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STORM-GENERATED OOLITIC IRONSTONES OF THE FAMENNIAN (Falb-Fa2a) IN THE VESDRE AND DINANT SYNCLINORIA (UPPER DEVONIAN, Belgium). [1]

by

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(8 figures, 6 plates)

ABSTRACT.- Four distinct levels with oolitic ironstones have been recognized within the Famennian (Falb-Fa2a ; "Nehden Stufe" equivalent : do II) of the sedimentary basin S and E of the Brabant Massif. These oolitic ironstones represent useful marker beds throughout the Vesdre and Dinant Synclinoria and they may be correlated with red/purple-stained shales and limestones of the Aachen area and of the southern borders of the Dinant Nappe. The ironstones consist of allochtonous ferruginized allochems, they surmount hardgrounds and coincide with paleontological condensations. The allochems originated in the different environments of a coastal area (shallow subtidal to supratidal) from which area they have been removed and subsequently been transported by storm wave events (turbid surficial clouds) to the open shelf. This transport is well-illustrated by the lateral evolution of macro- and microfacies. A working model for the origin of the Fammennian oolitic ironstones is proposed. The paleogeographic value of the oolitic ironstones as indicators of geotectonic activities, stratigraphic hiatus and virtual evaporite-associated metalliferous deposits within the Ardenno-Rhenish area is discussed.

RESUME.- Quatre niveaux différents à oolithes ferrugineuses ont été reconnus dans le Famennien (Falb-Fa2a ; équivalent de la "Nehden Stufe" : do II) du bassin sédimentaire au sud et à l'est du Massif du Brabant. Ces oolithes ferrugineuses représentent de niveaux-repères remarquables à travers les Synclinaux de la Vesdre et de Dinant, et ils peuvent être mis en correlation avec des sédiments pélitiques ou calcaires rouges/violacés de la région d'Aachen et du bord sud de la Nappe de Dinant. Les oolithes se composent d'allochèmes ferrugineux allochtones, ils surmontent des "hardgrounds", et ils coïncident avec des condensations paléontologiques. Les allochèmes se sont formés dans les différents milieux côtiers (du subtidal peu profond au supratidal), dont ils furent arrachés et transportés ensuite, par action de vagues de tempête. Ce transport est bien illustré par l'évolution latérale des macrofaciès et microfaciès de chaque niveau. Un nouveau modèle est proposé pour l'origine des oolithes ferrugineuses famenniennes. La valeur paléogéographique des niveaux d'oolithes ferrugineuses dans le Massif Ardenno-Rhenan est discutée, comme indicateurs d'activités géotectoniques, d'hiatus stratigraphiques et de dépôts stratiformes métallifères virtuels, associés aux évaporites.

I. INTRODUCTION

Since the end of the last century several distinct oolitic ironstones levels have been reported from the Upper Devonian (Frasnian and Famennian) strata of Belgium. The Famennian oolitic ironstones, considered economically as the more important, were previously mined as an iron ore, almost exclusively in the Namur Basin (Delmer, 1913 ; Ancion & Van Leckwijck, 1947). The first author noticed the purple staining of the shales in which the ironstones were imbedded and mentioned their different macrofacies (siliciclastic and calcareous matrix). These oolitic ironstones consist of different discontinuous levels, interstratified within the shales of the Lower Famennian at the northern and southern borders of the Namur Basin (thickness of the ore : 0.25 to 1.50 m). The discovery of a Strunian (Tnla) macrofauna within the shaly matrix of the oolitic ironstones at Couthuin, lead Van Leckwijck & Ancion (1956) to recognize an important stratigraphical hiatus (almost the complete Famennian) at the northern border of the Namur Synclinorium.

Initially the Famennian oolitic ironstones were thought to be restricted to the Namur and Theux Basins (Franquoy, 1869) until Fourmarier (1906) and Lohest

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& Forir (1897) discovered oolitic ironstones in the Famennian of the Dinant Basin (northern and eastern borders) and of the Vesdre Basin. Fourmarier (1898, 1906) moreover, showed their importance as stratigraphical marker beds within the lower part of the Famennian (the so-called "Assise de Mariembourg"). Anthoine (1913) observed two different closely spaced levels which he used to interpret the complex tectonics affecting the Lower Famennian shales of the Vesdre Valley.

Macar & Calembert (1938) furthermore described at least three distinct levels of oolitic ironstone within the same area. They demonstrated their stratigraphic value and emphasized the presence of one particular level just beneath the micaceous sandstones of Esneux (the basal strata of the "Assise Supérieure" or the Upper Famennian "Psammites du Condroz"). Although the levels were discontinuous and rather thin (mostly between 0.15 and 0.70 m) they could be traced over a few hundred meters.

Wulff (1922) and Schmidt (1951) noticed a thin calcareous oolitic ironstone layer within the Upper Famennian ? sandstones (in the "Montfort Sandstones") north of the Aachen anticline. This level contained hematitic and chloritic ooids. The same authors also reported a 90 cm thick red-stained limestone with iron ooids ("oolithisches Roteisenerz") from the Famennian of Walheim (eastern part of the Vesdre Valley). A petrographic study revealed numerous crinoid ossicles, replaced or impregnated by iron oxides ("pseudo-oolites").

Sartenaer (1957) reported the presence of the Cheiloceras Zone in the Famennian of the Vesdre Basin, and its apparent stratigraphic position with respect to the oolitic ironstone levels.

An oolitic ironstone ("oligiste oolithique") analogous to the Famennian levels occurs at the base of the Frasnian stage, especially at the northern border of the Dinant Basin. This level is also present in the Namur Basin, in the western part of the Dinant Basin and in the Vesdre Massif (de Magnée, 1933) ; this author reported chamosite ooids from the same level and noticed its lateral facies variation (from NW to SW in the Dinant Basin) : decrease of hematitic ooids, increase of chamositic ooids and gradual dispersing of the ferruginized elements.

II. LITHO- AND BIOSTRATIGRAPHICAL POSITION OF THE OOLITIC IRONSTONES

Four distinct levels with oolitic ironstones have been recognized within the Famennian of the Vesdre and Dinant Synclinoria (Dreesen, 1981) (fig. 3 and 5). Because of their essential siliciclastic facies, the exact biostratigraphic position (based on Conodonts) of the oolitic ironstones in the Namur Basin is not clear. Nevertheless, preliminary palynological investigations (Acritarchs) by Vanguestaine and co-workers (1981, unpublished) allowed a stratigraphic correlation between the Namur oolitic ironstones (lowest level at Huy - railroad section) and the lowest level in the Ourthe Valley (eastern border of the Dinant Basin) and in the Vesdre Valley.

The Famennian oolitic ironstones and associated red sediments represent true marker beds throughout the Dinant and Vesdre Basins ; some of them can be traced over more than 175 km (from the Aachen region to the Avesnois) (figs. 1 and 2).

Each level, ranging in thickness from a few centimeters to more than one meter, consists of ferruginized allochems imbedded in lenticular crinoidal-brachiopodal limestones. The limestone beds are contained within thicker shale or sandstone sequences. The oolitic ironstones occur at the transition from one lithofacies (formation or member) to another and represent periods of non-deposition (paleontological condensation).

The first level (I) is located at the transition from the "Schistes de Senzeilles" (with index Rhynchonellid *P. omaliusi* Gosselet) to the "Schistes de Mariembourg" (with index *P. dumonti* Gosselet). This level coincides with a condensation of at least the Uppermost *Palmatolepis triangularis* Zone and the Lower *P. crepida* Zone (Conodont zones) (0.5 to 1.0 million year according to time spans estimated for conodont zones by Sandberg & Poole, (1977).

The second level (II) is well-developed within the Vesdre area (Verviers region) but is rather indistinct within the Dinant Basin (consisting of a few dispersed ferruginized allochems). This level contains conodonts of the Middel *P. crepida* Zone and possibly oolites reworked from the lower level I.

The third level (III) is a well-defined level, especially within the Vesdre Basin, and is located at the base of the micaceous sandstones of the Esneux formation (lowermost Upper Famennian). An indistinct higher sublevel is present, which might be correlated with level IIIb of the Dinant Basin (see fig. 3 and 5). In the Vesdre Basin, the most important sublevel (IIIa) coincides with a condensation of the Uppermost *P. crepida* Zone and the Lower *P. rhomboidea* Zone.

This third oolitic ironstone level is also a remarkable paleontological marker bed, due to the presence of

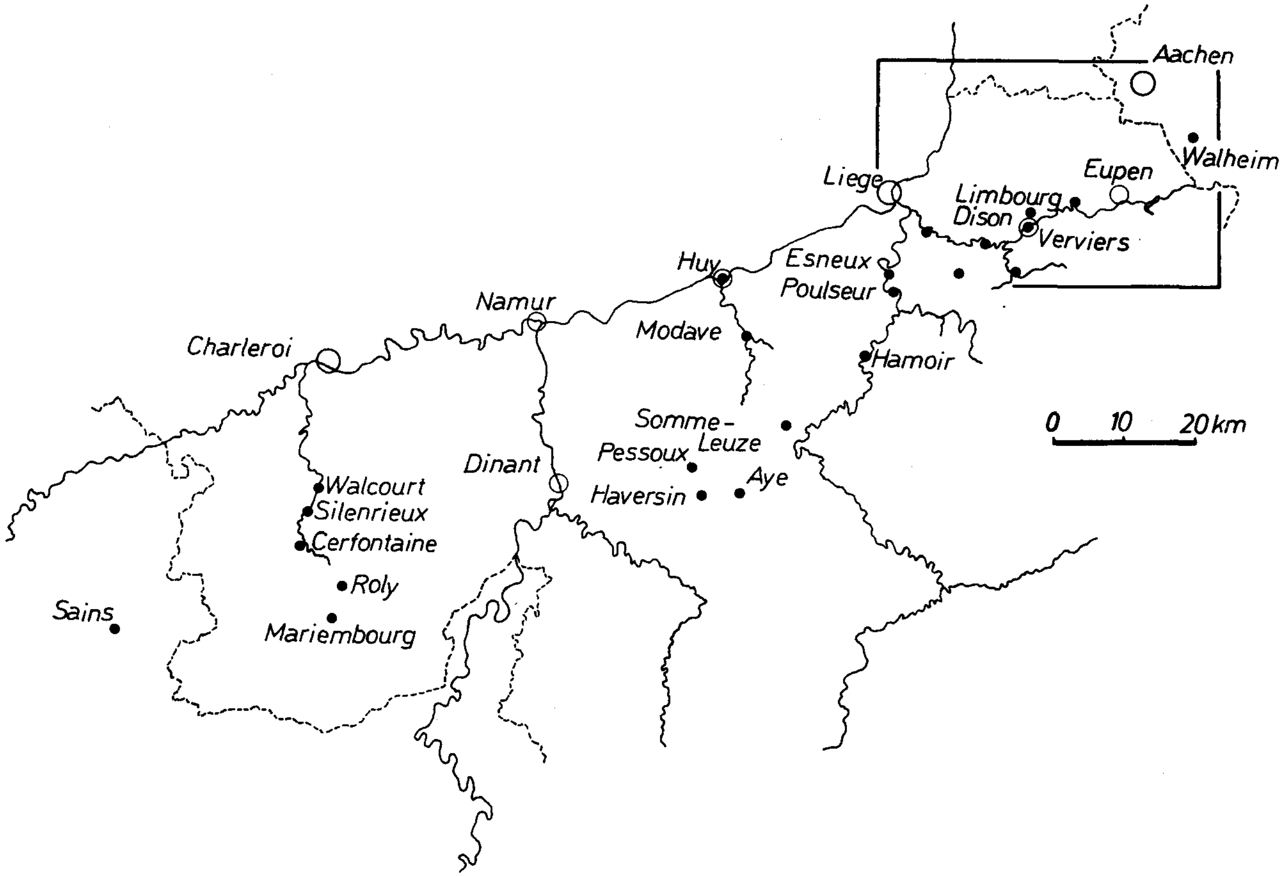

Figure 1.– Location map of the studied sections in Belgium and adjacent areas. Inset refers to fig. 2.

Goniatites and Rugose Corals. The following Cheiloceratids have been recognized (J. Price, Hull, U.K., personal communication : *Cheiloceras circumflexum* Sandberger and *Ch. amblylobum* Sandberger. *Campophyllum flexuosum* Goldfuss (E. Poty, Liège, pers. com.) is the only coral species recognized in this level, but it represents the first Famennian coral fauna after the mass extinction at the top of the Frasnian.

The following Rhynchonellids are frequently associated with level III : *Cam. letiensis* Gosselet, *Bas. basilicus* Sartenaer and *Evanescirostrum* sp. Sartenaer, In the Dinant Synclinorium, level III may clearly be subdivided into two distinct sublevels (III a and III b). The former correspond to the important concentration of ferruginized allochems at the base of the Esneux Formation in the Vesdre Basin, whereas the latter coincides with a condensation of the Uppermost *P. rhomboidea* and Lowermost *P. marginifera* Zones.

The youngest level finally (IV) occurs at the transition of the sandy Esneux Formation (or its southern shaly equivalent, the Aye Fromation) and the nodular limestones of the Souverain-Pré Formation. Biostratigraphically, this level corresponds to the Lower/Upper *P. marginifera* Zones transition.

III. GEOGRAPHICAL DISTRIBUTION OF THE FAMENNIAN OOLITIC IRONSTONES

The Lower Famennian oolitic ironstone levels (I and II) are well developed in the Vesdre Basin, whereas they are only hardly indicated in the Dinant Basin. On the northern and eastern borders of the latter basin, levels I and II consist of very dispersed and rare ferruginized allochems.

In the center and on the southern border of the same basin, these levels are absent, but they correspond most probably to a characteristic facies of red/purple shales (the so-called "Schistes de Mariembourg").

The (bio-) stratigraphical correlation between oolitic ironstones (levels I and II) and red-coloured

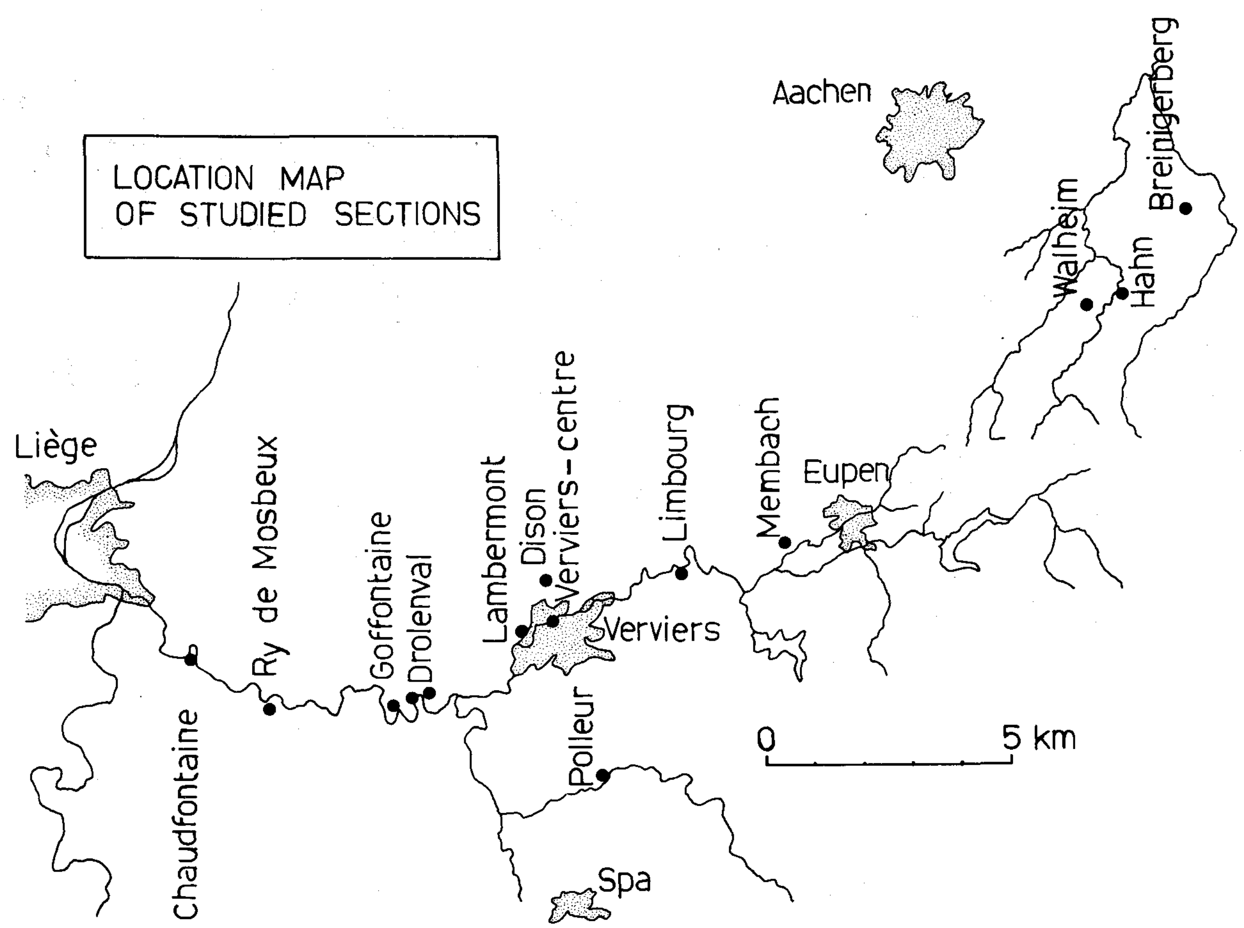

Figure 2.- Location map of the studied sections in the Vesdre Valley and the Aachen region.

sediments, has undoubtedly been proved for the Vesdre-Aachen region (Kasig, Dreesen & Bouckaert, 1979) (see fig. 4).

An analoguous correlation between the oolitical ironstone level III and the red cephalopod limestones of the Aachen region (the "*Cheiloceraskalk*"), as proposed by Dreesen in Thorez *et al.* (1978), has now been confirmed by new biostratigraphical data.

Oolitic ironstone levels IIIa and IIIb of the NE border of the Dinant Basin, correspond to red lenticular calcarenites (crinoidal wacke- and packstones) or grey crinoidal limestone lenses with pink crinoid ossicles, in the center and the SW of the same Basin. Goniatites have also been reported from this latter facies in the Avesnois region (N-France) (Bouckaert, Dreesen & Drijkoningen, 1978). They might indicate a relatively younger fauna *(Cheiloceras* together with *Prolobites)* than the *Cheiloceras* Limestone of the Aachen region (see fig. 5).

The youngest level (IV) is generally present within the Vesdre Basin (hardgrounds and ferruginized allochems) but it is particularly well-developed at the northern borders of the Dinant Syncline. Further to the S and SW of the same Syncline however, this level consist of a few dispersed ferruginized allochems only (which are visible in the dissolution residue after acetizing of the calcareous matrix).

IV. MACROFACIES AND MICROFACIES ANALYSIS OF THE OOLITIC IRONSTONES

According to its geographical position on the paleoshelf, the macro- and microscopic features of each

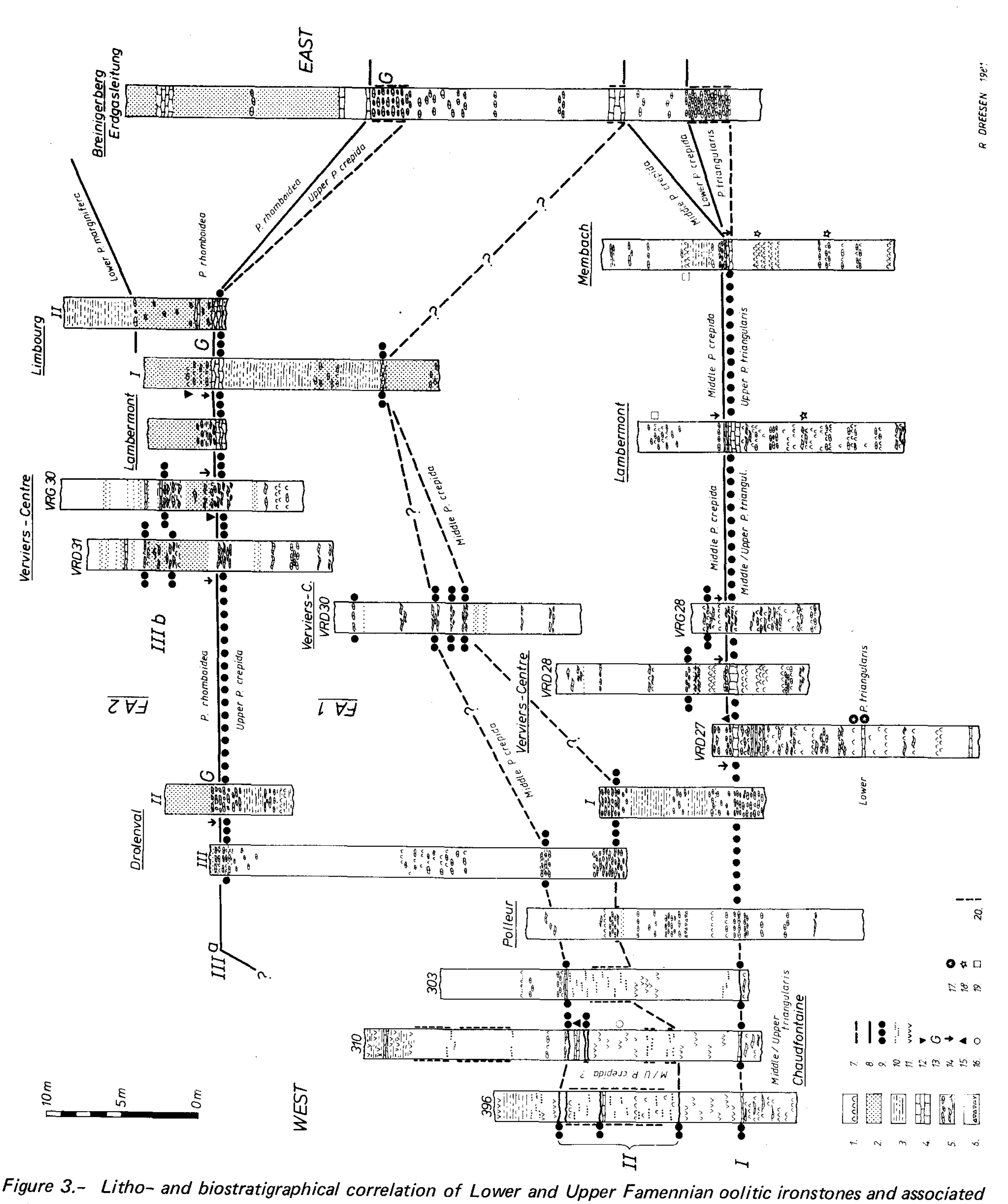

Figure 3.- Litho- and biostratigraphical correlation of Lower and Upper Famennian oolitic ironstones and associated red sediments in the Vesdre Syncline. Legend of symbols : 1. shales with coquinas ; 2. micaceous sandstones ; 3. shaly sandstones - sandy shales ; 4. compact limestone ; 5. lenticular and nodular limestone ; 6. calcareous breccia ; 7. litho-stratigraphic correlation line ; 8. biostratigraphic correlation line ; 9. oolitic ironstone levels I-III ; 10. crinoid layers ; 11. dolomitic "clouds" ; 12. rugose corals ; 13. goniatites ; 14. orthoceratids ; 15. P. dumonti *; 16.* P.gonthieri *; 17.* P. omaliusi *; 18.* P. triaequalis *; 19.* Cav. faniae *; 20. red and purple sediments.*

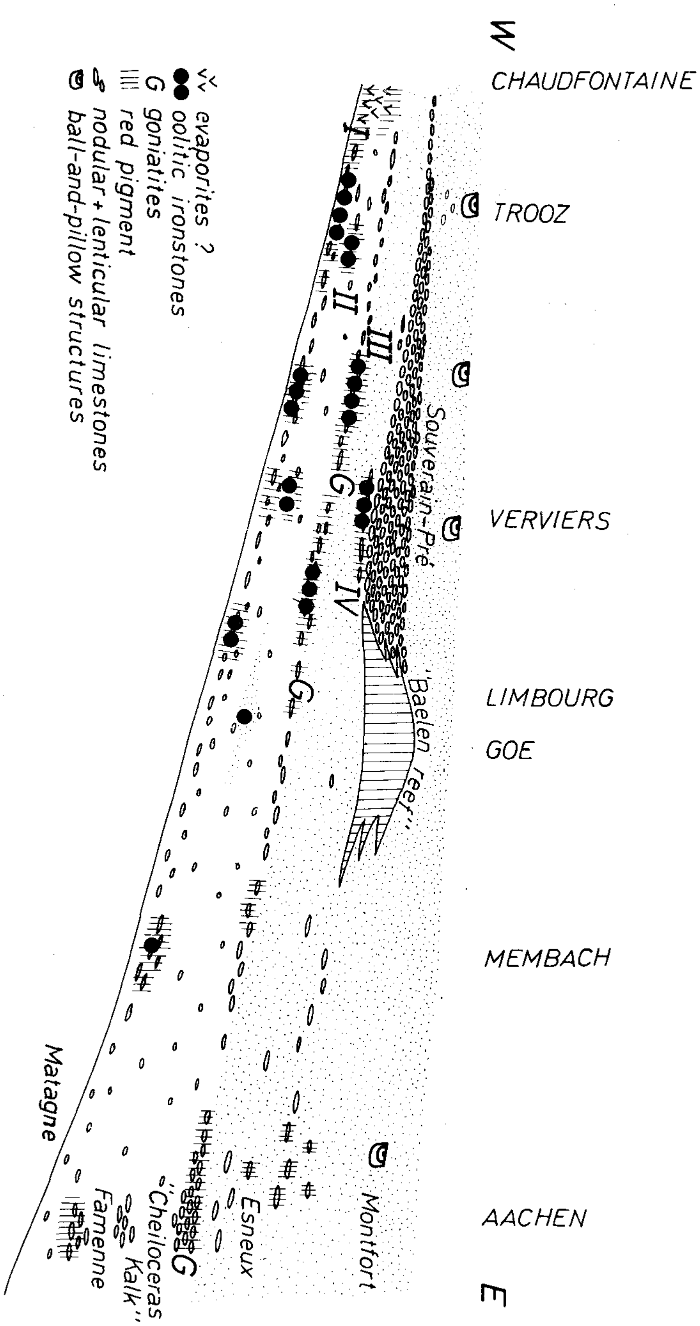

Figure 4.- Generalized WE-cross section through the famennian (fa1-Fa2C) in the Vesdre-Aachen area (white : shales ; dots : sandstones ; I to IV oolitic ironstone levels). After R. Dreesen in *Thorez* et al. *(1977)*

oolitic ironstone are different (see fig. 6). Observed differences are related to the distance from shore, from which area the ferruginized allochems have been removed (see further). An idealized lateral sequence consists of the following facies, from backshore-nearshore to offshore :

a. White to pinkish dolomitic limestone layers, imbedded in red- to purple-stained originally green shales, with dolomitic "clouds" (pseudomorphosed nodular anhydrite ?). A basal erosional unconformity is encrusted by stromatolitic algal mats. Ferruginized allochems (chloritic algal oncoids/oncolites, pisolites and algal-encrusted hematitic intraclasts) occur dispersed within the dolomitic matrix. (e.g.) Chaudfontaine borehole).

b. Red nodular and lenticular crinoidal-brachiopodal limestones (wackestones) with varying concentrations of non-sorted heterogenous ferruginized allochems : ooids, superficial ooids, algal-foraminiferal oncoids (*Osagia*-type) and oncolites, pisolites, coated bioclasts.

   Particular allochems may occupy the nuclei of superficial ooids, such as colonies of encrusting foraminefera (related to the genus *Aphralysia* Garwood), Charophycean-like oogonia (related to the genus *Sycidium* Sandberger) and Umbellinaceae (restricted however to level IV) (Dreesen & Vanguestaine, 1982). Basal unconformities with traces of boring organisms (endoliths), truncated fossils (brachiopod shells, crinoid ossicles) and ferruginized encrusting stromatolitic algal mats, are typical of hardgrounds.

   The occurence of ferruginized intraclasts (algal coated intraclasts and fragments of the algal crust), of bored skeletal grains (crinoid ossicles, pelecypod and brachiopod fragments, ostracode shells), and the record of paleontological condensations immediately above the basal erosional unconformity, confirms the presence of submarine hardgrounds (Bathurst, 1975 ; Bromley, 1975 ; Flügel, 1978).

   The amount of ferruginized allochems decreases from bottom to top, whereas that of the chloritic allochems increases in the same direction. Sulfides (pyrite, chalcopyrite, sfalerite) seem to be concentrated (dispersed microscopic crystals or aggregates) towards the top of each level ; some of these sulfides are interlayered within algal oncoids/oncolites or infill the cavities of particular allochems (such as the Charophycean-like oogonia)(Dreesen *et al.,* 1982). Macrofossils, such as Cephalopods (*Orthoceratidae* in level I-II, *Cheiloceratidae* in level III), Rugose corals (level III), Rhynchonellids and Spiriferids are

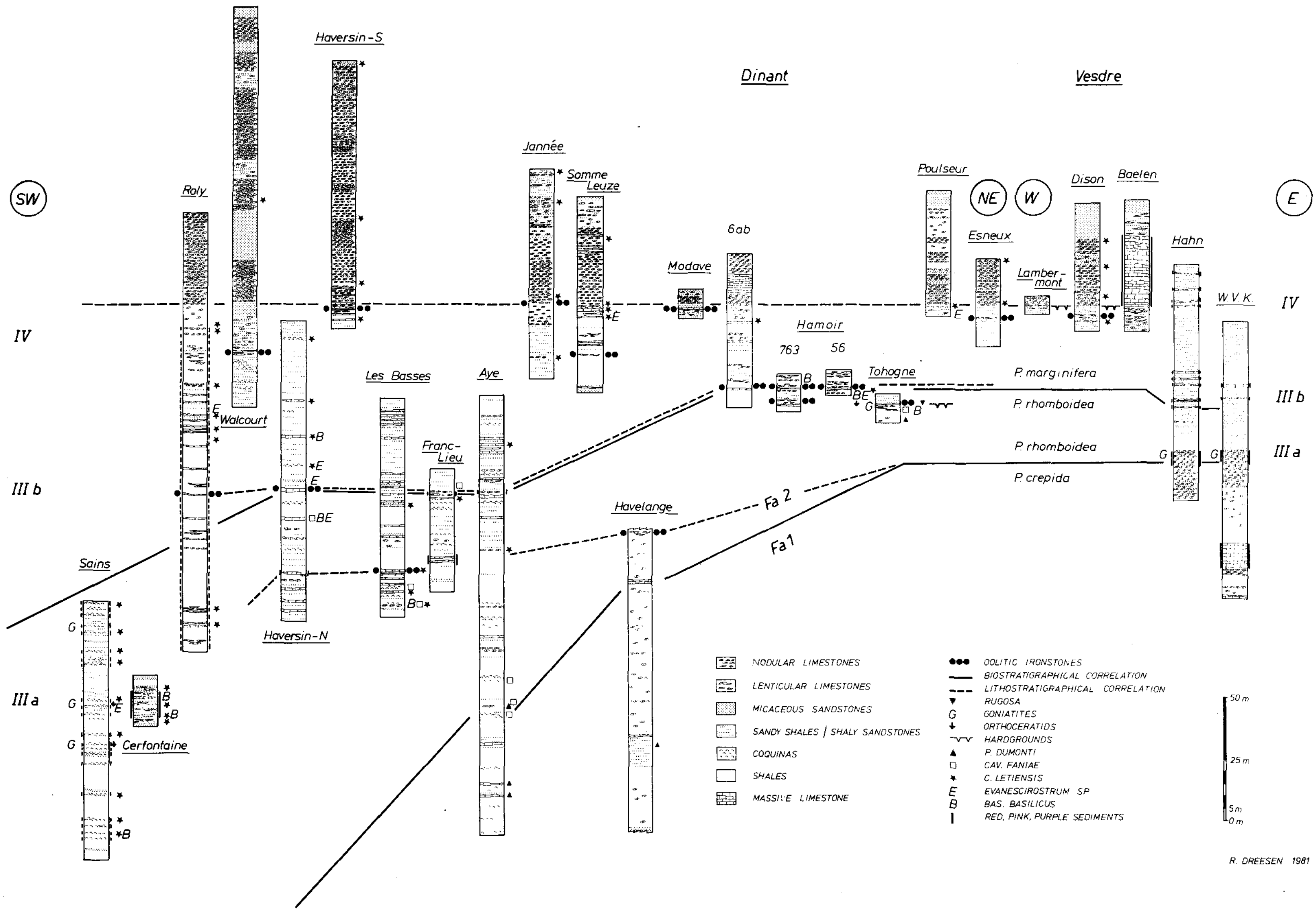

Figure 5.- Litho- and biostratigraphical correlation of Upper Famennian oolitic ironstones and associated red sediments in the Dinant and Vesdre Synclinoria.

frequently mixed up with all of the former allochems. (e.g. Lambermont, Drolenval, Verviers boreholes).

c. Grey to pink lenticular crinoidal calcarenites (wacke/ packstones) enclose irregular-based concentrations of ferruginized allochems. These allochems consist almost exclusively of slightly coated and (hematite)-chlorite-impregnated rounded skeletal grains (mostly crinoid ossicles). It is also not uncommon to observe red or pink crinoid ossicles with chlorite-pyrite infilled central chennals.
The lenticular shape, the sharp erosional base and quick lateral facies variation of the calcarenite, as well as the general bad sorting of the allochems (except for local graded bedding) is typical of calcareous storm layers, which settled down from turbid surficial clouds (Flügel, 1978 ; Vai, 1980 ; Kreisa, 1981). (e.g. Hamoir-Tohogne, Haversin, Aye-Sinsin).

d. Thin grey lenticular brachiopodal-crinoidal limestone beds (fossiliferous wackestones) countain very thin (up to a few centimeters) wholefossil packstones, of which the allochems (mostly crinoid ossicles) are red- to pink-stained only. Dispersed sulfides are common. (e.g. Havelange, Aublain, Sains).

e. Red to purple (depending on the hematite particle size) shales and nodular limestones (biomicrites, mudstones) without any ferruginized allochems, represent the most offshore facies of the oolitic ironstones (e.g. "Cheiloceraskalk", Mariembourg Shales).

V. WORKING MODEL FOR THE ORIGIN OF THE Falb-Fa2a OOLITIC IRONSTONES

Both the macro- and microfacies prove the oolitic ironstones to be allochtonous ; the ferruginized allochems most probably derived from different nearshore and backshore environments (shallow subtidal, intertidal, supratidal) and have been transported during storm events to more offshore settings of the shallow open shelf.
A new tentative model for their origin is here proposed, comprising four sequential stages (see fig. 7, A to D). This model partially fits the eluviation-replacement model of Kimberley (1979) (for the origin of SCOS-IF : sandy, clayey and oolitic, shallow-inland sea iron formations), which has been based on the original

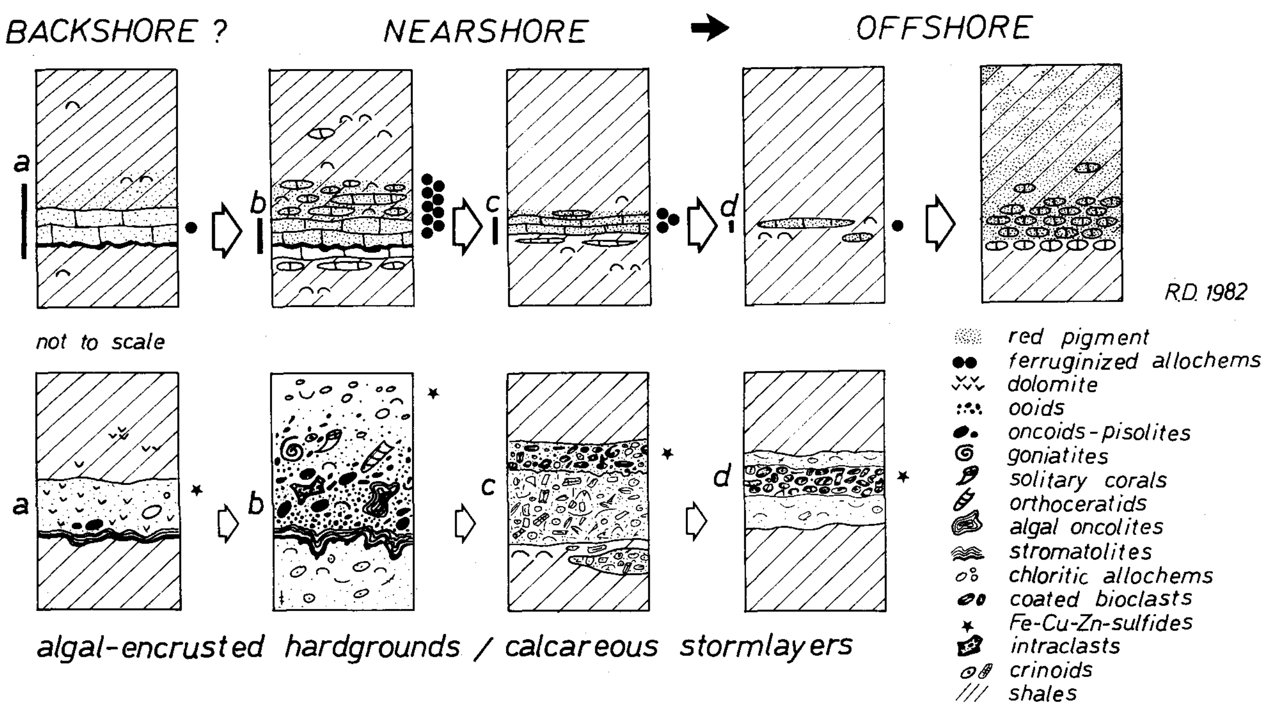

Figure 6.- Ideal lateral macrofacies and microfacies evolution sheme of the oolitic ironstones in the studied area. Lower row microfacies (a to d) correspond to sections (a to d) of the upper row macrofacies (height of each lithologic column in upper row about 2 m).

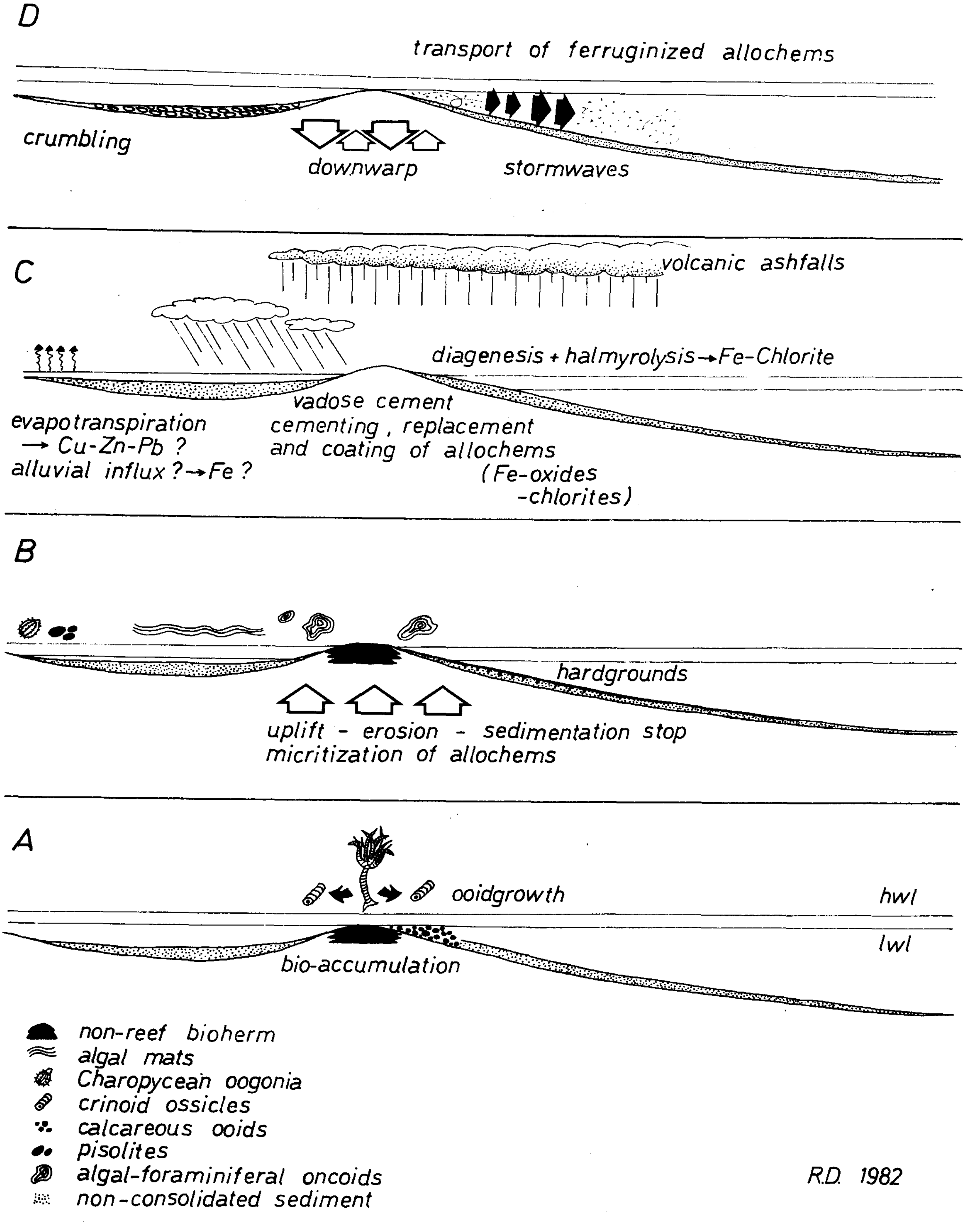

Figure 7.- Sequential stages (A to D) in the development of oolitic ironstones during the Fa1b-Fa2a in Belgium.

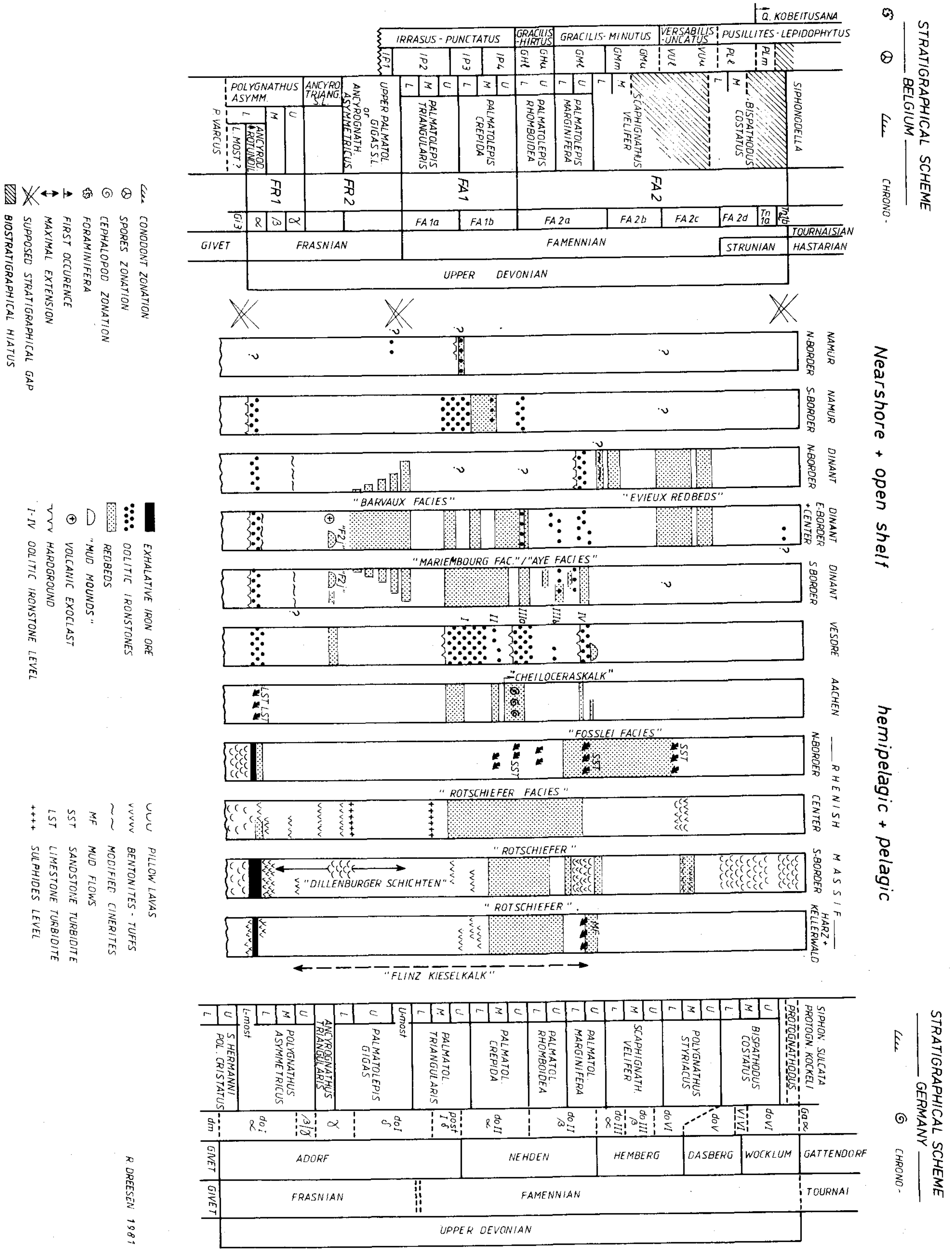

Figure 8.- Correlation scheme for the Upper Devonian in the Ardenno-Rhenish area showing stratigraphic position of oolitic ironstones, redbeds, turbidites and volcanic rocks.

statements (diagenetic replacement of calcareous ooids) by Sorby (1856) and Cayeux (1909).

A. BIO-ACCUMULATION AND OOID-GROWTH.

In a first stage, calcareous ooids, single-layer ooids, pseudo-ooids (rounded skeletal debris) accumulated in the shallow high-energy fore-barrier waters of a shoal, near the paleocoast. This shoal supported dispersed crinoidal mounds : stratigraphical reefs, consisting of large in-situ accumulations of crinoid stems and red mudstone (with *Stromatactis*-like cavity infillings) (the so-called "Baelen reefs" of Limbourg, Vesdre Syncline ; Dreesen, 1977, 1978 ; Dreesen & Thorez, 1980).

B. UPLIFT - SEDIMENTATION STOP

In a second phase, small-scale epeirogenic movements (at the border of the sedimentary basin) resulted in the uprise of the shoal, the mounds and the associated peri-mound sediments, from shallow subtidal to intertidal environments. Non-deposition furthermore resulted in the erosion of the crinoidal mounds (origin of the rounded crinoid ossicles), in the formation of algal-encrusted submarine hardgrounds and in paleontological condensation. Algal oncoids/oncolites with interlayered sessile foraminifera and stromatolitic algal mats developed also in the shallow subtidal to interdidal peri-mound area.

C. EMERSION - EVAPORITES - VOLCANIC ASHFALLS

During the next stage, supratidal conditions allowed the development of coastal sabkha evaporitic pans, whereas alluvio-lagoonal ponds were probably prolific for "Charophytes" and pisolites (the latter allochems were already present during phase B). The record of dog-tooth spar in some hardgrounds may even indicate a temporary subaerial exposure (Bathurst, 1975 ; Flugel, 1978). Following this exposure, iron oxides, hydroxides and silicates cemented, impregnated and coated (="replaced") all of the former calcareous allochems. The iron derived most probably from different sources : excess iron in solution was present in the surface waters of a density-stratified evaporitic pan (with possible alluvial influxes) (Sonnenfeld *et al.*, 1977) whereas the Fe-chlorites derived from the halmyrolysis-diagenesis of volcanic ashfalls. Chloritized (originally smectite ?) benthonite mud chips are still present in the calcareous matrix of some oolitic ironstones (including completely chloritized stromatolitic algal-encrusted hard-grounds) whereas idiomorphic zircon and apatite crystals have been recorded from the most nearshore facies (Namur Syncline). In the organic-rich bottom ooze of the evaporitic lagoon relative high values of base metal trace elements (Cu, Zn, Pb) may be concentrated, due to the adsorption-precipitation by decaying algae (Renfro, 1974 ; Sonnenfeld *et al.*, 1977). Continued seepage and surficial inflow of seawater to the system (tidal-storm flooding) would have served to concentrate metals to levels higher than the range of bituminous shales (ibidem).

D. TRANSPORT

A downwarp finally provoked storm waves which transported all of the ferruginized allochems (derived from different suenvironments) by means of turbid surficial clouds, to more offshore areas of the open shelf. The highest concentrations of ferruginized allochems occur in the most nearshore (shallow subtidal) settings. The most offshore areas are only reached by the finest and lightest hematitic pigment.

The dispersed sulfides (Fe-Cu-Zn-Pb), which are preferentially associated to chloritic allochems in the highest part of each level, have probably been derived from the supposed supratidal coastal sabkha complex (Dreesen & Thorez, 1982 ; Dreesen *et al.*, 1982).

VI. DISCUSSION : THE PALEOGEOGRAPHIC SIGNIFICANCE OF UPPER DEVONIAN OOLITIC IRONSTONES IN THE ARDENNO-RHENISH AREA

The Upper Devonian (Frasnian-Famennian) Clinton-type oolitic ironstones are restricted to particular stratigraphical intervals, which represent periods of geotectonic activity in the Ardenno-Rhenish sedimentary basin (epeirogenic movements, synsedimentary volcanism ; Dreesen, 1982) (see fig. 8).

According to Borchert (1960) oolitic ironstones were preferentially formed during periods of minor post-orogenic crust movements. Epeirogenic movements occured during most of the "Nehden Stufe" (Fa1b-Fa2a), provoking eustatic sea-level fluctuations and subsequent storm waves. The latter have been responsible for the transport of nearshore ferruginized allochems and siliciclastics into the open shelf area.

Moreover the presence of oolitic ironstones (and associated redstained sediments) on the Franco-Belgian paleoshelf in the Upper Devonian, reflects periods of regression, probable emersion phases and stratigraphical hiatus.

Fursich (1971) reported condensed oolitic limestones (Calcaires à oolithes ferrugineuses) as final product in the formation of a complex hardground sequence in the Bajocian of the Normandy coast (N-France). In this sequence Stromatolites, oncoids and ferruginous ooids formed during long periods of nonsedimentation, surmounting an encrusted and bored hardground.

It is worth noting further that the Upper Devonian oolitic ironstones coincide frequently with stage boundaries (Givetian-Frasnian ; Famennian-Tournaisian ?), substage boundaries (Lower/Upper Famennian) and even less important unity boundaries (zones or formations) in the area studied. This would imply that (chrono-) stratigraphical limits have formerly been placed at important paleogeographic breaks and stratigraphical gaps. A more detailed investigation (micropaleontology-sedimentology) of the transitional beds between stages and substages of the Pre-Permian in Belgium and adjacent regions, might therefore lead to the discovery of other obscured stratigraphical gaps !

In consequence, a devaluation might be expected of some of the international stage boundary stratotypes in Belgium.

Sellwood & Jenkins (1975) and Hallam & Bradshaw (1979) have reported the relationship between occurences of oolitic ironstones and regression phases within the marine Jurassic sediments of England. The latter regressions were attributed to tectonically-controlled eustatic sea-level oscillations.

Van Houten & Karasek (1981) otherwise described shallow marine to deltaic sequences from the Upper Devonian of W-central Lybia (N-Africa), in which oolitic ironstones always appeared at the transition from a regressive to a transgressive phase. These oolitic ironstones coincided with an important decrease of detrital continental influx, which was subsequently followed by a marine transgression.

Franke & Paul (1980) recognized an analogous relationship between the occurence of red pelagic and hemi-pelagic shales (the so-called "Rotschiefer" and "Fosslei") and periods of decreasing detrital influx in the Famennian of the Rheinisches Schiefergebirge. These pelagic redbeds could even be used as marker beds in the Famennian throughout the Rhenish sedimentary basin, a phenomenon related by the authors to special temporary paleogeographic conditions within the geosynclinal basin. The red coloration required a minimum of about 1,5 °/o hematite. This pigment could only survive where organic supply to the sediment was too low to consume the available oxygen. This deficit of organic matter is attributed by the authors to oligotrophic conditions, which could have been brought about by decrease in continental afflux from the "Caledonian source areas". It is not a coincidence that these periods of decreased "continental" influx correspond to the intervals in which oolitic ironstones, turbidites and synsedimentary volcanics developed in the Ardenno-Rhenish sedimentary area.

The time-spatial relationship of oolitic ironstones and evaporites is also important. Coastal sabkha complexes certainly developed during the Upper Famennian, whereas evaporitic conditions were probably already present during the Lower Famennian of Belgium. The unexpected concentration of base metals (Cu-Zn-Pb) in the oolitic ironstones of the Belgian Famennian, may be related to the presence of evaporite-associated metalliferous deposits within a sabkha complex.

Brockamp (1942) already stated that : "oolitic iron formations ... formed between quartz-sand rich coasts and offshore areas accumulating silicate mud, near or just within latitudinal belts of contemporaneous salt sedimentation".

It is interesting finally that the questionable Charophyte Sycidium, which occurs in some Belgian Famennian oolitic ironstones, has frequently been associated with evaporites (Racki, 1982).

Oolitic ironstones and their laterally associated red sediments, represent thus important marker beds within the Pre-Permian south and east of the Brabant Massif. They reflect non-negligible stratigraphical breaks, regression periods and virtual stratabound metalliferous deposits in the "miogeosynclinal" sedimentary basin.

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Prof. G. King (K.U. Leuven) read the manuscript whereas Mrs. G. Willems, Mrs. H. Van Horenbeek, Mr F. Wuyts and Mr. J. Ferdinand provided technical assistance. They all owe my profound appreciation.

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ADDENDUM

In their comparative study of Famennian strata of the Theux region, the Vesdre Valley and the E-border of the Dinant Basin, DUSAR, M. & DREESEN, R., 1976 (Etude biostratigraphique du Famennien inférieur dans les environs de Theux. Ann. Soc. Géol. Belg., 99 : 1976, 571-586), considered the oolitic ironstones as diachronic marker beds. This misinterpretation is largely due to inaccurate sampling within each oolitic ironstone layer. Only the best part (= the most calcareous part) of each oolitic ironstone level has been sampled for conodonts. In this way, upper and lower parts of a same oolitic ironstone level, in different localities, appeared to be diachronic, with respect to the conodont zonation. A condensation of conodont zones within each level has therefore never been suspected.

PLATE I

1. Lambermont 6 b (level IV ; Vesdre Sycline) : irregular-shaped, bored (arrow) and algal-encrusted (hematite-stained stromatolitic algae) hardground, between a lower brachiopodal wackestone and an upper crinoidal wackestone. Extreme base of the Souverain-Pré Formation.
2. VRD-28-6c - acetate peel (base of level I ; Vesdre Syncline) : same sample as Plate II, fig. 4. Girvanellid algal mat, enveloped by stromatolitic algae, surmounted by non-sorted ferruginized allochems : ooids, pisolites/oncoids and coated bioclasts. Note perfect concentric structure of the pisolites/oncoids.
3. Hamoir-Tohogne 5 (level IIIb ; Dinant Synclinorium) : erosional unconformity (arrows) at the base of a concentration of chlorite coated/impregnated bioclasts (mainly rounded crinoid ossicles),within a pink fossiliferous (crinoids-brachiopods) wackestone.
4. Havelange borehole : 85,50 m (level IIIa ; Dinant Synclinorium) : pinkish irregular-based whole -fossil packstone (encrinite) with chlorite-impregnated crinoid ossicles, within a fossiliferous (biomicritic) wackestone.

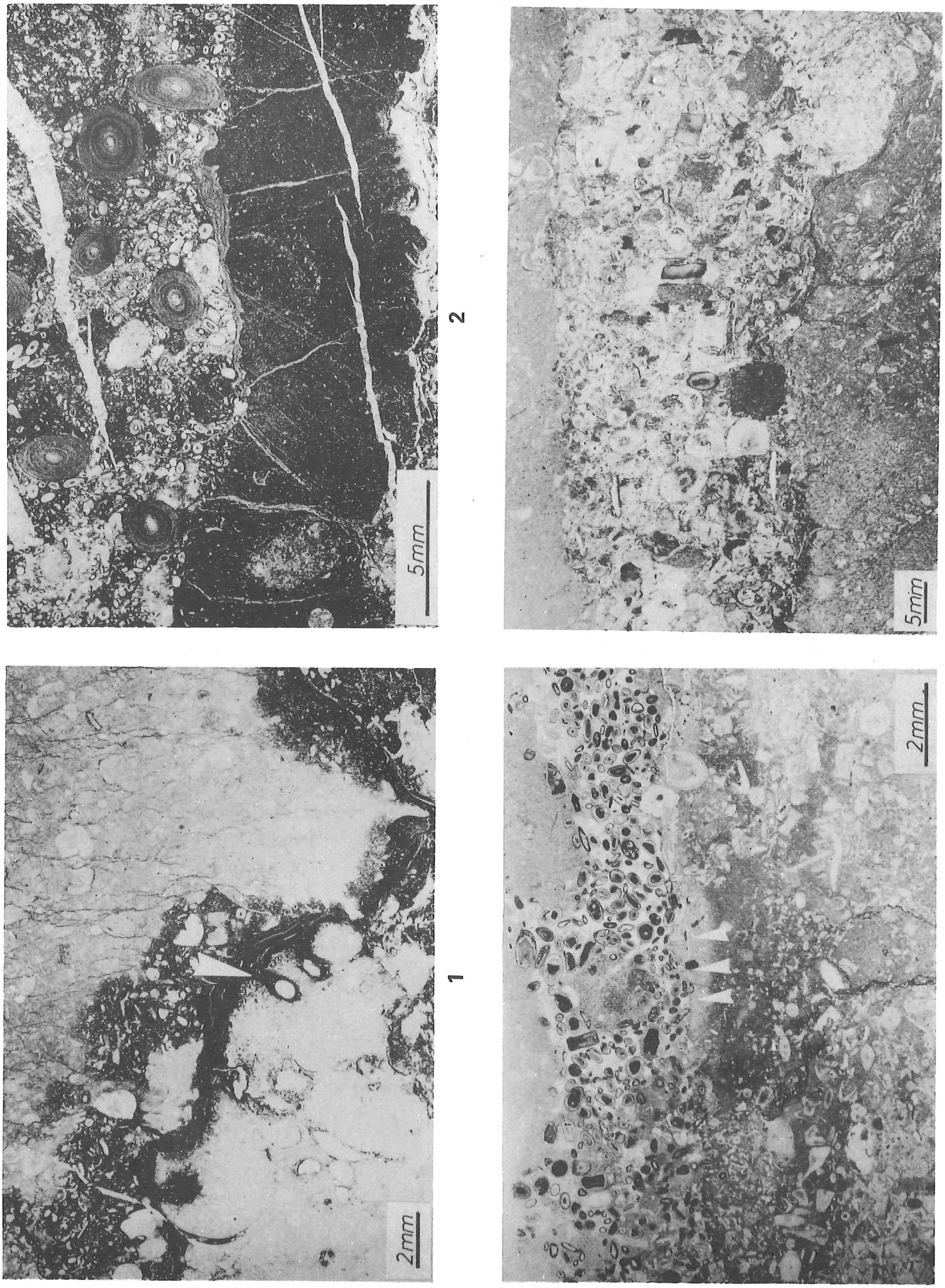
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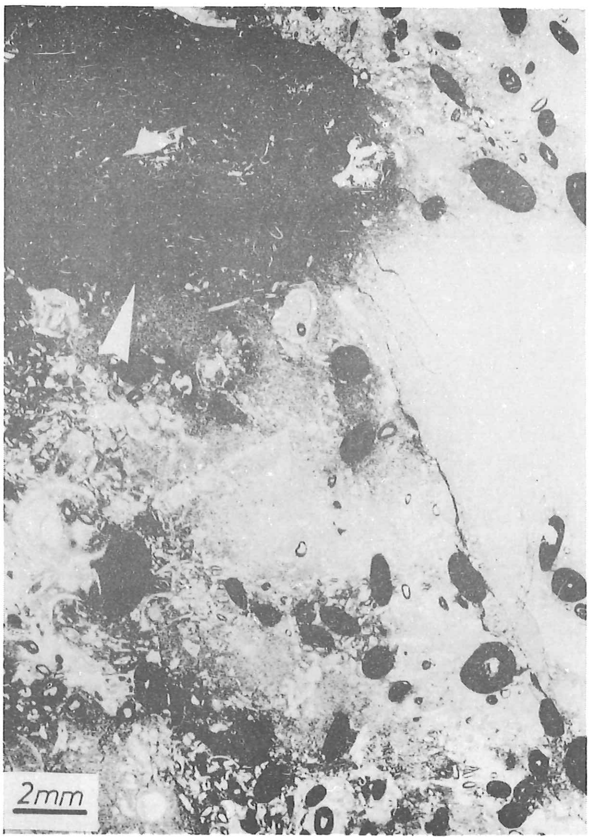
PLATE II

1. VRD-28-6b (level I ; Vesdre Syncline) : dispersed ferruginized (hematite) algal oncoids and ooids in a fossiliferous wackestone. In upper left corner (arrow) flattened algal oncolite with interlayered sessile foraminifera.
2. VRD-28-6b (level 1 ; Vesdre Syncline) : deformed algal oncolite (top left) and dispersed algal oncoids, ooids and coated bioclasts in a pink- to red-stained fossiliferous wackestone. Small-scale calcite-infilled fissures. Note the elongation of the algal oncoids parallel to local schistosity.
3. Limbourg 2 (level IIIa ; Vesdre Syncline) : ferruginized (hematite) algal-encrusted intraclast and concentrations of ferruginzed coated bioclasts and ooids within a fossiliferous wackestone.
4. VRD-28-6c (base of level I ; Vesdre Syncline) : basal unconformity, overlain by a pink-stained girvanellid algal mat (arrow) (note microstromatolitic algal envelop at bottom right) followed by a non-sorted variety of ferruginized allochems (ooids, pisolites and coated bioclasts).



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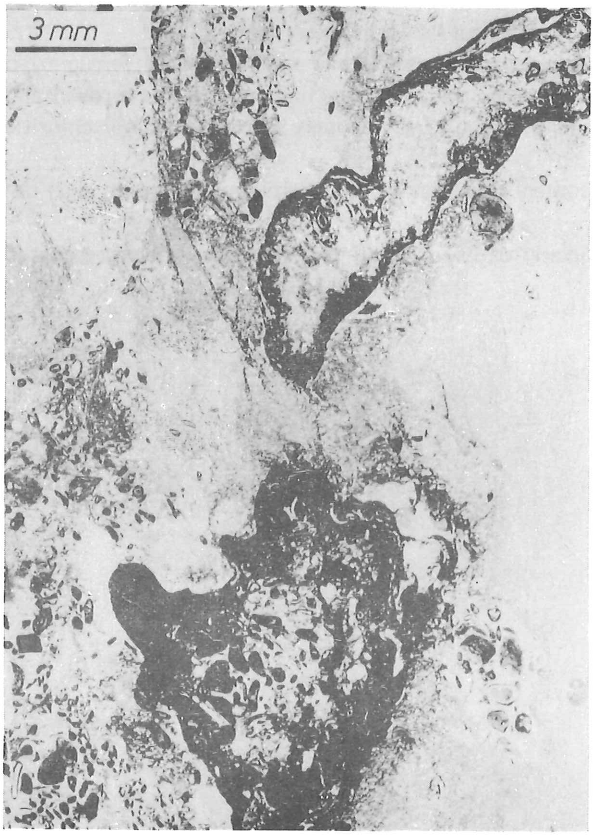

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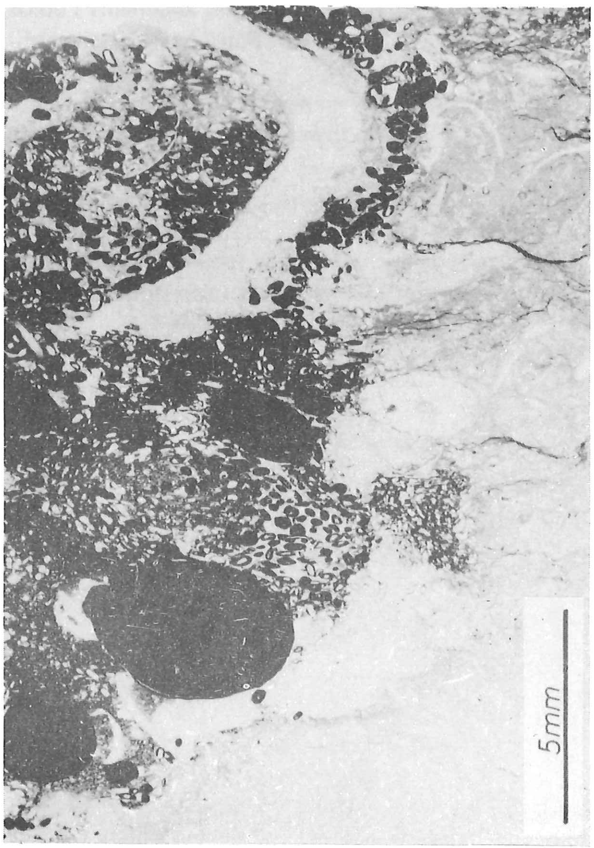
PLATE III

1. Drolenval 3a (base of level I : Vesdre Syncline) : basal erosional unconformity surmounted by non-sorted heterogenous ferruginized allochems (superficial ooids, algal oncoids). Brachiopod shell in upper right corner.
2. VRD-28-6a (top of level I ; Vesdre Syncline) : red-stained biomicritic wackestone with dispersed ferruginized (hematite) allochems : coated bioclasts (brachiopod shells, ostracods, crinoids) ; cephalopods (lower arrows) and rugose corals? (upper left arrow) are frequent. In upper half of the picture, strongly dispersed mainly chloritic allochems.
3. VRG-28-20 (base of level I ; Vesdre Syncline) : big algal- coated intraclast of fossiliferous wackestone, algal oncoids and ooids ; small-scale calcite-infilled fissures.
4. VRD-31-8b (level IIIa ; Vesdre Syncline) : intraclast (plasticlast) of ferruginized stromatolitic algal mat ; coated bioclasts are cemented within the outer hematitic algal tissue.



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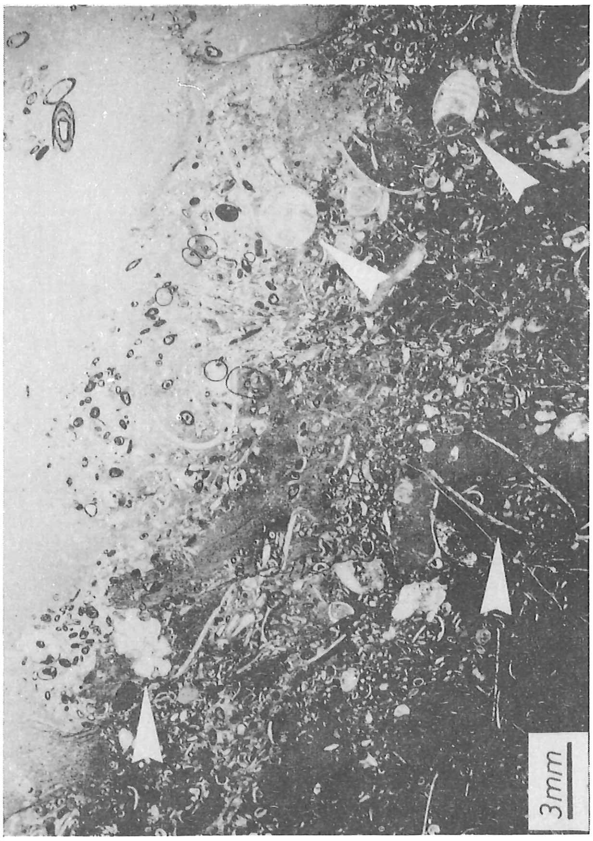

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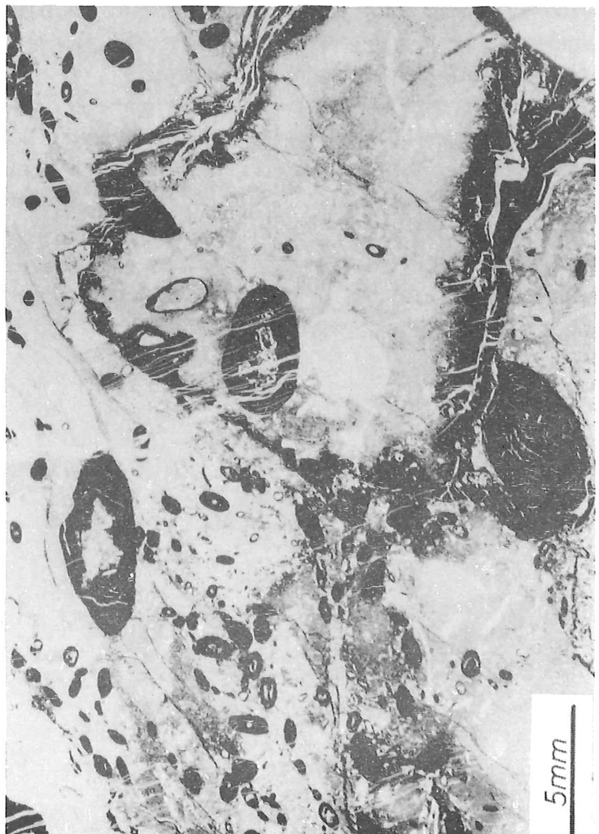

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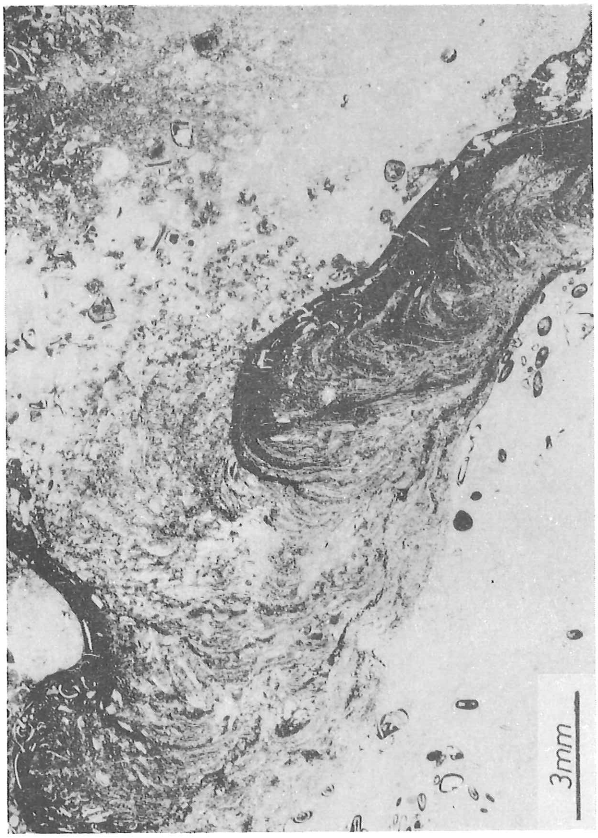

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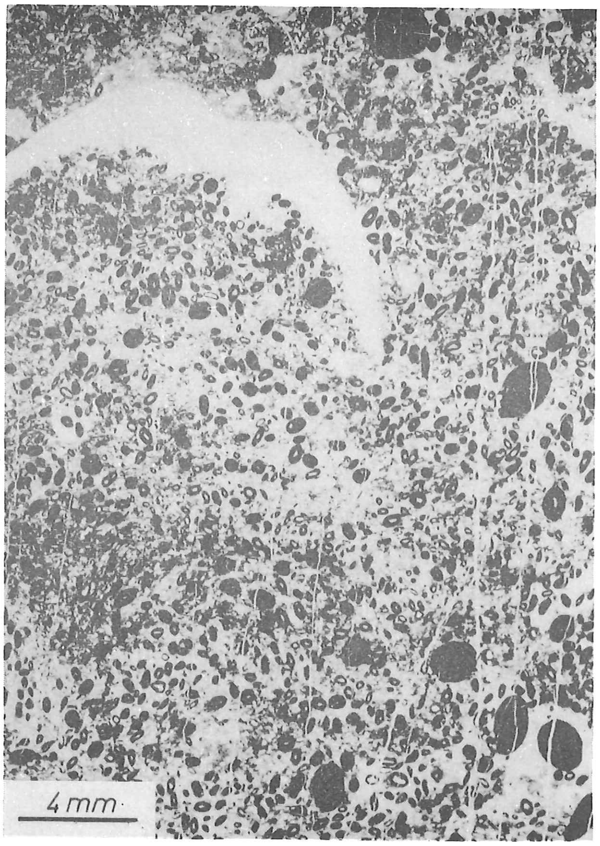
PLATE IV

1. VRD-27-2 (top of level I ; Vesdre Syncline) : non-sorted heterogenous ferruginized (hematite) allochems : ooids, algal oncoids, in a fossiliferous wackestone (note brachiopod shell in upper left corner). Small-scale calcite-infilled fissures run perpendicular to stratification.
2. Drolenval 3b (top of level I ; Vesdre Syncline) : ferruginized algal oncoids (nuclei composed of detrital or skeletal grains). Typical algal oncoids with interlayered sessile foraminifera are visible in lower part of section ("*Osagia*" type algal-oncoids). Note the distorted oncoids due to local schistosity.
3. Drolenval 10 (level IIIa ; Vesdre Syncline) : strongly dispersed ferruginized allochems : ooids, coated bioclasts (crinoids, ostracods) in a fossiliferous wackestone. Note presence of rugose coral (arrow).
4. VRG-30-2 (level IIIb ; Vesdre Syncline) ; concentration of slightly ferruginized allochems (chlorite-impregnated/ coated crinoid ossicles) in a biomicritic wackestone. Note pressure-solution in lower part (packstone) and incipient graded bedding upwards.



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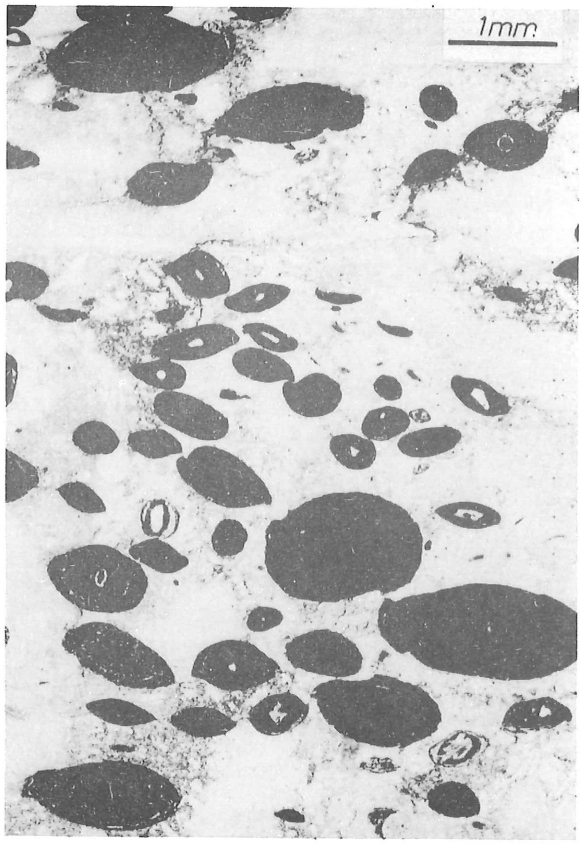

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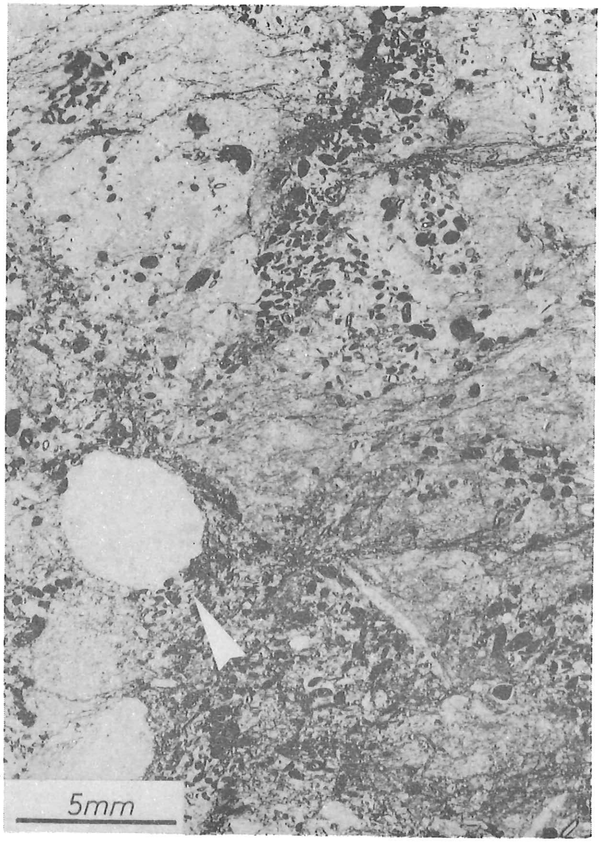

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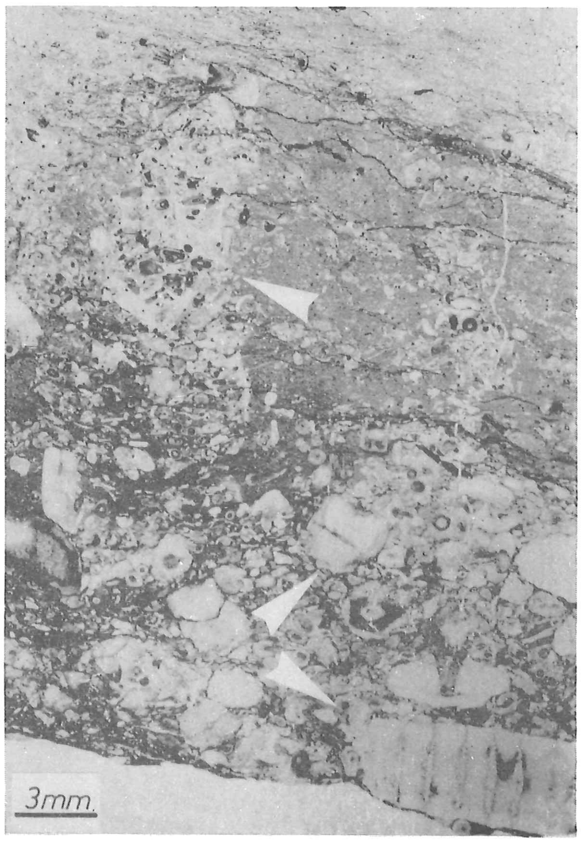

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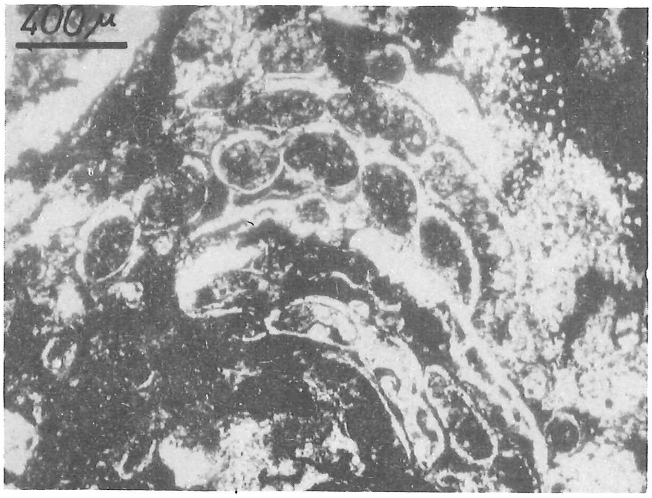
PLATE V

1. VRG-30-2 (level IIIb ; Vesdre Syncline) : particular ferruginized allochems (from bottom right to upper left) : Charophycean-like oogonium as nucleus of a superficial ooid (note the chloritic nucleus and the chlorite-infilled pores) ; irregular colonies of encrusting foraminifera (related to Aphralysia) and bored gastropod shell infilled with algal colonies.
2. VRD-31-8b (level IIIa ; Vesdre Syncline) : bored ostracod shells as nucleus of a hematitized superficial ooid.
3. VRG-30-8c (top of level IIIa ; Vesdre Syncline) : ferruginized superficial ooids and coated bioclasts ; note the strongly bored crinoid ossicle in the centre.
4. VRD-31-8b (idem level) : wacke/packstone with ferruginized rounded bioclasts (crinoids, brachiopod shell fragments) and particular superficial ooids (charophycean-like oogonia) at the left.
6. Silenrieux-Chapelle St Anne (level IV ; Dinant Synclinorium) : typical "pseudo-ooids" : slightly-coated rounded bioclasts : mainly crinoid ossicles, bryozoans, ostracods and Umbellinae (arrow). Biosparitic wacke/packstone.



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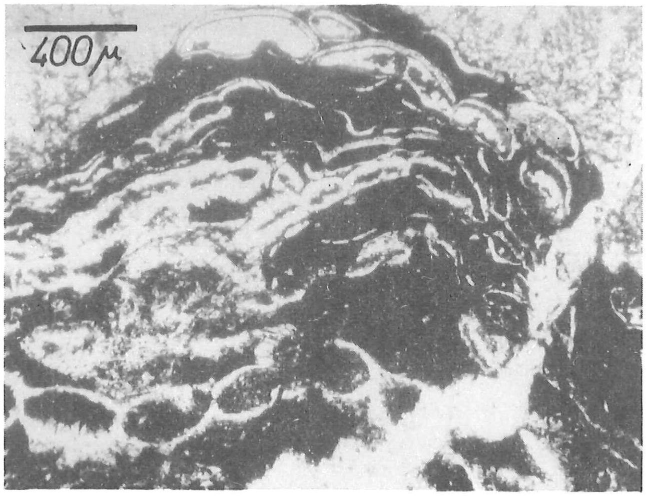

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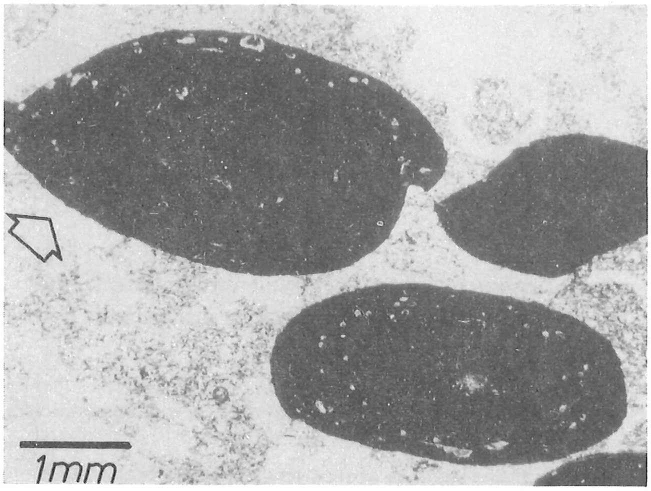

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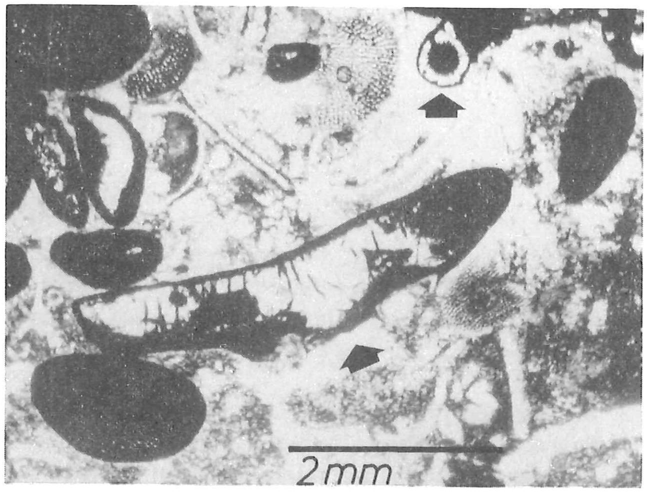

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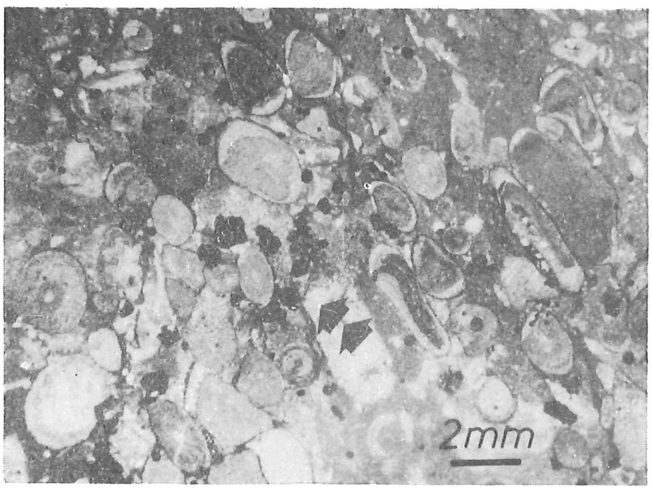

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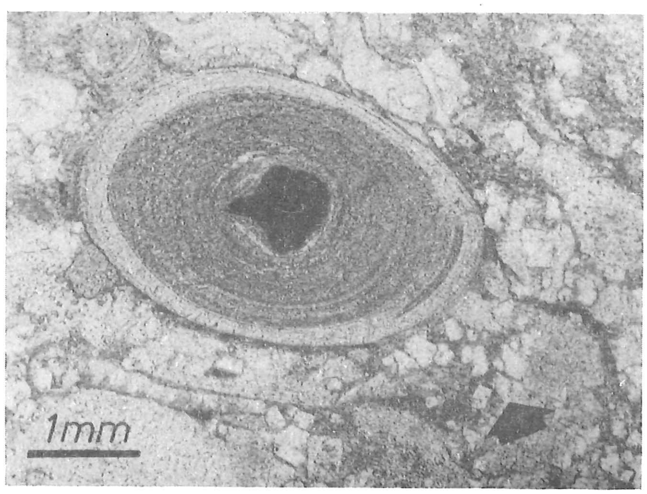

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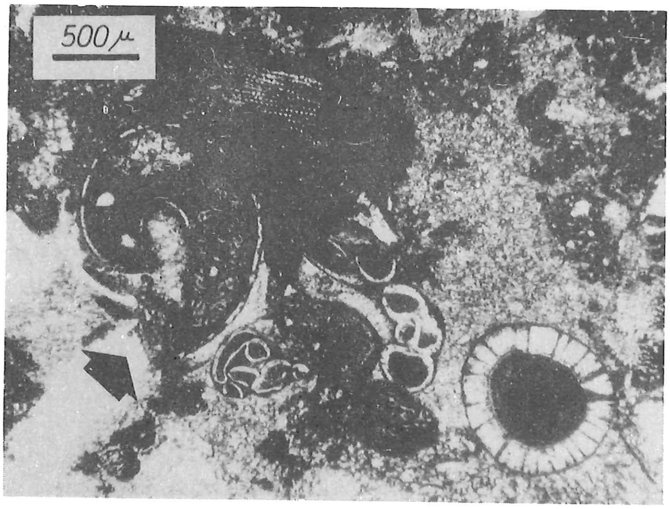
PLATE VI

1. VRD-31-8b (level IIIa ; Vesdre Syncline) : chaplet-like colonies of encrusting (sessile) foraminifera (related to the genus *Aphralysia).* The outer micritic wall is preferentially ferruginized whereas the main wall is sparitic with fine pores.
2. idem.
3. Drolenval 3b (top of level I ; Vesdre Syncline) : slightly deformed algal oncoids with interlayered sessile foraminiferal colonies ("*Osagia*" - type algal oncoids).
4. Limbourg 2 (level IIIa ; Vesdre Syncline) : hematite-coated/impregnated bioclasts with strongly bored brachiopod shell (centre) and a questionable hematite-infilled Charophycean-like oogonium (arrow).
5. VRG-30-2 (level IIIb ; Vesdre Syncline) : concentration of chlorite-coated/impregnated rounded bioclasts (crinoid ossicles). Black polygons (arrows) are idiomorphic sulfides. Wacke/packstone.
6. VRD-28-6a (top of level I ; Vesdre Syncline) : chloritic pisolite with opaque nucleus ; differences in color reflect differences in iron content of the concentric layers. Note incipient dolomitization (arrow).



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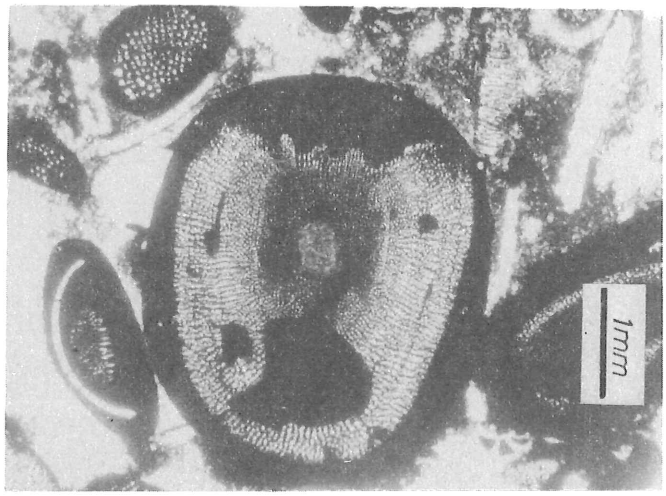

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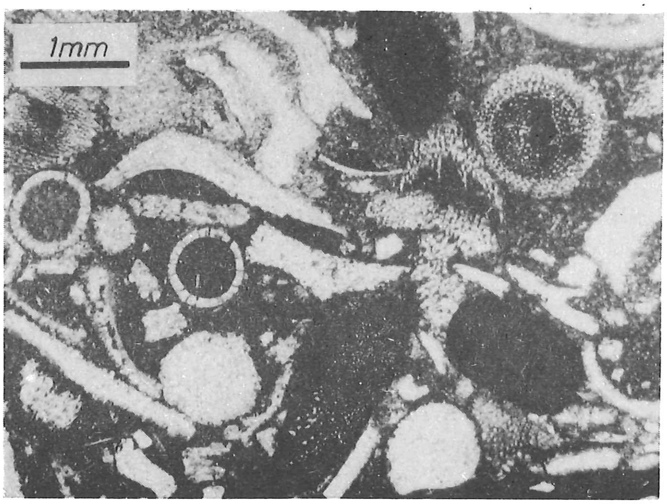

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