCOTT, 1972 and KENNEDY *et al.*, 1987 have considerably simplified the classification in the genus *Pseudaspidooceras* by grouping together a large number of species. At present, three taxa appear in succession at the border of the Cenomanian-Turonian boundary and in Early Turonian, thus from bottom to top :

— *P. pseudonodosoides* (CHOFFAT, 1898) from uppermost Cenomanian (*Neocardioceras juddii* Zone) characterised by a robust ornamentation;

— *P. flexuosum* from basal Turonian (*P. flexuosum* Zone) more slender, with curled ribs at mid-stage.

— *P. footeanum*, the genotype, from Early Turonian (*Mammites nodosoides* Zone) characterised by a squarer section and nearly straight ribs.

The two specimens described here, from the surroundings of Kalaat Senan, bear a close resemblance to *P. flexuosum* in their fine costulation and the strong, forward convexity of the ribs. The absence of looped ribs and the virtual disappearance of the ventrolateral tubercles are worth noting, but these characteristics are insufficient for classification since the only lateral imprint at our disposal is a large body chamber. The Texan example illustrated by KENNEDY *et al.* 1987, p.41, text-fig. 7 A-C presents a very similar morphology.

#### Vertical distribution

In Texas, and in the Western Interior of the USA in general, *Pseudaspidooceras flexuosum* is strictly limited to basal Turonian where the species names a zone (COBBAN, 1984). In the Kalaat Senan area, the location of the specimens between the levels of *Euomphaloceras septemseriatum* and *Mammites nodosoides* complies with this interpretation.

#### *Pseudaspidooceras* sp.

Pl. 17, fig. 2, 3, 4.

#### Material

3 more or less fragmented imprints from levels SM 178 in Oued Smara and levels ZH 21 (=SM 158) and ZH 22.8 (=SM 159.8) near Oued Zitoune. The three specimens come from the lower part of the Annaba Member.

#### Description

The material represents shells with a diameter between 3 and 5 cm. Only the flank is visible on these lateral imprints. The ornamentation is composed of strongly arched ribs, convex towards the aperture, ornamented by a more or less developed umbilical tubercle, situated fairly low on the flank, and a more prominent ventrolateral tubercle. The ribs are sometimes single (ZH 21), sometimes more irregularly developed (SM 178).

#### Discussion

The arched ribs, which are strongly inclined forwards, and

the presence of stria which are more or less protruding, closely resemble *Pseudaspidoceras*. The regular ornamentation of the specimen from level ZH 21 also links it to the morphology of the *Kamerunoceras*, but in this last genus, the umbilical tubercles are generally higher on the flank. A specific classification is unfortunately not possible due to the poor state of conservation of the material.

#### Vertical distribution

In the USA (COBBAN, 1984), as in Israel (FREUND & RAAB, 1969), the *Pseudaspidoceras* are known from uppermost Cenomanian (*N. juddii* Zone) to Early Turonian (*M. nodosoides* Zone). In the Kalaat Senan area, the material seems to be situated fairly low in Early Turonian.

Subfamily Mammitinae HYATT, 1900

Genus : *Mammites* LAUBE & BRUDER, 1887

Type species : *Ammonites nodosoides* SCHLÜTER, 1871, by monotypy.

*Mammites nodosoides* (SCHLÜTER, 1871)

Pl. 19, fig. 2 a-b, 3 a-b, 4 a-b.

- 1871 *Ammonites nodosoides* SCHLÜTER, p. 19, pl. 8, fig. 1-4.
- 1907 *Mammites nodosoides*, SCHLOTHEIM, PERVINDUIERE, p. 309, pl. 18, fig. 1 a-b.
- 1907 *Mammites nodosoides* var. *africana* PERVINDUIERE, p. 310, pl. 18, fig. 2, 3, text-fig. 118.
- 1981 *Mammites nodosoides* (SCHLÜTER), WRIGHT & KENNEDY, p. 75, pl. 17, fig. 3; pl. 19, fig. 3; pl. 20, fig. 4; pl. 22 fig. 4; pl. 23, fig. 1, 2, 3; pl. 24, fig. 2-3, text-fig. 19B, 23, 24 (with synonymy).
- 1983 *Mammites nodosoides* (SCHLÜTER), COBBAN & HOOK, p. 8, pl. 1, fig. 14, 15; pl. 3, fig. 21-22; pl. 4, fig. 4-9, 17-18; pl. 5, fig. 1-3, text-fig. 2.

#### Material

13 specimens ; 11 from Oued Smara, from levels SM 254, SM 255.50 at the top of the Annaba Member, and SM 287 (9 specimens) at the base of the Bireno Member ; the last two specimens are from Oued Zitoune at levels ZT 43 and ZT 69 in the lower part of the Bireno Member.

#### Discussion

The species *Mammites nodosoides* has just been revised in detail by WRIGHT & KENNEDY (1981) and COBBAN & HOOK (1983) with illustrations of the types and figures of abundant populations from the Anglo-Paris basin and the Western Interior. The fragments from the surroundings of Kalaat Senan belong to the above group and are typical of the spectrum of species variations. They all display in particular a rectangular whorl section, higher than it is wide and ornamentation where tuberculation is stronger than ribbing. On the internal whorls, the ribs occur in pairs from the conical umbilical tubercles and bear a prominent internal ventrolateral tubercle and a less pronounced external ventrolateral tubercle on the ventral shoulder. On the external whorls, the ribs are usually single and the ventrolateral tubercles fuse into a protruding horn.

#### Vertical distribution

Since de GROSSOUVRE (1901), the distribution of *Mammites nodosoides* is synonymous with Early Turonian to most

authors. The more recent works of WRIGHT & KENNEDY (1981), COBBAN (1984) have clearly demonstrated that the range of the species is in fact limited to the upper part of Early Turonian. The collections carried out in Central Tunisia confirm these observations.

#### Genus *Morrowites* COBBAN & HOOK, 1983, p. 9

Type species : *Mammites wingi* MORROW, 1935, by original designation

*Morrowites subdepressus* COBBAN & HOOK, 1983

Pl. 19, fig. 1 a-b.

1983 *Morrowites subdepressus* COBBAN & HOOK, p. 11, pl. 1, fig. 8-13, pl. 3, fig. 19-20; pl. 4, fig. 1-3, 12-16, pl. 7, text-fig. 6-7

#### Material

One specimen from Oued Smara at level SM 287 in the lower part of the Bireno Member.

#### Description

The internal mould fragment represents a third of an Ammonite whorl, with a diameter of approximately 90 mm. The shell is moderately evolute, with fairly depressed quadrangular whorls (ratio H/E = 0.75). The ribs occur in pairs from the rounded umbilical tubercles, or are single. All the ribs bear internal and external ventrolateral clavi, the last being pinched in the direction of coiling. Seven external ventrolateral clavi are visible on the preserved piece of whorl.

#### Discussion

The genus *Morrowites* was created for a group of Ammonites previously included in the genus *Mammites*, but which are distinguished by their more plain septa with a large bifid lateral lobe, a more depressed section, a comparatively less developed ornamentation, and more dense ribbing. Three species are described in the well documented series from the Western Interior in the USA. These are from the most compressed to the thickest :

— *Morrowites wingi* (MORROW, 1935) with a diameter of 50 to 200 mm, a section as large or slightly wider than it is high (H/E between 1.02 and 0.80), a fairly weak ribbing and up to 18 external ventrolateral clavi per whorl;

— *Morrowites subdepressus* COBBAN & HOOK, 1983, more depressed (H/E = 0.7 to 0.75), with an average of 16 ribs per whorl;

— *Morrowites depressus* (POWELL, 1963), whose evolute and very depressed shell is much wider than it is high (H/E = 0.65 to 0.59).

The proportions of the specimen described here are very similar to those of *M. subdepressus*, with, in particular, a ratio H/E of approximately 0.75, as well as a similar general morphology.

#### Vertical distribution

In the USA, *M. subdepressus* is a feature at the top of Early Turonian (in the *Mammites nodosoides* Zone) and at the base of Middle Turonian. In the Kalaat Senan area, the only specimen collected for the time being is accompanied by *M. nodosoides*.

Family : Vascoceratidae DOUVILLE, 1912

Subfamily : Vascoceratinæ DOUVILLE, 1912

#### Comments

A certain number of Ammonite imprints, a few centimetres in diameter, with an involute shell, a rounded ventral region and an attenuated ornamentation with very weak umbilical bullae from which indistinct ribs emerge, are present at the top of the Bahloul Formation in levels SM 134 - SM 137. These imprints have not yet been determined, but they could be Vascoceratidae or, to be more precise, representatives of the *Vascoceras* genus associated with *Euomphaloceras* cf. *septemseriatum* within SM 134 and then with *Pseudaspidoceras flexuosum* within SM 137 at the Cenomanian-Turonian boundary. Several specimens are illustrated in Pl. 18, fig. 2, 3, 4, 5.

#### Genus *Fagesia* PERVINQUIÈRE, 1907

Type species : *Olcostephanus superstes* KOSSMAT, 1897, by original designation.

#### *Fagesia superstes* (KOSSMAT, 1897)

Pl. 20, fig. 1 a-b; Pl. 21, fig. 2 a-b.

1897 *Olcostephanus superstes* KOSSMAT, p. 133, pl. 17, fig. 1 a-c.

1907 *Fagesia superstes* (KOSSMAT); PERVINQUIÈRE, p. 322.

1907 *Fagesia superstes* var. *tunisiensis* PERVINQUIÈRE, p. 323, pl. 20, fig. 1 a-c, 2 a-b.

1907 *Fagesia superstes* var. *spheroidalis* PERVINQUIÈRE, p. 324, pl. 20, fig. 3 a-b, 4a, text-fig. 122.

1983 *Fagesia superstes* (KOSSMAT); COBBAN & HOOK, p. 16, pl. 3, fig. 1-2; pl. 13, fig. 6-11; text-fig. 12 (with complete synonymy).

#### Material

12 specimens : 8 from Oued Smara at level SM 287 and 4 from Oued Zitoune at levels ZT 20.5, ZT 25.50, ZT 38 and ZT 79. All come from the lower part of the Bireno Member.

#### Description

The *Fagesia* collected in the lower part of the Bireno Member from the Oueds Zitoune and Smara sections show considerable variation both in diameter : from 5 cm to more than 20 cm in some individuals, and in the thickness of the whorl section, with forms as wide as they are high and with very globular variants. Despite the often fragmentary conservation of the shells and the fact that they are often badly deformed, all of them possess a narrow umbilicus with a subvertical umbilical wall bordered by a row of numerous umbilical tubercles (12 to 16 per whorl) and protruding, fine ribs, arched forwards. The ribs usually occur as paired beams from the umbilical tubercles, but some are intercalatory.

#### Discussion

The holotype of *Fagesia superstes* (KOSSMAT, 1897, pl. 17, fig. 1 a-c) is very depressed and bears 16 umbilical tubercles on the last whorl, each branching into two ribs. The specimens subsequently illustrated by PERVINQUIÈRE (1907) from Central Tunisia under the names *F. superstes* var. *tunisiensis* (less depressed than the type) and *F. superstes* var. *spheroidalis* (more depressed) and the material from New-Mexico

(USA), illustrated by COBBAN & HOOK (1983), show that the ribs occurring in pairs from the umbilical tubercles are not an absolute criterion and that intercalated ribs sometimes exist. On the other hand, the umbilical tubercles are always placed low on the flank, numbering 11 to 16 per whorl, and costal density is high. These are precisely the characteristics apparent in the collected specimens.

*Fagesia catinus* (MANTELL, 1822), frequent in Early Turonian of the boreal realm, has umbilical tubercles which are thicker, less abundant (7 to 11 per whorl), and most importantly, situated higher on the flank, which results in a subtrapezoidal shell section.

#### Vertical distribution

In the USA as in Central Tunisia, the distribution of the species seems limited to the summit of Early Turonian and the extreme base of Middle Turonian.

#### Genus *Neptychites* KOSSMAT, 1895

Type species : *Ammonites telinga* STOLICZKA, 1865 (= *A. cephalotus* COURTIER, 1860), by original designation.

#### *Neptychites cephalotus* (COURTIER, 1860)

Pl. 20, fig. 2 a-b, 3 a-b; Pl. 21, fig. 3 a-b.

1860 *Ammonites cephalotus* COURTIER, p. 248, pl. 2, fig. 1-4.

1907 *Neptychites cephalotus* (COURTIER); PERVINQUIÈRE, p. 393, pl. 27, fig. 1-4, text-fig. 152.

1907 *Neptychites gourguechoni* PERVINQUIÈRE, p. 400, pl. 27, fig. 8-9, text-fig. 155-156.

1907 *Neptychites xetiformis* PERVINQUIÈRE, pl. 27, fig. 5-7, text-fig. 153-154.

1979 *Neptychites cephalotus* (COURTIER); KENNEDY & WRIGHT, p. 670, pl. 82, fig. 3-5; pl. 83, fig. 1-3; pl. 84, fig. 3; pl. 85, fig. 1-5, pl. 86; fig. 5-6; text-fig. 2 (with synonymy).

1979 *Neptychites xetiformis* PERVINQUIÈRE; KENNEDY & WRIGHT, p. 679, pl. 84, fig. 1-2; pl. 5, fig. 1-3 (with synonymy).

1982 *Neptychites cephalotus* (COURTIER); AMEDRO & BADILLET, p. 190, pl. 2, fig. 1 a-b.

1982 *Neptychites xetiformis* PERVINQUIÈRE; AMEDRO & BADILLET, p. 140, pl. 2, fig. 2 a-b.

1983 *Neptychites cephalotus* (COURTIER); COBBAN & HOOK, p. 14, pl. 3, fig. 9-11; pl. 9, fig. 1-12; pl. 10, fig. 1-8; pl. 11, fig. 1-11; pl. 12, fig. 1-2.

#### Material

26 specimens distributed as follows : 2 from Oued Smara at level SM 181 in the Annaba Member; 4 from Oued Smara at level SM 287, at the base of the Bireno Member, and 20 from Oued Zitoune between levels ZT 10 and ZT 94.20 in the lower half of the Bireno Member.

#### Description

These 26 specimens have diameters between 3 and 23 cm. The shell is very involute with a subgigantic whorl section and a rounded ventre. The thickness of the whorl section varies considerably from one individual to another and shows a continuous series from compressed ( $H/E = 1.96$ ) to thick forms ( $H/E = 0.97$ ). The internal whorls of the phragmocone bear 4 constrictions per whorl. Then the ornament consists of a set of long ribs, rounded, slightly curved forwards, and crossing the siphonal line without a break. On the last whorls,

the ornament disappears and the shell becomes smooth. The modification appears earlier in the compressed forms than in the thick variants. The chamber of the compressed forms generally shows a lateral swelling near the aperture followed by a tightening of the shell, which, when viewed ventrally, gives a more or less fusiform aspect.

#### Discussion

KENNEDY & WRIGHT (1979), in their revision of the *Neptychites* of the type-Turonian, consider *N. cephalotus* and *N. xetiformis* to be two distinct species because of the greater shell thickness of the latter, the retention of the ribs on the body chamber, and its smaller size. COBBAN & HOOK (1983), on the other hand, classify the two species in the same group after studying a population of 45 specimens from New-Mexico (USA). "We are, however, regarding the entire assemblage as a single species (*N. cephalotus*) that has the normal range of Ammonite variation from small, stout, more strongly ornamented forms to large, slender, more weakly ornamented forms. The degree of stoutness did not enter into KENNEDY & WRIGHT's separation of *N. xetiformis* from *N. cephalotus* inasmuch as the holotype of *N. xetiformis* has essentially the same breadth to diameter ratio as one of the paratypes of *N. cephalotus*". The observations carried out on the *Neptychites* population collected in the Kalaat Senan area match COBBAN & HOOK's (1983) conclusions perfectly and *N. xetiformis* is considered here to be a junior synonym of *N. cephalotus*.

#### Vertical distribution

In the type-Turonian, *N. cephalotus* is only known in the basal part of Middle Turonian (in the *K. turoniense* Zone, see AMEDRO & BADILLET, 1982). The collections carried out in other parts of the world, in particular in the USA (COBBAN & HOOK, 1983; COBBAN, 1984) and in Israel (FREUND & RAAB, 1969), show that *N. cephalotus* really appears very low in Early Turonian. In the surroundings of Kalaat Senan, the species seems to present its maximum distribution, from Early Turonian to the base of Middle Turonian.

#### Genus *Paramammites* FURON, 1935

Type species: *Vascoceras polymorphum* PERVINQUIÈRE, 1907, by subsequent designation by REYMENT, 1954.

#### *Paramammites polymorphus* (PERVINQUIÈRE, 1907)

Pl. 21, fig. 1 a-b.

1907 *Vascoceras polymorphum* PERVINQUIÈRE, p. 336, pl. 21, fig. 2-6.

#### Material

A specimen from Oued Smara, from level SM 287, at the base of the Bireno Member.

#### Discussion

The specimen is a portion of phragmocone with a diameter of approximately 60 mm. The moderately evolute shell presents a polygonal section with a concave ventral region. The ornament is composed of a line of very prominent umbilical tubercles and thick ribs bearing internal and external protruding ventrolateral tubercles. In total, six rows of tubercles crown the whorl section: umbilical, internal ventrolateral and external ventrolateral.

The shape of the whorl section and the development of tuberculation on the lateral whorls of the phragmocone characterise the *Paramammites*. The comparison with PERVINQUIÈRE's (1907) illustrations shows that the specimen from Oued Smara is nearly identical to the holotype of *P. polymorphus* (PERVINQUIÈRE, 1907, pl. 21, fig. 2 a-b) from Sif et Tella in Tunisia.

#### Vertical distribution

In Tunisia, as in the chalks of the Northern Paris Basin *P. polymorphus* is known only in association with *Mammites nodosoides* in the upper part of Early Turonian.

#### Subfamily Pseudotissotiinae HYATT, 1903

##### Genus *Thomasites* PERVINQUIÈRE, 1907

Type species: *Pachydiscus rollandi* PÉRON, 1889, by original designation.

##### *Thomasites rollandi* (PÉRON, 1889)

Pl. 22, fig. 1 a-b, 4 a-b.

1889 *Pachydiscus rollandi* PÉRON, 1889, p. 25, pl. 17, fig. 1-3.

1907 *Thomasites rollandi* THOMAS & PÉRON: and var., PERVINQUIÈRE, p. 341, pl. 22, fig. 1-7

1907 *Thomasites meslei* PERVINQUIÈRE, p. 345, pl. 22, fig. 8-9.

1928 *Thomasites egyptiacus* DOUVILLE, p. 16, pl. 2, fig. 3.

1928 *Thomasites lefevrei* DOUVILLE, p. 16, pl. 2, fig. 4

1969 *Thomasites rollandi rollandi* (THOMAS & PÉRON): FREUND & RAAB, p. 43, text-fig. 9 f-i (with synonymy)

1969 *Thomasites rollandi globosus* PERVINQUIÈRE, FREUND & RAAB, p. 44, text-fig. 9 j

1969 *Thomasites rollandi complanatus* PERVINQUIÈRE: FREUND & RAAB, p. 44, text-fig. 9 k (with synonymy)

1981 *Thomasites cf. rollandi* (PÉRON): WRIGHT & KENNEDY, p. 99, pl. 22, fig. 1.

#### Material

Two specimens from Oued Zitoune collected in level ZT 12 and between levels ZT 42 and ZT 45, respectively, in the uppermost part of the Annaba Member and in the lower part of the Bireno Member.

#### Discussion

The weakly protruding ribs, the rapidly attenuated ornament and the virtual absence of siphonal tubercles allow a connection to be made between the two *Thomasites* and *T. rollandi*. They can also be compared to material described by PERVINQUIÈRE (1907) in Central Tunisia.

#### Vertical distribution

In Israel, *T. rollandi* is known from the *Vascoceras pioti* Zone to the *Choffaticeras luciae trisellatum* Zone, in other words throughout Early Turonian (FREUND & RAAB, 1969). The recent collections by WRIGHT & KENNEDY (1981) from the condensed levels of southwest England suggest however that the species already appears in terminal Cenomanian (*Neocardioceras juddii* Zone). In the present collections from the Kalaat Senan area, *T. rollandi* is only identified in the *M. nodosoides* Zone at the top of Early Turonian.

***Thomasites jordani* PERVINQUIÈRE, 1907**

Pl. 22, fig. 3 a-b.

1907 *Thomasites jordani* PERVINQUIÈRE; and var., p. 347, pl. 22, fig. 10-11.

1969 *Thomasites jordani jordani* PERVINQUIÈRE; FREUND & RAAB, p. 45, text-fig. 10 a (with synonymy).

1969 *Thomasites jordani laevis* PERVINQUIÈRE; FREUND & RAAB, p. 45, text-fig. 10 b-c.

**Material**

Two specimens collected in the lower half of the Bireno Member (but not at the base) in the outcrop of Fretissa-Est (probable equivalent of levels ZT 30 - ZT 50 of Oued Zitoune).

**Discussion**

These specimens closely resemble the type material from Draa el Miaad (Central Tunisia), described by PERVINQUIÈRE (1907), characterised by a row of siphonal tubercles which remain protruding even on the external whorls.

**Vertical distribution**

In Tunisia as in Israel, *T. jordani* is found in association with *M. nodosoides* and *Ch. luciae* at the top of Early Turonian.

***Thomasites* sp.**

Pl. 22, fig. 2; Pl. 23, fig. 3a-c.

**Material**

Some thirty specimens distributed in two groups. The first group represents a dozen specimens collected in the lower half of the Annaba Member in sections SM (149.50; 181) and ZH (13.4; 22.8; 51). The second one consists of material from the lower part of the Bireno Member - 14 specimens from Oued Smara at level SM 287, and 8 from Oued Zitoune between levels ZT 20.3 and ZT 45.70.

**Discussion**

The *Thomasites* from the Bireno Member are a group of weathered Ammonites whose specific determination is open to discussion, but most of which are probably close to *Thomasites rollandi*. These specimens do not merit any particular comment.

However, the first group collected in the lower part of the Annaba Member is much more interesting because of its stratigraphic position. It contains juvenile specimens with a diameter between 20 and 30 mm, preserved as crushed imprints at the surface of the limestone beds. The poor conservation of these Ammonites makes their classification particularly difficult, even at the generic level. Nevertheless its relatively thick shell, the morphology, the presence of protruding umbilical tubercles numbering 4 to 5 per whorl, the existence of a greater number of ventrolateral tubercles, and the convex ventral region are features which are common to *Thomasites* (compare with the example illustrated by PERVINQUIÈRE, 1907, pl. 22, fig. 1 a-b).

**Vertical distribution**

As can be seen from the most recent collections carried out both in the Tethyan realm (in Israel by FREUND & RAAB, 1969 and Nigeria by POPOFF *et al.*, 1986) as well as in the boreal realm (in southern England by WRIGHT & KENNEDY,

1981), the first *Thomasites* appear in the higher levels of the Cenomanian and their distribution extends right up to the top of Early Turonian, in the *Mammites nodosoides* Zone. With the knowledge available at present, the specimens from the Kalaat Senan area have all been classed as Early Turonian.

**Genus *Choffaticeras* HYATT, 1903, p. 37**

**Type species:** *Pseudotissotia meslei* PERON, 1897, by original designation.

***Choffaticeras luciae* (PERVINQUIÈRE, 1907)**

Pl. 23, fig. 1 a-b; Pl. 24, fig. 1 a-b.

1907 *Pseudotissotia (Choffaticeras) luciae* PERVINQUIÈRE, p. 354, pl. 24, fig. 1 a-b, 2 a-b, text-fig. 135, 136, 137.

1969 *Choffaticeras luciae trisellatum* FREUND & RAAB, p. 59, pl. 9, fig. 7-8, text-fig. 12 i-g, 13 a-h.

**Material**

Three specimens : the first two from Oued Smara, at level SM 287; the third from Oued Zitoune at level ZT 42. All three are situated in the lower part of the Bireno Member.

**Description**

Single keeled *Choffaticeras*, moderately thick, with a large umbilicus. The triangular whorl section shows a maximum thickness near the umbilical border. The umbilicus is itself bordered by fairly high subvertical walls. The converging flanks are at first slightly convex and then concave on the outer edge, which gives the siphonal keel a sharp morphology. The suture line is identical to that on the *C. luciae* holotype illustrated by PERVINQUIÈRE (1907, p. 355, fig. 136), with a deep and asymmetric first lateral lobe.

**Discussion**

Under the name *Choffaticeras luciae trisellatum*, FREUND & RAAB (1969) separated the thick variants whose shell thickness represents 60% to 80% of the whorl height from *Choffaticeras luciae*. This subspecies is not retained here because the dimensions indicated by PERVINQUIÈRE (1907, p. 355) for the *C. luciae* holotype give an E/H ratio of 75%; in other words the same. The comparison of the *C. luciae* type with the illustrations of *Choffaticeras barjonai* (CHOFFAT, 1898, pl. 3; pl. 18, fig. 3) also suggests close affinities between the two species, the most significant difference being the slightly greater thickness of the latter. It is possible that future collections will lead to the confirmation of the synonymy of *C. luciae* with *C. barjonai*, but the material at our disposal is not sufficient to demonstrate the existence of a continuous sequence from moderately compressed variants ("luciae") to thicker variants ("barjona").

With a shell thickness representing 58% to 62% of the whorl height, the three *C. luciae* from the Kalaat Senan area represent compressed variants of the species.

**Vertical distribution**

To our knowledge, in the only well dated outcrops where *C. luciae* was reported in Israel, the species is limited to the *Choffaticeras luciae trisellatum* Zone defined by FREUND & RAAB (1969), which also includes *Mammites nodosoides*. In the Kalaat Senan area, the two species are also found together, however the extension of *M. nodosoides* seems to go higher than that of *C. luciae*.

*Choffaticeras* sp.

Pl. 23, fig. 2 a-b, 5.

**Material**

It is distributed in two groups : the first from the lower half of the Annaba Member with 6 specimens collected within SM 149.50, SM 181, SM 219 and within ZH 22.8 and ZH 51, the second consists of a dozen specimens from the lower part of the Bireno Member within SM 287 (8 specimens), ZT 15 and ZT 47.

**Discussion**

The undetermined *Choffaticeras* from the Bireno Member are moulds or fragments of internal moulds of shells with a diameter between 10 and 15 cm. These are single keeled and fairly thick *Choffaticeras*, with a whorl section notably as wide as it is high. The flanks are convex and the siphonal keel is not sharp as in *Choffaticeras luciae*. An example is illustrated in Pl. 23, fig. 2.

The specimens from the Annaba Member are poor quality, juvenile imprints (diameter less than 30 mm). However, the ornamentation, with fine and dense ribs slightly curved forwards, resembles the small *Choffaticeras* described by DOUILLE, 1928, pl. 3, fig. 2, 2a, 2b, 3a, 3b, from Egypt and by FREUND & RAAB, 1969, pl. 9, fig. 3, from Israel.

**Vertical distribution**

The oldest *Choffaticeras* are known in the Israeli *Vascoceras cauvini* Zone, attributed to terminal Cenomanian by LEWY *et al.* (1984). The distribution of the genus extends at least until the top of Early Turonian in the *Mammites nodosoides* Zone or its equivalents in Israel (FREUND & RAAB, 1969), USA (COBBAN, 1984), and maybe even as far as the base of Middle Turonian in France : in the Uchaux Massif (AMÉDRO & DEVALQUE, unpublished). In the Kalaat Senan area, the collections are limited to the lower part of the Turonian.

Family Collignoniceratidae WRIGHT & WRIGHT, 1951

Subfamily Collignoniceratinae WRIGHT & WRIGHT, 1951

**Genus *Collignoniceras* BREISTROFFER, 1947**

**Type species** : *Ammonites woollgari* MANTELL, 1822, by designation by MEEK, 1876 (for the genus *Prionotropis* MEEK, 1876, *non* FIEBER 1853 for which BREISTROFFER, 1947, has proposed the new name of *Collignoniceras*).

***Collignoniceras woollgari* (MANTELL, 1822)**

Pl. 24, fig. 2 a-b.

1822 *Ammonites woollgari* MANTELL, p. 197, pl. 21, fig. 16; pl. 22, fig. 7

1981 *Collignoniceras woollgari* (MANTELL, 1822); WRIGHT & KENNEDY, p. 103, pl. 28, fig. 1-3; pl. 29, fig. 1-7; pl. 30, fig. 1-3 (with synonymy).

1982 *Collignoniceras woollgari* (MANTELL, 1822); AMÉDRO, COLLETÉ, PIETRESSON DE SAINT-AUBIN & ROBASZYNKI, p. 30, pl. 1, fig. 5, 6, 7

1988 *Collignoniceras woollgari* (MANTELL, 1822); KAPLAN, p. 11, pl. 1, fig. 1, pl. 1, pl. 2, fig. 1-7; pl. 7, fig. 1

**Material**

One specimen collected in the last beds of the Bireno

Member at a place known as Fretissa-Est (probably equivalent to level HM 142 in the Oued Hammadja section).

**Discussion**

The specimen illustrated in Pl. 24, fig. 2 is a typical representative of the species recently revised by WRIGHT & KENNEDY (1981). It consists of a portion of phragmocone with a diameter of 80 mm, which shows characteristic differentiation of the ribbing at that stage with long ribs, on which internal ventrolateral tubercles develop as horns, and short intercalated ribs limited to the external part of the flank and the ventral region.

**Vertical distribution**

*Collignoniceras woollgari* is a characteristic species of the boreal realm. Since WRIGHT (1957), the *C. woollgari* Zone has been synonymous for most authors with Middle Turonian (see the discussion of the substages of the Turonian, in ROBASZYNSKI coord., 1983). Recent collections carried out in France in the Aube area chalks now clearly demonstrate the continued existence of the species in the highest part of the Turonian stage, in association with *Romaniceras deverianum*, then with *Subprionocyclus neptuni* (GEINITZ, 1850) (AMÉDRO *et al.*, 1982).

The specimen described here is, to our knowledge, the first report of the species in Africa. Its presence in association with *Romaniceras (R.) kallei* allows us to class it at the base of Middle Turonian.

**Genus *Prionocyclus* MEEK, 1876**

**Type species** : *Prionocyclus wyomingensis* MEEK, 1876, by original designation.

***Prionocyclus novimexicanus* (MARCOU, 1858)**

Pl. 17, fig. 6 a-b; Pl. 25, fig. 1 a-b, 2 a-b, 3 a-b.

1858 *Ammonites novi-mexicanus* MARCOU, p. 36.

1946 *Prionocyclus wyomingensis* MEEK var. *elegans* HAAS, p. 200, pl. 19, fig. 1-7, 11-14; pl. 20, fig. 4, pl. 21, fig. 11-3, 5, pl. 22, fig. 1, 2; text-fig. 98-104.

1946 *Prionocyclus wyomingensis* MEEK var. *robusta* HAAS.

1979 *Prionocyclus novimexicanus* (MARCOU); HOOK & COBBAN, p. 38, fig. 3 E-L (with discussion of synonymy).

**Material**

More than one hundred specimens coming from Oued Hammadja in levels HMT 720 and 725 in the middle part of the Aleg Formation.

**Description**

Evolute shell. Subrectangular whorl section, higher than it is wide, with a maximum thickness in the internal third of the flank. The population shows an important morphological variability with a continuous series from compressed to thick forms.

The most compressed variants (with a ratio H/E of height to whorl thickness in the order of 1.60 to 1.65) are comparable with the holotype of the species recently redefined by HOOK & COBBAN, 1979, p. 37, fig. 3 E-G. The ornamentation consists of a set of fine ribs, slightly flexuous, numbering about 25 to 32 per half-whorl. The primary ribs arise from the level of an umbilical bulla radially extended, then crossing the flank in

a more or less marked sinuous manner, and bearing a small forwardly oblique tubercle on the ventrolateral shoulder. The secondary ribs, single or in pairs, appear fairly low on the flank, following the same course as the primary ribs, but not developing any ventrolateral tubercles. The ventral region bears a protruding keel bounded by two furrows, themselves framed by folds resulting from ventral endings of the strongly forward projecting ribs.

The thickest variants possess the same morphology but a more square section ( $H/E = 1.15$ ), a much less dense ribbing - about 10 to 12 ribs per half whorl - and more vigorous tuberculation.

All the intermediaries are found between these two extremes. It should be noted, however, that the compressed variants are the most frequent, representing more than 80% of the population.

#### Discussion

The material has been determined thanks to Dr. COBBAN. *Prionocyclus novimexicanus* is a rarely discussed species in textbooks and has often been confused with *P. wyomingensis*, whose lectotype has been illustrated by MATSUMOTO, 1965, pl. 16, fig. 1 a-c. The distinction between the two species is essentially based on the number of ventrolateral tubercles, one in *P. novimexicanus* and two in *P. wyomingensis*. The compressed forms of *P. novimexicanus* have a similar morphology to that of the holotype. On the other hand, the robust forms, which, according to COBBAN (*in litteris*) "occur also with the typical form in the United States, were named *P. wyomingensis* var. *robusta* by HAAS, 1946".

#### Vertical distribution

In North America, in the Western Interior, COBBAN (1953, 1984) distinguishes six successive zones of *Prionocyclus* in Middle and Late Turonian, the *P. novimexicanus* Zone being the next to last one. Elsewhere, some *Prionocyclus* are known only in Japan (MATSUMOTO, 1965). In this context, the discovery of numerous *P. novimexicanus* in Central Tunisia is interesting for three reasons : (1) in extending the geographical distribution of the genus; (2) in formulating the first report on the species *P. novimexicanus* outside the Western Interior; (3) in providing additional information to help correlate the upper part of the Turonian between the North American province of the boreal and Tethyan realms.

#### *Prionocyclus* sp.

Pl. 24, fig. 3 a-b.

#### Material

37 specimens from Oued Hammadja collected in the lower half of the Aleg Formation between levels HM 407 and HMT 748.

#### Discussion

The *Prionocyclus novimexicanus* nodular beds, known as the "Niveaux de la ferme Taga", coincide with levels HMT 720 and HMT 725 (= T5) in the Oued Hammadja section. A certain number of *Prionocyclus*, however, come from lower horizons (HM 407; HMF 60; HMT 686.50, 716) or higher ones (HMT 733, 739, 748). These are either external imprints, or fragments of more or less weathered internal moulds preserved as septaria. The fairly poor state of preservation of the samples did not permit us to make a specific determination of these Ammonites. It is possible that some of them may

belong to other species of *Prionocyclus*, which would provide additional clues to correlating Central Tunisia with the USA. The oldest specimen, from level HM 407, is illustrated in Pl. 24, fig. 3 a-b. It is an internal mould preserved in a calcareous nodule (septaria) enclosed in marls. It could correspond to *P. wyomingensis* MEEK but the badly preserved ventral region does not clearly show whether it bears one or two tubercles on the ventrolateral shoulder.

#### Vertical distribution

In the USA, the *Prionocyclus* appear in the lower part of Middle Turonian, in the interval between the disappearance of *Mammites nodosoides* and the appearance of *Romaniceras (R.) kallesi* (cf. COBBAN, 1984, fig. 3). The fact that *Prionocyclus* is clearly situated above the *R. (R.) kallesi* level indicates that it was introduced at a later stage in Central Tunisia. This diachronism may be the result of a migration from the USA to North Africa (see the discussion in paragraphs 4.5 and 4.8). On the other hand, the disappearance of *Prionocyclus* is placed at the Turonian-Coniacian boundary in the USA, as is the case in Tunisia.

#### Genus *Reesidites* WRIGHT & MATSUMOTO, 1954

Type species : *Barroisiceras minimus* HAYASAKA & FUKADA, 1951, by original designation.

#### *Reesidites minimus* (HAYASAKA & FUKADA, 1951)

Pl. 25, fig. 4 a-d, 5 a-d.

- 1951 *Barroisiceras minimum* HAYASAKA & FUKADA, p. 325, pl. 1, figs. 1-4, pl. 2, figs. 1-7.
- 1965 *Reesidites minimus* (HAYASAKA & FUKADA); OBATA, p. 39, pl. 4, figs. 1-3; pl. 5, figs. 1-6; text-figs. 1-25.
- 1965 *Reesidites minimus* (HAYASAKA & FUKADA); MATSUMOTO, p. 63, pl. 14, fig. 1, pl. 15, figs. 1-3; text-figs. 34-39.
- 1972 *Reesidites minimus* (HAYASAKA & FUKADA); ATABEKIAN & AKOPIAN, p. 6, pl. 1, fig. 4; pl. 2, figs. 1-3; pl. 3, fig. 6.
- 1978 *Reesidites minimus* (HAYASAKA & FUKADA); TANABE, OBATA & FUTAKAMI, p. 41, pl. 1, figs. 1-2.
- 1982 *Reesidites minimus* (HAYASAKA & FUKADA); MATSUMOTO & OBATA, p. 80, pl. 5, fig. 2; pl. 6, fig. 1; text-fig. 3.
- 1988 *Reesidites minimus* (HAYASAKA & FUKADA); COBBAN & KENNEDY, p. 66, figs. 1-3.

#### Material

33 specimens from Oued Hammadja collected from level HMF 66.

#### Description

These Ammonites are a set of small pyritized internal moulds, with a diameter between 8 and 25 mm, and which correspond to phragmocones. They always have very involute shells, strongly compressed, with a ratio of height to whorl thickness in the order of 1.75 to 2.20. The whorl section shows a maximum thickness at the umbilical edge, the weakly converging flanks, and a rooflike ventral region. At a diameter of 15 mm, 5 to 6 forwardly oblique umbilical bullae per half whorl can be seen. Each gives rise to 2 or 3 flexuose ribs to which shorter intercalatory ribs are added. All the ribs bear a well marked ventrolateral tubercle, which are then strongly projected forwards on the siphonal line, thus forming a crenellated keel. On the more compressed variants, the ribs

which do not usually protrude, attenuate and become more or less indistinct on the inner part of the flank. The costal density is fairly high with 15 to 22 ribs per half whorl.

#### Discussion

According to MATSUMOTO (1965), the *Reesidites* seem to constitute an intermediary stage within the Collignoniceratidae between the *Subprionocyclus* SHIMIZU, 1932, present in the upper part of the Turonian, and the *Forresteria* REESIDE, 1932, whose appearance marks the base of the Coniacian. The main characteristic of the genus *Reesidites* is the presence of a single row of tubercles on the ventrolateral shoulder as opposed to 2 with *Subprionocyclus*. Despite the difference in diameter, the material collected from the Kalaat Senan area closely resembles the specimens from Japan described by MATSUMOTO, 1965, pl. 15, figs. 1-2 as *Reesidites minimus*. However, the very involute shell and the presence of only one row of ventrolateral tubercles distinguish it from the *Subprionocyclus*. The only species which could possibly cause confusion is *Subprionocyclus hitchinensis* (BILLINGHURST, 1927), a finely costulated taxon (see the example given by WRIGHT, 1979, pl. 5, fig. 10). The ribs, however, always protrude very prominently in *Subprionocyclus*, even at small diameters, whereas they stay rounded in *Reesidites* as in our specimens. W.J. KENNEDY, to whom a certain number of specimens had been submitted, confirms this determination.

#### Vertical distribution

In Japan, where the species is well known, *R. minimus* characterizes the top of the Turonian stage, associated with *Subprionocyclus neptuni* over part of its extension (OBATA *et al.*, 1979). Two specimens, from New Mexico in the USA, have also just been described by COBBAN & KENNEDY (1988) from the *Prionocyclus wyomingensis* and *Scaphites whitfieldi* Zones (synonym of the *P. novimexicanus* Zone of HOOK & COBBAN, 1979).

In Central Tunisia, the association of *Reesidites minimus* with *Coilopoceras* and *Prionocyclus* apparently being close to *P. wyomingensis* and *P. novimexicanus* suggests a stratigraphic attribution comparable with that of New Mexico. It should be noted that this is the first mention of the species in Africa.

Family *Coilopoceratidae* HYATT, 1903

Genus *Coilopoceras* HYATT, 1903, p. 91

Type species : *Coilopoceras colleti* HYATT, 1903, by original designation.

*Coilopoceras* sp. cf. *requienianum* (d'ORBIGNY, 1841)

Pl. 26, fig. 1 a-b, 2 a-b.

#### Material

21 specimens from Oued Hammadja collected in the lower half of the Aleg Formation. 10 come from the interval HM 224 - HM 494; 10 from the interval HMF 45 - HMF 66. The last one was found in levels HMT 620-635.

#### Discussion

A certain number of calcareous nodules (septaria) disseminated in the lower part of the marls in the Aleg Formation are internal moulds of oxycone Ammonites linked to *Coilopoceras* HYATT, 1903. The material represents, for the most part,

fragmented and fairly weathered phragmocones. The shells, originally with a diameter around 15 to 20 cm, are involute and display smooth and compressed forms, or thicker and ribbed forms. The ornamentation in this case shows a more or less regular alternation of long ribs, which occur from a level of strong, radially extended umbilical swelling, and short intercalated ribs. The suture line is not easily seen due to the weathering of the shells. However, the specimen numbered H1, illustrated in Pl. 26, fig. 1, shows certain elements of the septum, and in particular the first lateral lobe, to be very wide and bifid.

At least with respect to specimen H1, the general morphology of the shell, and especially the suture line, is very similar to that of *Coilopoceras requienianum*, a species recently revised by KENNEDY & WRIGHT, 1984 and known in France, Israel and Egypt (LEWY & RAAB, 1978; LUGER & GRÖSCHKE, 1989) and maybe in North Africa (DOUVILLE, 1912). *Coilopoceras haugi* and *C. africanus* described by PERVINQUIERE (1910) in the Turonian of Algeria differ from our specimens by the presence of flexuous ribs and a greater division of the lateral lobe. The species from the New World, studied in detail by COBBAN & HOOK (1980) also differ from our material, either by the presence of ventrolateral tubercles (*Coilopoceras inflatum* COBBAN & HOOK, 1980), or by the suture line (*C. colleti* HYATT, 1903; *C. springeri* HYATT, 1903).

In fact, the *Coilopoceras* found in the Kalaat Senan area could reasonably be linked to *C. requienianum*. That is also the opinion of COBBAN (*in littérance*) : "specimen numbered H1 from Oued Hammadja is certainly a *Coilopoceras*. The specimen is badly weathered, but I would guess it is a *C. requienianum* (d'ORBIGNY)". Nevertheless, it is possible that other species will be identified in the future, as in Israel (LEWY 1967; LEWY & RAAB 1978) or in the USA (COBBAN & HOOK, 1980).

#### Vertical distribution

COBBAN & HOOK (1980) have clearly demonstrated the phylogeny *Hoplitoïdes/Coilopoceras* in their revision of the Coilopoceratidae of North Africa. In the Western Interior, the appearance of the *Coilopoceras* is situated in the upper half of the *Prionocyclus hyatti* Zone, just above the collection level of *Romaniceras (R.) kalleesi*. In the Oued Hammadja section in Central Tunisia the first *Coilopoceras* are situated in the same stratigraphic position, above the *R. (R.) kalleesi* Zone. That is also the case in France in the Uchaux Massif where the species *C. requienianum*, common in Late Turonian, already appears in Middle Turonian (AMEDRO & DEVALQUE, unpublished).

On the other hand, the *Coilopoceras* (including *C. requienianum*) persist as far as the border of the Turonian-Coniacian boundary in France (DEVALQUE *et al.*, 1983), while in Tunisia, Israel (LEWY & RAAB, 1978) and the USA (COBBAN, 1984), the last representatives of the genus come from levels attributed to the base of Late Turonian. This could simply be a sampling problem or a genuine phenomenon of provincialism.

Suborder : Ancyloceratina WIEDMANN, 1966

Superfamily : Turrilitacea GILL, 1871

Family : Baculitidae GILL, 1871

Genus : *Baculites* LAMARCK, 1799

Type species : *Baculites vertebralis* LAMARCK, 1799, p. 80, subsequently designated by MEEK, 1876, p. 391.

*Baculites* sp.

Pl. 23, fig. 4.

**Material**

One specimen from Oued Hammadja, at level HMT 720, in the middle part of the Aleg Formation.

**Discussion**

From a total of some 300 Ammonites, this *Baculites* is the only heteromorphe collected in the Turonian of the Kalaat Senan area. The absence of constrictions easily distinguishes it from *Sciponoceras*. However, its specific determination is more difficult. *Baculites undulatus* d'ORBIGNY, 1850, the only species known in the Late Turonian of Europe, has more numerous, less inclined ribs between the dorsolateral bullae. *B. yokoyamai* TOKUNAGA & SHIMIZU and *T. besairei* from Japan and Madagascar have a weaker ornamentation. The projection of the ribs and the development of bulla tend to be reminiscent of *B. incurvatus* DUJARDIN, 1837, but at present, this species is only reported in the Coniacian and the Santonian of Europe.

**Vertical distribution**

The genus *Baculites* is present throughout the world from Late Turonian to Maastrichtien. At Kalaat Senan, the collected sample was found with *Prionocyclus novimexicanus* in the upper part of the Turonian.

#### 4.3. COMPARISON WITH THE STUDIES BY PERVINQUIÈRE (1903, 1907)

Despite their age, the geological and paleontological studies made by PERVINQUIÈRE (1903, 1907) remain the basis of the Cretaceous stratigraphy of Central Tunisia. More recent works have been carried out on the Turonian in the same sector by the following oil company geologists : BUROLLET (1956), BISMUTH *et al.* (1981) (with bibliography) and in eastern Algeria by DUBOURDIEU (1953, 1956, 1958). Their research has clarified the lithology of the formations and defined their micropalaeontological content, but most of the stratigraphic attributions are based on PERVINQUIÈRE's studies. This is why it seems worthwhile in the present sections to replace the fauna collected by PERVINQUIÈRE in the Kalaat Senan area, and then enlarge the scope of comparison.

Situation of PERVINQUIÈRE's collections in the Kalaat Senan area :

PERVINQUIÈRE (1903, p. 101 and 127) successively describes :

- shaly marl, deep blue within, but nearly becoming white when exposed, and firm enough to hold on steep slopes, and causing small cascades in the Oueds (Bahloul Formation to give it its proper name);

- marls of a lighter blue without fossils (Annaba Member);

- marls with limestone beds splitting into cobbles or nodules, very rich in Ammonites, including the holotype *Pseudotissotia (Choffaticeras) massipiana* PERVINQUIÈRE, 1907 (lower two thirds of the Bireno Member). The correspondence between the former and the updated Ammonite determinations described by PERVINQUIÈRE in this lithological unit is as follows :

*Mammites nodosoides* SCHLOTHEIM (PERVINQUIÈRE 1907, pl. XVIII, fig. 1 a-b) = *Mammites nodosoides* (SCHLÜTER, 1891);

*Fagesia superstes* KOSSMAT (PERVINQUIÈRE 1907, pl. XX, fig. 1 a-c, 2 a-b, 3 a-b, 4) = *Fagesia superstes* (KOSSMAT, 1897);

*Neptychites cephalotus* COURTIER (PERVINQUIÈRE, 1907, pl. XXVII, fig. 1 a-b, 2 a-b, 3 a-b, 4 a-b) = *Neptychites cephalotus* (COURTIER, 1860);

*Neptychites xeriformis* PERVINQUIÈRE (PERVINQUIÈRE 1907, pl. XXVII, fig. 5 a-b, 6, 7 a-b) = *Neptychites cephalotus* (COURTIER, 1860);

*Thomasites rollandi* THOMAS & PERON (PERVINQUIÈRE 1907, pl. XXII, fig. 1 a-b, to 7 a-b) = *Thomasites rollandi* (PERON, 1889);

*Thomasites jordani* PERVINQUIÈRE (PERVINQUIÈRE 1907, pl. XXII, fig. 10 a-b, 11 a-b, 12 a-b, 13 a-b) = *Thomasites jordani* PERVINQUIÈRE, 1907;

*Pseudotissotia (Choffaticeras) massipiana* PERVINQUIÈRE (PERVINQUIÈRE 1907, pl. XXIV, fig. 3 a-b) = *Choffaticeras massipianum* (PERVINQUIÈRE, 1907).

— marl and limestone beds without fossils (upper third of the Bireno Member):

- very clayey brown marls (attributed to the "Senonian") containing a few cornstone limestone beds around the base and two or three very hard limestone beds higher up, the highest of which is very rich in "*Ostrea vesicularis*" LAMARCK (lower part of the Aleg Formation).

It is apparent that all the Ammonites collected by PERVINQUIÈRE in the Kalaat Senan area come from a single lithological unit : the lower part of the Bireno Member. Where PERVINQUIÈRE (1903, 1907) saw a homogeneous fauna attributed to the "Ligerian" *auct.*, two Ammonite zones can now be distinguished : a *Mammites nodosoides* Interval-Zone at the base, and a *Kamerunoceras turonense* Interval-Zone above. It should be noted that in the present three-fold division of the Turonian, these zones are situated on either side of the Early Turonian - Middle Turonian boundary.

More generally, in the area of Central Tunisia, the stratigraphic and palaeontological descriptions left by PERVINQUIÈRE (1903, 1907) suggest that most of the Turonian Ammonites come from lithological units equivalent to the lower two-thirds of the Bireno Member in the Kalaat Senan area. The only sampling carried out at higher levels is :

- at Djebel Fékirine : "*Acanthoceras* cf. *deverianum* d'ORBIGNY" and "*Pachydiscus peramplus* MANTELL" in an alternation of marls and limestones immediately above the Ammonitic limestone (probably an equivalent of the uppermost third of the Bireno Member and the basal part of the Aleg Formation);

- and Djebel Sif : "*Placenticeras prudhommei* PERON" and "*Sphenodiscus*" fairly close to "*S. requieni* d'ORBIGNY" in grey marls attributed to the "Senonian" (lower part, but not basal, of the Aleg Formation).

Equivalents of fossiliferous levels from the Taga farm have not been noted elsewhere.

In eastern Algeria, in the Ouenza and the Mesloula areas, some forty kilometres west of the sections studied here, DUBOURDIEU (1956, 1958) describes a fossiliferous succession comparable to PERVINQUIÈRE's; above clayey sediments lacking typical fossils (Annaba Member) :

- a carbonated "Ligerian" (Bireno Member) in which the Ammonites constitute a homogeneous population, whose evolution is impossible to understand, with "*Thomasites*

*jordani*, *Mammites melleguensis*, *Pseudaspidoceras* cf. *salmuriense*, *P. armatus*, *Neptychites cephalotus*, *N. cf. gourguechoni*!.

— a marly "Angoumien" (Aleg Formation *paris*) with *Coilopoceras requienianum*.

#### 4.4. THE ZONATIONS OF THE TETHYAN REALM. COMPARISON WITH THE TURONIAN OF KALAAT SENAN

Figure 11 shows the vertical distribution of Turonian Ammonites from the Kalaat Senan area. To appreciate the extent of the species, it is necessary to compare them with what is known in other parts of the world, both in the Tethyan and boreal realms.

The Kalaat Senan area belongs to the Tethyan realm (Fig. 14). This area is characterised at the Cenomanian-Turonian boundary and in Early to Middle Turonian by an abundance of Vascoceratidae: *Vascoceras* CHOFFAT, 1898, *Neptychites* KOSSMAT, 1895, *Fagesia* PERVINQUIERE, 1907, *Nigericeras* SCHNEEGANS, 1943, *Paramammites* FURON, 1935, *Thomasites* REYMENT, 1954, *Pseudotissotia* PERON, 1897, *Wrightoceras*, REYMENT, 1954 and *Choffaticeras* HYATT, 1903. Conversely, the upper levels of the stage usually only contain poorly diversified fauna with *Coilopoceras* being the most notable element.

At present, several problems arise from the vertical distribution of the Vascoceratidae. These are threefold:

- in the past, palaeontological collections were not always made precisely enough on the field with respect to lithological sequences, and published data is sometimes contradictory. For example, in Nigeria, in the Gongila Formation, *Vascoceras proprium* (REYMENT, 1954) (of which *Pachyvascoceras costatum* REYMENT, 1954 and *P. globosum* REYMENT, 1954 are junior synonyms according to KENNEDY, WRIGHT & HANCOCK, 1987) appears at three different levels in the works of BARBER (1957), WOZNY & KOGBE (1983), POPOFF *et al.* (1986) and MEISTER, 1989;
- the classification of Vascoceratidae as it stands is very confusing. The genus *Spathites* KUMMEL & DECKER, 1954 (of which *Fallotites* WIEDMANN, 1960 and *Spathitoides* WIEDMANN, 1960 are synonyms), belongs to the Mammitinae (Acanthoceratidae) (KENNEDY *et al.*, 1980). Yet some six genera have just been put in synonymy with the genus *Vascoceras* CHOFFAT, 1898 by BERTHOU, CHANCELLOR & LAUVERJAT (1985). These are *Paravascoceras* FURON, 1935, *Pachyvascoceras* FURON, 1935, *Paracanthoceras* FURON, 1935, *Broggiiceras* BENAVIDES-CACERES, 1956, *Discovascoceras* COLLIGNON, 1957 and *Provascoceras* COOPER, 1979. Also, the interpretation of the species varies from one author to the next and a certain number of Ammonites change names across national borders. Thus, according to KENNEDY, WRIGHT & HANCOCK (1987), *Imlayiceras washbourni* LEANZA, 1967, from Colombia, and *Proplacenticeras zeharensis* COLLIGNON, 1967, from Morocco, are probably junior synonyms of *Wrightoceras munieri* (PERVINQUIERE, 1907), a species originally defined in the Early Turonian of Tunisia;
- Finally, the associations of Vascoceratidae can be fairly diversified within the Tethyan realm. The Middle East sequences (DOUVILLE, 1928; FREUND & RAAB, 1969) are characterized by many *Choffaticeras* HYATT, 1903 (= *Leoniceras* DOUVILLE, 1911) whose species follow one after the other and take over from one another. On the other hand, there are few or no *Choffaticeras* in the Vascoceratidae series of Nigeria

(REYMENT, 1954; BARBER, 1957; POPOFF *et al.*, 1986) or in Brazil (BENGSTON, 1983) where *Pseudotissotia* PERON, 1897 (= *Bau-chioceras* REYMENT, 1954) and *Thomasites* PERVINQUIERE, 1907 (= *Gombeoceras* REYMENT, 1954, *Koulabiceras* ATABEKIAN, 1966 and *Feganites* STANKIEVICH & POJARKOVA, 1969) are dominant. These phenomena of provincialism may be linked to a sea-level rise of eustatic origin around the Cenomanian-Turonian boundary, which would thus have favoured the genesis of the marginal basin.

In conclusion, the vertical distribution of the Vascoceratidae is still not well known. The correlation of the Tethyan realm successions with the classic stages defined in France by d'ORBIGNY (1840-1852) is also very uncertain. Since the creation of the genus *Vascoceras* by CHOFFAT in 1898, authors have until recently attributed the Vascoceratidae series to the Turonian (CHOFFAT, 1898; REYMENT, 1954, BARBER, 1957, FREUND & RAAB, 1969). Since 1977, several observations such as the discovery of *Vascoceras diartianum* (d'ORBIGNY, 1850) associated with *Metoicoceras geslinianum* (d'ORBIGNY, 1850) in the type-Cenomanian in France (KENNEDY & JUINET, 1977), the collection of Cenomanian Ammonites: *Neolobites*, *Calycoceras*, *Pseudocalycoceras* and *Euomphaloceras* in the layers of *Vascoceras gamai* CHOFFAT, 1898 in Portugal (AMEDRO, BERTHOU & LAUVERJAT, 1983), and the coexistence of *Vascoceras cauvini* CHUDEAU, 1909 with *M. geslinianum* in Israel (LEWY *et al.*, 1984) tend to prove that a significant part of the associations with Vascoceratidae attributed to Early Turonian in the Tethyan realm could belong to the Cenomanian.

This explains why correlations are at present difficult to establish with the outcrops described in the Iberian Peninsula (WIEDMANN, 1960, 1980; BERTHOU *et al.*, 1985), in Morocco (COLLIGNON, 1965), in Brazil (BENGSTON, 1983) or in Nigeria (BARBER, 1957, POPOFF *et al.*, 1986). On the other hand, the zonal succession defined in Israel by FREUND & RAAB (1969) and recently updated by LEWY *et al.* (1978, 1984) is now better interpreted. This zonation is presented in Fig. 12.

In the uppermost Cenomanian of Israel, the *Euomphaloce-ras septemseriatum* Zone has produced *Metoicoceras geslinianum* (d'ORBIGNY, 1850) and can thus be equated with the *M. geslinianum* Zone of the boreal realm. The *Vascoceras cauvini* Zone contains *Pseudaspidoceras pseudonodosoides* (CHOFFAT, 1898) which has a vertical extension strictly limited to the *Neocardioceras juddii* Zone (COBBAN, 1984) in the western interior of the USA. The Cenomanian-Turonian boundary in Israel is placed at the base of the zone following the *Vascoceras pioti* Zone.

Above, the presence of *Mammites nodosoides* in the *Choffaticeras luciae trisellatum* Zone correlates closely with the higher part of Early Turonian in the boreal realm. The division of basal Turonian in Israel is thus very precise with three Vascoceratidae zones. These are from bottom to top: the *Vascoceras pioti* Zone, the *Choffaticeras securiforme* Zone and the *Choffaticeras quaasi* Zone.

On the other hand, Middle and Late Turonian are less well represented. The *Romaniceras inerme* (?) Zone contains different Euomphaloceratinæ which include, *Kamerunoceras turoniense* [= *Protextanites salmuriensis* (COURTILLER, 1867)] and *Romaniceras (R.) kallesi*. [The specimen numbered HU 23971 illustrated by FREUND & RAAB, 1969, pl. 1, fig. 1-2 as *Romaniceras inerme* (de GROSSOURE, 1889), with a section drawn in fig. 4b, is in fact a *Romaniceras (R.) kallesi*]. In France, these species are known to be present in the lower part of Middle Turonian of the type-Turonian in Tuffeau de Saumur (AMÉDRO & BADILLET, 1982; AMÉDRO *et al.*, 1988).

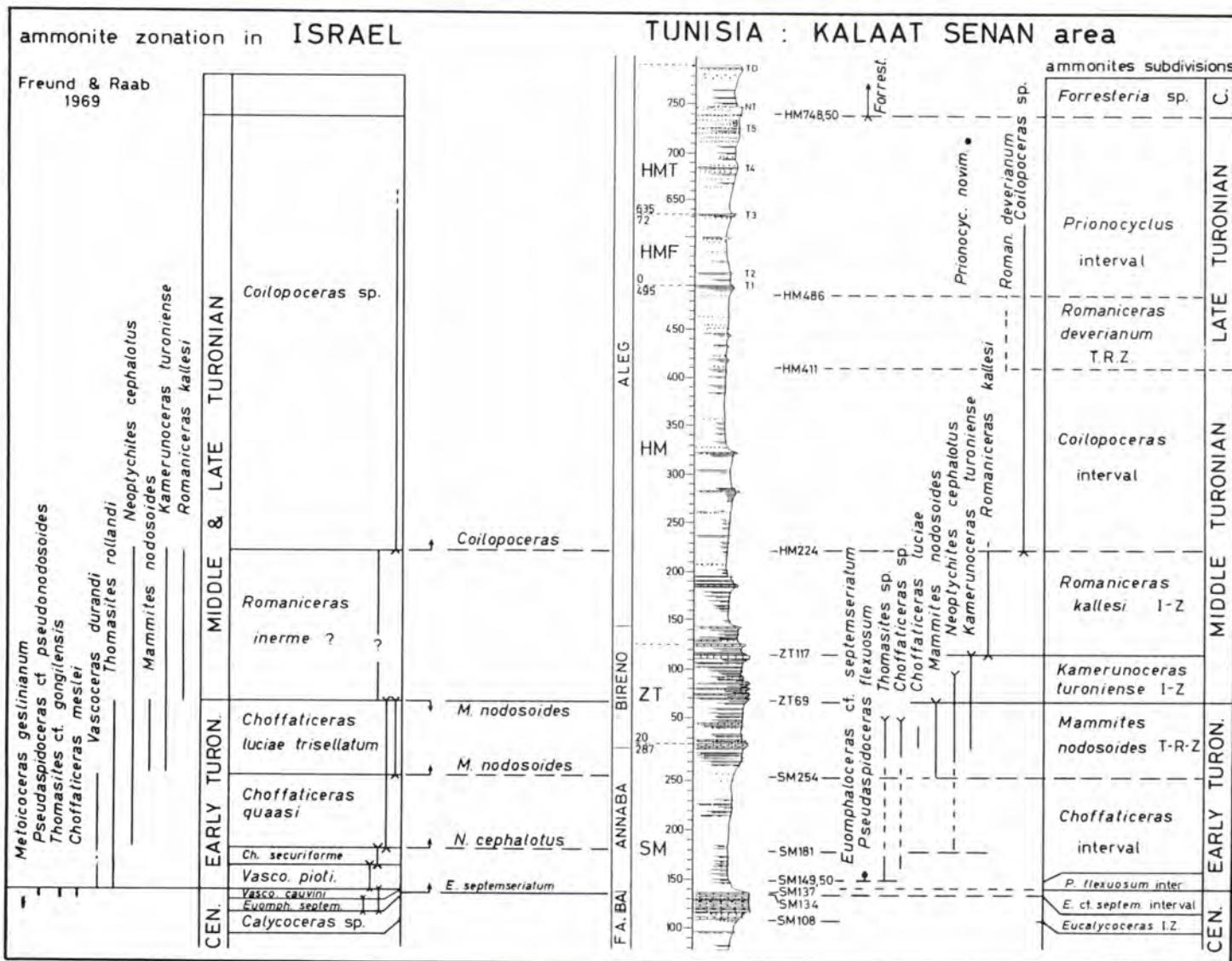


FIGURE 12  
Ammonite zones in Israel and Tunisia.

Finally, the inventory of the *Coilopoceras* sp. Zone (including the *C. requienianum* Zone of LEWY & RAAB, 1978) is limited to the index.

When this zonation is compared to the Turonian of Kalaat Senan (Fig. 12), several correlations can be made. These are from bottom to top :

- the presence of *Euomphaloceras septemseriatum* in the zone of the same name, as well as in SM 134;
- the distribution of *Mammites nodosoides* in the *Choffaticeras luciae trisellatum* Zone as well as in the interval between SM 254 and ZT 69;
- the presence of *Kamerunoceras turoniense* and of *Romaniceras (R.) kallesi* in the *Romaniceras inerme (?)* Zone as well as between ZT 69 and HM 230;
- the appearance of *Coilopoceras* in the upper zone of the Turonian in Israel, as well as in HM 224.

These similarities suggest strong affinities between the Late Cenomanian and Turonian of Kalaat Senan and Israel. It is possible that the successions are nearly identical and that the differences presently observed mostly reflect an incomplete sampling of the Annaba Member. Thus, the whole *Vascoceras pioti* Zone, the *Choffaticeras securiforme* Zone, and the *Choffaticeras quaasi* Zone could correspond to the SM 137 - SM 253 interval in which only crushed nuclei of *Thomasites* and of *Choffaticeras* have so far been found. The only correlation eventually usable within this interval would probably be the appearance of *Neptychites cephalotus* in SM 181, situated at the base of the *Ch. quaasi* Zone. But the value of this event remains to be confirmed. On the other hand, additional sampling might allow divisions to be distinguished in the *Romaniceras inerme (?)* Zone in Israel. Indeed, according to FREUND & RAAB (1969), the zone contains *Kamerunoceras turoniense* associated with *Romaniceras (R.) kallesi*. In Kalaat Senan as well as in the type-Turonian

(AMEDRO *et al.*, 1988), these two species relay each other phylogenetically without an overlap of extensions.

#### 4.5. THE ZONATIONS OF THE BOREAL REALM. COMPARISON WITH THE TURONIAN OF KALAAT SENAN

Unlike the Tethyan realm, the boreal realm is characterised during the greatest part of the Turonian by an abundance of Acanthoceratidae as Mammitinae and Euomphaloceratinae. The vertical distribution of the boreal Ammonites is well known in northwest Europe, particularly in the Anglo-Paris basin where the Turonian stage of d'ORBIGNY (1850-1852) is defined [the proceedings of the Colloquium on the Turonian held in Paris in 1981 give a summary on the stratotype]. Detailed investigations have also been carried out for almost 20 years in the Western Interior of the USA (COBBAN, 1984, with bibliography). Fig. 13 presents the zonal successions as defined in the two regions with comparisons of the distribution of the most characteristic species. Note that the meaning given to the *Collignoniceras woollgari* Zone in Europe and in the USA is significantly different. The Western Interior is affected by a phenomenon of endemism during Middle Turonian starting from the *C. woollgari* Zone (note the premature disappearance of *K. turoniense* and *Neptychites cephalotus*) and continuing in the zones following *Prionocyclus* (COBBAN & HOOK, 1979; COBBAN, 1984). Therefore the *C. woollgari* Zone sensu COBBAN & HOOK (1979) in the USA only corresponds to the base of the *C. woollgari* Zone sensu WRIGHT (1957) in Europe (all or part of the *Kamerunoceras turoniense* Zone of AMEDRO & BADILLET, 1982). That explains the difficulty in correlating the Middle and Late Turonian of Western Europe with the Western Interior. Some elements of correlation nevertheless do exist. These are, from bottom to top :

- the common presence of *R. (R.) kallesi* in the *R. (R.) kallesi* Zone and in the lower half of the *Prionocyclus hyatti* Zone;
- the appearance of the *Coilopoceras* at the base of the *Romaniceras (Y.) ornatissimum* Zone and in the upper half of the *P. hyatti* Zone;
- the appearance of *Baculites undulatus* d'ORBIGNY, 1850 in the *Subprionocyclus neptuni* Zone and its presence in the *Prionocyclus wyomingensis* Zone. It should be noted that no indication has yet been found for placing the Middle Turonian - Late Turonian boundary in the USA.

The juxtaposition of zonations used in the Anglo-Paris basin and the Western Interior with the Turonian faunal succession of Kalaat Senan is presented in Figure 13.

##### 4.5.1. With the Anglo-Paris basin

As a result of differing associations, no correlation can be made in the basal part of the Turonian (*Watinoeceras coloradoense* Zone) : Mammitinae in Europe; Vascoceratidae in Central Tunisia. On the contrary, the next three zones of the type-Turonian are easily found in the Kalaat Senan area, these being :

- the *Mammites nodosoides* Zone defined by the total extent of the species between levels SM 254 and ZT 69;
- the *Kamerunoceras turoniense* Zone; interval bounded by the disappearance of *M. nodosoides* and the appearance of *Romaniceras (R.) kallesi* from ZT 69 to ZT 117;

— the *Romaniceras (R.) kallesi* Zone, an interval bounded by the appearance of *R. (R.) kallesi* and *R. (Y.) ornatissimum* (which notably coincides with the appearance of the *Coilopoceras*) : from ZT 117 to HM 224-230.

Above these intervals close to type Turonian ones, the faunal associations become very distinct. Some elements of correlation nevertheless make it partially possible to draw a parallel between the successions. At the base, the event marked by the disappearance of *R. (R.) kallesi* and the appearance of *Coilopoceras* around HM 224-230 corresponds to the boundary between the zones of *R. (R.) kallesi* and the *R. (Y.) ornatissimum* in the Uchaux Massif in France (AMEDRO & DEVALQUE, unpublished).

Higher up, *Romaniceras (R.) deverianum*, zonal marker in the upper part of French Turonian (AMEDRO *et al.*, 1983) is present in the HM 411 - HM 486 interval.

Finally, the presence of *Reesidites minimus* within HMF 66 provides an indirect link with the *Subprionocyclus neptuni* Zone. In Japan, these two species are associated over the greater part of their extensions (OBATA *et al.*, 1979).

##### 4.5.2. With the Western Interior

The common presence of *Pseudaspidoeceras flexuosum* leads to a good correlation of the Cenomanian-Turonian boundary. The comments made in the previous paragraph also apply to the lower part of the Turonian : distinct associations up to SM 254, followed by a common interval which is characterised by the presence of *Mammites nodosoides*.

The phenomenon of endemism observed in the Western Interior at the base of Middle Turonian prevents the next zones, defined by COBBAN (1984) in the USA, from being used in Tunisia. However, the collection of many *Prionocyclus* starting from level HM 407 at Kalaat Senan suggests one (or several ?) faunal migrations from the USA to Central Tunisia at the boundary between Middle and Late Turonian. It should be noted that the appearance of *Prionocyclus*, which comes later in Tunisia than in the USA, is detected with respect to the *Romaniceras* phylogeny. In the USA, the oldest *Prionocyclus* represented by the species *P. percarinatus* appear below the collection level of *Romaniceras (R.) kallesi* at the bottom of Middle Turonian. In Tunisia, the first *Prionocyclus* are found only a few metres below *Romaniceras (R.) deverianum*, in other words, virtually at the bottom of Late Turonian.

The determinations now being made, as well as future collections, will allow us to improve the USA-Tunisia correlation by studying the *Prionocyclus* evolution. Six *Prionocyclus* species succeed each other in Middle and Late Turonian in the USA. For the time being though, the only species identified positively in the Kalaat Senan area is *Prionocyclus novimexicanus* (MARCOU, 1858) (determination by COBBAN, represented by several dozen specimens from the "ferme Taga" levels (HMT 720 and HMT 725).

In addition to the distribution of the *Prionocyclus*, the discovery of *Reesidites minimus* within HMF 66 now provides a final element of correlation with the USA as this species is known to exist in the *Prionocyclus wyomingensis* and *P. novimexicanus* Zones of the Western Interior (COBBAN & KENNEDY, 1988).

Comparison of vertical extensions of *Neptychites cephalotus* and *Kamerunoceras turoniense* in the Tethyan and boreal realms.

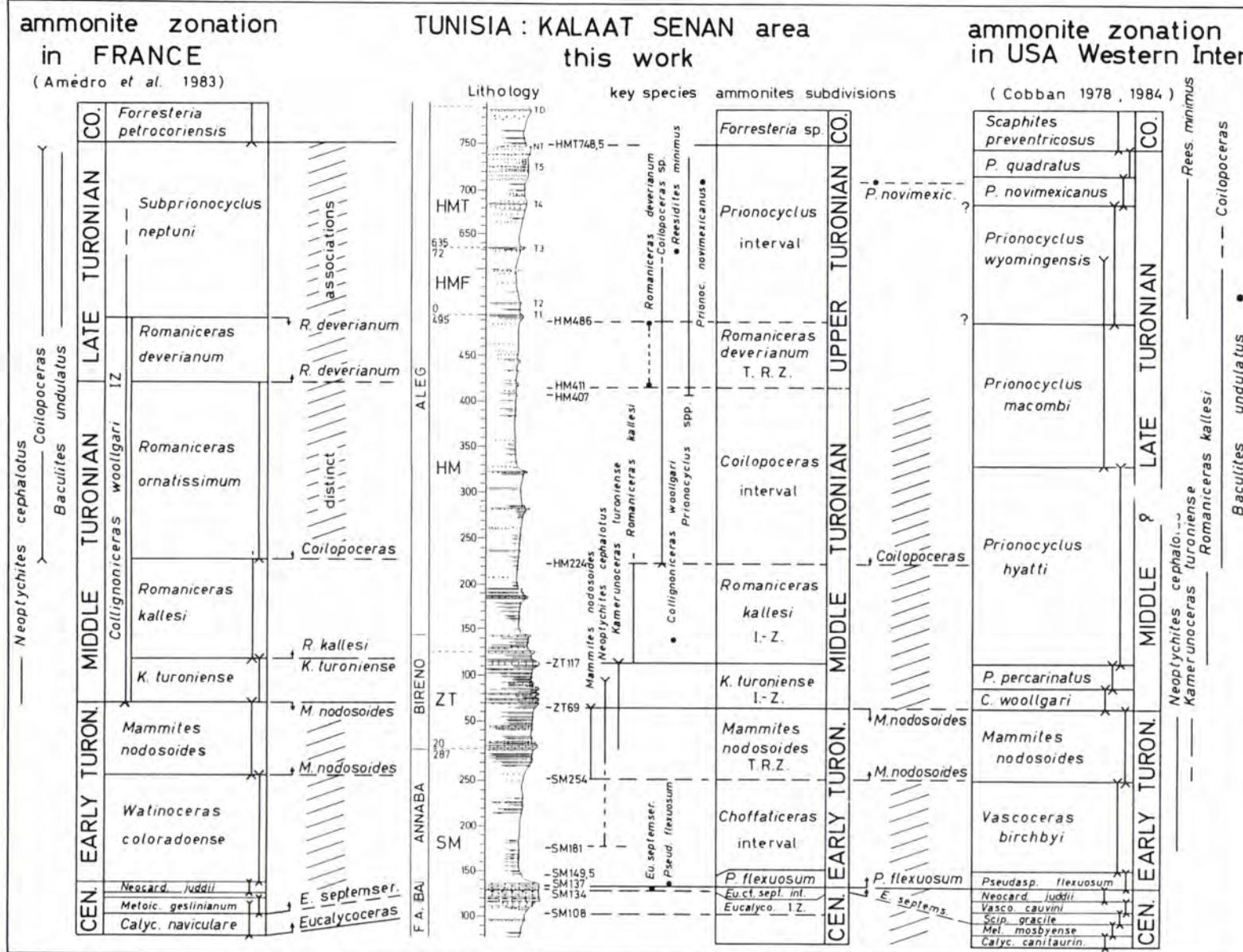


FIGURE 13  
Tentative correlation of Ammonite zonations in France, Tunisia and U.S.A.

Comparing Figures 12 and 13 reveals clear differences in the vertical extension of *Neptychites cephalotus* and *Kamerunoceras turonense* from one region to another. In the Western Interior, in the USA, *N. cephalotus* and *K. turonense* are known only at the summit of Early Turonian (COBBAN, 1984). In northwest Europe, in particular in the type-Turonian, their presence is limited to the base of Middle Turonian (AMEDRO *et al.*, 1983, 1988). In Central Tunisia and in Israel (FREUND & RAAB, 1969), the vertical distribution of the two species extends from Early Turonian to the base of Middle Turonian, thus covering the previously mentioned extensions. It does seem at present that the most complete extensions are those defined in the Tethyan realm (Tunisia and Israel), whereas those of the boreal realm correspond to a truncated phenomenon of provincialism (see discussion § 4.8).

#### 4.6. THE TURONIAN ZONATIONS IN THE KALAAT SENAN AREA, AND RELATIONS WITH THE PREVIOUS ZONATIONS

The two previous paragraphs mentioned that the palaeontological succession described in Israel (FREUND & RAAB, 1969) is the closest to that of Kalaat Senan. This is not surprising since the two successions belong to the Tethyan realm. The incomplete collections from the Annaba Member, which correspond to the interval where the Israeli zonation is most accurate, and the apparent absence of *Prionocyclus* in Israel, make the global use of the zonation by FREUND & RAAB impossible in the Turonian of Central Tunisia.

On the other hand, several strong affinities exist throughout the Turonian stage between Central Tunisia and the boreal realm, in particular in the type-Turonian. Also, by integrating the divisions suggested in Israel, somewhat modified, with several zones of the type-Turonian, a certain number of intervals can be defined in the Turonian of the Kalaat Senan surroundings. Some of these must be seen as simple divisions due to incomplete collections, but the others are real zones. The succession is, from bottom to top:

##### Late Cenomanian

— *Eucalycceras* sp. Interval-Zone. From SM 108 to SM 134. Interval defined between the appearances of the *Eucalycceras* and *Euomphaloceras septemseriatum*. Accompanying species: *Calycoceras* sp., *Pseudocalycoceras* sp.

— *Euomphaloceras* cf. *septemseriatum* and undetermined Vascoceratidae Interval. From SM 134 to SM 137. Interval defined between the appearances of *E. cf. septemseriatum* and *Pseudaspidoceras flexuosum*. This interval could correspond, as suggested by the correlation in Figure 13, to all the *Metoicoceras geslinianum* and *Neocardioceras juddii* Zones of the type-Cenomanian in France. Accompanying Ammonites: undetermined Vascoceratidae.

##### Turonian

(The position of the Cenomanian-Turonian boundary is discussed § 4.7).

— *Pseudaspidoceras flexuosum* Interval. From SM 137 to SM 149.50. Interval contained between the appearance of *P. flexuosum* and the frequent appearance of *Choffaticeras*. Accompanying Ammonites: undetermined Vascoceratidae.

— *Choffaticeras* Interval. From SM 149.50 to SM 254.

Interval contained between the frequent appearance of *Choffaticeras* sp. and the appearance of *Mammites nodosoides*. Accompanying species: *Neptychites cephalotus*, *Thomasites*.

— *Mammites nodosoides* Total-Range-Zone (defined in the chalks of the Anglo-Paris basin by WRIGHT, 1957). From SM 254 to ZT 69. Interval defined by the total extension of *Mammites nodosoides* as known at present. Accompanying species over the whole interval: *Lewesiceras* sp., *Kamerunoceras turonense*, *Morrowites subdepressus*, *Fagesia superstes* (this taxon is however quite frequent within SM 287 = ZT 20), *Neptychites cephalotus*; and in the lower two-thirds of the interval: *Paramammites polymorphus*, *Thomasites rollandi*, *T. jordani* and *Choffaticeras* sp. For a total of 94 Ammonites collected in the whole zone, the relative frequency of the genera is as follows: *Lewesiceras* (Pachydiscidae) = 6%; *Kamerunoceras* (Euomphaloceratinæ) = 8%; *Mammites* and *Morrowites* (Mammitinae) = 15%; *Fagesia*, *Neptychites* and *Paramammites* (Vascoceratinæ) = 32%; *Thomasites* and *Choffaticeras* (Pseudotissotinæ) = 36%. The Vascoceratidae (Vascoceratinæ and Pseudotissotinæ) are the most abundant, representing 68% of the Ammonite population, and thus clearly demonstrating that Central Tunisia belongs to the Tethyan realm.

— *Kamerunoceras turonense* Interval-Zone (defined in France in the type-Turonian by AMÉDRO & BADILLET, 1982).

From ZT 69 to ZT 117. Interval contained between the disappearance of *Mammites nodosoides* and the appearance of *Romaniceras (R.) kallesi*. Even though *Kamerunoceras turonense* appears in the zone before that of *M. nodosoides*, this species is, nevertheless, the only representative of the Euomphaloceratinæ and therefore also the most characteristic. Accompanying species: *Lewesiceras* sp., *Fagesia superstes* and *Neptychites cephalotus*.

— *Romaniceras (R.) kallesi* Interval-Zone (defined in France in the type-Turonian by AMÉDRO & BADILLET, 1982).

From ZT 117 to HM 224-230. Interval contained between the appearances of *Romaniceras (R.) kallesi* and *Romaniceras (Y.) ornatissimum*, which coincides markedly with the appearance of *Coilopoceras* (see discussion in paragraph 4.5). Accompanying species: *Lewesiceras* sp. and *Collignonceras woollgari*.

— *Coilopoceras* Interval. From HM 224-230 to HM 411. Interval contained between the appearances of *Coilopoceras* and *Romaniceras (R.) deverianum*. Accompanying species: *Lewesiceras* sp. and *Prionocyclus* sp. starting from level HM 407, in other words the last 4 metres.

— *Romaniceras (R.) deverianum* Total-Range-Zone (defined in France in the Vaucluse by DEVALOUE *et al.*, 1983). From HM 411 to HM 486. Interval corresponding to the total extension of *R. (R.) deverianum*. Accompanying species: *Lewesiceras* sp., *Prionocyclus* sp. and *Coilopoceras* sp. cf. *requienianum*.

— *Prionocyclus* Interval. From HM 486 to HMT 748.50. Interval contained between the disappearance of the *R. (R.) deverianum* and the appearance of *Forresteria*. It should be noted that the appearance of *Prionocyclus* in Central Tunisia is observed much earlier, starting from level HM 407, but this event is only the result of a faunal migration from the USA to North Africa - see discussion in paragraph 4.5. Accompanying species: *Lewesiceras* sp., *Placenticeras (Karamaites) stantoni*, *Prionocyclus novimexicanus* (for the time being identified between HMT 720 and HMT 725 in the level named

"de la ferme Taga", but the extension could be greater). *Reesidites minimus*, *Coilopoceras* sp. cf. *requienianum* (until within HMT 620-635) and *Baculites* sp.

### Coniacian

*Forresteria* Interval. Starting from HMT 748.5 and above. Interval defined at the base by the appearance of *Forresteria*.

## 4.7. THE BOUNDARIES AND SUBSTAGES OF THE TURONIAN IN THE KALAAT SENAN AREA

### Cenomanian-Turonian boundary

The Sub-commission on the Cretaceous Stratigraphy (BIRKELUND *et al.*, 1984) has recently made the recommendation to place the appearance of *Pseudaspidoceras flexuosum* at the base of the Turonian. Note that the genus is already represented in the *Neocardioceras juddii* Zone of terminal Cenomanian by an older species: *P. pseudonodosoides* (CHOFFAT, 1898). In Africa, *P. flexuosum* was, until now, only known in Nigeria, in association with *Vascoceras proprium* (REYMENT, 1954). Despite the poor conservation of the Ammonites in the last metres of the Bahloul Formation, the presence of *Pseudaspidoceras flexuosum* within SM 137 now makes it possible to accurately place the Cenomanian-Turonian boundary in the Kalaat Senan area. It coincides, at least in the studied sections, with the limit between the Bahloul Formation and the Annaba Member.

### Turonian-Coniacian boundary

Following the symposium held in Copenhagen in 1983 which discussed the boundaries of the Cretaceous stages, the Sub-commission on the Cretaceous Stratigraphy (BIRKELUND *et al.*, 1984) has recommended that the base of the Coniacian be defined by the appearance of *Forresteria petrocoriensis* (COQUAND, 1859). This appearance coincides with that of the genus. In the Kalaat Senan area, the *Forresteria*, which have morphologies close to those described by PARNES (1964) in the Negev desert in Israel, appear at level HMT 748.50 in Oued Hammadja in the lower third of the Aleg Formation. That is where the Turonian-Coniacian boundary would be most appropriate.

Note that PERVINQUIÈRE (1903) places the lower limit of the "Senonian" some 500 m lower down, in the basal part of the Aleg Formation. This stratigraphic attribution is no longer justified and seems to rely solely on the presence of a few limestone beds filled with fossils, including Oysters in the lower part of the Aleg Formation (in the absence of Ammonites, PERVINQUIÈRE frequently used the appearance of small Oysters including "*Ostrea boucheroni*" COQUAND, to place the lower limit of the "Senonian" in Central Tunisia). The present collections clearly demonstrate, through the presence of *Romaniceras (R.) kallesi*, that the base of the Aleg Formation is situated fairly low in Middle Turonian. The following description by PERVINQUIÈRE (1907, p. 272) of *Acanthoceras* cf. *deverianum* with 9 tubercles per rib (it is probably *R. (R.) kallesi*, but this remains uncertain due to the absence of illustration) in outcrops attributed to the end of the Turonian or more probably the beginning of the "Senonian" and the attribution to the "Senonian" of *Placenticeras prudhommei* and *Sphenodiscus* (= *Coilopoceras*) *requieni* (species cha-

racteristic of Late Turonian) marls highlights the differences in interpretation. This also justifies the doubts expressed by BISMUTH *et al.* (1981) about the definition of the Turonian-Coniacian boundary in Central Tunisia by PERVINQUIÈRE (1903, 1907) after the micropalaeontological studies carried out in Djebel Semmama.

Moreover, the erroneous determination of "*Muniericeras lapparenti de GROSSOUPRE*" and of "*Texanites* gr. *serratomarginatus* REDTENBACHER" in the upper part of the Bireno Member at Jbel Jerissa, some twenty kilometres north-east of the studied area (SEREPT unpublished report: BERTHE *et al.*, 1954), clearly illustrates the influence of earlier interpretations on more recent works. These two specimens, stored in the collections of the SEREPT in Tunis under numbers 0209 (pars) and 0210 respectively, are both, in fact, crushed internal moulds of *Romaniceras (R.) kallesi* from Middle Turonian. This places the Turonian-Coniacian boundary at the base of the *R. (R.) kallesi* Zone, in other words, 600 m too low.

### Divisions of the Turonian stage

The division of the Turonian stage into "Saumurien" (or "Ligérien") and "Angoumien" should be abandoned, since some confusion exists as to the meaning attributed to these substages which were inaccurately defined by COQUAND (1857) and de GROSSOUPRE (1901) — [see discussion in AMÉDRO & BADILLET, 1982]. The present tendency is towards a three-fold division: "Early", "Middle" and "Late" Turonian.

### Base of the Middle Turonian

The conclusions of the Colloquium on the Turonian held in Paris in 1981 (ROBASZYNSKI coord., 1983) recommend using the appearance of *Collignoniceras woollgari* to mark the base of Middle Turonian. In the Kalaat Senan area, only one specimen of *C. woollgari* was found. It was collected in the last bed of the Bireno Member in the Frétiessa-Est area. This isolated specimen does not mean that an extension can be defined. Nevertheless, the world-wide appearance of *C. woollgari* coincides markedly with the disappearance of *Mammites nodosoides*.

The present collections show that the youngest specimen of *M. nodosoides*, found in the Oued Zitoune section, comes from level ZT 69. Therefore, the first approach would be to situate the base of Middle Turonian immediately above this level.

### Base of the Late Turonian

There is disagreement between French and English authors as to the definition of the base of Late Turonian. The two concepts can be found in the conclusions of the Colloquium on the Turonian (ROBASZYNSKI coord., 1983). In one of them, AMÉDRO *et al.* (1983) use the appearance of *Romaniceras (R.) deverianum* to define the base of Late Turonian in accordance with traditional usage. In the other, KENNEDY *et al.* (1983) advocate using the appearance of *Subprionocyclops neptuni* (GEINITZ) to locate the base of the substage. *S. neptuni* is, at present, not known in Central Tunisia. *Romaniceras (R.) deverianum* is, however, represented by several perfectly situated specimens in measured sections of Oued Hammadja. By choosing the first definition, and taking into account the collections we have at present, the base of Late

Turonian can be placed at level HM 411. It should be noted that several specimens of *R. (R.) deverianum* have been collected and illustrated in the past by PERVINQUIÈRE (1907, 1910) in Tunisia, from Koudiat El Hamra and Djebel Guern Halfaya (under the name of *Tunesites choffati* PERVINQUIÈRE, 1907), and in Algeria, from Berronaghia (like *Acanthoceras* aff. *newboldi* KOSSMAT) (KENNEDY *et al.* 1980). These findings will probably lead to a better appreciation of the Middle Turonian - Late Turonian boundary throughout North Africa.

#### 4.8. FAUNISTIC PROVINCIALISM

The comparisons made in the previous paragraphs demonstrated that during the Turonian of the Kalaat Senan area one finds both Tethyan Ammonites: *Neptychites*, *Fagesia*, *Paramammites*, *Thomasites*, *Choffaticeras*, and boreal faunas: *Mammites*, *Kamerunoceras*, *Romaniceras*, *Collignonice-*

*ras* and *Prionocyclus*. The interpretation of the faunistic realms and provinces are shown in Figure 14. This association is, of course, very valuable in correlating the faunistic provinces. The discontinuous vertical distribution of the boreal forms suggests, however, that the communications were not constant during the Turonian between Central Tunisia (Tethyan realm) and the boreal realm. Moreover, changes in affinities, in some cases with the North European province of the boreal realm, reveal changes in the communications between the two realms. Figure 15 summarizes the influences of faunistic provincialism on the Turonian biostratigraphy of Kalaat Senan.

If communications seem constant within the Tethyan realm, between Central Tunisia and the Middle East (except perhaps in the upper part of the Turonian, due to the apparent absence of *Prionocyclus* in Israel), four events determine the evolution of relations between Central Tunisia and the boreal realm (Fig. 14).

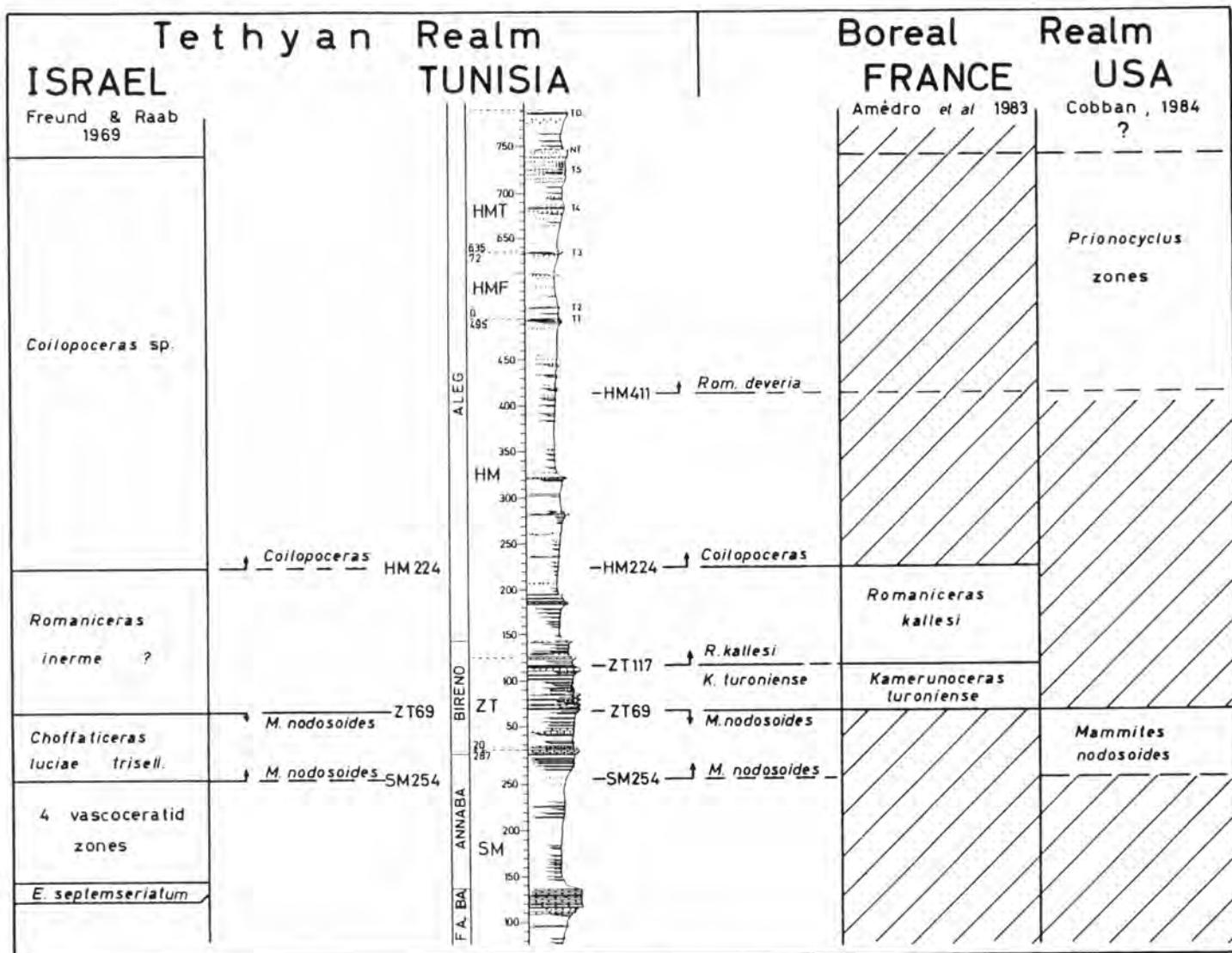


FIGURE 14  
Correlation of Ammonite zonations in Tethyan and Boreal realms.

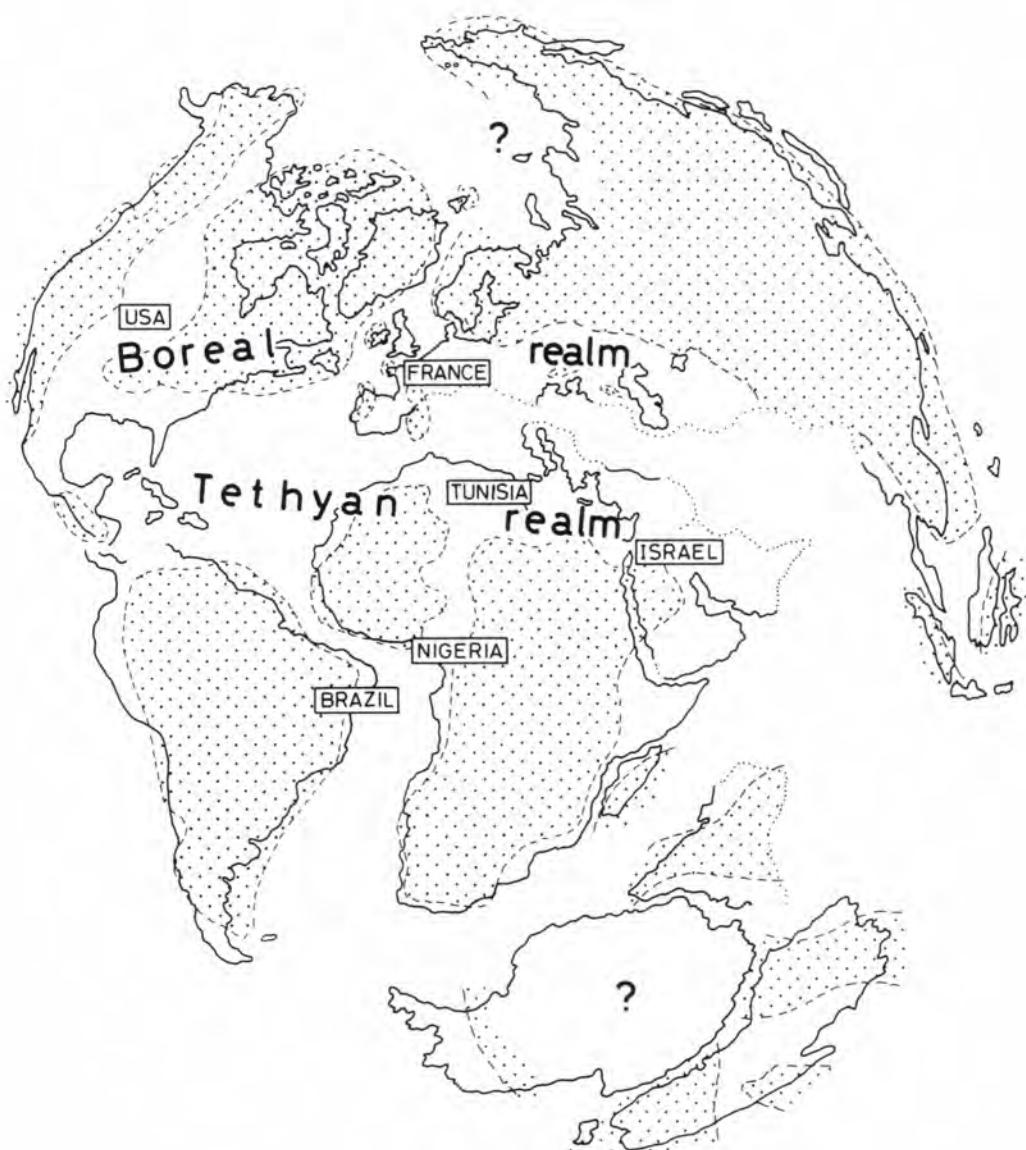


FIGURE 15

Paleogeographic sketch of the world during Turonian times. Continents following SMITH & BRIDEN (1977); Turonian seas (after KAUFFMAN, 1973 modified). Boreal realm is characterized by frequency of Mammitinae and Tethyan realm by abundance of Vascoceratidae.

— The first event is an opening of Central Tunisia towards the boreal realm and in particular towards the Western Interior of the USA at the base of the *Mammites nodosoides* Zone (SM 254). This event is marked by the introduction into Tunisia of *Mammites* and *Morrowites*, characteristic of the boreal realm, and by the common presence of several species which include *Kamerunoceras turoniense*, *Neptychites cephalotus*, and *Choffaticeras pavillieri*. On the other hand these three species are unknown in the *Mammites nodosoides* Zone of the Anglo-Paris basin which was, at that time, characterised by an abundant fauna of *Lewesiceras* (30 to 40 % of the Ammonite population). These are only occasionally found in Tunisia (6 %).

— The second event, situated at the upper limit of the *M. nodosoides* Zone (ZT 69), consists of a shift of communica-

tions between Tunisia and the boreal realm from USA towards the Old World. From the base of Middle Turonian, endemism which hits the Western Interior involves the end of the communications with Tunisia. This is marked by palaeontological associations which then become totally different. On the other hand, the *Kamerunoceras turoniense* Zone, followed by the *Romaniceras (R.) kallesi* Zone of Central Tunisian and of type-Turonian have most species in common.

— The third event corresponds to the end of communications between Tunisia and the boreal realm at the border of the upper limit of the *Romaniceras (R.) kallesi* Zone (HM 224).

— The last event is the re-establishment of the communications with the boreal realm during Middle Turonian, but

only with the North American province. This results in a migration of *Prionocyclus* from the Western Interior towards Tunisia (HM 407).

In conclusion, the paleogeographic control is very important in determining the vertical distribution of the Turonian boreal Ammonites in the Kalaat Senan area. Also, certain appearances such as those of *Mammites nodosoides* or *Prionocyclus* must be regarded with much caution since they could be the result of successive migrations and therefore not true isochronous events.

#### 4.9. CONCLUSIONS

The collection of nearly 300 Ammonites from the five measured sections makes it possible, for the first time, to draw a distribution table of the Turonian in Central Tunisia. The newly defined extensions lead to a better interpretation of PERVINQUERIE's (1907) historic collections. Several species are new to the area, like *Romaniceras (R.) kallesi*, *Reesidites minimus* and *Prionocyclus novimexicanus*, the latter being known only in the Western Interior of the USA. The association of boreal and Tethyan forms in several parts of the succession established good correlations with the boreal realm, in particular three type-Turonian zones, successively the *Mammites nodosoides* Zone, the *Kamerunoceras turonense* Zone and the *Romaniceras (R.) kallesi* Zone used in the Kalaat Senan area. Finally, the importance of paleogeographic factors to control the vertical distribution of boreal Ammonites is clearly demonstrated.

#### 5. — OTHER MACROFOSSILS AND BENTHIC FORAMINIFERA

(Fig. 16)

##### For macrofossils

- the correspondence is positive between macrofauna found in the field and macrofossil fragments isolated after washing. However, washing residues shows that several intervals where very few or no specimens of macrofauna were found on the field still contain elements of macrofossils. This is especially the case in Annaba Member which delivered Saccocomids and some Echinids and Bivalves since these seemed to be absent on the field. The same is true of the Aleg Formation between HM 250 and HM 400 and due to the fact that outcrops of this part of Aleg have a very limited surface from which to collect specimens on the field;
- generally, when macrofauna is abundant, numerous invertebrate groups are present. It should however be noted that nekto-benthic forms such as Ammonites are represented almost throughout the series (except between HM 250 and HM 400 for the same reason as above).

For microfossils, especially Benthic Foraminifera, a study at genus and species scale must be carried out, since several families are more or less abundant.

Note that all families are rare or absent in Annaba and the two lower oxygen episodes (Bahloul Formation and HM 285-HM 324 interval).

#### 6. — THE PLANKTONIC FORAMINIFERA (J.M. GONZALEZ DONOSO & D. LINARES)

##### 6.1. INTRODUCTION

We have studied the Planktonic Foraminifera contained in 170 samples distributed throughout the Turonian series of Kalaat Senan (SM, ZT, HM, HMF and HMT sections).

Each sample containing 250 g was washed using the normal procedures; all the specimens contained in the fractions 0.1-0.3 and >0.3 mm were picked from the resulting residue, half of these specimens being reserved for later studies. The contents in the other half were studied, special attention having been paid to those whose size was equal to or greater than 0.3 mm. All these operations were carried out in the Elf-Aquitaine laboratories under the supervision of R. DELOFFRE and F. CALANDRA.

Once the organisms were separated into morphotypes and identified, we selected a group of specimens (320 in total), since each one shows the characteristics of a morphotype or presents interesting features. All of these specimens were photographed in the three classical positions with a scanning electron microscope, at the Service of Electronic Microscopy of the University of Málaga.

Since we do not want to lengthen the bibliography, we have left out the references of the works used to identify the organisms. These references can be found in ROBASZYNSKI, CARON, *coord.*, and EWGPF (1979).

The Planktonic Foraminifera from the Turonian of Kalaat Senan show a very variable degree of conservation; there are intervals where the material is well preserved, others where this is not the case; the majority of the samples are not of very high quality but the degree of conservation is sufficient to avoid identification problems of a taphonomic origin.

In general terms, the microfauna of Planktonic Foraminifera is usually rich in morphotypes and relatively diverse, although there are some oligotaxic intervals (see chart). Unfortunately, a large part of Annaba and Bireno (samples SM 190 to HM 127) is oligotaxic. This part corresponds to a very important interval in which there should have occurred the appearance and diversification of a large part of the individualized lineages after the fini-Cenomanian crisis.

Sometimes the oligotaxic samples are very low in specimens, especially in the interval >0.3 mm, but in others, although there are few morphotypes (and species), the specimens are very abundant (Fig. 17).

In order to identify the different morphotypes we have for the most part followed the "Atlas of Mid Cretaceous Planktonic Foraminifera" (ROBASZYNSKI & CARON, *coord.*, and EWGPF, 1979) with some additions brought about by the usage of finer morphological criteria of differentiation. The descent relationships have been inferred by the existence of morphological resemblances (those which we suppose are not due to the phenomena of parallelism or convergence) and the presence of intermediate forms, also taking into account a careful reading of the literature on this subject, and the stratigraphic distribution of the morphotypes, inferred from the data of Kalaat Senan and the bibliography.

## PLATE 14

- Fig. 1 a-b. — *Lewesiceras* sp., from ZT 117, Bireno Member, Middle Turonian; a : ventral view, b : right side; natural size :  $\times 1$ .  
2. — *Placenticeras (Karamaites) stantoni* HYATT, 1903, from HMT 725, Aleg Formation, Late Turonian,  $\times 1$ .  
3. — *Placenticeras* sp., from HMT 686.50, Aleg Formation, Late Turonian,  $\times 1$ .



## PLATE 15

- Fig. 1. — *Kamerunoceras turoniense* (d'ORBIGNY, 1850), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .
- 2 a-b. — *Kamerunoceras turoniense* (d'ORBIGNY, 1850), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .
3. — *Romaniceras (Romaniceras) kallesi* (ZAZVORKA, 1958) from ZT 117, Bireno Member, Middle Turonian,  $\times 1$ .
4. — *Euomphaloceratinæ* gen. and sp. indet., from ZH 51 (level equivalent to SM 190), Annaba Member, Early Turonian,  $\times 1$ .
5. — *Euomphaloceras cf. septemseriatum* (CRAGIN, 1893), from the upper part of the Bahloul Formation (level equivalent to SM 134-135), near the farm at the vicinity of Oued Zitoune waterfall, Late Cenomanian (equivalent of the *M. geslinianum* Zone ?),  $\times 1$ .



1



3a



3b



2a



2b



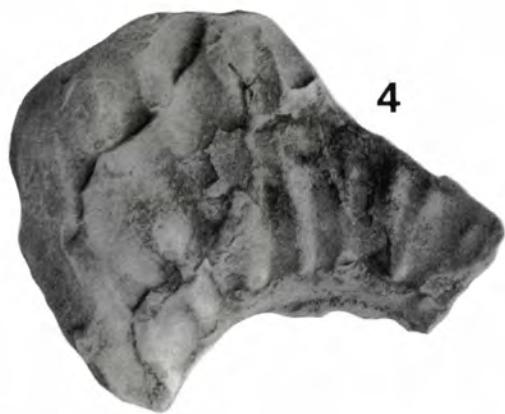
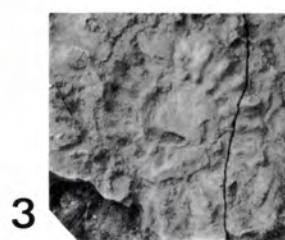
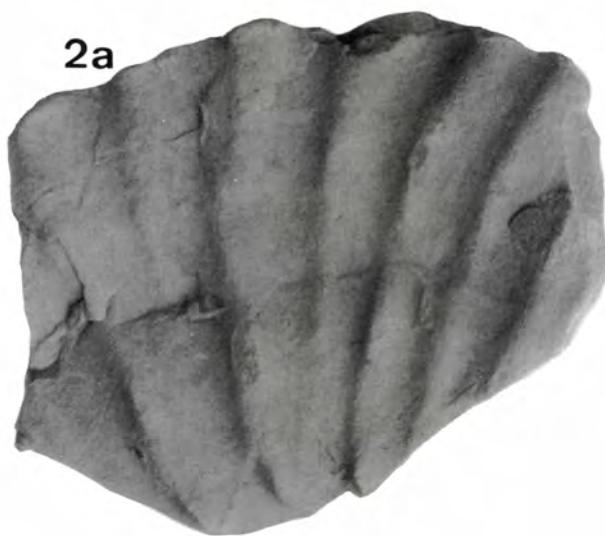
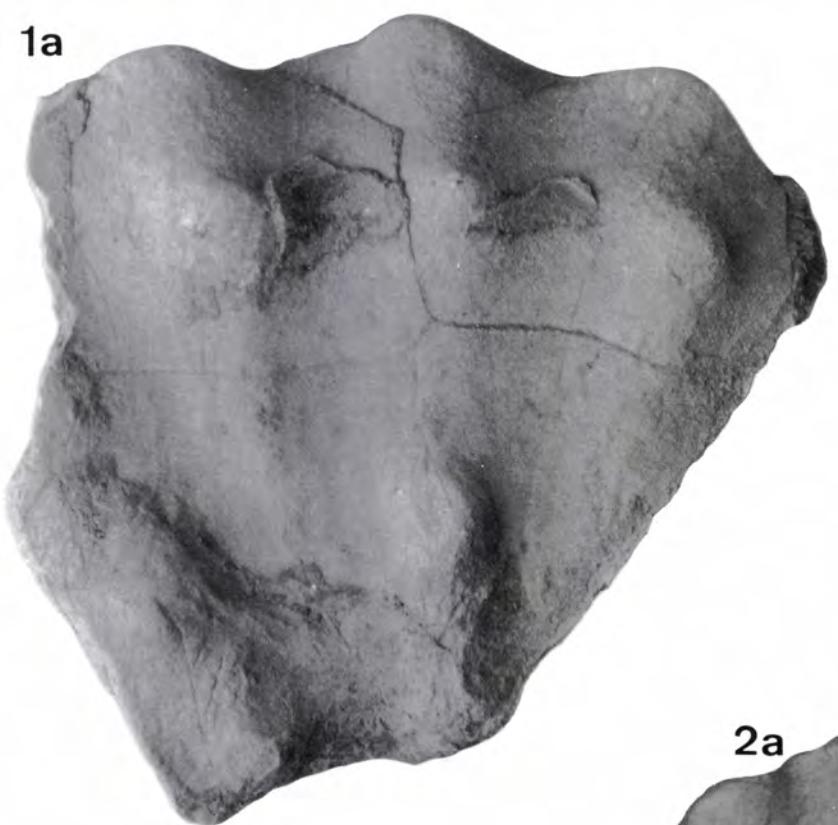
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5

## PLATE 16

Fig. 1-4. — *Romaniceras (Romaniceras) deverianum* (d'ORBIGNY, 1841). 1 : from HM 411, Aleg Formation; 2 : from HM 411, Aleg Formation, specimen slightly crushed; 3 : from HM 486, Aleg Formation, view of internal whorls; 4 : from HM 414, Aleg Formation. All Late Turonian,  $\times 1$ .

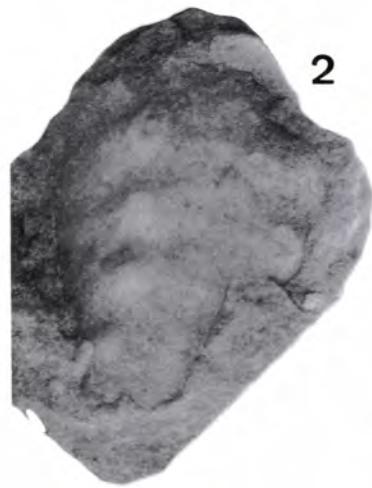


## PLATE 17

- Fig. 1. — *Pseudaspidoceras flexuosum* POWELL, 1963, from ZH section (ZH 0 = SM 137), topmost of Bahloul Formation, basal Turonian,  $\times 1$ .
2. — *Pseudaspidoceras* sp., indet. fragment, close to *P. flexuosum*, topmost of Bahloul Formation, near the farm at the vicinity of Oued Zitoune waterfall (level equivalent to SM 137), basal Turonian,  $\times 1$ .
  3. — *Pseudaspidoceras* sp. (?), from ZH 21 (= SM 158), Annaba Member, Early Turonian,  $\times 1$ .
  4. — *Pseudaspidoceras* sp., from ZH 22.8 (= SM 159.8), Annaba Member, Early Turonian,  $\times 1$ .
  5. — *Romaniceras (Romaniceras) kallei* (ZAZVORKA, 1958), collected 2 m below the top of Bireno Member, at "Fretissa-East", equivalent to HM 140, Middle Turonian,  $\times 0.8$ .
  6. — *Prionocyclus novimexicanus* (MARCOU, 1858), from HMT 725, Aleg Formation, robust variant described as *Prionocyclus wyomingensis* var. *robusta* by HAAS, 1946, Late Turonian,  $\times 1$ .



1



2



5a



5b



3



4



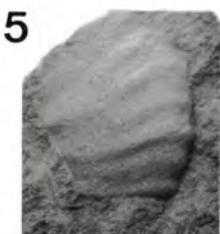
6a



6b

## PLATE 18

- Fig. 1. — *Pseudaspidoceras flexuosum* POWELL, 1963, from SM 137, at the topmost Bahloul Formation.  
Mould of external imprint of the right side of a crushed macroconch (35 cm in diameter), basal Turonian,  $\times 0.57$ .
2. — *Vascoceras?*, indet. Vascoceratid, from topmost Bahloul Formation at ZH section (ZH 0 = SM 137), basal Turonian,  $\times 1$ .
- 3-4-5. — *Vascoceras?*, indet. Vascoceratids, from the upper Bahloul Formation (beds equivalent to SM 135.50 - 137), near the farm in the vicinity of Oued Zitoune waterfall, latest Cenomanian,  $\times 1$ .

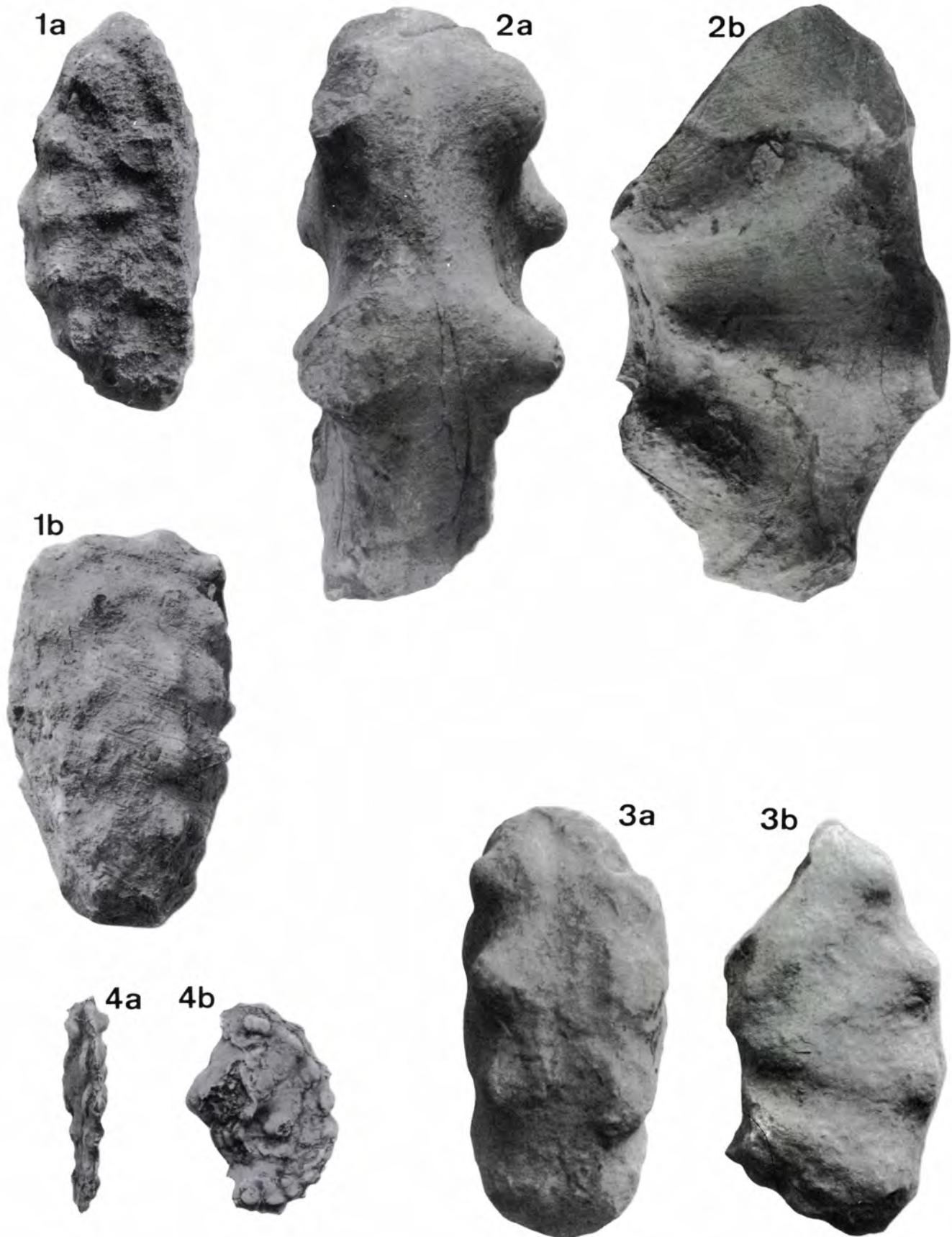


## PLATE 19

Fig. 1. — *Morrowites subdepressus* COBBAN & HOOK, 1983, from SM 287, Bireno Member, Early Turonian,  $\times 1$ .

2-3-4. — *Mammmites nodosoides* (SCHLUTER, 1871).

2-3 : from SM 287, Bireno Member; 4 : from SM 254, Annaba Member, Early Turonian; 2 :  $\times 0.84$ ; 3 and 4 :  $\times 1$ .

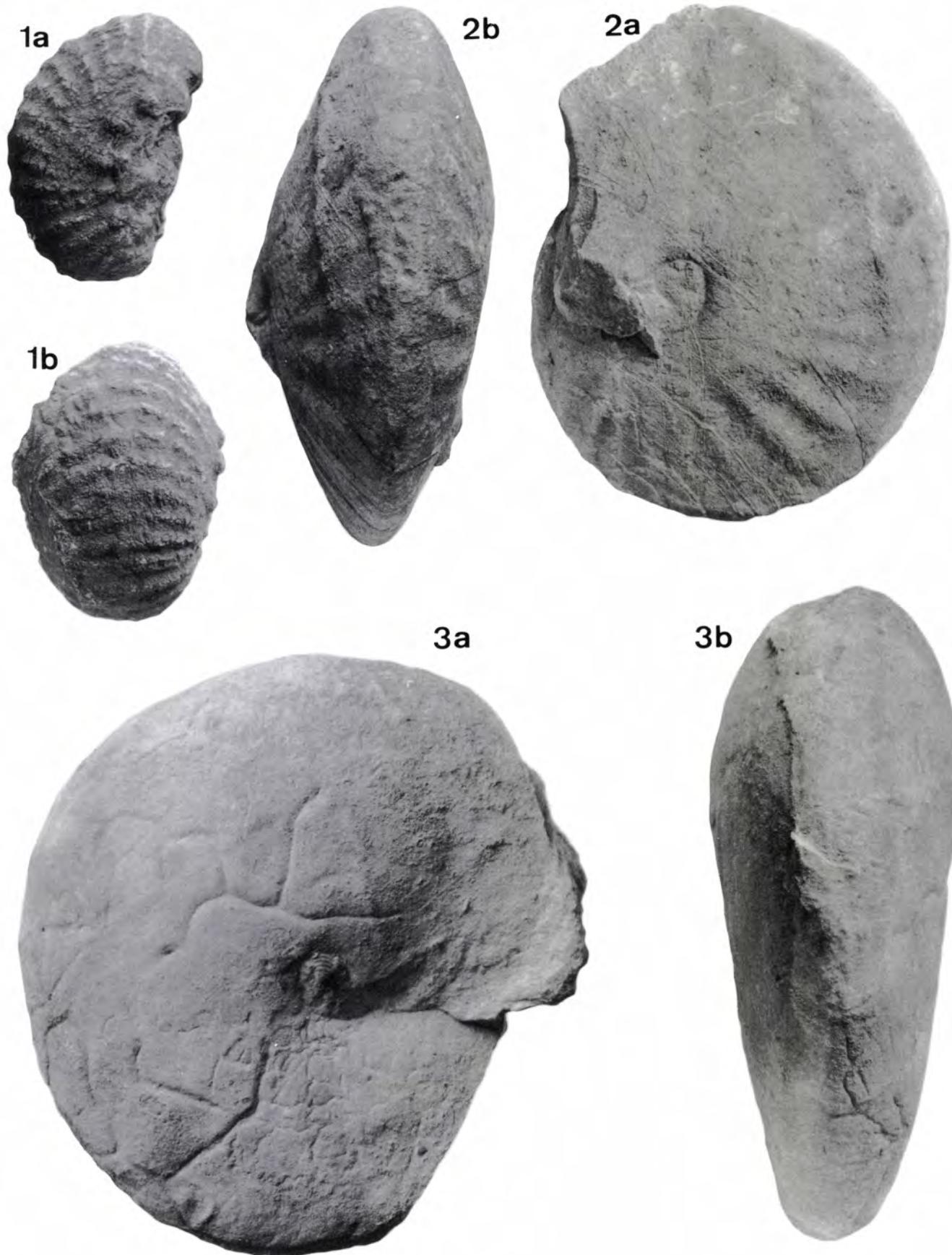


## PLATE 20

Fig. 1. — *Fagesia superstes* (KOSSMAT, 1897), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .

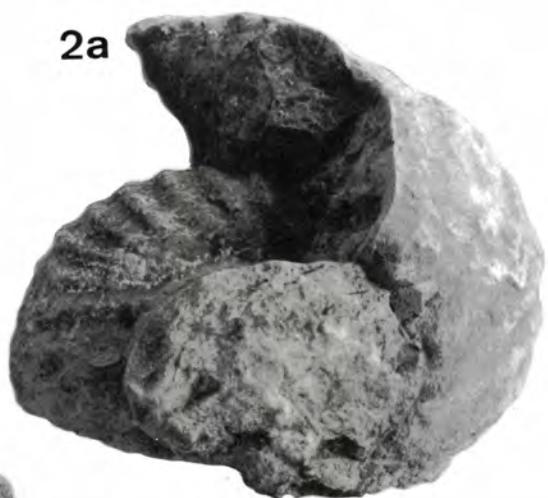
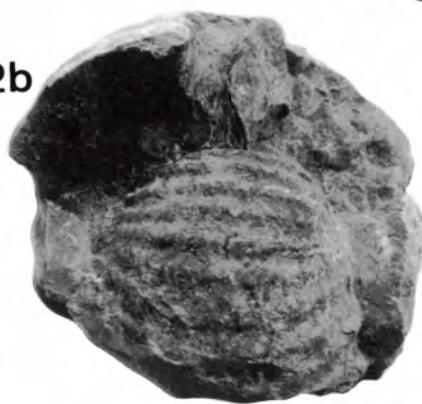
2-3. — *Neptychites cephalotus* (COURTILLER, 1860).

2 : thick variant from ZT 70.7, Bireno Member, Middle Turonian; 3 : flatter variant from ZT 15, Bireno Member, Early Turonian,  $\times 1$ .



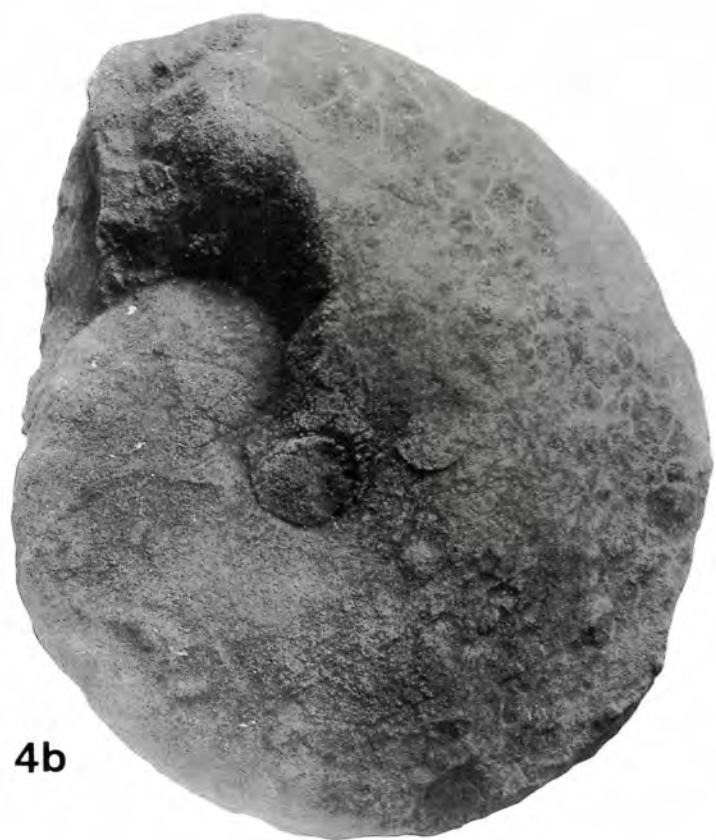
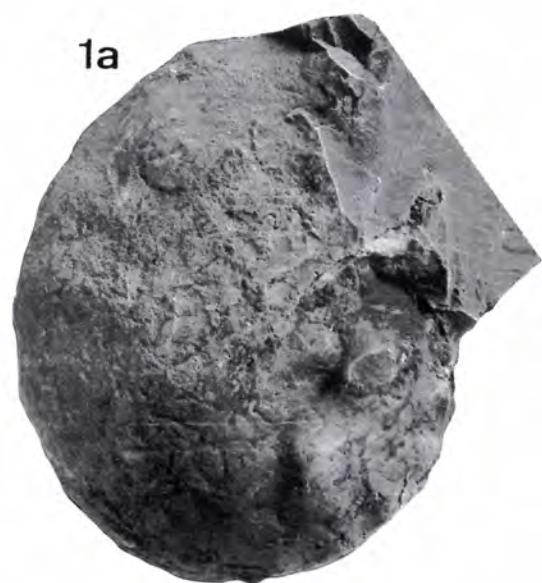
## PLATE 21

- Fig. 1. — *Paramammites polymorphus* (PERVINQUIERE, 1907), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .
2. — *Fagesia superstes* (KOSSMAT, 1897), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .
3. — *Neptychites cephalotus* (COURTILLER, 1860), thick variant from SM 287, Bireno Member, Early Turonian,  $\times 1$ .

**1a****1b****2a****2b****3a****3b**

## PLATE 22

- Fig. 1. — *Thomasites rollandi* (PÉRON, 1889). Specimen collected between ZT 42 and ZT 45, Bireno Member, Early Turonian,  $\times 1$ .  
2. — *Thomasites* sp., from SM 181, Annaba Member, Early Turonian,  $\times 1$ .  
3. — *Thomasites jordani* (PERVINOUIÈRE, 1907). Specimen from the lower half of Bireno Member, Fretissa-East, equivalent to levels from ZT 30 to ZT 50, Early Turonian,  $\times 1$ .  
4. — *Thomasites rollandi* (PÉRON, 1889). Specimen from the top of Annaba Member, in ZT 12, Early Turonian,  $\times 1$ .



## PLATE 23

- Fig. 1. — *Choffaticeras luciae* (PERVINQUIÈRE, 1907), from ZT 42, Bireno Member, Early Turonian,  $\times 1$ .  
2. — *Choffaticeras* sp., from ZT 15, Bireno Member, Early Turonian,  $\times 0.73$ .  
3. — *Thomasites* sp., from ZH section (ZH 51 equivalent to SM 188), Annaba Member, Early Turonian; 3a-b :  $\times 1$ ; 3c :  $\times 2$ .  
4. — *Baculites* sp., from HMT 720, Aleg Formation, Late Turonian,  $\times 1$ .  
5. — *Choffaticeras* sp., from SM 181, Annaba Member, imprint of right side, Early Turonian,  $\times 1$ .



4



## PLATE 24

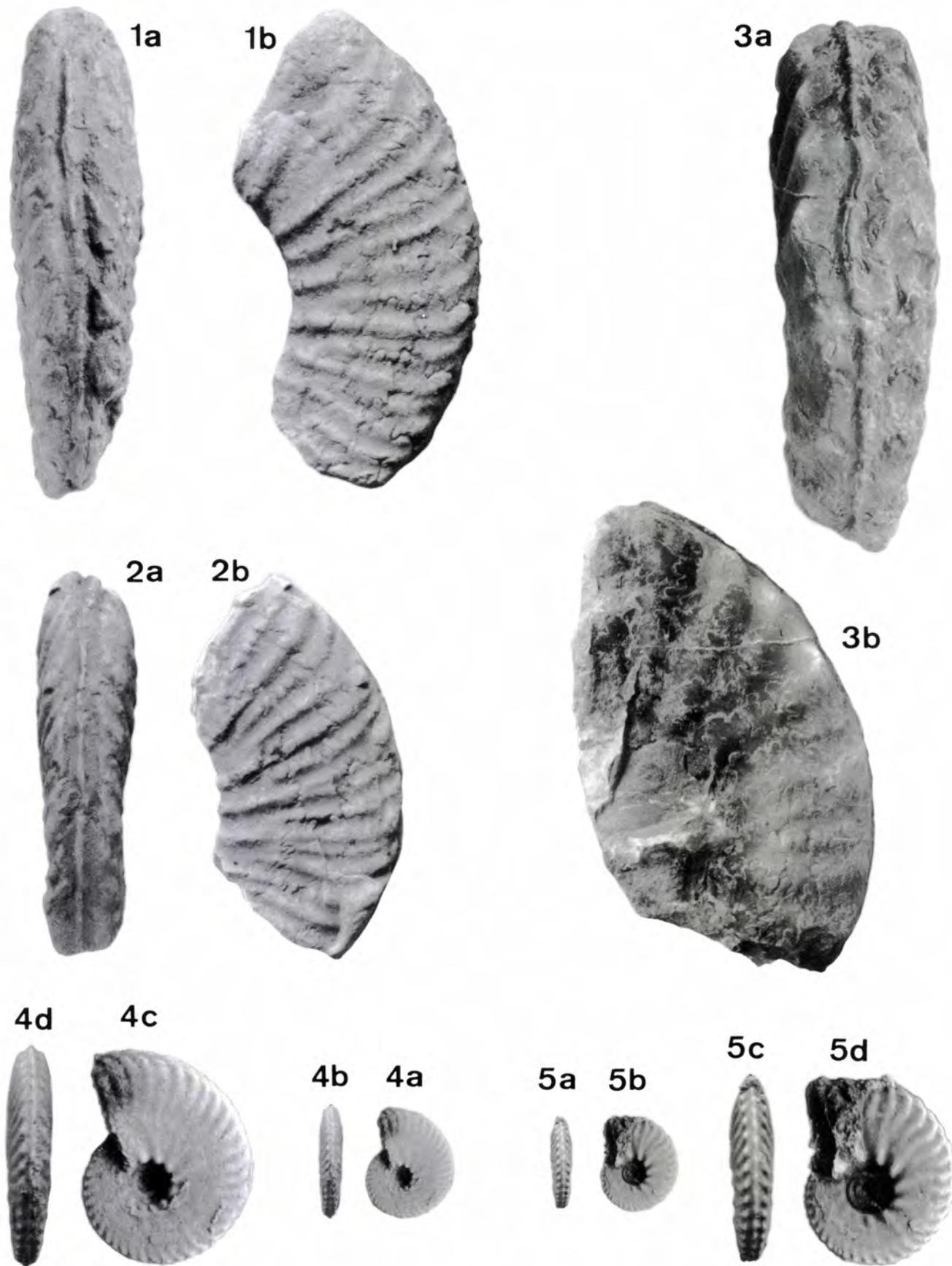
- Fig. 1. — *Choffaticeras luciae* (PERVINOUIÈRE, 1907), from SM 287, Bireno Member, Early Turonian,  $\times 1$ .  
2. — *Collignoniceras woollgari* (MANTELL, 1822). Specimen collected in the upper beds of Bireno Member, at Fretissa-East (equivalent to HM 142), Middle Turonian,  $\times 1$ .  
3. — *Prionocyclus* sp., from HM 407, Aleg Formation, uppermost part of Middle Turonian,  $\times 1$ .



## PLATE 25

Fig. 1-2-3. — *Prionocyclus novimexicanus* (MARCOU, 1858), 3 specimens from HMT 725, Aleg. Formation; 1 : flattened variant, as type species; 2 : other flattened variant; 3 : variant more robust; Late Turonian,  $\times 1$ .

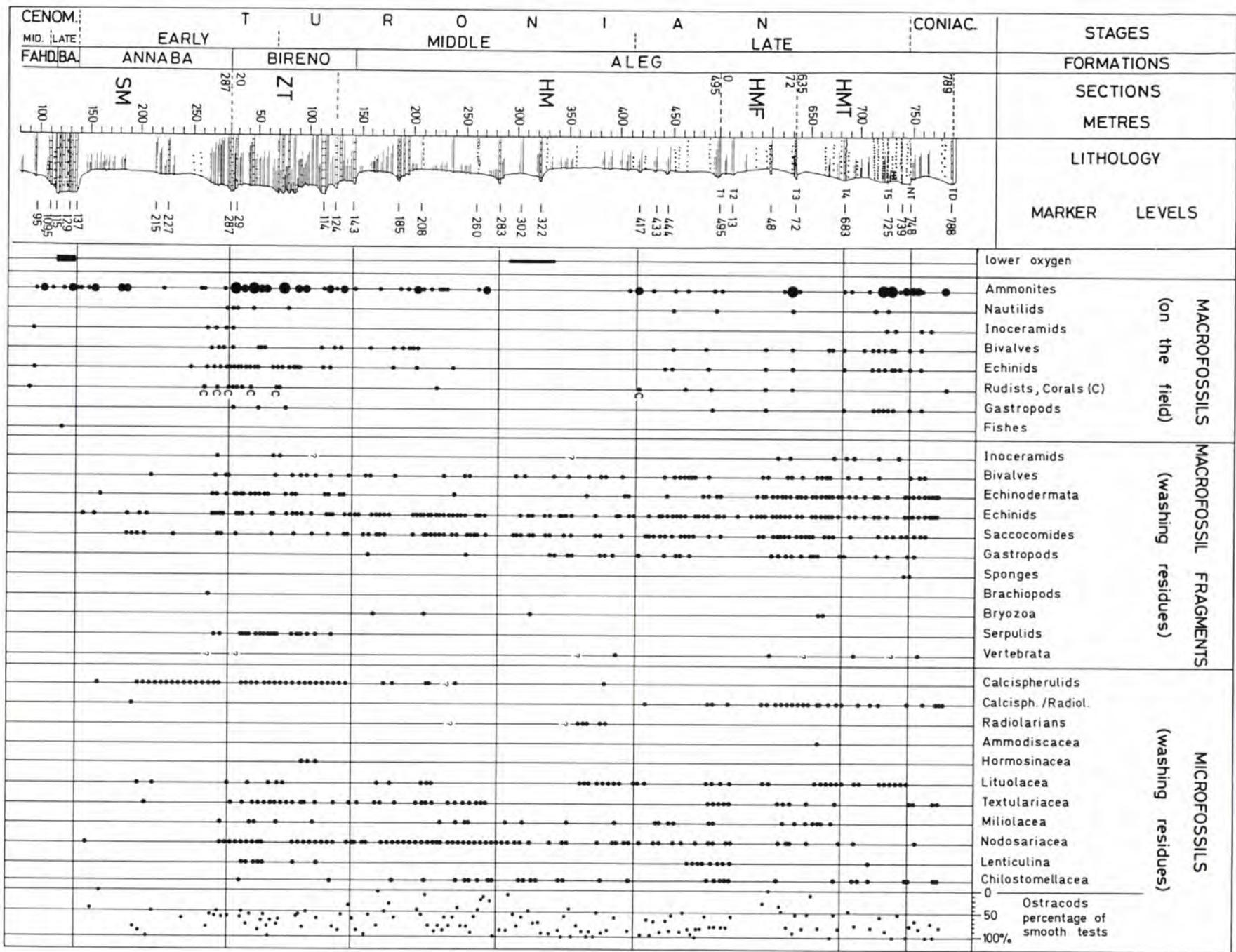
4-5. — *Reesidites minimus* (HAYASAKA & FUKADA, 1951), 2 specimens from HMF 66, Aleg Formation; 4 : flattened variant; 5 : robust variant; Late Turonian.  
4a-b, 5a-b :  $\times 1$  — 4c-d, 5c-d :  $\times 2$ .



## PLATE 26

Fig. 1-2. — *Coilopoceras* sp. cf. *requienianum* (d'ORBIGNY, 1841), 2 specimens from HMT 620-635, Aleg Formation; 1 : flattened variant; 2 : thick variant; Late Turonian,  $\times 1$ .





### On the nature of the organism groups denominated with species names

When studying the Planktonic Foraminifera contained in a sample, we generally come to the conclusion that some of these can be identified as members of species described in micropalaeontological literature; each one of these specimens displays some morphological characteristics, which allows us to assign it to one of these species, and not one of its characteristics is situated outside the morphological variability fields for the species described (Fig. 18, specimens 1 and 2).

Other individuals display characteristics that situate them outside the variability fields which we suppose have the species accepted as valid ones. For some such specimens we come to the conclusion that they are members of species which have already been described and represent unknown phenotypical variants (ontogenetic, ecophenotypical, geographical ones etc...), or ones not taken into account when the morphological variability field of such species were established (Fig. 18, specimens 3). Regarding other specimens, we may conclude that they are members of species which have not been described until now (Fig. 18, specimens 4). For others, we may come to the conclusion that they may be intermediate forms between two described species in view of the characteristics they exhibit (Fig. 18, specimen 5). We are going to start by focusing our argument on these organisms.

When we talk about the intermediate forms between two similar species, we are referring to organisms which show those characteristics common to both species in question and present several alternatives regarding the characteristics which permit us to differentiate between them. In some cases, there is a character showing a continuous variation, at least theoretically (e.g., the whorl expansion rate); the intervals which include the values of the character in each species do not overlap, but the intermediate forms show intermediate values (Fig. 19a).

In other cases, the character seems to present a discontinuous variation, (this could be an observation problem) or a continuous variation; one species displays a known character state in some chambers and another species shows another state in the same chambers, the intermediate form shows a character state in some of the chambers and the other state in the rest (e.g. the individuals of two species have subtriangular and subtrapezoidal chambers respectively in the last whorl; the intermediate forms have subtriangular first chambers and subtrapezoidal final ones in the last whorl) (Fig. 19b).

Finally, in other cases, intermediate specimens show, for some characters, states that are typical of a species and, for other characters, the distinctive states of the other species (e.g., a species has a primary umbilical aperture and tegilla and another one has an umbilical-extraumbilical aperture and portici; there are individuals with an umbilical-extraumbilical aperture and tegilla) (Fig. 19c).

The possible meanings of such intermediate forms differ, depending firstly on their association with one, two or none of the species which they are related to, secondly, on being abundant and frequent or scarce and sporadic, and finally on their filling the whole or a part of the morphological gap which separates both species. The case we are now interested in is that of organisms of two species and the intermediate forms coexisting in the same sample; all of them are relatively abundant and the different intermediate forms fill all of the morphological gap that separates them both. The most general and restrained hypothesis in cases of this type is that the two species and the intermediate forms constituted, in fact, a single biological species; what we have called species and intermediate forms are quite simply morphotypes (morphs or even ecophenotypes) of a single species. Applying this type of hypothesis to the study of the samples with Planktonic Foraminifera, many of the lists of species that are usually supplied would be reduced considerably and the number of parsimonious would be much higher. If the evolution of the Planktonic Foraminifera took place as the punctuated equilibria model indicates (ELDREDGE & GOULD, 1972) the only problem would consist of trying to establish the morphotypes that each species includes. In fact, the species would not have varied throughout its history, from the moment of its rapid appearance from a small isolated population (through a genetic revolution) to the moment of its extinction (Fig. 20a).

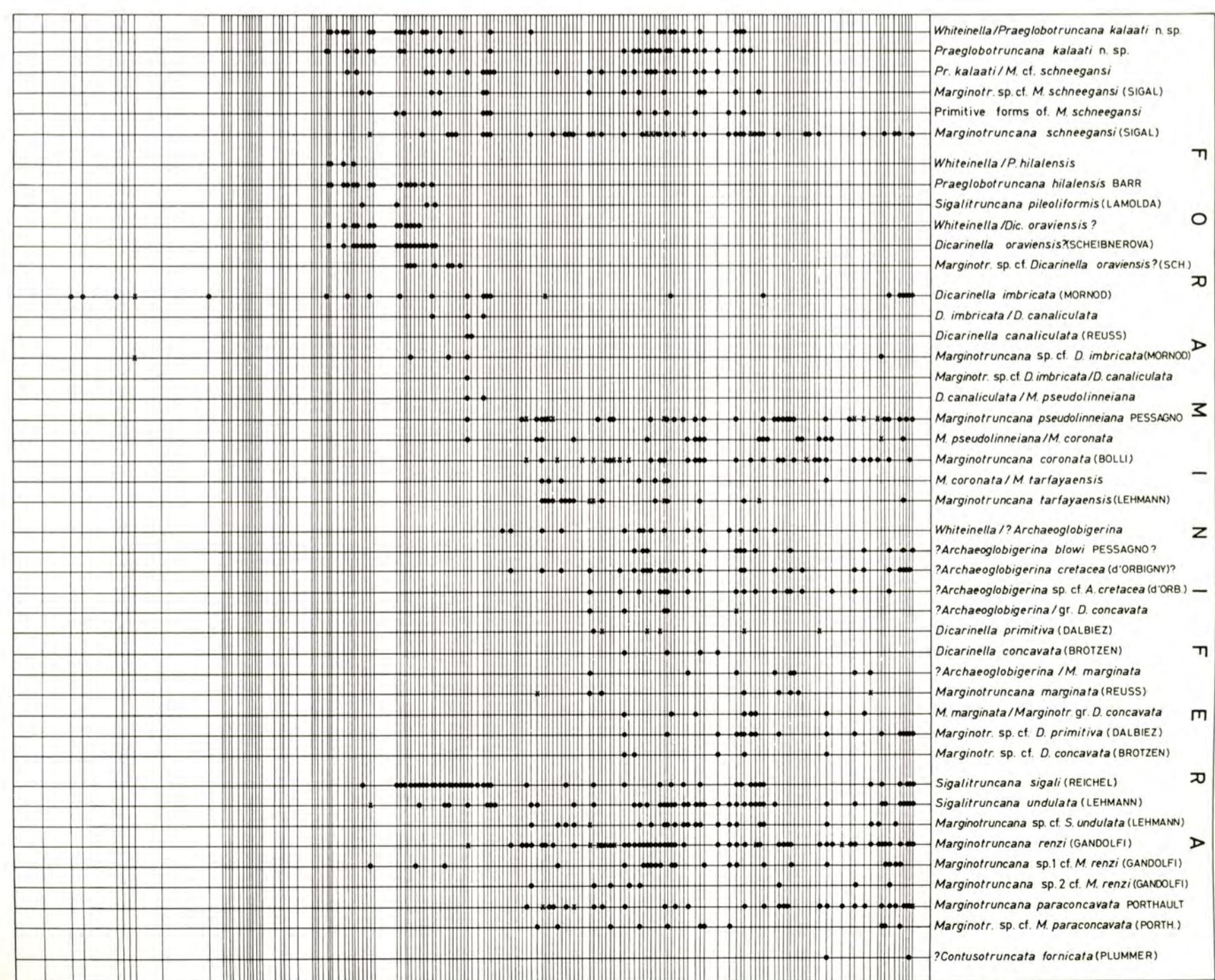
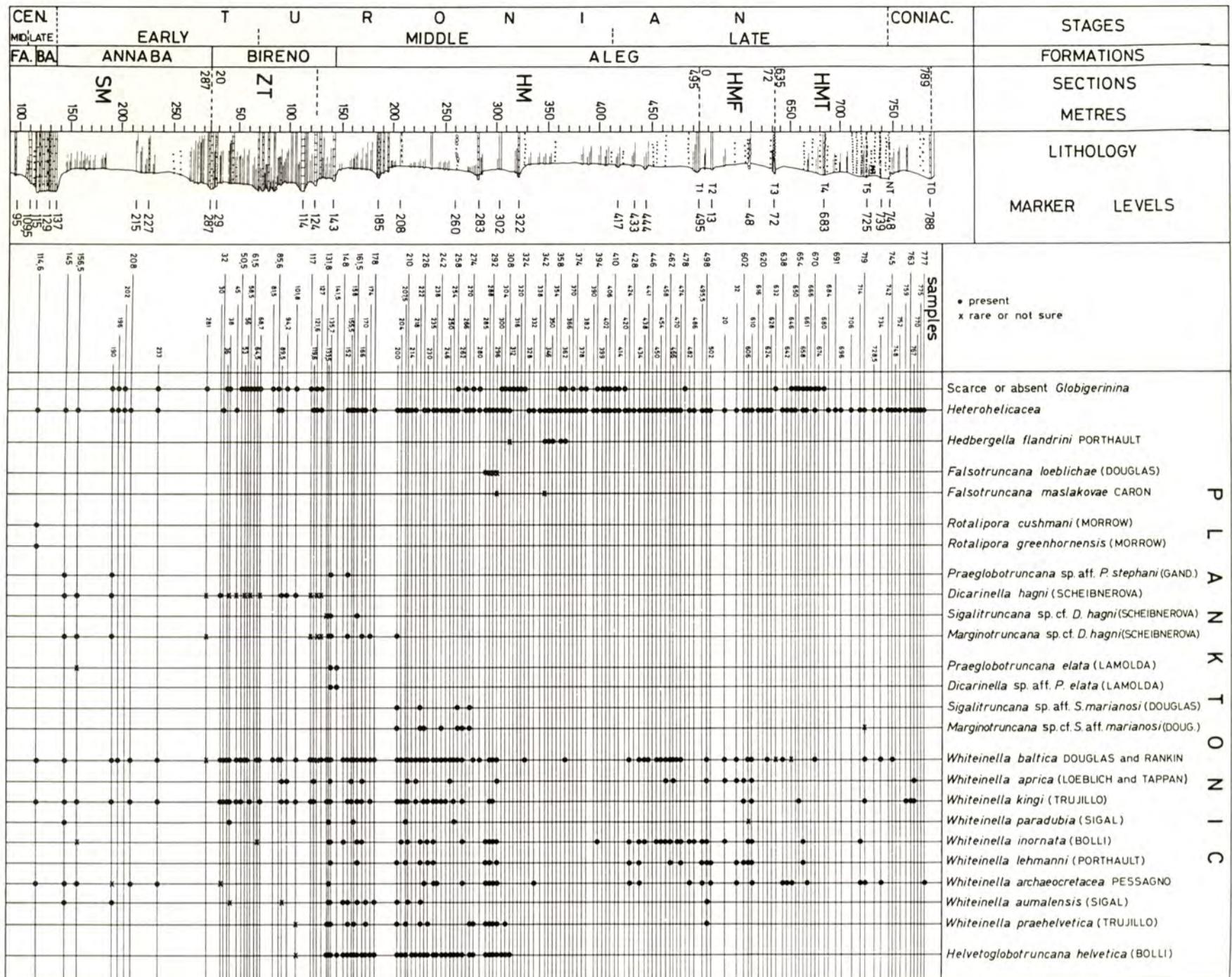
However the solution is not clear when studying a group of samples of different ages. Frequently, the different morphotypes and their intermediate forms, instead of appearing all at the same time and being conserved along the whole range of the species (as the punctuated equilibria model demands), appear successively through time and disappear in the same way, according to what would be expected from the phyletic change model (for reasons that would take too long to explain, we prefer this term to that of phyletic gradualism; see GONZALEZ DONOSO *et al.*, 1986) or its variant, the punctuated gradualism model of MALMGREN *et al.*, 1983 (it would be better to call this the punctuated change model) (Fig. 20b).

What can we do in such cases? One solution would be to follow the ideas of most phylogenetic systematists, and consider all the organisms of a lineage (the group of successive biospecies which are between two events of additive speciation, *sensu* WILEY, 1981 or between additive speciation and extinction) as belonging to the same species (Fig. 21, ab, bd, be, ef, etc.), no matter what the degree of morphological transformation may be that the populations have experienced during the life span of the lineage. In such a case, we would have to name in the same way organisms which can be morphologically, or even ecologically, very different (Fig. 21, 1 and 2), and place indistinguishable populations in different groups (Fig. 21, 3 and 4); furthermore the utility of the species, from a stratigraphic point of view, can diminish considerably for the long duration that many lineages seem to have.

Another solution could be to divide the lineages into

FIGURE 16

Vertical distribution of macrofossils, Benthic Foraminifera families and Ostracods in the Turonian succession of Kalaat Senan area



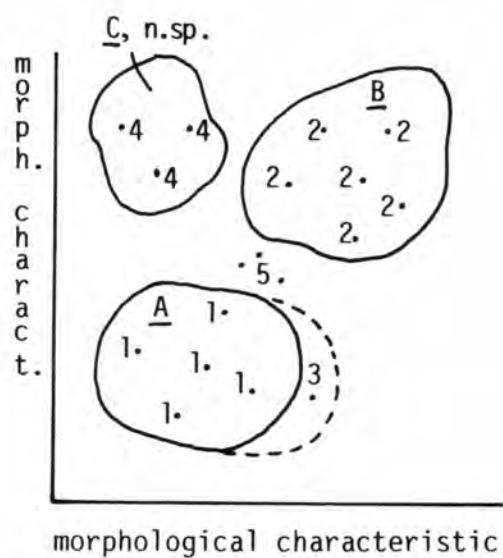


FIGURE 18

Theoretical example of the identification of individuals contained in a sample. A, B, C : supposed species - 1, 2, 3, 4, 5 : individuals.

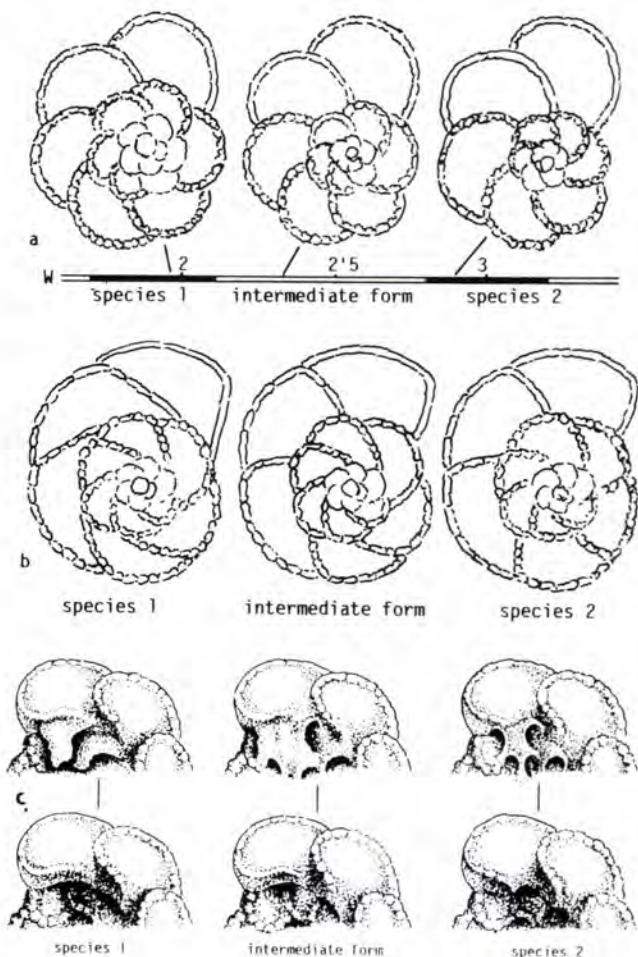


FIGURE 19

Examples of intermediate forms.

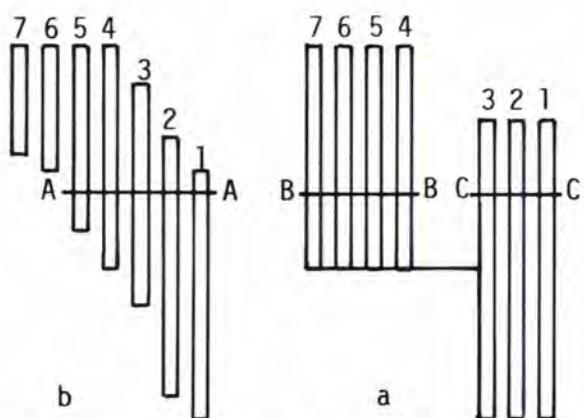


FIGURE 20

Time distribution of morphotypes to be expected according to the punctuated equilibria (a) and the phyletic change (b) models. 1, 2, 3, 4, 5, 6, 7 : morphotypes. A, B, C : biospecies.

segments, the chronospecies (Fig. 21, bc and cd), accepting, therefore, that a phyletic speciation exists; now the problem is in the procedure we have to follow to situate the limit between successive chronospecies. A way of situating such limits in an objective although arbitrary way (it is also arbitrary to divide an evolutive line into segments through the events of additive speciation) is to make them coincide with the appearances or disappearances of morphotypes or character states (GONZALEZ DONOSO & LINARES, 1981). But the problem, as in the last case, can consist of designating with the same specific name organisms which are very different morphologically and ecologically (e.g., Fig. 20b, specimens of morphotypes 1 and 5 in biospecies A); in order to avoid this

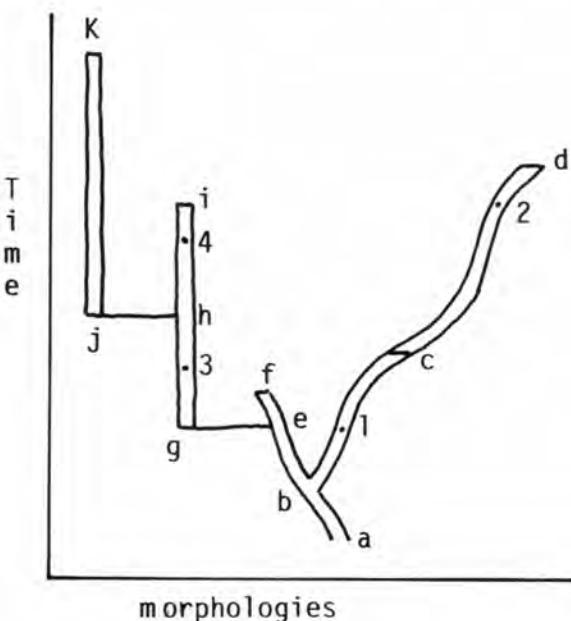


FIGURE 21  
Species and lineages. b : additive speciation by subdivision; c : phyletic speciation; eg, hj : additive speciation by genetic revolution

difficulty, there is a possibility, in both cases, of applying infrasubspecific names.

We do not intend to discuss in detail the advantages and disadvantages of these two solutions. We favour the second one, although we know that one is as arbitrary as the other. To apply either of them, it is necessary to recognize fully the evolutive history of the organisms which are going to divide into species: on the one hand it would be necessary to recognize which have been the events of additive speciation and when they took place; on the other hand it would be necessary to know the succession of appearances and disappearances of morphotypes. Unfortunately, it is not often that we find cases in which such evolutive history is reasonably well established and in the case in question, namely that of the Turonian Planktonic Foraminifera, the situation is very ambiguous; it is sufficient to glance through the extended bibliography existing from the 1940's, to realize that for each one of the species (morphotypes, in fact) several ancestral "species" have been proposed. This is the consequence of an evolutive history full of phenomena of parallel, convergent and iterative evolution in organisms with few distinctive characteristics.

What is the best approach in such cases? We believe the best solution is to leave things the way they are, using specific names to label morphotypes, taking into account that they are not species. Strictly speaking, it is incorrect, but we do not think it is important provided that we make it clear that the specific denominations do not correspond to species (or more properly, a determined type of species) but rather morphotypes. In any case, we think it is better than trying to establish species without a firm enough basis. For the purpose of dating the rocks, the important thing is to take into account a series of groups with a well-defined morphology and well-established stratigraphic range.

For all of these reasons, we have chosen to differentiate the traditionally recognized "species" in the Turonian of Kalaat Senan samples, emphasizing that they are nearly always morphotypes.

#### On the nature of the organism groups denominated by genera and subgenera names

A second question is that of the generic names we must use to designate the Foraminifera we have studied. Today, a list of the generic names applied to the Planktonic Foraminifera of the Cretaceous exists; some of them are used frequently, others less so, and the rest are considered to be synonyms by all the authors.

Each one of these names is often used to designate a group of Foraminifera which present some determined morphological characteristics: *Praeglobotruncana*, *Dicarinella*, *Marginotruncana* etc. The first problem appears because some authors ("splitters") prefer to distinguish many groups with little morphological variability, while others ("lumpers") tend to group species together more readily, including forms with very different characteristics. This is why there are generic names which have only been used by some authors.

What we have just discussed, would not have much importance if the Planktonic Foraminifera were organized in monomorphotypical lineages and if phenomena of parallelism, convergence and iterative evolution had not taken place between them. But the conviction that such phenomena exist

in the Foraminifera of the Cretaceous has meant that some authors have chosen to apply different generic names to strictly homeomorphous groups, thus forming a second list of generic names, which brings about the following difference of opinion: some authors work using such criteria; others prefer to follow strictly morphological criteria, because they consider that the phylogeny is not yet sufficiently known, or because they consider such points of view to be impractical or unnecessary.

Another source of difficulty is that the different morphotypes of a biospecies can, from a morphological point of view, belong to two or more genera; for instance, organisms of the first populations of some lineages can be sometimes assigned to the genus *Marginotruncana* and the last ones to *Globotruncana*, while in the intermediate populations we can find organisms assignable for their characteristics to the first one, others to the second one and others are forms with intermediate characteristics. This type of phenomena has been described in detail by SIGAL (1966). Since then, it has been referred to several times (e.g. CARON, 1971; LINARES, 1977, etc.) and is especially frequent in the periods of radiation (e.g. during the Turonian).

Bearing in mind what we have just discussed, the problem is as follows: if we classify genera using morphological criteria or, that is, if we assign to the same genus all the organisms that have some determined morphological characteristics, the majority of the genera would be polyphyletic groups of morphotypes (noting that a monophyletic group is one including a lineage and a series of lineages deriving from it); besides, the organisms of a biospecies will belong to several genera, which may seem highly unusual (Fig. 22). But we must take into account that the morphological genus and the species are defined using different criteria and are, therefore, members of two different classifications.

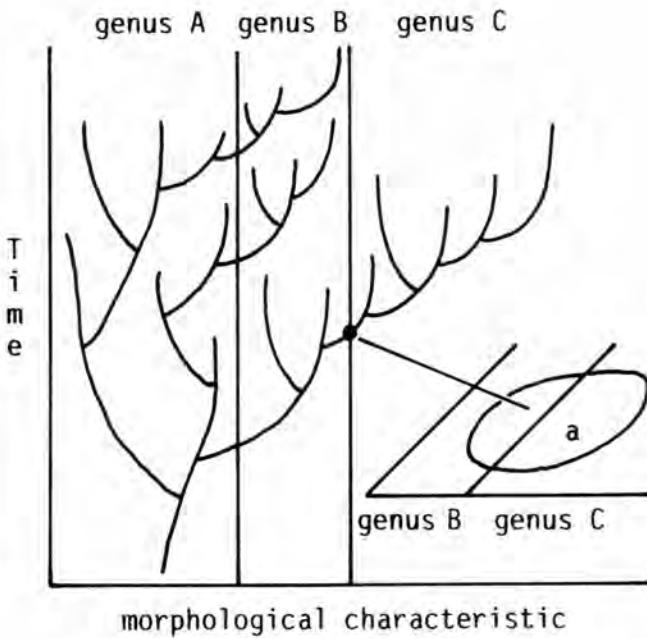


FIGURE 22

Problems related to the use of morphologic genera. A, B and C are paraphyletic, polyphyletic and monophyletic groups respectively. Biospecies *a* contains individuals pertaining to the morphological genera B and C.

Alternatively, we could choose to group together in one genus all the organisms of a lineage and those of the group of lineages derived from the former, in other words, use phylogenetic genera. For some, this solution is more satisfactory (and we tend to prefer it) but, in practice, it causes even more problems than the former. Firstly, morphologically and (presumably) ecologically very different organisms, would be denominated by the same name. Secondly, we cannot affirm that all the morphotypes which are assigned to a lineage do actually belong to it, or that the phylogenetic relations we are inferring are true. The classification into phylogenetic genera could, therefore, be overly subjective and less reliable than the classification into morphological genera and could, among other things, work against one of the functions of the classification: disseminating basic information in a clear and concise way for everybody.

Concerning this problem, we have chosen an idea formulated by TINTANT (1952) that we have already applied on a prior occasion (GONZALEZ DONOSO & LINARES, 1979): that is, using morphologic genus and phylogenetic subgenus, the latter only being used in those cases where we are fairly certain that the forms we are including constitute a monophyletic group (using the definition we have previously referred to).

Certainly, this solution might seem inadequate to some, since it means that the members of a subgenus can belong to several different genera, but in fact there is no real problem, since genus and subgenus are members of two different classifications: if it were possible to divide the lineages into chronospecies, the phylogenetic subgenera and the chronospecies (and the biospecies) would be members of one classification, while the morphological genera and the morphotypes would be members of another (GONZALEZ DONOSO *et al.*, 1986) (Fig. 23). The only difficulty we can find in such a case is a formal one, namely that the convention of a genus made up of several subgenera is broken.

In the following pages we are going to use a series of morphological genera, according to the diagnosis provided by ROBASZYNSKI, CARON and EWGP (1979): *Hedbergella* BRÖNNIMANN & BROWN, 1958, *Whiteinella* PESSAGNO, 1967, *Praeglobotruncana*, BERMUDEZ, 1952, *Dicarinella*, PORTHault, 1970, *Marginotruncana*, HOFKER, 1956 and *Archaeoglobigerina*, PESSAGNO, 1967, with some slight changes:

- Praeglobotruncana* has been restricted to the forms with a keel formed by an accumulation of pustules more or less clearly differentiated (in some cases they are indifferentiated, and form a continuous ridge). Therefore, the forms that show two series of pustules, at least in some chambers of the last whorl, have been excluded;
- Dicarinella* includes, therefore, the forms with two rows of pustules, close or separated by a peripheric band, that are present in some chambers (at least) in the last whorl and with all the umbilical sutures radial and depressed; those forms that present any sigmoidal umbilical suture, have been included in *Marginotruncana*;
- Marginotruncana* has been restricted to the forms in which the two rows of pustules are clearly individualized, although they can be very closed. Apart from these generic names we have used two more recent ones: *Falsotruncana* CARON, 1981 and *Sigalitruncana* KORCHAGIN, 1982;
- Falsotruncana* with the same diagnosis that CARON, (1981), provided.;
- Sigalitruncana*, to include the forms similar to *Margino-*

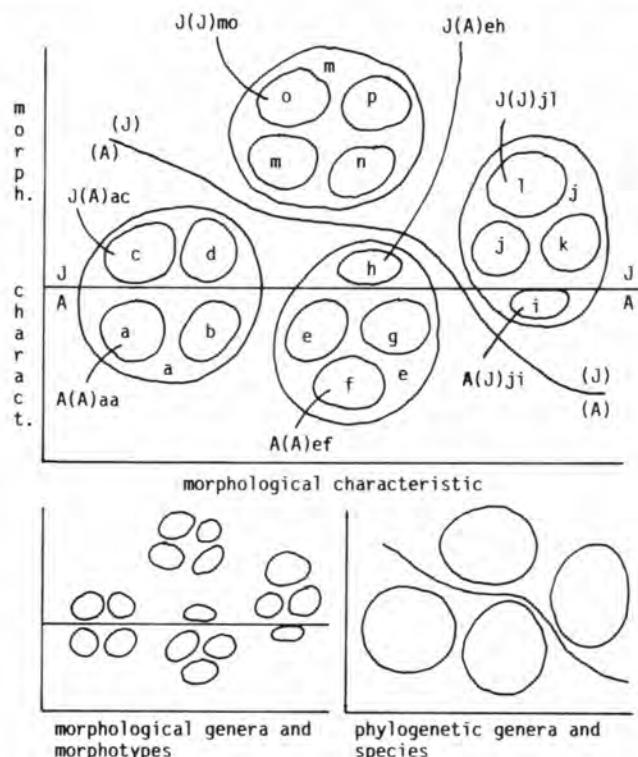


FIGURE 23  
Combination of the two types of classification and the corresponding denominations.

*truncana* but with a keel, formed by a single row of pustules or two imbricate rows (in general they are not distinguishable without using an SEM).

With regard to phylogenetic subgenera, as we have indicated before, we have only used them in the cases in which we are fairly sure that we are designating monophyletic groups of organisms. In one case, because of the taxonomic problems of the forms that could be assigned to a subgenus, we have chosen not to propose a new name for it but to talk, informally, of a "group". In other cases, under the denomination "advanced *Sigalitruncana* and *Marginotruncana*" we have included two polyphyletic morphological groups whose members, presumably, will have to be distributed among several recognized subgenera. For the remaining subgenera we have used, in the cases where it is possible, the names which designate morphological genera, while for others we have reused names of genera considered synonyms for morphological reasons, but whose type species belong to the phylogenetic subgenera in question, and also names of genera proposed with a phylogenetic intention (Fig. 24).

In some cases the morphologic genus and the phylogenetic subgenus coincide in name and contents (*Whiteinella* PESSAGNO, 1967, *Hedbergella* BRÖNNIMANN & BROWN, 1958, *Falsotruncana* CARON, 1981), while in other cases, the phylogenetic subgenus includes organisms which can be assigned to various morphological genera (*Falsomarginotruncana* SALAJ, 1987, *Carpathoglobotruncana* ION, 1983, group of *Dicarinella oraviensis* (SCHEIBNEROVÁ)?, *Rosalinella* MARIE, 1941, *Praeglobotruncana* BERMUDEZ, 1952 and *Marginotruncana* HOFKER, 1956) and in a further case (*Helvetoglobotruncana*

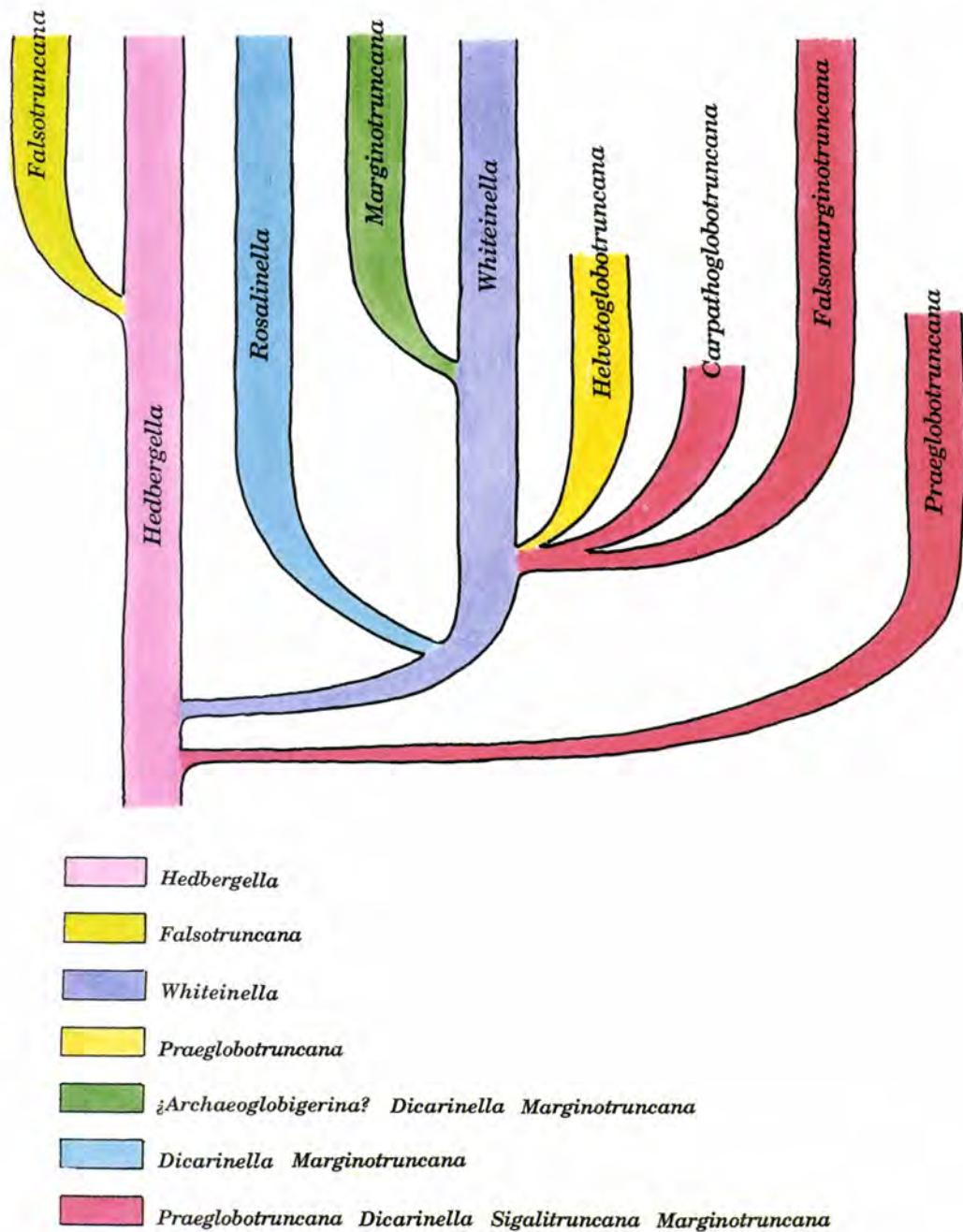


FIGURE 24  
Recognized subgenera and morphogenera included in each subgenus.

REISS, 1957) the organisms of the subgenus belong to a single morphological genus (*Praeglobotruncana*), but have representations and type species in another subgenera.

The following discussion has been based on the recognized subgenera; to illustrate the hypothesis of phyletic and phylogenetic relations we have decided to depict the morphotypes linked as if certain ones evolved from the others which, in some cases, cannot be absolutely correct. In fact, the genotype responsible for the appearance of a determined morphotype can come from the modification of a previous genotype, but the recombination of two or more prior

genotypes can also produce a new morphotype, with or without another type of transformation.

## 6.2. DESCRIPTION OF SUBGENERA (Pl. 27 to 43)

### 6.2.1. Subgenus *Hedbergella*

— *Hedbergella* (*Hedbergella flandriini* POTHault, 1970).

The representatives of *Hedbergella* are present along the section, especially in the thin fraction where these can be

confused with young *Whiteinella* and other Turonian forms.

Its study would need additional work, and we have not had enough time. This is why we have decided to discuss it later, when we also have data on the *Hedbergella* of the Albian and the Cenomanian of Kalaat Senan.

We will just point out the presence of *H. flandriini* PORTHAAULT in the HM 308 to HM 362 levels; in posterior levels it is not detected until the Coniacian.

#### 6.2.2. Subgenus *Falsotruncana*

- *Falsotruncana (Falsotruncana) loeblichae* (DOUGLAS, 1969).
- *Falsotruncana (Falsotruncana) maslakovae* (CARON, 1981).

CARON, 1981, indicated the existence of a series constituted by *Hedbergella hoelzii* (HAGH & ZEIL)-*Falsotruncana douglasi* CARON-*F. loeblichae* (DOUGLAS)-*F. maslakovae* CARON. The series in question would show the following successions : elliptical and pustulous periphery-periphery with two rows of pustules, except for the two elliptical final chambers-periphery with two keels except for the truncated final chamber; but throughout the series, the umbilical characteristics of *Hedbergella* (absence of portici) would be conserved.

The level HM 285 contains scarce organisms identified, without any doubt, as *Falsotruncana*. The majority of them can be identified as *F. loeblichae*, but some of them show characteristics which cause one to believe that the series is somewhat less lineal than CARON indicated; such specimens have the periphery of the first chambers like *F. douglasi*, but the periphery of the last chambers is intermediate between *F. loeblichae* and *F. maslakovae*.

The following levels, till HM 296, contain similar organisms which have some different characteristics, that make us doubt its attribution : they are dextral forms (while the *Falsotruncana*, as CARON indicates, is always sinistral and the forms of the level HM 285 are also sinistral) with a greater expansion rate and an umbilicus which seems more clearly delimited; it is difficult to decide if they are ecological variants of *Falsotruncana*, or forms which have evolved in a different direction from the one that leads to *F. maslakovae*, or a convergence.

Finally we have to point out the presence, in the levels HM 296 and HM 342, of scarce and badly preserved specimens that show characteristics similar to those of *F. maslakovae*, but are dextral and have imbricate chambers.

#### 6.2.3. Subgenus *Whiteinella*

##### *Whiteinella baltica* subgroup

- *Whiteinella (Whiteinella) baltica* DOUGLAS & RANKIN, 1969 [= *W. bornholmensis* (DOUGLAS & RANKIN, 1969) = *W. alpina* (PORTHAAULT, 1969)].
- *Whiteinella (Whiteinella) aprica* (LOEBLICH & TAPPAN, 1961).
- *Whiteinella (Whiteinella) kingi* (TRUJILLO, 1960) [= *W. brittonensis* (LOEBLICH & TAPPAN, 1961)].
- *Whiteinella (Whiteinella) paradubia* (SIGAL, 1952).

Under this denomination, we have included the *Whiteinella* whose chambers display a rounded or elliptically expanded axial periphery.

The organisms of this subgroup are present in the majority of the Turonian samples and they have relatively high fre-

quencies, especially in the lower part of the series. In the oligotaxic levels, they are frequently the predominant components or the only ones.

From a purely typological point of view and using the criteria pointed out in ROBASZYNSKI, CARON and EWGP, 1979, it is easy to identify the forms indicated above : forms with a maximum of 4.5 chambers in the last whorl can be attributed to *W. baltica*, those with 5.5 or more chambers and a moderately high trochospire to *W. kingi* (= *W. brittonensis*) those with a low trochospire and a broad umbilicus to *W. aprica* and those with a very high trochospire to *W. paradubia*.

However, when studying samples with abundant specimens from this group, one observes transitions between distinct "species" that imply that, in fact, they could be morphological variants pertaining to only one biological species.

Besides the common morphologies assigned to the forms cited above or recognized as intermediate forms, some variants exist (ones which have not been separated in the distribution chart). There are specimens similar to *W. aprica*, with a very lobate periphery, oblique spiral sutures and a maximum radius of each chamber situated at the back. Other specimens present a morphology similar to that of *W. baltica*, but display a true umbilical aperture, thus approaching a globigerina-like morphology. Finally, the pustules of some specimens show a tendency to line up in some chambers, thus sketching out the meridional pattern, a fact which has been pointed out on some occasions (e.g., PORTHAAULT, 1969).

##### *Whiteinella inornata* subgroup

- *Whiteinella (Whiteinella) inornata* (BOLLI, 1957)
- *Whiteinella (Whiteinella) gigantea* (LEHMANN, 1963) [= *W. lehmanni* (PORTHAAULT, 1969)].

Representatives of this subgroup occur during the whole Turonian series, but they are less frequent than those of the *W. baltica* subgroup. In these forms the first chambers of the final whorl show, from an axial view, a rounded periphery, whereas the last chambers are ogival, although not keeled.

The variability of these forms is relatively great. It seems that the majority of the morphological types of the *W. baltica* subgroup have their equivalents in the *W. inornata* subgroup and there are forms with intermediate morphologies among both subgroups. Apart from the differences in angularity of the profile of the chambers, it is characteristic that forms with a rounded periphery (with the cited exception) have spiral sutures which are quite straight and radial, whereas forms with an angular or ogival periphery usually exhibit more oblique or arcuate sutures. This appears to be related to the change in form of the periphery and can be somewhat accentuated in some specimens. Other variants of this subgroup show a very lobate periphery.

*W. inornata* (BOLLI), according to the original description, includes forms whose last and occasionally penultimate chambers are compressed and show sharp peripheral edges or a faint keel. However, PESSAGNO (1967), after observing type specimens, pointed out that true carinae are not present. Individuals with few chambers (equivalent to *W. baltica*) may therefore be attributed to the forms of BOLLI.

Although not mentioned in the original description of *P. ? gigantea* LEHMANN, the holotype has, according to the figure

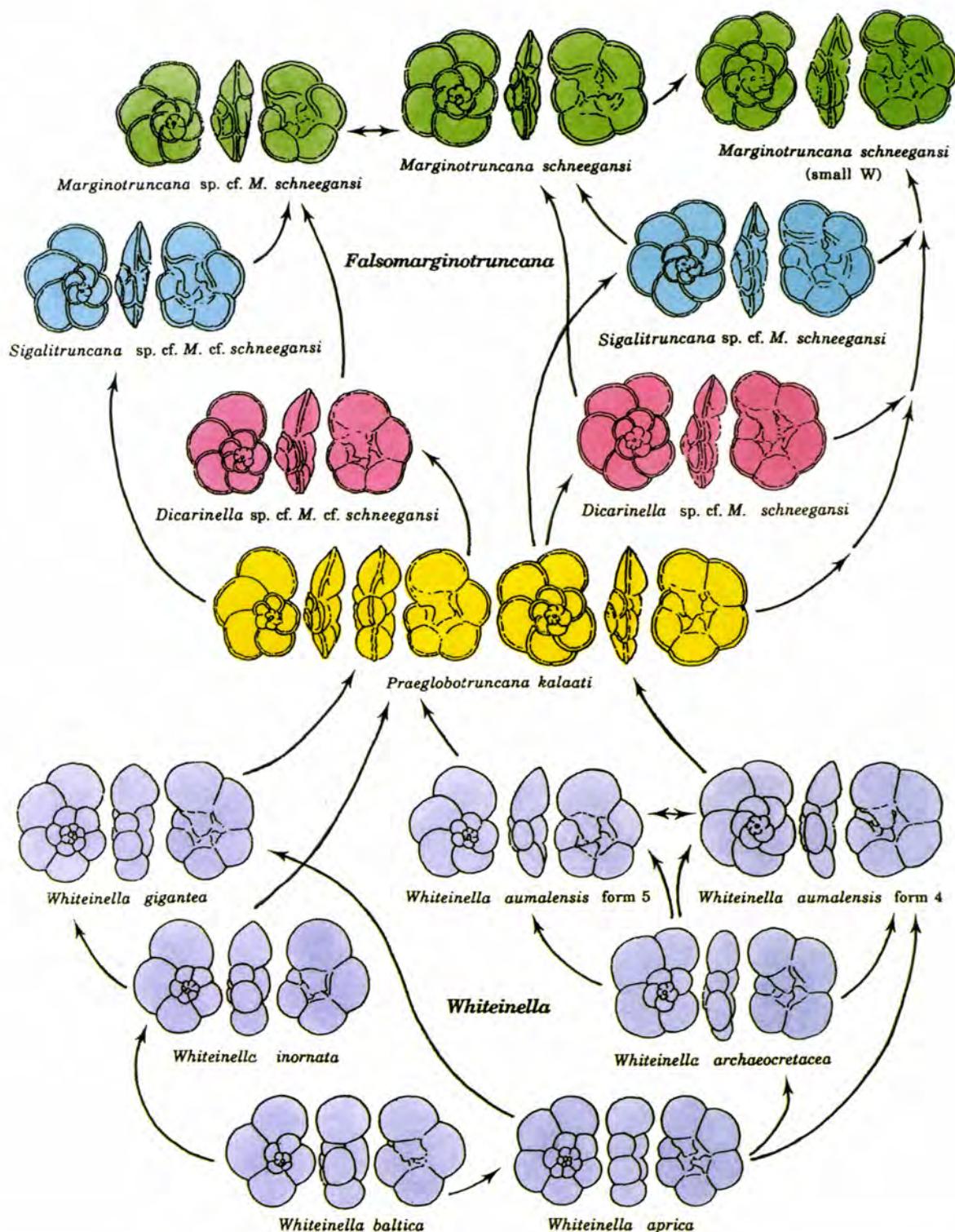


FIGURE 25

Inferred phylogenetic and morphoserial phyletic relationship among *Whiteinella* (part) and *Falsomarginotruncana* morphotypes.

of LEHMANN, an axial periphery similar to the holotype of *W. inornata*. Therefore, the name *W. gigantea* would be adequate for forms of the *W. inornata* subgroup which have 5 or more chambers and which can be considered the equivalents of *W. aprica* and/or *W. kingi* (according to article 59d of the I.C.Z.N., 1985, the name *Praeglobotruncana lehmanni* PORTHAULT is a synonym of *Praeglobotruncana ? gigantea* LEHMANN; see also SALAJ & GASPARIKOVA, 1983).

#### *Whiteinella aumalensis* subgroup

- *Whiteinella (Whiteinella) archaeocretacea* PESSAGNO, 1967.
- *Whiteinella (Whiteinella) aumalensis* (SIGAL, 1952).

These forms are less frequent than those of the *W. baltica* subgroup. The chambers of the last whorl have a compressed axial periphery which may be elliptic, ogival, or angular.

Some forms display an axial profile which varies from biconvex to slightly convexo-concave, chambers with elliptic axial periphery, and somewhat oblique, straight or slightly arcuate spiral sutures. These forms can be identified as *W. archaeocretacea* Pessagno. All conceivable transitions exist between them and the forms of the *W. baltica* subgroup.

Other forms show a convexo-plane to convexo-concave axial profile, some compressed chambers with an elliptic or ogival axial periphery, and slightly arcuate, (generally) slightly oblique spiral sutures. Although the original figures are very schematic, these forms can be identified as *W. aumalensis* (the description may also suggest an intermediate form between *Whiteinella* and *Praeglobotruncana*). Some specimens have features placing them between *W. aumalensis* and *W. archaeocretacea*, *W. aprica* or *W. gigantea*.

The variability of the forms which we have identified as *W. aumalensis* is relatively high, and a series of morphotypes can hardly be distinguished by the whorl expansion rate (estimated from the spiral medium radii of the successive chambers), by the shape of the spiral sutures and by the degree of lobation of the spiral outline. We can differentiate :

- a) individuals with a slightly lobate, nearly subcircular outline, and an expansion rate of about 2 or less (*W. aumalensis* form 1);
- b) individuals with a lobate outline and an expansion rate which varies between 2 and 2.5; the axial profile is convexo-concave and the superposition of each chamber above the preceding one, from a spiral view, is greater than in the preceding forms (*W. aumalensis* form 2);
- c) individuals with a very lobate outline and slow expansion rate, of about 1.6 (*W. aumalensis* form 3);
- d) individuals with a somewhat lobate outline and an expansion rate between 2 and 2.5; the axial outline tends to be convexo-plane or biconvex-asymmetrical and differs from form 2, apart from the profile and the minor lobation, by having a minor superposition of the chambers from a spiral view (*W. aumalensis* form 4);
- e) individuals with a lobate spiral outline and an expansion rate greater than 2.5; the superposition of each chamber above the preceding one can be larger than in the forms 1 and 2 (*W. aumalensis* form 5);
- f) individuals with characteristics similar to those mentioned above but with a more lobate spiral outline (*W. aumalensis* form 6).

All these forms (and those from the *W. inornata* subgroup) are the starting points of morphoseries including the distinct morphological genera *Praeglobotruncana*, *Sigalitruncana*, *Dicarinella* and *Marginotruncana*.

#### 6.2.4. Subgenus *Falsomarginotruncana*

- Intermediate forms between *Whiteinella* and *P. (F.) kalaati*, n. sp.
- *Praeglobotruncana (Falsomarginotruncana) kalaati*, n. sp.
- Intermediate forms between *P. (F.) kalaati*, n. sp. and *M. (F.) cf. schneegansi* (SIGAL, 1952) [*Sigalitruncana (Falsomarginotruncana) sp. cf. M. (F.) cf. schneegansi* (SIGAL, 1952) and *Dicarinella (Falsomarginotruncana) sp. cf. M. (F.) cf. schneegansi* (SIGAL, 1952)].
- Primitive forms of *M. (F.) schneegansi* (SIGAL, 1952) [*Sigalitruncana (Falsomarginotruncana) sp. cf. M. (F.) schneegansi* (SIGAL, 1952) and *Dicarinella (Falsomarginotruncana) sp. cf. M. (F.) schneegansi* (SIGAL, 1952)].
- *Marginotruncana (Falsomarginotruncana) sp. cf. M. (F.) schneegansi* (SIGAL, 1952).
- *Marginotruncana (Falsomarginotruncana) schneegansi* (SIGAL, 1952).

SALAJ (1987) established the genus *Falsomarginotruncana* (type species *Globotruncana schneegansi* SIGAL) in order to separate the Tethyan double-keeled species, usually assigned to the genus *Marginotruncana* but which do not have a direct phylogenetical connection with *M. marginata* (REUSS). *Falsomarginotruncana* is, therefore, an appropriate name for joining, in a phylogenetic subgenus, a group of forms derived from *Whiteinella*, including *Marginotruncana (Falsomarginotruncana) schneegansi* (SIGAL). From a morphological point of view, they belong to the genera *Praeglobotruncana*, *Dicarinella*, *Sigalitruncana* and *Marginotruncana* (Fig. 25).

Some specimens of *Whiteinella* assignable by their characteristics to *W. inornata*, *W. gigantea*, *W. archaeocretacea* and *W. aumalensis* (forms 4 and 5), display a concentration of pustules in the periphery or an incipient peripheral ridge. Such forms are, from a morphological point of view, the transition to other ones, which can be assimilated by their characteristics to morphotypes of *Whiteinella*, but keeled.

All the spiral sutures in these specimens are depressed, as in *Whiteinella*, but some individuals show the keel extended, totally or partially, in the spiral suture. This feature is frequent in the last chambers of the penultimate whorl and in the first chambers of the last whorl. It may also be seen in some specimens intermediate with *Whiteinella*. On the other hand, the spiral sutures of these specimens are usually more oblique than those of the corresponding *Whiteinella*, except for the *W. aumalensis* (form 4). From a morphological point of view, these forms can be identified as *Praeglobotruncana*, although no phylogenetic connection has been proved with the *P. stephani* group.

At the species level, we have not found any description which fits these forms. From a typological point of view, we could describe four (or more) forms by analogy with *Whiteinella*, corresponding to *W. inornata*, *W. gigantea*, *W. archaeocretacea* and *W. aumalensis*. However, as we have found transitions in different points of the series, it appears logical to think that when two or more types existed in a sample, they formed part of a unique biological species. In fact, one could argue that these forms would be part of the

same biological species as *Whiteinella*, since, as we said before, one finds the intermediate forms along the section. Not enough is known about the stratigraphical ranges of *Whiteinella* and *Praeglobotruncana* morphotypes to separate chronospecies in the group, but for practical reasons it seems suitable to propose a new denomination for this group of forms, namely *Praeglobotruncana (Falsomarginotruncana) kalaati*, n. sp. (see annex).

From the first samples of the HM section, some specimens of *P. kalaati* show the anterior part of the keel in some chambers divided into two branches: one spiral and one umbilical; the last one usually extends as an adumbilical ridge, smooth or pustulose, more or less individualized. The anterior part of the umbilical branch of the keel may be covered, totally or partially, by the next chamber, or remain exposed. Apart from their sutural peculiarities, these organisms also show the characteristics observed in *P. kalaati*, and it is possible to identify morphotypes comparable to *W. inornata*, *W. gigantea*, *W. archaeocretacea* and *W. aumalensis* forms 4 and 5. It is worth noting that some specimens comparable to *W. aumalensis* form 5 present an expansion rate inferior to 2.5, as in those of *W. aumalensis* form 4, although their spiral sutures are very oblique. They can be assigned to the morphological genus *Sigalitruncana*.

Other specimens have depressed umbilical sutures without adumbilical ridges, but display in axial view two badly individualized series of pustules, or even two close keels. They are comparable to the *W. aumalensis* forms 4 and 5, and can be assigned to the morphological genus *Dicarinella*. Similar forms were pointed out as primitive forms of *MARGINOTRUNCANA schneegansi* (SIGAL) by ROBASZYNKI, CARON and EWGF (1979, pl. 71, fig. 1) and as *Dicarinella schneegansi* (SIGAL) by LINARES (1977).

In the distribution chart these *Sigalitruncana* and *Dicarinella* are placed together under the denomination "intermediate forms between *P. kalaati*, and *M. cf. schneegansi*" (those corresponding to the series of *W. gigantea*, *W. inornata* and *W. aumalensis* form 5) and "primitive forms of *M. schneegansi*" (those corresponding to the series of *W. archaeocretacea* and *W. aumalensis* form 4).

Other specimens, also present in the lower part of the HM section, show both characteristics, two keels and a raised umbilical suture, joined in some chambers of the last whorl. Therefore, from a morphological point of view, they are *MARGINOTRUNCANA*: those pertaining to the series of *W. archaeocretacea* and *W. aumalensis* form 4 can be identified as *MARGINOTRUNCANA (Falsomarginotruncana) schneegansi* (SIGAL); those pertaining to the series of *W. lehmanni*, *W. inornata* and *W. aumalensis* form 5, with more oblique spiral sutures and, in some cases, a higher expansion rate, have been assembled under the denomination *M. (F.)* sp. cf. *M. (F.) schneegansi* (SIGAL). Forms with intermediate features occur between *M. schneegansi* and *M. cf. schneegansi*.

Lastly, we found specimens similar to the series of *W. aumalensis* form 4, but with a small expansion rate (inferior to 2); such individuals, among which are recognized the morphogenera *Praeglobotruncana*, *Sigalitruncana*, *Dicarinella* and *MARGINOTRUNCANA*, but not *Whiteinella*, have not been separated from their equivalents of the series of *W. aumalensis* form 4.

### 6.2.5. Subgenus *Helvetoglobotruncana*

- *Praeglobotruncana (Helvetoglobotruncana) helvetica* (BOLLI, 1945).

*Praglobotruncana (Helvetoglobotruncana) helvetica* (BOLLI) is an abundant form in the interval HM 131.8 to HM 308. Its morphology and large variability are well-known, so it would seem unnecessary to describe them (see, e.g., GONZALEZ DONOSO & LINARES, 1979). It also seems unnecessary to refer to its relations with *Whiteinella* from the subgroup *W. baltica*, *W. praehelvetica* (TRUJILLO) being the intermediate form between them.

On the other hand, it is convenient to mention that along the whole interval that contains *P. helvetica*, we can find *W. praehelvetica* and that the separation between both is arbitrary, as one usually finds all the imaginable intermediate types between the first and the second one. On the contrary, the forms of transition within the *W. baltica* subgroup are very rare (in fact, we have only found a few specimens which seem intermediate between *W. aprica* and *W. praehelvetica*).

### 6.2.6. Subgenus *Carpathoglobotruncana*

- Intermediate forms between *Whiteinella* and *P. (C.) hilalensis* BARR, 1972.
- *Praeglobotruncana (Carpathoglobotruncana) hilalensis* BARR, 1972.
- *Sigalitruncana (Carpathoglobotruncana) pileoliformis* (LAMOLDA, 1977).
- *Dicarinella (Carpathoglobotruncana) sp. cf. P. (C.) hilalensis* BARR, 1972.
- *MARGINOTRUNCANA (Carpathoglobotruncana) sp. cf. P. (C.) hilalensis* BARR, 1972.

From the first fossiliferous samples of the HM section, there are specimens of *W. aumalensis* (form 1) with a carinal sketch beginning to develop; these individuals form a transition with others, already single-keeled, that can be identified as *Praeglobotruncana hilalensis* BARR, according to the original description and figuration. Similarly to what we have observed in the group of *M. schneegansi*, the morphoseries continued in specimens with raised umbilical sutures which can be considered, therefore, to be *Sigalitruncana*, specifically *S. pileoliformis* (LAMOLDA), and in specimens with depressed umbilical sutures but with two keels, diverging towards the anterior part of the chamber; since we have not found any denominations for these forms, we have decided to designate them as *Dicarinella* sp. cf. *P. hilalensis* BARR. Finally we have found few individuals with characteristics of *MARGINOTRUNCANA*.

Since we have not found intermediate forms with *Falso-truncana*, although they both seem to come from the same species, it is reasonable to think they are different groups. *Carpathoglobotruncana* (ION, 1983, type species *M. pileoliformis* LAMOLDA) is the proper name for the corresponding phylogenetic subgenus.

### 6.2.7. *Dicarinella oraviensis?* (SCHEIBNEROVA) group

- Intermediate forms between *Whiteinella* and *D. oravensis?* (SCHEIBNEROVA, 1960).
- *Dicarinella oraviensis?* (SCHEIBNEROVA, 1960).

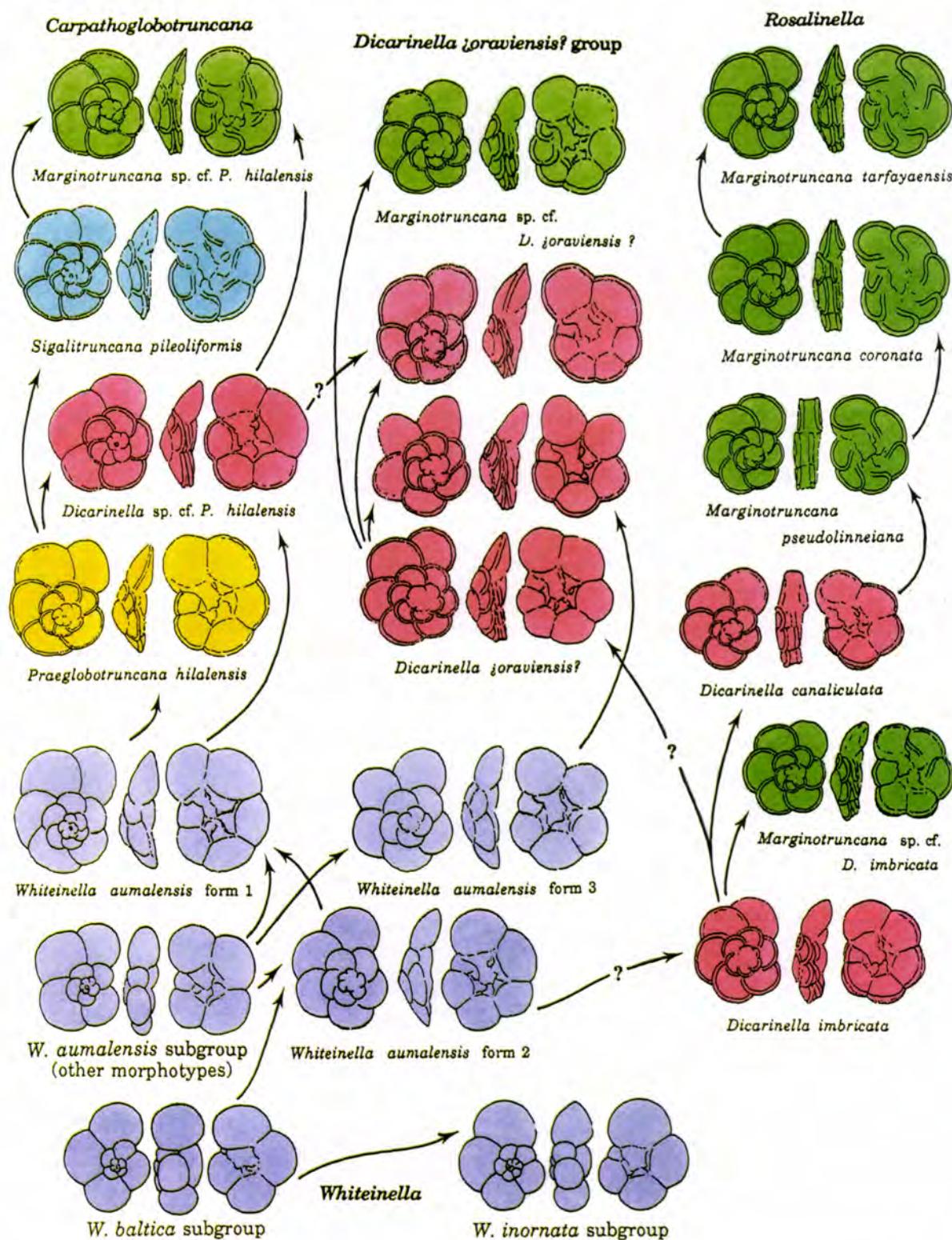


FIGURE 26

Inferred phylogenetic and morphoserial phyletic relationship among *Whiteinella* (part), *Rosalinella*, *Carpathoglobotruncana* and *Dicarinella oraviensis?* group morphotypes.

- *Marginotruncana* sp. cf. *Dicarinella oraviensis*? (SCHEIBNEROVA, 1960).

*W. aumalensis* (form 2) seems to mark the beginning of another morphoseries without single-keeled forms (*Praeglobotruncana* or *Sigalitruncana*). The morphoseries includes forms with two keels in the first chambers of the last whorl, diverging towards the anterior part of the chamber; therefore, these forms are *Dicarinella*. Together with them, we find others which are apparently related (although we do not totally reject the possibility that they might be related to *Carpathoglobotruncana*) but differentiated by their spiral side : first, the chambers gain gradually in height but the final two or three have a larger expansion rate, resulting in comparatively much larger chambers than the preceding ones (Fig. 26).

The determination of these forms is problematic. The first ones show similarities with some of those illustrated by ION (1983) such as *Praeglobotruncana oraviensis oraviensis* SCHEIBNEROVA, except in the presence of two keels; the second ones are similar to a form with two keels identified as *Praeglobotruncana gibba* KLAUS, morphotype *P. oraviensis* SCHEIBNEROVA, in ROBASZYNSKI, CARON 1979 and EWGPF (especially the specimen of the pl. 45, fig. 2, also from Tunisia). However, the form of SCHEIBNEROVA has a keel according to the original figures and description. For this reason, we have chosen to provisionally denominate our organisms as *Dicarinella oraviensis*? (SCHEIBNEROVA), until we have more data about the SCHEIBNEROVA form.

On the other hand, there are also specimens of *Dicarinella* with the characteristics of *W. aumalensis* (form 3). Since all the transitions between them and the above-mentioned morphotypes exist, we have chosen not to separate them from *D. oraviensis*? Similar organisms, but with a keel, have been figured by ION (1983) under the denomination *Praeglobotruncana* sp. aff. *P. oraviensis oraviensis* SCHEIBNEROVA.

In HM section too, but not in its first fossiliferous samples, there are a few specimens with a prolongation of the umbilical keel in the umbilical side of some chambers not covered by the following chamber and usually extended in an adumbilical ridge. As we have not found any adequate denomination for these forms, we have chosen to denominate them *Marginotruncana* sp. cf. *Dicarinella oraviensis*? (SCHEIBNEROVA). It should be pointed out that some of these organisms (and also perhaps some of the *Dicarinella* mentioned) show apertural plates with distal and proximal accessory apertures (tegilla?).

For reasons similar to those displayed in the last group, it seems appropriate to include all of these forms in a phylogenetic subgenus that need to be denominated; nevertheless, we have preferred to delay this proposal until the problems of specific identification and relationships with *Carpathoglobotruncana* and *Rosalinella* are resolved.

#### 6.2.8. Subgenus *Rosalinella*

- *Dicarinella (Rosalinella) imbricata* (MORNOD, 1950).
- Intermediate forms between *D. (R.) imbricata* (MORNOD, 1950) and *D. (R.) canaliculata* (REUSS, 1854).
- *Dicarinella (Rosalinella) canaliculata* (REUSS, 1854).
- *Marginotruncana (Rosalinella)* sp. cf. *D. (R.) imbricata* (MORNOD, 1950).

- *Marginotruncana (Rosalinella)* sp. cf. intermediate forms between *D. (R.) imbricata* (MORNOD, 1959) and *D. (R.) canaliculata* (REUSS, 1854).
- Intermediate forms between *D. (R.) canaliculata* (REUSS, 1854) and *M. (R.) pseudolinneiana* PESSAGNO, 1967.
- *Marginotruncana (Rosalinella) pseudolinneiana* PESSAGNO, 1967 [and *M. (R.) scorpionis* LAMOLDA, 1977].
- Intermediate forms between *M. (R.) pseudolinneiana* PESSAGNO, 1967 and *M. (R.) coronata* (BOLLI, 1945).
- *Marginotruncana (Rosalinella) coronata* (BOLLI, 1945).
- Intermediate forms between *M. (R.) coronata* (BOLLI, 1945) and *M. (R.) tarfayaensis* (LEHMANN, 1963).
- *Marginotruncana (Rosalinella) tarfayaensis* (LEHMANN, 1963).

*Rosalinella* MARIE, 1941 (type species *Rosalina linneiana* d'ORBIGNY) is the appropriate name for a phylogenetic subgenus made up of forms derived from *W. aumalensis* (form 2) (or from a similar form) during the Cenomanian and that would include well-known forms : *Dicarinella (Rosalinella) imbricata* (MORNOD), *D. (R.) canaliculata* (REUSS), *Marginotruncana (R.) pseudolinneiana* PESSAGNO, *M. (R.) coronata* (BOLLI), *M. (R.) tarfayaensis* (LEHMANN), *Globotruncana (R.) linneiana* (d'ORBIGNY) and *G. (R.) ventricosa* (WHITE).

*Dicarinella imbricata* (MORNOD) is present in the samples of the SM section posterior to the extinction of *Rotalipora* and in samples of the HM and HMT sections; it is usually a scarce form. From a morphological point of view, it can be assigned to the morphological genus *Dicarinella*, but phylogenetically it does not seem to have a relationship of descent with the *D. concavata* subgroup.

CARON (1976) pointed out the existence of an evolutionary line *Praeglobotruncana stephani*-*Dicarinella algeriana*-*D. imbricata*. When we observe the figuration of the holotype of *D. algeriana* (REICHEL, 1950), it seems obvious that it is a form with advanced characteristics (it could even be a *Marginotruncana*) related to *P. stephani*. But the topotypes of *D. algeriana* figured by ROBASZYNSKI, CARON and EWGPF (1979), with their incipient, well-separated keels and their slightly prominent or depressed spiral sutures, are forms with more primitive characteristics and they do not seem to be related to *P. stephani*, but to *Whiteinella*, and they can be intermediate between this and *D. imbricata* (or *D. canaliculata*). In short, we support a phylogenetic line *Whiteinella*-*D. "algeriana"* ROBASZYNSKI, CARON and EWGPF, non CARON-*D. imbricata*.

The Cenomanian *Whiteinella*, situated at the origin of this evolutionary line would be the *W. aumalensis* (form 2), or another with a similar spiral side; if that is certain, we could imagine an iterative evolution that would produce nearly homeomorphous forms, which differ as regards the width of the keel band (in fact we have sometimes had doubts when we have assigned some individuals to *D. imbricata* or to *D. oraviensis*?).

*Dicarinella canaliculata* (REUSS) is a very rare form in the section of Kalaat Senan and it is only present in the interval HM 268 to HM 285. It shows obvious similarities to *D. imbricata* and differs only in that it has parallel keels, instead of divergent ones in all the chambers of the last whorl. The transition from one form to another is represented by scarce organisms that are clearly intermediate : in them, the divergence of the keels diminishes, through an increase of the separation of the keel in the posterior part of the chamber.

They sometimes end up being parallel and the axial outline becomes subrectangular, but the final chamber and even the penultimate one do not have keels; they are shifted towards the umbilicus. In other individuals, the keels are present in all the chambers including the final one, like *D. canaliculata*, but they are somewhat divergent as in the intermediate ones mentioned.

In rare samples, dispersed along the HM and HMT sections there are forms, though always rare, comparable to *D. imbricata* and intermediate forms between *D. imbricata* and *D. canaliculata*, but showing some raised umbilical sutures; these forms have been identified as *Marginotruncana* sp. cf. *D. imbricata* and *M. sp. cf. D. imbricata/D. canaliculata*.

Finally in the interval HM 268 to HM 285, besides the typical *D. canaliculata* (and its intermediate forms with *D. imbricata*) there are specimens with raised umbilical sutures and adumbilical ridges in some chambers; in other chambers the adumbilical ridges are missing and the specimens have radial sutures, as is typical of *Dicarinella*. These individuals are intermediate with forms showing raised umbilical sutures and an adumbilical ridge in all chambers, the genuine *Marginotruncana pseudolinneiana* PESSAGNO.

The spiral sutures of *D. imbricata* are slightly arcuate and nearly radial in the individuals similar to the neotype; usually in more modern and presumably more advanced forms, they are more oblique, thus changing the form of the chamber from petaloid to crescentic. This last characteristic is present in the majority of *D. canaliculata*, typical *M. pseudolinneiana*, and specimens with a plane spiral side and a slightly convex ventral side (*M. scorpionis* LAMOLDA, no distinction made in this work between this and *M. pseudolinneiana*).

The evolution that leads from *D. imbricata* to *M. pseudolinneiana* continues with contrary as well as distinct trends and produces a well-known derivation, the *M. coronata* BOLLI: the subrectangular profile turns into a compressed biconvex configuration, the keels get closer, the chambers also develop a more petaloid configuration and are usually larger. Since the intermediate forms between *M. pseudolinneiana* and *M. coronata* are present from the levels where *M. pseudolinneiana* appears, one might think that the F.A.D. of this form in Kalaat Senan is posterior to its evolutionary appearance in other regions, probably for ecological reasons.

The evolutionary changes producing *M. coronata* continue, bringing about the appearance of *Marginotruncana tarfayaensis*, a form with close keels, more radial spiral sutures and sometimes of a larger size; there are a large number of forms with characteristics intermediate between them both.

The post-Turonian evolution of the group produces other forms: *Globotruncana linneiana* (d'ORBIGNY) and *G. ventricosa* (WHITE).

#### 6.2.9. Subgenus *Praeglobotruncana*

##### *Praeglobotruncana stephani* subgroup

- *Praeglobotruncana* (*Praeglobotruncana*) *delrioensis* (PLUMMER, 1931).
- *Praeglobotruncana* (*Praeglobotruncana*) *stephani* (GANDOLFI, 1942).
- *Praeglobotruncana* (*Praeglobotruncana*) *gibba* KLAUŠ, 1960.

- *Dicarinella* (*Praeglobotruncana*) sp. cf. *M. (P.) algeriana* CARON, 1966.
- *Sigalitrunca* (*Praeglobotruncana*) sp. cf. *M. (P.) algeriana* CARON, 1966.
- *Marginotruncana* (*Praeglobotruncana*) *algeriana* CARON, 1966.

From the base of the SM section until the sample SM101, we can find specimens of *Praeglobotruncana* s.str. among which we can recognize, from the convexity of the spiral side, *P. delrioensis* (PLUMMER), *P. stephani* (GANDOLFI) and *P. gibba* KLAUŠ. There are all the possible transitions among the three morphotypes and so they ought to belong to the same biological species in each of the samples where they are present.

Some of these organisms present two keels in the first chambers of the last whorl and others in all the chambers except for the last one, thus making them similar to *Praeglobotruncana* cf. *algeriana* CARON, 1966. We can talk morphologically about *Dicarinella* and we use the denomination *Dicarinella* sp. cf. *M. algeriana* to designate them (without separating the morphotypes corresponding to *P. gibba* and *P. stephani*).

Others, with a keel, but having umbilical sutures convex towards the front in some chambers, are the transition to others which have some chambers with prominent sutures and/or adumbilical ridges. They would morphologically be *Sigalitrunca* and we have called it *Sigalitrunca* sp. cf. *M. algeriana*.

Finally, others show two keels in more or less all the chambers (except in the last one) and sutures which are convex towards the front in some chambers, more or less raised and extended in an adumbilical ridge. These forms, with incipient characteristics of *Marginotruncana*, can be compared with the holotype of *P. algeriana*, according to the figures of REICHEL and what CARON indicated (1966, after the description of *P. cf. algeriana*). We have identified them as *Marginotruncana algeriana* (CARON).

##### *Dicarinella hagni* subgroup

- *Praeglobotruncana* (*Praeglobotruncana*) sp. aff. *P. (P.) stephani* (GANDOLFI, 1942).
- *Dicarinella* (*Praeglobotruncana*) *hagni* SCHEIBNEROVA, 1962.
- *Sigalitrunca* (*Praeglobotruncana*) sp. cf. *D. (P.) hagni* SCHEIBNEROVA, 1962.
- *Marginotruncana* (*Praeglobotruncana*) sp. cf. *D. (P.) hagni* SCHEIBNEROVA, 1962.

From the first levels of the section SM, we can also observe organisms with spiral sutures somewhat more oblique than the sutures of the series of *P. stephani*-*M. algeriana*.

These organisms form the transition to others, with more oblique sutures (giving a more crescent shape to the chambers from a spiral view). These forms appear in the level SM 88 and replace the series *P. stephani*-*M. algeriana* after the level SM 100. In the Turonian populations of these organisms, there are specimens whose final chambers in the last whorl take on a subtrapezoidal shape, from a spiral view, because of an inflection towards the limit between the spiral suture and the keel.

The single-keeled specimens with radial and depressed

umbilical sutures, corresponding to *P. stephani* and *P. gibba* for its spiroconvexity, are similar to the *P. stephani* figured by BELFORD & SCHEIBNEROVÁ (1971); here we are going to call them *P. sp. aff. P. stephani*.

Mixed with these specimens, there are others morphologically identical to them, but possessing two keels. They can, therefore, be assimilated to the genus *Dicarinella*. Since there is a similarity between these forms and those figured as *P. hagni* SCHEIBNEROVÁ by BELFORD & SCHEIBNEROVÁ (1971) and as *D. hagni* by ROBASZYNSKI, CARON and EWGP (1979, pl. 56, fig. 2), we refer to them using this last denomination.

Other specimens, although single-keeled, present raised umbilical sutures and/or perumbilical ridges in some chambers. Morphologically, therefore, one can assimilate them to the genus *Sigalitruncana* although we should note that the umbilical side of these forms is "more primitive" than that of the *S. sigali* (REICHEL): the sutures are slightly sigmoid (a little convex towards the front) and the surface of the chambers is convex. We are going to call them *Sigalitruncana* sp. cf. *D. hagni*.

Some specimens also exist which have two close or slightly separated keels and some chambers with umbilical

sutures like *Sigalitruncana* sp. cf. *D. hagni*. They can be included in the morphogenus *Marginotruncana*. We could also say that they are "more primitive" than the individuals of *M. renzi* (GANDOLFI) and *M. pseudolinneiana* PESSAGNO. Forms with these characteristics were figured by ROBASZYNSKI, CARON and EWGP (1979) as *D. hagni* (pl. 57, fig. 2) and we call them *Marginotruncana* sp. cf. *D. hagni*.

The group *P. sp. aff. P. stephani*-*D. hagni* becomes rare from the level SM 145 (LAD of *Rotalipora*), but the majority of the individuals non assimilable to *Whiteinella*, in the interval SM 145-HM 133.5, can be assigned to this group, or *D. imbricata* (MORNOD). From the level HM 133.5, the group becomes relatively common again until the level HM 272.

#### *Sigalitruncana marianosi* subgroup

- *Praeglobotruncana* (*Praeglobotruncana*) *elata* (LAMOLDA, 1977).
- *Dicarinella* (*Praeglobotruncana*) sp. cf. *P.* (*P.*) *elata* (LAMOLDA, 1977).

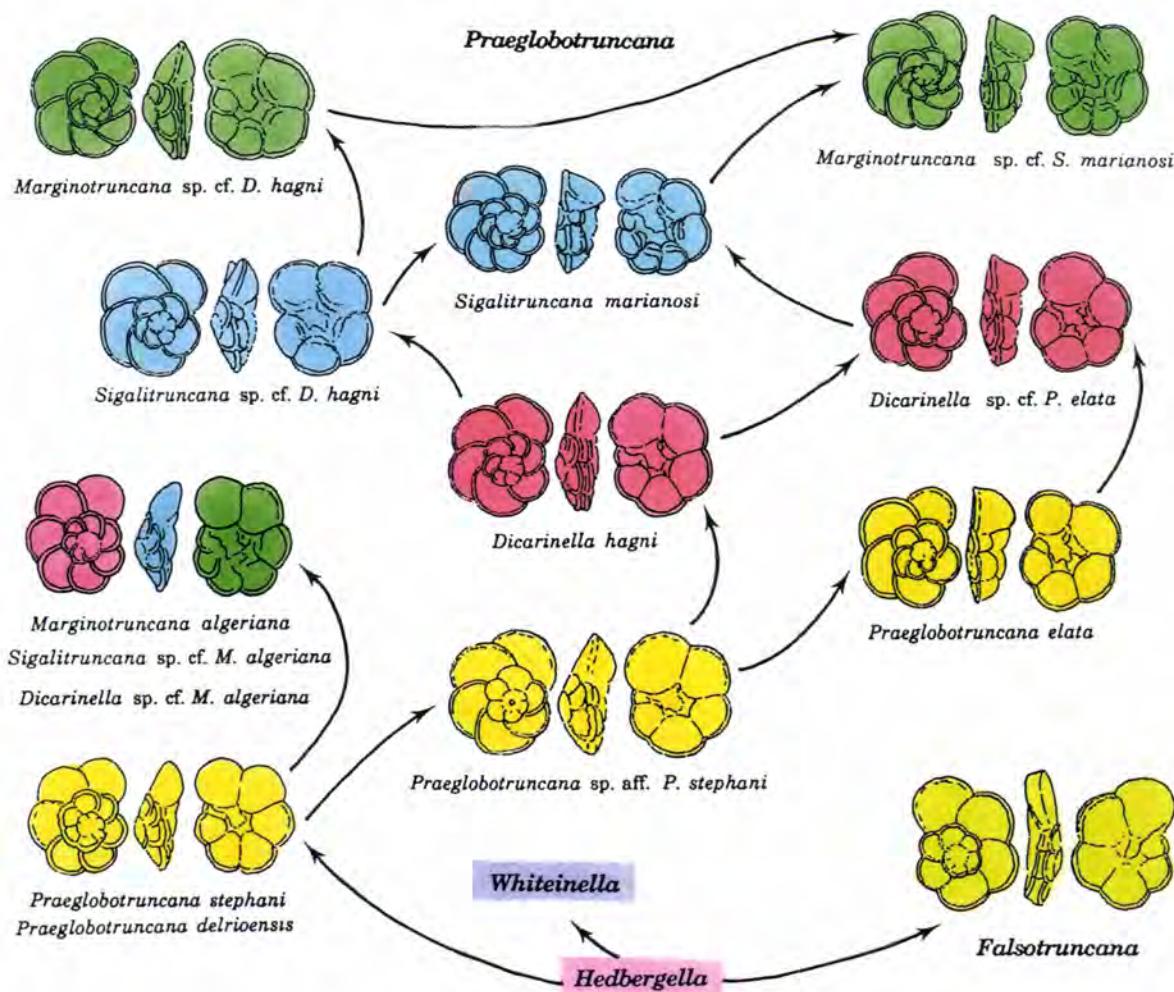


FIGURE 27  
Inferred phylogenetic and morphoserial phyletic relationship among *Praeglobotruncana* morphotypes.

- *Sigalitruanca (Praeglobotruncana) marianosi* (DOUGLAS, 1969).
- *Marginotruanca (Praeglobotruncana)* sp. cf. *S. (P.) marianosi* (DOUGLAS, 1969).

In the SM section and also with the forms that we have just mentioned, we observe more planoconvex forms, with a profile which can be compared to that of the *Praeglobotruncana delrioensis* (PLUMMER) topotype figured by ROBASZYNKI, CARON and EWGP (1979, pl. 43, fig. 2) or the hypotype of *Dicarinella hagni* (SCHEIBNEROVA) of ROBASZYNKI, CARON and EWGP (1979, pl. 56, fig. 1). These forms, not differentiated from the last ones, are the nexus between them and others very planoconvex, detected from the first fossiliferous samples of the HM section and, very occasionally, from the samples of the SM section.

The forms of this type, which by their characteristics can be assigned to the morphogenus *Praeglobotruncana*, are identical to *Dicarinella elata* LAMOLDA, according to the original description and figuration. Using the criteria adopted here, the holotype and some paratypes of the form of LAMOLDA would be *Praeglobotruncana*, while the other paratypes (e.g., text fig. 3) could be identified as *Dicarinella*. Forms with these characteristics also exist in our material and we have called them *Dicarinella* sp. cf. *P. elata* (LAMOLDA). It should also be mentioned here that a synonymy of the form of LAMOLDA (recognized by him, 1977) with *Globotruncana carpathica* SCHEIBNEROVA, 1963, is possible.

The equivalent forms to those cited, but with characteristics of *Sigalitruanca* or *Marginotruanca*, are also present in the section HM, but not in their first fossiliferous levels. The single-keeled forms are very similar to *Sigalitruanca marianosi* (DOUGLAS); we have not found any specific name suitable for the two-keeled ones, and have chosen to call them *Marginotruanca* sp. cf. *Sigalitruanca marianosi* (DOUGLAS). Lastly we would like to mention that all the possible intermediate forms between these ones and the *Dicarinella hagni* subgroup exist (Fig. 27).

#### 6.2.10. Subgenus *Marginotruanca*

- Intermediate forms between *Whiteinella* and ?*A. (M.) blowi* PESSAGNO, 1967.
- Intermediate forms between *Whiteinella* and ?*A. (M.) cretacea* (d'ORBIGNY, 1840).
- ?*Archaeoglobigerina (Marginotruanca) blowi* PESSAGNO, 1967.
- ?*Archaeoglobigerina (Marginotruanca) cretacea* (d'ORBIGNY, 1840).
- *Dicarinella (Marginotruanca)* sp. cf. ?*A. (M.) cretacea* (d'ORBIGNY, 1840).
- Intermediate forms between ?*A. (M.) cretacea* (d'ORBIGNY, 1840)-*D. (M.)* sp. cf. ?*A. (M.) cretacea* (d'ORBIGNY, 1840) and the subgroup of *D. (M.) concavata* (BROTZEN, 1934).
- *Dicarinella (Marginotruanca) primitiva* (DALBIEZ, 1955).
- *Dicarinella (Marginotruanca) concavata* (BROTZEN, 1934).
- *Marginotruanca (Marginotruanca) marginata* (REUSS, 1845).
- Intermediate forms between all the previous ones and the subgroup of *M. (M.)* sp. cf. *D. (M.) concavata* (BROTZEN, 1936).

- *Marginotruanca (Marginotruanca)* sp. cf. *D. (M.) primitiva* (DALBIEZ, 1955)
- *Marginotruanca (Marginotruanca)* sp. cf. *D. (M.) concavata* (BROTZEN, 1934).

From level HM 304 onwards, there are specimens from the three subgroups of *Whiteinella* which show two incipient rows of pustules, separated by a peripheral band which is variable in width, but is narrow in the majority of specimens. These indications of keels are usually limited to the first chambers of the last whorl. So, individuals of *W. baltica*, *W. aprica*, *W. kingi*, *W. archaeocretacea*, *W. inornata* and *W. gigantea* with two incipient keels, can be recognized.

These forms, which are present during the rest of the Turonian series, are obviously the transition between those of *Whiteinella* and other forms with more genuine keels, identifiable with *Archaeoglobigerina* (morphotypes *A. blowi* PESSAGNO and *A. cretacea* (d'ORBIGNY)) with the following reserves.

According to the original description of *Archaeoglobigerina* and its type species *A. blowi* PESSAGNO, this genus has a primary, interiomarginal, umbilical aperture and a tegilla with infralaminal and intralaminal apertures. The lectotype of *A. cretacea* (d'ORBIGNY) also seems to present an umbilical aperture, according to the figure of BANNER & BLOW (1960). However, the topotypes of *A. blowi* and the hypotype of *A. cretacea*, figured by ROBASZYNKI, CARON and EWGP, 1979 (all proceeding from the same sample) could have an umbilical-extraumbilical aperture, according to the extension of the union zone of the umbilical plate with the wall of the chamber.

If this is certain, we would have to change the description of the genus to include the forms with an umbilical-extraumbilical aperture. Then, the genus *Archaeoglobigerina* would include organisms with two keels and depressed spiral and umbilical sutures.

The majority of our specimens also have the interiomarginal umbilical-extraumbilical aperture (although there are also some with a strictly umbilical aperture) and the apertural structure seems to be constituted by portici in some of them and by tegilla in others. While we are waiting to finish a study on the topotype material of *A. blowi* and *A. cretacea* (this material is still being studied) we prefer not to commit ourselves and to call our forms ?*Archaeoglobigerina blowi* (the equivalent of *W. baltica* and *W. inornata*, with two keels) and ?*Archaeoglobigerina cretacea* (the equivalent of *W. kingi*, *W. aprica*, *W. gigantea* and *W. archaeocretacea*, with two keels).

Before continuing, we should point out the presence among the ?*Archaeoglobigerina* and among the intermediate forms with *Whiteinella*, of individuals with incipient characteristics of *Marginotruanca*, consisting of the beginning of an adumbilical ridge in the last chamber.

All the forms of the group indicated until now present depressed spiral sutures, but there are others, where a part of such sutures begins to be marked out by a row of pustules (the hypotype of *A. cretacea* figured by ROBASZYNKI, CARON and EWGP, 1979, is a specimen of this type). Such forms constitute the transitions to others which have raised spiral sutures although they present the ?*Archaeoglobigerina* umbilical side.

Organisms with these characteristics were represented by LINARES (1977) under the denomination of *A. cf. cretacea* and by PESSAGNO (1967, at the least in a part) and EL-NAGGAR (1971,

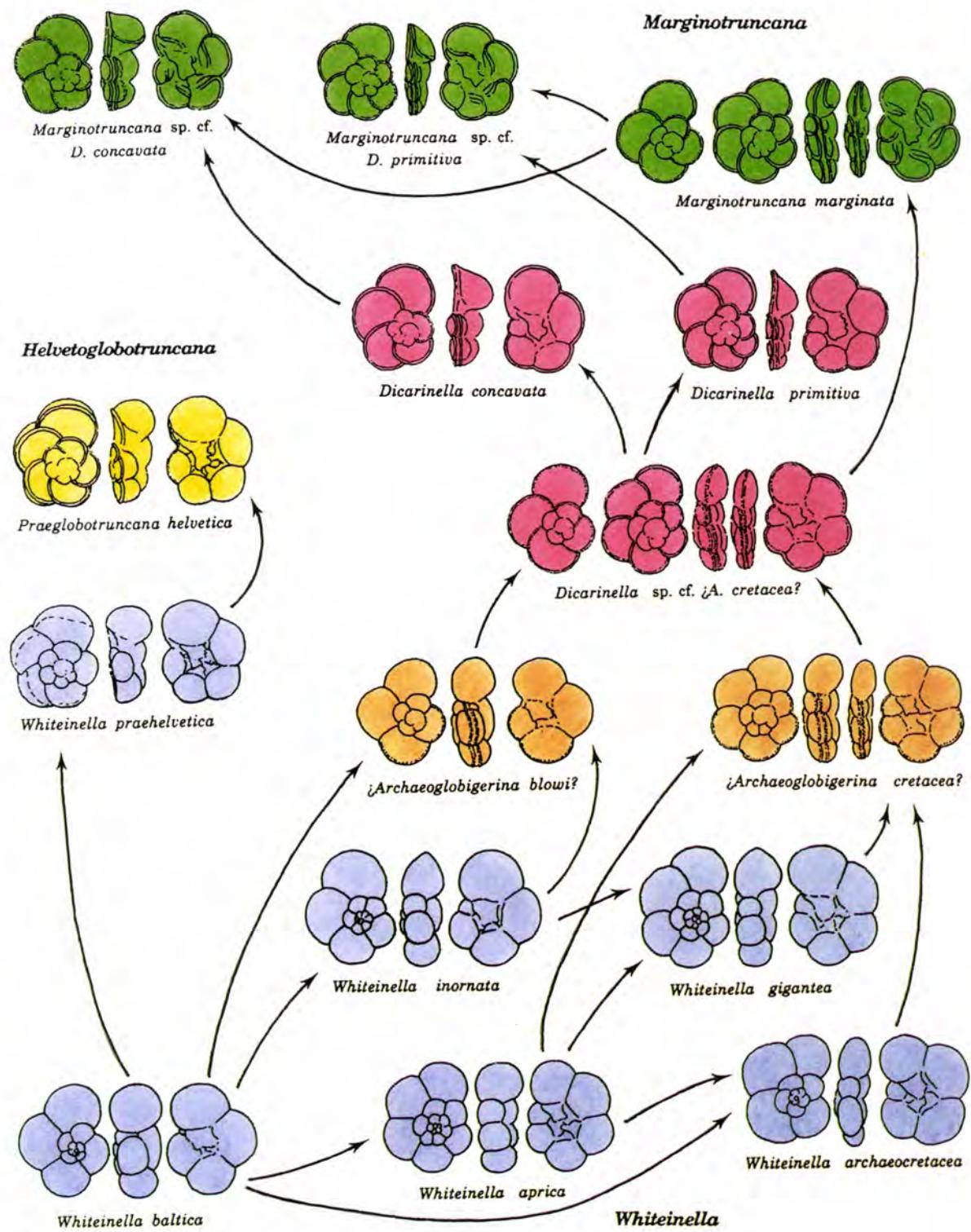


FIGURE 28

Inferred phylogenetic and morphoserial phyletic relationship among *Whiteinella* (part), *Marginotruncana* and *Helvetoglobotruncana* morphotypes.

at the least in a part) under the denomination *A. cretacea*. Morphologically, those forms can be considered as *Dicarinella*, so they have been identified as *D. sp. cf. ?A. cretacea* (d'ORBIGNY).

The forms from the group of *Dicarinella concavata* [*D. primitiva* (DALBIEZ, 1955), *D. concavata* (BROTZEN, 1936) and *D. asymetrica* (SIGAL, 1952)] have the chambers of the last whorl plano-convex to concavo-convex and the penultimate whorl chambers are subspherical. However, the first chambers of the last whorl can continue being subspherical in some individuals of the group; that is the case in the lectotype of *D. concavata* (KUHRY, 1970). If the *?Archaeoglobigerina*, the *Dicarinella* sp. cf. *?A. cretacea* (in both cases, morphotypes of rounded periphery as *W. aprica* and morphotypes of compressed elliptical periphery, as *W. archaeocretacea*) and the pair *D. primitiva*, *D. concavata*, are compared, it is easy to imagine a morphoseries in which the chambers of the last whorl, from an axial view, would change from rounded or elliptical to plano-convex (or even concavo-convex); the individuals with similar characteristics to the lectotype of *D. concavata* would be the intermediate terms of this morphoseries. In a certain way, there were an omen of this trend in the *W. inornata* group, in the forms with ogival asymmetrical final chambers.

In the Kalaat Senan materials, shortly after the appearance of *?Archaeoglobigerina*, *Dicarinella* sp. cf. *?A. cretacea* and forms (*?Archaeoglobigerina* and *Dicarinella* types) with the final chamber or the two final ones tending to a plano-convex begin to be detected. In the distribution chart, we have identified them as intermediate forms between *?Archaeoglobigerina* and the *D. concavata* subgroup. Nearly immediately afterwards, individuals assimilated to *D. primitiva* (DALBIEZ) are located and after that, others can be identified without any difficulty as *D. concavata*, if we compare them with the figures of the lectotype. The latter forms are very scarce and they appear sporadically along the rest of the Turonian materials. We have to wait until more recent levels (HRA section), in order for them to be abundantly found.

In view of what has been found, our hypothesis is somehow different from the usually accepted one, since the work of DALBIEZ (1955). Instead of thinking that the ancestral of the species *D. concavata* is another species of *Dicarinella* with a less convex umbilical side [*D. primitiva* (DALBIEZ) or *D. indica* (JACOB & SASTRY), but this is another problem], we think of a lineage, including, at the same time, forms with an axial periphery which would vary from rounded to elliptical compressed. As time passes, new characteristics in the organisms of the phylum would appear: the two keels, the raised spiral sutures and the final planoconvex chambers. From this point of view, *D. primitiva* and *D. concavata* would simply be morphotypes of the phylum, one with a rounded, the other with a compressed periphery and both possessing two keels, raised spiral sutures and planoconvex final chambers. Those Turonian *D. concavata* would be but "failed intents", changes sometimes developed iteratively but which did not get fixed or did not become frequent.

Finally, and as we have already shown, certain *?Archaeoglobigerina* and their intermediate forms with *Whitinella*, may display some of the characteristics of *Marginotruncana*. This feature develops, in a more open way, in specimens with some chambers (or in all of them) showing characteristics of *Dicarinella*; the result is a *Marginotruncana*, from the morphological and also the phylogenetic point of view. The forms with these characteristics corresponding to

*Dicarinella* sp. cf. *?A. cretacea* belong to *Rosalina marginata* (REUSS) (according to the neotype of JIROVA, 1956). It should be indicated that in the samples containing *M. marginata* (fairly rare) and the forms with a rounded periphery, corresponding to the morphoseries of the group of *W. baltica* and similar to the ones figured by STEMPROKOVA-JIROVA (1970) or by ROBASZYNSKI, CARON and EWGF (1979), there are other specimens with a more compressed periphery corresponding to the morphoseries of *W. archaeocretacea*. It is also necessary to point out that, in these forms, the separation between the keels varies considerably, the principal aperture can be nearly umbilical in some individuals and the apertural structure can be a tegilla.

The characteristics of *Marginotruncana* also develop among the forms with final plano-convex chambers; we have chosen to call this *Marginotruncana* sp. cf. *D. concavata* and *M. sp. cf. D. primitiva*. As well as the intermediate specimens between *Dicarinella* and *Marginotruncana*, there are other intermediate ones among the different types of *Marginotruncana* indicated (Fig. 28).

#### 6.2.11. Advanced *Sigalitruncana* and *Marginotruncana*

- *Sigalitruncana sigali* (REICHEL, 1950).
- *Sigalitruncana undulata* (LEHMANN, 1963).
- *Marginotruncana* sp. cf. *S. undulata* (LEHMANN, 1963).
- *Marginotruncana renzi* (GANDOLFI, 1942).
- *Marginotruncana* sp. 1. cf. *M. renzi* (GANDOLFI, 1942).
- *Marginotruncana* sp. 2. cf. *M. renzi* (GANDOLFI, 1942).
- *Marginotruncana paraconcavata* (PORTHAULT, 1970).
- *Marginotruncana* sp. cf. *M. paraconcavata* (PORTHAULT, 1970).

Now, we are going to look at a presumably heterogeneous group, that seems to include forms belonging to some of the subgenera already mentioned, but we must examine them more closely, before we try to ascribe them to these subgenera.

In the previous pages, we have talked about a series of forms which can be assigned by their characteristics to the morphogenus *Sigalitruncana*: *S. sp. cf. M. cf. schneegansi* (indicated in the distribution chart under the denomination *P. kalaati/M. cf. schneegansi*), *S. pileoliformis*, *S. sp. cf. M. algeriana*, *S. sp. cf. D. hagni* and *S. mariannosi*.

All of these forms have in common that only the umbilical side bears some of *Marginotruncana*'s characteristics: some chambers present adumbilical ridges and/or umbilical sutures convex towards the front, marked by pustules, but there is no clear, prominent, continuous pustulous ridge, which marks out the keel, the suture, and the adumbilical region of all the chambers. Such absences are due to the covering of the sutural ridge by the following chamber, or the fact that the suture is unmarked by pustules, or that the adumbilical ridge is weak or even absent.

*Sigalitruncana sigali* (REICHEL) is differentiated from all the forms that we have previously mentioned because it displays a pustulous ridge in all the chambers of the last whorl. At first, it would seem logical to think that this form would have its origin in the lineage of some of the other morphotypes of *Sigalitruncana*, because of the accentuation of the umbilical characteristics of *Marginotruncana*. What would be the lineage in question? If we compare the figures of the

holotype of *S. sigali* with the others of *Sigalitruncana*, it seems obvious that the most likely suggestions are *S. sp. cf. M. algeriana* and *S. sp. cf. M. schneegansi* (forms with a small expansion rate). But a revision of the bibliography shows that under the denomination of *S. sigali*, organisms with different characteristics have been represented, and some of them could be members of other lineages, because of the form of the chambers from a spiral view, the expansion rate of the spire and the biconvexity.

In short, we suspect that under this denomination of *S. sigali* (REICHEL) a polyphyletic group with partially homoeomorphical forms is designated. We think however that it is too soon to look more closely at the problem in light of the data we have; the only comment we will make is that all these types may have been present in Kalaat Senan.

A form close to *S. sigali*, from a morphological point of view, is *S. undulata* (LEHMANN); the main difference between them is the undulated spiral surface of the chambers. *S. undulata* also has umbilical sutures which are usually V-shaped, while those of *S. sigali* tend to be U-shaped. In addition, the spiral sutures of *S. undulata* are oblique and their expansion rate is greater. If we compare it with the primitive *Sigalitruncana* it seems that those of *S. sp. cf. M. cf. schneegansi* are the most similar, but for the time being, we prefer to leave *S. undulata* and *S. sigali* in the same group, until we have been able to make a more detailed study.

A phenomenon that we can point out, detected from the level HM 332, is the appearance of *S. undulata* with two keels more or less separated (all possible intermediate forms between *S. undulata*, single-keeled and the forms with two separated keels exist there). The interest in such forms comes from their possible (and highly likely) relationship with *Contusotruncana fornicata* (PLUMMER) (LINARES, 1977). If further studies support the verosimility of this group of relationships according to our intuition (*S. sp. cf. M. cf. schneegansi-S. undulata-M. sp. cf. S. undulata-Contusotruncana*), we would have to reject the phylogenetic subgenus *Falsomarginotrunca* and would have to include their forms in the phylogenetic subgenus *Contusotruncana*.

In the same way as what occurs to *Sigalitruncana*, *Marginotrunca* with more advanced characteristics than those mentioned until now (with the exception of *M. (R.) pseudolinneiana* and its derivatives) is also detected. Among them, the most common forms are those with two keels touching or very close together in the first chambers of the last whorl and a single keel in the final chambers. Such forms can be identified as *Marginotrunca renzi* (GANDOLFI) (for a discussion on the statute of this species, see LINARES, 1977 or ROBASZYNKI, CARON and EWGF, 1979; in this work we accept the point of view of CARON, 1966).

If we compare the illustrations of the holotypes of *M. renzi* and *S. sigali* provided by CARON (1966 and 1977, respectively) we will see few important differences except, of course, for the keel structure. This could support the existence of the evolutive relation between *S. sigali* and *M. renzi* first proposed by GANDOLFI (1957) and supported by many authors. But such a relationship does not necessarily have to consist of a lineage producing another one and the two coexisting, but can simply consist of both types being morphotype of the same evolutive line.

In this way, if we suppose, for example, that *S. sigali* really belongs to the evolutive line of *P. stephani* (one of the possibilities indicated), it would not make any sense to say

that *M. renzi* derives from *S. sigali* by the formation of two keels or that *M. renzi* derives from *M. algeriana* by the accentuation of the characteristics of *Marginotrunca*. The three would be morphotypes in an evolutive line which started, as far as we know, with *Praeglobotruncana delrioensis* (PLUMMER).

Analogically to *S. sigali*, it seems evident that under the name *M. renzi*, organisms which belong to different evolutive lines have been figured in the literature, and it seems that the forms we identified as *M. renzi* belong to several evolutive lines, according to the different expansion rates and morphologies of the chambers, from a spiral view. We have also preferred to delay the study of this problem; we shall just mention that the most common forms in Kalaat Senan seem to be related to *M. cf. schneegansi*.

In the range chart (Fig. 17), we have separated two morphotypes of *M. renzi* for different reasons. One of them, *M. sp. 1 cf. M. renzi*, includes forms which are similar to *M. renzi*, but which have two keels in all the chambers of the last whorl. If the morphoseries *Sigalitruncana-Marginotrunca* is valid, these forms should be posterior to those of *M. renzi* s.str., but in fact appear before them. The other morphotype, *M. sp. 2 cf. M. renzi*, is a form with few chambers, and seems to be related to *M. cf. schneegansi*. The interest in this form lies in its similarity with *Globotruncana mariei* BANNER & BLOW, a form that, apart from being situated in the base of the homonymous Senonian group, can otherwise be the ancestor of the *Globotruncana arca* CUSHMAN group (ROBASZYNKI *et al.*, 1983).

Another form, close to *M. renzi* and also present in the Turonian of Kalaat Senan, is *Marginotrunca paraconcavata* PORTHAULT, distinguishable from the first one by its plano-convex axial profile. We have also differentiated a form with few chambers, equivalent therefore, to *M. sp. 2 cf. M. renzi*, but plano-convex, and we have called it *M. sp. cf. M. paraconcavata*.

Other advanced *Marginotrunca*, such as *M. angusticarinata* (GANDOLFI) and *M. sinuosa* PORTHAULT, are not present in the Turonian of Kalaat Senan, but are found in the materials of the Lower Senonian.

#### Annex

*Praeglobotruncana* (Falsomarginotrunca) *kalaati*  
GONZÁLEZ DONOSO & LINARES, n. sp.  
Pl. 4, figs. 5-7, Pl. 5, figs. 1-2,5.

#### Description :

- Test trochospiral.
- Axial outline biconvex to convexo-concave. First chambers of the last whorl are rounded, elliptical or ogival, in lateral view, and final ones are ogival or angulous. One keel in the first chambers of the last whorl or in all of them.
- Spiral side with 2.5 to 3 whorls. Expansion rate between 2 and 3. Between 4 and 6 chambers in the last whorl, separated by nearly radial to rather inclined, nearly straight to slightly arcuate and depressed to raised sutures. These raised sutures are specially common towards the end of the penultimate whorl and the beginning of the last whorl. Spiral outline nearly always lobate, sometimes very lobate.

# PLATE 27

## Morphotypes of the phylogenetic subgenus *Whiteinella*, *Whiteinella baltica* subgroup

- Fig. 1a, b, c. — *Whiteinella baltica* DOUGLAS & RANKIN, from HM 155.5, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 155.5-1-3.  
Note the last whorl with 4 chambers.
- 2a, b, c. — Intermediate form between *Whiteinella baltica* DOUGLAS & RANKIN and *Whiteinella aprica* (LOEBLICH & TAPPAN), from HM 155.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 155.5-2-3.  
Note the last whorl with 5 chambers and compare with figs. 1 and 4.
- 3a, b, c. — Intermediate form between *Whiteinella baltica* DOUGLAS & RANKIN and *Whiteinella kingi* (TRUJILLO), from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 135.7-5-1.  
Note the last whorl with 5 chambers, the last chamber with a tendency towards an ogival shape (transition to *W. inornata* subgroup) and compare with figs. 1 and 5.
- 4a, b, c. — *Whiteinella aprica* (LOEBLICH & TAPPAN), from HM 296, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 296-5-4.  
Note a rudimentary meridional pattern in the n-3 chamber and compare with figs. 1 and 2.
- 5a, b, c. — *Whiteinella kingi* (TRUJILLO), from HM 161.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 161.5-3-1.  
Compare with figs. 1 and 3.
- 6a, b, c. — *Whiteinella aprica* (LOEBLICH & TAPPAN), from HM 155.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 155.5-3-1.  
Compare with figs. 1, 3 and 5.
- 7a, b, c. — *Whiteinella aprica* (LOEBLICH & TAPPAN), form with lobate periphery, from HM 235, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 235-4-1.  
Note the very lobate periphery in the last chambers, oblique spiral sutures and wide rectangular porticus.  
Compare with Plate 28, fig. 8 and plate 30, figs. 1 and 2.
8. — *Whiteinella baltica* (DOUGLAS & RANKIN), form globigerina-like, from HMT 646, Aleg Formation, Late Turonian, umbilical view  $\times 92.5$ , Univ. Málaga, HMT 646-1-1.  
Note the nearly umbilical primary aperture.
- 9a, b, c. — *Whiteinella paradubia* (SIGAL), from HM 254, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 254-1-1.  
Note the high trochospire.

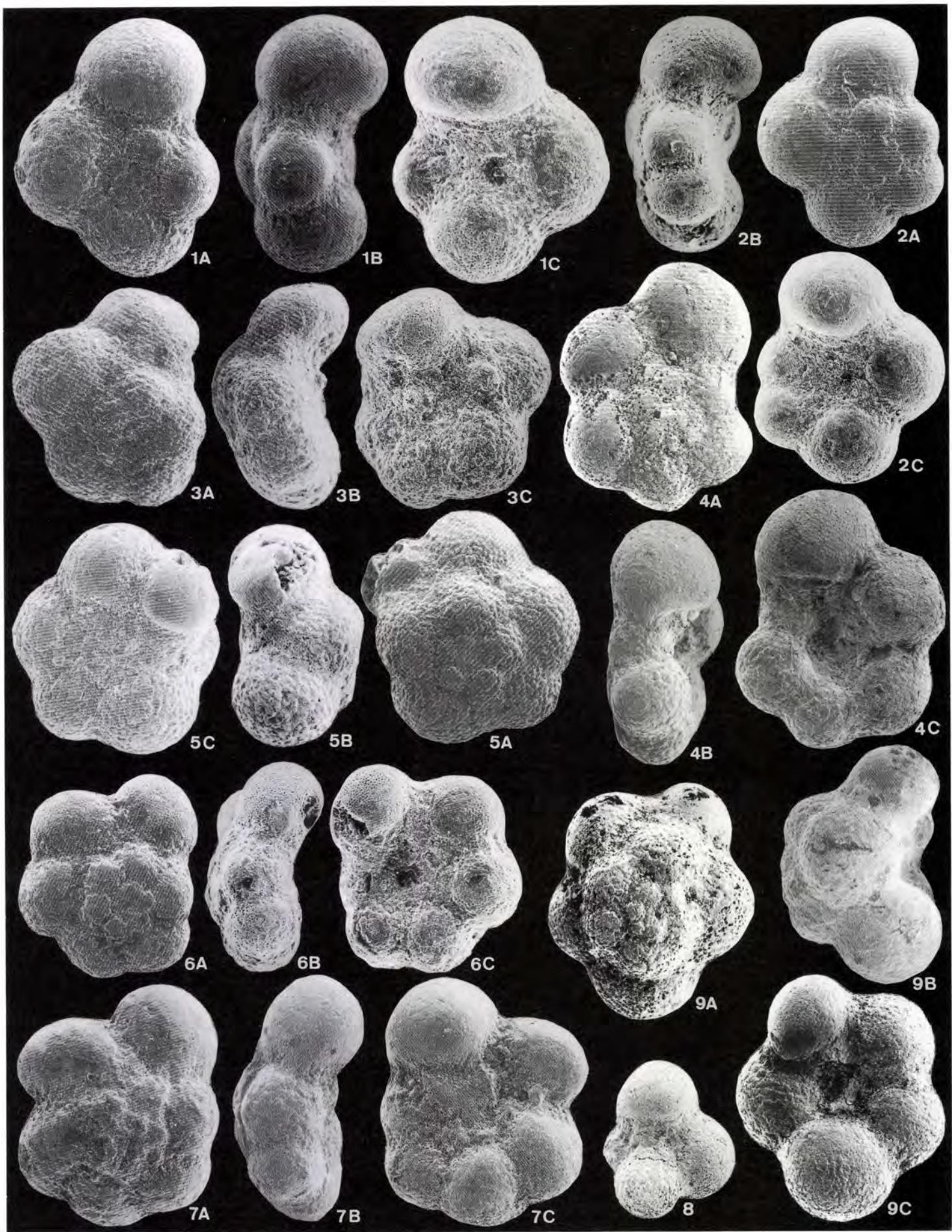


PLATE      **28**

**Morphotypes of the phylogenetic subgenus *Whiteinella*, *Whiteinella inornata* subgroup**

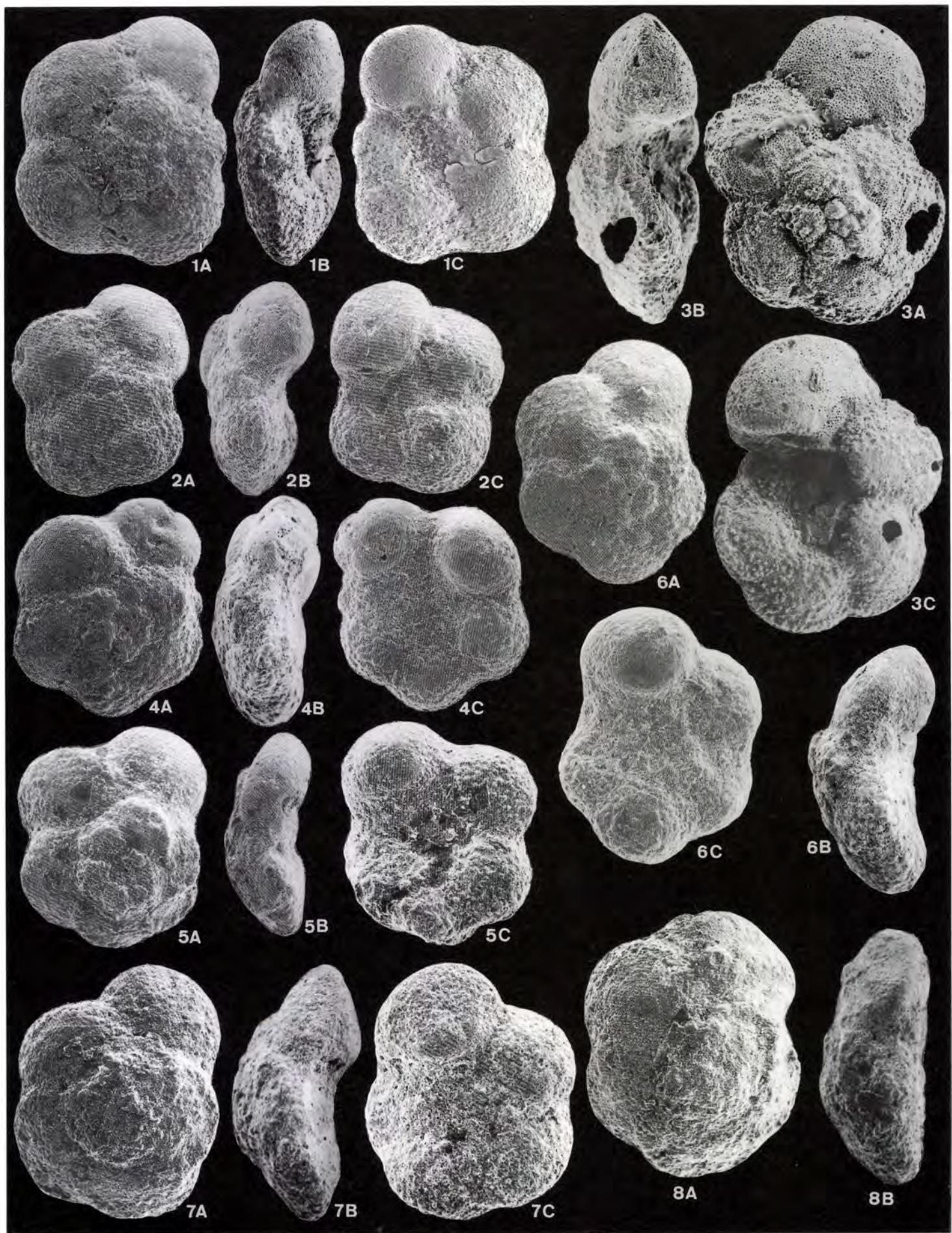
- Fig.1a, b, c. — Intermediate form between *W. baltica* subgroup and *Whiteinella gigantea* (LEHMANN), from HM 462, Aleg Formation, Late Turonian, spiral side  $\times$  92.5, Univ. Málaga, HM 462-2d-3.  
Note in axial view, the last chamber outline with a shape between rounded and ogival.
- 2a, b, c. — *Whiteinella gigantea* (LEHMANN), from HM 474, Aleg Formation, Late Turonian, spiral side  $\times$  92.5, Univ. Málaga, HM 474-9-1.  
Specimen with very oblique spiral sutures. Compare with *W. aumalensis* form 5.
- 3a, b, c. — *Whiteinella gigantea* (LEHMANN), from HMT 610, Aleg Formation, Late Turonian, spiral view  $\times$  110, Univ. Málaga, HMT 610-1-1.  
Compare with Plate 31, fig. 1 and Plate 27, fig. 4.
4. — Intermediate form between *Whiteinella gigantea* (LEHMANN) and *Praeglobotruncana kalaati* n. sp., from HM 482, Aleg Formation, Late Turonian, axial view  $\times$  92.5, Univ. Málaga, HM 482-5-1.  
Note the incipient peripheral ridge.
5. — *Whiteinella gigantea* (LEHMANN), from HM 207.5, Aleg Formation, Middle Turonian, axial view  $\times$  92.5, Univ. Málaga, HM 207.5-4-2.
- 6a, b, c. — Intermediate form between *Whiteinella gigantea* (LEHMANN) and *Praeglobotruncana kalaati* n. sp., from HMT 606, Aleg Formation, Late Turonian, spiral view  $\times$  92.5, Univ. Málaga, HMT 606-2-2.  
Note the rudimentary peripheral ridge and compare with fig. 5 and Plate 31, fig. 2.
- 7b,c. — *Whiteinella inornata* (BOLLI), from HM 446, Aleg Formation, Late Turonian, umbilical view  $\times$  92.5, Univ. Málaga, HM 446-3-1.
- 8a, b, c. — *Whiteinella gigantea* (LEHMANN), form with lobate periphery, from HMT 602, Aleg Formation, Late Turonian, spiral view  $\times$  92.5, Univ. Málaga, HMT 602-3-2.  
Compare with Plate 27, fig. 7 and Plate 30, fig. 2.
- 9a, b, c. — *Whiteinella inornata* (BOLLI), from HM 464, Aleg Formation, Late Turonian, spiral view  $\times$  92.5, Univ. Málaga, HM 462-4d-1.  
Compare with Plate 27, fig. 1.



PLATE      **29**

**Morphotypes of the phylogenetic subgenus *Whiteinella*, *Whiteinella aumalensis* subgroup**

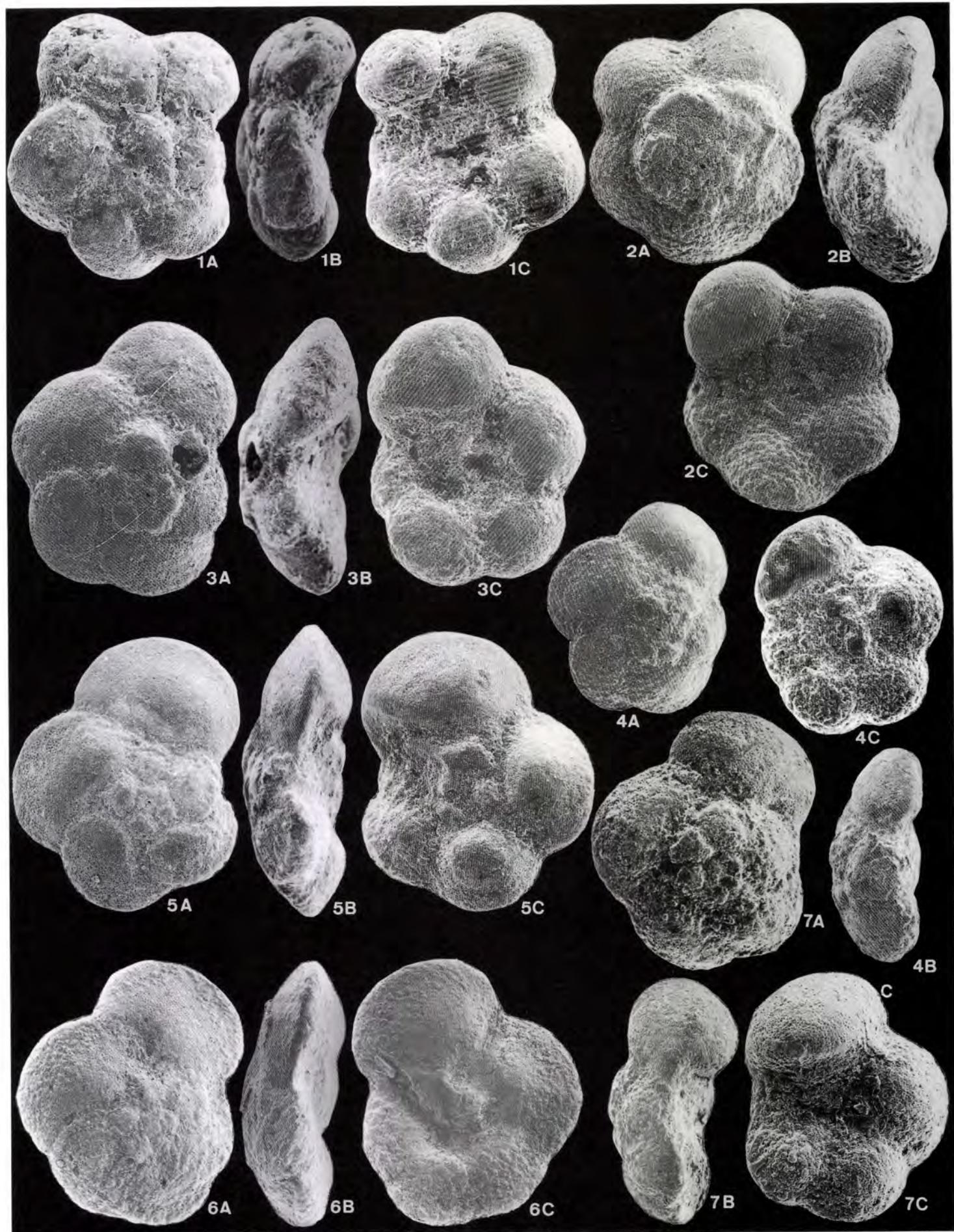
- Fig. 1a, b, c. — *Whiteinella archaeocretacea* PESSAGNO, from HM 332, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 332-3-1.  
 Note the peripheral pustules concentration, announcing the keel.
- 2a, b, c. — *Whiteinella archaeocretacea* PESSAGNO, from HM 133.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 133.5-4-2.  
 Note the peripheral pustules concentration, almost forming a keel.
- 3a, b, c. — *Whiteinella aumalensis* (SIGAL), form 4, with characteristics announcing *Sigalitrunca*, from HM 493.5, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 493.5-2-3.  
 Note the somewhat sigmoidal umbilical sutures, the incipient adumbilical ridges and the first chambers' spiral sutures marked by pustules.
- 4a, b, c. — Intermediate form between *Whiteinella baltica* subgroup and a form halfway between *Whiteinella aumalensis* (SIGAL), form 2 and form 4, from HM 166, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 166-3-3.
- 5a, b, c. — Intermediate form between *Whiteinella aumalensis* (SIGAL), form 2 and *Whiteinella aumalensis* (SIGAL), form 4, with characteristics announcing *Dicarinella* or *Praeglobotruncana*, from HM 204, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 204-7-1.  
 Note the peripheral pustules concentration and some raised spiral sutures.
- 6a, b, c. — Intermediate form between *Whiteinella gigantea* (LEHMANN) and a form halfway between *Whiteinella aumalensis* (SIGAL) form 2 and form 4, from HM 166, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 166-3-2.  
 Note the convexo-concave lateral outline, with the chambers' periphery rounded to ogival and the radial spiral sutures (characteristic of form 4).
- 7a, b, c. — Intermediate form between *Whiteinella aumalensis* (SIGAL) form 1 and *Whiteinella aumalensis* (SIGAL) form 2, with a tendency towards *Praeglobotruncana*, from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 135.7-9-1.  
 Note the slightly lobate spiral outline, the chambers' shape in spiral view and the incipient keel and slightly raised spiral sutures.
- 8a, b, c. — *Whiteinella aumalensis* (SIGAL) form 1 with incipient features of *Praeglobotruncana*, from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 135.7-8-1.  
 Note the almost subcircular outline, spiral sutures with perpendicular insertion, the incipient keel and slightly raised spiral sutures.



## PLATE 30

Morphotypes of the phylogenetic subgenera *Whiteinella*, (*W. aumalensis* subgroup)  
(morphological genus *Praeglobotruncana*) and *Falsomarginotruncana*

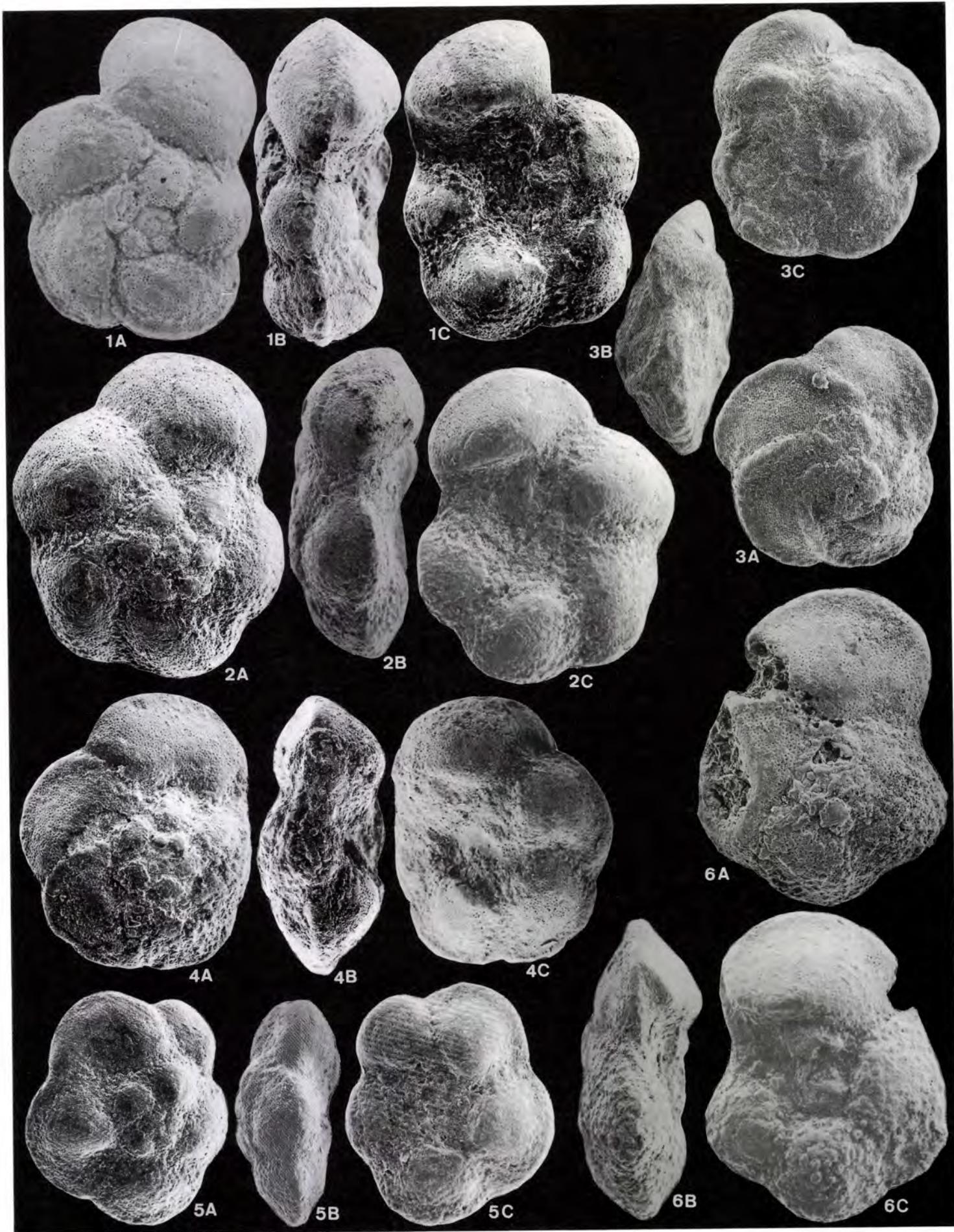
- Fig. 1a, b, c. — *Whiteinella aumalensis* (SIGAL) form 6, from HM 200, Aleg Formation, Middle Turonian, spiral view  $\times 85$ , Univ. Málaga, HM 200-4-1.  
Note the very lobate spiral outline and compare with figs. 2 and 3.
- 2a, b, c. — Intermediate form between *Whiteinella gigantea* (LEHMANN) and *Whiteinella aumalensis* (SIGAL) form 3, with characteristics announcing *Dicarinella*, from HM 222, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 222-6-1.  
Note the very lobate spiral outline, convexo-concave lateral outline with the chambers' periphery rounded to ogival and two rows of pustules.
- 3a, b, c. — *Whiteinella aumalensis* (SIGAL) form 5, from HM 200, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 200-3-2.  
Note the high expansion rate.
- 4a, b, c. — *Whiteinella aumalensis* (SIGAL) form 5, with a tendency towards *Praeglobotruncana*, from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 135.7-6-1.  
Note the rudimentary keel and some slightly raised spiral sutures.
- 5a, b, c. — *Praeglobotruncana kalaati* n. sp., holotype, from HM 242, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 242-4-7.  
Specimen of the *W. aumalensis* form 5 morphoseries : compare with figs. 3 and 4; note a damaged porticus.
- 6a, b, c. — *Praeglobotruncana kalaati* n. sp., paratype, from HM 254, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 254-3-1.  
Specimen of the *W. aumalensis* form 5 morphoseries; note a porticus.
- 7a, b, c. — *Praeglobotruncana kalaati* n. sp., paratype, from HM 470, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 470-9-1.  
Specimen of the intermediate between *W. inornata* and *W. archaeocretacea* morphoseries.



## PLATE 31

Morphotypes of the phylogenetic subgenus *Falsomarginotruncana* (morphological genera *Praeglobotruncana* and *Sigalitruncana*)

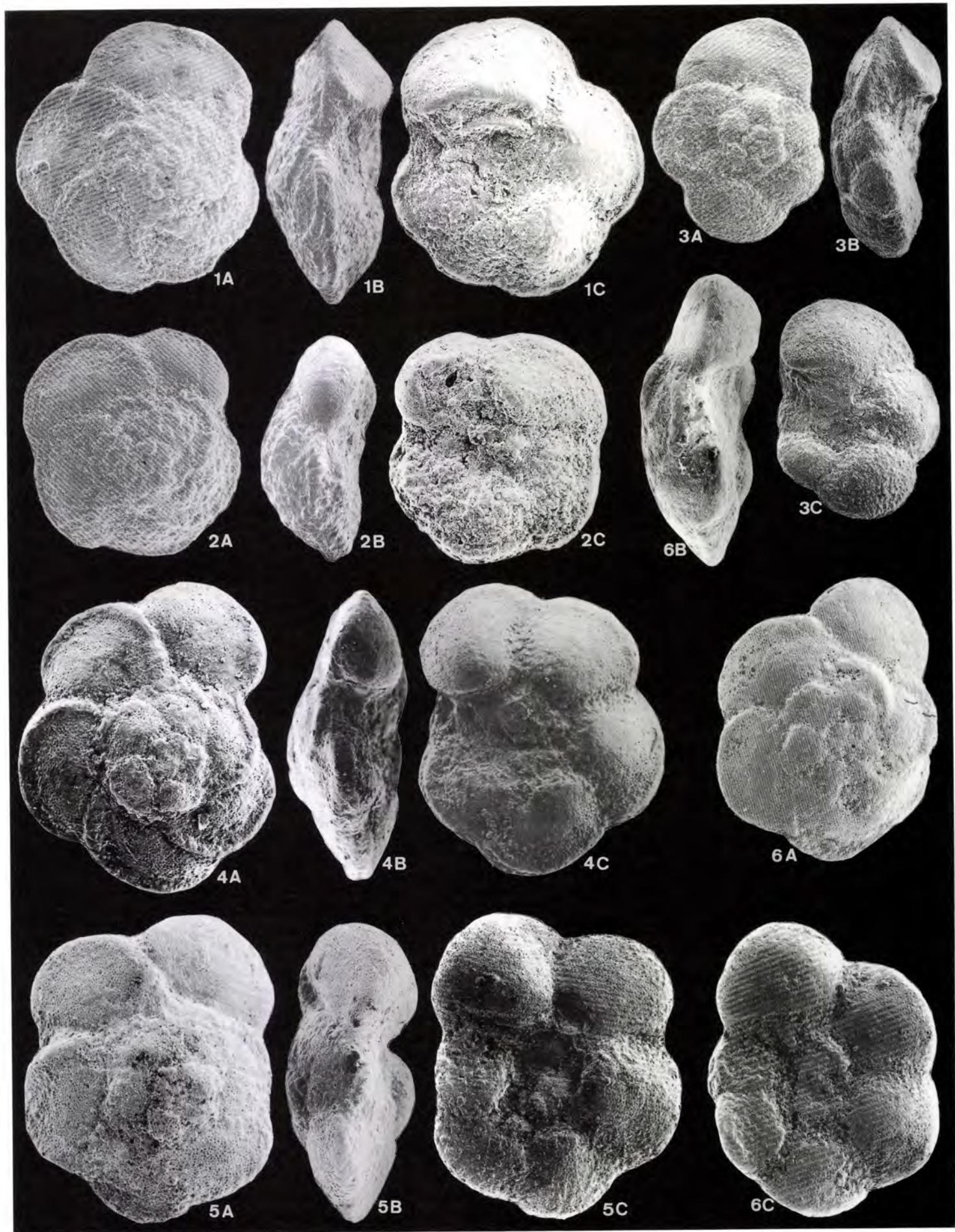
- Fig. 1a, b, c. — *Praeglobotruncana kalaati* n. sp. tending to *Dicarinella*, from HR 144, Aleg Formation, Coniacian, spiral view  $\times 110$ , Univ. Málaga, HR 144-8-1.  
 Specimen of the *W. gigantea* morphoseries. Note the tendency towards the two keels differentiation.
- 2a, b, c. — *Praeglobotruncana kalaati* n. sp., paratype, from HMT 610, Aleg Formation, Upper Turonian, spiral view  $\times 110$ , Univ. Málaga, HMT 610-1-3.  
 Specimen of the *W. gigantea* morphoseries.
- 3a, b, c. — *Sigalitruncana* sp. cf. *Marginotruncana* cf. *schneegansi* (SIGAL), from HM 230, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 230-2-1.  
 Specimen of the *W. aumalensis* form 5 morphoseries. Note some raised umbilical sutures and adumbilical ridges. Compare with Plate 30, fig. 2 and Plate 32, fig. 1.
- 4a, b, c. — *Sigalitruncana* sp. cf. *Marginotruncana* cf. *schneegansi* (SIGAL), from HM 493.5, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 493.5-3-1.  
 Specimen of the *W. gigantea* morphoseries. Note the more primitive umbilical characteristics than the specimen in fig. 3.
- 5a, b, c. — *Praeglobotruncana kalaati* n. sp., paratype, from HM 616, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 616-7-1.  
 Specimen of the *W. archaeocretacea* morphoseries. Note the beginnings of adumbilical ridges in some chambers.
- 6b, c. — Intermediate form between *Praeglobotruncana kalaati* n. sp. and *Sigalitruncana* sp. cf. *Marginotruncana* cf. *schneegansi* (SIGAL), from HMT 610, Aleg Formation, Late Turonian, umbilical view  $\times 92.5$ , Univ. Málaga, HMT 610-10-1.  
 Specimen of the *W. archaeocretacea* morphoseries. Note the chambers' shape in umbilical view: *Sigalitruncana* in chambers n and n-1, *Praeglobotruncana* in n-2 and n-3. However, the n-2 and n-3 chambers have not developed keels, as in *Whiteinella*.



## PLATE 32

**Morphotypes of the phylogenetic subgenus *Falsomarginotruncana* (morphological genera *Marginotruncana*, *Sigalitruncana*, *Praeglobotruncana* and *Dicarinella*)**

- Fig. 1a, b, c. — *Marginotruncana* sp. cf. *Marginotruncana schneegansi* (SIGAL), from HM 462, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 462-9d-6.  
Specimen of the *W. gigantea* morphoseries. Note two keels in the first chambers of the last whorl and sigmoidal umbilical sutures in the final chambers.
- 2a, b, c. — Intermediate form between *Marginotruncana* sp. cf. *M. schneegansi* (SIGAL) and *Marginotruncana schneegansi* (SIGAL), from HM 462, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 462-9d-2.
- 3a, b, c. — *Sigalitruncana* sp. cf. *Marginotruncana schneegansi* (SIGAL) [Primitive form of *M. schneegansi*], from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-15-2.  
Specimen of the *W. inornata* morphoseries. Note the characteristics of *Sigalitruncana* developed only in the final chambers; the keel is poorly developed in the first chambers of the last whorl.
- 4a, b, c. — Intermediate form between *Praeglobotruncana kalaati* n. sp. and *Dicarinella* sp. cf. *M. schneegansi* (SIGAL) [Primitive form of *M. schneegansi*], from HMT 610, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HMT 610-4-3.  
Specimen of the *W. aumalensis* form 4 morphoseries. Note the two poorly differentiated keels.
- 5a, b, c. — *Marginotruncana schneegansi* (SIGAL), from HM 285, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 285-5-2.  
Specimen of the *W. aumalensis* form 4 morphoseries. Note the two rows of pustules differentiated only in the first chambers and the umbilical characteristics of *Marginotruncana* hardly developed in some chambers (as is typical in this form).
- 6a, b, c. — *Marginotruncana schneegansi* (SIGAL), from HM 254, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 254-2-1.  
Note the expansion rate, smaller than the specimen in fig. 5.



## PLATE 33

**Morphotypes of the phylogenetic subgenera *Falsomarginotruncana*, *Carpathoglobotruncana* and *Dicarinella* ? *oraviensis* group**

- Fig. 1a, b, c. — *Praeglobotruncana* sp. cf. *Praeglobotruncana kalaati* n. sp., form with small expansion rate, from HM 200, Aleg Formation, Middle Turonian, spiral view  $\times 75$ , Univ. Málaga, HM 200-6-2.  
Note the low expansion rate.
- 2a, b, c. — Intermediate form between *Praeglobotruncana* sp. cf. *P. kalaati* n. sp. and *Sigalitruncana* sp. cf. *Marginotruncana schneegansi* (SIGAL) with low expansion rate, from HM 285, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 285-3-4.  
Note the low expansion rate, and the beginnings of raised umbilical sutures and adumbilical ridges.
- 3a, b, c. — *Praeglobotruncana hilalensis* BARR, from HM 148, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 148-1-2.  
Compare with Plate 29, fig. 8. Note the beginnings of adumbilical ridges [a tendency towards *Sigalitruncana pileoliformis* (LAMOLDA)].
- 4a, b, c. — *Praeglobotruncana hilalensis* BARR, from HM 133.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 133.5-5-2.
- 5a, b, c. — *Dicarinella* sp. cf. *Praeglobotruncana hilalensis* BARR, from HM 210, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 210-1-1.  
Note two divergent keels in the first chambers.
- 6a, b, c. — *Dicarinella* ? *oraviensis* (SCHEIBNEROVÁ), from HM 238, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 238-3-1.  
Note the depressed umbilical sutures and two divergent keels. Compare with Plate 29, fig. 5.
- 7a, b, c. — *Marginotruncana* sp. cf. *Dicarinella oraviensis* (SCHEIBNEROVÁ), from HM 238, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 238-4-1.  
Note some raised umbilical sutures and adumbilical ridges. Compare with fig. 6.

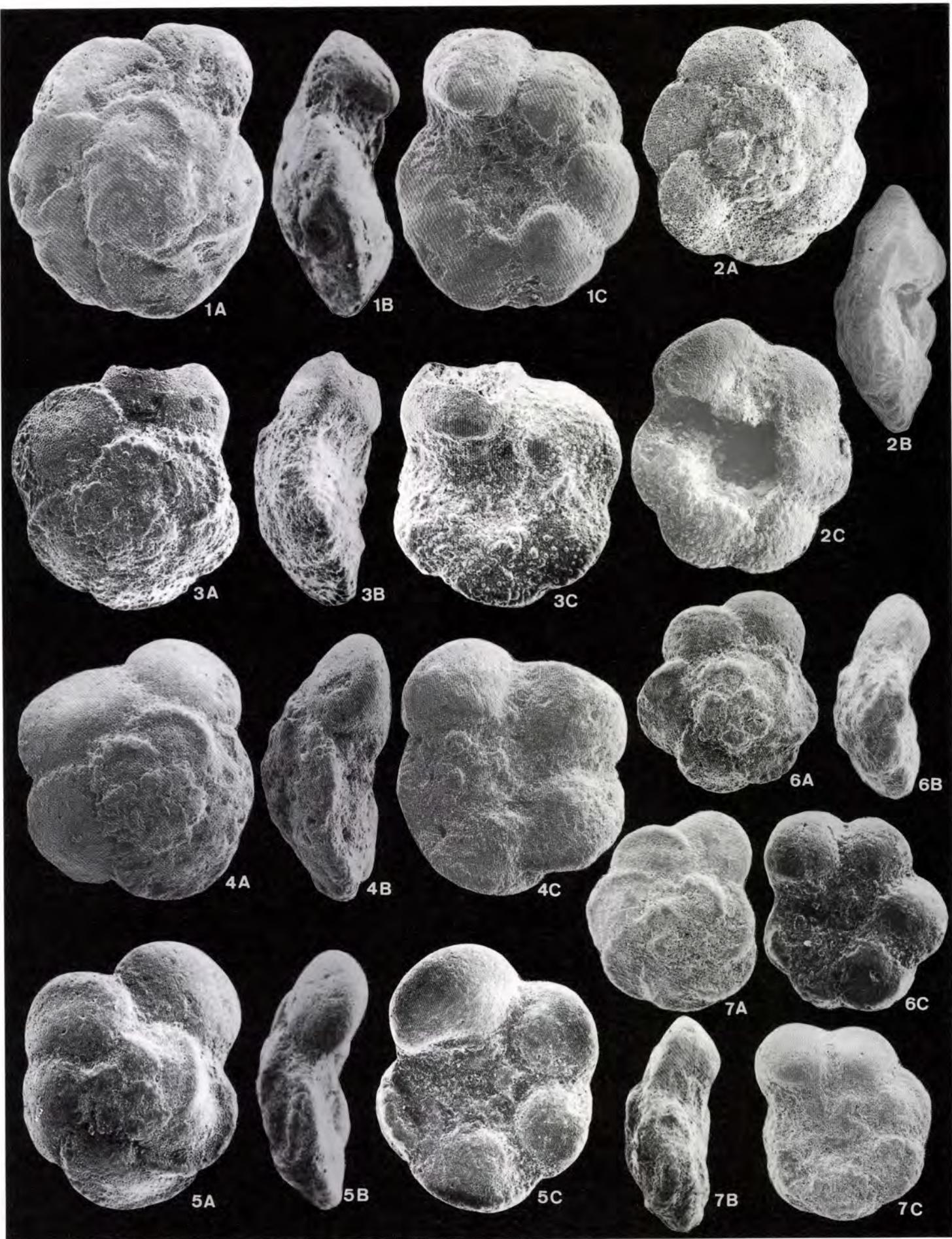


PLATE      **34**

**Morphotypes of the *Dicarinella* ? *oraviensis* group (morphological genera *Dicarinella* and *Marginotruncana*)**

- Fig. 1a, b, c. — *Dicarinella* ? *oraviensis* (SCHEIBNEROVA), from HM 226, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 226-3-2.  
Note the two keels and depressed umbilical sutures.
- 2a, b, c. — *Dicarinella* ? *oraviensis* (SCHEIBNEROVA), or *Dicarinella imbricata* (MORNOD), HM 235, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 235-2-1.  
Note two divergent keels. This specimen could be a convergent form with *D. imbricata* or *D. imbricata* itself. Compare with fig. 1 and Plate 35, fig. 4.
- 3a, b, c. — *Marginotruncana* sp. cf. *Dicarinella* ? *oraviensis* (SCHEIBNEROVA), or *Marginotruncana* sp. cf. intermediate forms between *D. imbricata* (MORNOD) and *D. canaliculata* (REUSS), from HM 210, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 210-1-3.  
Note two separated keels and raised umbilical sutures and adumbilical ridges in some chambers. Compare with Pl. 33 figs. 6 and 7 and Pl. 35, fig. 7.
- 4a, b, c. — *Dicarinella* ? *oraviensis* (SCHEIBNEROVA) from HM 200, Aleg Formation, Middle Turonian, spiral view  $\times 75$ , Univ. Málaga, HM 200-2-2.  
Specimen intermediate between forms with high final expansion rate (as fig. 6) and "normal" forms (as pl. 33, fig. 6). Compare also with Pl. 29, fig. 8.
- 5a, b, c. — *Marginotruncana* sp. cf. *Dicarinella* ? *oraviensis* (SCHEIBNEROVA), from HM 262, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 262-4-1.  
Note the two keels, raised umbilical sutures, perumbilical ridges and apertural plates with distal accessory apertures (tegilla?).
- 6a, b, c. — *Dicarinella* ? *oraviensis* (SCHEIBNEROVA) with high final expansion rate, from HM 133.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 133.5-3-2.  
Note the comparatively greater size of the final chambers. Compare with fig. 4 and also with *Dicarinella* sp. cf. *P. hilensis* in Pl. 33, fig. 5.

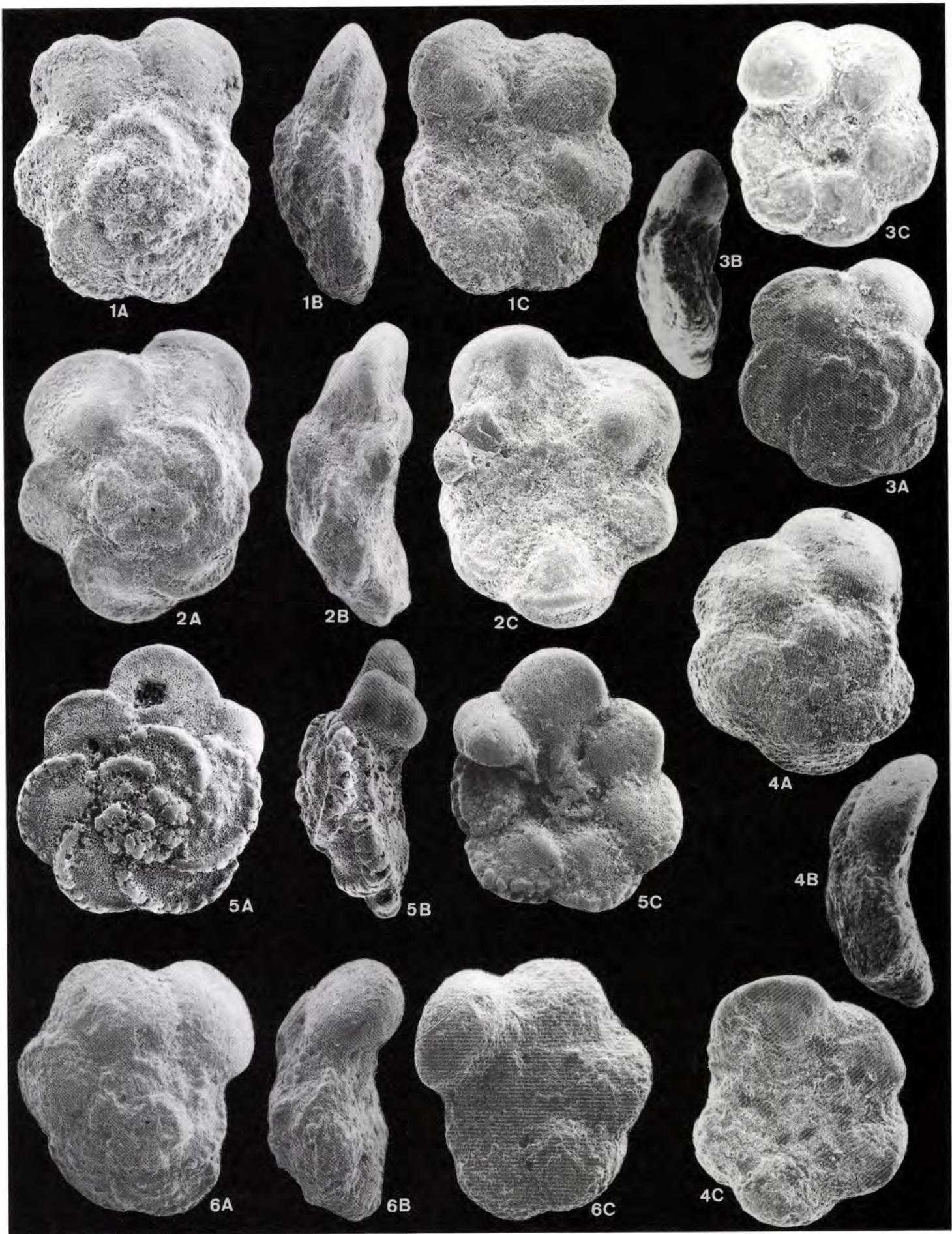


PLATE      **35**

Morphotypes of the *Dicarinella* ?*oraviensis* group (morphological genus *Dicarinella*) and of the phylogenetic subgenus *Rosalinella* (morphological genera *Dicarinella* and *Marginotruncana*)

- Fig. 1a, b, c. — *Dicarinella* ?*oraviensis* (SCHEIBNEROVA) with high final expansion rate, from HM 166, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 166-4-3.
- 2a, b, c. — *Dicarinella* ?*oraviensis* (SCHEIBNEROVA) with high final expansion rate, from HM 235, Aleg Formation, Middle Turonian, spiral view  $\times 85$ , Univ. Málaga, HM 235-3-1.  
Note the presence of a distal accessory aperture.
- 3a, b, c. — *Dicarinella* ?*oraviensis* (SCHEIBNEROVA) with very lobate outline, from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 135.7-10-1.  
Specimen of the *W. aumalensis* form 3 morphoseries. Compare with Pl. 30 fig. 2 and Pl. 34 fig. 1.
- 4a, b, c. — *Dicarinella imbricata* (MORNOD), from HM 152, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 152-2-3.  
Note the two divergent keels and damaged portici.
- 5a, b, c. — *Dicarinella imbricata* (MORNOD), from HM 470, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 470-1-1.  
Note spiral side more primitive than in anterior specimen.
- 6a, b, c. — *Marginotruncana* sp. cf. *Dicarinella imbricata* (MORNOD), from HMT 745, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 745-2-1.  
Note the two divergent keels, some raised umbilical sutures and adumbilical ridges.
- 7a, b, c. — Intermediate form between *Dicarinella imbricata* (MORNOD) and *Dicarinella canaliculata* (REUSS), from HM 235, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 235-2-2.  
Note the two nearly parallel keels and the final chamber unkeeled and shifted towards the umbilicus; note also the imbricated aspect in the sequence of the chambers.



## PLATE 36

**Morphotypes of the phylogenetic subgenus *Rosalinella* (morphological genera *Dicarinella* and *Marginotruncana*)**

Fig. 1a, b, c. — *Dicarinella canaliculata* (REUSS), from HM 268, Aleg Formation, Middle Turonian, spiral view  $\times 185$ , Univ. Málaga, HM 268-12-1.

Note the two widely spaced parallel keels over the entire test, the depressed umbilical sutures and remains of chambers imbrication.

2a, b, c. — Intermediate form between *Dicarinella imbricata* (MORNOD) and *Dicarinella canaliculata* (REUSS), from HM 285, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 285-8-1.

Note the two parallel keels, but final chambers unkeeled and shifted towards the umbilicus; note also the imbricated aspect in the sequence of the chambers. This specimen has spiral characteristics which are more primitive than the specimen in Pl. 35, fig. 7.

3a, b, c. — *Marginotruncana* sp. cf. intermediate forms between *Dicarinella imbricata* (MORNOD) and *Dicarinella canaliculata* (REUSS), from HM 272, Aleg Formation, Middle Turonian, spiral view  $\times 100$ , Univ. Málaga, HM 272-2-6.

Note the two slightly divergent and widely spaced keels in all the chambers, the imbricated aspect in the sequence of the chambers and the raised umbilical sutures and perumbilical ridges in some chambers.

4a, b, c. — Intermediate form between *Dicarinella canaliculata* (REUSS) and *Marginotruncana pseudolinneiana* PESSAGNO, from HM 270, Aleg Formation, Middle Turonian, spiral view  $\times 170$ , Univ. Málaga, HM 270-2-9.

Note the two widely spaced parallel keels over the entire test, the non-imbricated aspect in the sequence of the chambers and the raised umbilical sutures and perumbilical ridges in some chambers.

5a, b, c. — Intermediate form between *Marginotruncana pseudolinneiana* PESSAGNO and *Marginotruncana scorpionis* LAMOLDA, from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-7-1.

Note the profile shape intermediate between subrectangular (*M. pseudolinneiana*) and planoconvex (*M. scorpionis*).

6. — *Marginotruncana coronata* (BOLLI), from HMT 691, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 691-6-5.

Specimen with some atypical characteristics for this morphotype : spiro-convex profile and one keel in the final chambers.

7. — Intermediate form between *Marginotruncana coronata* (BOLLI) and *Marginotruncana tarfayaensis* (LEHMANN), from HM 462, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 462-2-4.

Compare with the holotype of *M. tarfayaensis* figuration : spiral side and axial profile are almost identical in both specimens, but the keels are separated in the Kalaat Senan specimen.

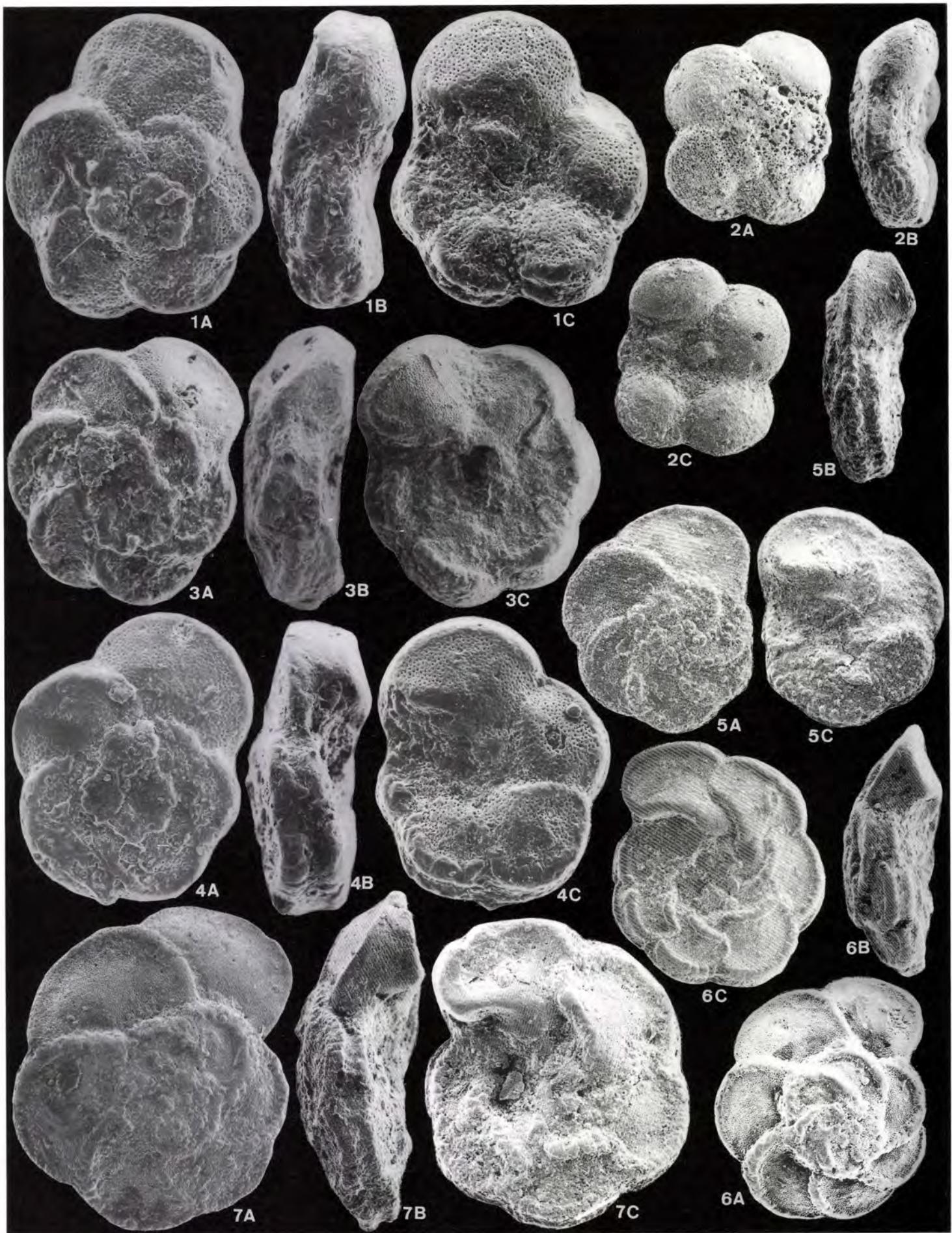


PLATE **37**

**Morphotypes of the phylogenetic subgenus *Praeglobotruncana* (morphological genera *Praeglobotruncana*, *Sigalitruncana* and *Dicarinella*)**

- Fig. 1a, b, c. — *Praeglobotruncana* sp. aff. *Praeglobotruncana stephani* (GANDOLFI), from SM 88, Fahdène Formation, Late Cenomanian, spiral view  $\times 130$ , Univ. Málaga, SM 88-5-1.  
Note the spiral sutures, more oblique than in typical *P. stephani*, the small umbilicus and one keel with pustules tending to form two rows.
- 2a, b, c. — *Praeglobotruncana* sp. aff. *Praeglobotruncana stephani* (GANDOLFI), from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 85$ , Univ. Málaga, HM 135.7-1-5.  
Note the more advanced spiral side than in the specimen in fig. 1: all the chambers (except the first ones) have raised spiral sutures.
- 3a, b, c. — Intermediate form between *Praeglobotruncana* sp. aff. *Praeglobotruncana stephani* (GANDOLFI) and *Sigalitruncana* sp. cf. *Dicarinella hagni* (SCHEIBNEROVA), from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 85$ , Univ. Málaga, HM 135.7-1-1.  
Note the beginnings of perumbilical ridges and the umbilical sutures which are convex towards the front, but not raised.
- 4a, b, c. — *Sigalitruncana* sp. cf. *Dicarinella hagni* (SCHEIBNEROVA), from SM 96, Fahdène Formation, Late Cenomanian, spiral view  $\times 130$ , Univ. Málaga, SM 96-6-1.  
Note the slightly raised spiral sutures and perumbilical ridges in some chambers.
- 5a, b, c. — Intermediate form between *Dicarinella hagni* (SCHEIBNEROVA) and *Dicarinella* sp. cf. *Praeglobotruncana elata* (LAMOLDA), from SM 101, Fahdène Formation, Late Cenomanian, spiral view  $\times 110$ , Univ. Málaga, SM 101-5-2.  
Note the two keels in the first chambers of the last whorl, the depressed umbilical sutures and the planoconvex profile, comparable to those of the *Praeglobotruncana delrioensis* (PLUMMER) topotype and *Dicarinella hagni* (SCHEIBNEROVA) hypotype figured by ROBASZYNSKI, CARON and EWGP (pl. 43, fig. 2 and pl. 56, fig. 1, respectively).
- 6a, b, c. — *Dicarinella hagni* (SCHEIBNEROVA), from SM 101, Fahdène Formation, Late Cenomanian, spiral view  $\times 110$ , Univ. Málaga, SM 101-5-1.



## PLATE 38

Morphotypes of the phylogenetic subgenus *Praeglobotruncana* (morphological genera *Marginotruncana*, *Dicarinella* and *Sigalitruncana*)

- Fig. 1a, b, c. — Intermediate form between *Marginotruncana* sp. cf. *Dicarinella hagni* (SCHEIBNEROVÁ) and *Marginotruncana* sp. cf. *Sigalitruncana marianosi* (DOUGLAS), from HM 133.5, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 133.5-2-1.  
Note two keels in the first chambers of the last whorl, slightly raised spiral sutures and perumbilical ridges in some chambers and then compare with the specimen in Pl. 37, fig. 5.
- 2a, b, c. — *Marginotruncana* sp. cf. *Dicarinella hagni* (SCHEIBNEROVÁ), from SM 101, Fahdène Formation, Late Cenomanian, spiral view  $\times 130$ , Univ. Málaga, SM 101-3-2.  
Note a porticus, two rows of pustules in the first chamber of the last whorl, raised first umbilical suture, depressed final one and intermediate ones which are depressed but marked with pustules. Compare with the *Praeglobotruncana* specimen in Pl. 37, fig. 1.
- 3a, b, c. — *Marginotruncana* sp. cf. *Dicarinella hagni* (SCHEIBNEROVÁ), from SM 190, Annaba Formation, Early Turonian, spiral view  $\times 130$ , Univ. Málaga, SM 190-4-1.  
Specimen with atypical characteristics: very crescentic chambers in spiral view and two well-separated keels.
- 4a, b, c. — *Dicarinella* sp. cf. *Praeglobotruncana elata* (LAMOLDA), from HM 135.7, Aleg Formation, Middle Turonian, spiral view  $\times 75$ , Univ. Málaga, HM 135.7-2-1.  
Note the planoconvex profile, the two keels and the depressed umbilical sutures.
- 5a, b, c. — *Sigalitruncana marianosi* (DOUGLAS), from HM 272, Aleg Formation, Middle Turonian, spiral view  $\times 85$ , Univ. Málaga, HM 272-8-2.  
Note the raised umbilical sutures, adumbilical ridges and the single keel.
- 6a, b, c. — *Marginotruncana* sp. cf. *Sigalitruncana marianosi* (DOUGLAS), from HM 262, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 262-3-2.  
Note the raised umbilical sutures, adumbilical ridges and two keels in the first chambers of the last whorl.

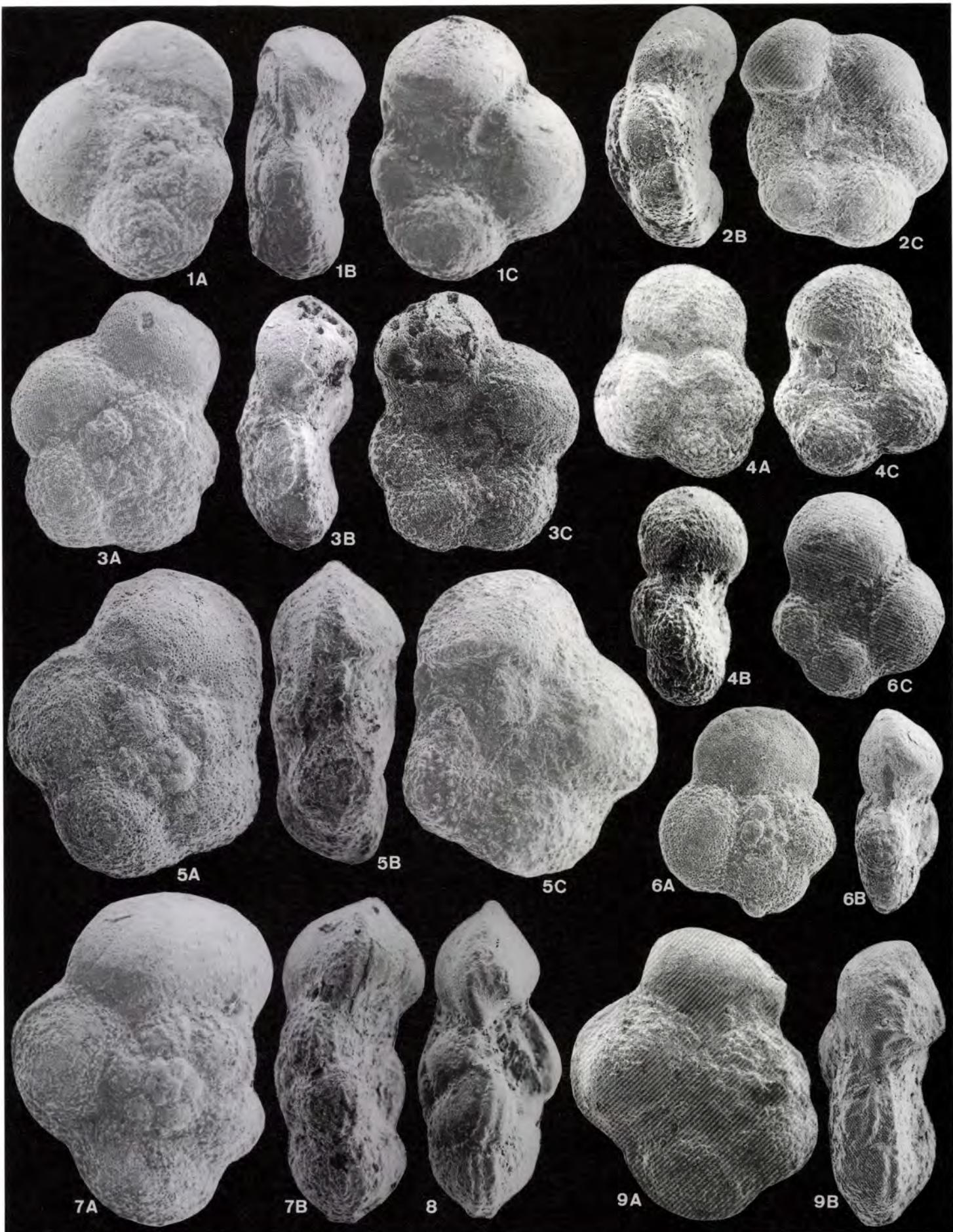


## PLATE

## 39

Intermediate forms between the phylogenetic subgenera *Whiteinella* and *Marginotruncana* and morphotypes of the phylogenetic subgenus *Marginotruncana* (morphological genera ?*Archaeoglobigerina*, *Dicarinella* and *Marginotruncana*)

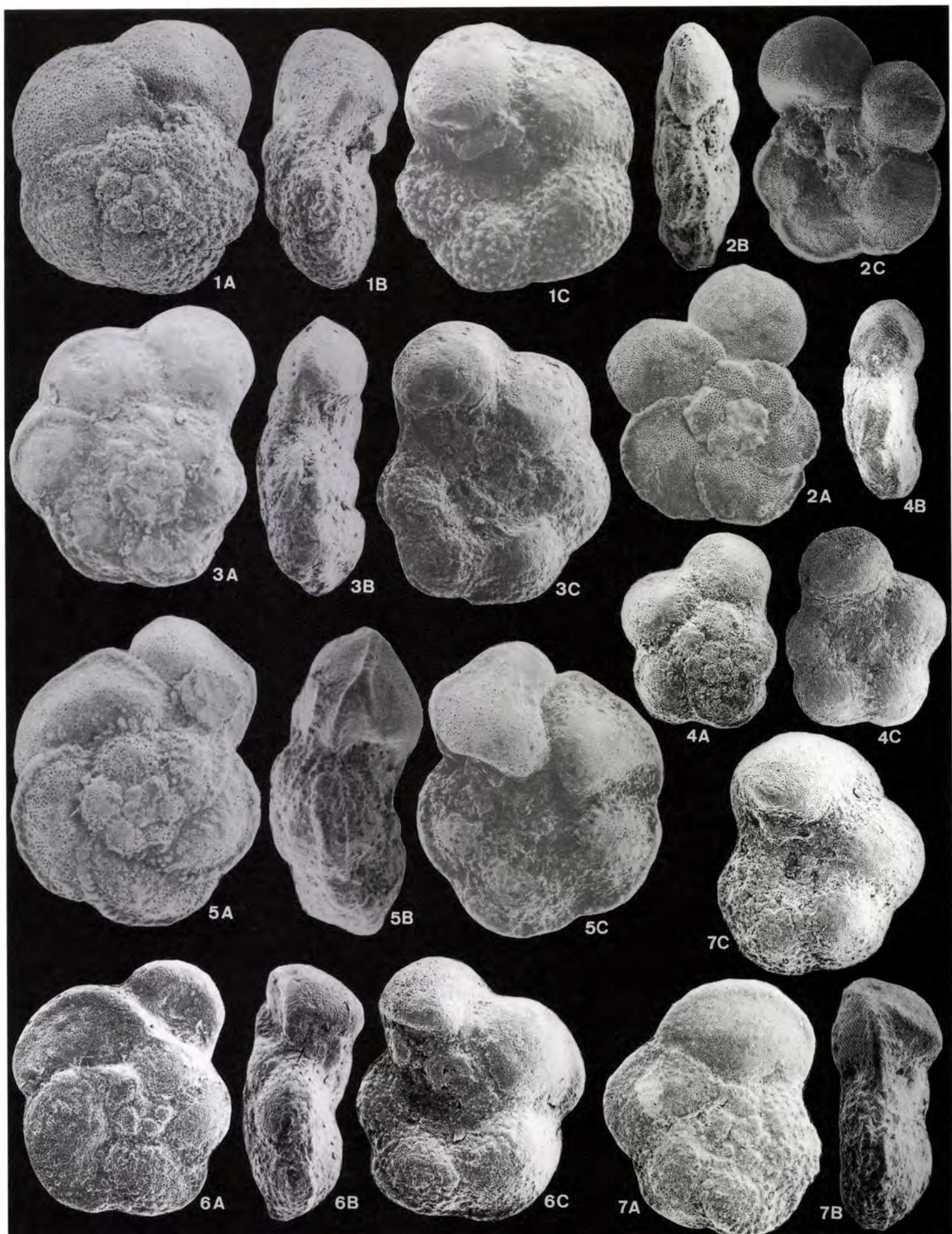
- Fig. 1a, b, c. — Intermediate form between *Whiteinella baltica* DOUGLAS & RANKIN and ?*Archaeoglobigerina blowi* PESSAGNO, from HMT 602, Aleg Formation, Late Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 602-1-1.  
Note a damaged porticus; taking into account its extension it could be an umbilical-extraumbilical primary aperture. Note also two tenuous rows of very tiny pustules, an incipient adumbilical ridge in the last chamber and a tendency towards a planoconvex shape in the last chamber.
- 2a, b, c. — ?*Archaeoglobigerina cretacea* (d'ORBIGNY), from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-11-1.  
Note the broken apertural plate; taking into account its extension it could be a umbilical-extraumbilical primary aperture. Note also two closely spaced thin rows of tiny pustules. Specimen of the *W. aprica* morphoseries.
- 3a, b, c. — ?*Archaeoglobigerina cretacea* (d'ORBIGNY), from HM 474, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 474-11-2.  
Specimen of the *W. aprica* morphoseries.
- 4a, b, c. — Intermediate form between *Whiteinella baltica* DOUGLAS & RANKIN and ?*Archaeoglobigerina blowi* PESSAGNO, from HM 462, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 462-1d-3.  
Note two incipient rows of tiny pustules.
- 5a, b, c. — ?*Archaeoglobigerina blowi* PESSAGNO, from HMT 734, Aleg Formation, Late Turonian, spiral view  $\times 130$ , Univ. Málaga, HMT 734-1-1.  
Specimen of the *W. inornata* morphoseries. Note an adumbilical ridge in the last chamber despite the depressed umbilical and spiral sutures.
- 6a, b, c. — ?*Archaeoglobigerina blowi* PESSAGNO, from HM 482, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 482-1-1.  
Specimen of the *W. inornata* morphoseries. Note an adumbilical ridge in the last chamber despite the depressed umbilical and spiral sutures (an incipient adumbilical ridge) and the tendency of the last chamber towards a planoconvex shape.
- 7a, b. — ?*Archaeoglobigerina blowi* PESSAGNO, from HMT 610, Aleg Formation, Late Turonian, spiral view  $\times 130$ , Univ. Málaga, HMT 610-6-1.  
Specimen of the *W. inornata* morphoseries.
8. — *Marginotruncana marginata* (REUSS), from HMT 610, Aleg Formation, Late Turonian, lateral view  $\times 110$ , Univ. Málaga, HM 610-10-2.  
Specimen of the *W. gigantea* morphoseries. Compare with the specimen in fig. 7.
- 9a, b. — Intermediate form between ?*Archaeoglobigerina cretacea* (d'ORBIGNY), and *Dicarinella* sp. cf. ?*A. cretacea* (d'ORBIGNY), from HMT 638, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HMT 638-2-2.  
Specimen of the intermediate between *W. aprica* and *W. gigantea* morphoseries. Note the depressed spiral sutures, which are marked by pustules. Compare with the specimens in figs. 7 and 8.



## PLATE 40

Morphotypes of the phylogenetic subgenus *Marginotruncana* (morphological genera ?*Archaeoglobigerina*, *Dicarinella* and *Marginotruncana*)

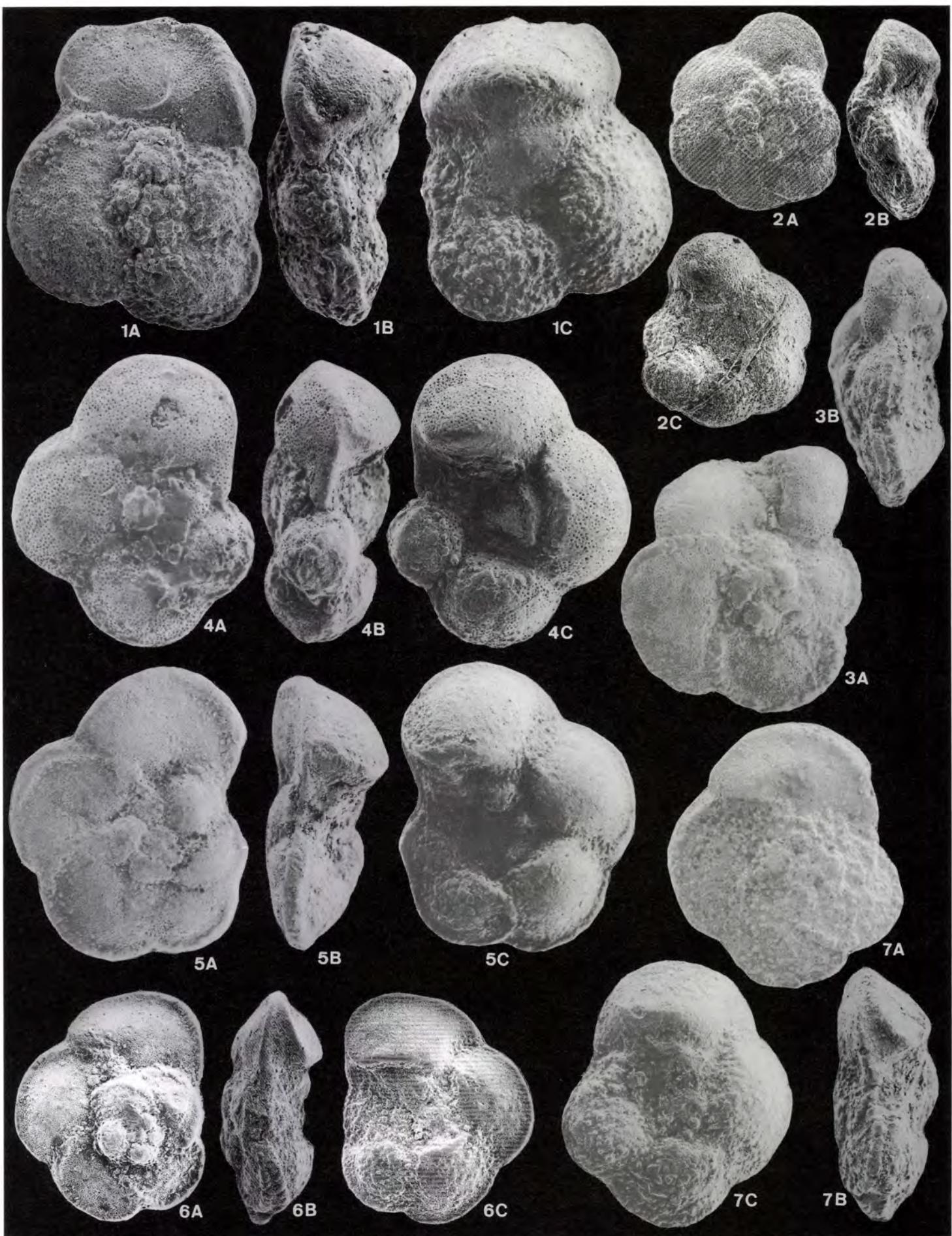
- Fig. 1a, b, c. — Intermediate form between ?*Archaeoglobigerina cretacea* (d'ORBIGNY), and *Dicarinella* sp. cf. ?*A. cretacea* (d'ORBIGNY), from HM 420, Aleg Formation, Late Turonian, spiral view  $\times 130$ , Univ. Málaga, HM 420-1-1. Specimen of the *W. gigantea* morphoseries. Note some spiral sutures marked by pustules and an apertural plate; primary aperture probably umbilical, given the apertural plate extension.
- 2a, b, c. — *Marginotruncana marginata* (REUSS), from HRA 30, Aleg Formation, Coniacian, spiral view  $\times 150$ , Univ. Málaga, HRA 30-2a-4-3. Specimen of the *W. archaeocretacea* morphoseries. Note raised umbilical and spiral sutures and apertural plates with distal accessory apertures; primary aperture probably umbilical, given the apertural plate extension.
- 3a, b, c. — Intermediate form between *Dicarinella* sp. cf. ?*Archaeoglobigerina cretacea* (d'ORBIGNY), and *Marginotruncana marginata* (REUSS), from HMT 719, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HMT 719-1-1. Specimen of the intermediate between *W. aprica* and *W. gigantea* morphoseries. Compare with the specimen in fig. 1 and note the raised spiral sutures; note also some rudiments of adumbilical ridges (transition to *Marginotruncana*).
- 4a, b, c. — Intermediate form between *Dicarinella* sp. cf. ?*Archaeoglobigerina cretacea* (d'ORBIGNY) and *Marginotruncana marginata* (REUSS), from HMT 654, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 654-1-1.
- 5a, b, c. — Intermediate form between *Dicarinella* sp. cf. ?*Archaeoglobigerina cretacea* (d'ORBIGNY) and *Marginotruncana marginata* (REUSS), from HR 140, Aleg Formation, Coniacian, spiral view  $\times 110$ , Univ. Málaga, HR 140-2-4. Specimen of the *W. gigantea* morphoseries. Note the umbilical sutures which are convex towards the front, but not raised.
- 6a, b, c. — *Dicarinella concavata* (BROTZEN), from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-10-3. Note the rounded first chamber of the last whorl and the planoconvex to concavo-convex shape of the following ones. According to the spiral sutures, this form can be considered intermediate between ?*Archaeoglobigerina* and *Dicarinella*. Specimen in unforeseen stratigraphic position.
- 7a, b, c. — *Dicarinella concavata* (BROTZEN), from HM 462, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 462-7d-3. Note the chambers planoconvex shape, with the exception of the final one, atypical for this morphotype. Specimen in unforeseen stratigraphic position.



## PLATE 41

Morphotypes of the phylogenetic subgenus *Marginotruncana* (morphological genera *Dicarinella* and *Marginotruncana*)

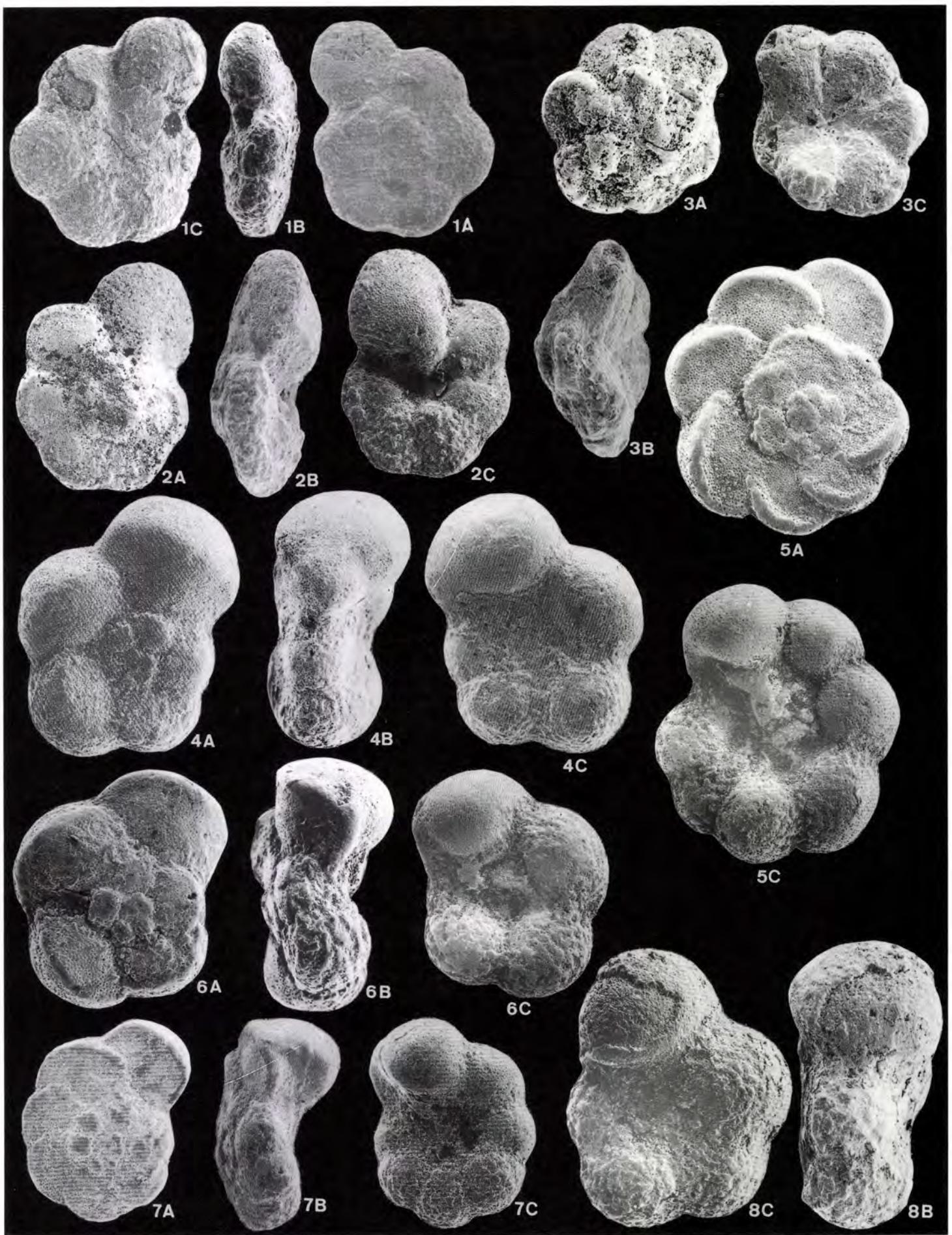
- Fig. 1a, b, c. — Intermediate form between *Dicarinella* sp. cf. ?*Archaeoglobigerina cretacea* (d'ORBIGNY), and *Dicarinella concavata* (BROTZEN), from HM 424, Aleg Formation, Late Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 424-1-4. Note the rounded first chambers of the last whorl and the convexo-concave shape of the final one. Note also a large porticus; according to its extension, the primary aperture can be umbilical.
- 2a, b, c. — Intermediate form between *Dicarinella* sp. cf. ?*Archaeoglobigerina cretacea* (d'ORBIGNY), and *Dicarinella concavata* (BROTZEN), from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-10-4. Note the rounded first chambers of the last whorl and the almost planoconvex final one. Note also a large porticus; according to its extension, the primary aperture can be extra-umbilical/umbilical.
- 3a, b. — *Dicarinella concavata* (BROTZEN), from HMT 610, Aleg Formation, Late Turonian, spiral view  $\times 110$ , Univ. Málaga, HMT 610-1-1. Specimen with anomalous final chambers (Kummerform). Note the rounded first chamber and the planoconvex posterior ones. Specimen in unforeseen stratigraphic position.
- 4a, b, c. — Intermediate form between ?*Archaeoglobigerina blowi* PESSAGNO and *Marginotruncana* sp. cf. *Dicarinella concavata* (BROTZEN), from HMT 728.5, Aleg Formation, Late Turonian, spiral view  $\times 130$ , Univ. Málaga, HMT 728.5-2-1. Note the rounded first chambers of the last whorl and the almost planoconvex final one, the depressed spiral sutures with some tiny pustules, the adumbilical ridges and the umbilical sutures which are radial in some chambers, convex towards the front in the rest. Note also a large porticus in the penultimate chamber; according to the broken last porticus extension, the primary aperture can be extra-umbilical/umbilical.
- 5a, b, c. — *Marginotruncana* sp. cf. *Dicarinella concavata* (BROTZEN), from HMT 610, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HMT 610-3-1. Note the raised umbilical sutures and adumbilical ridges in some chambers.
- 6a, b, c. — Intermediate form between *Marginotruncana* sp. cf. *Dicarinella primitiva* (DALBIEZ) and *Marginotruncana* sp. cf. *Dicarinella concavata* (BROTZEN), from HMT 691, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 691-3-1. Note the umbilical convexity, intermediate between those of *D. primitiva* and *D. concavata*, the adumbilical ridges and the umbilical sutures, which are radial in some chambers, convex towards the front in the rest.
- 7a, b, c. — *Marginotruncana* sp. cf. *Dicarinella primitiva* (DALBIEZ), from HMT 719, Aleg Formation, Late Turonian, spiral view  $\times 110$ , Univ. Málaga, HMT 719-2-1. Note the umbilical convexity and the umbilical sutures which are convex towards the front.



## PLATE 42

**Morphotypes of the phylogenetic subgenera *Falsotruncana*, *Whiteinella* and *Helvetoglobotruncana* (morphological genus *Praeglobotruncana*)**

- Fig. 1a, b, c. — *Falsotruncana* sp. cf. *Falsotruncana loeblichae* (DOUGLAS), from HM 285, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 285-6-1.  
Note the sinistral test, the two incipient rows of pustules in the first chambers and the almost subrectangular profile in the final one.
- 2a, b, c. — *Falsotruncana* sp. cf. *Falsotruncana loeblichae* (DOUGLAS), from HM 296, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 296-9-1.  
Note the dextral test, the high expansion rate, the clearly delimitated umbilicus and two rows of pustules in the first chambers.
- 3a, b, c. — *Falsotruncana* sp. cf. *Falsotruncana maslakovae* CARON, from HM 296, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 296-1-1.  
Note the dextral test and the imbricated sequence of chambers.
- 4a, b, c. — *Whiteinella praehelvetica* (TRUJILLO), from HM 222, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 222-10-1.  
Note the chambers' profile, planoconvex to concavo-convex, unkeeled.
- 5a, c. — *Praeglobotruncana helvetica* (BOLLI), from HM 262, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 262-1-8.  
Note raised spiral sutures and keel; note also the portici.
- 6a, b, c. — *Praeglobotruncana helvetica* (BOLLI), from HM 262, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 262-1-3.  
Note an incipient meridional pattern. Compare with specimen in fig. 5.
- 7a, b, c. — *Praeglobotruncana helvetica* (BOLLI), from HM 238, Aleg Formation, Middle Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 238-2-1.
- 8b, c. — *Praeglobotruncana helvetica* (BOLLI), from HM 304, Aleg Formation, Middle Turonian, spiral view  $\times 120$ , Univ. Málaga, HM 304-2-1.



## PLATE 43

Advanced *Sigalitruncana* and *Marginotruncana*

Fig. 1a, b, c. — *Sigalitruncana* sp. cf. *Marginotruncana algeriana* (CARON), from SM 101, Fahdène Formation, Late Cenomanian, spiral view  $\times 110$ , Univ. Málaga, SM 101-4-2.

Note the single keel, umbilical sutures and adumbilical ridges, which are more evolved than the *Marginotruncana algeriana* holotype.

2a, b, c. — *Sigalitruncana sigali* (REICHEL), from HM 285, Aleg Formation, Middle Turonian, spiral view  $\times 75$ , Univ. Málaga, HM 285-2-1.

Note the porticus. Compare with the specimens in fig. 1 and Pl. 32, figs. 4, 5 and 6.

3a, b, c. — *Marginotruncana* sp. cf. *Sigalitruncana undulata* (LEHMANN), from HM 493.5, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HM 493.5-4-1.

Note the undulated chambers' spiral surfaces and two keels in the first chambers. Compare with the specimens in Pl. 31, fig. 3 and Pl. 32, fig. 1.

4a, b. — *Marginotruncana* sp. cf. *Sigalitruncana undulata* (LEHMANN), from HM 493.5, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 493.5-5-1.

Compare with fig. 3; note two well-separated keels.

5a, b, c. — ? *Contusotruncana fornicate* (PLUMMER), from HMT 691, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 691-11-1.

Note the porticus. Specimen in unforseen stratigraphic position.

6a, b, c. — *Marginotruncana paraconcavata* PORTHAULT, from HMT 646, Aleg Formation, Late Turonian, spiral view  $\times 75$ , Univ. Málaga, HMT 646-4-1.

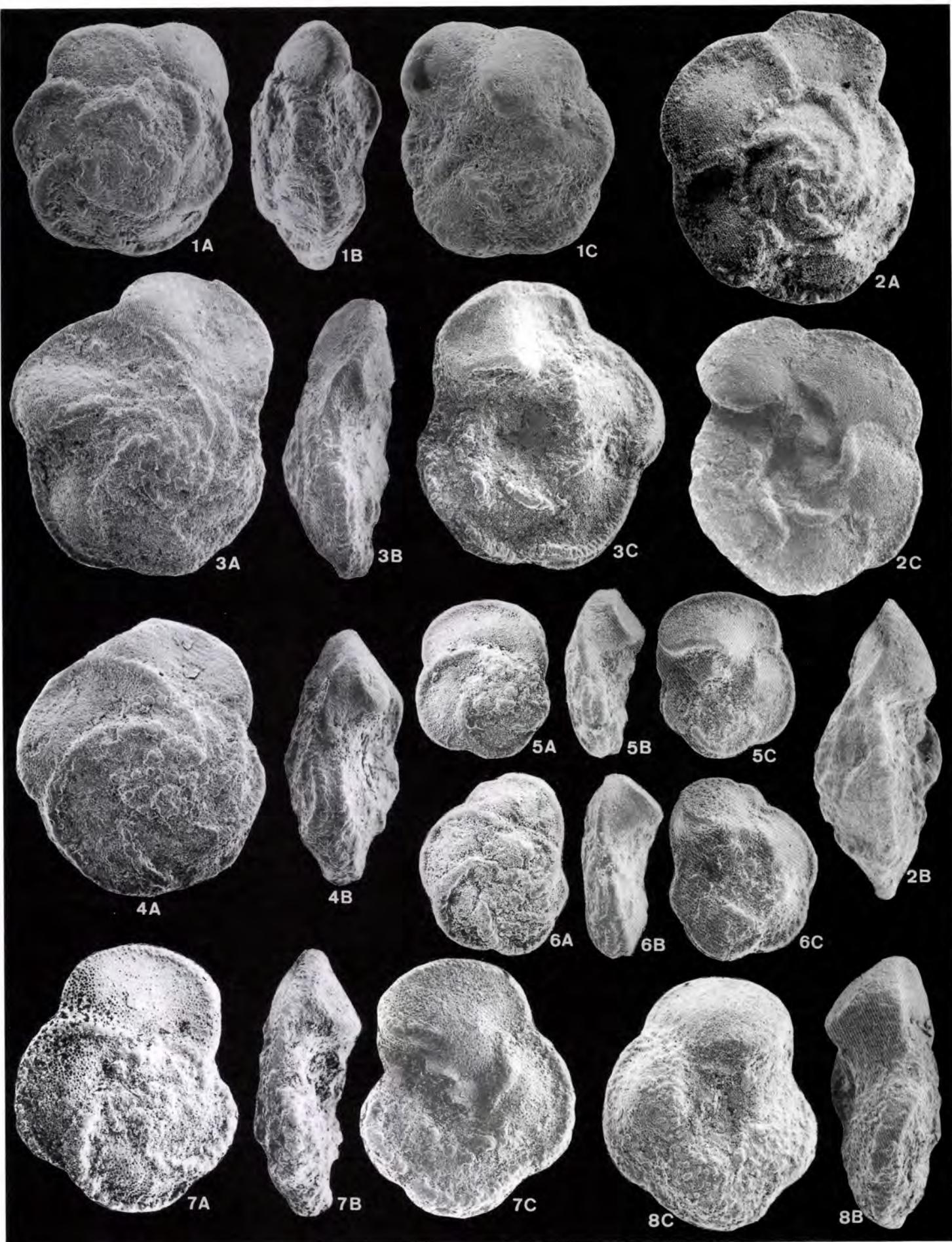
Note the planoconvex profile.

7a, b, c. — *Marginotruncana* sp. 2 cf. *Marginotruncana renzi* (GANDOLFI), from HM 332, Aleg Formation, Middle Turonian, spiral view  $\times 110$ , Univ. Málaga, HM 332-8-3.

Note the biconvex profile and 4 chambers in the last whorl.

8b, c. — *Marginotruncana* sp. cf. *Marginotruncana paraconcavata* PORTHAULT, from HM 466, Aleg Formation, Late Turonian, spiral view  $\times 92.5$ , Univ. Málaga, HM 466-4-2.

Note the planoconvex profile and 4 chambers in the last whorl.



— Umbilical side with sutures depressed, radial to slightly convex towards the front. Large umbilicus, in general more than 1/3 of the maximum diameter. Interiomarginal, umbilical-extraumbilical primary aperture. Umbilical system apparently formed by large portici.

**Observations :** *Praeglobotruncana barbui* NEAGU, 1969, of the Upper Cenomanian from the Carpathian is similar to the morphotypes of our species which show similarities with the forms of the group *W. aumalensis*, especially *W. archaeocretacea* and *W. aumalensis* form 5, but it can be differentiated from them because it has some very thick and prominent spiral sutures (so, it is a form, although older, more « advanced »). Obviously, we do not have good enough reasons to not consider both forms as ecophenotypical or geographical variants of the same species, but the differences between them are typologically important and we have not been able to observe individuals which could be a nexus between them, neither in our materials nor among the figurations of Neagu. On the other hand, it should be pointed out that we have not been able to detect organisms which we can compare with those of Neagu in our Cenomanian materials.

**Derivatio nominis :** Of Kalaat Senan, Tunisia.

**Type Specimen :** Holotype (Pl. 4, fig. 5) and paratypes (Pl. 4, figs. 6-7 and Pl. 5, figs. 1-2, 5) deposited in the collections of the Département of Geology, University of Málaga, Spain.

**Type Level :** Holotype from level HM 242, Aleg Formation, Middle Turonian. Paratypes from the Middle and Late Turonian and from Coniacian.

**Type Locality :** Holotype and paratypes from Oued Hammada section. Other paratypes from Oued Haraoua section, Kalaat Senan, Central Tunisia.

## 7. — THE CALCAREOUS NANNOFOSSILS (S. GARTNER)

### 7.1. NANNOFOSSIL BIOSTRATIGRAPHY

The Late Cenomanian to Early Coniacian sediments from the area near Kalaat Senan in Tunisia yielded Nannofossils in greatly varying abundance (Fig. 29). Some few marly samples contain very numerous coccoliths, others do not. Calcareous marls generally yielded few coccoliths, some less than 1 % of the sediment. Every sample contained adequate numbers to date and to characterize the sample, even though some required an extensive search in order to document the assemblage as completely as necessary for proper evaluation. Preservation of Nannofossils is generally not very good but adequate. Dissolution is not a serious problem in any sample although light etching is clearly apparent in some marly and clayey samples. Overgrowth is a more serious problem and is evident in all calcareous marl samples. In some samples the number of species that can be identified is significantly reduced by calcite overgrowth.

The census data for Calcareous Nannofossils is presented in checklist form in Figure 30. From the census data a biostratigraphic summary chart has been prepared and is given on Figure 29. Seventeen species have been selected as known or potential stratigraphic markers. Among them are nearly all stratigraphic markers that have been cited in previous studies and these can be used to correlate the sediment sections near Kalaat Senan to reference sections elsewhere.

PERCH-NIELSEN (1985) summarized and compared the various Calcareous Nannofossils zonations published to that time. Additional studies of Cenomanian and Turonian Nannofossils have been done subsequently by WATKINS (1985) in the North American western interior mid-Cretaceous, by COOPER (*in JARVIS et al.*, 1988) of the Cenomanian - Turonian transition on the Dover coast in southeast England, and by BRALOWER (1988) of the same interval from several widely scattered sections. JIANG (1989, unpublished dissertation) also analyzed this interval in east-central Texas.

It should be noted that VERBEEK (1977) has previously examined the Nannofossils from the Cenomanian and Turonian near El Kef to the north of Kalaat Senan and the biohorizon succession he recognized remains valid. However, he did not rigorously relate his succession to the lithostratigraphy and, consequently, a direct correlation cannot be made with his results.

Three biohorizons occur close together near the bottom of the interval studied. These are the highest occurrence of *Lithraphidites alatus*, *Axopodorhabdus albianus*, and *Cruciliopsis chiasta*, all near the top of the Fadhene Formation. All three of these biohorizons may extend somewhat higher and into the superjacent Bahloul Formation, however, at this location the Bahloul Formation yielded poor nannofossil assemblages which include only long-lived species. BRALOWER (1988) reports all three species from the Bahloul Formation, and VERBEEK (1977) report two of these species to extend to about the same level in his composite section near El Kef. The third species, *Axopodorhabdus albianus* (VERBEEK apparently identified this as *Podorhabdus dietzmanni*), allegedly extends well above the other two, although VERBEEK may have included more than one species under this name. COOPER (*in JARVIS et al.*, 1988) documented all three biohorizons in the Late Cenomanian, within or immediately above the "Plenus marl" along the Dover coast, and MANIVIT notes similar occurrences for *Axopodorhabdus albianus* and *Lithraphidites alatus* near Calais (AMEDRO *et al.*, 1978), and for *Cruciliopsis chiasta* and *Lithraphidites acutus* in the Cenomanian of Boulonnais (AMEDRO *et al.*, 1978). *Axopodorhabdus albianus* was reported to extend into the Turonian in the last study. In the Turonian type area MANIVIT reports one of these markers, *Lithraphidites acutus*, to extend into the Early Turonian (ROBASZYNSKI *et al.*, 1982).

The next younger datum is the lowest occurrence of *Gartnerago obliquum* (small variant) at the base of the Annaba Member, and immediately above that the highest occurrence of *Corollithion kennedyi*. Both of these species have conflicting ranges associated with them in previous studies and their utility for biostratigraphy remains uncertain.

The next higher datum, the lowest occurrence of *Quadrum gartneri* in the lower part of the Bireno Member, is widely documented and generally taken to mark the Cenomanian/Turonian boundary (see, e.g. PERCH-NIELSEN, 1985). This datum, too, has some uncertainty associated with it. MANIVIT (*in ROBASZYNSKI et al.*, 1982), WATKINS (1985), and COOPER (1988)

Stratigraphic ranges of selected nannofossil marker species. Note that in the Bireno Member, nannofossils constitute less than 1% of the coccolith-size sediment. Between the sample suite designated by the prefixes HM and HMT approximately 29 m of section (suite HMF) is not included in the nannofossil analysis.

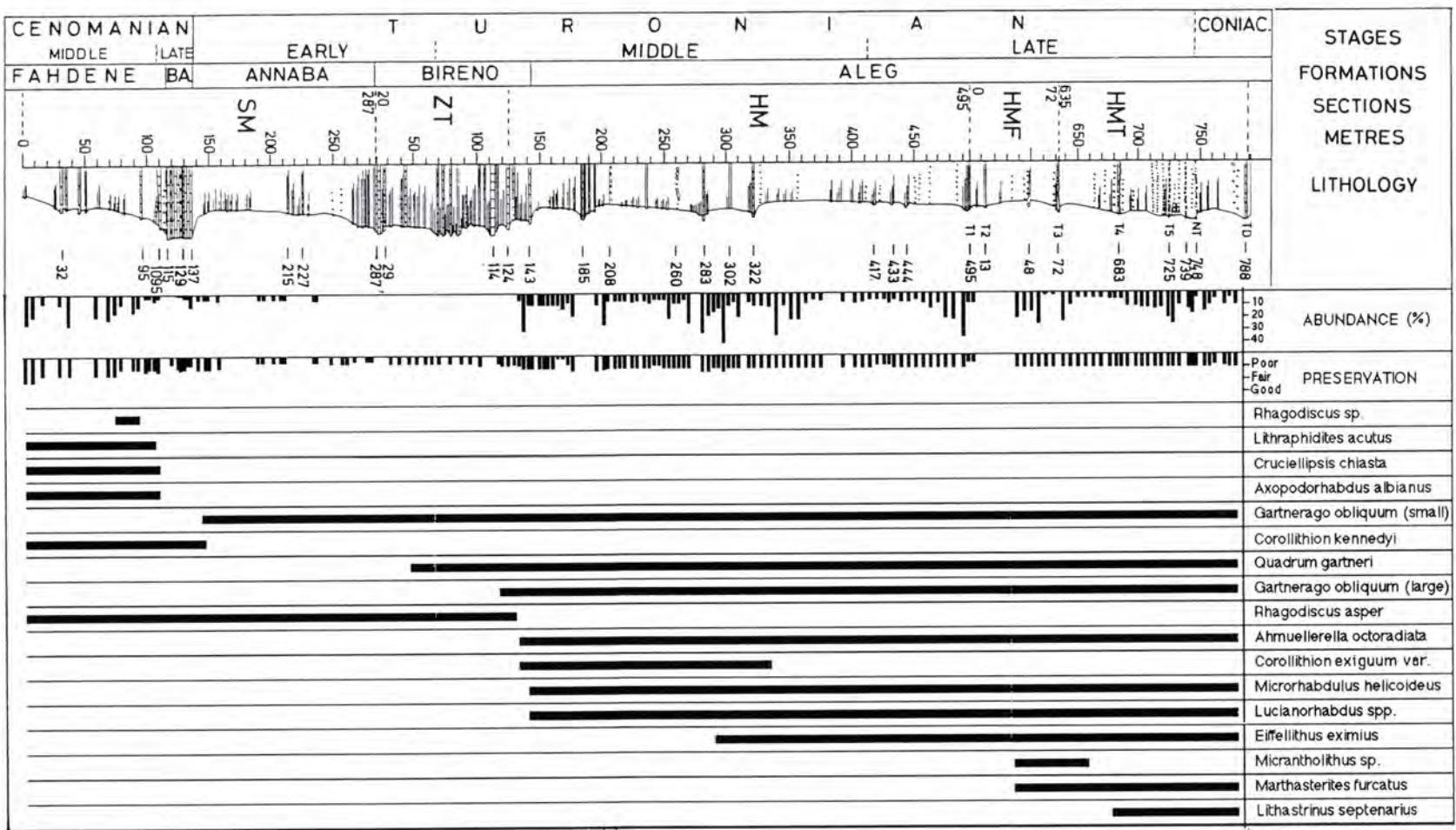
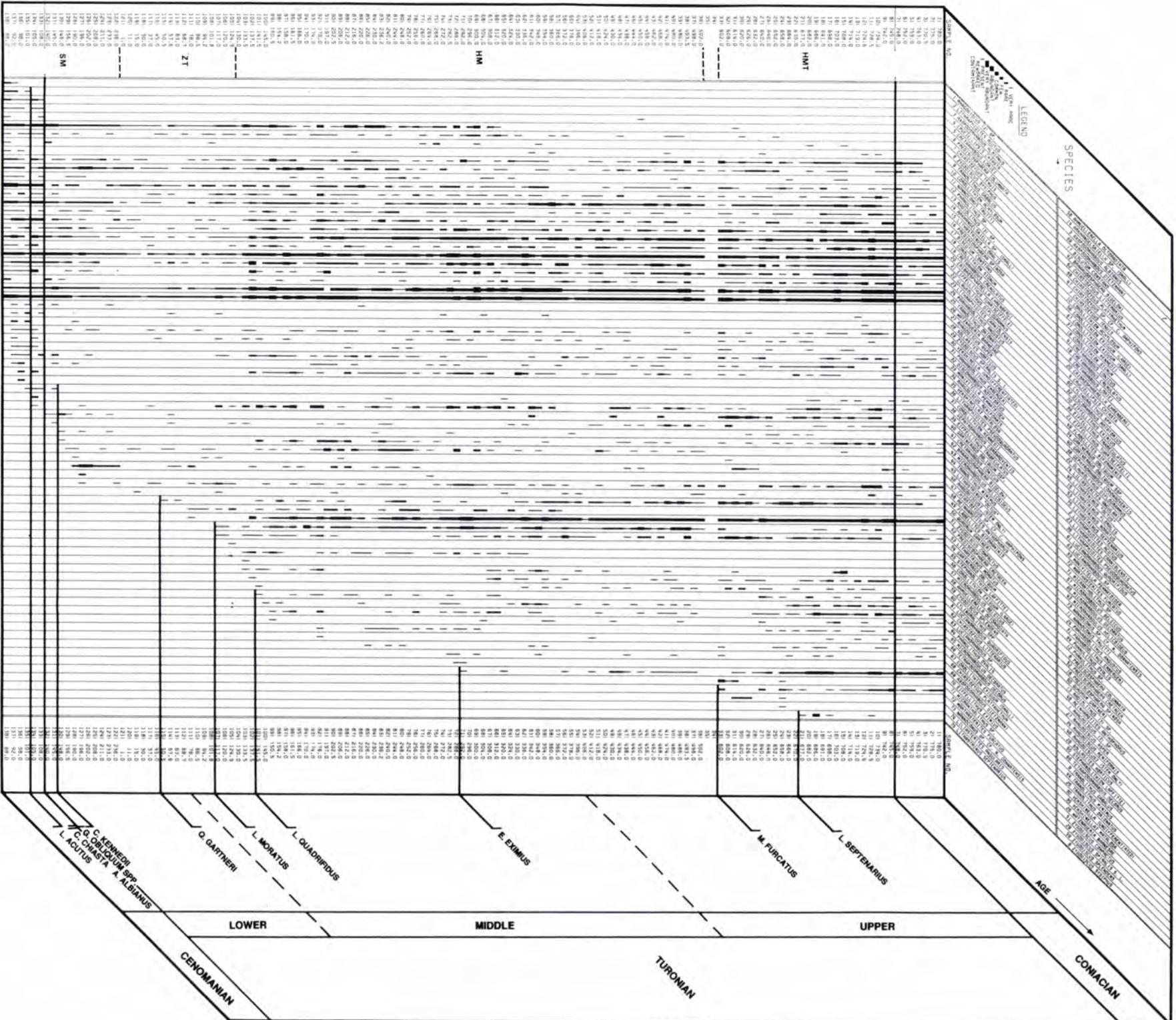


FIGURE 29



place this datum just above the Cenomanian/Turonian boundary, whereas BRALOWER (1988) places it within the upper part of the Cenomanian, although his data seem somewhat uncertain.

Near the top of the Bireno Member and immediately above it six biohorizons occur close together. These are the lowest occurrence of *Gartnerago obliquum* (large variant), highest occurrence of *Rhagodiscus asper*, and the lowest occurrence of *Ahmuelerella octoradiata*, *Corollithion exiguum* var., *Microrhabdulus helicoideus*, and *Lucianorhabdus* spp. All of these biohorizons have been noted previously by various investigators although a compilation of all published ranges of these species would have unacceptably large error bars. In this study the meager Nannofossil content of the highly calcareous Bireno Member may have caused some of these biohorizons (lowest occurrences) to be displaced upward, rendering the data somewhat unreliable.

The next biohorizon upward, the lowest occurrence of *Eiffellithus eximus*, is generally considered a reliable marker within the Turonian because, even though the species may be rare toward the lower limit of its occurrence, it is present consistently. *Corollithion exiguum* var. occurs to about 50 m above the lowest occurrence of *Eiffellithus eximus* in the Aleg Formation.

Next above is the lowest occurrence of *Marthasterites furcatus*, another widely documented biohorizon. This species may occur only sporadically towards the lower limit of its range, indeed, throughout its range, but is nevertheless used widely because it is readily identified even when rare. It first occurs just below the top of the Turonian. A species of *Micrantholithus* apparently not described and documented previously has its lowest occurrence at the same level as *Marthasterites furcatus* but extends only a short distance above that. This short-lived form may prove a useful marker, although the upper limit of its occurrence may be beyond the interval studied here.

The highest marker encountered in this study is the lowest occurrence of *Lithastrinus septenarius*, apparently still within the upper Turonian.

## 7.2. NANNOFOSSILS IN SEQUENCE STRATIGRAPHY

Very little has been done by way of formal studies to promote utilization of Calcareous Nannofossils in sequence stratigraphy aside from providing a biochronologic framework for the sediments. On an informal level remarkable success has been attained in Late Neogene sediments in the gulf of Mexico and elsewhere by using the simple but robust measure of changes in the Nannofossil abundances in a section within the framework of Nannofossil biohorizons (SHAFFER, 1987; HUANG, personal communications). In an outer shelf to slope environment the pelagic contribution such as coccoliths to the sediments is relatively constant when compared to fluctuations in other (non-pelagic) sediments

that can result from even a minor change in sea-level. While coccolith-poor detrital or carbonate sections may indicate stable or even falling sea-level, it is the coccolith-rich shales and mudstones that most clearly indicate the condensed sections associated with rising sea-level and maximum inundation, and these are easily identified. Thus, an abundance plot of coccoliths in the sediment is a simple yet powerful measure of relative sea-level changes through time at a particular location.

The estimated abundance of nannofossils for every sample is given on Figure 29. Since no concentrating techniques were used in preparation, the estimates are not biased other than the inherent bias of the examiner, which should be reasonably constant for all samples.

## 7.3. SYSTEMATIC NOTES

### *Ahmuelerella octoradiata* (GORKA)

*Discolithus octoradiatus* GORKA, 1957, p. 259, pl. 4, fig. 10.  
*Ahmuelerella octoradiata* (GORKA). REINHARDT, 1966, p. 24, pl. 22, fig. 3, 4.

This species is distinctive and, although rare towards its lower limit, is a useful biomarker.

### *Axopodorhabdus albianus* (BLACK)

Pl. 44, figure 10a, 10b

*Podorhabdus albianus* BLACK, 1967, p. 143.  
*Axopodorhabdus albianus* (BLACK). WISE & WIND, 1977, p. 297.

### *Corollithion exiguum* STRADNER var.

Pl. 44, figure 6a, 6b

*Corollithion exiguum* STRADNER, 1961, p. 83, fig. 58.61.

*Corollithion exiguum* STRADNER is represented by two distinct morphotypes, one nearly twice as large as the other, but otherwise very similar. It is the smaller form that is commonly illustrated under this name. The larger form was recorded only in the lower part of the Aleg Formation.

### *Corollithion kennedyi* (CRUX)

Pl. 44, figure 1

*Corollithion? completum* PERCH-NIELSEN, VERBEEK, 1977, p. 110, pl. 10, fig. 4.

*Corollithion kennedyi* CRUX, 1981, p. 634, fig. 4.

The highest occurrence of this species seems to be a useful marker. Although there is some uncertainty about its range, this can perhaps be ascribed to taxonomic ambiguity.

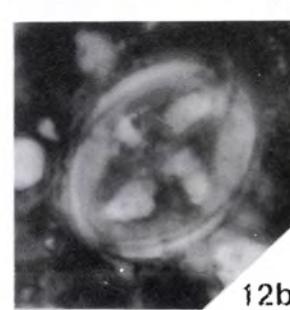
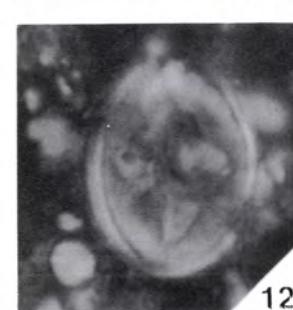
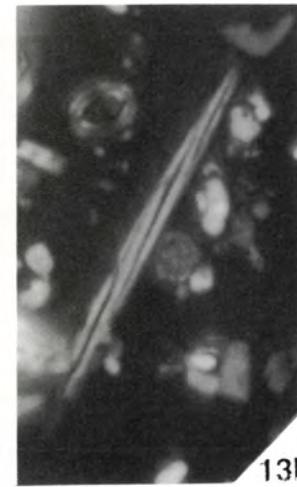
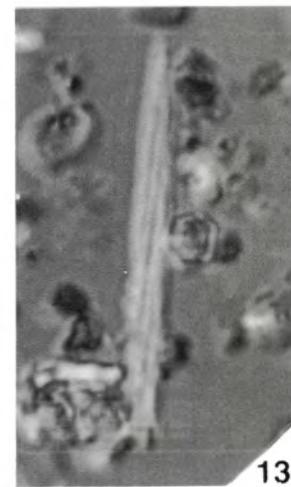
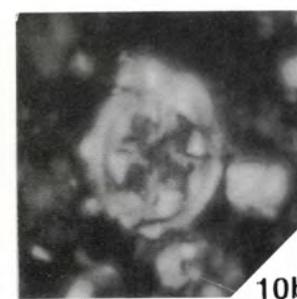
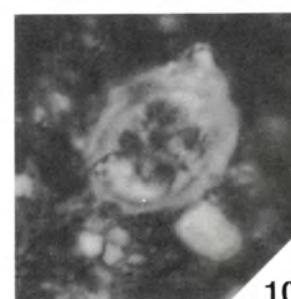
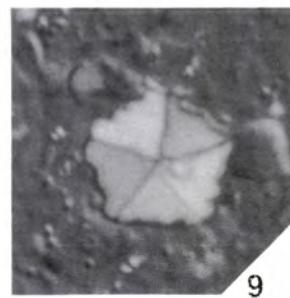
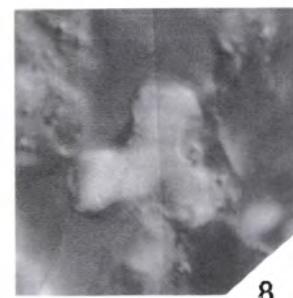
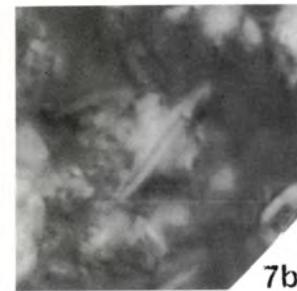
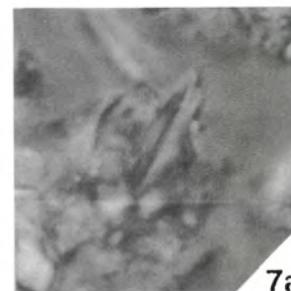
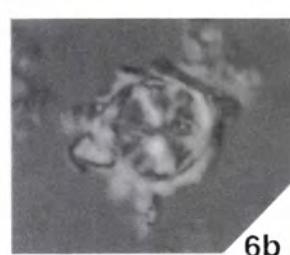
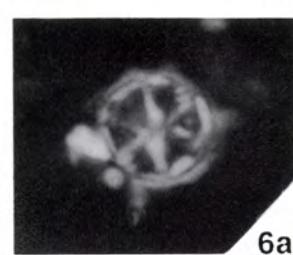
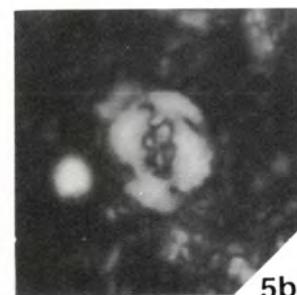
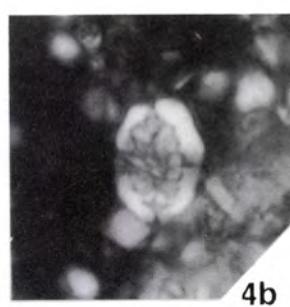
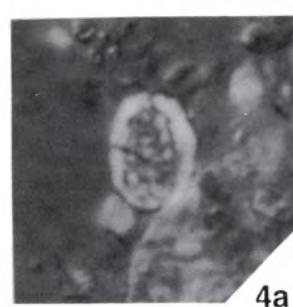
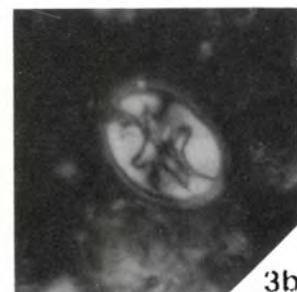
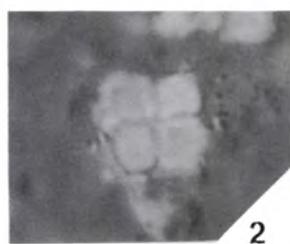
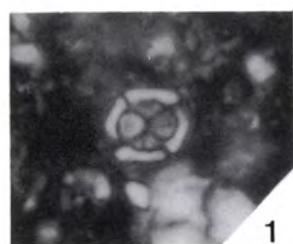
FIGURE 30

Checklist of calcareous nannofossils from the Late Cenomanian to Early Coniacian of Kalaat Senan area.

## PLATE 44

All illustrations are magnified approximatively  $\times 2500$ .

- Fig. 1. — *Corollithion kennedyi* CRUX. Sample SM 35.5, Fadhène Formation. Cross-polarized light image. Middle Cenomanian.
2. — *Quadrum gartneri* PRINS & PERCH-NIELSEN. Sample HMT 620, Aleg Formation. Interference contrast image. Late Turonian.
- 3a-3b. — *Eiffellithius eximius* (STOVER). Sample HMT 686, Aleg Formation. 3a : interference contrast image; 3b : cross-polarized light image. Late Turonian.
- 4a-4b. — *Rhagodiscus* sp. Sample SM 88, Fahdène Formation. 4a : interference contrast image; 3b : cross-polarized light image. Middle Cenomanian.
- 5a-5b. — *Cruciellipsis chiasta* (WORSLEY). Sample SM 35.5, Fahdène Formation. 5a : interference contrast image; 5b : cross-polarized light image. Middle Cenomanian.
- 6a-6b. — *Corollithion exiguum* STRADNER var. Sample HMT 288, Aleg Formation. 6a : interference contrast image; 6b : cross-polarized light image. Middle Turonian.
- 7a-7b. — *Lithraphidites acutus* VERBEEK & MANIVIT. Sample SM 35.5, Fahdène Formation. 3a : interference contrast image; 3b : cross-polarized light image. Middle Cenomanian.
8. — *Marthasterites furcatus* (DEFLANDRE). Sample HMT 685, Aleg Formation. Interference contrast image. Late Turonian.
9. — *Micrantholithus* sp. Sample HMT 685, Aleg Formation. Interference contrast image. Late Turonian.
- 10a-10b. — *Axopodorhabdus albianus* (BLACK). Sample SM 35.5, Fahdène Formation. 10a : interference contrast image; 10b : cross-polarized light image. Middle Cenomanian.
- 11a-11b. — *Gartnerago obliquum* (STRADNER) small variant. Sample HMT 686, Aleg Formation. 11a : interference contrast image; 11b : cross-polarized light image. Late Turonian.
- 12a-12b. — *Gartnerago obliquum* (STRADNER) large variant. Sample HMT 686, Aleg Formation. 12a : interference contrast image; 12b : cross-polarized light image. Late Turonian.
- 13a-13b. — *Microrhabdulus helicoideus* DEFLANDRE. Sample HR 125, Aleg Formation. 13a : interference contrast image; 13b : cross-polarized light image. Coniacian.



*Cruciellipsis chiasta* (WORSLEY)

Pl. 44, figure 5a, 5b.

*Helenea chiastia* WORSLEY, 1971, p. 1310, pl. 1, fig. 42-44.  
*Cruciellipsis chiasta* (WORSLEY), Roth & Thierstein, 1972,  
 p. 437, pl. 6, fig. 8-13.

This species is rare and often poorly preserved in the Fahdene Formation. It seems to be a useful marker nevertheless.

*Eiffellithus eximius* (STOVER)

Pl. 44, figure 3a, 3b.

*Clinorhabdus eximius* STOVER, 1966, p. 138, pl. 2, fig. 15, 16;  
 pl. 8, fig. 15.

*Eiffellithus eximius* (STOVER), PERCH-NIELSEN, 1968, p. 30,  
 text-fig. 5d; pl. 3, fig. 8-10.

There is wide general agreement about the range of this species. It is very useful marker.

*Gartnerago obliquum* (STRADNER) large variant

Pl. 44, figure 12a, 12b.

*Arkhangelksiella obliqua* STRADNER, 1963, p. 176, pl. 1, fig. 2,  
 2a.

*Gartnerago obliquum* (STRADNER), REINHARDT, 1970, p. 66.

This large variant of the species seems to have its lowest occurrence somewhat higher in the section than does the smaller variant. Further documentation of the occurrences of both variants seems desirable and may prove useful. STRADNER's original citation seems to refer to the larger variant.

*Gartnerago obliquum* (STRADNER) small variant

Pl. 44, figure 11a, 11b.

This variant is consistently smaller than the commonly illustrated specimens of this species. It is not clear whether the smaller morphotype is a different species although the lack of intermediate forms might suggest that. It is documented separately here so as to accumulate data that would demonstrate potential utility.

*Lithastrinus septenarius* FORCHHEIMER

*Lithastrinus septenarius* FORCHHEIMER, 1972, p. 53, pl. 24,  
 fig. 1-4; pl. 27, fig. 2.

This distinctive stellate, seven-rayed species appears to be a very useful marker.

*Lithraphidites acutus* VERBEEK & MANIVIT

Pl. 44, figure 7a, 7b.

*Lithraphidites acutum* VERBEEK & MANIVIT, in MANIVIT *et al.*,  
 1977, p. 176, pl. 1, fig. 7, 8.

This species is rare and, although distinctive, may be difficult to see among the debris that is common in calcareous marl.

*Lucianorhabdus* spp.

The several species of *Lucianorhabdus* cannot always be identified in these samples because of heavy overgrowth. Consequently they are lumped into one group at this stratigraphic level. The lowest occurrence of the genus remains a useful marker.

*Marthasterites furcatus* (DEFLANDRE)

Pl. 44, figure 8.

*Discoaster furcatus* DEFLANDRE, in DEFLANDRE & FERT, 1954,  
 p. 168, pl. 13, fig. 14.

*Marthasterites furcatus* (DEFLANDRE), DEFLANDRE, 1959, p. 139,  
 pl. 2, fig. 3-12; pl. 3, fig. 1, 5.

This species is rare initially but sufficiently consistent to be a useful marker.

*Micrantholithus* sp.

Pl. 44, figure 9.

This species of *Micrantholithus* is only slightly similar to the much older *Micrantholithus speetonensis* PERCH-NIELSEN, but the details of the periphery are quite distinct. This species is fairly common in common in a short interval of the Aleg Formation but may occur higher in the section than documented here as well. It may prove to be a useful marker.

*Microrhabdulus helicoideus* (DEFLANDRE)

Pl. 44, figure 13a, 13b.

*Microrhabdulus helicoideus* DEFLANDRE, 1959, p. 141-142,  
 pl. 4, fig. 9, 10.

This species is infrequently cited although it is a consistent, if rare, element in the assemblage. Apparently most investigators identify it as a stem fragment from another coccolith. It is almost certainly a distinct species as there is no coccoliths bearing a similar stem that first appears at this level.

*Quadrum gartneri* PRINS & PERCH-NIELSEN

Pl. 44, figure 2

*Quadrum gartneri* PRINS & PERCH-NIELSEN, in MANIVIT *et al.*,  
 1977, pl. 1, fig. 9, 10.

This distinctive species is one of the more reliable biomarkers in the mid-Cretaceous. Its lowest occurrence is very close to or just above the Cenomanian/Turonian boundary.

*Rhagodiscus asper* (STRADNER)

*Discolithus asper* STRADNER, 1963, p. 177, pl. 2, fig. 4, 4a, 5, 5a.  
*Rhagodiscus asper* (STRADNER), REINHARDT, 1967, p. 166.

This species becomes exceedingly rare and sporadic towards the upper limit of its range and its highest occurrence may be uncertain in the absence of other evidence.

*Rhagodiscus?* sp.  
Pl. 44, figure 4a, 4b.

This elliptical coccolith is of uncertain affinity. The center of the disk has a coarsely rhagoid structure that is distinct from the rim. No stem was observed and a stem-supporting structure cannot be confirmed. The range of this form appears to be very short and restricted to the Late Cenomanian. The species is very rare.

## MINERALOGY

### 8. — THE CLAY MINERALS (C. DUPUIS)

The mineralogical composition of the clay fraction ( $<2\text{ }\mu\text{m}$ ) has been established with 18 samples : 3 from the Late Cenomanian, 15 from the Turonian, 1 from the Coniacian. Some Paleocene reference samples, collected about 2 000 m higher in the Kalaat Senan series, were also studied in order to test the burial metamorphism effect. Preparations of oriented slides, measurements and interpretations of the X-ray diffraction diagrams were carried out using HOLZAPFEL's procedure (1985). In addition some transmission electron microscopy (TEM) observations were practised in order to control the presence of fibrous clays.

The following main minerals were identified : chlorite, illite, irregular mixed-layers (10-14V, 10-14S and 14C-14S), smectite, vermiculite and kaolinite. TEM checks on the test samples SM 124, SM 279, ZT 36, HM 636 have not revealed fibrous clays. Their distribution along the section allows us to distinguish five mineralogical units (Fig. 31).

Unit 1 (below SM 124-140) corresponds with the top of Fahdène Formation and with the whole Bahloul Formation. It records the weaker kaolinite content of the observed assemblages : about 5 %, and a marked decrease in chlorite. Illite is slightly represented as in the most part of the section (10-15 %). It is noticeable that the Bahloul Formation contains a very small clay fraction.

Unit 2 (between SM 124-140 and ZT 36-77) comprises the Annaba Member and the base of the Bireno Member. Illite reaches its maximum presence in it, 15 to 30 %, and outlines two maxima which coincide downwards, with the first kaolinite shove and upwards, with a chlorite shove. The proportions of the two minerals vary inversely. The 14C-14S mixed-layers are not very abundant (20 % maximum or absent).

Unit 3 (between ZT 36-77 and HM 213-258), overlapping the top of the Bireno Member and the base of the Aleg Formation, is characterized by the occurrence of vermiculite (10 to 20 %) found only as traces elsewhere in the section. A peak of kaolinite, more or less linked with an increase of chlorite marks the base of the unit (35 %). Such a sign of positive correlation between the two minerals, brings together this unit with the previous one and underlines the limit between units 2 and 3.

Unit 4 (from HM 213-258 to HMT 636-717) in the Aleg Formation, keeps the same kaolinite-chlorite trends, but does not contain vermiculite any more, except as traces.

It is the appearance of the smectite which defines better unit 5 (from HMT 636 to the top) around the Turonian-Coniacian limit in the Aleg Formation. Moreover kaolinite and chlorite, which are always linked, continue to decrease in accordance with the tendency initiated in the top of the previous unit.

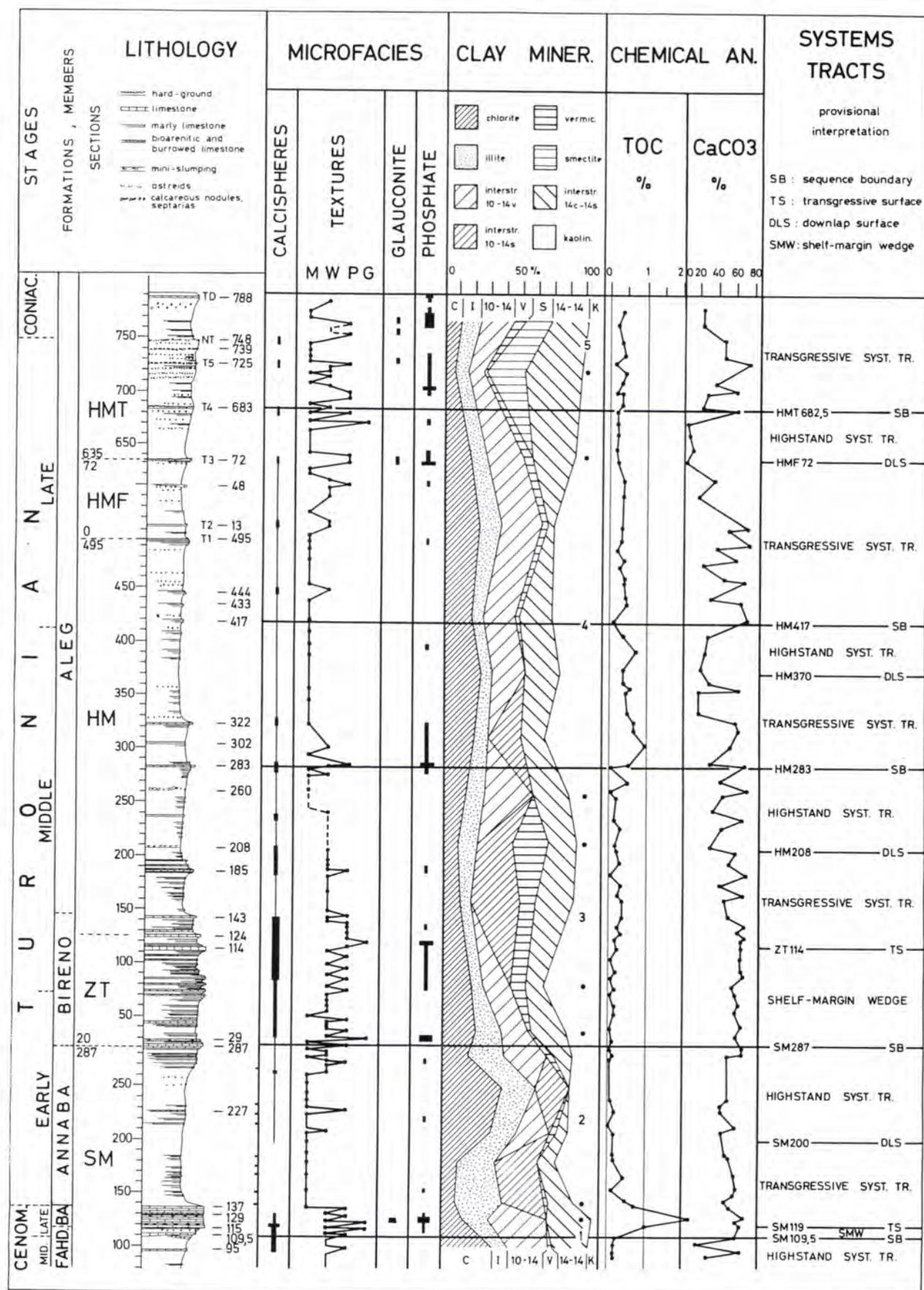
The smectite vanishing at the top of unit 5 could be interpreted as the indication of a burial-metamorphism beginning (KISCH, 1969) compatible with the thickness of the overlying series, estimated at about 2 000 m before erosion. The comparison of mineralogical compositions of the Coniacian sample and Paleocene marl containing 40 % of smectite and no 14C-14S mixed layers, encourages us to choose such an interpretation. Smectite decrease and the presence of the 14C-14S mixed-layers (DAOUDI *et al.*, 1989) leads to the same conclusion. Nevertheless, the illite crystallinity remains poor and without improvement in relation to the thickness. Eventually the imprint of the metamorphism seems very weak and it appears that, in accordance with the deepness reached, the section is situated near the diageneisis-burial metamorphism limit (KISCH, 1969).

Thus it is possible to interpret the observed variations as inherited and to search within them for the expression of palaeogeographic modifications which occurred during the Turonian. From this point of view, the most striking feature is probably the smectite behaviour and the dominance of the association of irregular mixed-layers of chlorite-kaolinite which was previously recorded near the same stratigraphical position in the Djebel Semmama sections, at about 50 km to the south of the studied area (BISMUTH *et al.*, 1981). In that paper, a more or less similar mineral association with minor amounts of illite, like in Kalaat Senan, has been described (but not commented upon) from the Middle Cenomanian to the Middle Turonian. Above and below, smectite reaches or exceeds 50 % of the clay fraction and, in this case, burial metamorphism can be excluded. At the western end of the Maghreb, a comparable situation was recently published for the Agadir Basin (DAOUDI *et al.*, 1989). These two sections exhibit a calcareous lithology along the concerned stratigraphical interval, which can explain the peculiarities of the clay mineralogy. Such an hypothesis can be proposed for the Kalaat Senan section too, in which the limestone content varies between 10 % and 80 % (ROBASZYNSKI *et al.*, in press.).

In the present succession, detailed variations of mineralogical composition are probably significant : the notable increase of the illite content at the base of the Annaba Member, the rapid and opposite fluctuations of kaolinite and chlorite percentages before the Middle Turonian followed by their positive correlation upwards and the coming of appreciable quantities of vermiculite near the transition between the Bireno and Aleg units (Fig. 31).

Waiting for new results from Cenomanian and Coniacian samples, it is still unwise, of course, to continue the interpretation further. Nevertheless, it seems possible to make the hypothesis that, during the Early Turonian, tectonic movements triggered the erosion of altered rocks and released illite, kaolinite, chlorite and 10-14 mixed-layers found unit 2. In unit 3 the phenomenon would continue with vermiculite and 10-14 and 14-14 mixed-layer increases.

This sedimentary message, in which some complexity has been put forward in the Kalaat Senan region, appears to be



recorded in the two extremities of the Maghreb, in Tunisia and in Morocco too. It keeps the same main characters and is situated at about the same stratigraphical position (if the used biostratigraphical criterions are coherent). Its origin would be sought in a generalised and synchronous event in North Africa, as a tectonic instability or an important transgressive pulsation.

Lastly, the clay minerals distribution reveals some relationships with the eustatic fluctuations independently established in section 9. Taking into account the uncertainties linked to the spacing of the sampling, Figure 31 shows a certain coincidence between the mineralogical units and the sequential pattern of the Turonian: unit 2 with the sequence SM 109.5-287; unit 3 with the sequence SM 287-HM 283 and the base of unit 5 with the beginning of the sequence HMT 682.5. In addition, unit 2 admits a separation into two parts which fully supports the subdivision of the sequence SM 109.5-287. On the other hand, unit 2 does not clearly confirm the existence of the two sequences HM 283-HM 417 and HM 417-HMT 682.5. For this reason, either a new evaluation of the sequential argumentation at this level could be necessary or a certain restriction of the mineralogical approach could be postulated.

However, clay mineralogy could be added to the set of arguments used in order to document the sequential division of the Turonian of Kalaat Senan. It seems very likely that future progress in the understanding of the origin and the distribution of the clay mineral in this interval will be able to contribute substantially to the improvement of such a kind of scale.

## SEQUENCES AND CONCLUSIONS

### 9 — AN ATTEMPT AT SEQUENCE STRATIGRAPHIC INTERPRETATION OF THE TURONIAN SUCCESSION IN THE KALAAT SENA AREA

(J. HARDENBOL)

A sequence stratigraphic analysis of the Turonian at Kalaat Senan in Central Tunisia suggests the presence of three complete and two partial sequences. The sequence interpretation is based on field observations of stacking patterns in the carbonate and shale packages aided by detailed thin-section analysis of the microfacies, abundance of calcareous nannofossils and  $\text{CaCO}_3$  content (Fig. 31). The age interpretation is based on Ammonite, Planktonic Foraminifera and calcareous nannofossil biostratigraphy (Fig. 32). The Cenomanian — Turonian and Turonian-Coniacian boundaries appear to be flooding surfaces in transgressive systems tracts. The lower boundary of the lowermost Turonian se-

quence is just below the base of the Bahloul Formation (SM 109.5) in the Late Cenomanian. The first Turonian Ammonites are recovered from a flooding surface in the transgressive systems tract at the base of the Annaba Member (SM 137). The remainder of the Annaba Member constitutes the transgressive and highstand systems tracts. A second sequence boundary is placed at the base of the Bireno Member (SM 287). Most of the Bireno Member may be a shelf margin wedge with only the top few metres interpreted as transgressive. Three sequence boundaries are interpreted in the Aleg Formation s.s. (HM 283, HM 417 and HMT 682.5) mostly on the basis of changes in Nannoplankton abundance and changes in  $\text{CaCO}_3$  content. The Turonian-Coniacian boundary at HMT 748 is a flooding surface. The sequences boundaries at HM 293, HM 417 and HMT 682.5 appear to be downdip from shelf margin or lowstand wedges. The overall faunal content of the Turonian section in the Kalaat Senan area suggests a basinal depositional setting. The effects of eustasy on the deposition in a basinal setting is limited to subtle changes in the proportion of the principal sediment components. The Turonian represents the upper portion of a second-order eustatic supercycle that started in the Late Albian (98 Ma) and lasted until the Late Turonian (90 Ma) (HAQ *et al.* 1987). The maximum flooding in this second-order cycle occurs just above the base of the Turonian in the Annaba Member at SM 200. The effect of eustasy on biotic turnover is not yet understood but it appears that if a causal relationship exists the second-order cyclicity is more important than the third and higher-order cyclicity. The turnover in Planktonic Foraminifera in the Cenomanian-Turonian supercycle includes the demise of the genera *Rotalipora* and *Praeglobotruncana* and the onset of *Dicarinella*, *Whiteinella* and *Marginotruncana*. The long-ranging genus *Hedbergella* and the genus *Whiteinella* flourished during the transition. In the Kalaat Senan area it appears that many new arrivals (which may not be global first occurrences) of Planktonic Foraminifera and Calcareous Nannofossils are associated with transgressive systems tracts of third-order cycles, especially those in the Early and Middle Turonian.

#### 9.1. INTRODUCTION

The sequence stratigraphic model presented by HAQ *et al.* (1987) suggests the deposition of sediments in discrete packages separated by surfaces as a function of three principal variables, e.g. basement subsidence, sediment supply and eustasy. The packages or systems tracts can be grouped in type 1 or type 2 sequences. (VAN WAGONER *et al.* 1988). The systems tracts include a lowstand systems tract, transgressive systems tract and a highstand systems tract in a type 1 sequence. In a type 2 sequence the shelf margin systems tract overlies the sequence boundary and is followed, as in the type 1 sequence, by transgressive and highstand systems tracts.

FIGURE 31

Stratigraphic position of sequence boundaries, transgressive surfaces and downlap surfaces relative to the lithologic section, the microfacies, clay minerals, total organic carbon and  $\text{CaCO}_3$  content.

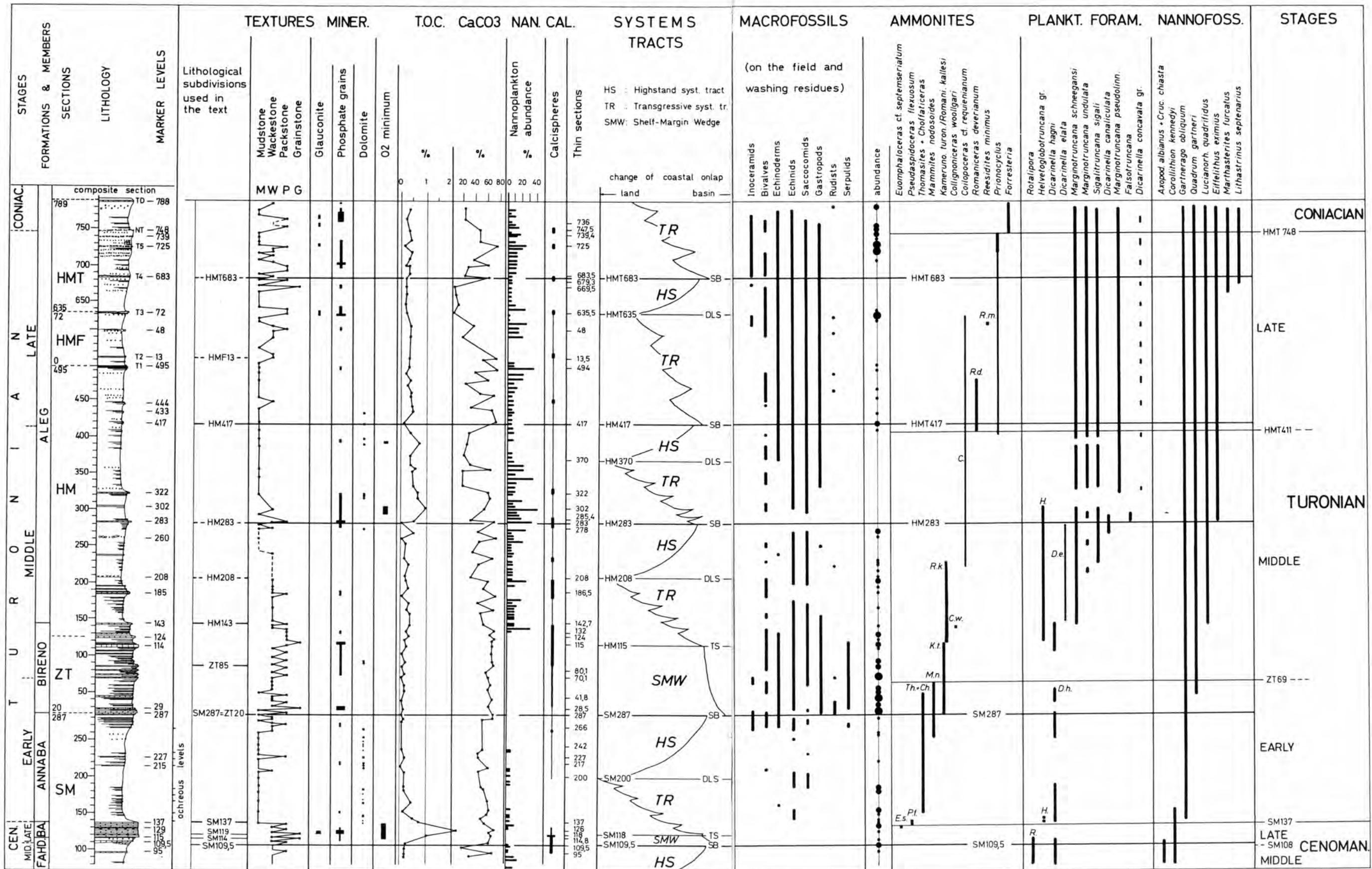


FIGURE 32

Synthetic chart with main results related to lithology, microfacies, nannofossils abundance, vertical distribution of biomarkers and sequence stratigraphic interpretation.

The sequence stratigraphic interpretation of the Turonian section in the Kalaat Senan area is based on field observations limited to a relatively small geographical area. Ideally a sequence stratigraphic interpretation should be supported by either an interpreted seismic grid and, or a set of facies cross-sections correlated within biostratigraphic constraints. A sequence stratigraphic interpretation of a single section may recognize the essential surfaces but the uniqueness of the interpretation can be adversely affected by the lack of three dimensional information on the stratigraphic completeness of the section and geometry of the sequences.

The data base available for the sequence stratigraphic interpretation was not assembled for that specific purpose. The field data provide a measured section distinguishing between friable marls and indurated limestones. This distinction is sometimes quite subjective because of differential diagenetic and weathering factors. The primary field observations provide information on physical surfaces, facies changes and the stacking of packages of sediment with different facies characteristics. The field observations were complemented by a number of laboratory analyses designed to provide either additional facies information or strictly biostratigraphic data. Many of the laboratory analyses were carried out on either marls or limestones. Only the calcimetry was done on both marls and limestones, which made the  $\text{CaCO}_3$  content an invaluable link between the microfacies analysis of the thin sections and the calcareous nannofossil abundance obtained from the marls.

Field interpretation of sequences in the Turonian section is based on the premise that the sediments observed in the area represent three principal sources. Terrigenous muds make up approximately half of the sediment in the section while the other half is made up of detrital platform-derived carbonate and locally produced pelagic carbonate. Changes in the proportion of these principal components are responsible for the lithological changes observed in the field (Fig. 33).

The changes in lithologic character in the Turonian section as a result of changes in the proportion of terrigenous mud and carbonate are illustrated by the changes in the  $\text{CaCO}_3$  content. Fig. 32 shows low-frequency trends in the calcium

carbonate content, in addition to high-frequency fluctuations in carbonate content caused by sampling limestone beds as well as marls. A general upward increase in the mud component in the section is an indication of a long-term progradational effect. The sequence stratigraphic interpretation presented here is based on the premise that the terrigenous mud component dominates during high stands of sea-level, which is most pronounced in the Aleg Formation. The lowstands contain the most reworked skeletal material as wackestone, packstone, and grainstone, whereas the transgressive deposits show a decrease in detrital carbonate and an increase in pelagic carbonate, witnessed by an increase in Calcareous Nannofossils and Planktonic Foraminifera.

In Tunisia several lines of evidence point to an open marine setting basinal of a carbonate shelf. Planktonic Foraminifera and Calcareous Nannoplankton represent the oceanic influence whereas the presence of numerous detrital limestone beds and the overall thickness of the Turonian section ( $>800$  m) support the proximity to a carbonate shelf and a major land mass (southwards). In this type of setting transgressive systems tracts and highstand systems tracts should be manifested quite differently (Fig. 33). In the transgressive systems tract the terrigenous influence is decreasing when sediment is trapped updip in drowning river valleys and estuaries while the pelagic influence is increasing, notably in the diversity and abundance of Planktonic Foraminifera and Calcareous Nannoplankton. In the highstand systems tract the terrigenous component is increasing when sediment supply overtakes the slowing eustatic rise. As a result, the pelagic component is diluted. The lowstand systems tract and the shelf margin systems tract are thought to behave like highstand systems tracts in a prograding or at least aggrading mode. The principal difference between highstand and lowstand deposits is that the depositional shelf is covered by the sea during the highstand whereas during the lowstand or shelf margin systems tracts the shelf is at least partially exposed. The expected higher depositional energy in the lowstand and shelf margin systems tracts may favor the deposition of detrital carbonate while the muds are dispersed down dip. In a slope setting where terrigenous mud, pelagic carbonate, and shelf carbonate are the principal

SYSTEMS TRACTS	TERRIGENOUS MUD	DETritAL CARBONATE	PELAGIC CARBONATE
SHELF MARGIN WEDGE	HIGH/LOW	HIGH	LOW
HIGHSTAND	HIGH	LOW	LOW
TRANSGRESSIVE	LOW	LOW	HIGH
LOWSTAND	HIGH/LOW	HIGH	LOW

FIGURE 33

Expected distribution of terrigenous muds, detrital carbonate and pelagic carbonate as a function of systems tracts.

sediment component, highstands are expected to be high in terrigenous muds, the transgressive deposits are expected to be high in pelagic carbonate and the lowstand and shelf margin deposits are expected to be highest in detrital shelf carbonate.

## 9.2. SEQUENCE INTERPRETATION

The salient characteristics of the Turonian section near Kalaat Senan were pointed out by BUROLLET (1956) when he defined the mappable lithologic limits or formations. The nature of the Bahloul-Annaba-Bireno and Aleg Formations and Members reveals major changes in facies as a result of changes in sediment supply, subsidence and eustasy. The most obvious change seems to be the upward decrease in detrital carbonate and increase in pelagic carbonate. It appears that during the Turonian the distance from shore or carbonate platform is increasing, possibly as the result of increased subsidence. The sequence stratigraphic analysis presented here attempts to identify the eustatic frequency signal rather than its amplitude.

The sequence interpretation compares well with the model published by HAO *et al.* (1986) albeit with some modifications. HAO *et al.*, based their sequence interpretation on the platform deposits in the type area near Tours (France). They identified four sequences pertaining to the Turonian. The more basinal Tunisian section is more complete than the platform section in the type area which allowed us to identify one additional sequence at 89.2 Ma in the latest Turonian. In

the type area this sequence is merged with the 90 Ma sequence at the base of the Late Turonian. The expanded section in Kalaat Senan allowed a more precise positioning of the sequences relative to the Ammonite zones. As a result the ages of the sequence boundaries were modified slightly from HAO *et al.* (1987) (Fig. 34).

### Sequence 92.2 Ma : Late Cenomanian

The lowermost Turonian sequence has its lower boundary in the Late Cenomanian very close to the boundary between the Fahdène and Bahloul Formations (SM 109.5). The lower position of the Bahloul Formation constitutes a distal shelf margin wedge. The contact with the underlying Fahdène Formation is sharp with several thick limestone beds in the basal Bahloul Formation overlying the marly Fahdène Formation. The top of the shelf margin wedge or transgressive surface is placed at SM 119.

The remainder of the Bahloul Formation consists of thin-bedded dark organic-rich (up to 2.39 % TOC at SM 129) silty shale interbedded with planktonic ooze laminae. The organic-rich Bahloul Formation is widespread in Tunisia and may be time-equivalent with the organic-rich deposits of the Bonarelli event in Italy (SCHOLLE & ARTHUR, 1980). In the Kalaat Senan area most of the organic-rich deposits are low in the transgressive systems tract. The Bahloul Formation is overlain by calcareous marls with few interbedded limestones of the Annaba Member of the Aleg Formation. The lower portion of the Annaba Member shows a decrease in coarse detrital carbonate while the overall carbonate content remains fairly

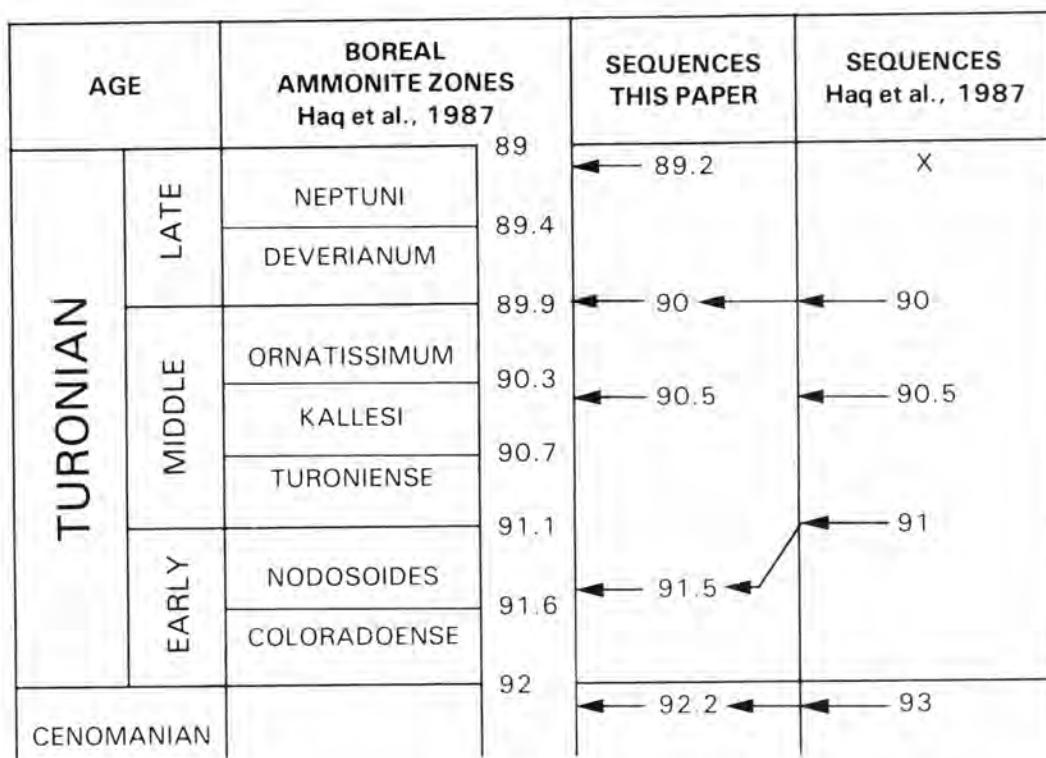


FIGURE 34

Comparison of sequences for the Turonian used in this paper with HAO *et al.* (1987). The numerical ages for the Ammonite zones are interpolated between 92 and 89 Ma assuming equal duration for each Ammonite zone. Sequence 89.2 Ma is a new sequence that was not distinguished from the 90 Ma sequence in the type area of the Turonian by HAO *et al.* (1987).

high. The fact that the Lower Annaba Member becomes finer towards the top is consistent with a transgressive systems tract. The downlap surface at SM 200 represents the maximum flooding not only in the 92.2 Ma sequence but in the 98-90 Ma supersequence as well. The Planktonic Foraminifera genus *Rotalipora* becomes extinct prior to this flooding event while the genus *Marginotruncana* s.s. appears soon after the event. The genera *Whiteinella* and *Hedbergella* flourish during the transition. The Annaba Member above the downlap surface at SM 200 has the characteristics of a highstand systems tract. The gradual return of thin wackestone and packstone detrital limestone beds supports the prograding nature for this interval.

#### Sequence 91.5 Ma : Early Turonian

The 91.5 Ma sequence boundary is placed at the boundary between the Annaba and Bireno Members. The contact between Annaba marls and Bireno detrital limestones marks a major change in facies. The lower eight metres of the Bireno Member is a detrital carbonate with abundant Ammonites especially at the base. The uppermost bed of the eight-metre unit, which contains some phosphate grains, is overlain by three prograding packages with marls at the base and detrital limestones at the top. The bulk of the Bireno Member is interpreted as a lowstand deposit with a thin carbonate lowstand at the base overlain by a prograding lowstand wedge. The Bireno Member seems to fit the criteria of a type 1 sequence even though elsewhere this sequence is interpreted as a type 2 sequence, which points to anomalies in the subsidence history at this location. The abundance of detrital carbonate, and the scarcity of pelagic carbaonte is the main criterion for the lowstand interpretation. The transgressive surface is placed at ZT 114 on top of a thick carbonate bed above which the detrital carbonate content is decreasing, while the abundance of pelagic calcareous Nannoplankton is increasing markedly. Both changes are indications that the depositional system is becoming more distal, which is consistent with the interpretation of a transgressive systems tract. The upper boundary of the Bireno Member is placed at a flooding surface in the transgressive systems tract on one of the last backstepping detrital carbonate pulses into the basin at HM 143. The downlap surface or maximum flooding event is placed in the overlying Aleg Formation at HM 208 on top of a thin limestone bed paved with abundant small shells. The highstand systems tract is marly with a few prominent detrital limestone beds. The abundance of Calcareous Nannoplankton remains relatively high with suggest an aggrading rather than prograding depositional mode.

#### Sequence 90.5 Ma : Middle-Middle Turonian

At HM 283 in the Aleg Formation there is a brief increase in detrital carbonate indicative of an increased progradation. The overlying interval shows, however, a marked increase in the pelagic calcareous Nannofossil content and an increase in phosphates suggesting a renewed transgression. The close proximity of indications of increased progradation and subsequent transgression suggests a merged sequence boundary and transgressive surface downdip of a shelf margin wedge (HM 283). The downlap surface at HM 370 marks a significant decrease in overall  $\text{CaCO}_3$  content and a decrease in the calcareous nannofossil content.

#### Sequence 90 Ma : Boundary Middle and Late Turonian

A marked increase in detrital carbonate at HMT 417 in discrete limestone beds, in an overall marly section is interpreted as the next sequence boundary. The calcareous nannofossils abundance remains constant at first but increases significantly somewhat higher in the section. The interval from HMT 417 to HMF 13 characterized by pulses of detrital carbaonte in a marly matrix with a rather strong and increasing upward pelagic signature is indicative of a transgressive systems tract rather than a distal lowstand wedge, which was our conclusion in an earlier preliminary paper (ROBASZYNSKI *et al.*, in press) before the Nannofossil abundance was available.

#### Sequence 89.2 Ma : Latest Turonian

The final sequence boundary close to the Coniacian boundary manifests itself in much the same way as the two previous sequences by an increase in detrital carbonate in discrete limestone beds combined with an increase in the abundance of pelagic calcareous nannofossils. The sequence boundary and transgressive surface are combined at HMT 682.5 distal from a shelf-margin wedge. The interval from HMT 682.5 to HMT 748 was interpreted as a shelf-margin wedge in an earlier preliminary publication based on the increase of detrital carbonate in several conspicuous limestone beds. However, the abundance of pelagic Calcareous Nannofossils suggests a transgressive systems tract for the interbedded marls. The conspicuous limestone beds are interpreted as flooding surfaces in a transgressive systems tract. The flooding surface at HMT 748 marks the Turonian-Coniacian boundary with the first appearance of the Ammonite genus *Forresteria*.

#### 10. — CONCLUSIONS

The Kalaat Senan area situated between the El Kef basin to the North and the Jbel Semmana platform to the South offers exposures of a complete succession of Middle and Upper Cretaceous marine sediments. This succession is representative for an extended area comprised between Tajerouine, Jerissa, Thala and Kalaat Senan as well as for areas extending towards Maktar and eastern Algeria. Its intermediary position between the basin and the platform offers the advantages of a wider range of lithologies and paleontological contents representative of either domain.

The analysis covers aspects of the lithology (lithofacies and microfacies), the biostratigraphy (Ammonites, Planktonic Foraminifera and Nannoplankton), some physical and chemical properties (mineralogy, T.O.C. and  $\text{CaCO}_3$ ) and converges in an attempt at a sequence stratigraphic interpretation. The most significant accomplishments resulting from this multidisciplinary approach are the following :

**Boundaries** — According to the recommendations of the Subcommission on Cretaceous Stratigraphy, the lower boundary of the Turonian is defined by the first appearance of the Ammonite *Pseudaspidoceras flexuosum* which was found at the base of the Annaba Member of the Aleg Formation (SM 137). The upper boundary of the Turonian is defined by the first appearance of Coniacian Ammonites belonging to

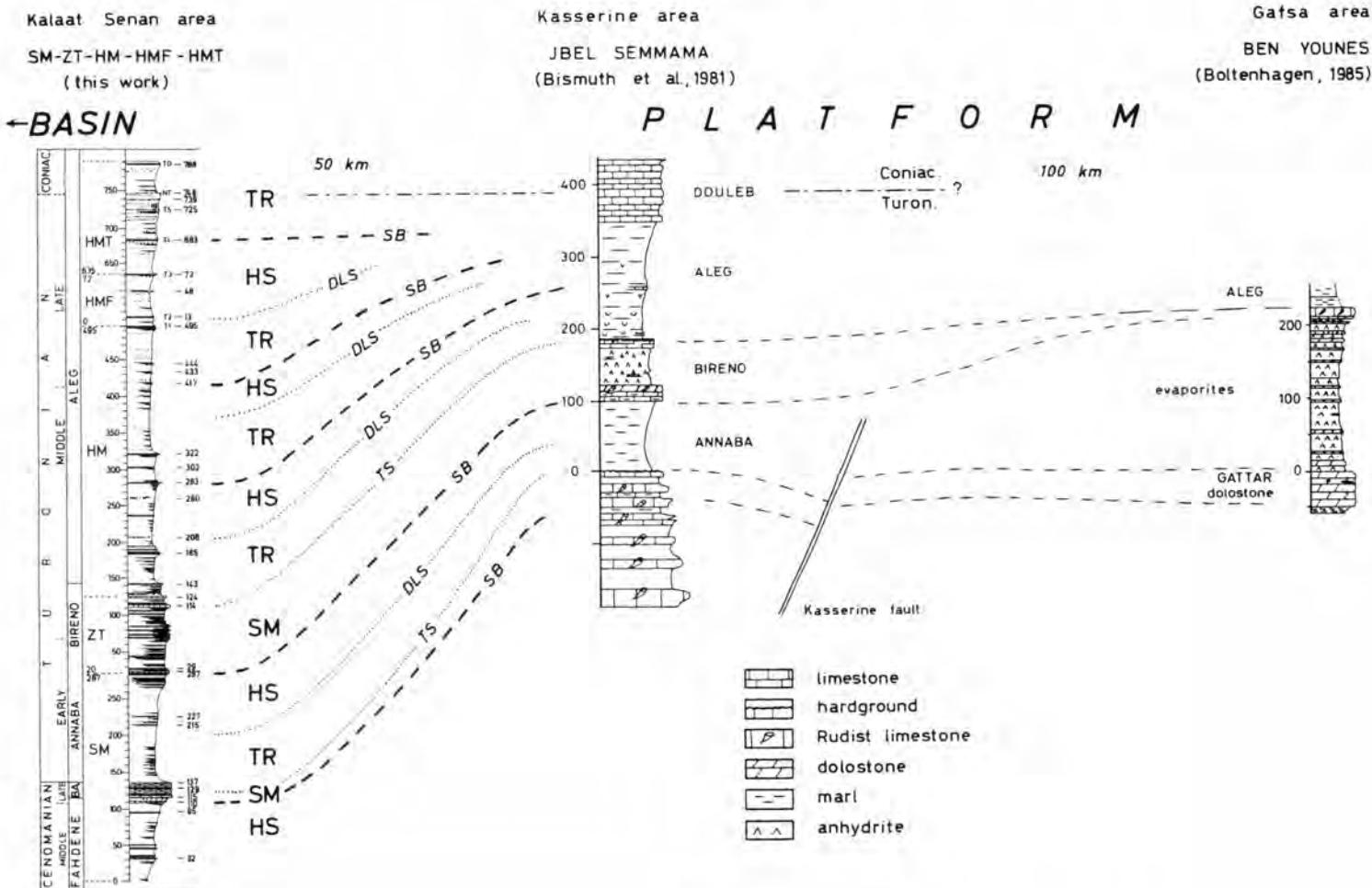


FIGURE 35  
Comparison between the Turonian of Kalaat Senan area (basin) and Semmama-Ben Younes (southern platform).

the genus *Forresteria*, which were recovered from within the Aleg Formation (HMT 748.5). As a result the Bahloul Formation which is generally attributed to the Early Turonian appears to be Late Cenomanian in age at least in the Kalaat Senan area.

**Thickness.** — The Turonian in the Kalaat Senan area is 810 metres thick and comprises the Annaba Member (150 m), the Bireno Member (123 m) and the lower part of the Aleg Formation s.s. (537 m).

**Bioevents.** — Towards the Cenomanian-Turonian boundary faunal changes are particularly pronounced. After the extinction of the Ammonite genera *Calycoceras*, *Pseudocalycoceras* and *Euomphaloceras* and the extinction of the Planktonic Foraminifera of the *Rotalipora* group as well as several species of calcareous nannofossils, new genera of Ammonites such as *Pseudaspidoceras*, *Thomasites* and *Choffaticeras* appear as well as Planktonic Foraminifera of the *Helvetoglobotruncana helvetica* group.

— The Turonian-Coniacian boundary is well defined by Ammonites but not by any of the other groups;

— The Ammonite genera *Pseudaspidoceras*, *Prionocyclus*, *Reeisidites* and *Forresteria* are described for the first time in Tunisia;

— The disappearance of *Rotalipora* in the Late Cenomanian is related to the development of a dysaerobic environment (Bahloul Formation), as is the disappearance of *H. helvetica* (dark marls level in the Aleg Formation). The development of this type of environment coincides with a major transgressive event;

— Species of Planktonic Foraminifera belonging to the genera *Whiteinella*, *Dicarinella*, *Marginotruncana* and *Sigalitotruncana* appear with the onset of the Turonian and many individuals possess morphological characters intermediary between these genera. Of interest is the appearance of *D. concavata* in the Late Turonian even though it is often cited as a Coniacian taxon;

**Microfacies.** — This approach provides insight into the way sediments respond to changes in relative sea-level. As such microfacies is essential for a sequence stratigraphic interpretation.

— In shelf margin wedges, wackestones, packstones occur commonly, benthic macrofossil bioclasts are abundant and varied, while Calcispheres reach a maximum.

— In transgressive systems tracts, textures are dominated by wackestones passing upwards to mudstones, phosphatic and glauconitic grains increase in number, keeled Planktonic

Foraminifera become diversified and Calcispheres are still found occasionally in great number.

— In highstand deposits, textures are mostly wackestone to mudstone. Calcispheres are rare, phosphatic and glauconitic grains are generally absent and the number of Foraminifera decreases in the calcareous beds.

**Sequences.** — Sediments in the Turonian interval can be organized in three complete and two partial sequences. The lower and upper boundaries of the Turonian at SM 137 and HMT 748 respectively are flooding surfaces in transgressive systems tracts. These sequences appear to be synchronous, within the available biostratigraphic constraints, with the sequence recognized in the type area of the Turonian in France.

— The lower sequence stands in the Late Cenomanian and will be studied in more detail as part of a later project on the Cenomanian of Kalaat Senan.

— The maximum flooding surface of the lower surface at SM 200 in the Early Turonian corresponds to one of the highest sea-levels during the Cretaceous. It represents not only the maximum flooding of a 3rd-order cycle but also of the 2nd-order super cycle that begins in the Late Albian and ends at the Middle-Late Turonian boundary.

— A sequence stratigraphic correlation between the platform and the basin (Fig. 35) is based on published facies and stratigraphic information from the Jbel Semmama platform area to the south and data from this study for the Kalaat Senan bassinal area.

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