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DEPOSITIONAL ENVIRONMENT, PALEOECOLOGY AND DIAGENETIC HISTORY OF THE "MARBRE ROUGE A CRINOIDES DE BAELEN" (LATE UPPER DEVONIAN, VERVIERS SYNCLINORIUM, EASTERN BELGIUM)[1]

by

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(12 figures and 19 plates)

RESUME. - Le "marbre rouge à crinoïdes de Baelen" est la seule structure récifale connue dans le Famennien du Massif Ardenno-Rhénan. Son origine semble être liée à la présence d'une faille transversale profonde (le linéament de Trier-Verviers) dans le Synclinorium de Verviers. Pendant une pulsation transgressive éphémère et un arrêt momentané des apports détritiques siliciclastiques, des carbonates se sont déposés sur des hauts-fonds marins offshore. Crinoïdes, algues vertes et éponges hexactines auraient d'abord abaissé la vitesse des courants locaux, tout en piégeant la boue calcaire.

Par la suite, cyanobactéries et algues ont largement contribué à la production de boue calcaire et ont fixé les bioclastes en place. Une subsidence discontinue aurait permis au "récif" d'atteindre régulièrement la base des vagues : ces oscillations sont réflétées par l'interstratification fréquente d'encrinites (calcaires packstones et grainstones crinoïdiques) dans la masse de boue calcaire. Cette dernière se présente sous forme de calcaire mudstone algaire, crypto-algaire (à stromatactis) et spiculitique, passant localement à des calcaires mudstones et floatstones algaires. Une cimentation sparitique précoce des cavités crypto-algaires aurait consolidé la masse de boue calcaire.
Des arguments paléoécologiques semblent indiquer un milieu de plateforme calme et/ou relativement profond pour les mudstones (présence d'éponges siliceuses et d'assemblages particuliers d'ostracodes silicifiés) mais toujours dans la zone photique (supérieure ?) vu l'abondance des Issinelles. Par contre, le contenu micropaléontologique des encrinites suggèrerait plutôt un milieu subtidal peu profond et plus agité (foraminifères pluriloculaires souvent brisés, oncoïdes à girvanelles, gastéropodes vermétiformes).

L'histoire diagénétique du complexe calcaire de Baelen a révélé l'influence successive d'eaux phréatiques marines (sparite fibro-radiée), marines-météoriques mixtes (silicifications, dolomitisations) et météoriques (calcite syntaxiale, coronae de dissolution géopétales, dédolomitisation), ce qui indiquerait une remontée progressive et une émersion probable du récif après son édification. Enfin, une forte pression-solution a produit des textures diagénétiques remarquables dans les calcaires impurs : structures stylolaminitiques et stylonodulaires. Le complexe calcaire de Baelen représenterait donc un récif stratigraphique, se situant dans un milieu de plate-forme ouverte, sur un site prédestiné, près de la base des vagues, et montrant certaines analogies avec les "mud mounds" et les récifs à débris sparitisés.

Un nouveau genre et deux nouvelles espèces sont décrits : *Baculella gemina* n. gen. n. sp. Conil & Dreesen (Microproblematica) et *Processobairdia dreeseni* n. sp. Bless (Ostracoda).

ABSTRACT. - The "Marbre rouge à crinoïdes de Baelen" is the only Famennian reef-analogous structure known thus far in the Ardenno-Rhenish Massif. Its location within the Verviers Synclinorium is linked to the presence of deep-seated transversal faults. During a short-term transgressive pulse and a decrease of siliclastic detrital influx, carbonates were deposited on offshore, submarine structural highs. Initially, crinoids, dasyclads and sponges lowered the current velocity and trapped the lime mud. Subsequently, cyanobacteria and algae produced lime mud and/or fixed skeletal grains in place. Subsidence was important but discontinuous, so that the carbonate buildup has intermittently reached the wave base during its growth. These oscillations are reflected by the irregular but frequent interstratification of crinoidal packstones and grainstones within the mudstones. The latter include cryptalgal, algal and spiculitic mudstones, grading locally into algal bindstones and floatstones.

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Early-diagenetic (synsedimentary) spar-cementing of the cavities consolidated the calcareous lime buildup. Paleoecological evidence points to a quiet and/or relatively deep shelf environment for the mudstones (siliceous sponges, silicified ostracode assemblages) whereas the abundance of Issinellids would still indicate the (upper ?) photic zone. The micropaleontological content of the crinoidal pack/grainstones rather suggests more shallow subtidal conditions (broken plurilocular foraminifers, girvanellid oncoids, vermetid gastropods). The observed diagenetic processes reveal subsequent influences of marine (fibroradiaxial calcite), mixed marine-meteoric (silicifications, dolomitization) and meteoric (syntaxial rim cements, solution coronas, dedolomitization) phreatic waters, indicating a gradual uplift and possible emersion of the Baelen buildups after their deposition. A strong pressure solution produced conspicuous iden-supported stylolaminitic or stylonodular fabrics within the impurer limestones facies. Thus the Baelen limestone complex is a stratigraphic reef, located on a predestinated mounding site in an open marine shelf setting near wave base, displaying characteristics of both a mud mound and a spar-cemented debris reef.

Baculella gemina n. gen. n. sp. Conil & Dreesen (Microproblematicum) and *Processobairdia dreeseni* n. sp. Bless (Ostracoda) are described as new.

ZUSAMMENFASSUNG. – Der "Marbre rouge à crinoïdes de Baelen" im Synclinorium von Verviers ist die einzige z. Zt. bekannte riffähnliche Struktur im Famennium der Rhenò-Ardennischen Masse. Die Karbonatbildung erfolgte, bei reduzierter Schüttung klastischen Materials während einer kurzzeitigen Transgressionsphase, auf Hochzonen, die an tiefreichende Transversalstörungen gebunden sind. In der Anfangsphase wirkten Crinoiden, Grünalgen und Schwämme als Sedimentfänger, im weiteren Verlauf fungierten Algen und Cyanobakterien als Kalkschlammbildner und/oder fixierten Sediment und Bioklasten. Dabei wurden an Krypto-Algengefüge reiche spiculitische und Algen-mudstones gebildet, die lokal in Algen-bindstones bis -floatstones übergehen. Die unregelmässig verteilte aber häufige Einschaltung crinoidenreicher packstones und grainstones spricht dafür, dass das buildup – bei rascher aber unregelmässiger Subsidenz – zeitweise bis in den Bereich der Wellenbasis aufwuchs.

Der Fossilinhalt der mudstones lässt auf Ablagerung in einem ruhigen und/oder mässig tiefen Schelf-Bereich schliessen (Kieselschwämme, Zusammensetzung der Ostracodenfauna), wobei Massenvorkommen von Issinelliden für den (höheren ?) Bereich der photischen Zone sprechen. Der Mikrofossilinhalt der Crinoiden-packstones und -grainstones weist dagegen auf ein flacheres Subtidal hin (zerbrochene pluriloculare Foraminiferen, Girvanellen-Onkoide, vermiforme Gastropoden).

Die Hohlräume der Algen-Schwamm-buildups (Krypto-Algen-Hohlräume, Stromatactis) wurden frühdiagenetisch (synsedimentär ?) zementiert. Im weiteren Verlauf der Diagenese ist eine Abfolge von marinen (radiaxialer fibröser Zement) über marin-meteorische (Verkieselung, Dolomitisierung) zu meteorisch-phreatischen Bedingungen (syntaxialer rim-Zement, solution coronas, Dedolomitisierung) erkennbar. Dies spricht für eine sukzessive Hebung und möglicherweise für Trockenfallen des Buildup der Ablagerung der Karbonate. Abschliessend führte intensive Drucklösung v. a. in den unreinen Kalken an der Basis und am Top zur Ausbildung stylonodularer, stylolaminitischer und iden-support-Gefüge. Der Kalk von Baelen wird daher als stratigraphisches Riff interpretiert, das sich in einer tektonisch vorgezeichneten Position im offenen marinen Schelfbereich nahe der Wellenbasis bildete und sowohl Merkmale eines mud mound als auch eines "spar-cemented debris reef" zeigt.

Folgende Taxa werden neu beschrieben : *Baculella gemina* Conil & Dreesen n. gen. n. sp. (Microproblematicum), *Processobairdia dreeseni* n. sp. Bless (Ostracoda).

1. INTRODUCTION - HISTORICAL OUTLINE

Although mined at least since the 18th century, the "Marbre rouge à crinoïdes de Baelen" has been worked intensively between 1925 and 1940 in a few small quarries and some underground galleries at Les Forges, Baelen, north of the Vesdre Valley (Figs. 1-2). It has been mined also in the area between the Limbourg castle and Hèvremont. Unfortunately some of the latter outcrops have been destroyed by trash dumping. This red marble has been used mainly for decorating private and public buildings not only in the immediate surroundings of Baelen ("la Ville Haute de Limbourg") but also in the city of Verviers (Gare Centrale).

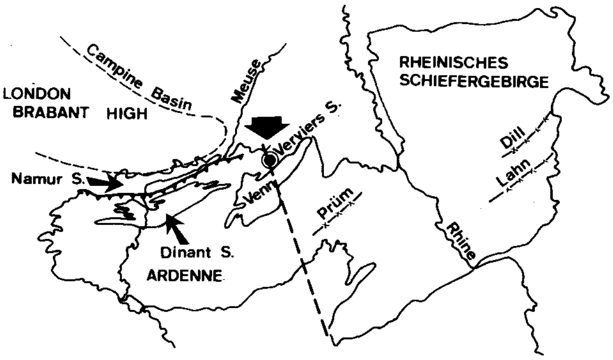


Figure 1
Location of the Baelen-Limbourg area and tectonic sketch map of the Ardenno-Rhenish Massif. Note presence of transversal fault (Verviers-Trier dislocation, Dvořak, 1973).

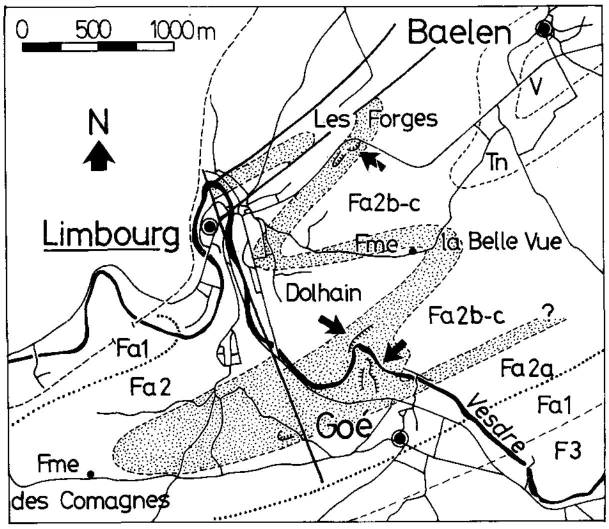


Figure 2
Geological map of the Limbourg area (after Fourmarier, 1953). Stippled area represents known and supposed extension of the Baelen Limestones. Arrows point to studied Les Forges and Goé sections. (F 3 : Upper Frasnian shales, Fa 1 : Famenne shales, dotted line : oolitic ironstone level IIIa, Fa2a : Esneux micaceous sandstones, Fa2b-c : micaceous sandstones of the Montfort and Evieux Formations, Tn : Tournaisian and V : Visean carbonates).

The red marble is restricted to the Baelen-Limbourg-Goé area. It represents the only massive carbonate deposit within the Upper Famennian regressive micaceous Condroz Sandstones. This limestone was locally known as "Marbre de Bailou" or "Jaspe", according to its extraction site (Groessens, 1982). Except for one possible occurrence of Baelen-type red crinoidal limestones of probable Famennian age near Anseremme (Dinant, central Synclinorium of Dinant; Stainier, 1892) and one occurrence of pinkish coarse encrinites in the basal upper Famennian of the Hamoir region (Ourthe Valley, eastern border of Dinant Synclinorium; Dusar & Dreesen, 1984), these massive red-stained crinoidal limestones seem to be restricted to the Famennian of the Baelen-Limbourg area, in the Verviers Synclinorium.

In its type-locality at Les Forges, Baelen, only the massive core of the limestone complex has been worked for facing-bricks. The more shaly, heterogeneous crinoidal limestones below and above the red marble core - locally known as "pierre poitée" or "peastone" because of the numerous crinoid ossicle sections - have not been mined, owing to their rapid desintegration and poor polishing properties.

Geologists know this particular crinoidal limestone since the late 19th century, but its exact origin and stratigraphic position remained unclear. Already in 1882, Dewalque placed the "Marbre rouge de Baelen" in the second unit (Assise) of the "Psammites du Condroz" (Upper Famennian micaceous sandstones). He noticed a certain analogy moreover with the red "F2j"-type mud mounds from the Frasnian type-region at the southern border of the Dinant Synclinorium.
Dupont (1886) mentioned the presence of stromatactis structures. He listed the first megafossils (brachiopods) from this particular level, which proved its Upper Famennian age.

Otherwise Gosselet (1888), was the first in correlating the Baelen limestones with the Souverain-Pré Formation of the Ourthe Valley, south of Liège. The latter had been originally defined by Mourlon in 1875 as the basal unit of the Psammites du Condroz : the "Assise du macigno noduleux de Souverain-Pré" (Fa2a). Dewalque (1901) lowered its stratigraphical position and included the "Marbre rouge à crinoïdes" in the top of the Assise d'Esneux (Fa1c), following the legend of the first official geological map of Belgium (1892) (Sheet n^{o} 136 : Limbourg-Hestreux-Brandenhaeg, 1 : 40000). Wulff (1922) correlated the "Marbre rouge à crinoïdes" with the red nodular crinoidal limestones ("Crinoidenkalk") which occur at the very base of the "Esneux Schichten" in the Aachen region. However these particular limestones most probably correspond to a local facies of the so-called "Cheiloceraskalk", which in turn represents a distal facies of oolitic ironstone level IIIa in the Verviers-Walheim region (see Fig. 3; Dreesen, 1982; Dreesen *et al.*, 1984). This low stratigraphic position for the Baelen marble had been adopted also by Bellière (1953) in the first petrographical study on the red crinoidal limestones and their stromatactis structures.
Fourmarier (1953) returned to the idea that the "Marbre rouge de Baelen" is a time-equivalent deposit of the Souverain-Pré Formation, a statement confirmed later on by Sartenaer in 1957.
Bouckaert, Conil & Thorez (1967) documented the biostratigraphical position of the Baelen marble by means of micro-fossils (conodonts, foraminifers). Eventually, a refinement of this biostratigraphic position (conodonts) as well as a paleogeographic reconstruction of the Souverain-Pré Formation and of its reef-analogous member (Baelen marble) in the Vesdre Massif has been worked out by Dreesen (1977, 1978). Different hypotheses have been proposed for the origin of these particular crinoidal limestones.
Bellière (1953) emphasized the reef-analogous character of the massive stromatactis-bearing facies ("calcaire construit") in the quarry of Les Forges, Baelen. According to Lombard (1957) the Baelen limestone had been deposited on top of a temporary sandy shoal, protected from detrital influxes. Thus, the Baelen limestone would not represent a major break in the detrital sedimentation, but rather a transitional calcareous episode at the Lower/Upper Famennian contact. Dreesen (1977, 1978) and Dreesen & Thorez (1980, 1981) interpreted the Baelen limestones as reef-analogous accumulations of crinoidal debris (crinoidal "mud mounds") on sandy shoals, which formed a

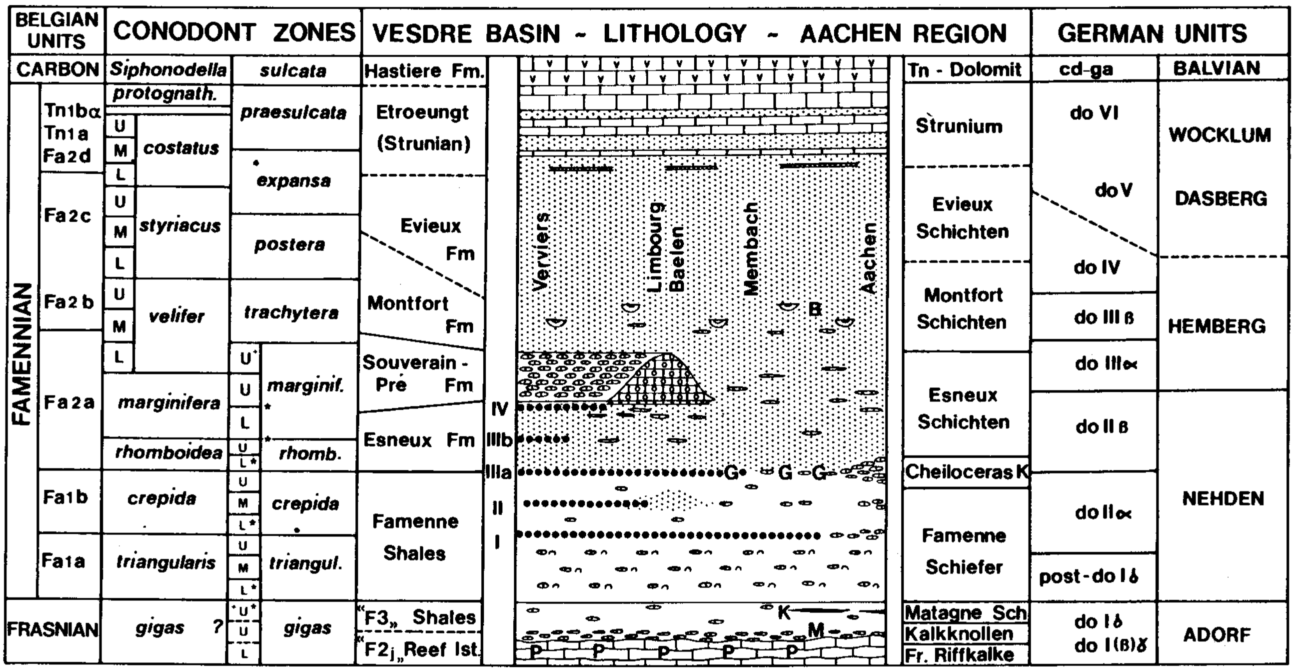


Figure 3
Stratigraphical correlation scheme of the Verviers-Aachen region. Roman numerals refer to oolitic ironstones of Dreesen (1982). Asterisks represent condensed conodont zonal intervals. (M : Manticoceras, *P :* Phillipsastrea, *G :* Cheiloceras, *K : "Kellwasser"-type limestones, B : ball- and - pillow" structures).*

discontinuous ramp on the silicoclastic shelf. Foraminiferal-crinoidal nodular limestones with Umbellinaceans occur in the more protected "back-mound" area, whereas the coetaneous micaceous sands with some coarse encrinitic lenses represent the front of the shoals. The supposed reef-affinity of the Baelen limestones has now been confirmed by microfacies analysis and study of the organisms which have lived in situ. The Baelen limestone complex represents a relatively shallow-marine algal-sponge-crinoidal carbonate buildup or reef mound, resembling knoll reefs or spar-cemented debris reefs (Dreesen & Flajs, 1984). Its position on the shelf and its depositional history seem to have been influenced by the presence of a deep-seated fault - the so-called Verviers-Trier dislocation - east of Verviers (Dreesen *et al.*, 1984).

The Baelen carbonate buildups or reef mounds are the first reefs recognized thus far in the uppermost Devonian (Famennian) of the Ardenno-Rhenish Massif. The complex reef ecosystem that gave rise to the extensive Siluro-Devonian buildups collapsed during the late Frasnian. The bulk of the coralline reef builders had almost vanished by the close of the Frasnian. Stromatoporoids had been reduced to a few genera, rugose corals underwent dramatic changes, and tabulate corals became extinct. The uppermost Devonian and Dinantian reef communities had few, if any, "reef building" taxa. The niches of the corals and stromatoporoids had been occupied by pelmatozoans and bryozoans (James, 1983).

This is also true for the Baelen reef mounds : crinoids, and to a minor extend green algae and siliceous sponges, initially lowered the current velocity and trapped the lime mud, whereas their skeletal debris have been subsequently fixed in place by encrusting non-calcified and porostromate algae.

Of special interest is the occurrence of numerous siliceous sponge spicula in close connection with stromatactis structures within the Baelen reef mound core. Siliceous sponge spicula are locally abundant in the red mud mounds and perireefal settings of the Upper Frasnian Neuville Formation in the Philippeville area (S border of the Dinant Synclinorium) (Fraipont, 1911; Termier *et al.*, 1981). Well-preserved Hexactinellid sponges (complete molds) have also been described from Upper Famennian micaceous sandstones (Grès de Watissart) at Jeumont and Cousolre (Northern France; Waterlot, 1946, 1950) as well as in the Montfort Formation (?) of the Hoyoux Valley (between Huy and Modave; N-border of Dinant Synclinorium, Legraye, 1929). Sponge-constructed stromatactis mud mounds have been described further from the Silurian of Québec, Canada (Bourque & Gignac, 1983). Well-preserved sponges have also been reported from early Famennian stromatactis mounds in the Devonian reef complexes of Canning Basin, Western Australia (Playford, 1980).

The purpose of this paper is to illustrate the different primary calcareous microfacies and the organisms which lived in-situ. The depositional environment is discussed and an attempt is made to reconstruct the complex diagenetic history of the Baelen reef limestone.

2. - GEOLOGICAL SETTING AND BIOSTRATIGRAPHICAL POSITION

The Baelen limestone complex is located in the eastern part of the Vesdre Massif or the southeastern part of the so-called Verviers Synclinorium (Graulich *et al.,* 1984), which is a complex Variscan (Hercynian) tectonic unit representing the eastern extension of the Dinant Nappes, south of the London-Brabant Massif (Fig. 1). This Verviers Synclinorium is composed of several smaller autochthonous, allochthonous and para-autochthonous tectonic units. Most probably the Devono-Carboniferous formations of the Baelen-Limbourg area belong to an allochthonous unit, which is bordered to the N by a satellite fault of the Magnée-Soiron Fault, which in turn forms the eastern prolongation of the Midi-Eifel-Aachen overthrust. The Baelen-Limbourg area is located on the northwestern extremity of a deep-seated transversal fault - the so-called Verviers-Trier dislocation (Dvorak, 1973) - which was present before the Midi-Eifel overthrusting. The latter has transported the Dinant Nappes, including the Verviers Synclinorium, in a northern direction parallel to the SE-NW paleofault. The Baelen limestones have been mapped in detail by Fourmarier (1953). These occur in SW-NE trending folds, of which the southern flat and NE-dipping Goé Syncline is the most conspicuous one (Fig. 2). A N-S transversal fault represents the western limit of the Baelen limestone, which dissappears abruptly NE of Goé. From there on, thin-bedded micaceous siltstones and sandstones occur with minor crinoidal limestones intercalations, bearing a coeval microfauna (Dreesen, 1977, 1978). Actually, the "Marbre rouge à crinoïdes de Baelen" is considered to be a local, reefoid member at the base of the Souverain-Pré Formation (Fa2a).

Samples from the sandy lenticular crinoidal limestones (bioclastic wackestones) at the transition between the Esneux micaceous silt/sandstones and the Baelen crinoidal limestones, NE of the Ferme des Comagnes (Fig. 2), yield rich conodont assemblages indicating the top of the Lower *P. marginifera* Zone or basal Upper *P. marginifera* Zone.

No conodonts have been extracted from the massive spar-cemented stromatactis-bearing limestones of lithological unit D (see further) because of the unfavourable facies. The coarse-grained crinoidal-foraminiferal limestones (crinoidal wacke/packstones) and sandy nodular crinoidal limestones (bioclastic wackestones) from either the basal units B and C or from the toplayers of Unit F, yield poor and monotonous conodont faunas, suggesting an (Upper ?) *P. marginifera* Zone (Dreesen, 1978).
Sandy nodular crinoidal limestones (basal unit A ? or lateral facies of reefoid limestones) in the low verges of a country road, east of the Ferme de la Belle Vue, yield also a poor, non-diversified assemblage of Polygonathids of the *semicostatus* group and rare Palmatolepids, typical of the (Upper ?) *P. marginifera* Zone (Dreesen, 1978). The basal strata of the Souverain-Pré Formation in the Verviers Synclinorium contain an identical conodont fauna, whereas its upper part reaches into the uppermost *P. marginifera* (former Lower *S. velifer*) Zone. This nodular limestone facies displays a maximum development within the Dinant Synclinorium, where its top reaches into the Lower *P. trachytera* (former Middle *S. velifer*) Zone (Dreesen, 1978).

Otherwise, the lenticular bioclastic wackestones of the Esneux-Baelen transitional beds contain a thin algal-encrusted mineralized hardground, which can be correlated with oolitic ironstone level IV in the western part of the Verviers Synclinorium and at the Northern border of the Dinant Synclinorium (Dreesen, 1982). Most of these ironstone levels show a biostratigraphical condensation, which might explain here the apparently mixed Lower and Upper *P. marginifera* conodont faunas (Fig. 3).

Bouckaert, Conil & Thorez (1967) described plurilocular foraminifers (Endothyridae and Tournayellidae) from a level immediately above the Baelen crinoidal limestone complex. The first lenticular bioclastic limestones just above the mound bear a foraminifer assemblage which is typical of the Zone with *Sept. rausea* and *Quas. bella* (or stage II of the *Quasiendothyra* Biozone). These foraminifers represent some of the oldest Endothyrids and Tournayellids ever recorded in the Devonian of Western Europe.

The stratigraphically important megafauna is restricted to a few rhynchonellids which have been collected at the base and at the top of the Baelen limestone complex. All the specimens can be assigned to "*Camarotoechia*" *letiensis* s. l., which characterizes the Upper Famennian, and the Souverain-Pré "facies" in particularly (Gosselet, 1897; Sartenaer, 1957; Beugnies, 1965).
The conodont faunas indicate the (Upper) *P. marginifera* Zone. This allows further correlation with the German orthozonation and local stratigraphic units (Rheinisches Schiefergebirge). It is located at the transition of the do IIβ and do IIIα or at the transition of the Nehden and Hemberg "Stufen" (Fig. 3).
Thus, the age of the Baelen Member of the Souverain-Pré Formation in the Verviers Synclinorium is undoubtfully Upper Famennian (Fa2aβ).

3. - LITHOLOGICAL UNITS

The Baelen Limestone complex is subdivided into six succeeding lithological units, in ascending order (Fig. 4, 5 and 6) :

Unit A (thickness minimum 8 m) consists of regularly alternating layers of bluish-grey small (5-10 cm)

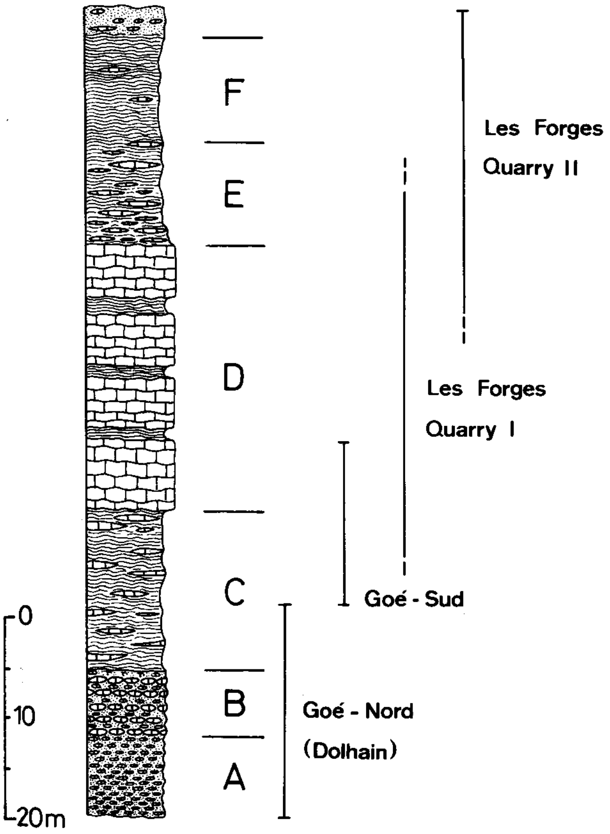


Figure 4
Compiled columnar section of the Baelen limestone complex, lithological units and stratigraphic position of the studied sections.

and medium-sized (10-15 cm) nodular sandy crinoidal limestones in a calcareous, micaceous sandstone matrix. The selective weathering of the limestone nodules in this unit has produced a characteristic cavernous appearance. The very base of this unit and the lithological contact with the underlying Esneux Formation (micaceous siltstones and sandstones) are not or badly exposed. It is rather a gradual transition with an increasing number of crinoid ossicles and of crinoidal limestone lenses. An algal-encrusted mineralized hardground locally occurs within this transitional zone. This hardground is an important stratigraphical marker bed, corresponding to oolitic ironstone level IV in the Vesdre Basin (Fig. 3).

Unit B (thickness 6 m) is characterized by an irregular alternation of thick, nodular to lenticular, bluish-grey sandy crinoidal limestones (15-30 cm) and even thicker, but less fréquent, pale-grey lenticular encrinites. Coarse crinoidal debris occur as irregular patches or as "Schlieren" within the former nodular limestone beds. The upper part of the unit is particularly rich in dense-packed, dolomitized/silicified *Baculella gemina* n. gen.. n. sp. Conil & Dreesen. Chert and dolomite occur as small irregular spots or thin discontinuous lenses in the core of some of the nodular/lenticular beds. The amount of crinoidal debris increases upwards, not only within the limestone beds but also within the enclosing sandy matrix.

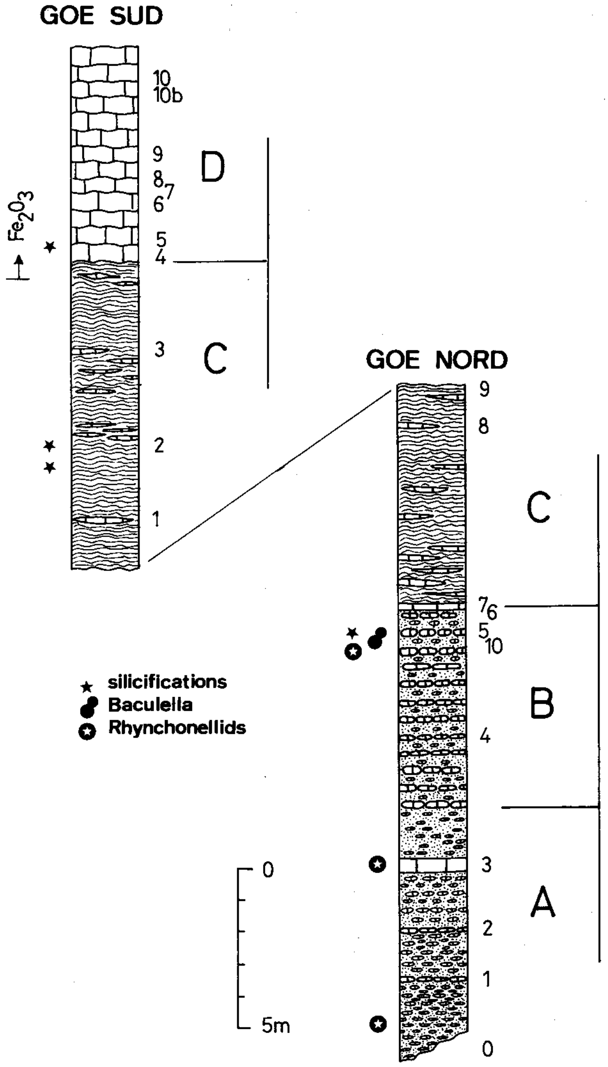


Figure 5
Detailed columnar section, lithological units and location of studied samples at Goé-Nord and Goé-S (Fe_2O_3 refers to start of red staining).

Unit C (thickness, 16,50 m) is a heterogenous sequence. It consists of thinly and thickly interlayered pale-grey lenticular encrinites and wavy-bedded, pseudo-laminitic, thin bioclastic limestones (maximum a few mm per lamina), which are frequently interlarded with large, mostly silicified or dolomitized crinoid stems. Usually, the latter are well-oriented and subparallel to the stratification. Graded bedding, reverse graded bedding and even cross-bedding have been observed within the encrinitic beds.
Silicifications are irregular, discontinuous, and preferably affect the larger crinoid ossicles. Red staining (hematitic pigment) starts about 70 cm below the base of the surmounting massive limestones (unit D).

Unit D (thickness 31 m) consists of thick-bedded (beds of 50 to 150 cm) massive spar-cemented limestone, composed of partially dolomitized and well-compacted heterogenous lithologies : thinly and thickly interlayered encrinites and pseudo-laminites, with stromatactoid structures. Alternating lithologies (microfacies), parallel-oriented and sparite-infilled stromatactoid structures and different colours (white, grey, pink, red) are responsible for the characteristic banding of this unit.

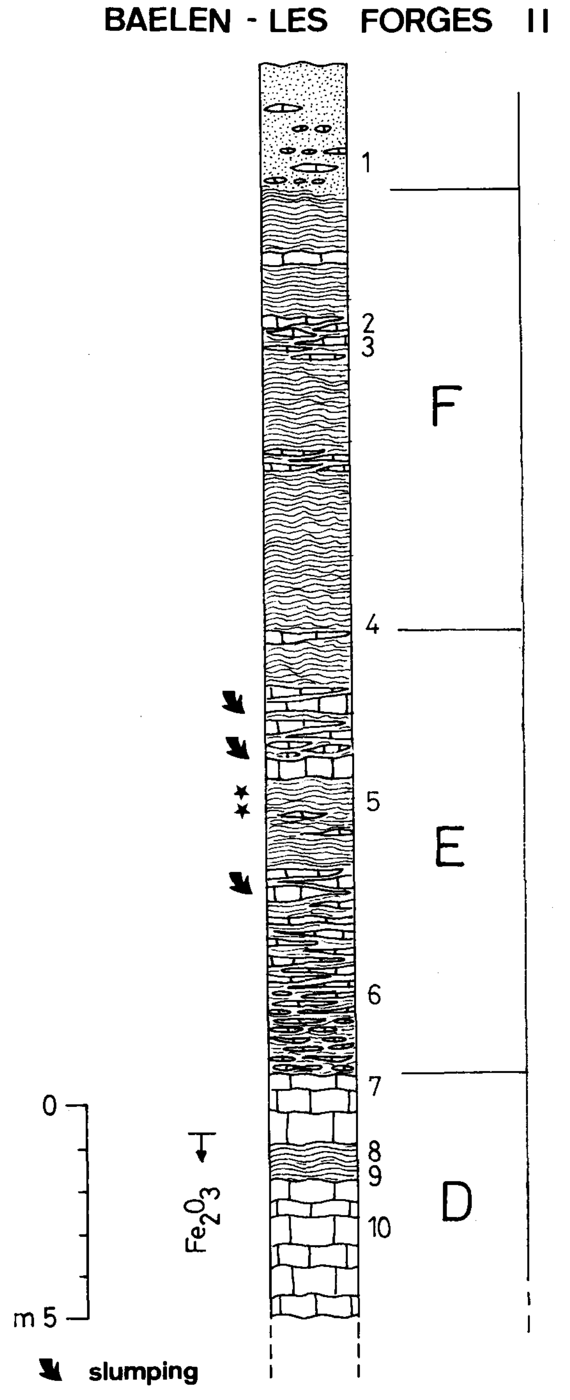


Figure 6
Detailed columnar section, lithological units and location of studied samples at Baelen-Les Forges Quarry II (legend see fig. 5).

The pseudo-laminitic facies are often strongly red-stained with conspicuous white crinoid ossicles, whereas the stromatactoid-bearing limestones are mostly variegated (pink-grey-white) according to the nature of the cement. Four sequences of massive banded limestones of 6-7 m each are separated by thin (maximum 150 cm) red-stained pseudo-laminitic intervals with dispersed white crinoid ossicles. Slumping and brecciation phenomena occur in the upper part of the unit and they affect especially the thick encrinitic lenses.
Unit D represents the core of the Baelen Limestone complex and the only part which has been quarried ("Marbre rouge de Baelen").

Unit E (thickness 15 m) is characterized by thinly and thickly interlayered nodular and lenticular pale-grey encrinites and wavy-bedded pseudo-laminitic limestones. Larger (up to 50 cm) encrinitic lenses are concentrated in the basal part of this unit, and they are often affected by slumping phenomena, although tectonic influences cannot be excluded (presence of a fault NW of the Les Forges quarries).
The number and the thickness of the encrinites is decreasing upwards. The enclosing pseudo-laminitic limestone matrix otherwise is enriched with micaceous sand (brownish-green calcareous micaceous sandstone). Chert and dolomite occur as small spots and discontinuous lenses, preferentially affecting larger crinoids, at irregular intervals throughout the unit. The red staining has completely disappeared from about 2 m above the base of the unit.

Unit F (thickness 15 m) is analogous to unit E, but with less and smaller encrinitic lenses. The carbonate content is decreasing whereas the detrital material is increasing towards the top of the unit.

The transition to the surmounting thin-bedded micaceous sandstones is characterized by a gradual disappearance of the lenticular and pseudo-laminitic limestone beds.

A few dispersed crinoidal limestone lenses embedded within brownish-green micaceous silt and sand mark the top of the Baelen Limestone complex. A few meters above this transitional zone, there is no trace left of the important carbonate sedimentation below. The Baelen limestone complex displays an apparently cyclic lithologic succession, which is largely due to differences in limestone microfacies, detrital continent, sparitic cementation and intensity of pressure solution. Bellière (1957) already noticed the presence of two alternating basic lithologies : heterogenous argillaceous limestones and purer stromatactis-bearing limestones; Lombard (1977) emphasized the cyclicity of the Baelen complex : micaceous sandstones - crinoidal and stromatactis limestones - micaceous sandstones.

Pressure solution affected both types of limestones but it is most conspicuous in the "heterogenous argillaceous" facies because of its higher detrital content :

insoluble residues such as clays, quartz, micas, Fe-oxydes and relatively more insoluble allochems (crinoids, brachiopods, ostracodes) accumulated along pressure-solution surfaces and formed thin (less than 1 mm and up to several mm) undulating or wavy-bedded "argillaceous" laminae (= so-called stylocumulates). The purer limestone facies on the other hand contain less or no siliciclastics. They have been affected by a pervasive cementation which has slowed down or even inhibited strong compaction.

Nevertheless, pressure solution is obvious in this micro-facies as well, particularly in the packed crinoidal packstones/grainstones : here intergranular pressure solution at grain contacts can be observed, as well as truncation of grains by adjacent grains (especially crinoid ossicles). But fragile structures such as stromatactis cavities, sponge spicula and thin-shelled ostracodes have resisted high pressures because they were imbedded within a relatively pure, more "plastic" micritic matrix. Hence, differences in the siliciclastic content, in the proportion of lime mud and in the degree of early cementation made the basic carbonate microfacies respond differently to compaction and subsequent pressure solution.

As a result, the primary microfacies of the heterogenous limestones (unities C, E and F) have been strongly overprinted by diagenetic processes, producing stylolaminitic, stylocumulate and stylonodular fabrics. Red coloration is strongest within the stylocumulates of the compressed impure heterogenous carbonate facies, and only faint within the spar-cemented pure stromactactis limestones.

4. - CARBONATE MICROFACIES

The six lithological units of the Baelen limestone complex are characterized by one or more primary microfacies. The basal units A and B are composed of alternating nodular and lenticular bioclastic wackestones and packstones, which are embedded in calcareous, micaceous sandstones. The contact between wacke/packstone nodules and the enclosing sandy matrix is not always very sharp but often gradual. The calcareous, micaceous sandstone contains allochems as well.

The overlying "argillaceous" limestone units C, E and F consist of different and irregularly alternating microfacies :

- cryptalgal bindstones or algal biomicrites, grading into spiculitic wackestones, packed biomicrites or algal floatstones.
- crinoidal wackestone/packstone, grading into grainstone/rudstone, often displaying graded bedding, reverse graded bedding or even cross-bedding.

These microfacies alternate and grade into each other, whereas a strong compaction produces iden-supported to stylocumulate fabrics (resulting in "secondary" packstone, grainstone or even rudstone). The central unit D (core of the Baelen limestone complex) essentially consists of the same, but "purer" microfacies, with a higher frequency of stromatactis peloidal and spiculitic mudstones.

Spar cementation has been pervasive here, the lime mud is exempt of siliciclastics, so that compaction only produced a strong packing and a relatively weak stylolitization. Iden-supported or stylocumulate fabrics are absent or limited to short, deeply red-staining "argillaceous" intervals (Fig. 4).

4.1.- THE BASAL, SANDY BIOCLASTIC WACKESTONE

Thin-bedded, lenticular and sandy bioclastic wackestones occur in the transitional zone of the Esneux micaceous sandstones to the Baelen crinoidal limestones. A thin (less than 1 cm) mineralized and algal-encrusted hardground subdivides the wackestones into two separate microfacies. The wackestone below the hardground contains 35 °/o of skeletal grains (ostracodes 20 °/o, brachiopods 10 °/o, crinoids, gastropods, bryozoans and girvanellids 5 °/o) and varying amounts of siliciclastics (quartz and micas between 10 and 50 °/o). The large brachiopod shells are well-oriented, and complete specimens are often infilled by fibroradiaxial calcite (Pl. 12 : 1-2). Peloidal mudstone occurs below large ostracods and brachiopod shells (umbrella effect) and has infilled most of the gastropods. Bioturbation is common and burrows have been infilled with sandy lime mudstone.

The wackstone above the hardground is a fairly spar-cemented crinoidal wackestone, which underwent strong compaction and pressure-solution. The latter produced conspicuous stylocumulates of detrital grains at the contact with the hardground. Bioclasts (35 °/o) mainly consist of bored crinoid ossicles, with some upturned brachiopod shells, brachiopod spines and some rare Rhodophycean and Codiacean algae.

The hardground is composed of microstromatolitic crusts (with interlamellar sparite-infilled encrusting organisms and sparry calcite laminae) enclosing partially ferruginized skeletal grains in a chloritic-phosphatic matrix. The biogene allochems consist of bored and encrusted crinoid ossicles, reworked ostracodes (different orientations of geopetal fillings), large recrystallized brachiopod shells and gastropods. Sulphides are common within the ferruginized stromatolitic crusts. A concentration of dolomite rhombs occurs very locally within the basal part of the hardground. Subsolution and fracturing processes are responsible of the lateral discontinuity of the hardground.

4.2.- THE ALGAL, CRYPTALGAL AND SPICULITIC MUDSTONES

The lower strata of the Baelen limestone complex (units A and B) display aligned limestone nodules in a calcareous micaceous sandstone matrix. The latter is strongly bioturbated whereas the former is locally enriched with ? dasyclads *(Issinella)* producing local algal bindstones. Sponge spicula are only sporadically present. The smaller limestone nodules of unit A are sandy biomicrites or mudstones containing about 20 °/o of skeletal grains. The biogene framework is composed of thin-shelled ostracods (25 - 30 °/o), dasyclad segments (20 °/o), crinoid ossicles and brachiopods (Rhynchonellids). Both the ostracodes and brachiopods are geopetally infilled.

The larger nodular limestones of unit B as well as the bulk of the limestones of the higher units (before their compaction), essentially consist of cryptalgal mudstones, grading into algal mudstones. Irregular laminoid-fenestral fabrics as well as peloid textures abound. The biogene allochems reach 15 to 20 °/o of the rock-volume and these are essentially ? dasyclads (*Issinella,* 50 - 60 °/o). Non-encrusting *Girvanella* colonies, isolated *Disonella, Kamaena,* agglutinate foraminifers and sponge spicula represent minor constituents. These algal mudstones become locally enriched with either ? dasyclads, producing algal bindstones, or with *Baculella,* producing conspicuous floatstones (e.g. top layers of unit B).

Silicified thin-shelled ostracods, small Endothyrids, and *Baculella*-twins have been collected from the dissolution residues of acid-etched mudstones. Very often the cryptalgal/algal mudstones become enriched with hexactinellid sponge spicula, producing spiculitic mudstones or wackestones (Pls. 13-14).

Supposed relicts of sponge network (length up to several cm) and/or felted spicula are commonly observed in thin section (Pl. 13 : 2). The calcareous, micaceous sandstone matrix still contains sheetlike accumulations of dasyclad segments, as well as some reworked brachiopods (indicated by the presence of internal biomicritic sediment with geopetally infilled *Baculella*).

These accumulations of bioclasts in the sandstone do not represent stylocumulates (relicts of pressure solution). This is suggested by the non-corroded aspect of the green algae (? primary aragonitic skeleton). Indeed, the surrounding calcareous sandstone must have protected the algal mudstone against pressure solution phenomena. Otherwise, the gradual decrease of siliciclastics matches an increase in lime mud production and an increase of the carbonate content in the sandstone. The resulting impure limestones, have been strongly affected by pressure solution. The micrites (mudstone) have been dissolved in the first place, producing "secondary" grain-supported microfacies (packstones, grainstones and even rudstones). Insoluble residues and/or less-soluble (calcitic) allochems have been concentrated along stylolytic seams, and produced wavy-bedded stylocumulates (clays, quartz, micas, silicified crinoid ossicles, corroded ostracodes, highly-corroded dasyclads). All transitions have been observed, ranging from only slightly stylolitized mudstones/wackestones to iden-supported stylolaminitic or stylonodular limestones (Pls. 18-19), depending on the amount of siliciclastics and the degree of compaction. This diagenetic fabric has been responsible of the typical pseudolaminitic outlook of the units C, E and F, just below and above the massive stromatactis-bearing core of the Baelen complex.

4.3.- THE STROMATACTIS MUDSTONES

Stromatactis mudstone is a characteristic microfacies of the core of the Baelen limestone complex (lithological unit D) and alternates with crinoidal pack/grainstones. The stromatactis mudstone is different from the above mudstones by the larger amount of spar-cemented cavities (making up to 50 °/o of the rock volume), by its relatively cleanness (exempt of siliciclastics) and by the absence of *Baculella. Issinella* is very rare to absent.

Stromatactis displays a wide range of sizes and morphologies. Peloidal textures are very frequent, especially in the vicinity of the stromatactis cavities. Sponge spicula are abundant and produce locally spiculites. Crinoids are dispersed within the lime mud matrix and often enclosed in the cavities. Internal spar cements include fibro-radiaxial (early) and blocky (late) calcite cements. Solution coronas preferentially developed below the larger, dispersed, crinoid ossicles. Brachiopods and ostracodes are present and often geopetally infilled.

The red staining is conspicuous but affects the lime mud only. Silicifications and dolomitizations are practically absent. Pressure solution produced thin, red-stained stylolitic seams.

4.4.- THE CRINOIDAL PACKSTONES AND GRAINSTONES

Lenticular crinoidal packstones/grainstones are frequently interstratified at irregular intervals within the former mudstones. Graded bedding, reverse graded bedding, cross bedding and slumping are common.

The packstones/grainstones are weakly to medium-sorted. Locally these grade into rudstones. Crinoid ossicles represent the bulk (50 to 90 °/o) of the biogene components (over 50 °/o of the rock volume). They are often undissociated (stems up to several cm), rarely broken and frequently silicified. Silicified/dolomitized crinoid ossicles form local rudstone patches or irregular laminae within the normally strongly spar-cemented grainstone. Syntaxial rim cements are very frequent, overgrowing the echinoderm skeletal grains (including also the silicified crinoid ossicles) (Pls. 15-16).

The bioclastic framework not only consists of crinoid ossicles but also of plurilocular foraminifers (Endothyrids-Tournayellids), fenestellid and encrusting bryozoans, serpuloid gastropods, encrusting girvanellids (forming primitive oncoids), rare ostracodes and brachiopods.

Minor allochems include mudstone intraclasts and rare dasyclad segments. *Baculella* and sponge spicula are absent. Compaction is moderately high, prducing secondary rudstone-like rock types and intergranular sutural contacts (truncated grains).

5.- MICROFLORAL-MICROFAUNAL CONTENT

5.1.- STROMATACTIS AND RELATED STRUCTURES

Stromatactoid structures abound in the massive spar-cemented core (unit D) of the Baelen limestone complex. They are imbedded in peloidal lime mudstones (displaying "crumbly" fabrics or "textures grumeleuses" *sensu* Cayeux, 1935) or spiculitic wackestones. In contrast with the "normal" aspect of stromatactis, the Baelen stromatactoid structures display less-developed digitate upper surfaces. Long planar and ramifying areas of sparite with parallel undulating floors and roofs, concordant to the bedding plane, are more common (= so-called "zebra" limestones, Pratt, 1982). These "zebra" stromatactis must not be confounded with zebra textures in dolomitic rock sequences, in which the banded white sparry dolomites are secondary after dilatant evaporitic precursors (Beales & Hardy, 1980).

Crinoids are often "floating" (= three-dimensionally supported) or "contoured" by the sparry calcite within the stromatactoid structures. Smaller stromatactoid structures (several mm up to 1 cm) show a characteristic gondola shape, with more or less symmetrical lateral expansions (Pl. 14 : 4). Irregular and roughly symmetrical invaginations can also be observed within the columnar connections between two or more succeeding planar stromatactoids.

These structures are completely infilled with fibrous and blocky calcites. Internal sediments have not been observed. Peloids seem to "hang down" from the roofs of some stromatactoid structures (Pl. 14 : 7-9). The original fibrous calcite (with curved twin lamellae) has been recrystallized into a clear blocky spar cement. This fibrous cement grew centripetally from both the top and basal surfaces, and nucleated around enclosed crinoid ossicles, to form isopachous fibro-radiaxial cement crusts; the next generations of fibrous sparite subsequently grew towards the center of the cavity and stopped eventually along a median crystallization suture. Remaining central pore spaces have later been filled by blocky calcites.

None of the sparite cements is red-stained by the hematitic pigment, which is common to the enclosing sediment. Some fibrous calcite generations are greyish (incorporated organic matter ?) whereas the blocky spar is always clear. The origin of stromatactis and related spar-cemented cavities is still a matter of speculation.

Attemps to relate stromatactis to water-escape structures (Heckel, 1972) or to submarine-cemented crusts (Bathurst, 1980, 1982) proved to be unsatisfactory within the stromatactis-bearing red mud mounds of the Upper Frasnian reef complexes in the Philippeville region (Dinant Synclinorium) (Tsien, 1980; Tsien *et al.*, 1980).

According to the latter authors, stromatactis behaved like a true organic colony. This statement is based on an apparently ecologically-induced morphological differenciation which seems to be analogous to that observed in *Alveolites, Phillipsastrea* and stromatoporoids within the same reef mounds. Thus the spar cement of stromatactis might represent recrystallized biologically precipitated micrite or algal-cyanobacterial replacements of colonial bacterial accretions.

A similar bacterial origin has also been proposed by Monty (1982). In his opinion the fibrous sparite is a microbial sparite resulting from cavity-dwelling filamentous microbial growth, and assimilated to cavity-dwelling stromatolites.
Moreover, the fibrous sparite-generating activity of those encrusting organisms, would have lead to an early cementation and to the consolidation of the originally soft muddy sediment (mud mounds).

Bourque & Gignac (1983) otherwise stressed the close association of siliceous sponges and stromatactis in Silurian mud mounds of Québec, Canada. They believed that stromatactis originated as an early marine cementation of growth cavities in the sponge network and of cavities created by the decay of local uncemented sponge tissues.

Our observations of stromatactis-related spar-cemented cavities in the Baelen limestones complex, are more likely to confirm the latter sponge cavity cementation model. Analogous sponge spicule network and peloidal lime mud network occurs in the vicinity of the stromatactis structures.

Relicts of a calcified and closely packed spicular network are still visible. Peloidal fabrics and cement-supported peloids with abundant, still undissolved hexactinellid sponge spicula surround or "enclose" the stromatactis cavities. "Overhanging" or pendant peloids occur along the roof of the cavities, whereas the first isopachous fibrous rim cements must have grown centripetally from peloidal floors.

Early-diagenetic cementation of those cavities produced thus the stromatactis : isopachous fibrous rim cements grew centripetally from both the floor and roof of the cavity system and eventually remaining pore space was filled later by late-diagenetic blocky calcite. Stromatactis is thus indeed the cement fill of a system of cavities, as suggested by Bathurst (1980) and confirmed recently by Bourque & Gignac (1983).

Moreover, silicifications (replacements and infilling) of *in-situ* organisms (foraminifera, ostracodes, *Baculella*) and skeletal debris (mainly crinoid ossicles) occur in the facies immediately underlying and surmounting the massive, spar-cemented stromatactis-bearing limestone. These are almost totally absent in the compact core itself (unit D).

Partial dissolution of siliceous sponge spicula (observed in thin section) but especially silica precipitation within the mixed water phreatic zone, may account for the observed silicifications in units B, C and E (see further).

5.2.- ALGAE, FORAMINIFERS AND MICROPROBLEMATICA

5.2.1. - Non-calcareous algae - cyanobacteria

The bulk of the lime mud ((micrite) in the mudstones probably has been produced and/or fixed by non-calcareous algae. Cryptalgal, laminoid-fenestral fabrics are very common and may be related to non-calcified algal and/or bacterial mats (Monty, 1976). Pelletoidal or peloidal textures are frequent, especially in the vicinity of the larger cavities (stromatactis) and might be the result of algal or bacterial-induced decomposition of organic tissue (sponge tissue ?) (Bourque & Gignac, 1983).

5.2.2. - Calcareous algae

5.2.2.1. - Porostromate Cyanophyceae

Girvanella is very common and occurs either as free-living colonies in the algal mudstones (*G. problematica, G.* ? sp.), or as colonies encrusting skeletal grains in the crinoidal packstones and grainstones (*G. wetheredi*). The latter even form primitive girvanellid oncoids. The diameter of the filaments allows a further subdivision (Pl. 2 : 2-4).

5.2.2.2. - Chlorophyta

Different biologic affinities have been proposed in the literature for *Issinella* Reitlinger, 1954 and *Pseudoissinella* Mamet & Rudloff, 1972.

Termier, Termier & Vachard (1977) considered *Issinella* and *Pseudoissinella* as Moravamminida Pokorny, 1951, which, in turn, would represent paleozoic representatives of the *Ischyrospongia* (hypercalcified sponges with fibrous and porous skeleton).

Mamet & Roux (1975) and Cnudde & Mamet (1983) otherwise attributed these forms rather to the green algae, in particularly to the Dasycladacean algae. Moreover, their attribution to the Codiacean algae seems also possible (E. Flügel, pers. comm.). An analogous problem concerns the taxonomic position of *Kamaena* Antropov and related forms (Tappan, 1980). These broad morphological group of tubiform microfossils has been refered to the Codiaceae, the Dasycladaceae, the red algae, the foraminifers and even the sponges (Riding, 1977).

In our opinion, no clear evidence exists for assigning those Issinellidae to the sponges. Moreover, the attribution by Termier *et al.* of *Issinella* to the *Ischyrospongia* is still questionable (1977, p. 215).

According to our microfacies interpretation, the Issinellidae would have lived in an open marine shelf environment, most probably just below wave base (see Chapter 7). Their frequent occurrence within micaceous sandstones does not fit very well the habitat of a filter-feeding organism (sponges).

Furthermore, *Issinella* is practically absent from the stromatactis mudstones and associated spiculites of the central (unit D). In anyway, it appears that these problematic calcareous microfossils had not a very large bathymetrical distribution : they are especially abundant within shallow subtidal environments (asociated to stromatoporoids, calcareous algae and foraminifera) of the Strunian (Ardennes shelf), as well as in lagoonal facies of the Tn3c-V1b (bafflestones with *Kamaena, Paleoberesella* and *Girvanella*). Moravamminids are also known from the deepest parts of the photic zone but these forms lack the fine fibroradiated wall-structure of *Issinella*. They are more likely to represent *Kamaena*-like forms (Lees *et al.*, 1977, 1978). Their stratigraphic range extends from the late Devonian (Upper Frasnian?, Famennian, "Strunian") into the Dinantian (Tournaisian, Visean).

Very locally, a few fragments of Codiacean algae have been observed (e.g. in the algal mudstones of the unit B at Goé-Nord section).

5.2.2.3. - Rhodophyta

One fragment of a Corallinacean algae (?) has been observed in thin section from the bioclastic wackestone with ferruginized hardground, directly below the Baelen limestones (Ferme des Comagnes outcrop) (Pl. 2 : 1; Pl. 12 : 1).

5.2.3. - Foraminifers

Silicified agglutinate (?) foraminifers have been found in the dissolution residue of the acid-etched mudstones. They might be assigned to *Tolypammina* and *Hyperammina,* although their attribution to Moravammidae cannot be excluded (see legend of Pl. 3). In the same residues some well-preserved silicified plurilocular foraminifers have been discovered (Pl. 4 : 1-11) as well. Endothyrids and Tournayellids are common in the crinoidal packstones and grainstones from units C to F, and from above the reef mound. In the lower units (A - B) only few primitive Endothyrids (silicified) occur as well as the fragile genus *Disonella.* Thus far no intermediate fauna has been discovered in Western Europe between the *Nanicella*-Semitextulariidae foraminiferal assemblage (or Df1 Zone; Bultynck & Mouravieff, 1967) and the *Quasiendothyra*-fauna (Df3 Zone; Bouckaert, Conil & Thorez, 1967). The first fauna is endemic and disappears together with the coral reefs at the end of the Frasnian. The second one suddenly appears within the (Upper) *P. marginifera* Zone in the Franco--Belgian sedimentary basin.

The primitive Frasnian Tournayellids *(Eotournayella, Pseudoglomospira)* are the precursors of the Famennian and Dinantian pluriloculars. These seem to have survived only in a few places in the world. They gave rise to the *Septatournayella* or Df2 foraminiferal assemblage (Shilo *et al.*, 1984, p. 140).

Two migrations from Eastern Europe have temprarily introduced Famennian foraminiferal assemblages in Western Europe. The oldest one, described herein, is relatively diversified but ephemeral. It is dominated by highly variable *Septabrunsiina,* among which the precursors of *Quasiendothyra.* The following species have been recognized : *Baelenia gosseleti, Septatournayella rauserae potensa, Quasiendothyra bella.* This association ranges into the *P. trachytera* conodont Zone (former Middle *Sc. velifer* Zone).

Hereafter, plurilocular foraminifers are extremely rare until the Strunian transgression. This transgression coincides with a second faunal migration. The latter contains more evolved Quasiendothyrids and is accompanied by stromatoporoids and rugose corals. The migration of the Baelen foraminiferal fauna seems to be linked to an important, possibly worldwide, paleogeographical event and to the development of widespread ecologically suitable environments within and beyond the Franco-Belgian basin.

5.2.4. - Microproblematica

A new microproblematicum, *Baculella,* has been discovered in the basal lithological units of the Baelen limestone complex. Several hundred large and paired "calcispheres" have been observed in thin section as well as with the hand lens in the algal or spiculitic mudstones of unit B (in the Goé-N-section). These spheres are often silicified and dolomitized so that internal molds can be easily isolated from the mudstone by acid-etching. The biological affinity of *Baculella* is still unclear. Its general morphology is very close to that of the Parathuramminacean (?) *Saccaminopsis.* According to the nature of its wall *Baculella* is close to *Issinella,* and might as well represent a Chlorophycean algal colony (maybe similar to dasycladacean strings, as *Mizzia* for instance). *Baculella* is locally so abundant that the enclosing mudstone grades into a floatstone. *Baculella* and *Issinella* may also locally form algal bindstones (Pls. 6, 8).

Baculella n. gen. Conil & Dreesen

Derivatio nominis : Baculeolum (Lat.), Baelen.

Genotype : *Baculella gemina* n. sp. Conil & Dreesen.

Diagnosis :

Unilocular piriform chambers which end anteriorly into a narrow neck. The height of the unit reaches 1800 microns. Numerous sections show the association or connection with a second chamber. The neck of the first chamber penetrates the second one without significant thickening of the wall. The junction is always very narrow with respect to the width of the chambers. The wall is clear, fibroradiated and finely perforated, and somewhat darkening towards the exterior. Pore diameter about 2-3 microns.

Remarks

The morphology of the chambers, their size, and the neck-like junction are reminiscent of *Saccaminopsis* (Upper Visean), but their wall is different. The finely perforated structure of the wall of *Baculella* is analogous to that of *Issinella.*

Range

Lower part of Upper Famennian (Lower - Upper *P. marginifera* Zone).

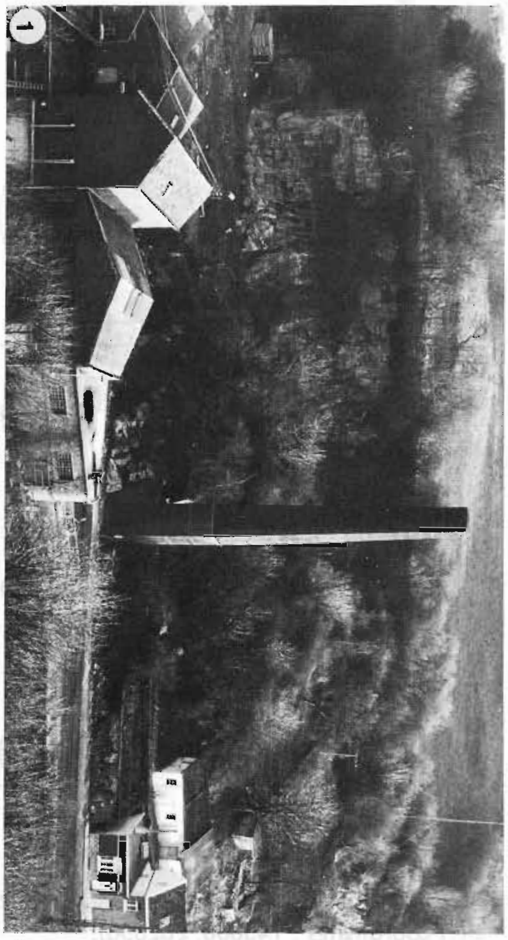
Baculella gemina n. sp Conil & Dreesen

Derivation nominis : Geminus : double, paired.

Holotype : thin section Goé-N-10 a, Pl. 5 : 4.

PLATE 1

1. type locality of the "Marbre rouge à crinoïdes de Baelen", quarries I (left) and II (extreme right) at Les Forges, Baelen. Upper lithological units D to F (1976 photograph).
2. basal lithological units A to C at the Goé-N-section.
3. Goé-N-section : top of unit A : weathered aligned wackestone nodules.
4. Goé-N-section : unit C : weathered stylolaminites.
5. Les Forges, Baelen, quarry I : NE-wall : top of massive unit D and transition to unit E. Inset refers to fig. 6.
6. detail of previous fig. : from base to top : pale-grey to pinkish stromatactis mudstone, red-stained "argillaceous" interval with numerous white crinoid ossicles and lenticular crinoidal grainstones.
7. Baelen, Les Forges, N of quarry I : crinoidal pack/grainstones displaying slump deformation (unit E).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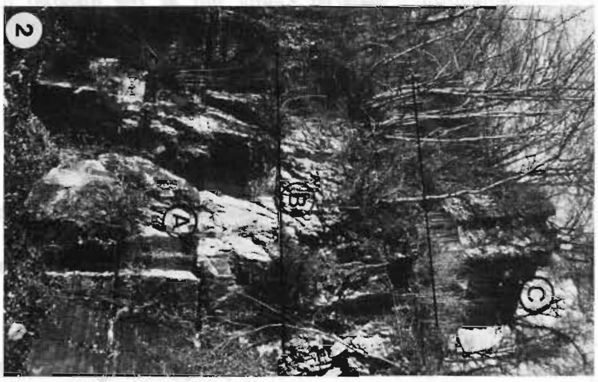
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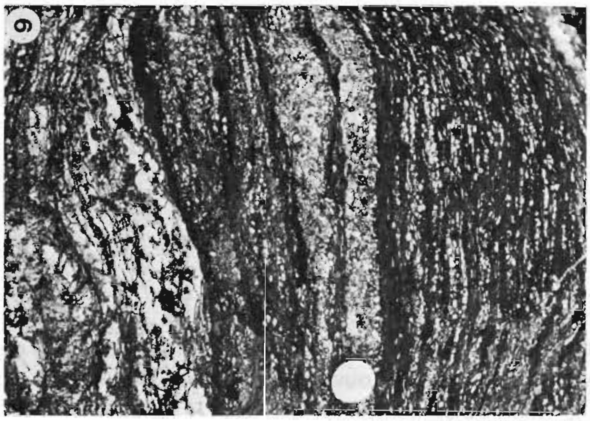
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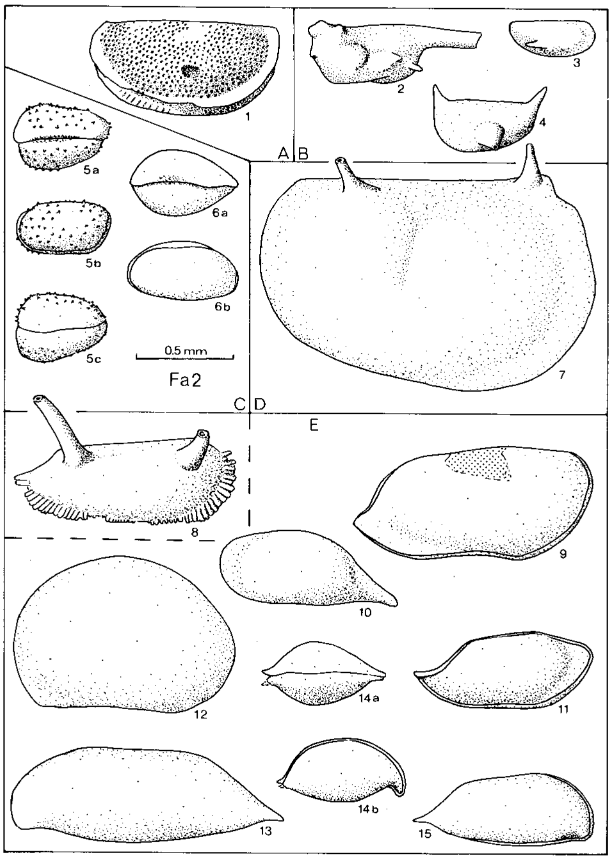


Figure 7

Ostracode assemblage from sample Goé-N-10, basal Upper Famennian. Material kindly put at the disposal of M.J.M. Bless by R. Dreesen, RWTH Aachen.

1. Kirkbya *cf.* ima *Bushmina 1979*
2. Berounella *sp.*
3. Monoceratina *sp.*
4. Tricornina robusticerata *Blumenstengel 1969.*
5. Microcheilinella shiloi *Bless 1984.*
6. Microcheilinella *sp.*
7. *Beyrichiacean sp. 104 Becker & Bless 1974 (cf.* Bouckaertites komiensis *Tschigova 1977).*
8. Processobairdia dreeseni *Bless nov. sp., holotype, right valve.*
9. Bairdia (Rectobairdia) *sp.*
10. Bairdia? *sp.*
11. Bairdia (Rectobairdia) *cf.* philippovae *Egorov 1953*
12. Bairdiocypris *sp.*
13. Acratia *sp.*
14. Acratia (Cooperuna) *sp.*
15. Acratia (Cooperuna) *sp.*

Locus typicus : Limbourg, Dolhain, Sheet 43/5-6, Lambert coordinates : 145800, 262050).

Stratum typicum : Fa2a, top of unit B at Goé-N (Dolhain), 150 cm below base of unit C; Baelen limestone complex.

Diagnosis

A paired *Baculella* species, in which the chambers are attached to each other under a more or less pronounced angle. The total height reaches 3350 microns. The wall is 35-40 microns thick.

Range

Basal part of Upper Famennian; Baelen member of the Souverain-Pré Formation, Verviers Synclinorium. Base of Souverain-Pré Fm in borehole A 200 (Belg. Geol. Survey) at Roly, S of Philippeville. Dinant Synclinorium (in : Dreesen, 1978, fig. 15, sample 2 and p. 41). Lower-Upper *P. marginifera* Zone.

5.3. - OSTRACODES

Only one sample (Goé-N-10) from the basal Upper Famennian (Upper *marginifera* conodont zone) of the Goé-Nord section has yielded a rich ostracode assemblage. Several hundred silicified specimens have been picked out of the light fraction of the residue after dissolving the limestone. The assemblage consists of at least fifteen species (fig. 7; pl. 9) among which Bairdiaceans *(Bairdia, Acratia)* predominate, both in the number of species (six out of fifteen) and in the number of individuals (60 to 70 %).

PLATE 2 : Algae and incertae sedis

cf *Rhodophycea*
1. COM-1 (23299), x 75

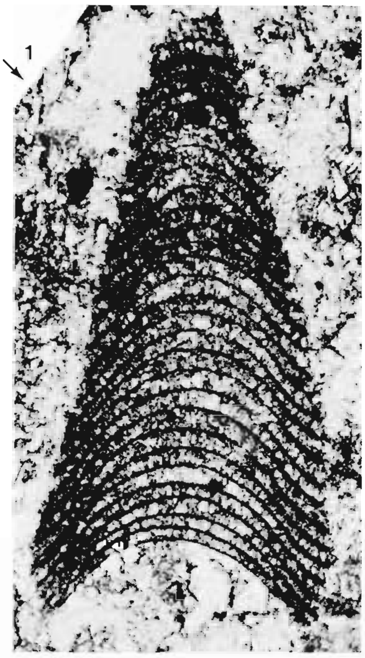
Girvanella problematica Nicholson & Etheridge, 1878
2. 76-Bae-8 (23064), x 75

Girvanella wetheredi Chapman, 1908
3. Bae-LF-12 (23298), x 75

Girvanella wetheredi Chapman, 1908
4. 76-Bae-3 (23059), x 75

Incertae sedis
5-6. 76-Bae-9 (23048, 23049) x 75
7. 76-Bae-2 (23056) x 75
8. 76-Goé-2 (23303) x 75

Thin sections RC and original photographs (number between brackets) have been stored at the Laboratoire de Paléontologie, Mercator Building, Place Louis Pasteur, Université Catholique de Louvain, Louvain-la-Neuve. All other thin sections and original photographs have been stored at the Geol. Paläont. Institut der RWTH Aachen, West-Germany.



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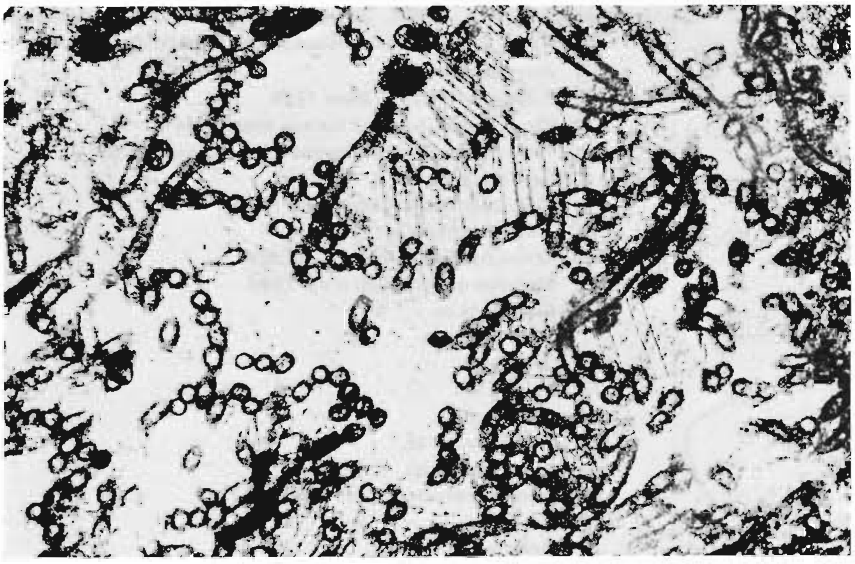

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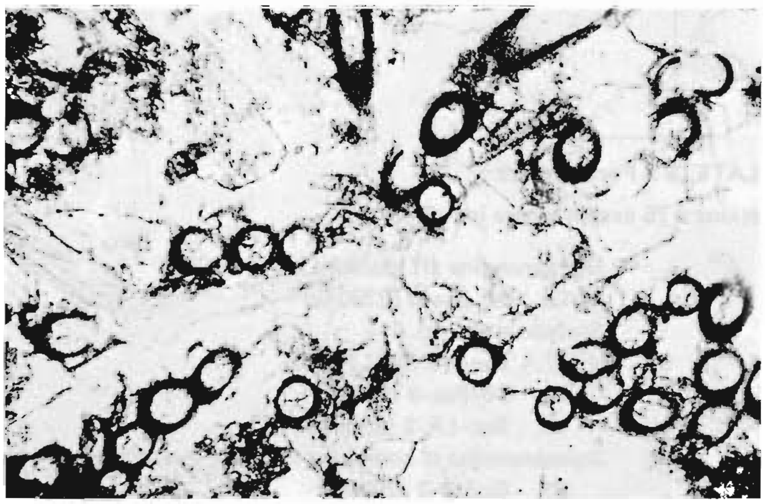

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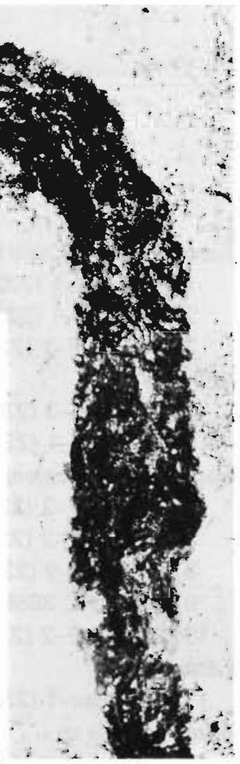

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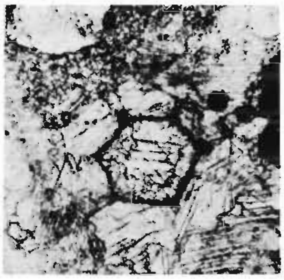

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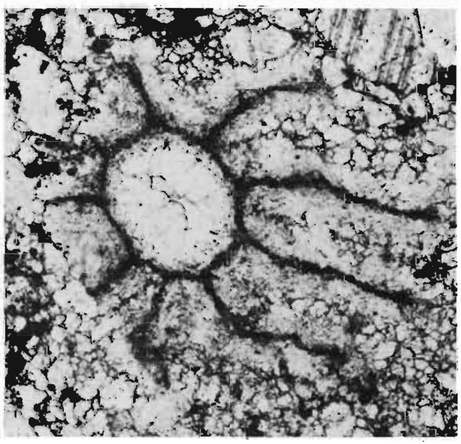

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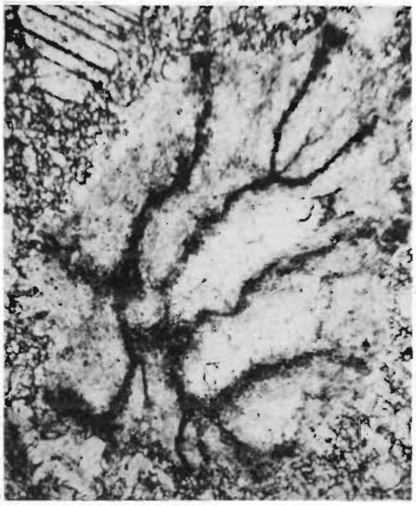

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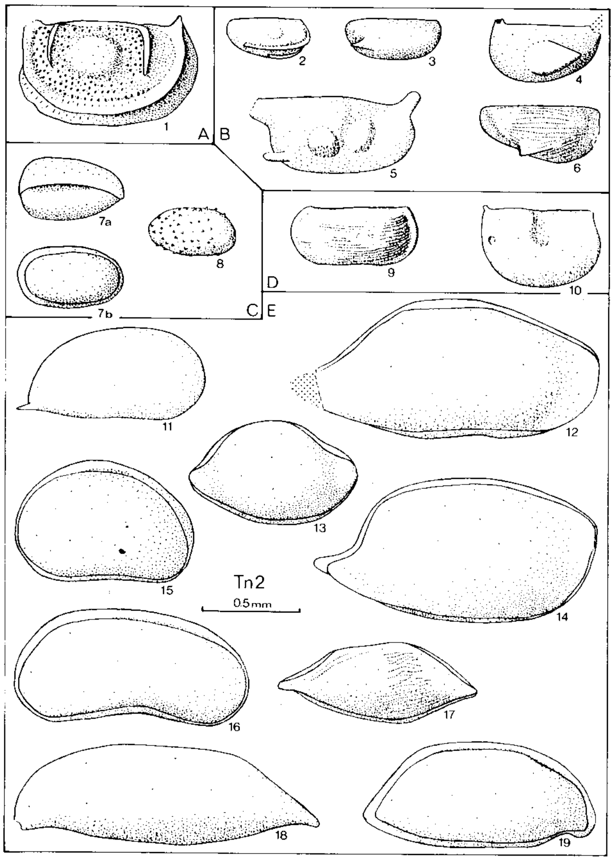


Figure 8

*Characteristic ostracode assemblage for the Middle Tournaisian (*Chernyshinella *foraminifer zone) of the Omolon region, North-eastern Siberia, USSR. Specimen from Mol Suite and Sikambr Suite (after Bless, in Shilo, Bouckaert* et al., 1984).

1. Amphissites *sp.*
2. Pribylites? kolesovi *Bless 1984*
3. Pseudomonoceratina? razinae *Bless 1984*
4. Tricornina *aff.* robusticerata *Blumenstengel 1969*
5. Berounella *sp.*
6. Monoceratina simakovi *Bless 1984*
7. Microcheilinella *sp.*
8. Microcheilinella shiloi *Bless 1984*
9. Moorites onoprienkoi *Bless 1984*
10. Coryellina *ps.*
11. Baschkirina *sp.*
12. Bairdia *sp.*
13. Bairdia *sp.*
14. Bairdia sp.
15. Bairdiocypris *sp.*
16. Bairdiacypris *sp.*
17. Acratia smirnovae *Bless 1984*
18. Acratia *sp.*
19. Acratia *sp.*

PLATE 3 : Foraminifers

(all magnifications x 75 except where indicated)

Disonella lucens Conil & Lys, 1964
1. Goé-N-1 (23296)
2. Goé-N-1 (23297)
3. Bae-LF-1 (23269)

Bisphaera sp.
4. 76-Bae-3 (23057)
5. 76-Bae-1 (23267)

Septabrunsiina baeleni Conil, 1967
6. Bae-LF-2 (23276)
7. Bae-LF-2 (23272)
8. 76-Bae-9 (23050)
9. Bae-RC 3368 (4523)
10. Bae-LF-2 (23270)

cf *Baelenia* sp.
11. 76-Bae-1 (23052)

Septabrunsiina sp.
12. Bae-LF-2 (23271)

Septabrunsiina sp. 1
13. 76-Bae-9 (11530)

Septabrunsiina sp. 2 transitional form to *Baelenia*
14. Bae-LF-2 (23274)

Septabrunsiina sp.
15. Goé-S-1 (23047)

Septabrunsiina aff. *donica* Lipina, 1965
16. 76-Bae-9 (23304a)

Septabrunsiina sp. 2
17. Bae-RC 3367 (4520)
18. 76-Bae-9 (23304b)
19. Bae-LF-2 (23269)

Septabrunsiina cf *comblaini* (Conil & Lys, 1964)
20. Goé-S-2 (23300)

Septabrunsiina cf *educta* Conil & Lys, 1977
21. Goé-S-1 (23268)

Septabrunsiina cf *baeleni* Conil, 1967
22. 76-Bae-9 (23063)

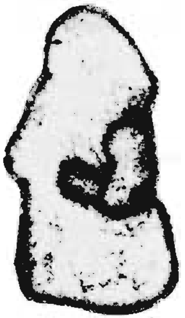
Septabrunsiina sp.
23. Bae-RC 3368 (4521)
24. Bae-RC 3390 (4617)

cf *Baelenia* sp.
25. Bae-LF-2 (23068)

Septabrunsiina sp.
26. Bae-LF-7 (23065)

Septabrunsiina aff. *baeleni* Conil & Lys, 1967
27. 76-Bae-9 (23051)

Problematic specimens recovered from acid-etched limestone residues. Their attribution to either Moravaminidae or to microgranulated or agglutinate foraminifers is uncertain. *Parathikinella* or *Eonodosaria* ? : Fig. 28 (298/8), x 34, Goé-N-10, Caligellidae ? : Figs 31, 34 (297/19, x64; 280/34, x68), Goé-N-10. Fig. 29 : 331/35, x 43; Fig. 30 : 331/27, x 75; Fig. 32 : 331/29. x 85; Fig. 33 : 297/20, x 85. All specimens from Goé-N-10.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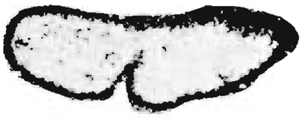
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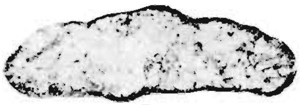
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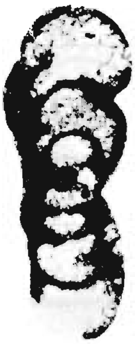
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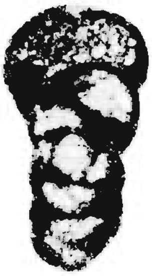
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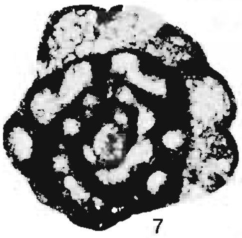
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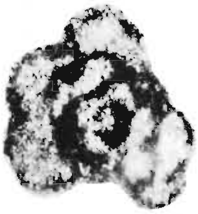
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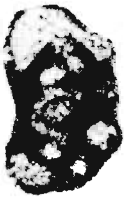
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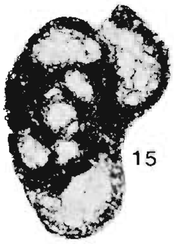
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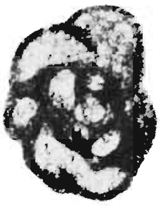
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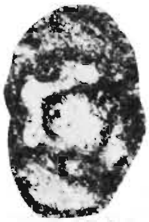
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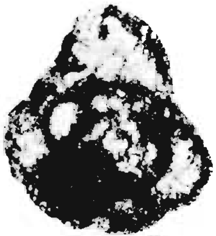
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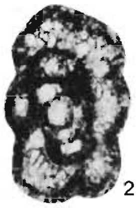
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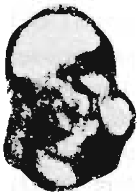
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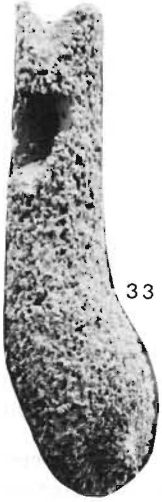
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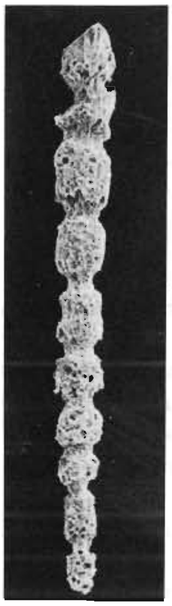
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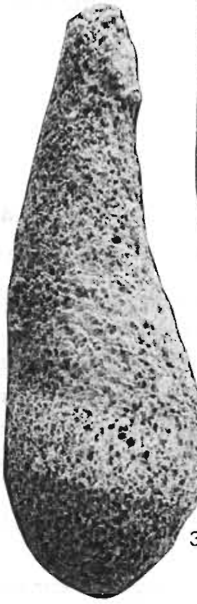
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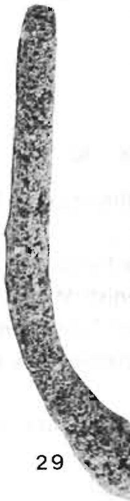
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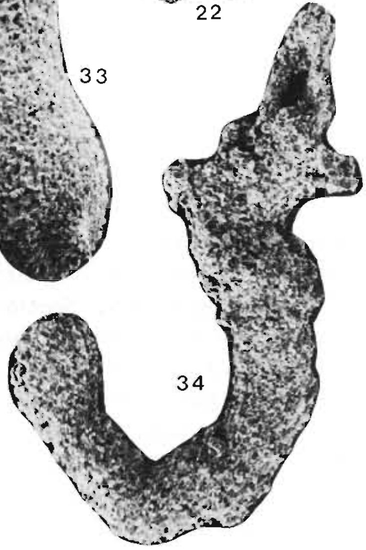
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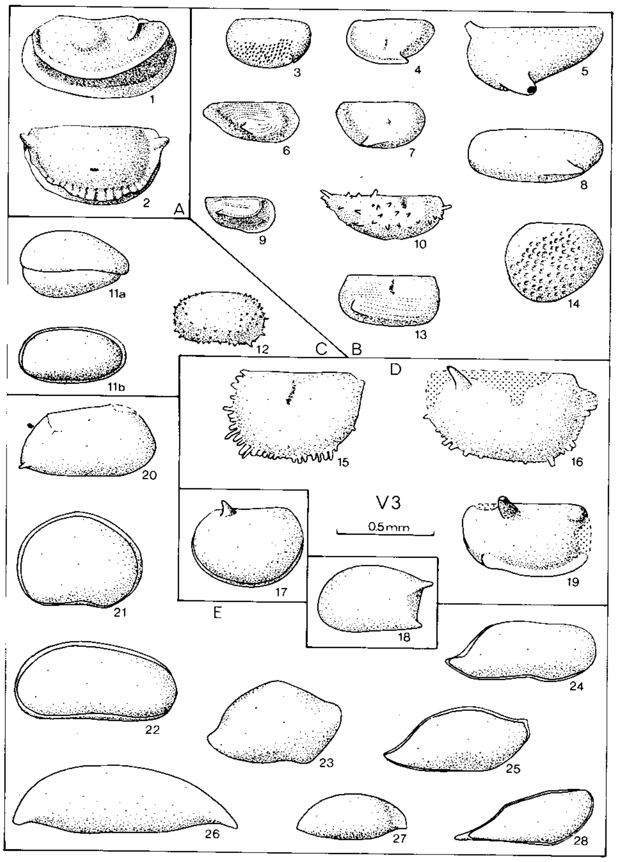

Figure 9

Characteristic ostracode assemblage for the Upper Visean of Southwestern Morocco. Material kindly put at the disposal of M.J.M. Bless by O.J. Simon, Free University of Amsterdam.

1. Amphissites *sp.*
2. Kirkbya *sp.*
3. Pseudomonoceratina? *sp.*
4. Monoceratina? *sp.*
5. Tricornina *aff.* robusticerata *Blumenstengel 1969*
6. Monoceratina simakovi *Bless 1984*
7. Monoceratina *sp.*
8. Pseudomonoceratina? razinae *Bless 1984*
9. Monoceratina *sp.*
10. Saalfeldella *sp.*
11. Microcheilinella *sp.*
12. Microcheilinella shiloi *Bless 1984*
13. Kirkbyella *sp.*
14. Discoidella *sp.*
15. Jordanites? *sp.*
16. Janischewskya *sp.*
17. Shishaella *sp.*
18. Healdia *sp.*
19. Selebratina? sp.
20. Baschkirina *sp.*
21. Bairdiocypris *sp.*
22. Bairdiacypris *sp.*
23. Bairdia *sp.*
24. Bairdia *sp.*
25. Bairdia *sp.*
26. Acratia *sp.*
27. Acratia *sp.*
28. Bairdia *sp.*

The assemblage doesn't seem to improve the biostratigraphic age determination based on the conodonts.

Tricornina robusticerata has been described originally from the Frasnian Lower to Upper *gigas* conodont zone of the Harz (Blumenstengel, 1969). But closely related if not conspecific forms occur in the Middle Tournaisian of Omolon (NE-USSR; this paper fig. 8; Bless *in* : Shilo *et al.*, 1984) and in the Late Visean of Morocco (this paper, fig. 9). The Beyrichiacean ostracode species 104 *sensu* Becker & Bless, 1974 has been observed in nodular limestones of the Fa1a-b of the Hony section (conodont samples BT 28 to BT 34 of Bouckaert & Thorez, 1965; *crepida* conodont zone) and Fa2a of the Poulseur section (*marginifera* conodont zone) in the Ourthe Valley of Belgium (Becker *et al.*, 1974). This species might be closely related to *Bouckaertites komiensis* Tschigova 1977 from the *Oxyclymenia-Gonioclymenia* cephalopod zone (= Fa2c in Belgium) of the Russian Platform.

PLATE 4 : Foraminifers

(all specimens from sample Goé-N-10. Magnification x 130.

Some silicified foraminifers have been collected from the residues of acid-etched limestone. Their size correspond to that of the Tournayellids illustrated on Plate 1.

The wall of these primitive *Septabrunsiininae* may be microgranulated. On the other hand, real agglutinate foraminifers are rather rare in the Devonian and Carboniferous limestones of the Ardenno-Rhenish Massif. Although the morphology of some of the illustrated silicified specimens is reminiscent of that of the Silesian *Trochammina* or *Ammobaculites,* we interprete these forms rather as silicified tests of Tournayellidae. The latter are particularly abundant in the foraminiferal Df3 alpha subzone.

Trochoid (e.g. Fig. 5) and unrolled forms (Figs. 10, 11) had never been observed before in thin sections of limestones from this particular stratigraphic interval.

The specimens with irregular involute coiling, with conspicuous sutures, and with a small number of chambers, most probably belong to the genus *Septabrunsiina,* whereas the unrolled forms could be assigned to *Rectoseptaglomospiranella.*

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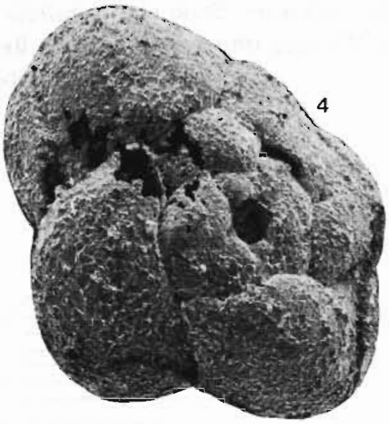

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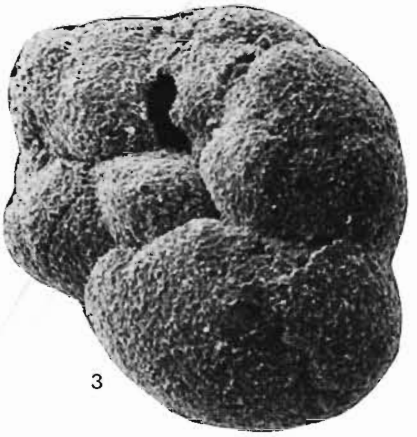

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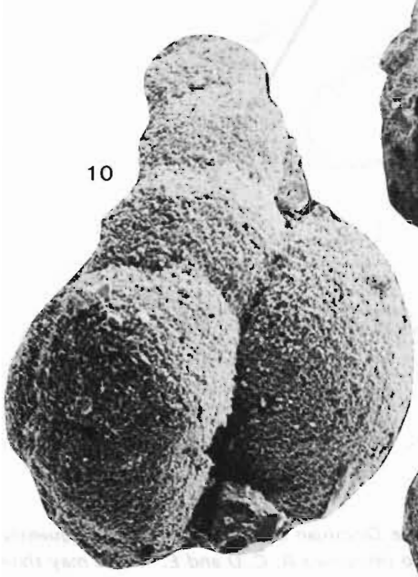

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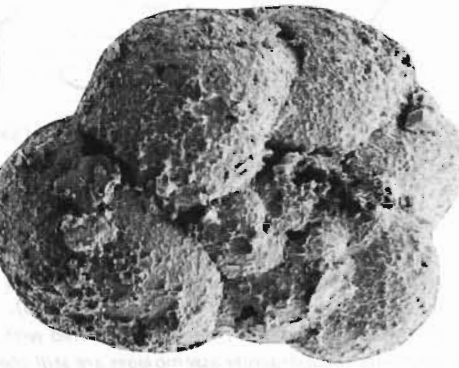

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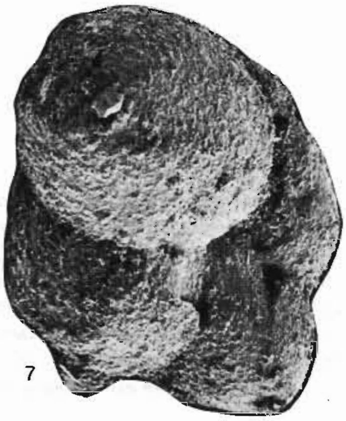

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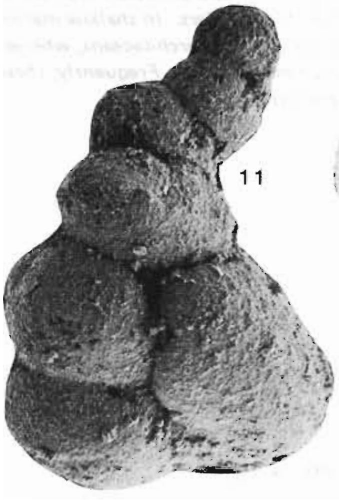

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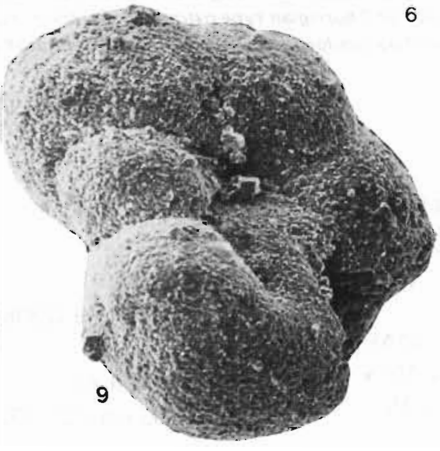

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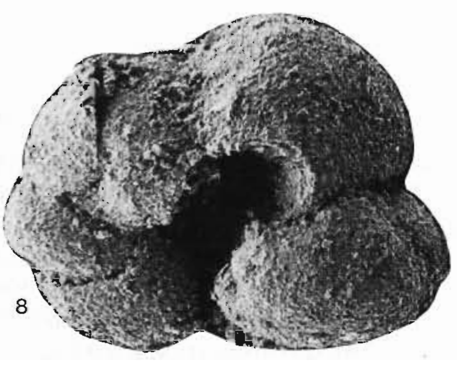

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Microcheilinella shiloi is a rather long-ranging form, also known from the Upper Famennian to Middle Tournaisian of Omolon (NE-USSR; Bless *in :* Shilo *et al.*, 1984) and the Late Visean of Morocco (this paper, fig. 3).

Processobairdia dreeseni Bless nov. sp. (fig. 11) is one of the about a dozen species of the genus *Processobairdia* known thus far from Poland, Germany, Spain and Belgium. Representatives of this genus have been described from the Frasnian (only one species, *P. dorso-*

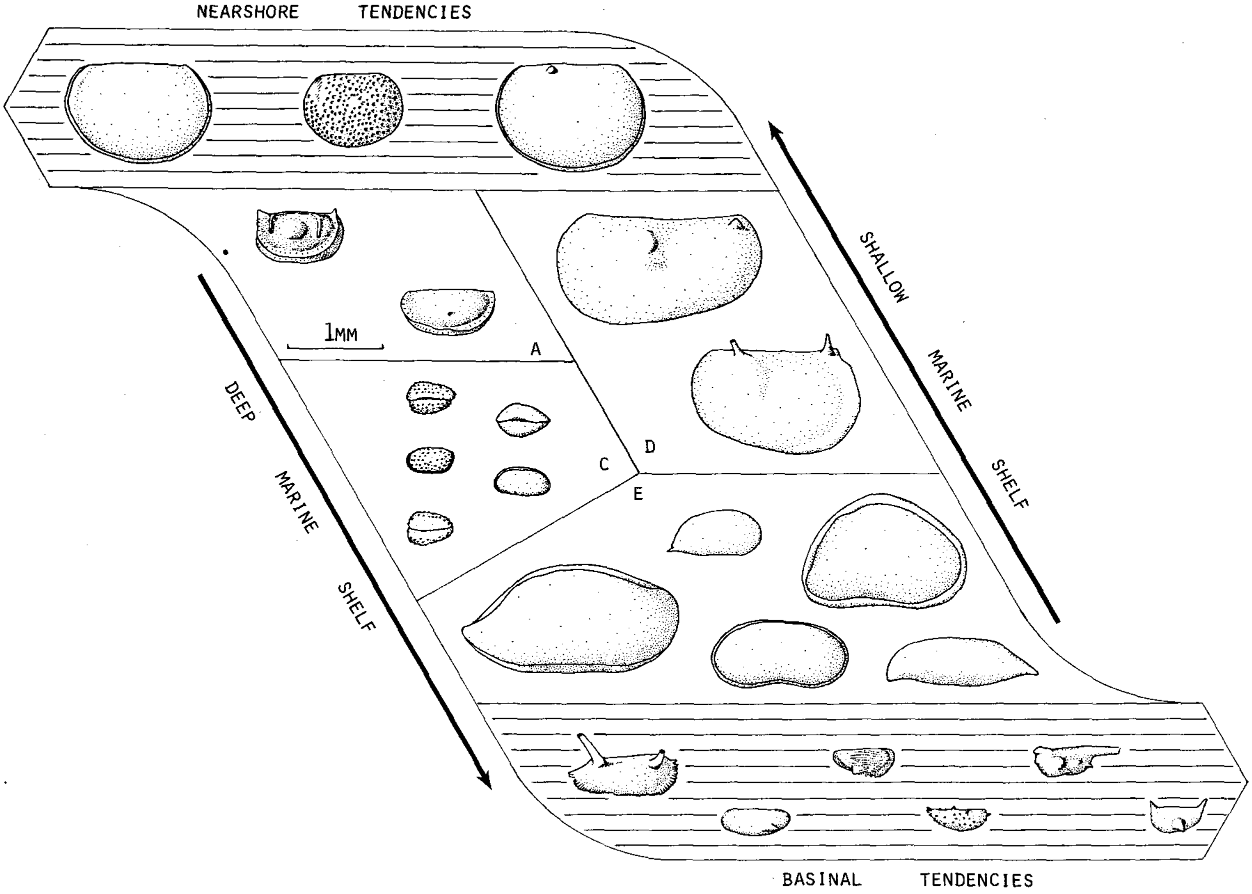

Figure 10

Cartoon showing important ostracode groups occuring in open marine shelf deposits of Late Devonian and Dinantian age. Frequently, these assemblages are characterized by the (predominant) presence of ostracodes belonging to categories A, C, D and E. These may show an admixture of either Paraparchitacean type ostracodes (usually large forms as shown in the top row of the figure) or Thuringian type ostracodes (normally with one or more spines or spinelets as shown in the bottom row). The presence of Paraparchitacean type ostracodes suggests a shallow marine shelf. In the Dinantian deposits these are associated with multilocular foraminifers. In shallow marine nearshore or shallow restricted marine environments the ostracode assemblages are still characterized by o.a. Paraparchitaceans, whereas categories A, C, D and E tend to be absent. The presence of Thuringian type ostracodes points to a deep marine shelf. Frequently, these are associated with primitive foraminifers (unilocular forms or sometimes Endothyrid type species).

PLATE 5 : Algae and incertae sedis

Baculella gemina Conil & Dreesen, gen. et sp. nov.

1-6. all specimens from Goé-N-10, x 30. (23292, 23293, 23293, 23291, 23282).

4. (specimen 23921) is holotype (Goé-N-10A).

6-7. details of wall (23074, 23053) (Goé-N-10) x 140.

8. 330/35 (Goé-N-10), small specimen, x 75. All specimens are spar-infilled.

cf. *Salebra* sp.

9. Goé-N-9 (23067) x 30.

Pseudoissinella sp.

10. Goé-N-10, (23280) x 75.

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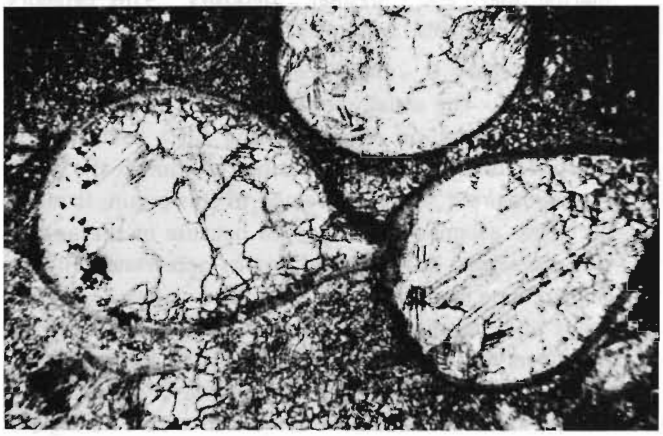

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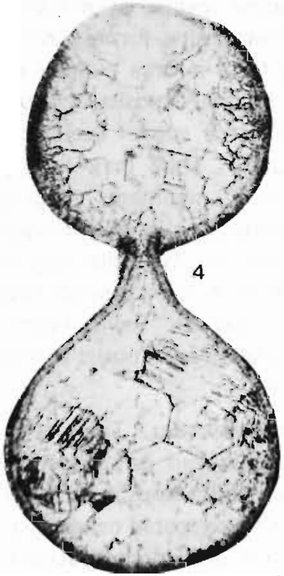

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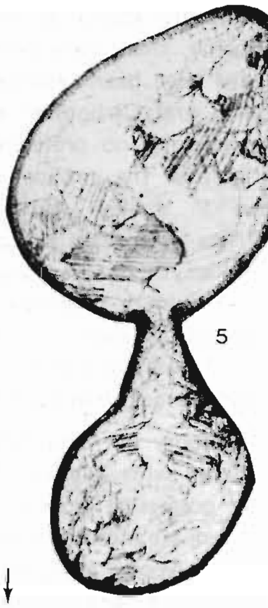

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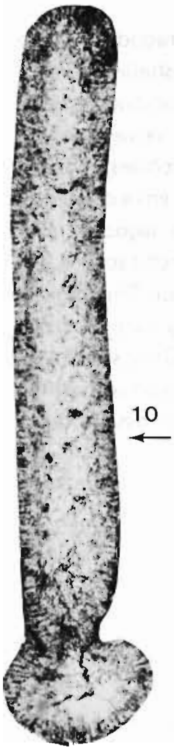

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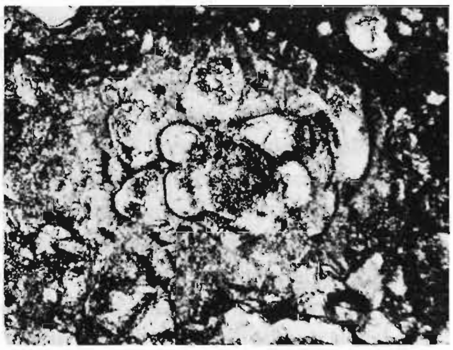

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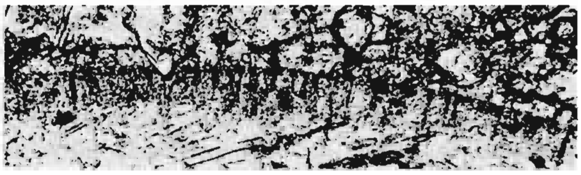

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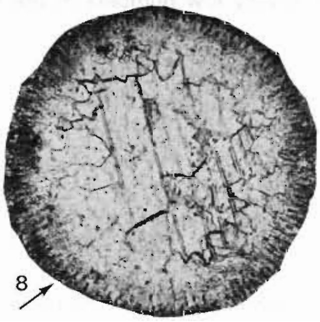

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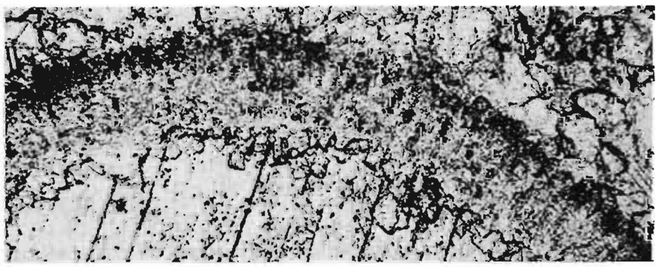

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noda, is known from Germany and Spain; cf. Blumenstengel 1965 and Becker, 1982) and Famennian.

In contrast to the apparently limited biostratigraphical value of the Goé ostracode assemblage stands the importance of the same for paleoecological interpretations. This association shows a remarkable resemblance with similar assemblages of Dinantian age from the Omolon region (NE - USSR) and from Morocco (figs 7 and 9).

This resemblance may be best exhibited by distinguishing a few categories within these associations. The composition of each category is purely subjective and may include one or more taxa of different systematic levels. These categories are characterized by ostracodes showing some obvious similarities in their carapaces and/or by taxa which seemingly lived together in some special environment.

Category A - Kirkbyacean ostracodes. This superfamily is characterized by a straight-backed, clearly reticulate carapace possessing one or two marginal rims or frills. Lobes, "shoulders", nodes and carinae may be well-developed in some taxa like *Amphissites* or practically absent as in some species of *Kirkbya.* Presumably, these have been swimming forms. Kirkbyaceans have been reported from a large number of Devonian and Carboniferous marine deposits. Apparently, there is no preference for a special ecological niche within the marine realm. They may locally abound in shallow marine shelf sediments ranging from pure carbonates to carbonaceous or bituminous silts and clays. But they also occur in large numbers in so-called Kulm or Thuringian-type deposits representing a deep marine shelf or even "basinal" environment. However, these are practically absent in deposits of the lagoonal or brackish-water facies.

Category B - Thuringian ostracodes. These comprise forms with relatively thin-shelled carapaces frequently possessing large spines and thorns. In some cases, these are associated with Myodocopid ostracodes, such as *Polycope* or *Discoidella* or Entomozoaceans. This group includes forms which will have lived in a pelagic environment (notably the Myodocopids). Many spinous forms may have preferred a benthonic or near-benthonic paleobiotope and lived crawling on floating thallose algae and other marine plants. Because of their resemblance to present-day psychrospheric ostracode assemblages, the Thuringian ostracodes are considered as cold-water forms. They preferably occur either in deep-sea (say below 500 m) environments or in regions of upwelling water.

Category C - *Microcheilinella*-type ostracodes. These are rather small, thick-shelled forms with the width of the carapace equalling or exceeding its height. Characteristic for the three assemblages considered here is the presence of both smooth and finely spinous forms. Presumably, these have been true burrowing species, preferring a soft, muddy substrate. *Microcheilinella* has been recognized in many marine deposits ranging from shallow marine shelf to "basinal" Kulm or Thuringian-type facies.

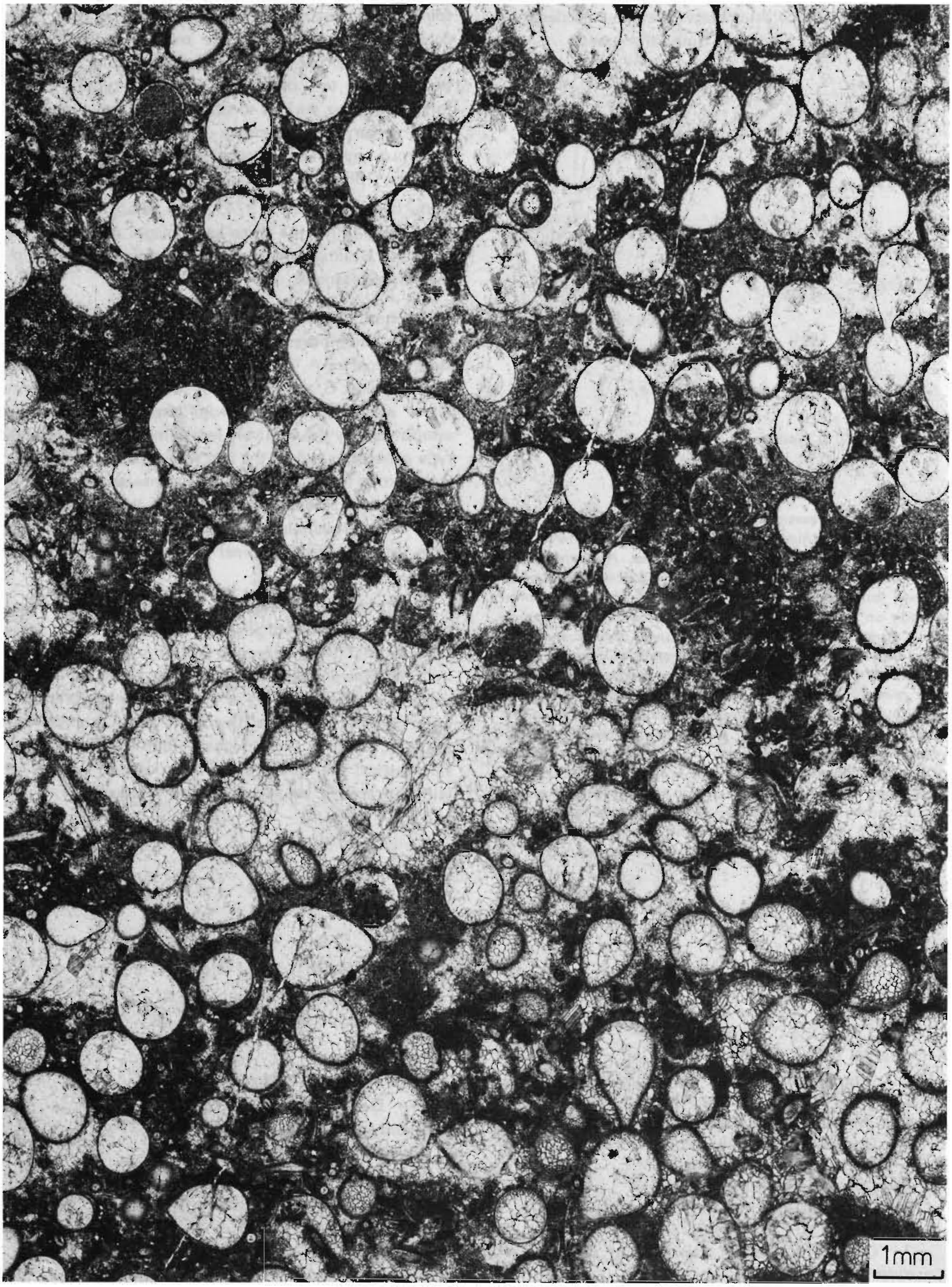
Category D - A rather heterogeneous group of Palaeocopid ostracodes that may be splitted up into smaller ones in future. These ostracodes occur in open marine shelf and "basinal" deposits. This category includes probable swimmers, crawlers and burrowers.

Category E - Bairdiacean and Bairdiocypridacean ostracodes. The usually smooth-shelled ostracodes have been burrowers or crawlers living on a soft, muddy substrate or on marine vegetation. Although the genus *Processobairdia* seems to belong to this group, it might be better assigned to category B because of the usually well-developed lateral spines and its occurrence in Thuringian-type assemblages of Late Devonian age. Bairdiaceans and Bairdiocypridaceans seem to have preferred the open marine environments. These are practically absent in extremely shallow nearshore deposits. Bairdiocypridaceans are absent or rare in true Thuringian-type assemblages.

Category F - Paraparchitacean ostracodes. Two groups may be distinguished : smooth-shelled genera such as *Paraparchites, Shemonaella,* and *Dorsoobliquella,* and genera with a spine on one or both valves such as *Shishaella, Shivaella* and *Pseudoparaparchites.* Both groups are common in many marine shelf environments. The smooth-shelled forms also occur in lagoonal and possibly brackish-water deposits. Paraparchitaceans are practically absent in "basinal" (Kulm or Thuringian-type) sediments and absent or extremely rare in strata deposited on the "deep" marine shelf. Only specimens with a spine on one or both valves have been sometimes observed in very low numbers in the latter assemblages.

PLATE 6

Algal floatstone with important accumulations of *Baculella gemina* and *Issinella* sp. Note the presence of twins, geopetal infilling and spar cementing. Thin section Goé-N-10 a. For details of *Baculella* twins see Plate 5.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In practice, categories B and F seem to have preferred completely different ecological niches. The few specimens in the Morocco assemblages may be considered as artefacts (probably washed in from other areas).

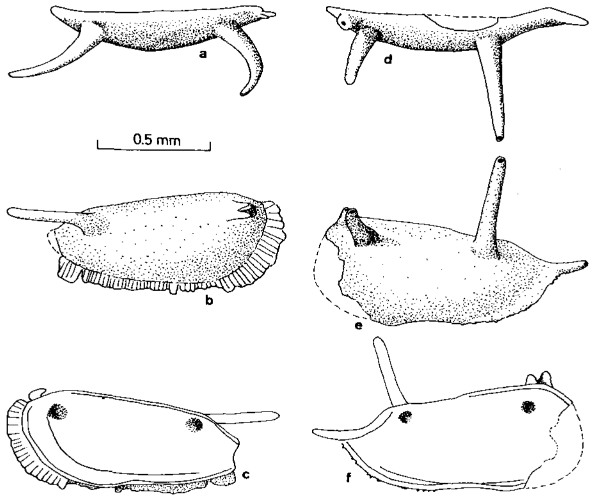

Figure 11
Processobairdia dreeseni *Bless nov. sp., paratypes. Sample Goé-N-10, basal Upper Famennian, Upper* marginifera *conodont zone. a-c : right valve; d-f : left valve. Holotype figured on figure 1-8 and on plate 9, figure 4. Species characterized by two long erect spines in anterodorsal and posterodorsal position on each valve and by a short, stout spine on anterodorsal margin of left valve. Frill-like row of partly fused spines along anteroventral to posteroventral margin. Surface otherwise smooth. Differs from* P. bicerata *Blumenstengel 1965 by very large spines in anterodorsal and posterodorsal position on each valve, by a short, stout spine on anterodorsal margin of left valve, and by frill-like row of partly fused spines along anteroventral to posteroventral margin. All other known species of this genus possess a lower number of spines on at least one of both valves. Marginal spines have been observed in some species (*P. nodocerata *Blumenstengel 1965,* P. spinomarginata *Blumenstengel 1965,* P. spinanterocerata *Bless & Michel 1967). But these are much smaller than those in* P. dreeseni.

Category G - Healdiacean ostracodes. Characterized by the presence of posterior ridges and/or spines. Presumably, these ostracodes have been incapable of swimming and were crawling or burrowing forms. They occur in marine deposits ranging from very shallow shelf to "basinal" (Thuringian-type). Therefore, it is rather curious to observe that they are absent in many marine shelf deposits of Late Devonian and Carboiferous age (Late Devonian of Western Canada, Lethiers, 1981; Late Devonian and Dinantian of Belgium, Becker & Bless, 1974; Bless *et al.*, 1981; Crasquin, 1983). In the three assemblages discussed here only one Healdiacean specimen has been recognized in the Morocco sample.

The above review shows that the Goé, Omolon and Morocco assemblages are characterized by exactly the same categories A, B, C, D and E. Ostracodes of categories F and G are completely or practically absent. These assemblages differ from true Thuringian-type associations by the relatively low number of Thuringian-type ostracodes and by the fact that within this category B the exotic forms with very large spines are rare. Therefore, it seems reasonable to believe that these assemblages show more resemblance to marine shelf associations than to so-called "basinal" (Kulm or Thuringian) ones.

On the other hand, the practical absence of category F (Paraparchitaceans) in these assemblages suggests that these represent a relatively deep marine shelf. Paraparchitaceans have been reported from many extremely shallow marine or even lagoonal or brackish-water deposits of Late Devonian and Carboniferous age. In many of these deposits (both carbonates and siliciclastics) the Paraparchitaceans occur in association with ostracodes belonging to the categories A, C, D and E.

PLATE 7 : Algae, incertae sedis, gastropoda

Kamaena sp.
1. Goé-N-4, longitudinal section, x 30
2. Goé-N-10, silicified specimen, x 85

Baculella gemina Conil & Dreesen gen. et sp. nov.
3. Goé--N-10, silicified-dolomitized internal mold, x 35
4. Goé-N-10A (23309) x 30
5. Goé-N-10A (23307) x 75
6. Goé-N-10 (23279) x 75
7. Goé-N-10, silicified internal mold, x 130

Pseudoissinella sp.
8. Goé-N-12 (23277) x 75, longitudinal section

Salebridae
9. 76-Goé-1 (23301) x 30
11. Goé-N-9 (23067) x 30

Vermetid gastropods (serpuloids)
10. Goé-N-10A (23311) x 30
14. Bae-LF-2 (23275) x 75

Incertae sedis
12. 76-Goé-1 (23312) x 30

Issinella sp.
13. 76-Goé-19 (23288) x 75, transversal sections.


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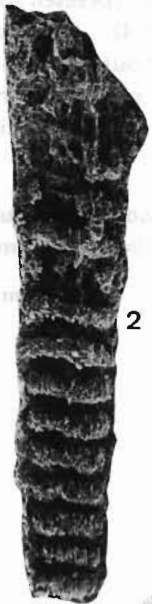
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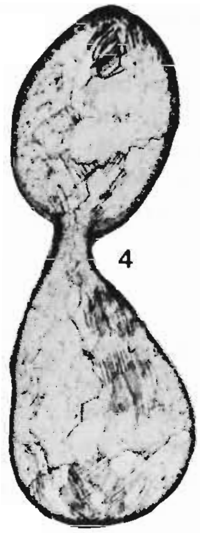
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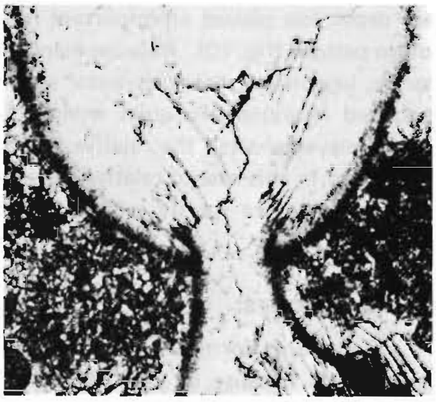
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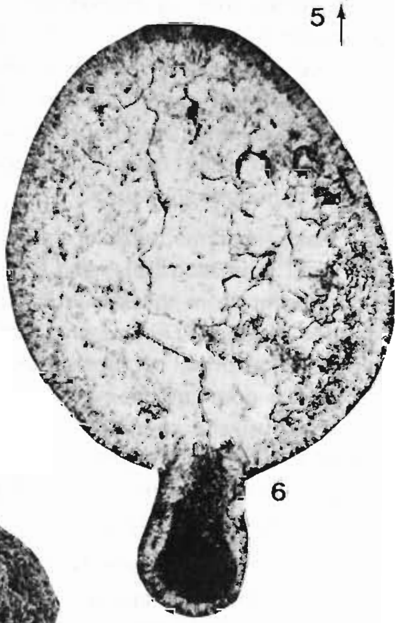
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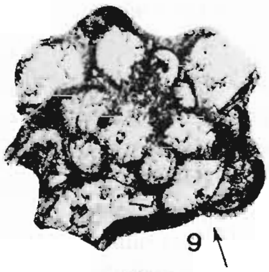
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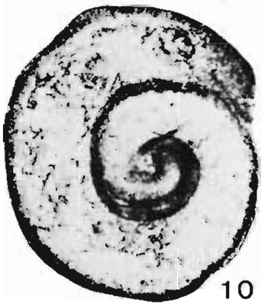
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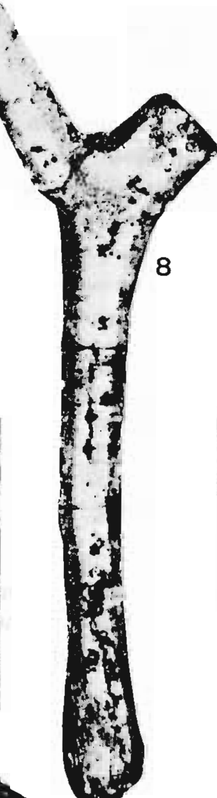
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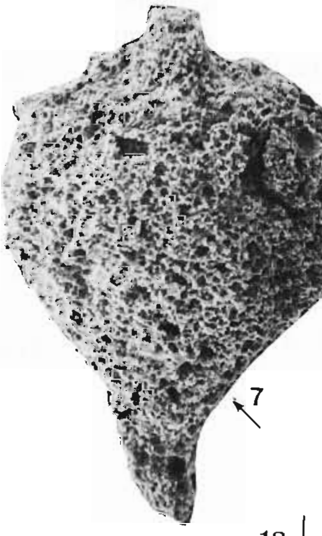
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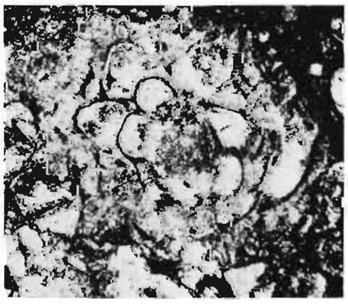
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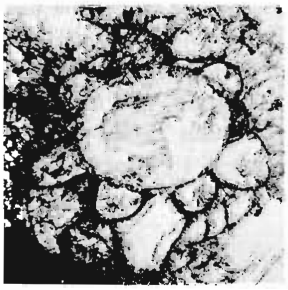
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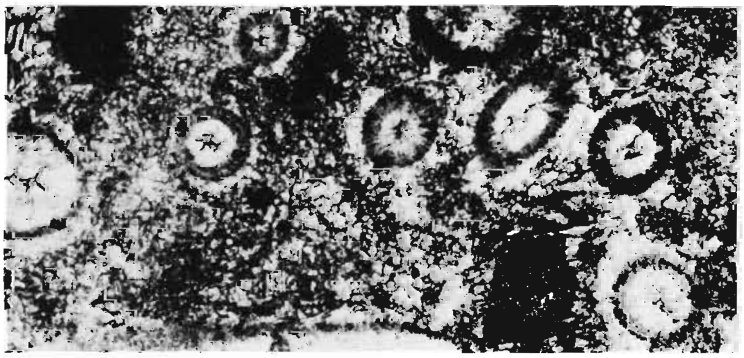
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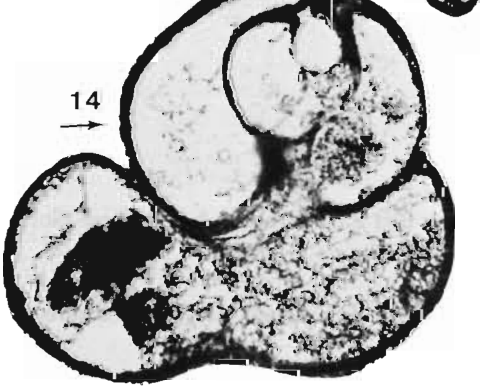
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Since Paraparchitaceans and Thuringian-type ostracodes seem to exclude each other, we must accept that depth has played an important role in their distribution pattern (fig. 10). Because many of these shallow-marine, lagoonal or brackish-water sediments have been deposited in extremely quiet environments (e.g. bituminous clayey shales), the relative depth is not necessarily related in this case to relative water-energy. Maybe, water temperature (partly related to depth) played an important role ?

5.4. - CONODONTS

Conodonts form only a minor constituent of the Baelen reefs because of their different habitats : true pelagic forms such as *Palmatolepis* are relatively rare, nektobenthic *"Icriodus"* and *Pelekysgnathus* are absent, whereas the more euphotic *Polygnathus semicostatus* is the most common form. Moreover, the non-calcified algal and bacterial colonies which stabilized the lime muds, might have been poisonous to the (nektobenthic) conodont animal.

Platform conodonts are extremely rare within these algal lime mudstones and wackestones. They are totally absent from the spiculitic mudstones with spar-cemented cavities. The coarse-grained crinoidal-foraminiferal wackestones, packstones and grainstones otherwise yield a poor and non-diversified conodont fauna, almost exclusively composed of Polygnathids of the *semicostatus*-group (mostly less than 20 conodonts per kg). Palmatolepids are rare (5 to 10 °/o at most) and Icriodids are virtually absent.

The richest conodont faunas have been collected from crinoidal-brachiopodal wackestones (enclosing a mineralized algal-encrusted hardground) at the very base or just below the Baelen limestone complex. This lithology (e.g. sample CON-1) yield 680 conodonts per kg, containing 80 °/o of Polygnathids of the *semicostatus*-group, 10 °/o of Palmatolepids, 6 °/o of Icriodids (*"Icriodus"* and *Pelekysgnathus),* 3 °/o of *Alternognathus* and 1 °/o of *Polylophodonta.* This would indicate a mixed Polygnathid-Palmatolepid and Polygnathid-Icriodid biofacies, which is characteristic of the sandy (inner) shelf environment (Dreesen & Thorez, 1980; Sandberg & Dreesen, 1984). The Polygnathid (-Palmatolepid) biofacies without Icriodids of the Baelen reef mound itself might suggest a temporary, relative deepening of the environment but still within a shelf setting.

Platform conodont distribution
in the Baelen limestone complex

	basement	mound	top
P. marg. marginifera	x	x	x
P. stoppeli	x		
P. rhomboidea	x		
P. q. inflexa	x		
P. q. inflexoidea		x	x
P. quadrantinodosa	x		
P. glabra pectinata	x		
P. glabra lepta	x		
P. glabra distorta	x	x	x
Pg. semicostatus	x	x	x
Pg. procerus	x	x	x
Pg. fallax	x		
Pg. communis communis		x	
Pg. glaber glaber	x		
Polylophodonta triphyllatus	x		
Pg. nodocostatus nodocostatus		x	x
Alternognathus pseudostrigosus	x		
Pelekysgnathys inclinatus	x		
"Icriodus" chojnicensis	x		x
Pel. inclinatus-"I." costatus M1	x		

(*Pg. semicostatus* represents at least 80 °/o of the platform conodont population in all stratigraphical levels of the Baelen limestone complex).

5.5. - SPONGES

Sponge spicules are frequent throughout the Baelen limestone complex. They abound within the stromatactis-bearing mudstones and *Baculella* - wackestones or floatstones. Although only isolated spicules

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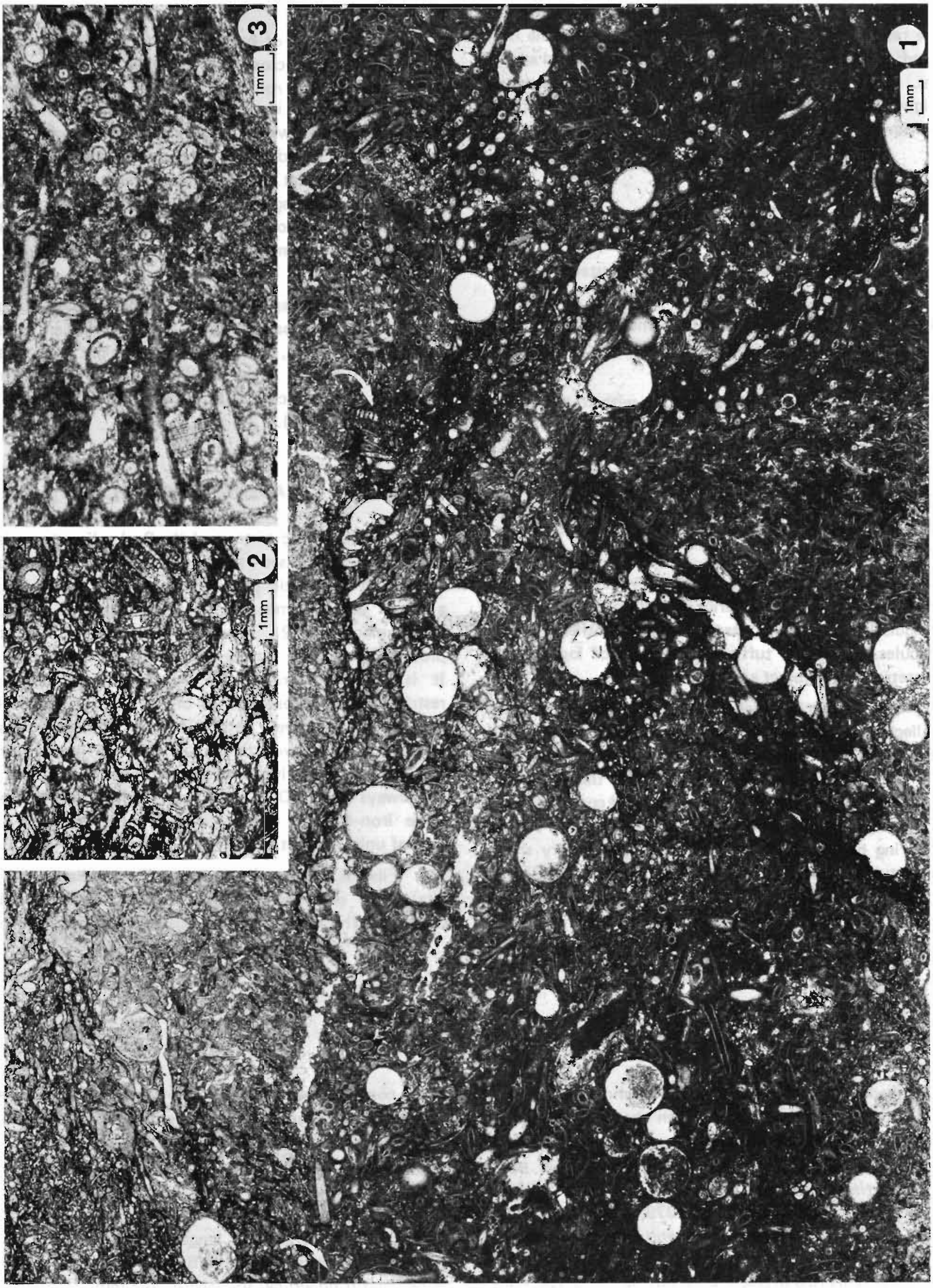
PLATE 8

1. *Issinella*-bindstone with sections of *Baculella* and rare *Kamaena* (arrows). Bed 2 of borehole A 200 (Geol. Surv.) Roly, Dinant Synclinorium, base of Souverain-Pré Formation.
2. Detail of Fig. 1. Note dense packing of *Issinella* thalli.
3. Thin section 76-Goé-19. Transversal and longitudinal sections of Issinellids. For details of wall structure see Pl. 7, fig. 13.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have been found, supposed fragments of sponge network (felted spicules) have locally been observed in thin section. The siliceous spicules are commonly found in the residues of the acid-etched limestones. All the isolated spicules have been assigned to hexactinellid sponges. Most probably they are related to *Arakaspongia* Rigby, Chamberlain & Black 1970 (J.K. Rigby, personal written communication).

Different types of spicula have been recognized (Pl. 10-11).

1. smooth or weakly nodose hexacts (body-wall spicules, accessory spicules);
2. small, smooth or weakly nodose hexasters (hexacts whose rays split into two or more rays);
3. anchor-needles or root tuft elements (pentact-like spicules with long shafts and short, sharply reflected rays);
4. large, five-rayed armoring spicules with rough, agglutinate-like surfaces (composed of 5 tangential or dermal rays and 1 proximal ray).

Arakaspongiid sponges are broad, open bowl to gobletshaped, moderately thick-walled sponges (height about 10 cm), whose walls are pierced by large circular to irregular parietal gaps.

The large armoring spicules might have formed the dermal layer, with the interior of the wall composed of irregularly oriented hexacts, hexasters and other types of spicules. The root tuft was composed of longshafted anatetraenes (Rigby *et al.,* 1970).

Some much larger and smooth spicules in our collection otherwise, strongly resemble the large gastral spicules of the Upper Devonian hexactinellid *Pelicaspongia* Rigby 1970 (Pl. 10 : 13, 15-17) : those spicules display irregularities in ray diameter and constrictionof some rays near the ray junction. Most rays are evenly tapering but in some spicules the rays are very short and stubby, producing short conical structures (Rigby, 1970). These sponges are thick--walled vasiform sponges with large circular parietal openings and a skeleton composed of specialized gastral and dermal layers of large, smooth and simple hexactines (height of sponge about 6 cm).

The presence of both large and small hexactines (megascleres and microscleres) as well as the presence of dermal spicules and root tuft elements, suggests that the sponges had lived in situ within the Baelen mound. Their abundance within algal mudstones might also suggest that a muddy bottom was their preferred substratum and habitat. In the Middle and Late Paleozoic these kinds of sponges occur all the way from shallow water muddy environments to moderately clear water carbonate environments as well (J.K. Rigby, pers. comm.).

Hexactinellid sponges were certainly major trapping organisms within parts of the Upper Devonian reefs (e.g. Canning Basin, Australia). They might also have played a major role in reef building especially in Upper Devonian stromatactis mud mounds (Rigby, 1979; Termier *et al.,* 1981).

6. - DIAGENETIC HISTORY

The diagenetic history of the Baelen limestones is complex and comprises 4 sequential stages, characterizing succeeding diagenetic processes in a marine phreatic, a mixed water, a meteoric phreatic and a subsurface environment (fig. 12). The red staining (Fe_2O_3) is most probably a primary feature of the carbonate sediment. It is obviously stratabound and almost completely restricted to the central core of the mound (unit D) which has the lowest detrital content (quartz, micas and clays). Moreover the early-diagenetic fibrous spar infillings of the cavities in the mudstones of this unit, are always clear. Only very locally, one may observe some iron-bearing (jaspilitic) chert occurrences (e.g. base of unit D in section Goé-S).

Fibrous sparite (isopachous fibro-radiaxial calcite) grew centripetally in stromatactis and related cavities in the mudstones and algal wackestones, which

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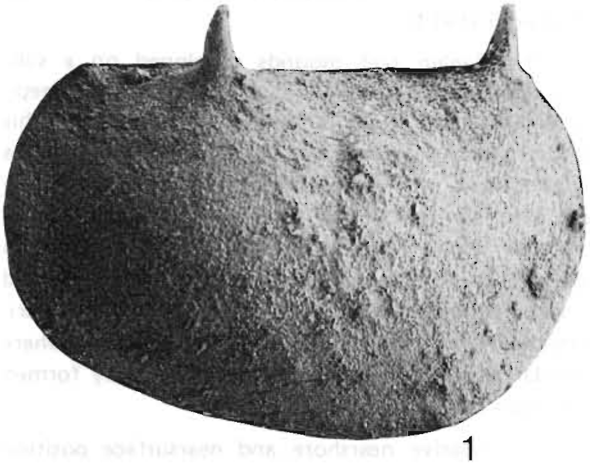
PLATE 9

Ostracodes from the basal Upper Famennian (upper *P. marginifera* conodont zone) of the Goé-Nord section (sample Goé-N-10). Material stored with the paleontological collections of the Natural History Museum Maastricht, coll. number 198481.

1. Beyrichiacean sp. 104 Becker & Bless 1974 (cf. *Bouckaertites komiensis* Tschigova 1977), length : 1,7 mm.
2. *Kirkbya* cf. *ima* Bushmina, 1979, length : 1,0 mm.
3. *Tricornina robusticerata* Blumenstengel 1969, length: 0,5 mm.
4. *Processobairdia dreeseni* Bless nov. sp., holotype, right valve (also figured on figure 7-8), length : 1,15 mm.
5. *Microcheilinella shiloi* Bless 1984, length : 0,5 mm.
6. *Bairdia (Rectobairdia)* cf. *philippovae* Egorov 1953, length : 0,9 mm.
7. *Acratia (Cooperuna)* sp., length : 0,9 mm.
8. *Bairdiocypris* sp., length : 0,6 mm.
9. *Acratia (Cooperuna)* sp., length : 0,7 mm.



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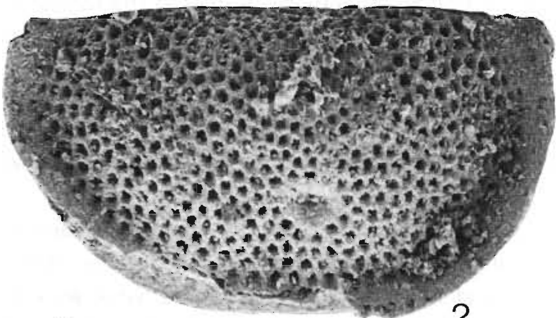

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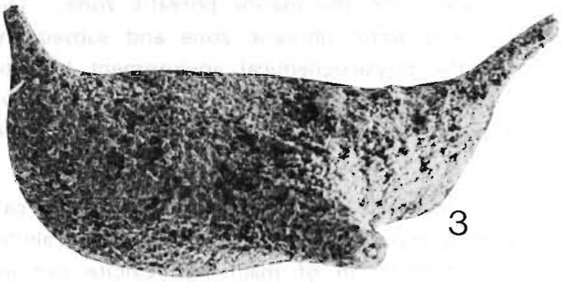

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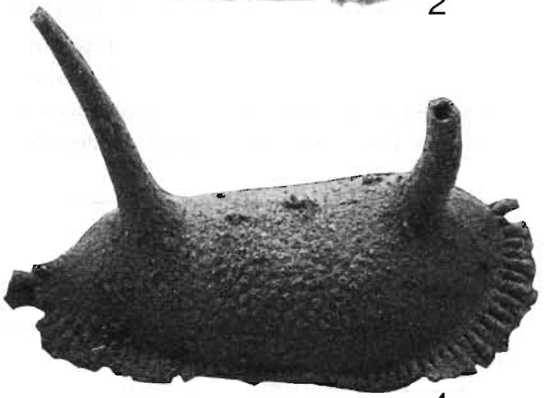

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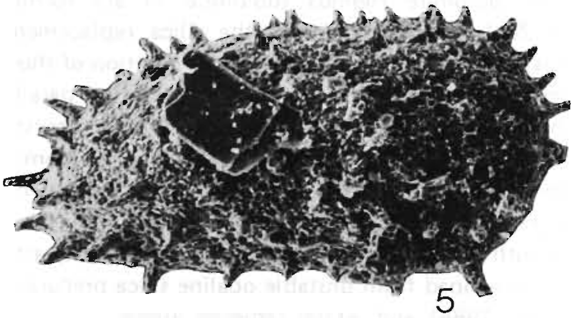

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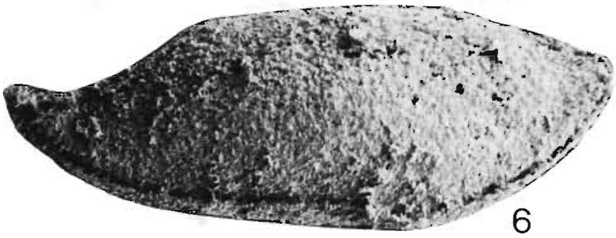

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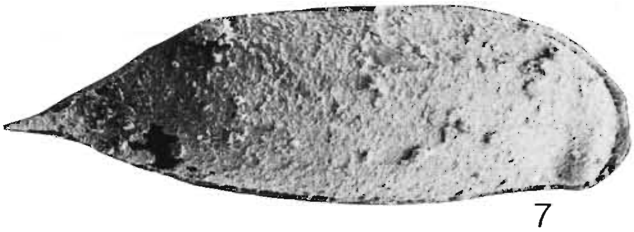

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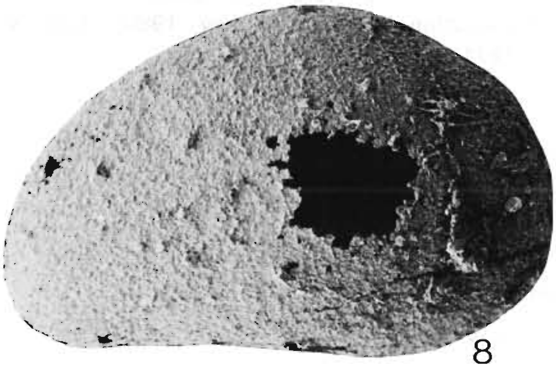

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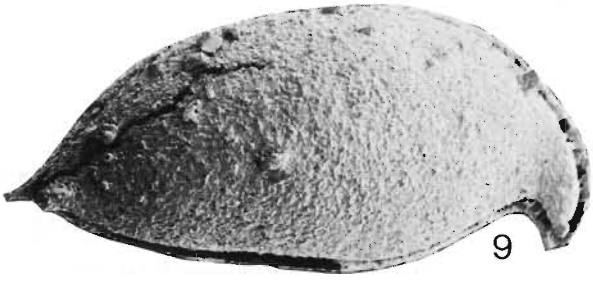

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resulted in an early-diagenetic cementation of preferably the purer limestone facies, in a marine phreatic zone. Algal and bacterial activity promoted the formation of pel(let)oidal micrite in the cavity-bearing mudstones. During the next diagenetic stage, partial dissolution of the carbonates (lime mud and allochems), a selective replacement by silica and a subsequent dolomitization took place in a mixed marine-meteoric phreatic water environment.

Syntaxial rim cements and solution coronas further developed almost simultaneously within the different (high- and low-porosity) microfacies, whereas a dedolomitization affected the previously precipitated dolomite rhombs. These processes clearly indicate influences of meteoric phreatic waters (Walkden & Berry, 1984). The observed silica and dolomite occurrences are compatible with the mixed water chert model of Knauth (1974) and Laschet (1984), and with the dorag (or schizohaline) model of Badiozamani (1973) and Folk & Siedlecka (1974).

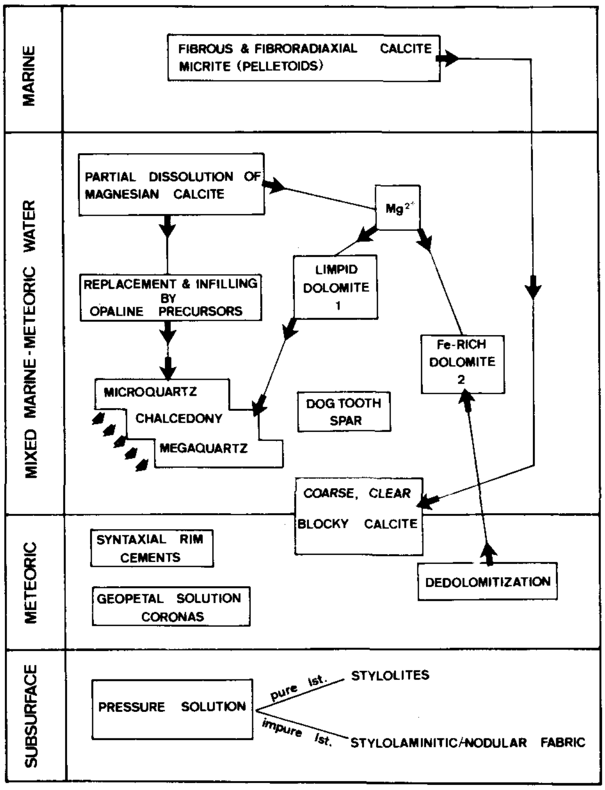


Figure 12
Sequence of observed diagenetic events and succeeding diagenetic stages in the Baelen limestone complex.

The Baelen reef mounds developed on a submarine positive area, related to the presence of a deep-seated transversal fault. Vertical movements along this fault resulted in important subsidence and microfacies differenciation (alternating deposition above and below wave base) during the reef growth. After their deposition, the Baelen crinoidal mud mounds have been uplifted near to the surface where they became eroded by wave action. The latter erosion supplied the crinoidal debris to the protected shelf environment, where crinoidal wackestones have been subsequently formed (Souverain-Pré facies).

The relative nearshore and nearsurface position of the Baelen mounds allowed the influx of silica-rich meteoric waters into the marine phreatic zone. The resulting mixed water phreatic zone and subsequent change of the physicochemical environment lead to the partial dissolution of carbonates and to a selective silicification of allochems, in particularly of crinoid ossicles.

Under meteoric water influences magnesian calcite is quickly transformed into low magnesian calcite. Incongruent dissolution of magnesian calcite can locally increase the Mg:Ca ratio, promoting dolomite formation.

In this mixed water phreatic zone, perfectly limpid, gemlike dolomite rhombs (dolomite 1) are formed (Folk & Land, 1975) during the silica replacement. This is evidenced by the frequent incorporation of those rhombs in the silica, and by their orientation parallel to the twin lamellae of the replaced calcite monocrystal (Pl. 17 : 1-3, 7). A fine rim of small limpid dolomite crystals ("sugar rim") borders the outer margin of the silica replacements (Pl. 16 : 1, 4). Most silica occurs as length-slow (LS) chalcedony and microquartz, which developed from unstable opaline silica precursors (Laschet, 1984) and which replaced allochems in the crinoidal wacke/packstones and grain/rudstones. LS-chalcedony develops mainly in an environment with higher Mg-concentration (Kastner, 1980) and/or with evaporitic solution influences (Arbey, 1980; Folk & Pittman, 1971).

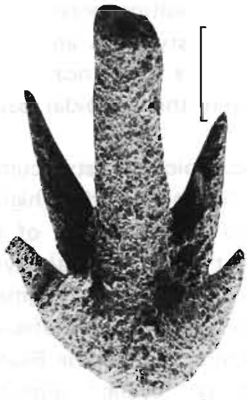
PLATE 10 : Sponges

Arakaspongiid sponge spicula (scale bar is 100 microns)

1, 2. anchor-needles, root tuft elements (anatetraenes).
3-4. slightly nodose tetracts
5-12, 14 : smooth hexacts (Fig. 5 is a pyritized hexact).

? Pelikaspongiid sponge spicula (scale bar is 100 microns)

13, 15-17. large gastral spicules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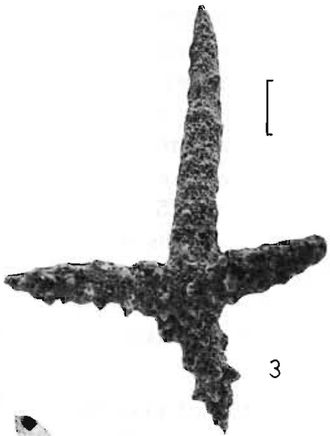
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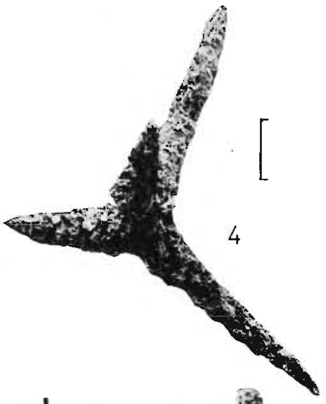
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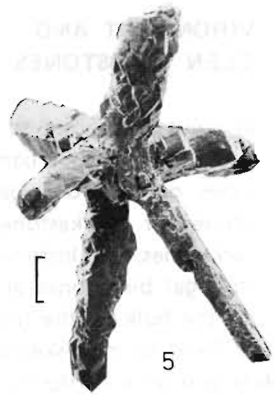
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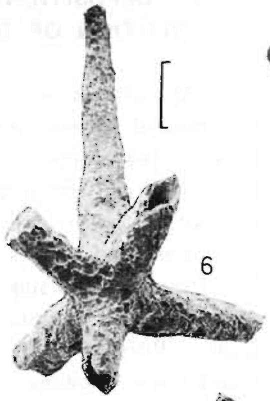
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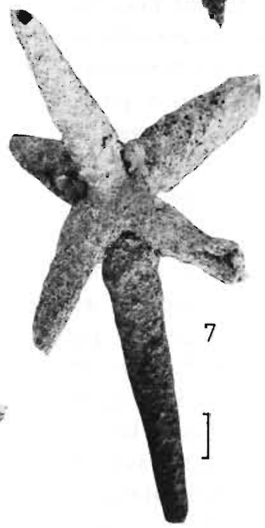
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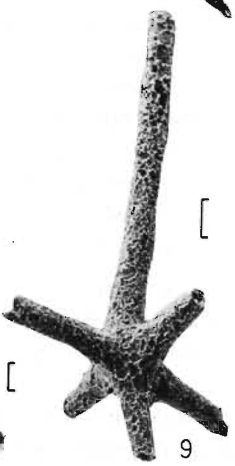
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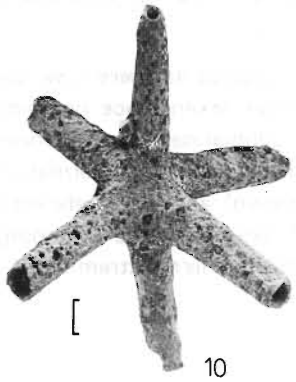
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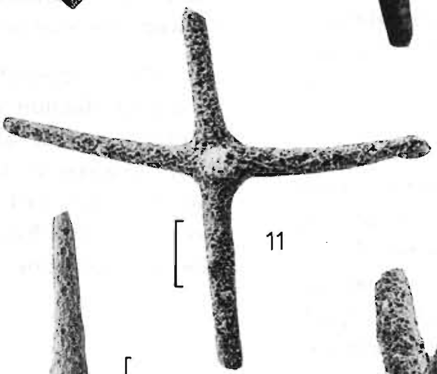
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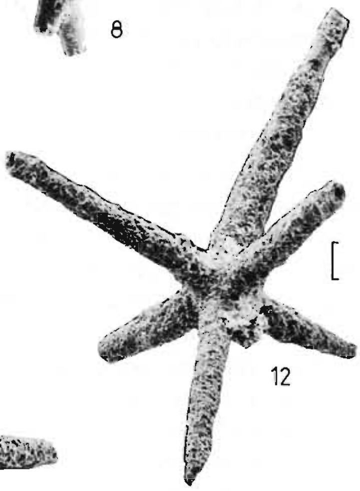
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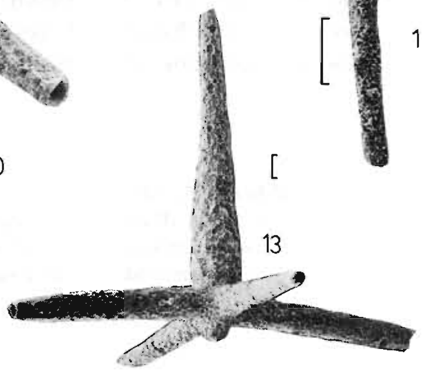
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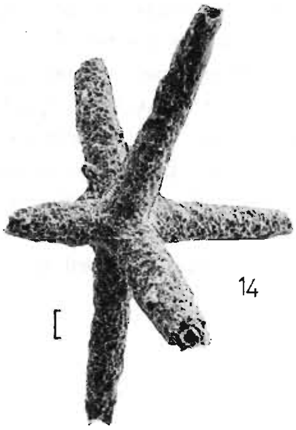
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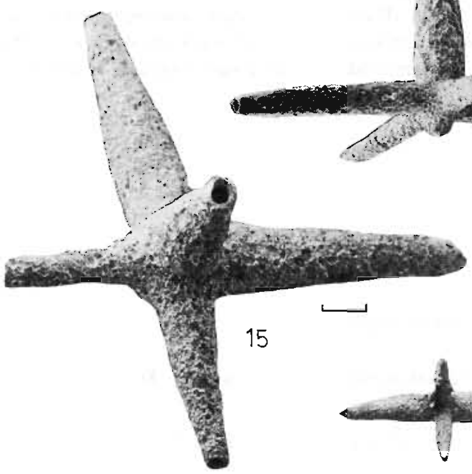
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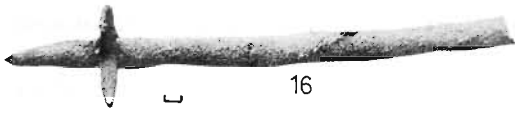
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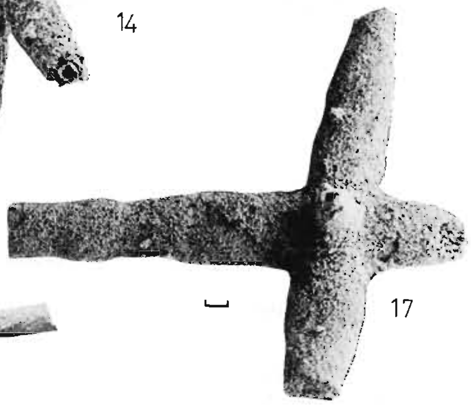
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Although evaporitic conditions are certainly present along the southern border of the Brabant Massif during the Famennian (Dreesen & Thorez, 1981; Goemaere, 1984) (1), it is unlikely that the Baelen carbonate buildup has been silicified and dolomitized through evaporative reflux (seepage refluction) as originally suggested by Dreesen & Flajs, 1984. Indeed, the Baelen mounds were not associated spatially with evaporite deposits of sufficient volume and extent. LS-chalcedony occurs also, besides megaquartz, as fills of internal cavities of ostracodes and *Baculella* in the mudstones (Pl. 16 : 2, 3, 5, 6). The walls of some of these cavities have been encrusted by dog tooth spar (scalenohedral calcite) before their silicification.

Megaquartz represents the final stage of the silica precipitation, and indicates a more stable physicochemical environment. Locally, length-fast (LF) chalcedony has been observed as cavity-fill as well. This might be due to a local different micro-environment (lower pH and high silica content) as opposed to the higher pH and somewhat lower silica content for the LS-chalcedony and megaquartz.

A second, probably ferroan-type of dolomite occurs as inter- and intragranular large rhombs, especially within the crinoidal wacke/packstones and grain/rudstones. While the growth of the former limpid dolomite was inhibited by silica, the latter could develop greater rhombs in the more porous carbonate matrix. Silicification did not affect the second type of dolomite because of a different physicochemical micro-environment. This ferroan dolomite became later dedolomitized, displaying cloudy or "rusty" (limonitic ?) corroded rhombs (Pl. 17 : 4-6).

The following observed diagenetic processes would indicate that the Baelen mounds had reached the surface, where they became influenced by meteoric phreatic waters : blocky calcite replaced the former fibrous calcite of the cavities in the mudstones, limpid spar syntaxially overgrowed echinoderm skeletal grains in the crinoidal wacke/packstones and grainstones, whereas solution coronas developed preferably below crinoid ossicles in the stromatactis mudstones (Pl. 17 : 8-9). The tendency for coronas to have enlarged preferentially beneath grains (= geopetal coronas) could even indicate the downward percolation of fluids in a vadose environment (Walkden & Berry, 1984).

A strong compaction and resulting pressure solution finally produced numerous stylolites and associated intergranular sutural contacts or truncation of grains by adjacent grains, within the crinoidal packstones and grainstones.
Pressure solution produced conspicuous stylocumulates otherwise in the impurer limestone facies (higher detrital content), which lead to the formation of secondary, grain-supported rock types. A final stylolaminitic to stylonodular diagenetic fabric (Longman, 1980) characterizes the impure carbonate lithofacies, underlying and overlying the central core of the Baelen mound, and is responsible of its "cyclic" outlook.

7. - DEPOSITIONAL ENVIRONMENT AND EVOLUTION OF THE BAELEN LIMESTONES

Microfacies and ecological arguments point to a reef mound environment for the Baelen limestone complex. The dominant microfacies consists of algal, cryptalgal and spiculitic mudstones or wackestones, alternating with crinoidal packstones, grainstones, rudstones, and with subordinate algal bindstones and floatstones. It is suggested that the bulk of the lime mud has been produced and/or fixed by non-skeletal algae. Piles of crinoidal debris and/or a hardground could have provided a starter area for organically-induced lime mud accumulation.

When rates of clastic deposition were low, carbonate production could have taken place on tectonically-controlled offshore submarine highs. Indeed, abrupt changes in facies of the underlying formations (late Frasnian, early Famennian) and the preferential location of the Baelen reef mounds in the Limbourg-Goé area, coincide with the northern extremity of a

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(1) GOEMAERE, E., 1984. Le Famennien supérieur de la Vallée du Bocq (Durnal) : lithologie, sédimentologie, particularités minéralogiques et paléontologiques. Thèse de Licence inédite, Univ. Liège, Belgique, in press.

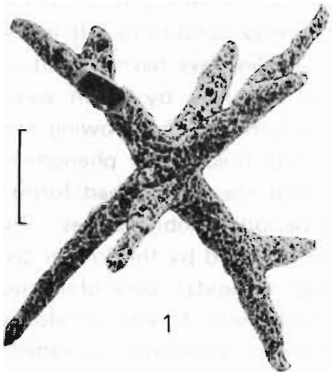
PLATE 11 : Sponges

Arakaspongiid sponge spicula (scale bar is 100 microns)

1-11. smooth to slightly nodose small hexasters

12-17. large, five-rayed armored spicules (Fig. 16 is six rayed).

All hexactinellid spicula have been isolated by formic acid-etching of mudstones and wackestones. Lithological units C, E and F at Goé-Nord and Baelen-Les Forges sections, Baelen, Limbourg.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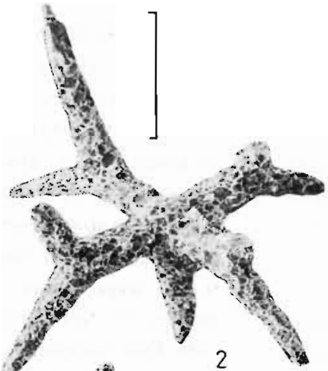
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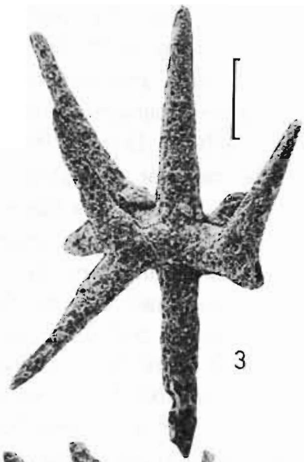
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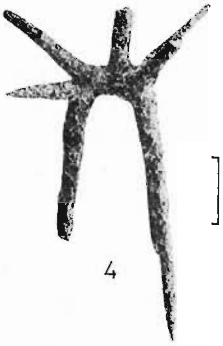
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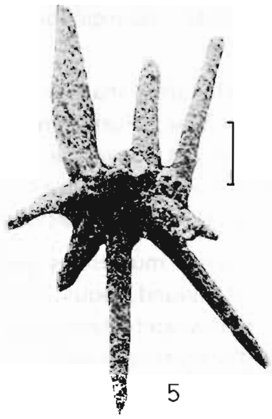
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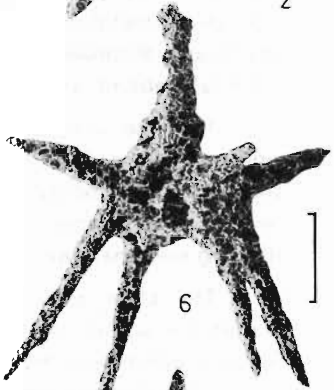
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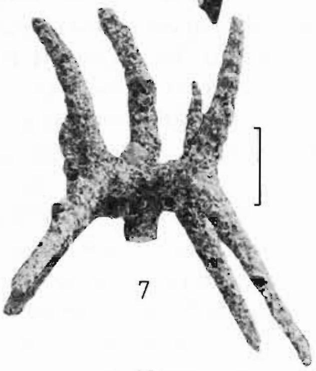
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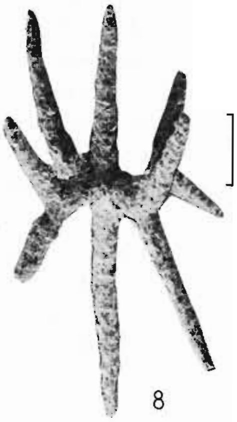
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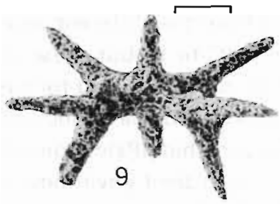
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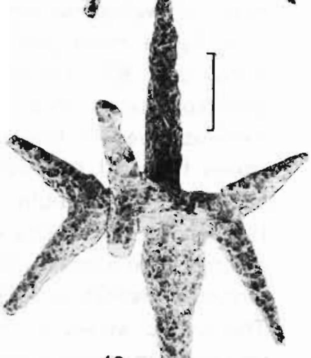
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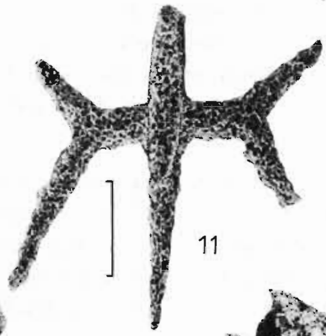
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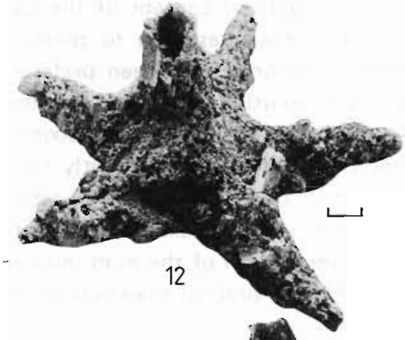
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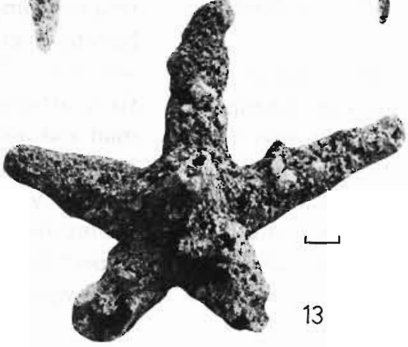
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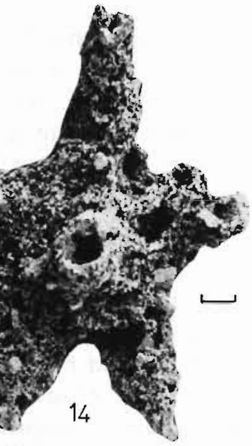
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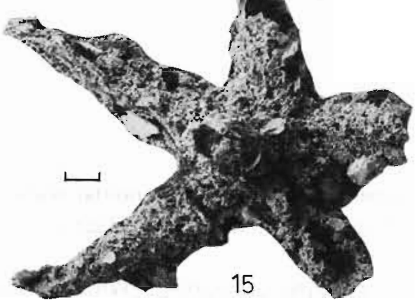
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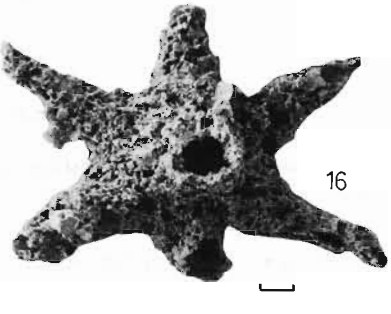
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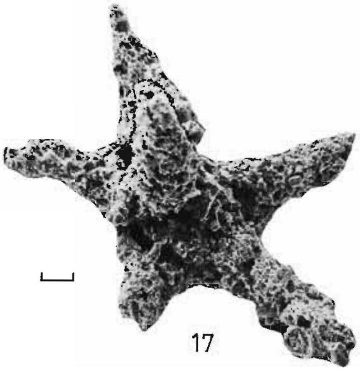
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deep-seated fault or unstable zone, the so-called Verviers-Trier dislocation (NNW-SSE directed transversal fault, Dvorak, 1973). Nevertheless, the exact lithological relationship with enveloping sediments, and the recognition of possible back-reef and fore-reef facies is still unclear. In former paleogeographical reconstruction attempts (Dreesen, 1979; Dreesen & Thorez, 1980) the Souverain-Pré nodular limestones were interpreted as a back-mound facies of the Baelen complex. This statement was based on ecological arguments: frequency of calcispheres, Umbellinaceans, Girvanellid oncoids, *Cryptophyllus,* green algae, and on the presence of shallow-marine conodont biofacies. Crinoids, sponges and dasyclads might have formed a suitable trapping and baffling agent (lowering of the local current velocities) so that the lime mud banks developed as self-propagating systems. Subsequently their skeletal debris have been fixed in place by encrusting algae. Laminoid-fenestral fabrics are very common in the mudstones whereas their purer (siliciclastic-free) facies contain larger, stromatactoid cavities. Both cryptalgal structures are associated with pelletoidal or peloidal micrite and hexactinellid sponge spicules. It seems probable that the larger cavities might have originated through algal/bacterial decay of sponge tissue, as recently suggested by Bourque & Gignac (1983). The presence of stromatactis in the purest lime mud facies could also favour the idea of a sponge network origin (filter-feeding organisms). Early-diagenetic (synsedimentary ?) marine cementation of all the cryptalgal cavities resulted in stabilization of the lime mud and/or consolidation of the algal mudmound.

It is suggested here that these algal--sponge mudstones have been deposited in a "quiet" environment, below wave base, but still within the photic zone. This latter statement is inferred from the abundance of Issinellids, which have been related here to dasycladacean green algae.

The frequent and irregular interstratification of coarse crinoidal packstones, grainstones and rudstones within the algal mudmound, would suggest that the mound had intermittently reached the wave base or that the mound had been affected by storm wave activity. These crinoidal grain/rudstones often display graded, reverse graded and cross bedding, whereas slumping and brecciation mainly affect the encrinites in the upper units of the limestone complex.

The former sedimentary structures, as well as the relatively poor sorting of the encrinites, and the mass accumulations of large, often undissociated crinoid stems, suggest rather low energy conditions. It is also possible that the crinoid ossicles have been picked up and transported over short distances by storm waves or currents around and in between the growing reef mounds. The slumping and brecciation phenomena otherwise, might indicate that the mound had formed a considerable relief with periodic mobile slopes. The latter could also have been triggered by the former tectonic movements. These crinoidal pack/grain/rudstones contain broken plurilocular forams (Endothyrids-Tournayellids), biomicritic intraclasts, girvanellid oncoids, vermetid gastropods, fenestellid and encrusting bryozoans, Bisphaerids and Issinellids. Sponge spicula are totally absent, as well as *Baculella.*

This association would indicate rather shallow subtidal conditions, at or above wave base. Furthermore, the lenticular crinoidal wackestones just above the Baelen limestones contain calcispheres and *Umbellina,* indicating even shallower, more protected shelf conditions.

The close association of both mudstones and grainstones within the Baelen reef mound, would thus indicate alternating deposition below and above wave base. A well-preserved, silicified smooth-shelled ostracode fauna from one algal mudstone/floatstone level (basal unit B) reflects relatively deep or quiet, open shelf conditions. Numerous ostracode shells have also been observed in thin section from the different mudstones facies of the higher units (C to F) but these are not silicified and could therefore not be isolated for further study. Conodonts are restricted to the grainstones and represent a monotonous Polygnathid-(Palmatolepid) biofacies, indicating a sandy (inner) shelf environment. The cyclic aspect of the Baelen limestone complex results from differences in detrital content of the carbonate microfacies and in their response to pressure solution. The impurer limestones have been preferentially affected by pressure solution, dissolving the lime mud and leaving behind the impurities and large, slightly or non-corroded bioclasts. The latter frequently form secondary grain-supported rock types. The actual grainstone/mudstone ratio is thus exaggerated with respect to the original composition of the mud mound. This would also imply that the original thickness of the

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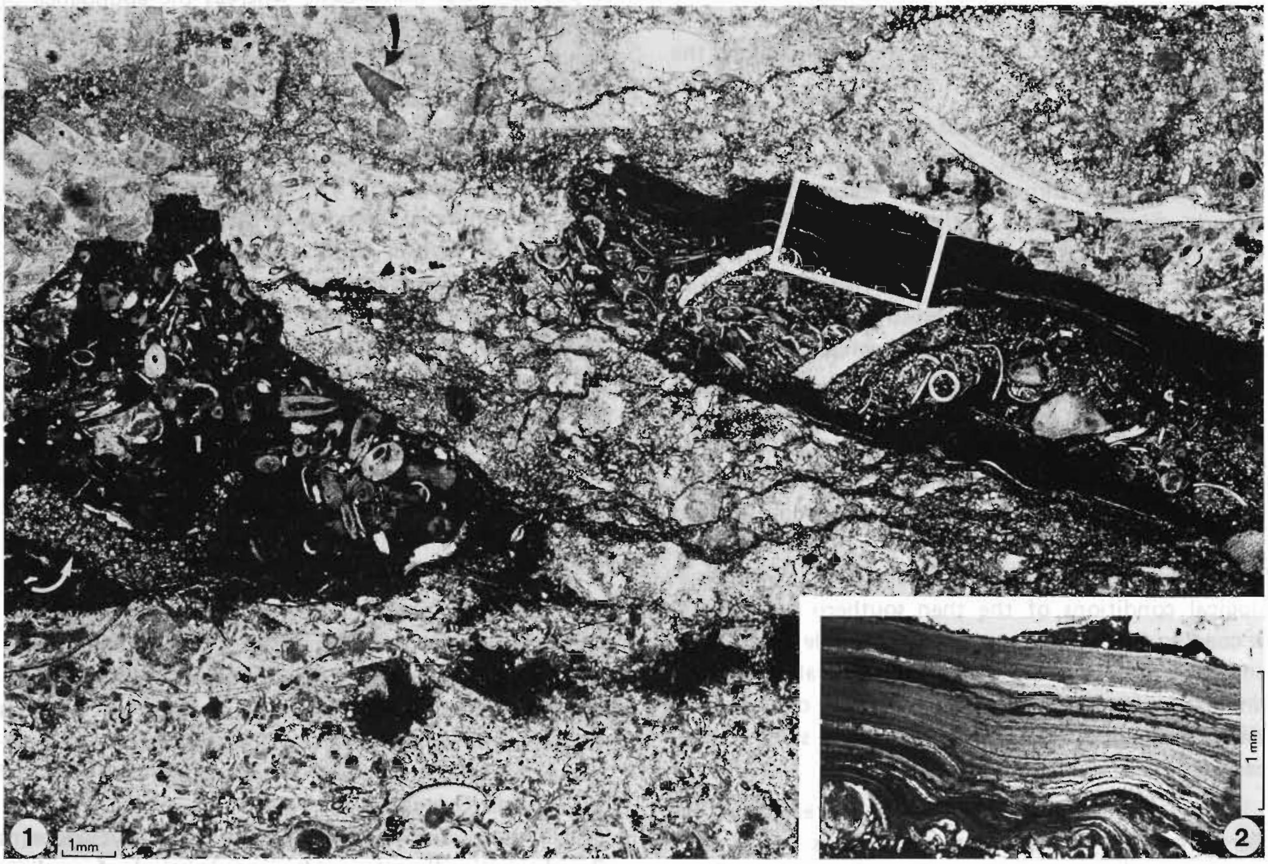
PLATE 12 : Microfacies

1. Ferruginized hardground between a lower ostracode wackestone and an upper spar-cemented crinoidal wackestone with stylocummulates of detrital grains. Note presence of Rhodophycean algal fragment (black arrow, for detail see also Pl. 2, fig. 1). Inset refers to Fig. 2.
2. Ferruginized microstromatolitic crust with interlamellar sparite-infilled encrusting organisms. White arrow points to a local concentration of dolomite rhombs. Thin section COM-1.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carbonate sediments could have been over 150 m, indicating an important short-term subsidence within the lower part of the upper *marginifera*-zone. The latter is most probably related to vertical movements along the above deep-seated fault.

The diagenetic history of the Baelen reef mounds reflects a gradual uplift, after deposition, from full marine conditions, through a mixed-water zone into the meteoric diagenetic-zone. Although the origin of the Baelen reef mounds is most probably related to synsedimentary vertical movements, this reef episode coincides with a short-term transgressive pulse within the Upper Famennian regressive megasequence.

This transgressive episode has been recognized in different places of the world and might represent a worldwide event (Sandberg, pers. comm.). It is interesting to note that the Baelen event coincides with an important migration of foraminifera from eastern Europe, which might be related to a major change in the paleogeographical (ocean currents) and paleoclimatological conditions of the then southern hemisphere. In conclusion, we suggest that the Baelen limestone complex represents a low-diversity algal-sponge-crinoidal carbonate buildup, which grew on a predestinated mounding site, in an open marine shelf setting, near wave base.

No clear evidence exists for the exact bathymetrical position of the Baelen reef mounds.
Environmental interpretation of mudmounds and related buildups, merely depends on the nature and the ecology of the in situ living organisms, as well as on the relationship with enveloping and coeval lateral sediments.

However, many micro-organisms within Paleozoic mudmounds are still incertae sedis, so that paleoecological interpretation is difficult or unsatisfactory. Moreover, clear relationships with enveloping sediments depend on the degree and quality of exposure.
Alternating low and high water turbulence points to a position near wave base, whereas the abundance of calcareous algae, in particularly that of dasyclads, would indicate the higher part of the photic zone. The abundance of hexactine spiculitic mudstones is also an important characteristic of the Baelen mounds. Sponges may have played an important role in the construction of many of the enigmatic cryptalgal mudmounds common throughout the Phanerozoic record (Bourque & Gignac, 1983; Narbonne & Dixon, 1984). Early dissolution of siliceous spicules is common in reef environments, and may have caused fossil sponges to be under-represented in ancient reefs (Land, 1976; Hartmann, 1977). Dissolution appears to be more pronounced under conditions of rapid carbonate deposition and synsedimentary cementation, both of which are present during growth of the Baelen reef mound. Recent sponge reefs occur in platform interior settings rather than in platform marginal settings typical of coralgal ecologic reefs.

Paleozoic platform interior or shelf buildups are also more variable in compositions than platform marginal ones (corals and stromatoporoids) with local development of crinoidal, bryozoan or algal reef mounds (Wilson, 1975). Skeletal sand shoal/mudmound complexes are also common in recent inner shelf areas of the Florida Keys (Multer, 1977).
Local concentrations of thin-walled dasycladaceans 2 - 4 mm in diameter and approximatively 1 cm long represent meadows of baffling organisms within Silurian sponge reefs in Canada (representing locally more than 10 °/o of the facies), whereas blue-green and red algae functioned as binders, encrusting skeletal grains and growing as lamellar sheets over the sediment (Narbonne & Dixon, 1984).

The enveloping sediments of the Baelen reef mounds are essentially micaceous silt- and sandstones. Coeval formations include sandy nodular crinoidal-foraminiferal wackestones (protected shelf facies) and

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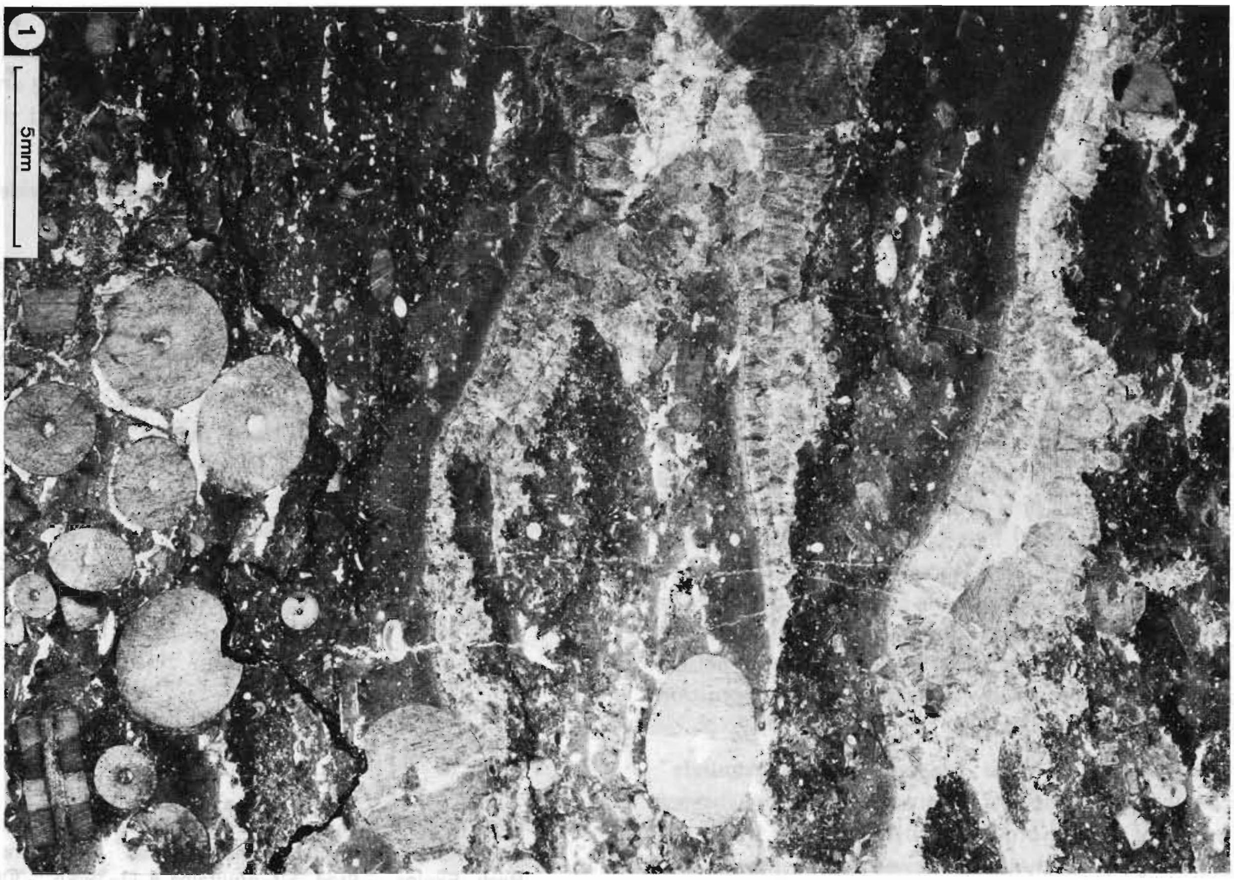
PLATE 13 : Microfacies

1. Spiculitic mudstone/wackestone with stromatactis. Note the laminoid fenestral (LF) fabrics and the sections of sponge spicula within the mudstone, the solution coronas below the larger crinoid ossicles (bottom; see also Pl. 17, fig. 8, 9) and the well-developed iron-stained stylolites. Accessory biogene components : thin-shelled ostracodes, bryozoans and Issinellids. Thin section Bae-LF-10. For details of upper left part see fig. 3, of central part see Pl. 12, fig. 3).
2. Spiculitic mudstone with possible relict of sponge network (bottom). Note presence of Issinellids at the top. Thin section Goé-N-10.
3. Spiculitic mudstone with stromatactis and good sections of sponge spicula. Note relationships of stromatactis to peloidal textures (arrows, for details see Pl. 14, figs 7-9). Ostracodes and crinoid ossicles are commonly enclosed within spar cement of stromatactis. Two generations of sparite can be observed within stromatactis structure at bottom. Thin section Bae-LF-10.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micaceous sands with lenticular crinoidal wacke/packstones (inner sandy shelf ?). The site of mounding appears to have been predestinated (synsedimentary block-faulting) whereas the relatively high sedimentation rate reflects important subsidence during growth of the Baelen mounds.

According to Pratt (1982) the bioclastic lime mudstone of mudmounds ("Waulsortian" reefs or Knoll reefs), regardless of their age, comprises a reefoid framework of unlaminated stromatolites that arose from organic binding and submarine cementation of locally generated sediment deposited from suspension. Generally, those mudmounds seem to have formed in moderately deep water (sometimes exceeding 100 m) on ramp-style carbonate shelf-to-basin slopes (Wilson, 1975). Pratt (1982) interpreted them as moderately deep-water cryptalgal bioherms formed by the trapping and the binding of lime mud and bioclasts by organic mats probably made of blue-green algae. The relatively deep to moderately deep-water environment has been inferred from the "deeper water" aspect of the laterally equivalent and enclosing limestones or shales, from faunal evidence (particularly the presence of pelagic organisms) and from the overall paleogeographic position in relation to coeval deposits.

In contrast to these "deeper water mudmounds" the Baelen reef mounds are characterized by the absence of typically pelagic organisms, by the higher frequency of green algae, and by the shallower water aspect of coeval sediments. Moreover the abundance of high-turbulence crinoidal grainstones (including Girvanellid oncoids and vermetid gastropods) suggests the vicinity of the wave base.

It is clear finally that synsedimentary tectonics have played an important role in controlling the depositional history of the shelf south and southeast of the London-Brabant Massif, during late Devonian times.

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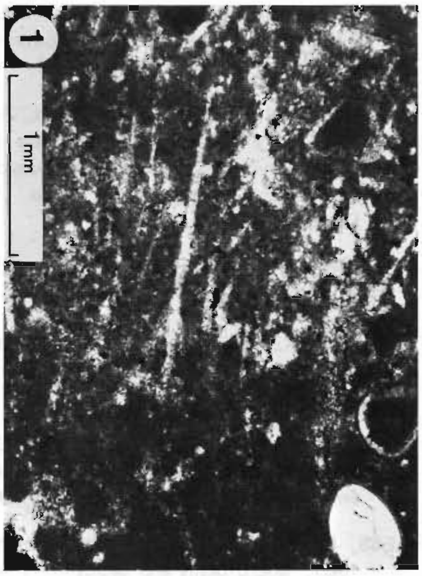
PLATE 14 : Microfacies

1. Spiculitic mudstone, Goé-N-10.
2. Concentration of slightly corroded dasyclad segments with characteristic fibroradiated wall. Sandy wackestone affected by pressure solution, Goé-N-9.
3. Crinoidal packstone with encrusting and non-encrusting Girvanellids. For details of algae see Pl. 2, figs 2, 3, 5. Thin section 76-Bae-8.
4. Gondola-shaped small stromatactoid structure enclosing crinoid ossicles. Spiculitic mudstone/packstone. Bae-F-10.
5. Parathuramminidae within a sandy wackestone. Lenticular limestones directly overlying the Baelen limestone complex at Les Forges Quarry II. Thin section 76-Bae-11.
6. Non-encrusting *Girvanella* colony, Bae-LF-7.

7-9. Peloidal textures associated to laminoid-fenestral fabrics. Bae-LF-10 (Figs 7-8 : details of Pl. 13, fig. 3).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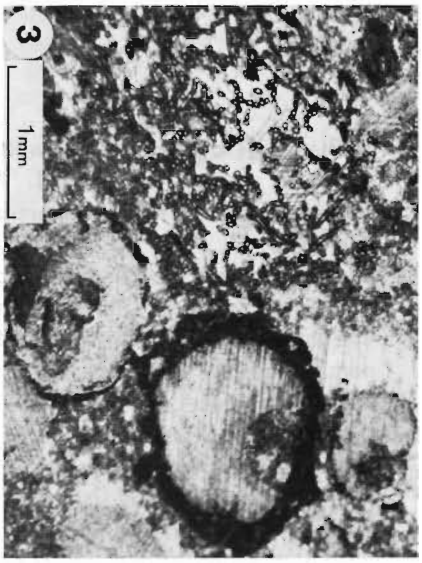
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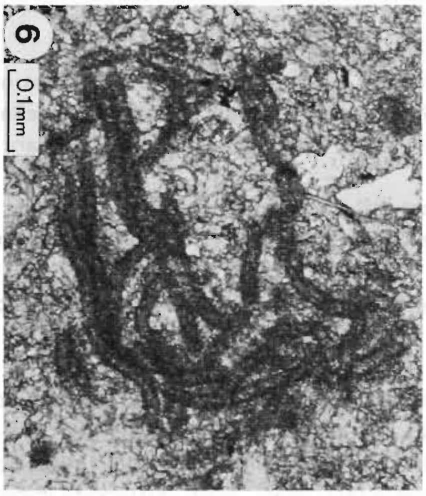
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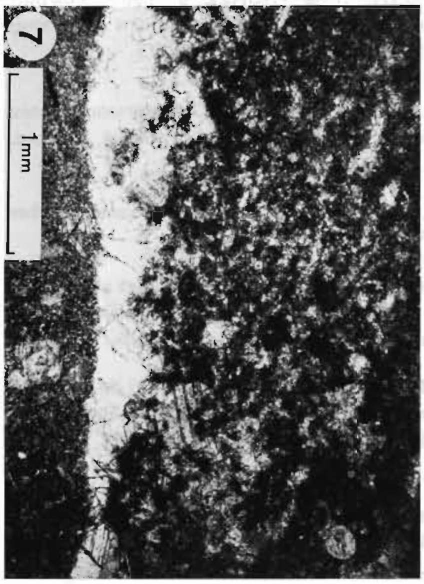
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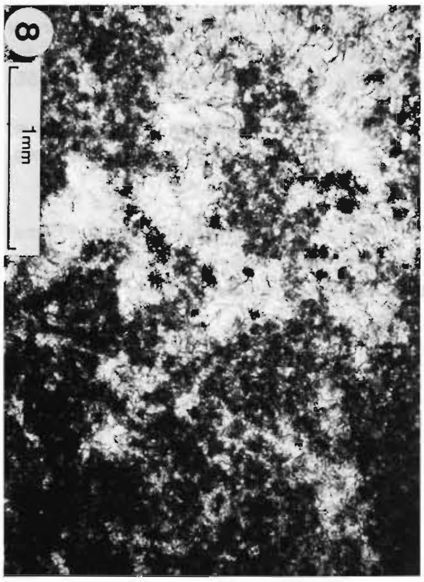
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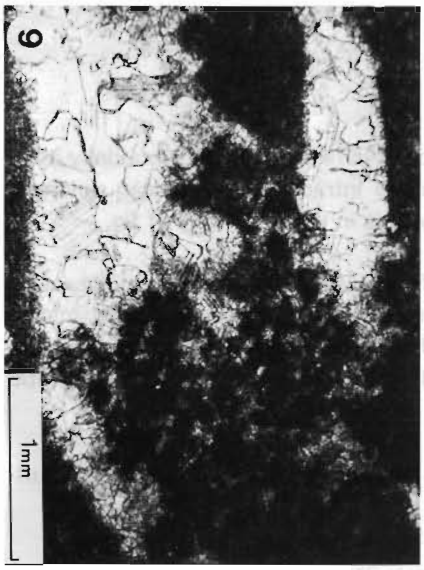
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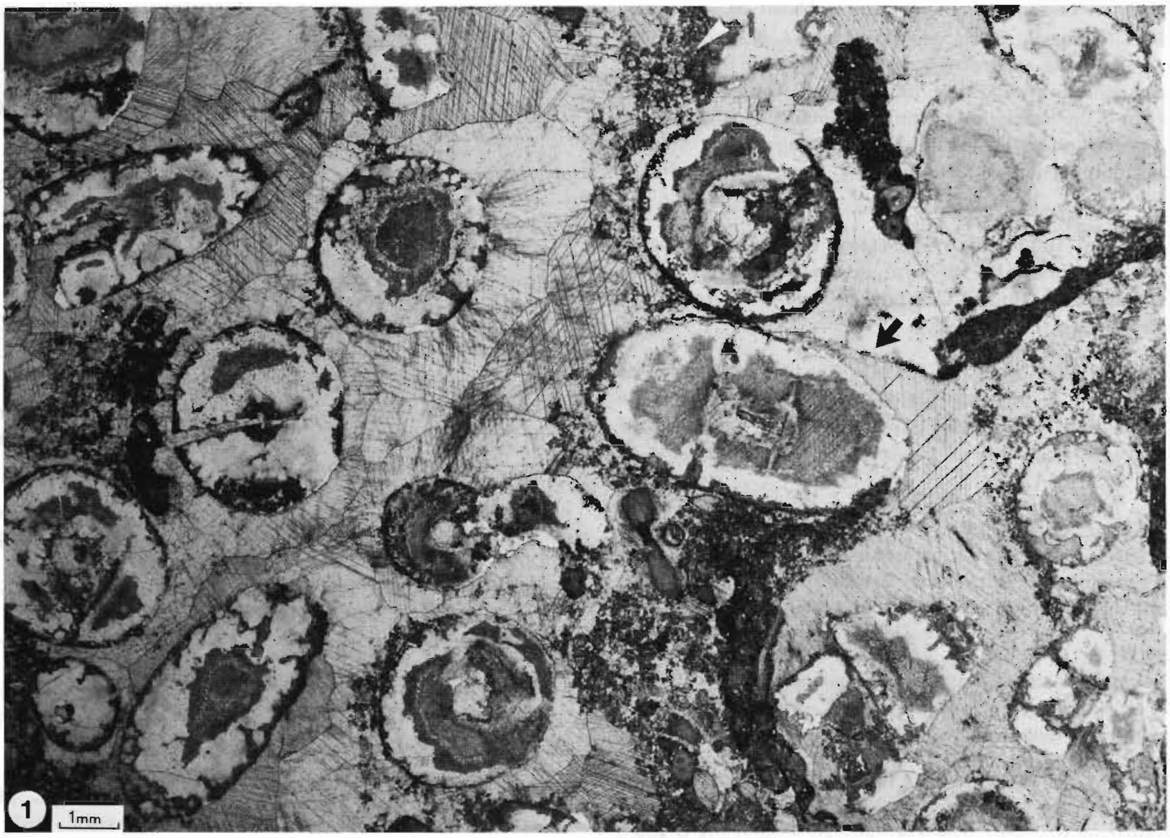
PLATE 15 : Microfacies

1. Sicified large crinoid ossicles (white areas : silica). Dark areas represent non-silicified carbonate syntaxially overgrown by spar cement (arrow). Note presence of dark bioclastic wackestone intraclasts and ferroan dolomite clusters (white arrow). Intergranular sutural contacts of crinoid ossicles are visible in lower left part of fig. Bae-LF-5.
2. Spar-cemented crinoidal wacke/packstone with silicified crinoid ossicles and foraminifera, underlying "argillaceous" dissolution residues. Relicts of the former sandy bioclastic wackestone are still visible as wavy-bedded laminae. The latter are affected by vertical stylolites reaching into the underlying limestone and defining incipient stylonodular fabrics. Pressure solution will not affect the silicified crinoid ossicles, they will be contoured by stylolitic seams only. Bae-LF-6.

3-5 : details of fig. 2, Bae-LF-6.

3. Syntaxial overgrowth on crinoid ossicle. Silicified ossicle with limpid dolomite rhombs (at left). Corroded plurilocular foraminifera and Issinellids (at right and at bottom). Detail of fig. 4.
4. Spar-cemented crinoidal-foraminiferal packstone with conspicuous syntaxial overgrowths.
5. idem with abundant plurilocular foraminifera. Vermiform gastropode in central part of fig.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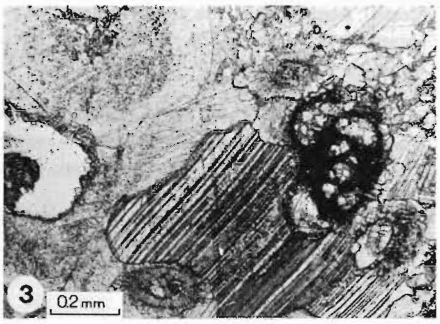
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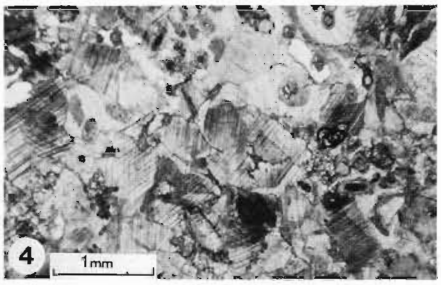
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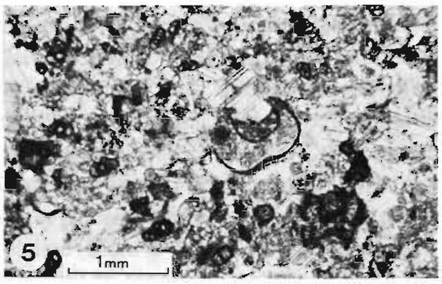
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PLATE 16 : Silicifications

(same scale in all figures)

1,4. Zebraic chalcedony with enclosed dolomite rhomb and surrounding dolomite ("sugar" rim). Spherulitic LS-chalcedony at bottom left (crossed nicols). Silicified crinoid ossicle. Fig. 1 : Bae-LF-5, fig. 4 : Goé-S-1.

2,3. Scalenohedral calcite (dog tooth spar) and megaquartz infilling *Baculella* (fig. 2 : crossed nicols). Goé-N-10.

5,6. Silicified and megaquartz-infilled ostracode shell. Shell wall and primary dog tooth spar have been replaced by microquartz. Hematitic rim is bordering the former scalenohedral calcite crystals. Dolomite rhombs are enclosed within the different quartz varieties (fig. 5 : crossed nicols) Goé-S-5.

7. Spherulitic LS-chalcedony replacing crinoid ossicle (crossed nicols Bae-LF-5).

8,9. Irregular silicification of crinoid ossicle. Dissolution relict within former sandy wackestone. Note corroded outline of ossicle and presence of limpid dolomite rhombs within spherulitic chalcedony. Bae-LF-6.


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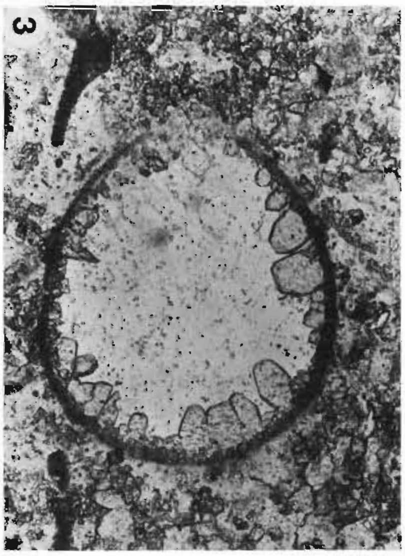
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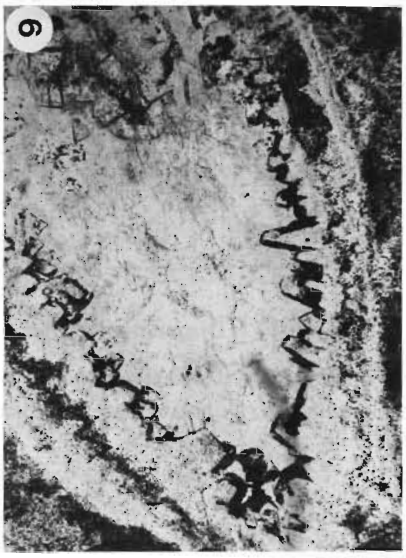
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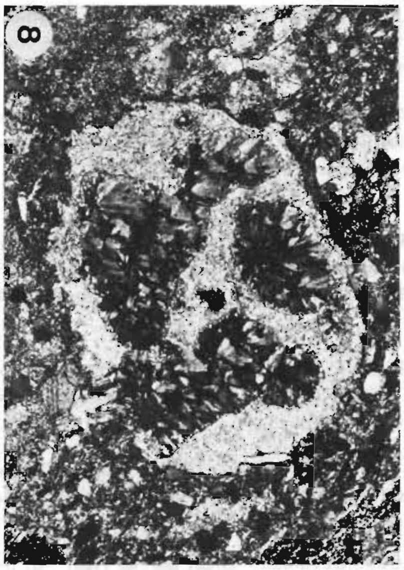
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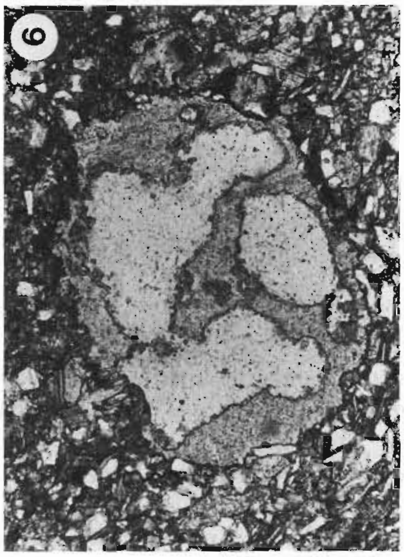
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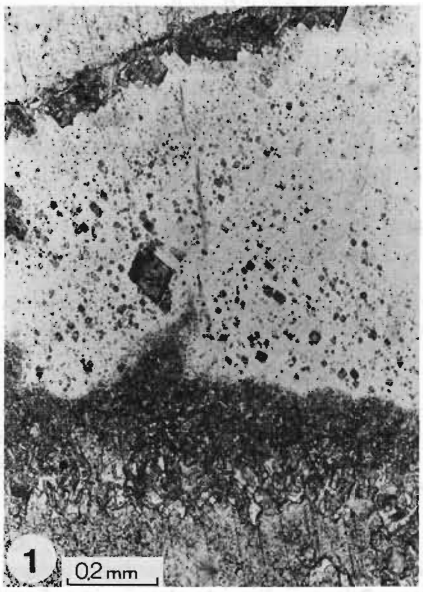
PLATE 17 : *Diagenetic features*

1-3, 7. Limpid dolomite rhombs within silica-replaced crinoid ossicles. Note preferential orientation of perfectly rhomb-shaped dolomite crystals parallel to twin lamellae of replaced calcite (fig. 7 is a detail of fig. 1) Bae-LF-5.

4-6. Dedolomitization phenomena within crinoidal-foraminiferal wacke/packstones. (fig. 4 : Bae-LF-7, fig. 5 : Bae-LF-2, fig. 6 : Bae-LF-7).

8, 9. Solution coronas preferentially located below larger crinoid ossicles (geopetal coronas cf. Walkden & Berry, 1984) within stromatactis-bearing spiculitic mudstones-wackestones. Detail of Pl. 13, fig. 1. Bae-LF-10.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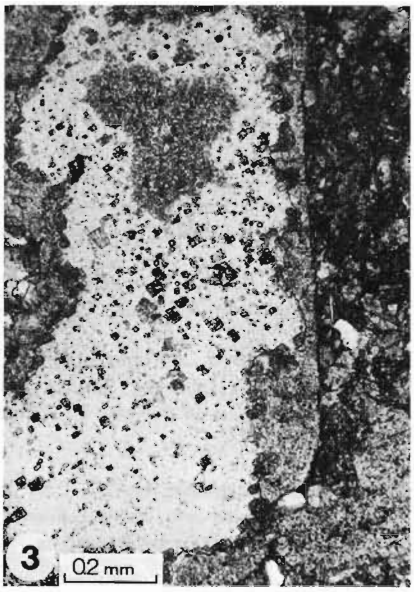
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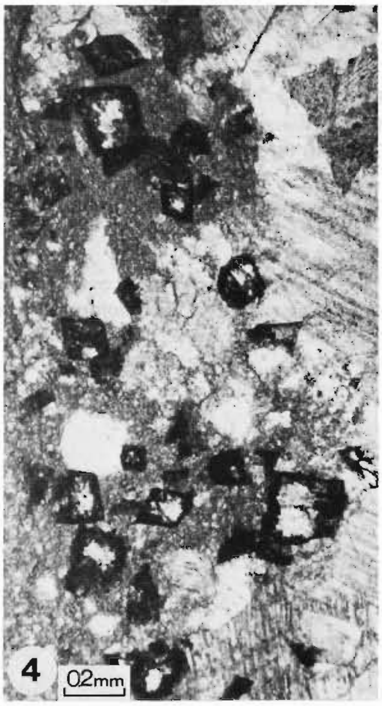
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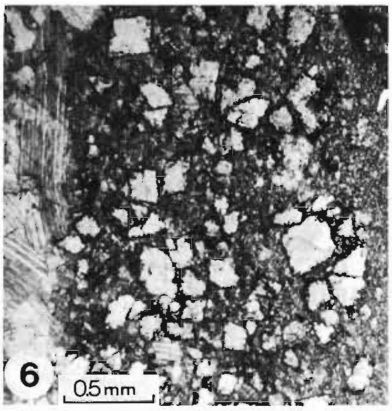
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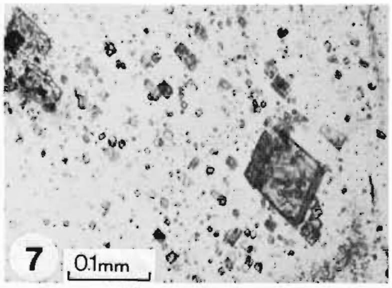
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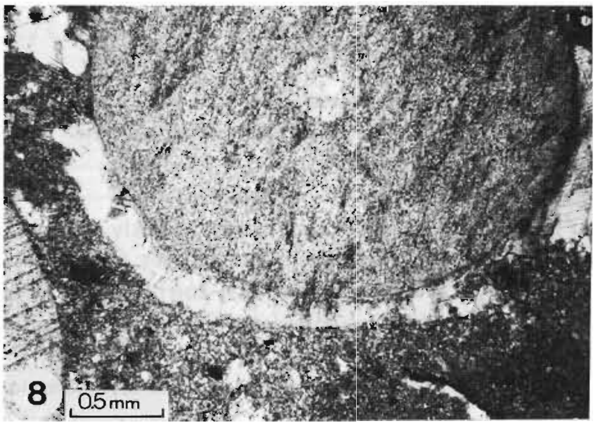
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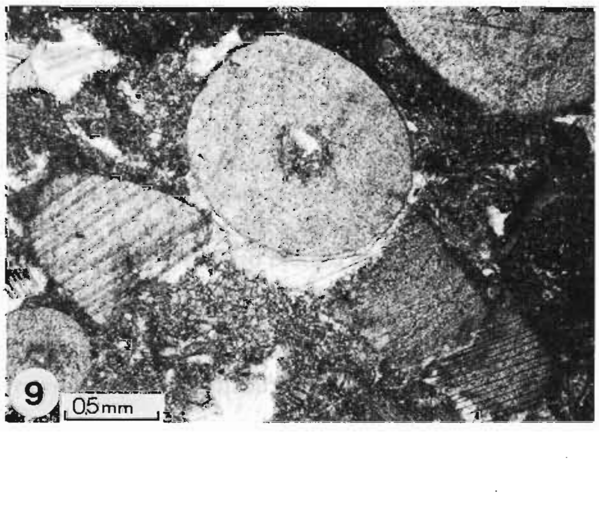
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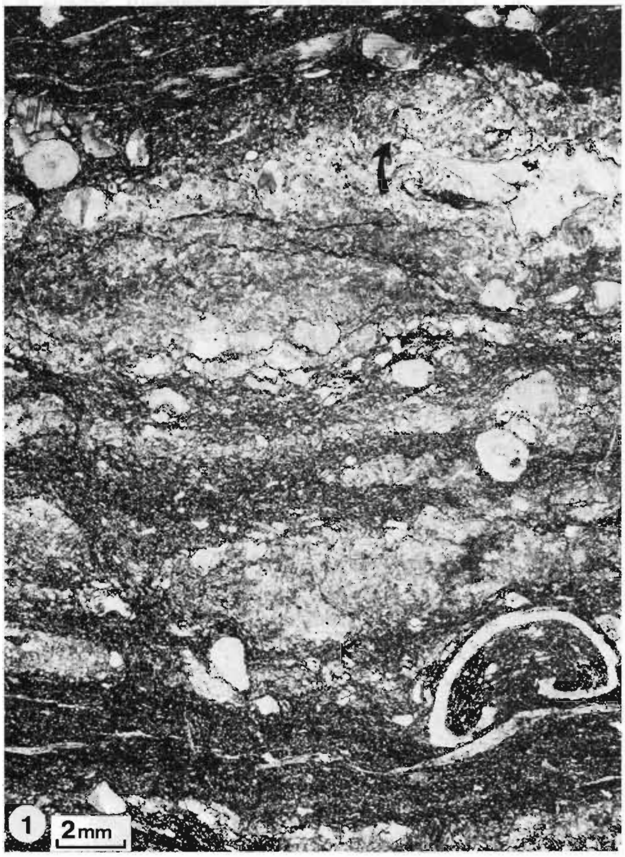
PLATE 18 : Different stages of pressure solution within impure limestones

1. Partially dissolved spar-cemented crinoidal wackestone with *Girvanella* colony arrow, see also Pl. 2, fig. 3) and large brachiopods. Incipient stylonodular fabric in lower left. Stylolaminitic fabric at top and bottom. Note truncation and intergranular sutural contacts of larger crinoid ossicles. Bae-LF-12.
2. Graded-bedded spar-cemented crinoidal packstone with syntaxial overgrowth in basal half of fig. . Conspicuous hematitic stylocummulates at lower and upper bed surfaces. Concentration of larger, slightly corroded, mostly silicified crinoid ossicles leads to formation of coarse grain-supported "secondary" rock types. Goé-S-10b.
3. Wavy-bedded iron-stained pseudolaminitic fabric with secondary concentration of less-corroded bioclasts. Small stylonodules are visible in lower half. Conspicuous stream-lining of stylocummulates around large, slightly corroded crinoids with sutural contact. Goé-S-8.
4. "Secondary" crinoid rudstone, resulting from selective dissolution. Dark material is iron-stained stylocummulate. Goé-S-8.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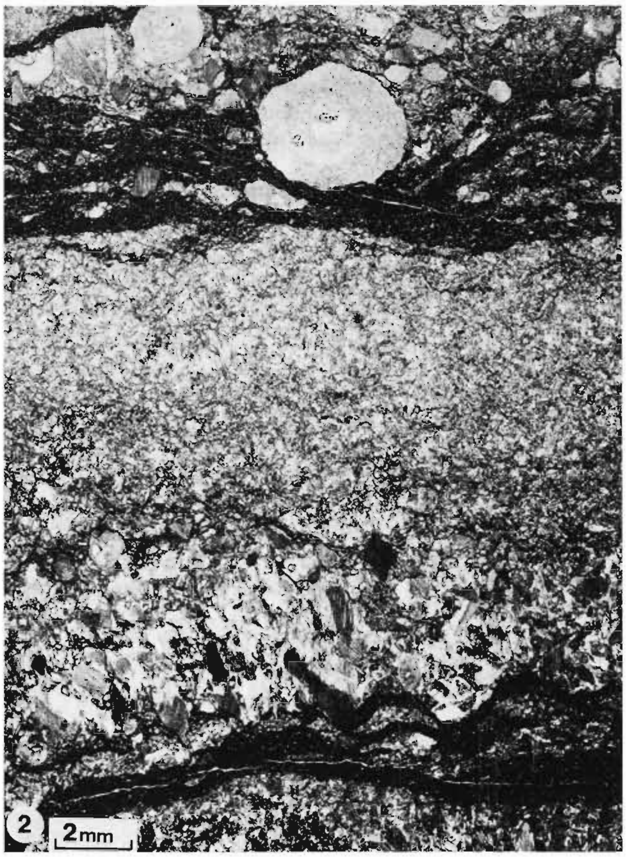
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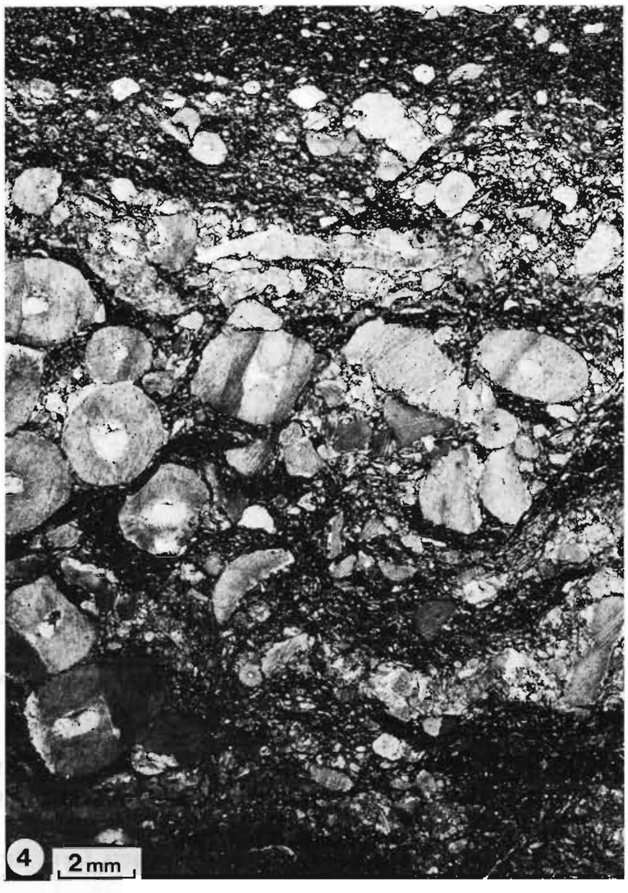
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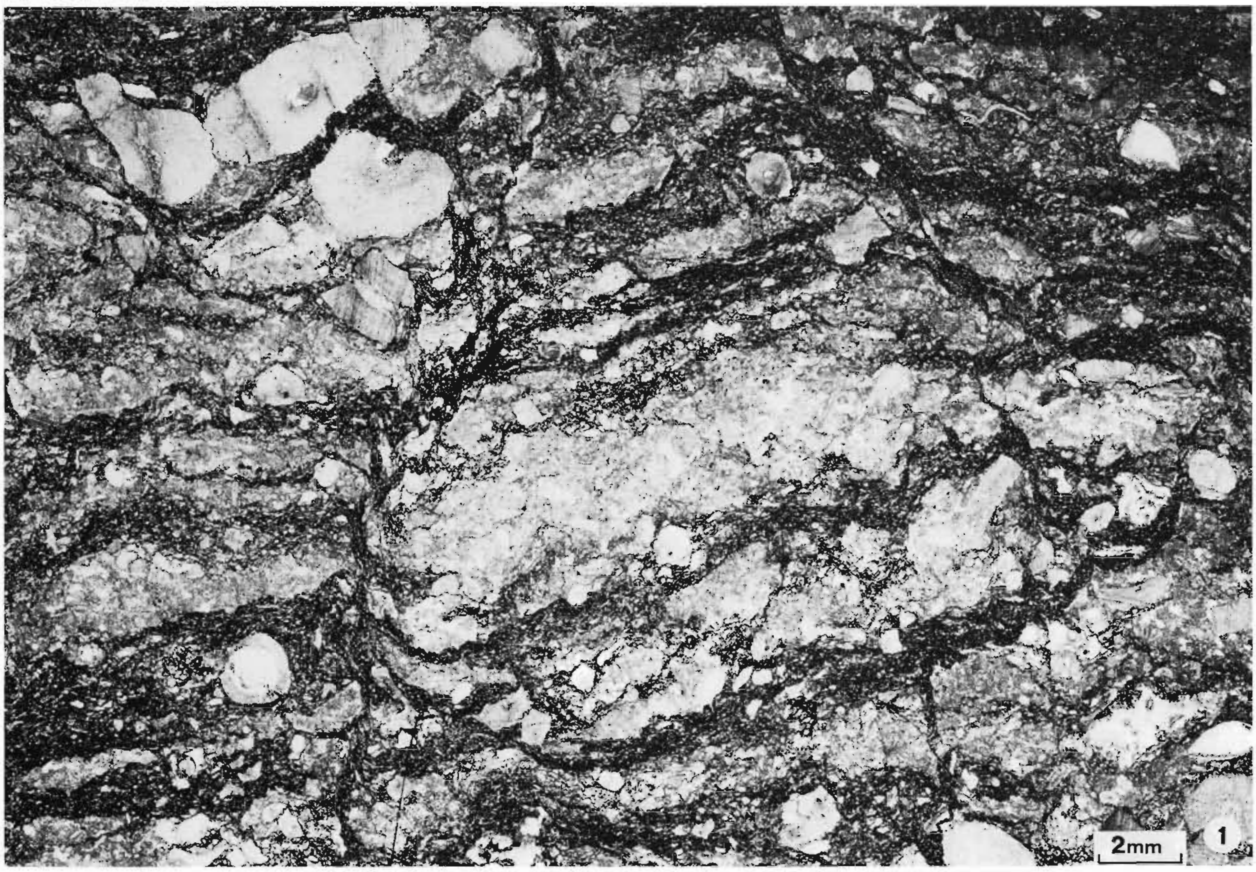
PLATE 19 : Pressure solution

1. Stylolaminitic fabric grading into stylonodular fabric through a system of horizontal and vertical stylocummulates. Original microfacies has been preserved within the larger idens and consists mainly of crinoidal wackestones with Issinellids, ostracodes, brachiopods, bryozoans and cryptalgal fabrics. Bae-LF-8.
2. Wavy-bedded stylolaminitic fabrics with idens of "secondary" crinoidal rudstone (upper left, syntaxial overgrown crinoid ossicles with sutural contacts form fitted fabrics) and packstone (base). Crenulated laminae consist essentially of recrystallized carbonate without recognizable biogenic allochems. Bae-LF-8.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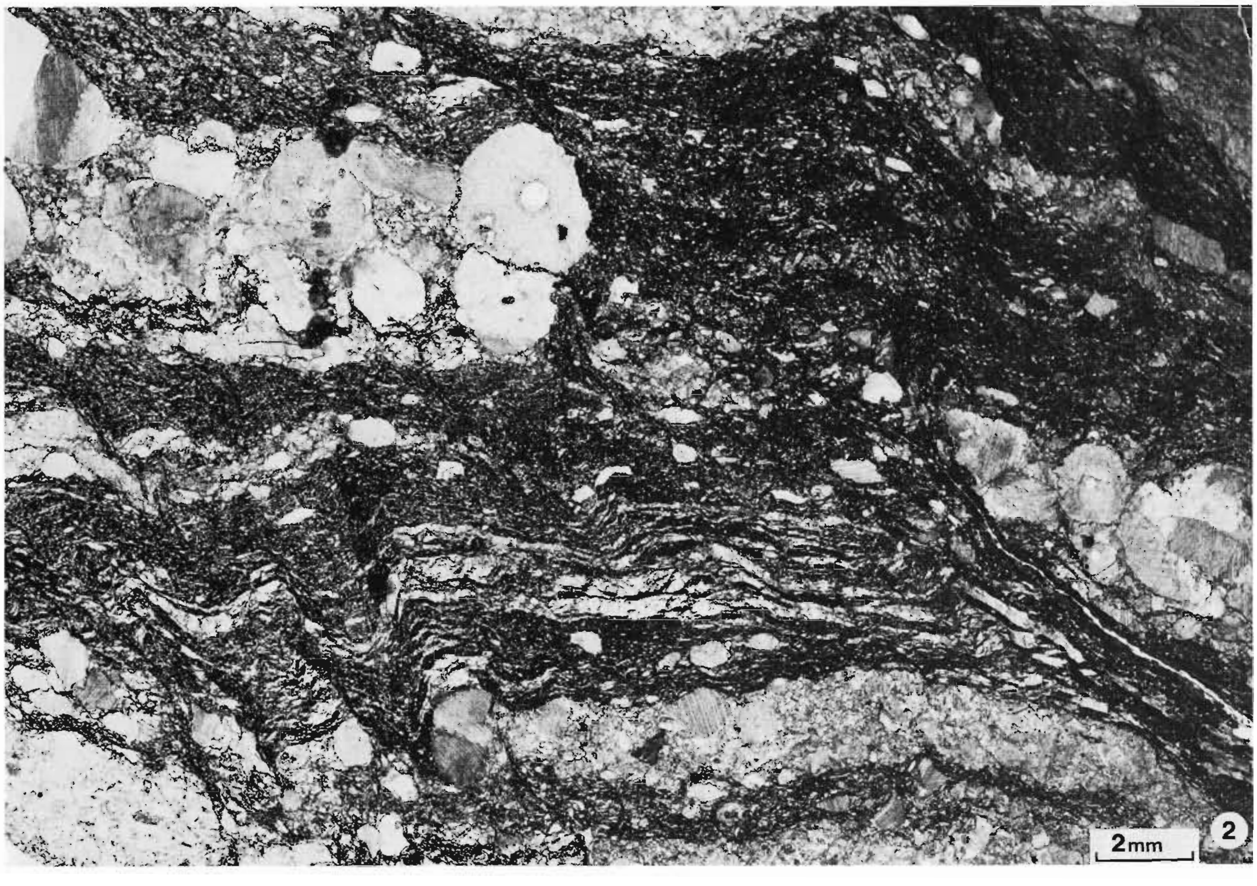
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