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A MODEL OF A REGRESSIVE DEPOSITIONAL SYSTEM AROUND THE OLD RED CONTINENT AS EXEMPLIFIED BY A FIELD TRIP IN THE UPPER FAMENNIAN "PSAMMITES DU CONDROZ" IN BELGIUM

by

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(40 figures)

ABSTRACT. - A detailed and pluridisciplinary case study of the "Psammites du Condroz" resulted in a paleogeographical model for the Upper Famennian in the eastern part of the Dinant Synclinorium, South of the London-Brabant High.

This model illustrates the complex interplay of paleoclimatological, paleohydrodynamical, paleoecological and tectono-sedimentary events in a nearcoastal, shallow siliciclastic shelf setting (the Ardenne shelf). Eleven sedimentary phases clearly demonstrate the complex progradational style of the Group and the influence of synsedimentary tectonic activity (block tilting).

The overall progradation of nearshore mega-environments to the South and the Southwest reflects a major regressive event during the late Famennian.

The bulk of the studied sediments is composed of well-sorted, fine-grained arkosic sands, which originated through a current-induced destruction of delta lobes located outside the studied area and a subsequent transport of the prodelta sands towards the shelf. Short-term transgressive pulses episodically interrupted the regressive megasequence, allowing the temporary development of protected shelf carbonates. Subsequently these carbonates became reworked by longshore currents, storm waves and density currents, producing characteristic sandy, nodular limestone facies.

Very locally, important accumulations of crinoidal debris formed incipient carbonate buildups, the mounding sites of which are linked to the presence of deep-seated faults (block-faults).

Only exceptionally, algal-sponge-crinoidal mud mounds could develop during a temporary waning of the siliciclastic supply and local favourable ecological conditions : these "Baelen-type" mounds represent the only reef-like structures known so far in the Upper Famennian of the Ardenno-Rhenish Massif, after the Frasnian-Famennian boundary reef extinction.

RESUME. - L'étude détaillée et pluridisciplinaire des "Psammites du Condroz" a permis l'élaboration d'un modèle paléogéographique pour le Famennien supérieur dans la partie orientale du Synclinorium de Dinant, au sud du Massif Brabant-Londres.

Ce modèle illustre les interférences complexes entre la paléoclimatologie, le paléohydrodynamisme, la paléoécologie et les événements tectono-sédimentaires marquant un "shelf" proche du rivage et de faible profondeur d'eau, réceptacle de sédiments siliciclastiques (le Shelf ardennais). Pour le Groupe des Psammites du Condroz, onze phases sédimentaires successives s'inscrivent suivant un style de progradation complexe et y impliquent l'influence d'une activité tectonique synsédimentaire (basculement de blocs).

La progradation complète des méga-environnements côtiers vers le sud et le sud-ouest correspond à un événement régressif majeur durant le Famennien terminal.

Le matériau sédimentaire, composé de sables arkosiques fins et bien classés, résulte de la destruction, par les courants, de lobes deltaïques en dehors de la zone étudiée, ainsi que du transport de ces sables prodeltaïques vers le "shelf". Des pulsations transgressives épisodiques interrompent la mégaséquence régressive en permettant le développement temporaire de carbonates de "shelf" protégé. Ces carbonates furent ensuite remaniés par les courants côtiers, par les vagues de tempête et par les courants de densité en produisant un faciès nodulaire (calcaire sableux) caractéristique.

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Tout à fait localement, d'importantes accumulations de débris de crinoïdes ont formé des structures carbonatées en voie de développement dont la localisation est pilotée par le rejeu de failles profondes ("block-faulting").

Exceptionnellement, des "mud mounds" (monticules de boue calcaire) à algues, éponges et crinoïdes se sont développés de manière temporaire à l'occasion d'apports déclinants de siliciclastiques et grâce à des conditions écologiques locales favorables. Les "mounds" de Baelen représentent les seules structures récifales connues dans le Famennien supérieur du Massif ardenno-rhénan et se placent après l'extinction des récifs à la limite Frasnien-Famennien.

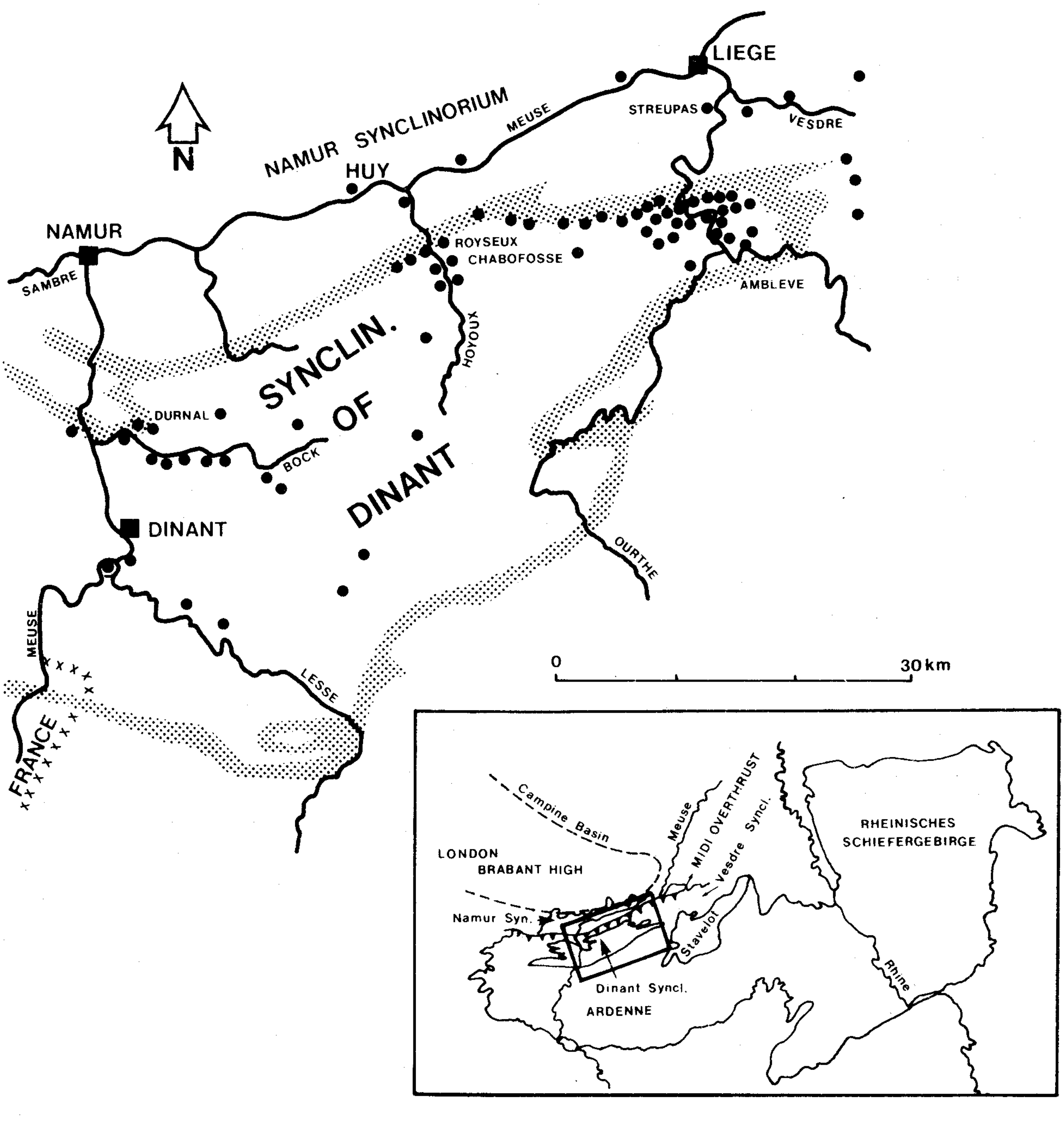

Figure 1. - Location map of the river valleys and studied outcrops in the eastern part of the Dinant Synclinorium and in the Vesdre Synclinorium. The stippled band represents the limits of exposure of the Famennian rocks in the eastern part of the Dinant Synclinorium

INTRODUCTION

The Famennian stage in Belgium represents the sudden insertion of several hundred meters of siliciclastics in between two widespread and thick transgressive carbonate sequences on the Condroz Platform, South of the London--Brabant High. The latter was fully emerged during the Famennian (Fig. 1). The two carbonate sequences correspond to the Frasnian and Dinantian. Their transition to the Famennian siliciclastics is characterized by mixed siliciclastic-carbonate series : shales and nodular shales in the topmost Frasnian (Matagne Shales), and alternating shales and limestone in the basal Tournaisian.

During the last two decades, numerous investigations have been carried out on the litho- and biostratigraphy as well as on the sedimentology and paleogeography of the Upper Famennian "Psammites du Condroz", particularly in their type-area : the eastern part of the Dinant Synclinorium (Fig. 1). Multidisciplinary studies and teamwork have resulted in the proposal of a new litho- and biostratigraphic framework encompassing the "Psammites du Condroz" in both the eastern part of the Dinant Synclinorium and the Vesdre Synclinorium (Becker, Bless, Streel & Thorez, 1974; Bouckaert, Streel & Thorez, 1968; Bouckaert & Streel (Eds), 1974; Dreesen, 1976, 1978, 1982; Dreesen, & Dusar, 1975; Dusar & Dressen, 1976, 1984; Dreesen & Thorez, 1980, 1982; Dreesen, Bless, Conil, Flajs & Laschet, 1985; Goemaere, Thorez & Dreesen, 1985; Thorez, 1964a, 1969; Thorez, Streel, Bouckaert & Bless, 1977; Thorez, Dreesen & Goemaere, 1985).

Although many problems remain unsettled, in particular those related to a comparable stratigraphical and sedimentological reconstruction for the "Psammites du Condroz" in the Namur Syncline and in the western part of the Dinant Synclinorium, the amount of data already obtained allows a reliable paleogeographic interpretation of the depositional environments (at different scales of the depositional system) into a larger scope that includes the Upper Famennian of Belgium and Germany (Paproth, Thorez & Dreesen, 1986). This paleogeographic interpretation bridges, for the first time, the Condroz and the German Platforms, and emphasizes some common tectonic characteristics.

1. - GEOGRAPHIC AND TECTONIC SUMMARY

The "Psammites du Condroz" Group is well--exposed South of the London-Brabant High in three main tectonic units : the allochtonous Dinant Synclinorium, the Namur and Vesdre Synclinoria (Fig. 1). Outcrops also exist in the well-known "Theux Window" of the Stavelot-Venn High.

The Dinant Synclinorium is separated from the other synclinoria by the Midi-Eifel-Aachen Overthrust. The importance of the latter remains a matter of debate among geologists. There is still a general disagreement about the most appropriate model. Some authors suggest a maximum shortening of some 10-15 Km between the allochthonous Dinant Synclinorium and the autochthonous Namur Syncline (i.e. Michot, 1980). Other geologists accept a shortening of more than 100 Km (Bless, Bouckaert & Paproth, 1983) as expressed within the concept of the Dinant Nappe(s). The choice of one of the hypotheses might have, of course, immediate implications for the paleogeography of the "Psammites du Condroz".

Adopting a shortening of 100 Km for the overthrust - the latter having found its acme during the Asturian phase - would imply the impossibility to match a complete lateral extension of facies over the area, originally comprising an "extended" Namur Syncline and the Dinant Synclinorium. On the other hand, as demonstrated in this paper, rapid changes of thicknesses and of facies are the rule in the "Psammites du Condroz" and this condition hampers all direct appreciation of the importance of the shortening.

2. - STRATIGRAPHIC SUMMARY

The lithostratigraphic framework of the "Psammites du Condroz" (Bouckaert, Streel & Thorez, 1968; Thorez, Streel, Bouckaert & Bless, 1977) matches the recommendations of Hedberg's code referring to Formations and Members. The newly proposed stratigraphic scheme (Fig. 2) has not yet been adopted by the Devonian Stratigraphic Committee of Belgium. It is based on biozonations and ecozonations for spores, conodonts, ostracodes and, locally, on foraminifera (see Fig. 2 and 3 in Streel, 1986), and clearly demonstrates the diachronism of facies of the different Formations in the "Psammites du Condroz". The combination of sedimentology and biostratigraphy shows that the classic "layer-cake" lithostratigraphic scheme (still used by Belgian geologists) must now be completely abandoned. The biostratigraphic and lithostratigraphic framework, as presented in Figure 2, has been essentially based on studies in the eastern part of the Dinant Synclinorium; it can, however, be extrapolated to the neighbouring areas of the Namur Syncline and the Vesdre Synclinorium.

For the purpose of the International Symposium on Micropaleontological Limits held in Namur in 1974 (Bouckaert & Streel, eds), a micropaleontological grid was proposed not only for the Famennian, but for practically the entire Devonian and Dinantian in Belgium. A total of 13 biostratigraphic levels has been introduced and numbered from 31 to 44 for the Upper Famennian "Psammites du Condroz". These so-called Micropaleontological Guide Marks (mgm) combine the above quoted microfossil range into an intercalibration of multiple zonal schemes for both local and intrabasinal correlations. This reference grid has been the main

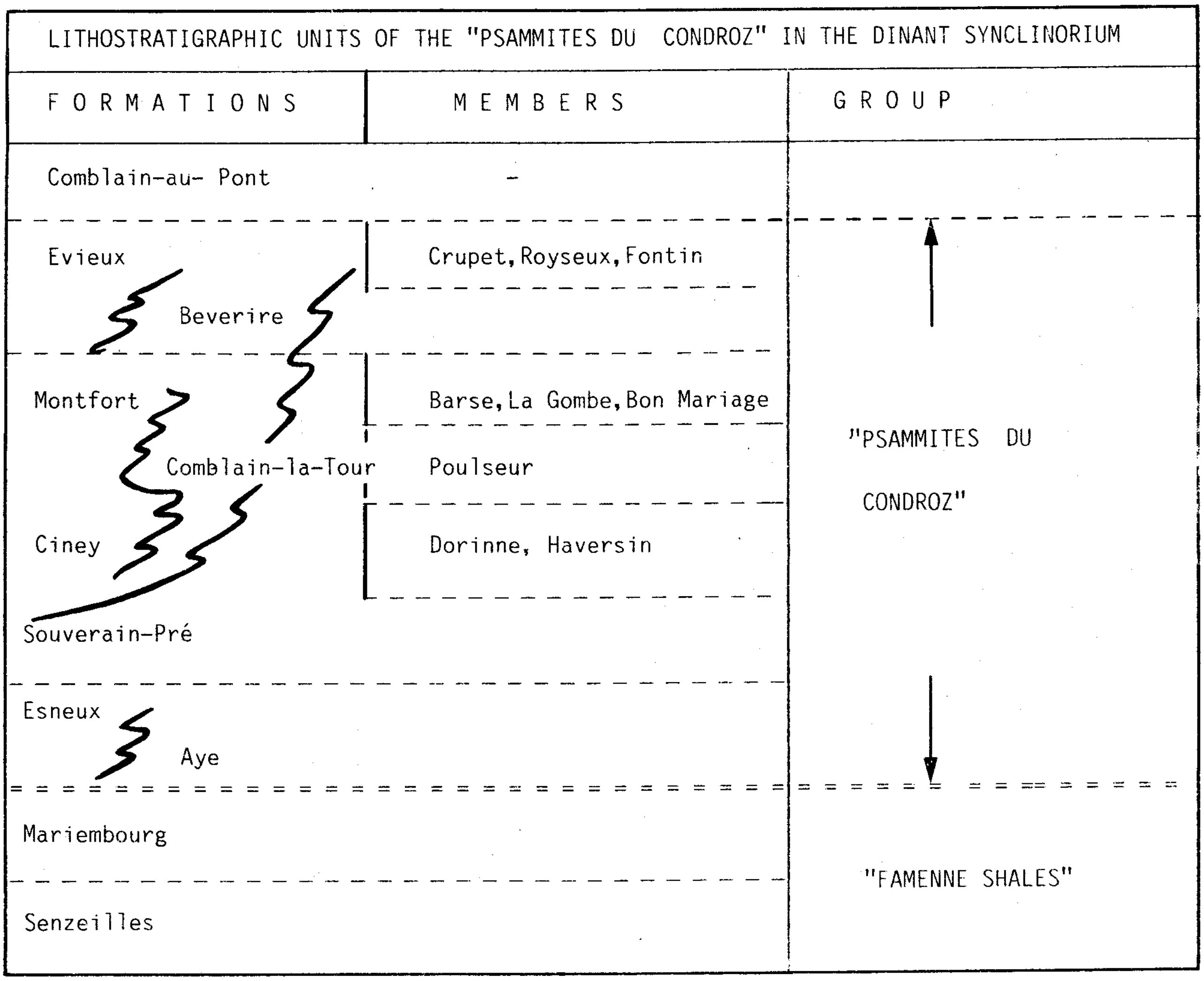

Figure 2. - General lithostratigraphic scheme for the Upper Famennian "Psammites du Condroz" in the eastern part of the Dinant Synclinorium. (Thorez, Streel, Bouckaert & Bless, 1974).

inter-regional (valley-to-valley) correlation tool on which the paleogeographic model for the "Psammites du Condroz" has been based (Thorez, Streel, Bouckaert & Bless, 1977).

Such an intercalibration of multiple zonal schemes has appeared necessary because of : the rapid lateral and vertical lithological changes, even within a single valley (such as the classic Ourthe valley); the local lack of appropriate lithologies for microfossil studies (i.e. the absence of crinoidal limestone bearing conodonts); the complex tectonic character of the outcrops (with succession of anticlines and synclines) within the Dinant Synclinorium, and the occurrence of several longitudinal faults; and, eventually, the diachronic nature of the series at the scale of the Formations and within the latter (as exemplified by the Ourthe valley, Figs. 3 and 4), that affects both the stratigraphic and the paleogeographic reconstructions.

Furthermore, local correlations within the different valleys (Ourthe-Amblève, Hoyoux, Bocq, Meuse and Lesse) (Fig. 1) can be controlled by using local and regional marker-beds : redbeds and "ball-and-pillows" (Thorez, 1969). The latter, in particular, crosscut all kinds of facies and, consequently, the depositional environments comprised between two biostratigraphic levels.

The combination of all these correlation tools provided the stratigraphic framework for the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium, where over 65 outcrops and quarries have been thoroughly investigated between the top of the Esneux Sandstones (mgm 32), and the base of the Strunian (mgm 44). This allows a slice-by-slice paleogeographic reconstruction comprising 11 successive sedimentary phases. Three of these are presented in Paproth, Dreesen & Thorez (1986) and interest the Lower *P. rhomboidea* (32), Lowermost *S. velifer* (36) and *VCo* (40) zonal bases over a broader area, that not only comprises the eastern part of the Dinant Synclinorium but also the Vesdre Synclinorium and coeval series in the Federal Republic of Germany. Detailed paleogeographic reconstructions for 7 of the 11 sedi-

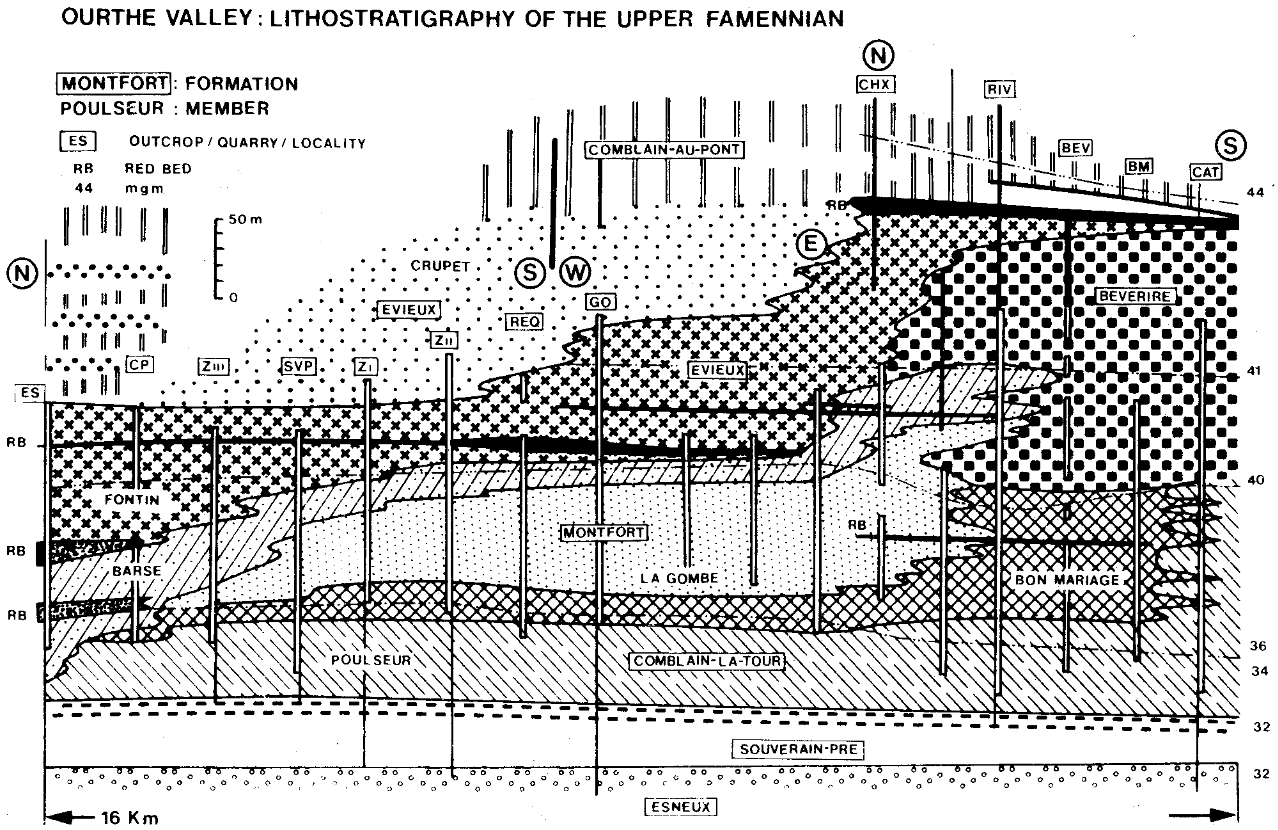

Figure 3. - Lithostratigraphic scheme of the Upper Famennian "Psammites du Condroz" in the classic Ourthe valley, South of Liège (northeast corner of the Dinant Synclinorium). Biostratigraphic interval 32 to 44.
The following Formations (and related Members) are shown from base to top : Esneux, Souverain-Pré, Comblain-la-Tour (Poulseur Member), Montfort (Bon Mariage, La Gombe and Barse), Evieux (Fontin and Crupet) Beverire, and Comblain-au-Pont. (Thorez, 1969; Becker *et al.*, 1974).

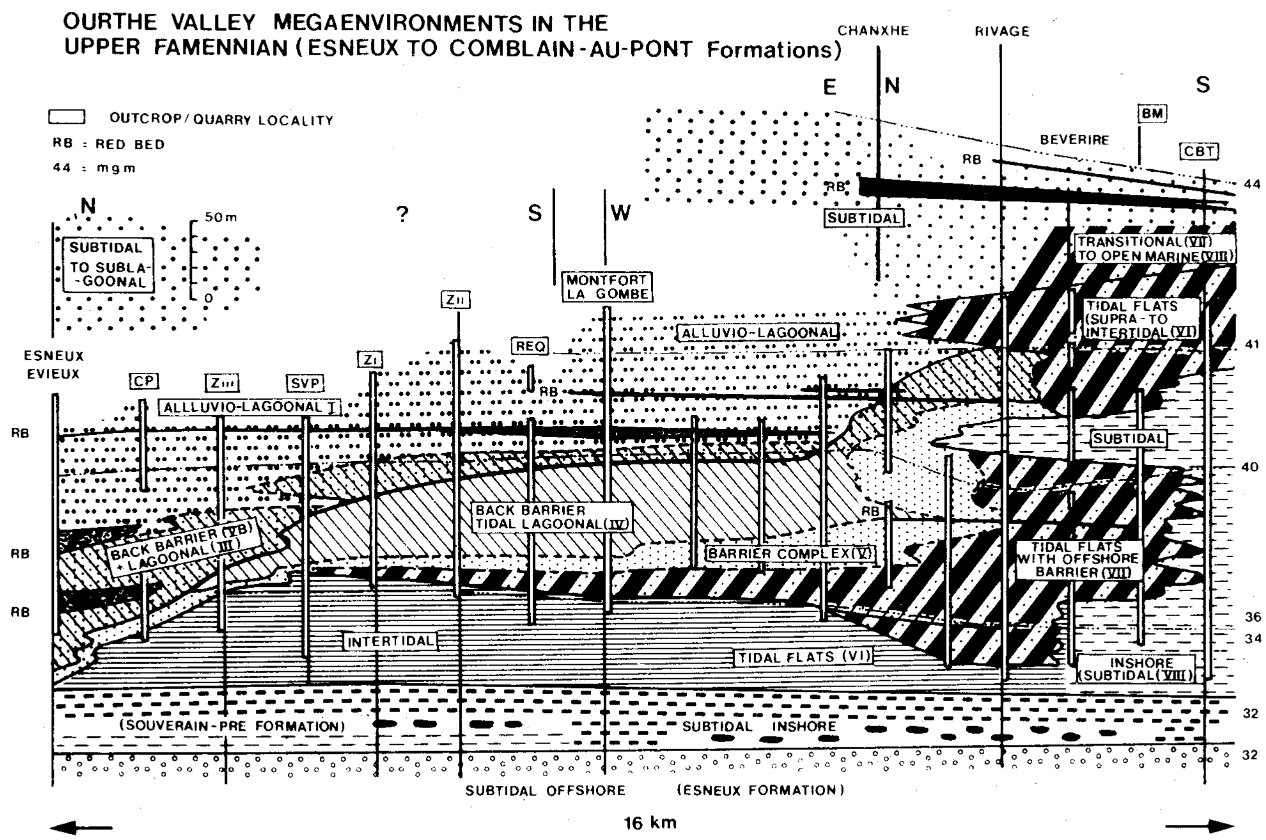

Figure 4. - Lateral and vertical association of megaenvironments of the "Psammites du Condroz" in the Ourthe valley, South of Liège (to be compared with the corresponding lithostratigraphic framework, Figure 3) (THOREZ, 1969).

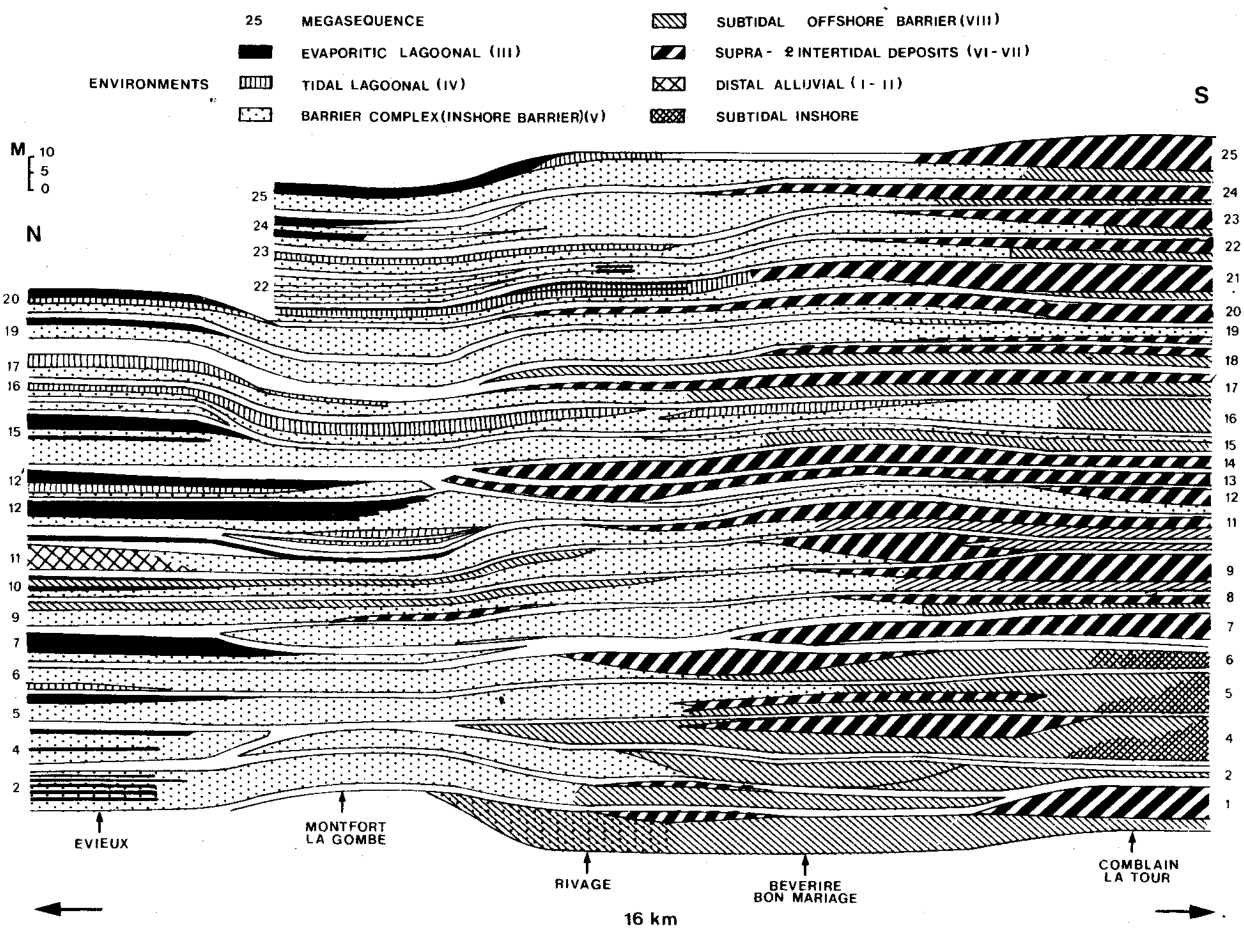

Figure 5. - Major rhythms and depositional environments in the upper Famennian (Montfort Formation) in the Ourthe valley.

mentary phases are given in the present paper, but are palinspastically reconstructed and restricted to the eastern part of the Dinant Synclinorium.

3. - COMPOSITION OF THE SEDIMENTS

The bulk of the "Psammites du Condroz" is composed of well-sorted, fine-grained, arkosic sandstones. The mean grain size oscillates between 45 and 120 μm. The siliciclastics are differently enriched in micas (muscovite-biotite flakes) and chlorite. The latter character is responsible for the occurrence of internal bedding stratification. The feldspar content is of about 25 °/o in the Montfort Formation and increases to more than 50 °/o in the youngest Formations, Evieux and Beverire, before decreasing to 5 °/o in the Strunian. Beside arkosic sandstones, there exists also siltstones and mudstones bearing the same lithological characteristics, in particular the high amount of fresh feldspars; these comprise plagioclase (albite-oligoclase), orthoclase some microcline and about 5 °/o of micro- or mesoperthite (Thorez, 1969).

However, other lithologies are represented and comprise carbonates (limestones and dolomites), and various mixed siliciclastic-carbonate rocks.

Limestones always show some siliciclastic contamination and - according to their petrographic characteristics - belong to lime mudstones, wackestones, packstones and grainstones. Their microfossil content comprise Ostracods, Girvanellids (Algae), Umbellinaceans, Foraminifera, associated with Brachiopods and Crinoids. Practically all limestones are indicative for open marine conditions. However, some lime mudstones, containing well-preserved thin-shelled Ostracodes along with some oncoids and stromatolites, rather suggest sublagoonal environments.

By their fine grain-size (around or below 5 μm), the dolomite appears as the product of evaporation processes within lagoonal pans (Thorez, 1969; Goemare *et al.*, 1986). The sediment suggests "primary" (early diagenetic) dolomite, and is devoid of any fossil.

The dolomite stage has been reached penecontemporaneously with the sedimentation and well before the burial. This is supported by the frequent occurrence of reworked millimetric to centimetric dolomite pebbles (intraformational conglomerate) in the directly overlying arkosic sandstone beds. These pebbles show the same petrographic characteristics as those of residual dolomite beds found laterally. The "prin-

MEGAENVIRONTMENTS IN THE UPPER FAMENNIAN OF THE HOYOUX VALLEY

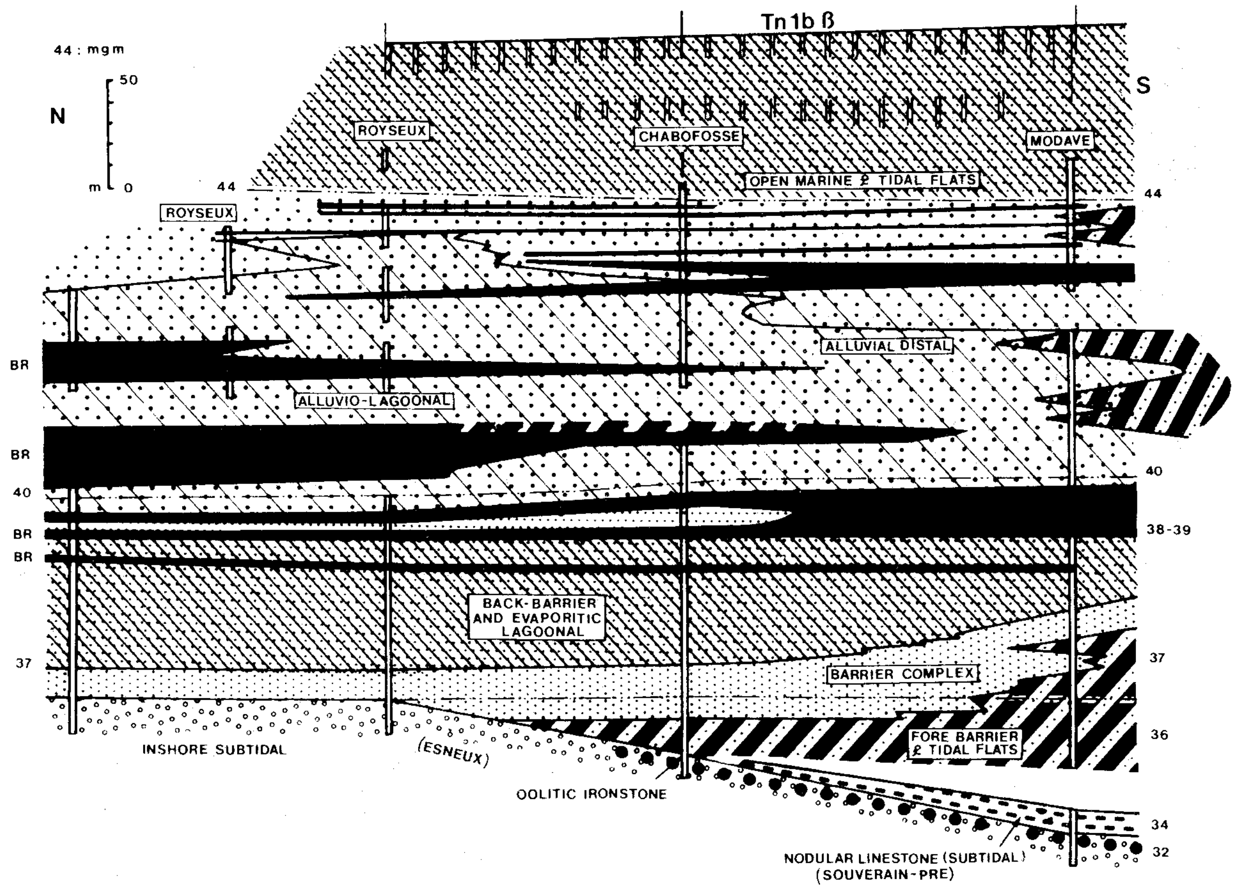

Figure 6. - Lateral and vertical association of megaenvironments of the "Psammites du Condroz" in the Hoyoux valley in the biostratigraphic interval 32 to 44 (Thorez, 1969).

mary" character of the dolomite is also supported by the close association of this sediment with still preserved or pseudomorphosed sulfate (anhydrite or gypsum) occurring as thin beds or as "nodules" within the dolomite.

Mixed lithologies consist of a siliciclastic skeleton with a carbonate (calcareous or dolomitic) contaminated by quartz, feldspars, micas and/or mud. Mixed siliciclastic-dolomitic material bears either a fine-grained dolomite exhibiting the same petrographic character as in the pure dolomite beds (with a dusty nucleus and a rather subrounded form) or hyaline, xenomorphic crystals set intergranularly in a winnowed sandstone. In the former case, the dolomitic mud produced in the lagoonal pans has possibly percolated through the porous siliciclastics. In the later case, the dolomite has precipitated within the pores of the winnowed sands through an evapotransporation of Mg-rich brines. Early - dolomitized ostracodal micrites are very rarely found and were occasionally encountered in some beds of the youngest formation in the Bocq valley. Another mixed dolomitic-siliciclastic material - frequently found in the Hoyoux and in the northern part of the Ourthe valleys - concerns micaceous dolomites. Here the micrometric dolomitic material is associated with micas settled either as separated millimetric layers or intimately mixed with the dolomite.

Mixed calcareous-siliciclastic materials comprise the same microfacies as that of purer limestone types. They show both sandy wackestones, packstones and grainstones with brachiopods and pelecypods, bryozoans, thick-shelled ostracodes, conodonts, Umbellinaceans and Girvanellids. The algae often coat or encrust rounded bioclasts, producing cortoids or primitive algal oncoids. Some of these mixed microfacies contain Foraminifera (Tournayellids and Endotyrids) (Bouckaert, Conil & Thorez, 1964). This lithotype occurs as centimetric to decimetric laterally persistent or lenticular beds, or as nodules (angular to subrounded intraclasts). Sandy lime mudstones contain thin-shelled ostracodes, and are often cryptalgal and sometimes peloidal with cryptalgal cavities. These biomicrites usually form tiny millimetric to centimetric, rather continuous beds on top of dark mudstones. Locally they contain abundant Umbellinaceans (Tectocharophytes).

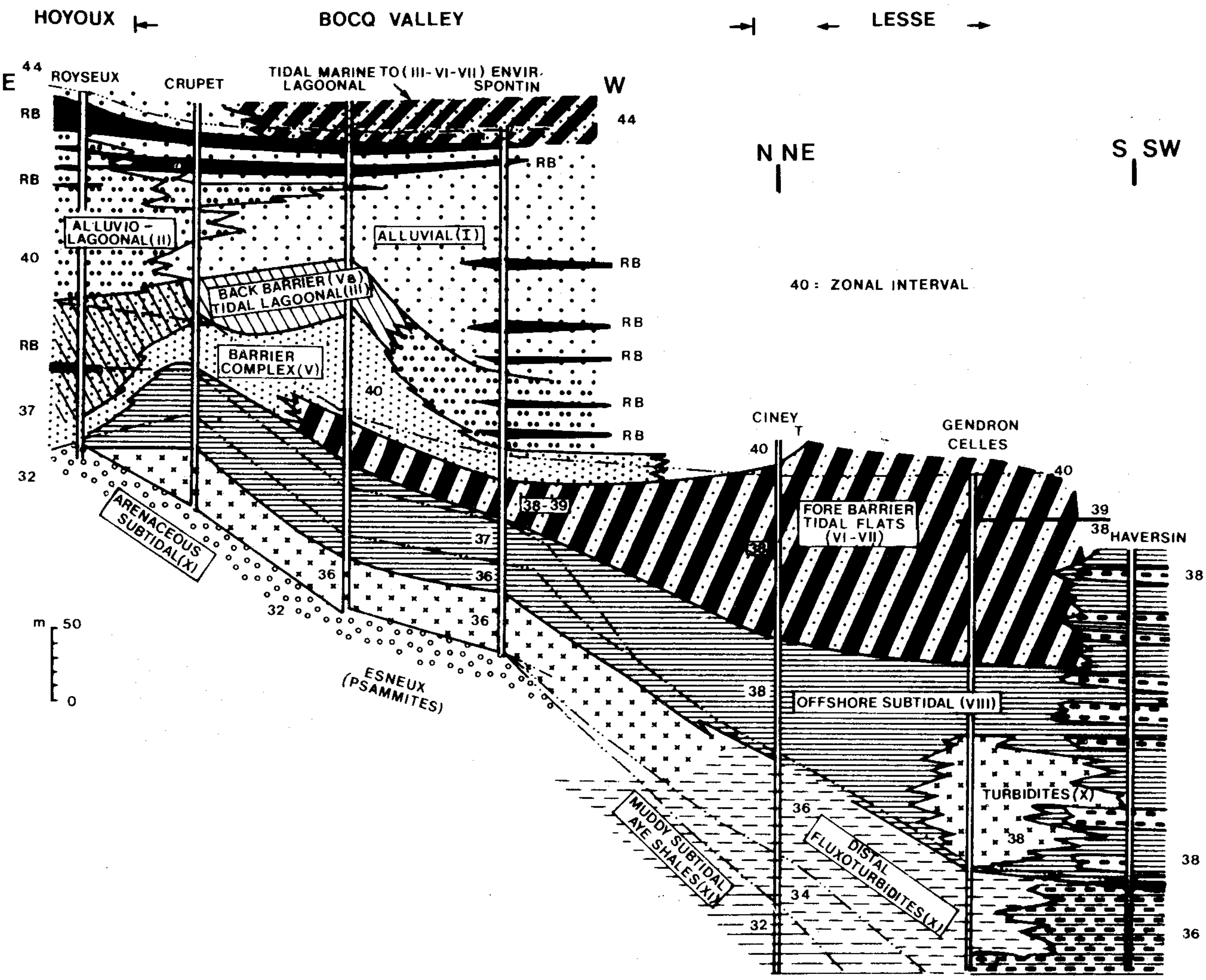

Figure 7. - Relation between the megaenvironments of the "Psammites du Condroz" in the Hoyoux, Bocq and Lesse valleys (Thorez, 1969)

Very locally, too, crinoidal limestones produced incipient carbonate buildups (grainstone accumulations; spar-cemented debris reefs) located on tectonically-controlled highs. Only exceptionally (i.e. the Baelen-Limbourg area, Vesdre valley) crinoidal wackestone, packstone and grainstones alternate with algal, cryptalgal (stromatactis-bearing) and spiculitic mudstones, building up important reef-analogous structures (algal-sponge-crinoidal carbonate buildups) (Dreesen & Flajs, 1984; Dreesen *et al.*, 1985) (see further).

The usual colour of the siliciclastics varies from grey to blue (depending upon the carbonate admixture and mica content). However, locally (particularly in the youngest Formations of Evieux and Beverire), the micaceous arkosic sandstones display a characteristic "red" colour (purple, pink to deep red). However, in the latter case the sediment has preserved its high and fresh original feldspar content. These minerals do show only a micrometric film of sesquioxides (formerly goethite, now diagenetically dehydrated into hematite) around the fresh core of feldspar. Opaque minerals (chromite, magnetite, ilmenite and hemo-ilmenite) as well as the biotite have, in parallel, suffered the mild effects of a post-sedimentary but pre-burial oxidation process that followed a first reduction phase (Goemaere, 1984). This hypothesis is supported by the preservation, in some parts of these "red" beds, of pyritized carbonaceous plant fragments, and by geochemical evidences (Dreesen & Thorez, 1982; Goemaere, 1984; Thorez, in preparation). Particularly the oxidation phase has produced very fine-grained acicular aggregates of rutile replacing the hemo-ilmenite grains; these aggregates would have become destroyed by a long transport over the depositional area, and are consequently the product of an *in situ* post-sedimentary process.

4. - THE RHYTHMIC PATTERN OF THE SEDIMENTATION

The various lithologies are not arbitrarily distri-

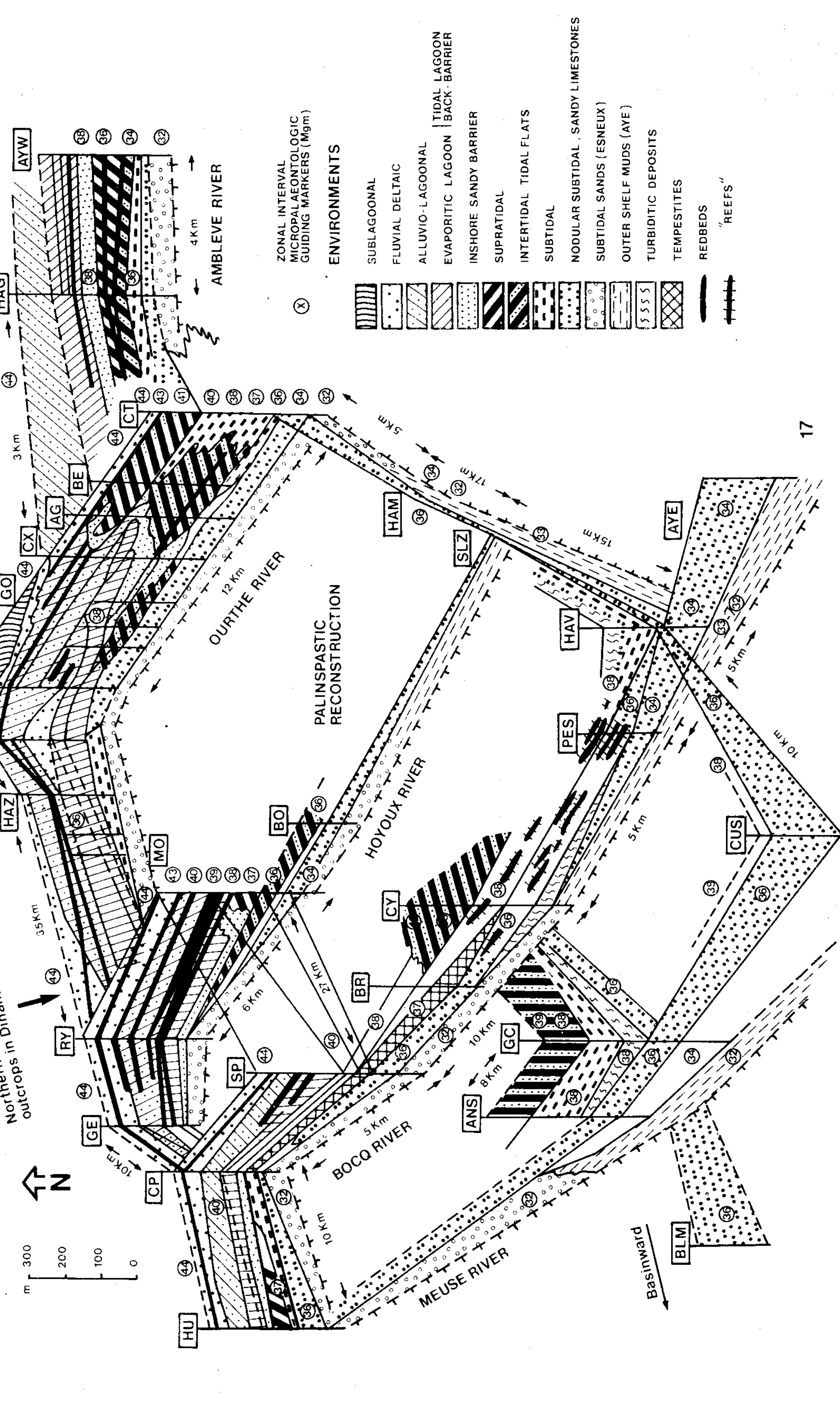

Figure 8. - Cartoon of lateral and vertical succession of depositional megaenvironments of the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium (Thorez, 1969; Thorez *et al.*, 1977, modified).

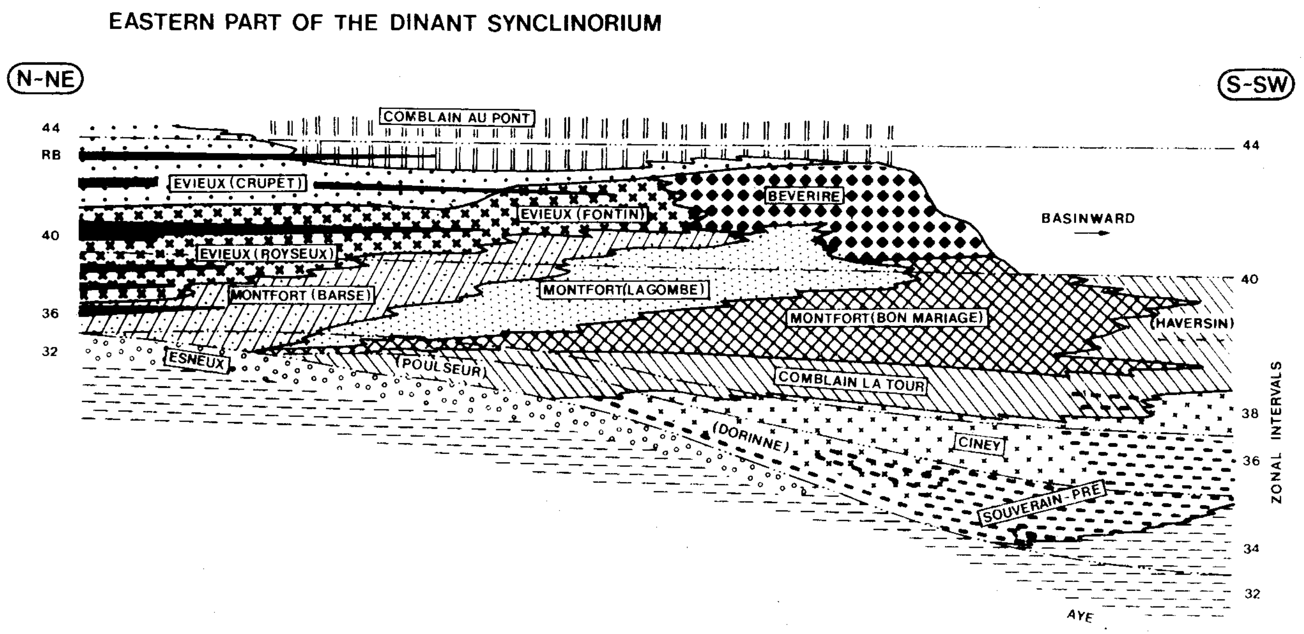

Figure 9. - Generalized NNE-SSW section through the Upper Famennian "Psammites du Condroz" showing lateral and vertical relationship between Formations and Members (not to scale) (Thorez, 1969; Thorez *et al.*, 1977).

buted in the series. On the contrary, they are linked one to another in specific ways within minor and major rhythms. One of the important features of the "Psammites du Condroz" is indeed the occurrence of a rhythmic system of accumulation. The rhythms combine interrelated lithologies, grain-size evolutions (coarsening-upward or fining-upward trend), and variable but specific sedimentary structures. These rhythms exist at different scales : decimetric to metric minor rhythms, and metric to decametric (5 to 8 m) major rhythms. The former are generally integrated in the latter, and reproduce somewhat the same lithologies and grain-size evolution (Thorez, 1964a, 1969; Becker *et al.*, 1974; Goemaere *et al.*, 1985). The kinds and variability of the rhythmic pattern and its evolution are illustrated in Figures 11 to 22 and 32.

The rhythms characterize different environments : distal alluvial (deltaic), alluvio-lagoonal, evaporitic and tidal lagoonal, sand barrier (the latter with typic coarsening - upwards grain-size trend or reverse graded bedding), tempestites (storm deposits), fluxoturbidites (Thorez, 1969). Also, tidal flats deposits (with sub-, low and high inter- and supratidal subenvironments) are built up according to a rhythmic pattern (Thorez *et al.*, 1986). Figure 32 depicts the lateral relation between these various rhytmic patterns and the corresponding depositional environments at the scale of the minor rhythms (sequences).

Thanks to the detailed investigation of the "Psammites du Condroz" from one outcrop to another, with the support of the biostratigraphy and that of a set of marker beds (redbeds and ball-and pillows levels), some of the composite, major rhytms have appeared continuous over a certain distance (exceeding even 15 Km as in the Ourthe valley). Consequently these rhythms play the role of a local correlation tool (rhythmostratigraphy).

5. - DEPOSITIONAL ENVIRONMENTS AND PROCESSES

Minor and major rhythms are a "trade mark" of the "Psammites du Condroz" particularly in the Montfort, Evieux and Beverire Formations. Their lithologies, textures, thickness of superposed lithologies, grain-size evolution and associated sedimentary structures (Figs. 11 to 22) enable to identify the depositional environments in which they occurred. One may note the persistence of the same kind of minor and major rhythms during a certain period of time encompassing even an entire Formation (i.e. the Barse Member of the Montfort Formation; the Beverire Formation). This signifies that environmental conditions persisted sufficiently vertically on the same position in the sedimentary basin as to reproduce practically the same rhythmic (and thus depositional) patterns. However, from one locality to another (within a same valley) and from one area to another (within the Dinant Synclinorium), there also appears a general vertical and diachronic lateral change in the rhythmic pattern, reflecting consequently changes in the depositional environmental conditions. These changes characterize the general progradation (regression) of the "Psammites du Condroz" (Figs. 4, 6, 7 and 8).

All the reconstructed environments clearly indi-

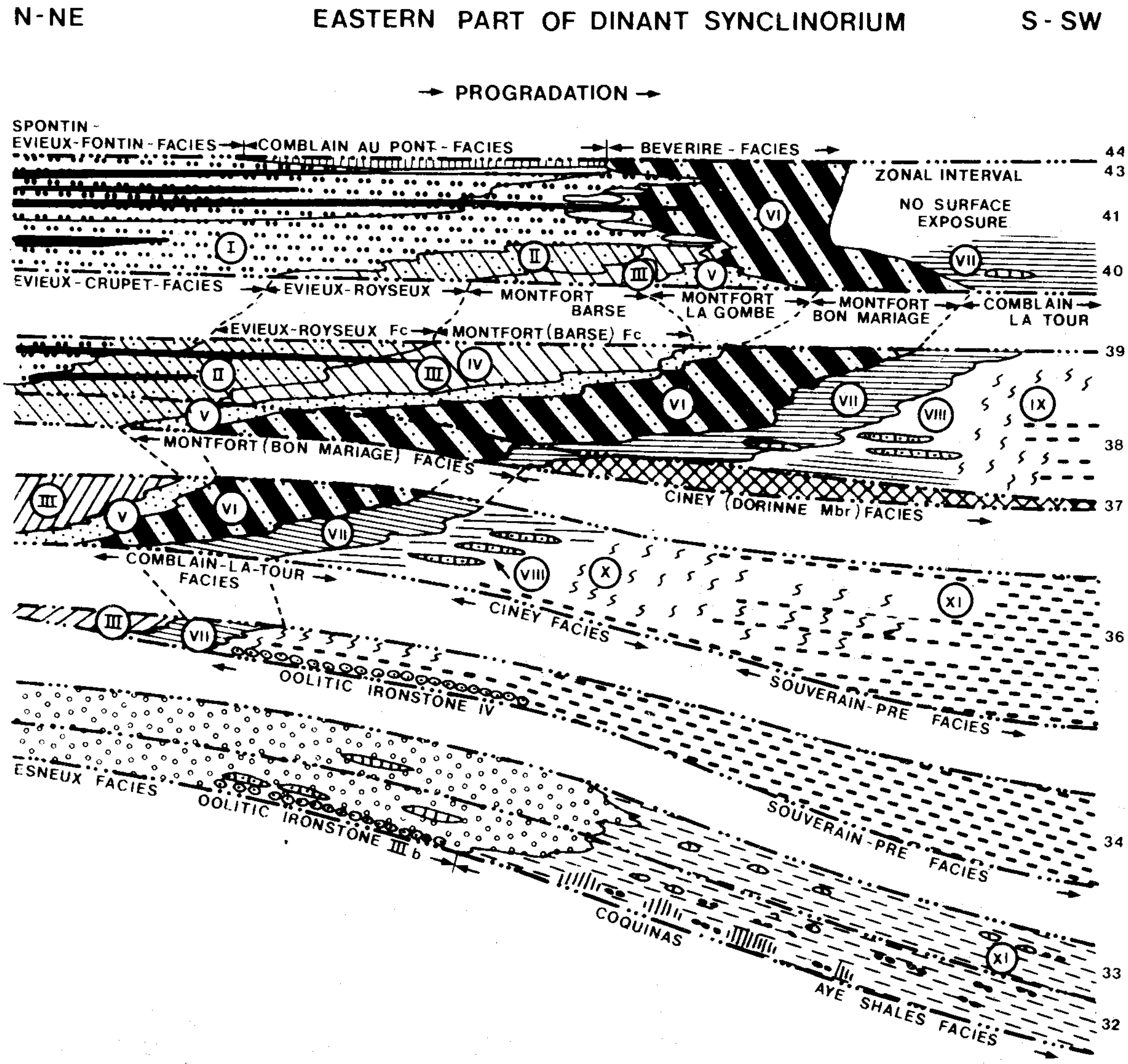

Figure 10.- Generalized section of the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium, showing, in five separate but superposed slices (characterized by the corresponding mgm - Micropaleontological Guide Marks -), the time-space evolution of the principal sedimentary facies and depositional megaenvironments, and the overlapping process that produced the regressive (progradational) character of the Upper Famennian in the studied area. Roman ciphers refer to the various depositional environments, also found within the minor lateral sequence (Fig. 33) : I. deltaic or distal alluvial; II. sabkha; II-III. alluvio-lagoonal with tidal delta; III. evaporitic lagoonal; IV. back-barrier with tidal lagoon; V. sand barrier complex; VI. sublagoonal and/or supra- and intertidal; VII. tidal flats (with supra-, high and low inter-, and subtidal subenvironments); VIII. local, incipient crinoidal carbonate buildup; IX. tempestites (storm deposits); X. fluxoturbiditic deposits; XI. outer shelf muddy deposits. Corresponding lithostratigraphic subdivisions are schematically indicated. Reconstruction not to scale. (Thorez 1969; after Dreesen & Thorez, 1982, modified).

cate the permanence of (very) shallow waters during the buildup of the rhythms, for both the deposition of the siliciclastics and that of the carbonates (especially the evaporitic dolomites). In some cases emersion even temporarily occurred, as demonstrated by crescent-marks, polygonal dessication cracks, erosive mounds, etc.)

On the other hand, several horizons of caliche-bearing paleosoils exist, particularly in the Evieux Formation. Along with lagoonal depositional environments (as supported by the occurrence of dolomite, anhydrite and gypsum), sabkha conditions temporarily prevailed resulting in the partial reddening of some siliciclastic deposits (Lejeune, in preparation).

The vertical succession of several dozens of major rhythms, all of them exhibiting shallow water conditions, implies a continuous balance between the rate of the subsidence of the rate of deposition. Only in the southwestern part of the Dinant Synclinorium a deeper bathymetry developed (marked by the deposition of fluxoturbidites : Figs. 22 and 32). And even in these latter environments, it is suggested that the water depth never exceeded more than to fifty meters.

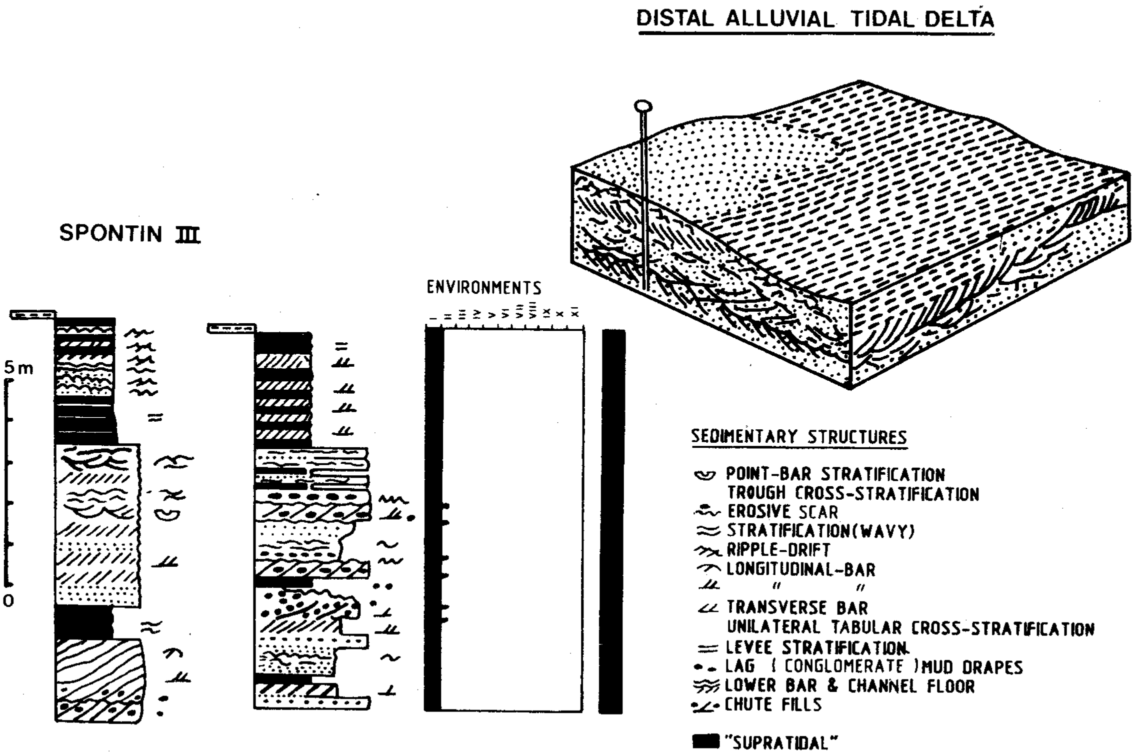

Figure 11. - Distal alluvial and tidal delta sequences, with characteristic lithologies and sedimentary structures. The block diagram shows the position of the observed rhythmic motifs within the depositional environment. (Roman ciphers refer to the identified environments, as in Figure 32, for the lateral minor sequence). Topmost part of Evieux Formation; Spontin (Bocq valley).

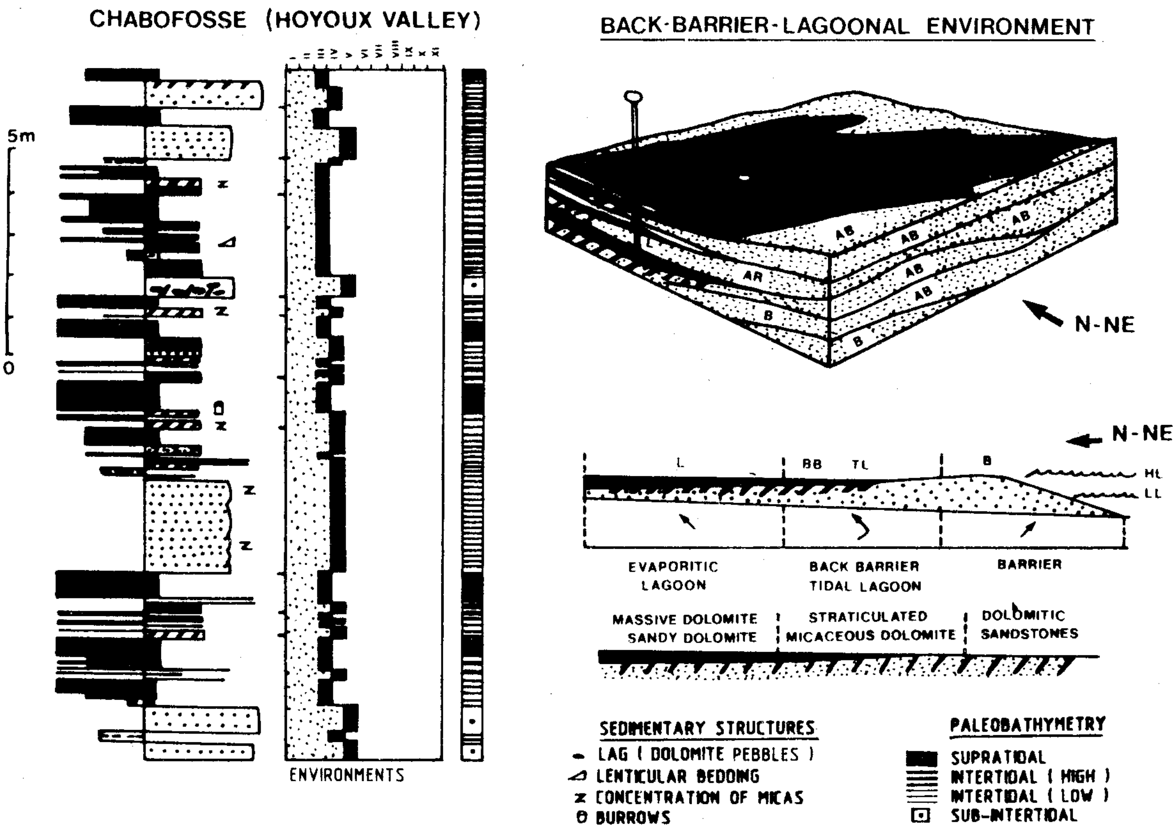

Figure 12. - General stratigraphic section illustrating the binomial dolomite- arkosic sandstone minor rhythms in the back-barrier and evaporitic lagoonal environments. Surface sediment facies distribution of the dolomites over the lagoonal pan. Montfort Formation, Barse Member; Chabofosse (Hoyoux valley).

The overall progradation of nearshore (alluvial, lagoonal and barrier) mega-environments to the South and the Southwest reflects a major regressive event during the late Famennian in the eastern part of the Dinant Synclinorium. This regression is also perceptible in the neighbouring areas (Namur Syncline, Vesdre Synclinorium, Belgium, and in Germany) (Paproth, Dreesen & Thorez, 1986). The mechanism and the trends for this progradation is easy to demonstrate thanks to the slice-by-slice paleogeographic reconstruction (see further) and to the study of the vertical and lateral changes within the minor and major rhythms (Thorez, 1969; Thorez, Streel, Bouckaert & Bless, 1977).

6. - PALEOGEOGRAPHIC EVOLUTION

During late Devonian times, the Condroz Platform corresponded to a relative shallow epicontinental sea bordering the southern, windward side of the Old Red Continent (Paproth, Dreesen & Thorez, 1986). The latter continent was intersected by the Caledonian mountain belt. The frequent occurrence of redbeds, evaporites and of pedogenic carbonates (calcretes, dolcretes) on and around the Old Red Continent and at several levels of the youngest formations in the "Psammites du Condroz" is symptomatic of prevailing arid to semi-arid climatic conditions within the Tropical Trade Wind Belt (between 10^{o} and 20^{o}S paleolatitude, see Figure 1 in Paproth, Dreesen & Thorez, 1986). In the southern hemisphere, the easterly tropical trade winds drove a warm, equatorial sea current westward between the Equator and about the latitude of 20^{o}S (Heckel & Witzke, 1979). This south-equatorial current flowed through the Paleotethys Sea towards Europe, split at the east-end side of the Russian Platform, with a branch moving southwestward through the basins of Central Europe, as a strong Western Boundary Current (W.B.C.). The latter incoming warm, south-equatorial boundary current passed through the Polish Basin, and was deflected towards the Ardenno-Rhenish Basin, encroaching the northern shelf area. Here, the W.B.C. was forced to pass through narrow seaways, in between the London-Brabant High (an emerged structure during Famennian times) and the (episodically) emerging or shallow water

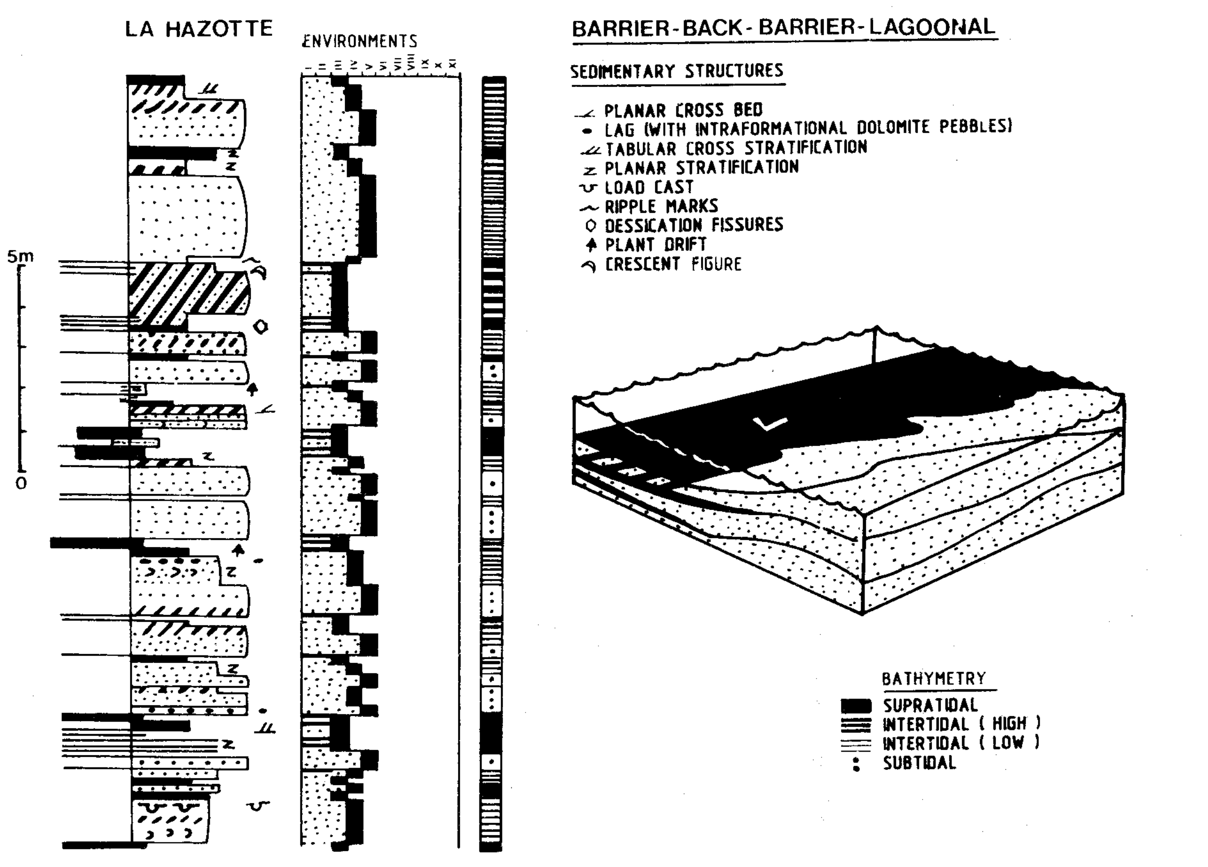

Figure 13.- Back-barrier barrier sequences with minor intercalation of the lagoonal environment (represented by thin micaceous dolomite beds). The inferred alternating depositional environments, supported by the minor rhythmic motifs, are comprised between evaporitic lagoonal (III), back-barrier (IV) and barrier (V). Corresponding paleobathymetry oscillates between supratidal (dolomites), high and low intertidal (back-barrier and barrier, partly), and subtidal (lower part of the barrier system). Montfort Formation, Barse Member; La Hazotte (NW of Esneux, Ourthe valley).

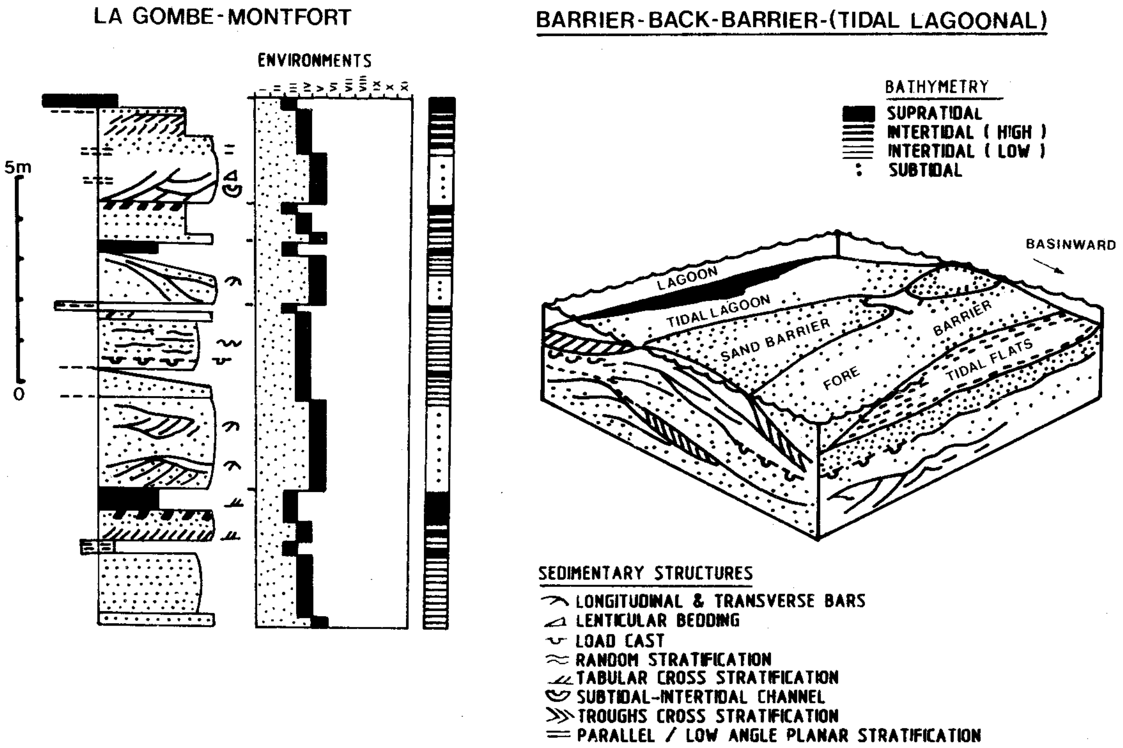

Figure 14. - Barrier/back-barrier, plus intermittent tidal lagoonal environments, with predominantly sandstone deposition displaying typical coarsening-upward grain-size evolution from one minor rhythm to another. Montfort Formation, La Gombe Member; La Gombe locality, Ourthe valley.

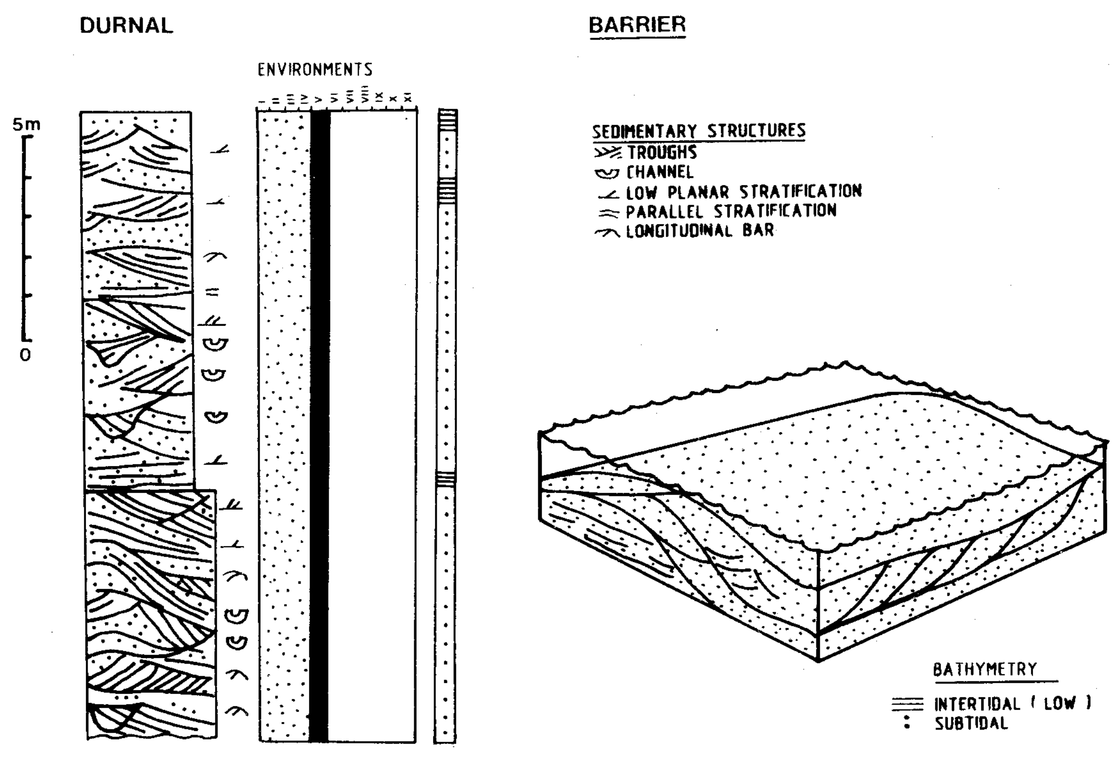

Figure 15. - Barrier complex formed by thick, lenticular arkosic sandstone beds displaying troughs, and bidirectional (herringbone) cross stratification, with local channeling and longitudinal submarine bar. Shoreface of the barrier complex. Topmost Montfort Formation; Durnal (Bocq valley).

Ardenno-Rhenish Shoals, through what can be named here the "Vesdre Corridor". The W.B.C. was sufficiently strong and permanently flowing as to redistribute the alluvial discharges of prograding deltas coming from the northern hinterland (Netherlands and North-German High and Lowlands). As a consequence, the Upper Famennian "Psammites du Condroz" in Belgium originated through a current-induced destruction of delta lobes developed outside the here investigated area (Paproth, Dreesen & Thorez, 1986).

Subsequently, the reworked sediments of the deltas were rhythmically redistributed on the Condroz Platform. Here, changes in the local hydrodynamic conditions as well as in the geomorphology of the depositional area produced the rhythmicity of the deposits and formed the basis of the seaward progradation of the more inshore environments towards the S-SW.

Longshore drift currents acting permanently along the paleocoast (the southern border of the London-Brabant High), tidal currents and storm and wave action contributed, separately or simultaneously, in the dispersion of the reworked sediments which had originated from the northern source area. These currents and waves are responsible for the general good sorting of the siliciclastics in the "Psammites du Condroz", and for their improved grain-size as well as for the coarsening- and fining-upwards trends found in the rhythms. Moreover, these currents and waves contributed to the dispersion of the siliciclastics over the depositional area : as the sands accumulated in more inshore settings (i.e. as the sand bar complex), the finer material, silts and muds, was deposited in more offshore settings.

Hydrodynamically and geomorphologically the "Psammites du Condroz" originated through the interplay between the permanent W.B.C. activity and that of more local tidal currents, waves and storms, and of eventual density currents (the latter being responsible for the fluxoturbidite deposits in the southwesternmost part of the investigated area, i.e. near Gendron Celles).

The source area for the "Psammites du Condroz" siliciclastics was possibly a large alluvial plain fringed by the London-Brabant High and the Zandvoort-Krefeld High (Fig. 1 in Paproth, Dreesen & Thorez, 1986). This area was submitted to arid to semi-arid conditions. The alluvial discharges must have been intermittent during very short but more humid phases. Although "flashy" fluvial regimes, with brief, episodic and high discharge periods (as can be expected in such

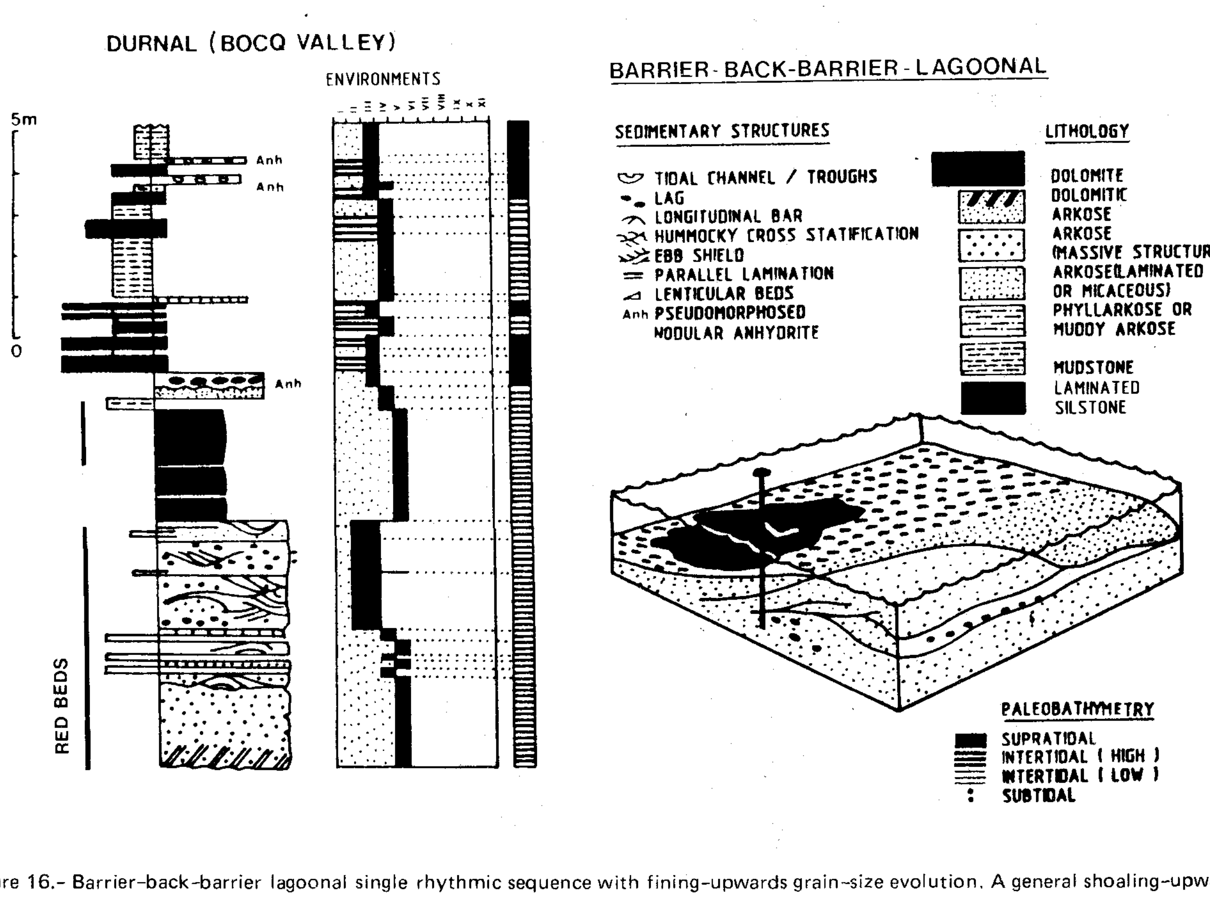

Figure 16.- Barrier-back-barrier lagoonal single rhythmic sequence with fining-upwards grain-size evolution. A general shoaling-upward sabkha sequence takes place at the end of the principal sandstone deposition, with typic pseudomorphosed (nodular) anhydrite level. The upper part of the sequence is characterized by alternating black-shales and "primary" dolomite, with some pseudomorphosed (dolomitized) anhydrite levels. Some reddening of the siliciclastics occurred postsedimentary (sabkha environment). Basal part of Evieux Formation; Bocq valley).

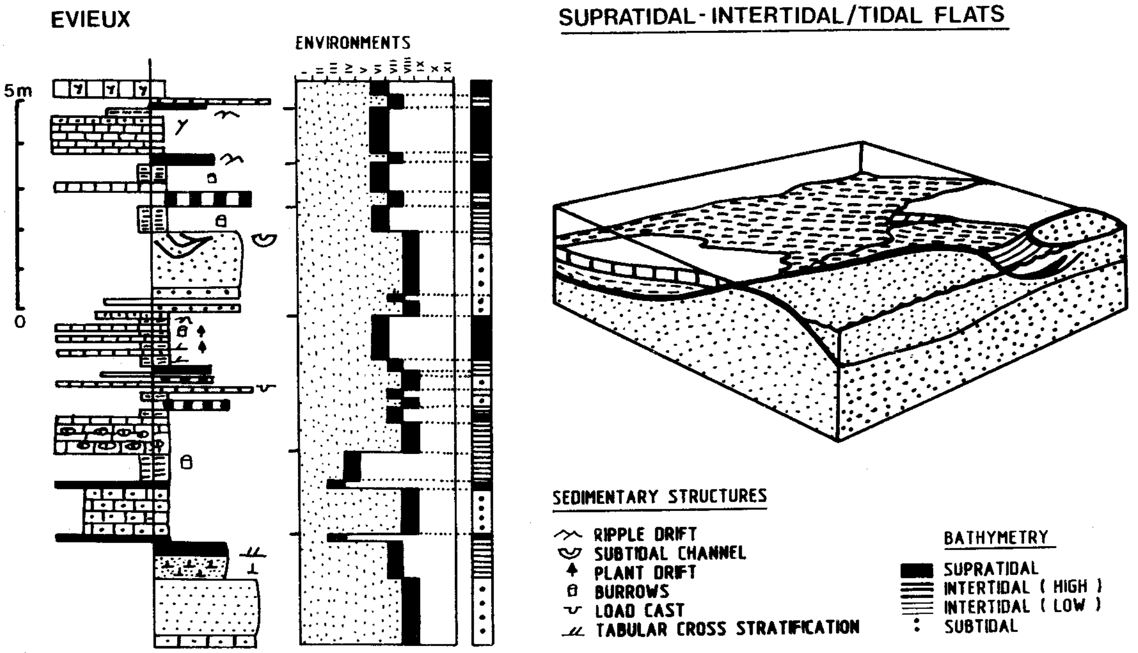

Figure 17. - Supratidal and intertidal tidal flats sequences, with minor rhythms capped by ostracodal micrites (corresponding to sublagoonal conditions of the depositional environments). Evieux Formation; Evieux (Esneux), Ourthe valley.

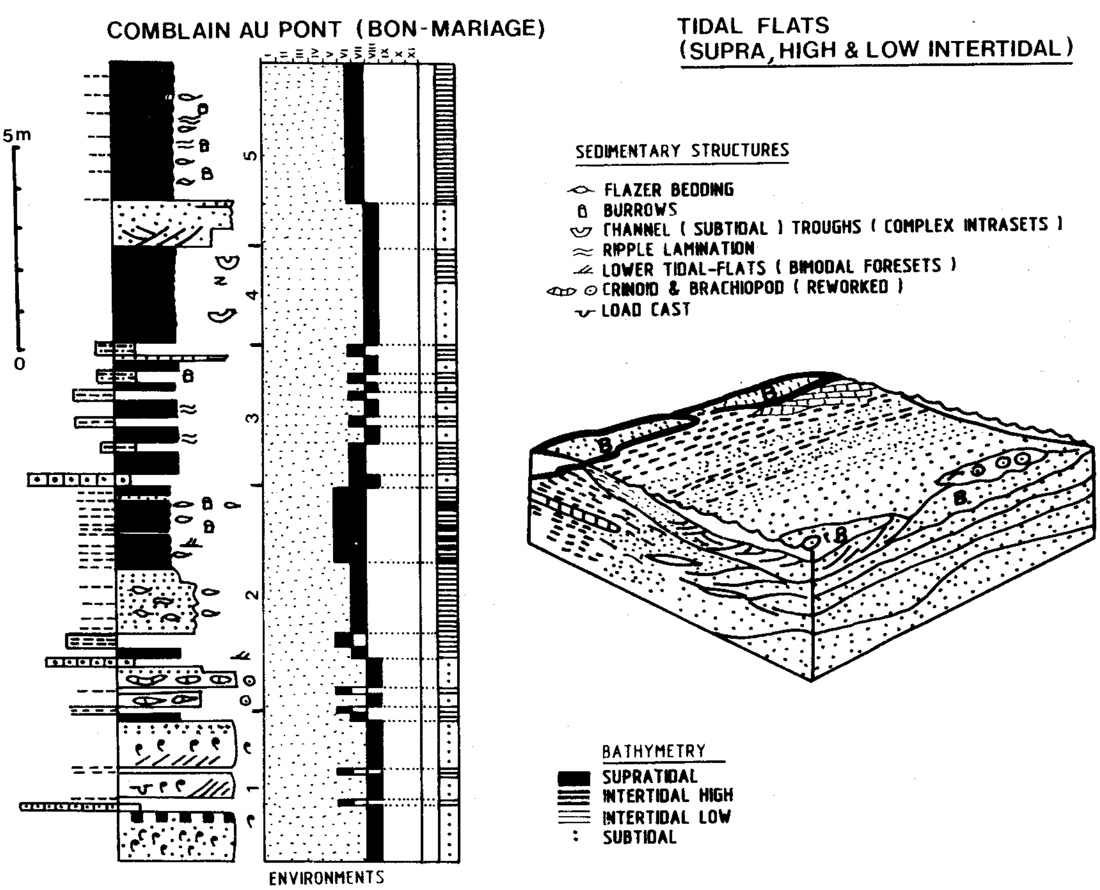

Figure 18. - Five superposed minor rhythms (shallowing-upward sequences) accumulated within mainly low to high intertidal, and supratidal depositional environments. The lithological and textural contents of these rhythms vary according to time, as well as the associated sedimentary structures and thickness of the different beds. Montfort Formation, Bon Mariage Member, Comblain-au-Pont (Bon Mariage), Ourthe valley.

climatic conditions) are more likely to supply coarse (even pebbly) material to the delta front complex, the Upper Famennian sediments remained essentially fine-grained in Germany and in Belgium. However, some granule deposits have been observed in a borehole near Maastricht, Southern Netherlands (Bless *et al.,* 1980).

The eolian activity near or over the Mid-Netherlands High might have produced a fine-grained and fresh (arkosic) material which, through N-NW winds, accumulated in the Lowlands of the German Platform. From there, episodic but more humid period favoured a fluvial reworking, and subsequent transport of the fine-grained siliciclastics towards the sea, by intermittent "flashy" rivers developing a deltaic system along the paleocoast. From there, the siliciclastics were redistributed by the W.B.C. current acting as a current (and wave)-destructive system for the delta lobes. The material was finally transported westward to the shallow-water Condroz Platform, accumulating and producing the characteristic series of the "Psammites du Condroz".

Such an hypothesis for the source area of the "Psammites du Condroz" siliciclastics could actually replace the one forwarded previously (Thorez, 1969). Indeed, the source area of the fine-grained and well--sorted arkosic sandstones has long puzzled many geologists. A northern source, within the Scandinavian Caledonian Belt or a more southern but actually covered area (Denmark ?) has been suspected by Michot (*in* Thorez, 1969) because of the occurrence, among the feldspars, of about 5 $^{0}/o$ of mesoperthite. The latter is a typical feldspar for the catazone of southern Norway (Michot, 1980). However, the Famennian mesoperthite is only a minor component among the other feldspars, (essentially albite-oligoclase, orthoclase, with some microcline).

The hypothesis for a northern source area in Norway seems actually to be rejected for three reasons. Firstly, if a catazonal source, as evoked above, has to be retained, the contribution of the mesorpethite should have been more important. Secondly, this source is too far from the final setting of the sediments. And finally, a Norwegian area was characterized, during Famennian times, by humid tropical climatic conditions. The latter conditions would have induced a

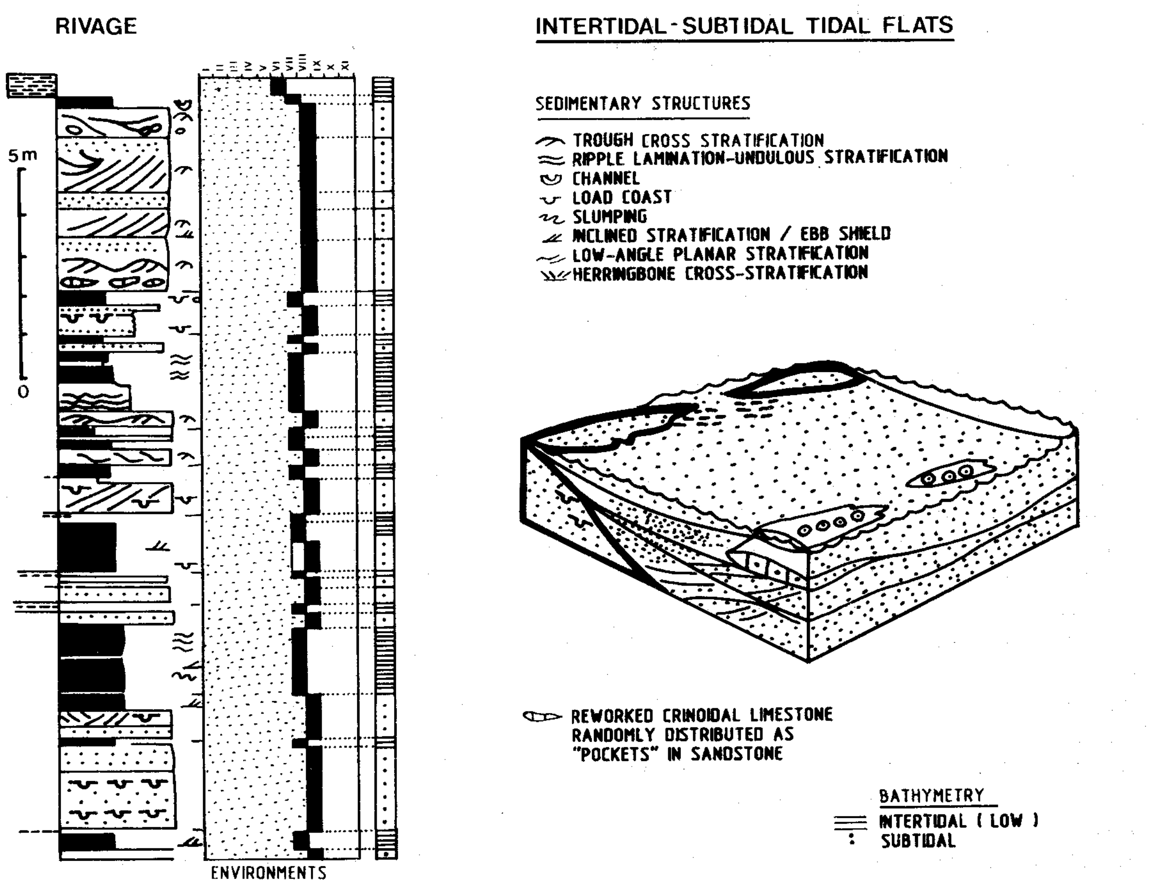

Figure 19.- Several rhythmic motifs accumulated within general intertidal (low)- and subtidal tidal flats. Note absence of muddy sediment intercalation. Characteristic is the repeated occurrence of ball- and pillow levels and cross stratifications in many arkosic beds. The complete section has been accumulated within inter- to subtidal environments, with local influence of storms (cf. reworked crinoidal limestone beds, embedded as "nodules" in a arkosic sandstone matrix). Montfort Formation (Bon Mariage Member); Rivage (Ourthe valley).

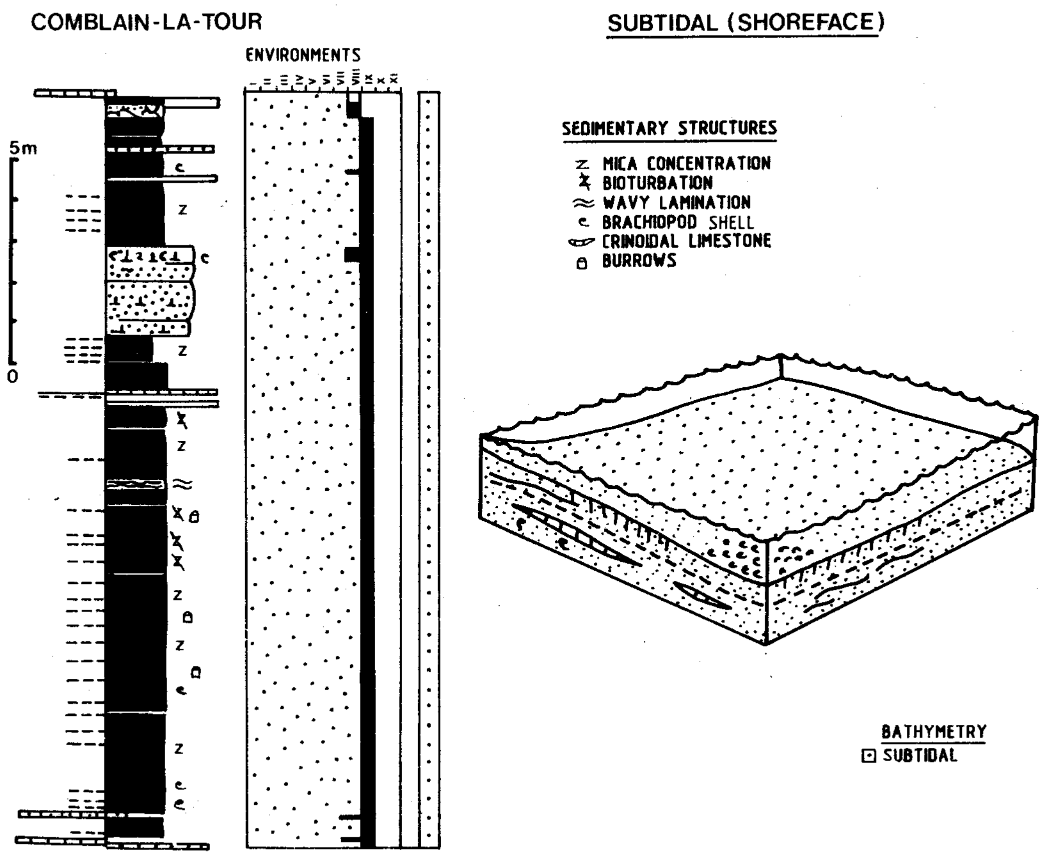

Figure 20. - Subtidal finely laminated and thin arkosic sandstones, with minor (millimetric) intercalations of micaceous siltstone and of local (lenticular) crinoidal limestone. Some of the sandstone beds show reworked Brachiopod shells dispersed within the siliciclastics or concentrated as coquinas. Comblain-la-Tour Formation : Comblain-la-Tour (Ourthe valley).

deeper weathering of the feldspars.

Considering the freshness of the feldspars in the "Psammites du Condroz" and their large and increasing amounts (from 26 °/o in the Montfort Formation, up to 50 °/o in the Evieux Formation) as well as the remarkable richness in muscovite-biotite flakes, instead of a Norwegian source, an alternative source area is here proposed : the Mid-Netherlands High, where possibly a Precambrian gneissic substratum could have been submitted exclusively to physical weathering (i.e. eolian activity) during the then prevailing arid to subarid climatic conditions. The Mid-Netherlands High was possibly emerged during the Famennian as an inversed structure (Paproth, Dreesen & Thorez, 1986). The gradual increase of the feldspar/quartz ratio (from 26 °/o up to 50 °/o in the "Psammites du Condroz" and the subsequent feldspar drop to 5 °/o in the so-called Comblain-au-Pont Formation as well as the parallel but gradual general decrease of the mica content towards the younger formations, are possibly explained by a gradual change of the same source rock composition : these trends might, indeed, result from the progressive denudation (or "peeling") of a metamorphic basement rock, producing successively phyllitic and feldspathic sediments, and later on, less phyllitic and arkosic materials. A gneissic source is also supported by the occurrence of a very limited suite of heavy minerals in the "Psammites du Condroz": red and yellow rutile, zircon, blue and green tourmaline, and apatite (Vandenven, 1960 ; Thorez, 1969). As the Famennian material is characterized by a high content in feldspars, a direct indication is also provided that concerns the original absence of any ferromagnesians at the source area : would these minerals have been present, they should be found back in the final sediments.

The sudden drop of the (still fresh) feldspar content by the end of the Famennian could be related to the final levelling of the suspected Mid-Netherlands source area or by a sudden climatic change (?) (Streel, 1986). In the Comblain-au-Pont Formation and in the Strunian, one can observe (particularly in the eastern part of the Dinant Synclinorium and in the Vesdre Synclinorium), a general decrease of the coarse siliciclastics, and a parallel increase of finer sediments (silts, and mostly muds). This change indicates that, through time, only the finest siliciclastics were introduced in the depositional environments; maybe sands were no more delivered to the delta system N-NE of the here considered area. A clay-mineralogical study would have theoretically produced some clues about such a possible climatic change. However, the diagenesis appears to have been too important for tracing the occurrence of some degraded clay minerals (vermiculite, smectite, kaolinite, mixed layers), indicative of moderate to deep weathering conditions. The clay fraction extracted from the different lithologies of the "Psammites du Condroz" (in the eastern part of the Dinant Synclinorium at least) shows predominantly mica (muscovite and well-crystallized illite) associated to a Fe-chlorite (Thorez, 1969; Goemaere, 1984). Only a minor fraction concerns a mixed layer illite-vermiculite or illite-chlorite (the latter possibly indicating the moderate weathering state of the associated biotite).

7. - THE DYNAMIC OF THE PROGRADING "PSAMMITES DU CONDROZ" IN THE DINANT SYNCLINORIUM

The complete progradational style of the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium, in the Namur and Vesdre Synclinoria, will be discussed in a forthcoming paper. However, some of the most characteristic trends of the Famennian regression in the Ardenno-Rhenish area have already been indicated in Paproth, Dreesen & Thorez (1986) for three sedimentary phases (1, 7 and 9), encompassing approximately the lower part of the *P. rhomboidea* Conodont Zone, the uppermost *P. marginifera* Conodont Zone (former lower *S. velifer* Zone) and the *VCo* Spore Zone (Paproth *et al., op. cit.,* Figs. 6, 7, 8). However the latter reconstructions do not involve any palinspastic development as for the paleogeographic maps (Figs. 23 to 31 this paper) here presented.

The geographic location of the studied outcrops and quarries in the investigated area is shown in Figure 23. A series of cartoons (Figs. 24 to 30) illustrates the reconstructed progradational (regressive) evolution of the "Psammites du Condroz", phase after phase : The general trend is summarized in Figure 31, which takes into account all the depositional environments encountered through time and space in the investigated area, and which is based on the eleven sedimentary phases.

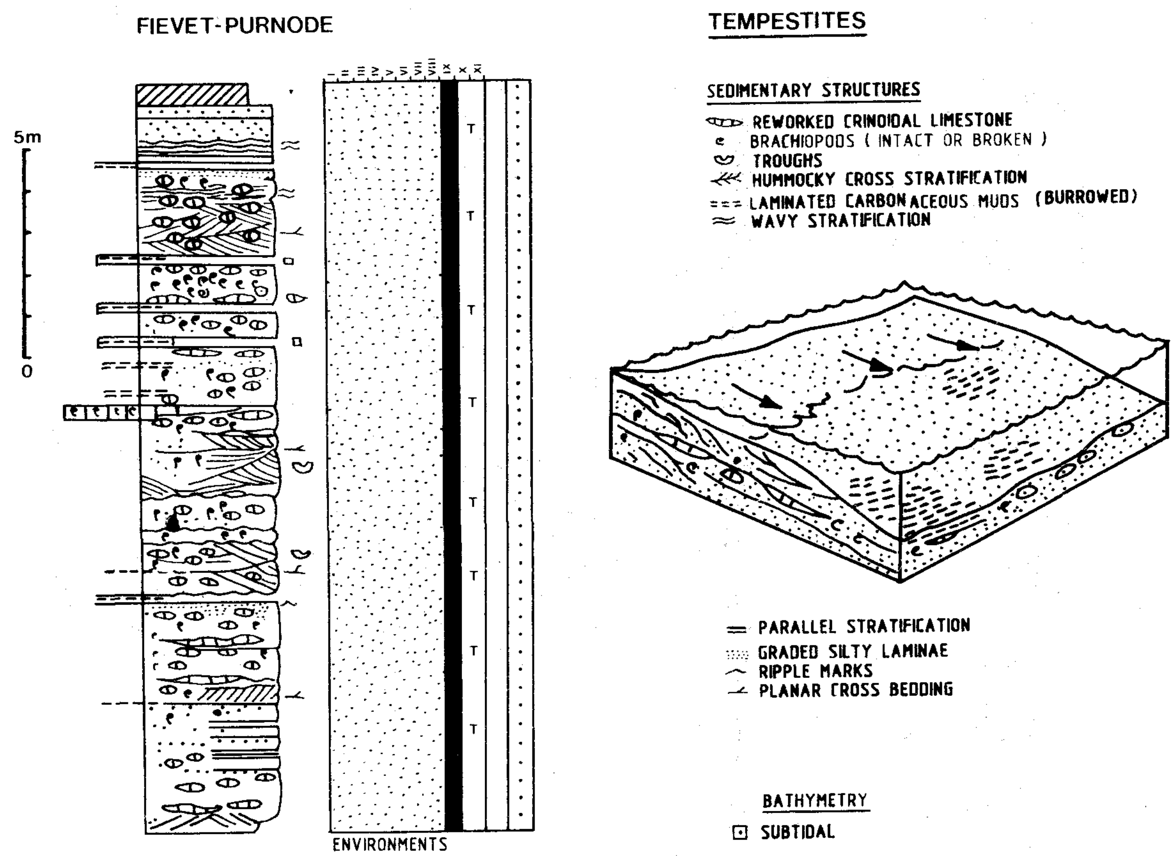

Figure 21.- Tempestite (storm deposits) accumulation. The successive tempestites form characteristic decimetric sequences displaying from base to top : a basal erosional unconformity, massive non-graded and then graded -bedded arkosic sandstone enclosing numerous brachiopod shells; sandy biosparites occur in those beds as thin lenses or as subrounded clasts. The tempestites usually end with a laminated siltstone (with wave ripple bedding), and, more rarely with a thin (millimetric) lenticular mud layer. Hummocky stratification and lenticular bedding are commonly observed. Ciney Formation (Dorinne Member), Fievet-Quarry (Purnode), Bocq valley.

From these reconstructions, it clearly appears that the regression started from the NE-corner of the eastern part of the Dinant Synclinorium. This conclusion is supported by the general model of Paproth, Dreesen & Thorez (1986, Fig. 1), which points to a source area located North of Aachen.

The progradation gradually extended to the S-SW, matching thus the direction of the deflected W.B.C. current passing through the "Vesdre Corridor" and reaching the Condroz Platform. The most inshore sediments (distal alluvial, alluvio-lagoonal, evaporitic and tidal lagoonal, sand barrier) essentially occur along the northern flank of the Dinant Synclinorium. The most offshore (subtidal) environments developed in the southern and southwestern parts of the Dinant Synclinorium, where more marine conditions prevailed throughout the Upper Famennian. However, this open marine shelf remained relatively shallow (inner shelf) and passed only to deeper waters in the area of Gendron-Celles (with episodic fluxoturbidites).

7.A. - SEDIMENTARY PHASE 1 (*Zonal interval 31 to 32*)

Figure 24 depicts the paleogeographical nearshore deposition of the Esneux Sandstones and the offshore coeval Aye Shales. The Esneux facies exists also in the Namur and Vesdre Synclinoria and extends to Aachen. The Esneux Sandstones which may, locally, exceed 100 m are interpreted as wave-influenced deposits, and are composed of millimetric to decimetric evenly laminated micaceous siltstones and fine-grained sandstones. Wave-ripple marks are the main characteristic sedimentary structure. Carbonate episods are rare and consist of local lenticular crinoidal to brachiopodal limestones (probably storm-generated deposits as suggested by their relative poor sorting and the mixed conodont biofacies content).

To the South and Southwest, this predominantly sandy formation grades into a more pelitic sediment, the so-called Aye Shales. The overall paleobathymetry for both formations is that of a subtidal wave-influenced environment.

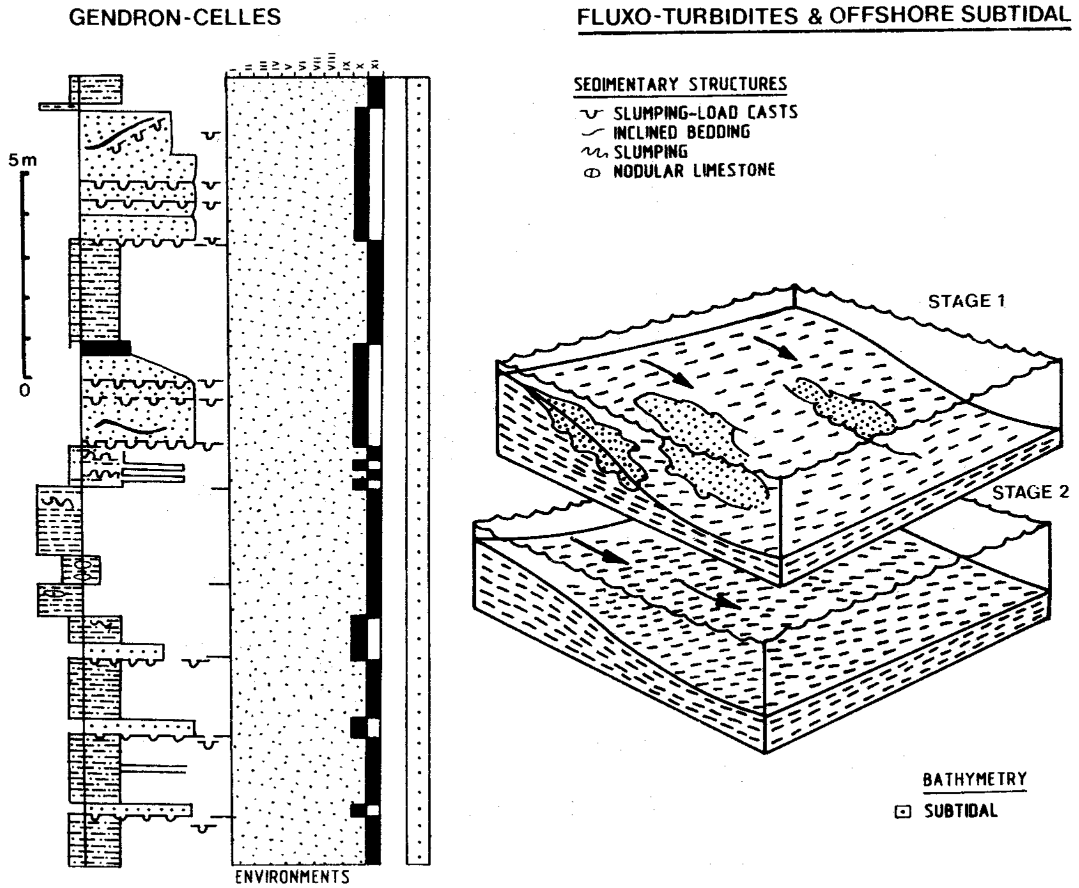

Figure 22. - Fluxo-turbiditic deposits, composed of poorly sorted siltstones, interrupted by thick massive or poorly straticulated sandstones with frequent slumping and ball-and pillows in their basal parts. Some of the siltstones bear crinoidal limestone "nodules" (clasts) derived from incipient carbonate buildups located "uphill" from the source area and reworked by density currents. These carbonate buildups occurred in rather shallow water. Ciney Formation; Gendron-Celles, Lesse valley.

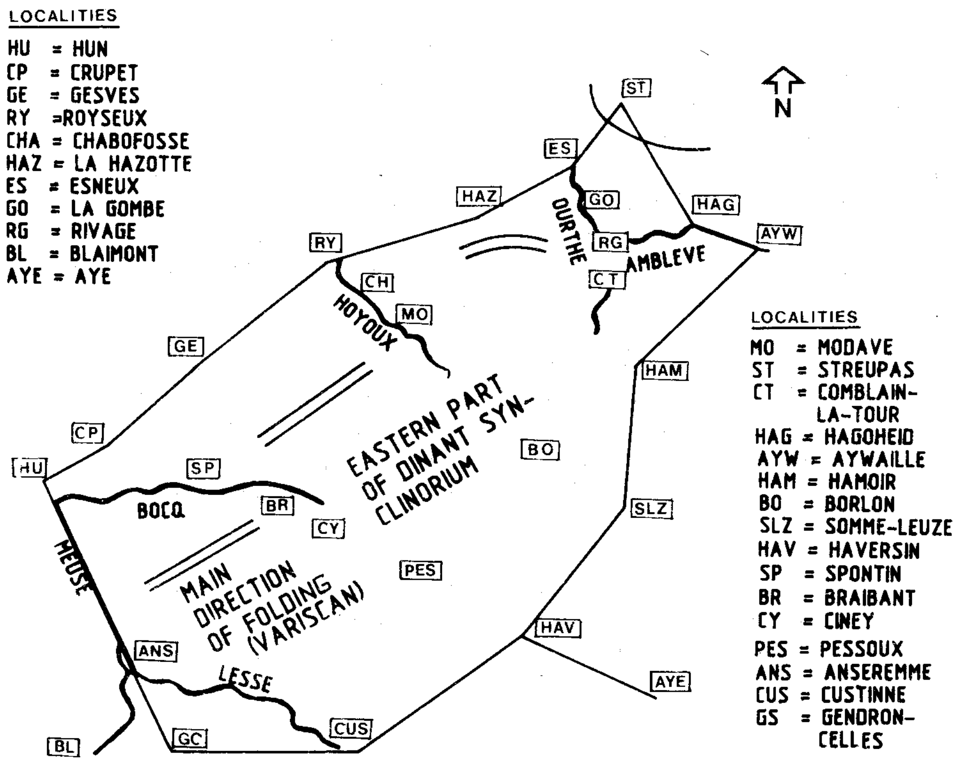

Figure 23. - Location of the main outcrops in the eastern part of the Dinant Synclinorium, after tectonic defolding (palinspastic reconstruction). This serves as a background for the slice-by-slice reconstruction of the progradational evolution of the "Psammites du Condroz" in Figures 24 to 31.

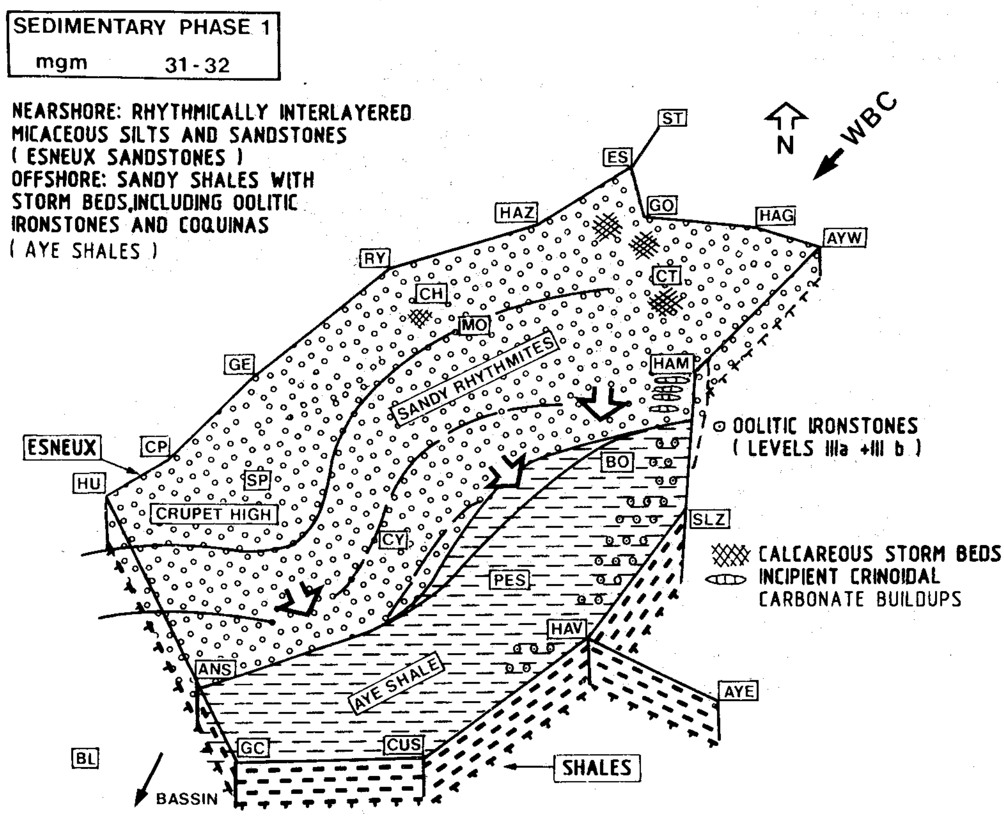

Figure 24.- Seaward progradation of the Esneux Sandstone facies, with a more pelitic sedimentation on the outer shelf (cf. Aye Shale facies).

As evoked before, the detrital material was derived from reworked pro-delta sands to the N-NE of the studied area and transported westward by the W.B.C. current. Later on, the waves have redistributed the material over the entire paleobasin, accumulating the coarser fraction (silts and fine sands) on the inshore parts (on the northern flank of the Dinant Synclinorium and in the Namur and Vesdre Synclinoria), whereas the finer fractions were transported offshore (southern part of the Dinant Synclinorium) accumulating there as the Aye Shales.

During this first sedimentary phase, two different sedimentological features marked the depositional area in the Dinant Synclinorium. Firstly, around Crupet (Fig. 24) an old "high" is perceptible (cf. Crupet Cap), and can be traced back at least to the Frasnian (Beugnies, 1964). It will influence the paleogeography of the "Psammites du Condroz" during the later phases. Secondly, two oolitic ironstone levels (levels IIIa and IIIB of Dreesen, 1982) are intercalated in the mixed sandy-pelitic sediments of the area comprised between Hamoir and Haversin (southernmost part of the Dinant Synclinorium).

7.B. - SEDIMENTARY PHASE 2 (Zonal interval 32 to 34)

This sedimentary phase is characterized by an important transgressive event which succeeded to the regressive trend in the Esneux Sandstones. This second phase consists of a nodular limestone facies of varying thickness (up to 80 m in the Ourthe valley). This peculiar facies is composed of centimetric, subangular to subrounded limestone clasts embedded in a calcareous sandstone or sandy shale; the two latter lithologies match the petrography of either the Esneux Sandstones or of later Formations. However, the mean content of feldspars only reaches here 15-20 °/o. The mixed microfacies can be defined as a very sandy bioclastic micrite/ microsparite, grading into allochemic feldspathic finegrained sandstones (according to the petrographic nomenclature of Mount, 1985). Microfacies analysis of the limestone clasts (essentially crinoidal-foraminiferal wackestones and packstones), points to a protected

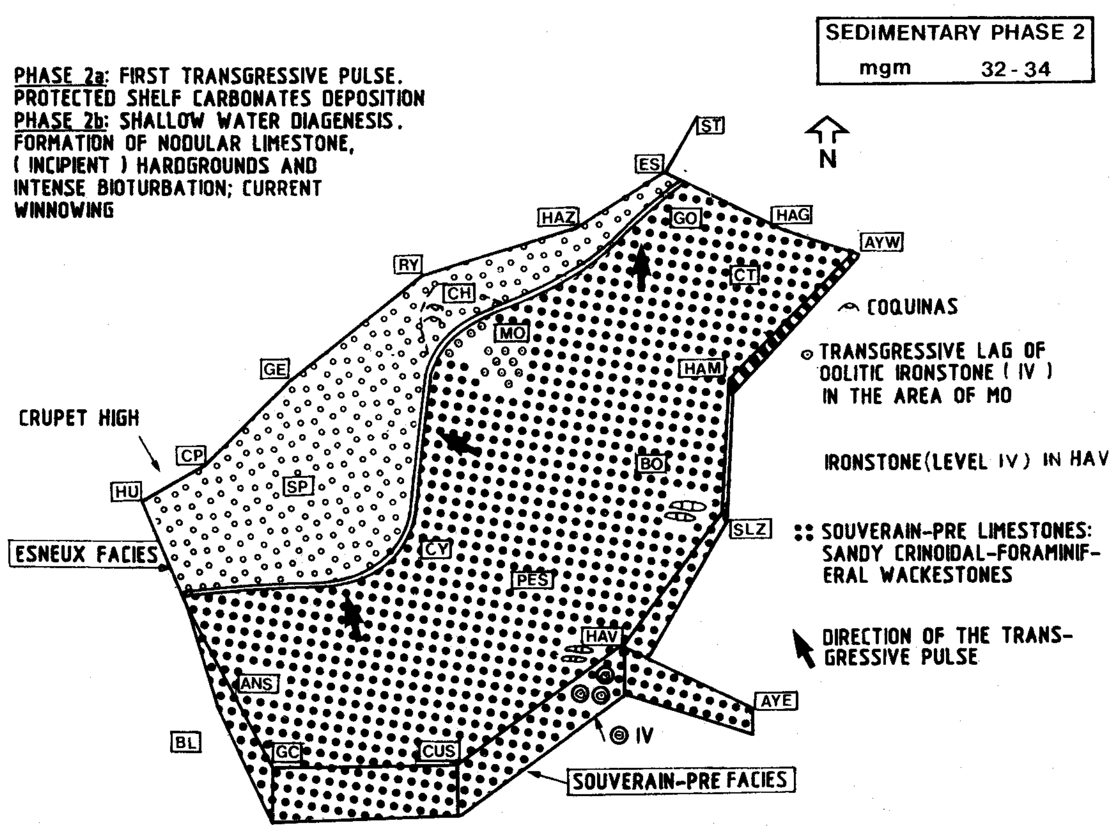

Figure 25.- First marine transgressive pulse (interval 32 to 34) affecting most of the southern and eastern parts of the Dinant Synclinorium and extending to the East, where the "Marbre Rouge à Crinoïdes de Baelen" was formed contemporaneously in the Vesdre Synclinorium. This transgressive pulse corresponds to the Souverain-Pré nodular limestone facies. Note that the northern flank of the Dinant Synclinorium acted as an emerged or shallow water area. An oolitic ironstone horizon (level IV of Dreesen, 1982) occurs at the base of the nodular limestones near Haversin (as an allochthonous deposit). At Modave and Chabofosse the coeval oolitic ironstone (also level IV) was deposited as a transgressive lag.

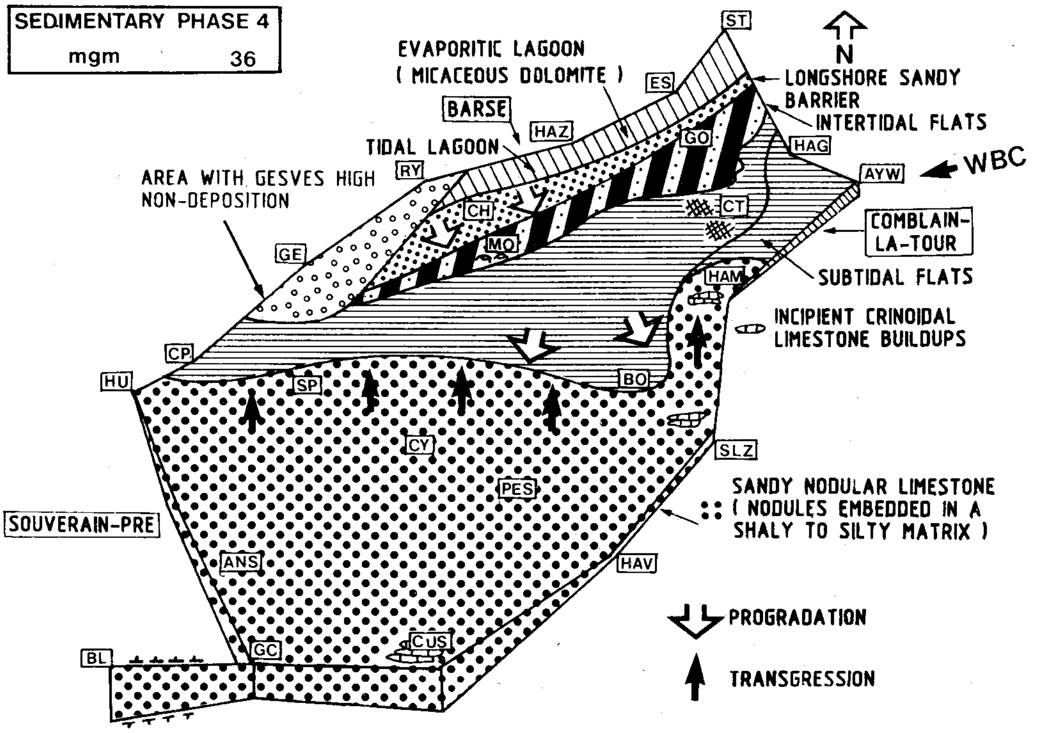

Figure 26.- Increasing basinward progradation of the "nearshore" environments (tidal flats-sand barrier- evaporitic lagoonal) a long the northern and northeastern flank of the Dinant Synclinorium. The barrier system has been encroached by the Souverain-Pré nodular limestone facies. When the latter retreated progressively to the South and South-West, a second transgressive pulse developed to the North-West around Hun-Spontin.

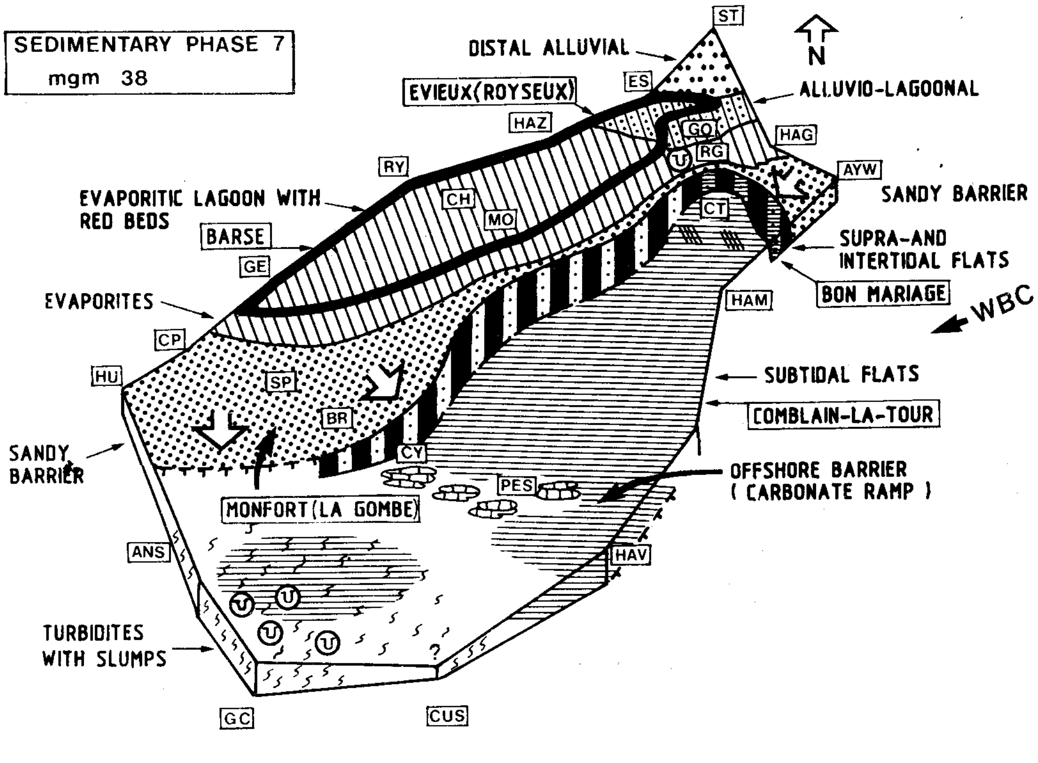

Figure 27.- Southwestern and western progradation of the inshore sandy barrier, with simultaneous development of back-barrier evaporitic lagoons. The intertidal environmental belt and also the subtidal deposits prograded basinward. The latter overlapped the Souverain-Pré facies. There was still an offshore carbonate barrier (incipient carbonate buildups) along a line joining Ciney and Haversin. In the southwesternmost part of the area, turbiditic deposits accumulated with frequent slumpings and ball-and-pillow levels. The evaporitic lagoon comprises several redbeds which extend from Gesves to Esneux.

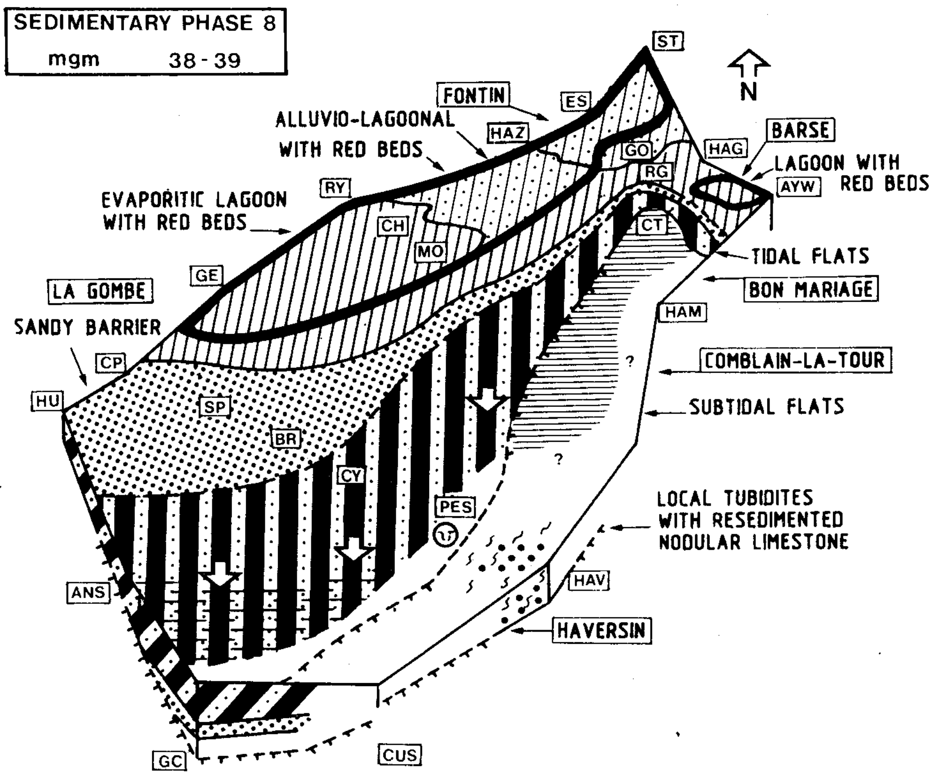

Figure 28.- Maximum progradation of the inshore depositional environments (sand barrier and tidal flats). The latter even overlapped the fluxoturbidites in the South-West. The evaporitic lagoonal facies replaced the evaporitic environment. Fluxoturbidites only occur near Haversin.

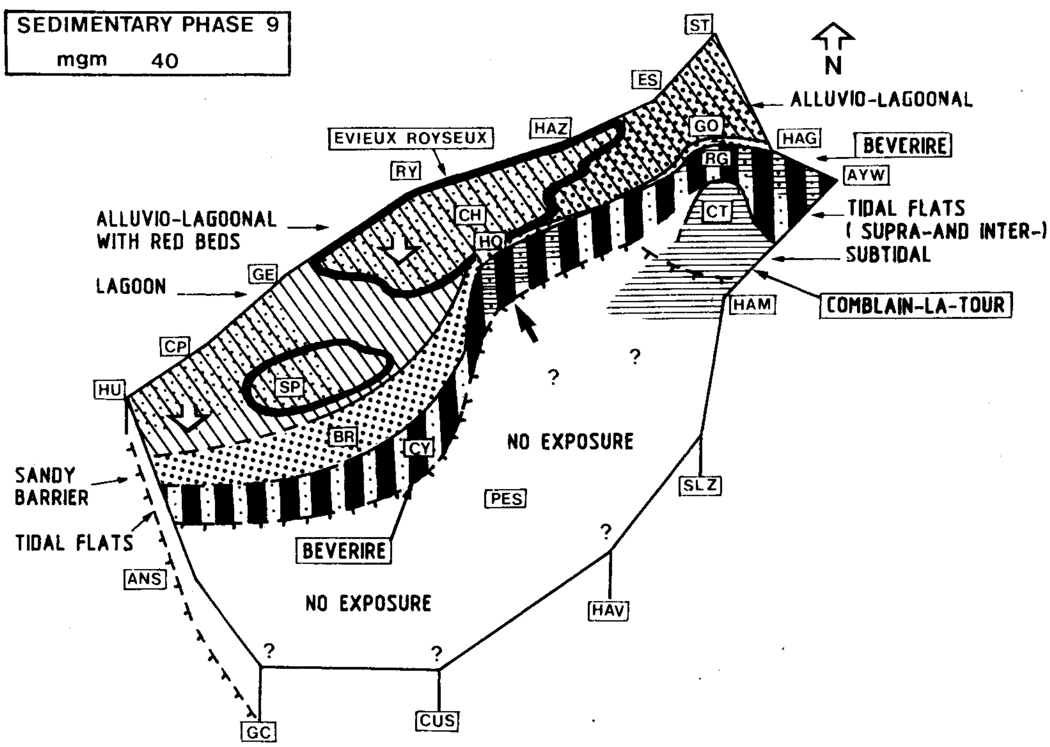

Figure 29.- Standstill of the barrier system in the northwestern sector. The barrier had become sensibly reduced in its lateral extension as compared with the situation during sedimentary phase 8. On the contrary, the alluvio-lagoonal environments prograded along the northern flank of the Dinant Synclinorium protected by interrupted sand barriers, allowing frequent intermixing of alluvio-lagoonal and tidal flat deposits.

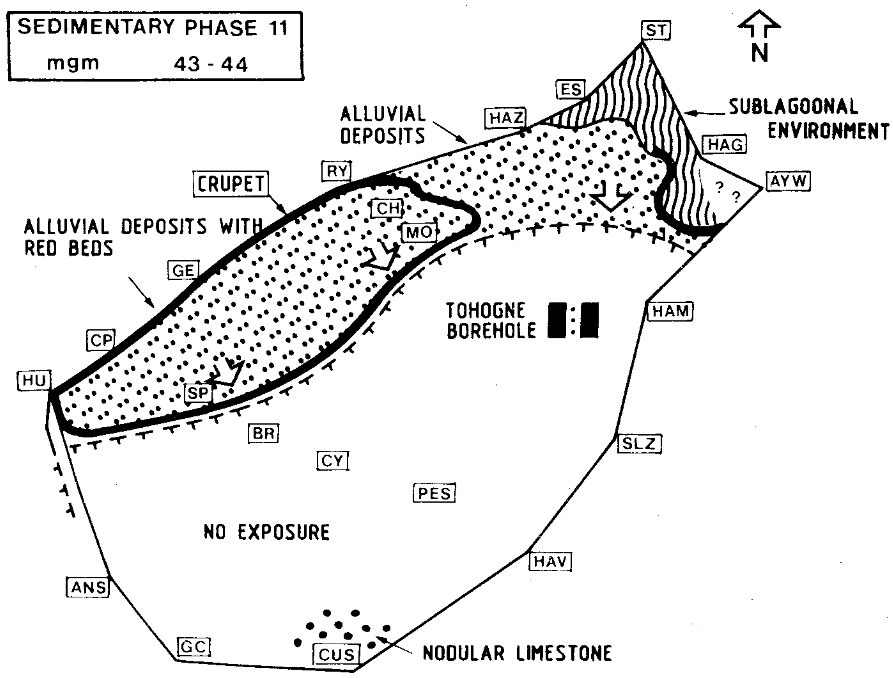

Figure 30.- Maximum progradation of the "Psammites du Condroz" on the northern flank of the Dinant Synclinorium. Sublagoonal conditions returned in the Ourthe valley were ostracodal micrites are interlayered within the siliciclastics. The development of this depositional environment has been favoured by the lateral (south-southwestward) progradation of the alluvial system.

subtidal shelf environment (Dreesen & Thorez, 1980; Dreesen *et al.,* 1985). This nodular limestone facies corresponds to the Souverain-Pré Formation. If well-developed in the Ourthe valley, the formation wedges on the contrary to the North (i.e. in the Hoyoux valley) where it is only 2 m thich near Modave. Only the Crupet Cap seems to have escaped from the effects of this transgressive pulse (non-deposition). This nodular facies would retreat progressively to the S-SW because of a renewed influx of siliciclastics. The diachronism of the Souverain-Pré Formation is thus caused by differential subsidence and oscillations of the onlap : the Formation becomes younger towards the West and Southwest.

This nodular facies represents an episodic high-energy event : after a temporary decrease of the siliciclastic supply - which is attributed to a deviation of the W.B.C., by a relatively and temporary erection of a tectonic barrier : the Fraipont High between the Dinant paleobasin and the Vesdre paleobasin (see Fig. 34) - bioclastic carbonates accumulated in a protected, subtidal shelf environment. The sediments underwent an early consolidation (proto-hardgrounds). Subsequently they crumbled to small clasts due to the possible effects of earthquakes. The clasts were redistributed locally and acquired their final subangular to subrounded shapes. It is also possible that storms have contributed to the dispersion of these clasts and to their subsequent embedding into a more sandy matrix. An indirect clue for seismic activity during the sedimentation of the "Psammites du Condroz" is the presence of several levels of ball-and-pillows (cf. "pseudo-nodules") in the directly superposed Ciney, Comblain-la-Tour and Montfort Formations. In the latter Formation, twelve distinct levels of ball-and-pillow structures have been traced from the North to the Southwest in the Ourthe valley (where they serve as local marker-beds), crosscutting all depositional environments (from the alluvio-lagoonal in the North to the subtidal flats in the Southwest).

With the lowering of the Fraipont tectonic barrier and the return of the W.B.C. in the eastern part of the Dinant Synclinorium, the nodular facies progressively shifted but diachronically in a south-western direction during phases 3 and 4 (Fig. 26). Evenmore, in the area of Spontin (Bocq valley), the retreat of the Souverain-Pré facies is, there, marked by a local transgressive pulse.

During the sedimentary phase 2, a coeval deposit of the Souverain-Pré Formation in the Vesdre area it gave birth to the so-called "Marbre rouge à crinoïdes de Baelen" (Dreesen & Flajs, 1984; Dreesen *et al.,* 1985) (see further). The latter algal-sponge-crinoidal carbonate buildup was located on a tectonic high. These reefoid structures produced a NW-SE oriented, temporary (fraction of one single Conodont zone) and discontinuous barrier. This barrier allowed the development of a protected shelf carbonate platform in the Vesdre paleobasin in a back-barrier position, and favoured subsequently the formation of bioclastic limestones found westward in the Dinant Synclinorium. This reefoid

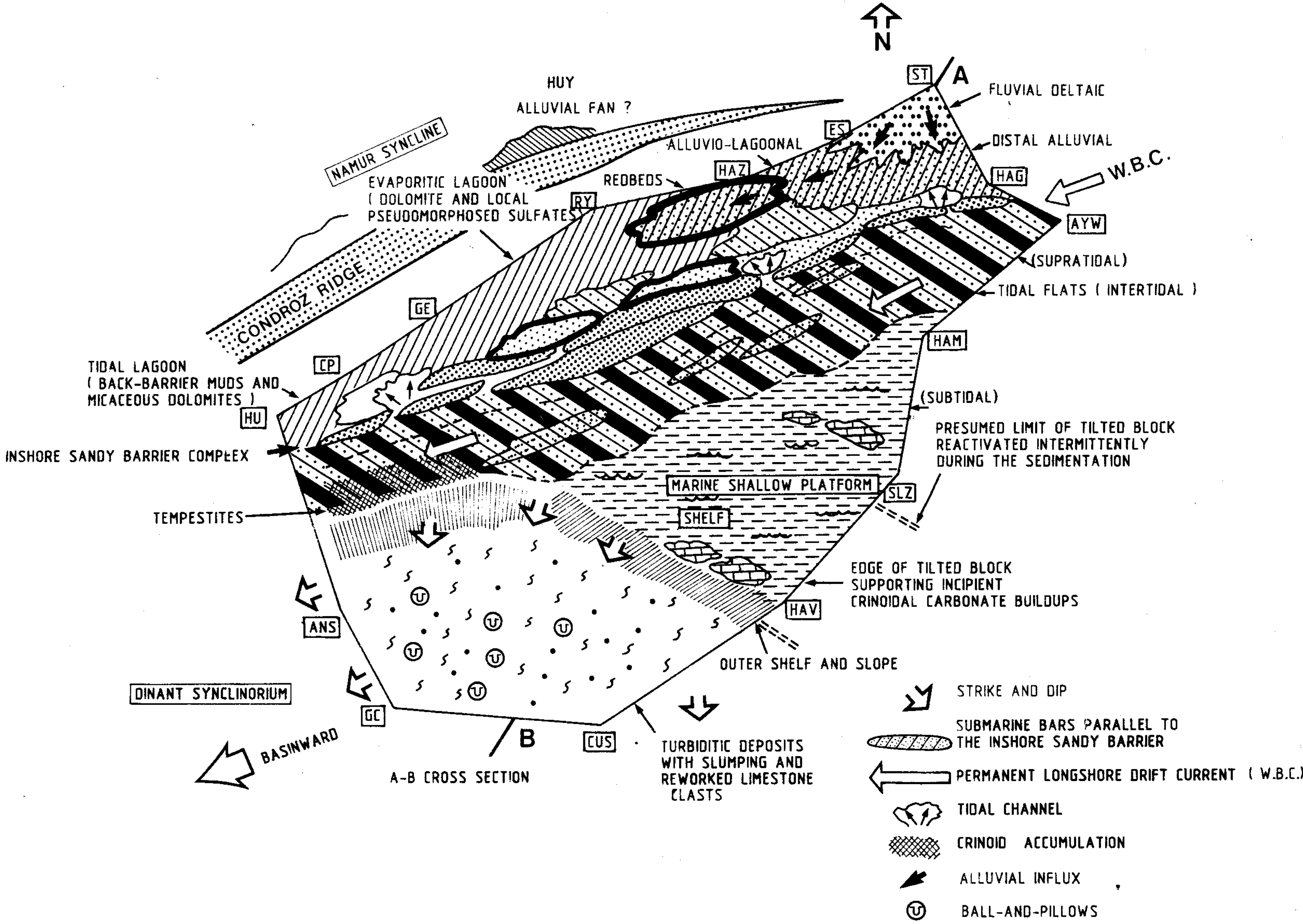

Figure 31.- Idealized relationship of depositional environments in the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium, based on the compilation of eleven sedimentary phases. This cartoon shows the principal contemporaneous depositional micro- and megaenvironments. The nodular Souverain-Pré limestone facies is not depicted here.

structure is located on the Verviers-Trier lineament of Dvořák (1973) and runs parallel to the "tectonic" barrier of Fraipont. These crinoidal mounds became quickly dismantled and winnowed by current and wave activity, allowing a return of the siliciclastic influx in the Vesdre and Dinant areas, which provoked the progressive retreat of the Souverain-Pré facies to the S-SW. Some less developed (incipient) crinoidal mounds (protomounds) could have been present also along the Somme-Leuze-Haversin line (Fig. 25).

Analogous but much smaller reefoid crinoid accumulations (spare-cemented debris reefs) have been observed in the Hamoir area, in somewhat older series (within the upper part of the Esneux Formation) (Dusar & Dreesen, 1984).

7.C. - SEDIMENTARY PHASE 4 (approximatively level 36)

The paleogeography during this sedimentary phase is rather complex. In the South and South-west, the nodular limestone facies of the Souverain-Pré Formation persisted with an increasing thickness basinward (over 100 m near Gendron-Celles, Blaimont and Custine); the formation is only 2 to 3 m thick in northern parts of the Dinant Synclinorium. With the disappearance of the Fraipont tectonic barrier (see above), the W.B.C. passed again through the Vesdre Corridor, and delivered again huge amounts of siliciclastics all over the Condroz Platform. These were concentrated on the northern shelf area but tidal currents, waves and storms have redistributed the sediments into different depositional environments : tidal flats, barrier, tidal lagoons (Fig. 26).

The barrier complex resulted from the long-shore current activity accumulating the coarser material as narrow and elongated long-shore bars. Behind the latter, tidal lagoons were formed, extending from Streupas to the Hoyoux valley, in the North and North-east of the Dinant Synclinorium. Tidal lagoons are essentially characterized by rhythms with a winnowed basal sand and a micaceous dolomite top. The barrier

THE LATERAL SEQUENCE OF DEPOSITIONAL ENVIRONMENTS IN THE MINOR RHYTHMS

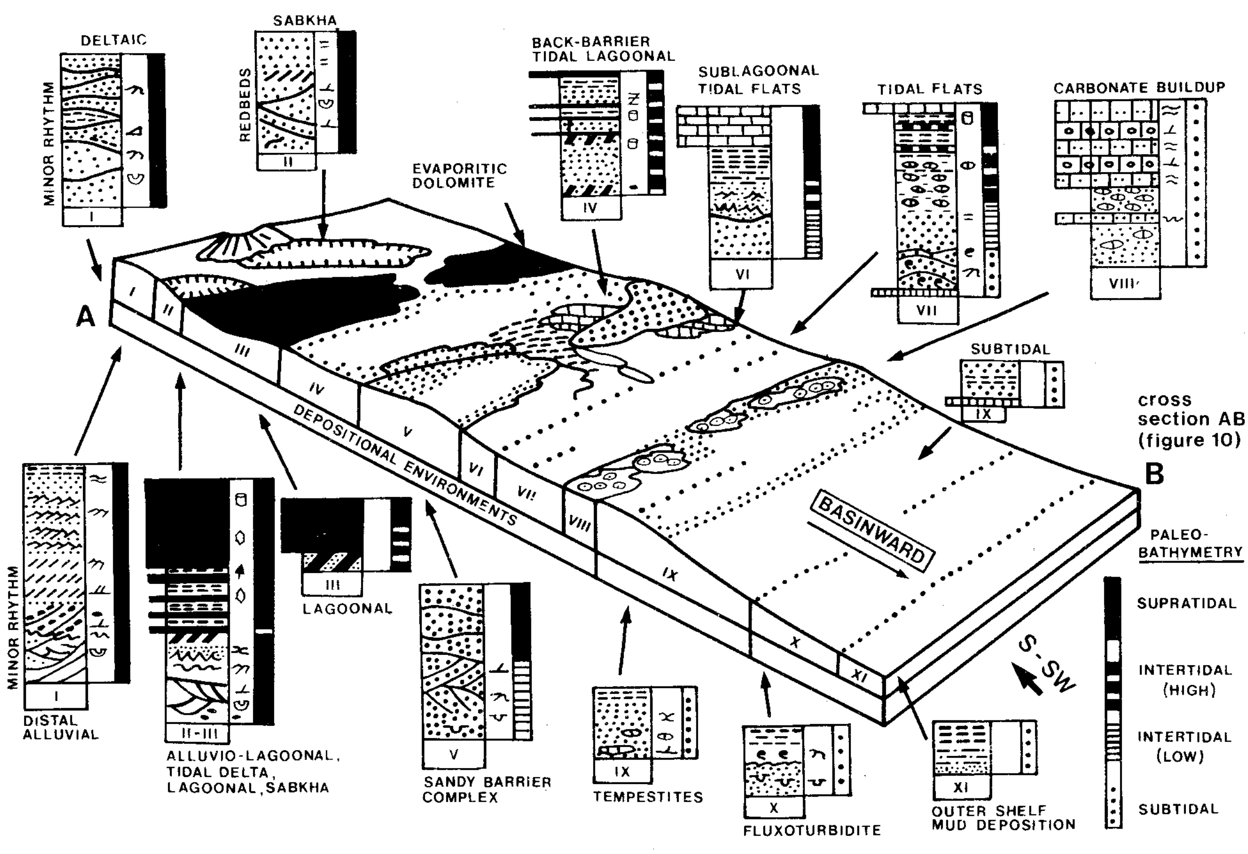

Figure 32.- Cartoon showing lateral sequence of depositional environments at the scale of minor (metric) rhythms (cf. cross section A-B in Figure 31) during the progradational accumulation of the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium. Typical minor sequences, lithologies, sedimentary structures, paleobathymetries and their lateral shift are depicted. The Souverain-Pré nodular limestone facies has not been represented. Roman ciphers (cf. depositional environments) are the same as in Figure 10.

system appears also encroached on a reduced Crupet Cap (= Gesves High).

Offshore of the barrier complex extended the subtidal flats with typically alternating sands, silts, (minor) muds and bioclastic limestones in centimetric layers (cf. The Comblain-la-Tour Formation in the Ourthe valley). During the same time interval, in the northern and northeastern parts of the investigated area, tempestites accumulated in the Spontin area (cf. Ciney Formation, not shown in Figure 26). These tempestites developed decimetric sequences displaying characteristic structures and textures of recent storm deposits (Aigner, 1982) as observed, i.e. in the Bocq valley near Spontin, with from base to top : a basal erosional unconformity, a massive ungraded to graded-bedded arkosic sandstone enclosing numerous Brachiopods and some lenticular sandy biosparites; laminated siltstones (with wave ripple bedding) and ending with a thin (often unpreserved) mud deposit. Hummocky cross-stratification and lenticular bedding (at the scale of the outcrop) are commonly observed in these tempestites, the total deposition of which exceeds 80 m. The formation of these tempestites suggests an environment below normal wave base, with episodic high-energy storm waves, possibly caused by hurricanes (more than 60 preserved rhythmic tempestites have been observed in the Bocq valley : an area which might have been well-exposed during Famennian times to tropical hurricanes). Hurricanes were, indeed, very common in paleolatitudes between about 10^{o} to 45^{o}S (with a maximum frequency between 10^{o} and 20^{o}S) (Duke, 1985).

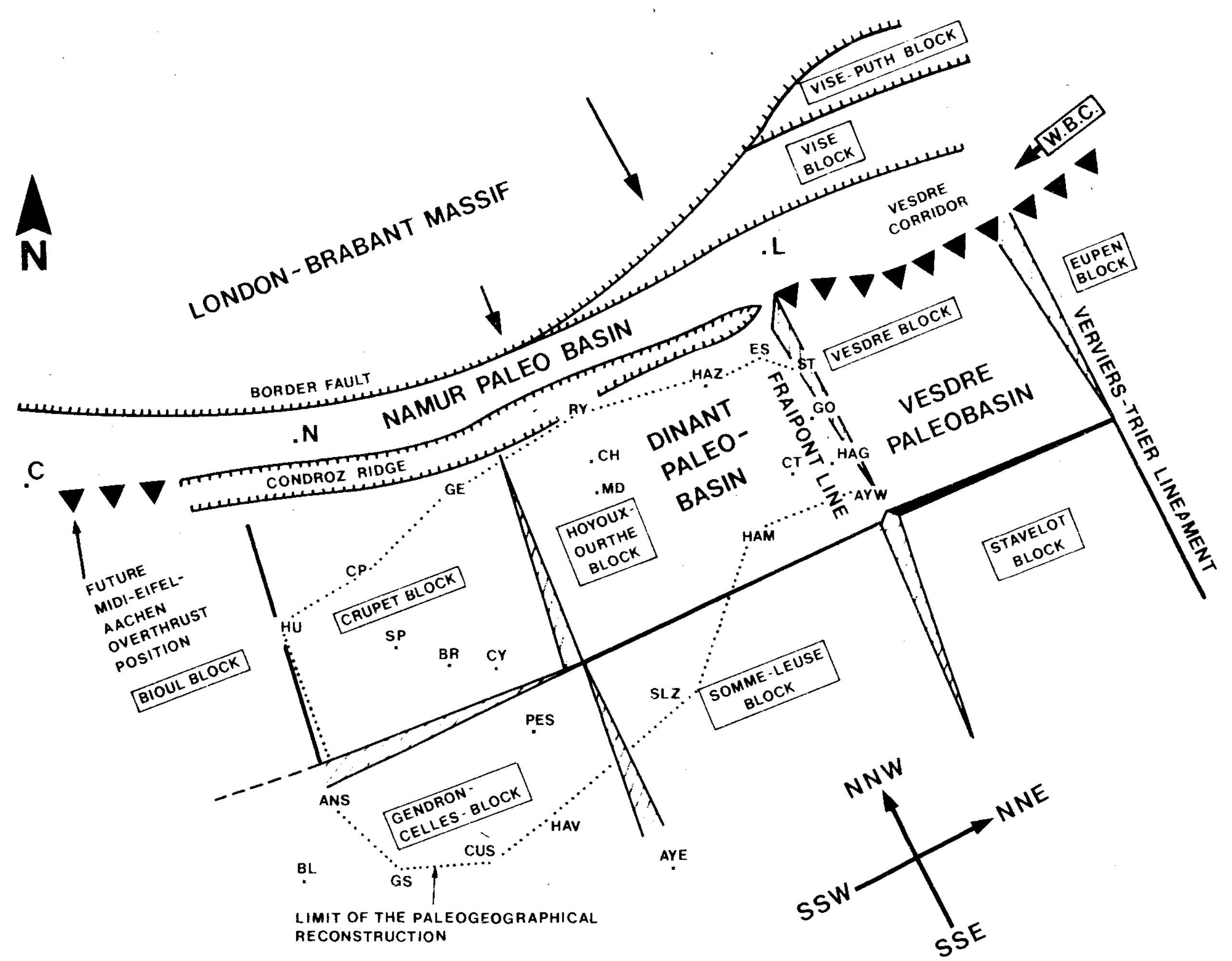

Figure 33.- Inferred blocks within the eastern part of the Dinant Synclinorium. The limits of the investigated area (dotted line) are the same as in the paleogeographic reconstructions (figures 23 to 31). The faults match the NNW-SSE, and SSW-NNE trends of blocks indentified in FRG (Paproth *et al.*, 1986, this volume, Fig. 4). The irregular reactivation of these blocks, as well as that of the neighbouring ones, has influenced the paleogeographic evolution of the "Psammites du Condroz" (Figures 23 to 30). The palinspastic reconstruction is pre-tectonic (prior to the Variscan tectonic phase), but delineates the separation of the Namur and Dinant paleobasins by the emersion of the "Condroz Ridge", an elongated structure dating back to "Evieux" times, and practically located on the later Midi-Eifel-Aachen Overthrust which, displaced the Dinant paleobasin over the autochthonous Namur paleobasin by a shortening of the paleobasin of some 10 km.

The microfacies of the enclosed carbonates and/or allochems within these sandy tempestites indicate a protected shelf area, from which area both the siliciclastics and the carbonates were removed and subsequently swept across the open shelf. This explains the frequent occurrence of mixed conodont biofacies. Moreover, even lagoonal sediments have been reworked as indicated by the occurrence of some detrital evaporitic dolomite grains within the tempestites (Goemare, 1984).

7.D. - SEDIMENTARY PHASE 7 (approximatively level 38)

The paleogeography of this sedimentary phase remains complex although a clear partition persisted between the North and the South (Fig. 27). In the North, the barrier complex has extended as far as the Hun area, whereas remaining rather narrow in the viscinity of Aywaille (Amblève valley). The barrier is fringed offshore by tidal flats (mostly inter- and supratidal sediments) (cf. Bon Mariage Member of the Montfort Formation). In the southern area, approximatively South of a line between Braibant-Ciney and Rivage, the main part of the shelf was occupied by subtidal flats with continuous deposition of alternating sands, silts and limestones (cf. Comblain-la-Tour Formation). These subtidal flats extended as far as Haversin in the southern part of the investigated area. These are fringed in turn, by a series of incipient crinoidal carbonate buildups along a line linking Ciney and Haversin, and located along a gentle slope ramp corresponding to the suture between two tectonic blocks (see further).

South of the sandy barrier complex (in the Hun-Braibant area), and to the Southwest of the tectonic ramp, fluxoturbidites were deposited (in an area located between Anseremme, Gendron-Celles and Custinne). These fluxoturbidites accumulated in shallow waters, and consisted (Fig. 22) of poorly sorted siliciclastics frequently embedding subrounded clasts of crinoidal limestones (derived and transported basinward from the proto-mounds along the Ciney-Haversin line). Moreover these shaly turbiditic sediments are irregularly interrupted by relative thick metric, poorly sorted arkosic sandstones with characteristic slumps and ball-and-pillow structures in their basal part.

Behind the barrier system, the sedimentary rhythms consist of winnowed metric arkosic sandstones, with intergranular evapotranspirated dolomitic cement; they are capped by thin (micaceous or not) dolomitic layers which originated through direct physico-chemical precipitation of magnesian brines on the floor of the lagoonal pans. The minor and major rhythmic structures are well-exposed in the Barse Member of the Montfort Formation of the Hoyoux valley (Chabofosse) (Fig. 12). The top of the series, which represents a typical evaporitic lagoonal environment, and which can reach 100 m, includes some redbeds. The origin of these redbeds is related to a sabkha regime (as in the Bocq valley), but may, locally,. correspond to alluvial deposits with conspicuous paleosoils (Chabofosse). The top of the paleosoils exhibits all characters of a dolcrete. Figure 27 shows the extension of the evaporitic lagoonal system, and that of the associated redbeds.

In the northeasternmost corner (in the area of Esneux and Streupas), the sedimentation acquired an alluvial to alluvio-lagoonal character, indicating a S-SW shift of the barrier and back-barrier depositional environments, now accompanied by a seaward progradation of the most inshore facies. However these alluvial deposits will, be restricted to the back-barrier area throughout later phases : they are indicative of the destruction of the delta lobes (outside the investigated area) and of reworked deposits now reaching the Dinant paleobasin. However, alluvial deposits have been encountered in the Vesdre area (i.e. Soumagne borehole) as well.

7.E. - SEDIMENTARY PHASE 8 (zonal interval 38 to 39)

The major change during sedimentary phase 8 was the extension of the intertidal and supratidal flats (cf. Bon Mariage Member of the Montfort Formation) into the area formerly occupied by fluxoturbidites (Anseremme-Pessoux and Custine) (compare Figs. 27 and 28). North of the barrier, the alluvio-lagoonal deposits also prograded in a S-SW direction. An evaporitic system, with some intercalated sabkha redbeds, replaced the barrier-back-barrier environments in the area between Hagoheid and Aywaille (Amblève valley). In the vicinity of Haversin, there are still some fluxoturbiditic deposits (Haversin Member of the Ciney Formation). The subtidal deposits corresponding to the Comblain-la-Tour Formation are restricted to an area Southeast of the line Comblain-la-Tour and Pessoux.

7.F. - SEDIMENTARY PHASE 9 (approximatively, level 40)

The lack of exposures in the South (due to post-Variscan erosion and Tertiary pene-planation) does not allow a complete paleogeographic reconstruction for the "Psammites du Condroz". However, the picture for the northern area is more complete. The barrier system has become remarkably reduced in the northwestern sector, whereas it has practically disappeared in the northeastern sector (where alluvio-lagoonal deposits are in direct contact with intertidal and supratidal deposits) (Fig. 29). Red beds have reached the Bocq valley where alluvial deposits alternate with lagoonal episods. The latter comprise directly physico-chemically precipitated dolomites, but also anhydrite layers (actually pseudomorphosed into dolomite) (Goemaere, 1984; Goemare *et al.*, 1986). In the area of Hagoheid and Aywaille, a "transgressive" pulse can be noticed that is represented by tidal flats deposits surmounting former lagoonal deposits with some redbeds.

7.G. - SEDIMENTARY PHASE 11 (zonal interval 43 to 44)

As quoted above, the lack of exposures allows only a limited paleogeographic reconstruction of the northern flank of the Dinant Synclinorium. Isolated data are obtained from the Tohogne borehole where the deposits still bear a tidal flats character (Fig. 30). Otherwise all the preserved sediments have an alluvial signature (Evieux Formation).

Redbeds have typically prograded further to the S-SW, surmounting the alluvio-lagoonal deposits of the former sedimentary phase. In the northern part of the Ourthe valley (Esneux), siliciclastics with a more muddy character were deposited, and alternate with micritic limestones (comprising a more sublagoonal microfauna) (i.e. the outcrop along the railway directly South of Esneux). These limestones comprise ostracodes, tiny gasteropods, Umbellinaceans and algal oncoids; all of these indicate an intermittent influence of marine waters. These limestones point to a "transgressive pulse" starting from the NE beyond the investigated area (and originated, thus, in the Vesdre paleobasin). However, the sublagoonal environment is interrupted by an alluvial influx (with particularly well-developed sedimentary structures : cross-bedded sandstones, slumps, truncated layers, etc.) capped by a dolcrete (Lejeune, in preparation). In the meantime there are some indications that a Souverain-Pré like nodular limestones-facies has developed and has been preserved in the vicinity of Custinne.

8. - PALEOGEOGRAPHIC MODEL FOR THE "PSAMMITES DU CONDROZ" IN THE DINANT SYNCLINORIUM

Figure 31 shows an idealized and compiled paleogeographic model for the Upper Famennian combining all data obtained from individual maps and from the study of eleven successive sedimentary phases. It shows here the main depositional patterns of the "Psammites du Condroz" in the eastern part of the Dinant Synclinorium, but it may be actually extrapolated to the neighbouring areas (Namur and Vesdre Synclinoria, Thorez *et al.*, in preparation). A cross-section (A-B) shows the lateral juxtaposed depositional environments (with their specific associated rhythmic motifs) at the scale of a lateral minor sequence (Fig. 32).

The superposition of the different paleogeographic maps shows the persistence of the main sedimentation caracteristics, despite some lateral shift, from the NE to the SW, of inshore to offshore environments : distal (deltaic) alluvial, alluvio-lagoonal, evaporitic and tidal lagoonal, barrier complex, tidal flats, marine (subtidal) shallow platform with fluxoturbidites and tempestites. Of particular interest is the elongated S-SW narrow barrier system which permanently separated the depositional environments into back-barrier and more open marine environments. The whole system resulted from the activity of a longshore drift current (W.B.C.) that has progressively built up elongated submarine sand bars, then emerging bars (these becoming coalescent and forming a permanent barrier complex behind which evaporitic conditions prevailed and favoured the physico-chemical precipitation of dolomites and occasionally of sulphates). The permanent activity of the W.B.C. has hampered all seaward development and deposition of alluvial sediments, and has forced the latter to prograde only along a S-SW direction, but always behind the sand barrier complex. Tidal flats developed, thus, apparently abnormally, in between this inshore sand barrier and a more offshore temporary barrier, which is composed of incipient crinoidal carbonate buildups (located along a tectonic ramp).

9. - SYNSEDIMENTARY TECTONICS

The paleogeographic reconstruction of the "Psammites du Condroz" in the Dinant Synclinorium (this paper) but also in the Namur and the Vesdre Synclinoria (Thorez *et al.*, in preparation), as well as the paleogeographic reconstruction for the paleobasin South of the London-Brabant High and extending into the Federal Republic of Germany reveal the influence of another important mechanism which has largely controlled the evolution of the depositional environments (see Fig. 4 in Paproth, Dreesen & Thorez, 1986). This mechanism is related to synsedimentary tectonic movements, episodically occurring along deep-seated block-faults, which are intermittently and locally reactivated during certain sedimentary phases, in particular in the Dinant Synclinorium.

The existence of block-tiltings was already referred to by Bless *et al.* (1983) in the area immediately North of the London-Brabant High. The supposed limits of such blocks have been established with more accuracy by Paproth, Dreesen & Thorez (1986, Fig. 4). Six of these blocks display general NNW-SSE and SSW-NNE trends. The first direction corresponds to that of the important structural lineaments recognized by Dvořák (1973) in the Rheinisches Schiefergebirge. In Belgium, at least 10 blocks have been distinguished, the limits of which, particularly in the Dinant-Namur-Vesdre Synclinoria, show the same NNW-SSE and SSW-NNE trends (Fig. 33). These are the Bioul, Crupet, Hoyoux-Ourthe, Gendron-Celles, Somme-Leuze blocks for the Dinant Synclinorium; the Vesdre, Stavelot and Eupen blocks for the Vesdre Synclinorium; two other but smaller blocks, that of Visé and Visé-Puth are bordering, to the East, the London-Brabant High. It is not clear yet if similar blocks exist in the Namur Syncline.

All of the blocks form a conspicuous chess-board-like configuration with the same trends as the blocks identified in the Federal Republic of Germany. These blocks existed at least since the basal Frasnian,

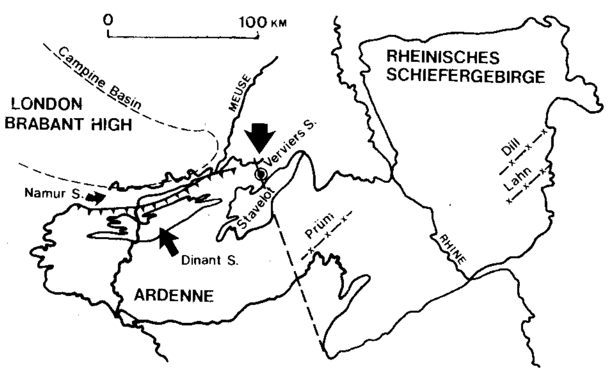

Figure 34
Tectonic sketch map of the Ardenno-Rhenish Massif, and location of the Baelen-Limbourg area with respect to the Verviers-Trier lineament.

and have been differentially reactivated in time and space during the deposition of the "Psammites du Condroz". Their differential tilting is responsible for some temporary or permanent depositional features as depicted previously (cf. sedimentary phases 1, 2, 4, 7, 8, 9 and 11). They also have been reactivated after Famennian times.

Differential, intermittent and asymmetrical tilting of these small blocks influenced the paleogeography of the "Psammites du Condroz". These movements have triggered a number of episodic, both turbulent and non-turbulent, tectono-sedimentary events within the investigated area. All these events emphasize local geotectonic activity.

Non-turbulent episodic events comprise : the differential rate of subsidence; the persistence of local shoals; the transitory presence of small highs with incipient carbonate buildups; the occurrence of non-deposition areas (as the Crupet High later on occupied by the barrier system); transitory transgressive pulses (as the one responsible for the formation of the nodular limestone series characterizing the Souverain-Pré Formation); the Baelen reef-like structures (located along the Verviers-Trier lineament); repetitive shallowing-upward rhythms (particularly those showing the reverse graded bedding), and eventually the lateral progradation (in a SSW direction) of the whole progradational "Psammites du Condroz" complex along the northern flank of the Dinant Synclinorium.

Turbulent episodic events include the triggering of fluxoturbidites; the development of several levels with ball-and-pillows ("pseudonodules") crosscutting different depositional environments in the Ourthe valley; the formation of the limestone clasts in the Souverain-Pré Formation. Presumably the latter are related to the effects of earthquakes caused by the asymmetrical tilting of the tectonic blocks in the eastern part of the Dinant Synclinorium and in the Vesdre area. Differential tilting of the Visé and Visé-Puth blocks has caused the non-deposition of Upper Famennian sediments on the former whereas the sediments accumulated on the Visé-Puth block (and pierced by a borehole near Maastricht) bear tidal flats characteristics. At the same time, alluvial sediments accumulated in the Namur, Vesdre and Dinant Synclinoria.

Similar blocks may occur in the western part of the Dinant Synclinorium, and their presence would thus extend the tectonic picture to the West of the investigated area.

Widespread oolitic ironstones levels showing density-stratification (Dreesen, 1982), and tempestites (with characteristic hummocky stratification, mixed lithologies and mixed conodont biofacies) suggest high-energy events related to tropical hurricanes and possibly to tsunamis (the latter in turn being related to earthquakes). Hurricanes may have produced the storm deposits, whereas tsunamis and the activity of the W.B.C. current have largely contributed to the dispersion of ferruginous ooids over large shelf areas producing excellent marker-beds (Dreesen, *op. cit.).* These peculiar oolitic sediments were originally formed along coastal embayments in close association with evaporites during a temporary emersion of the protected shelf area. The shallowing-upward sequences were tectonically controlled by block-tilting and the temporary erection of barriers (e.g. the Baelen-Limburg reefs and the Fraipont High). Later on, with the dissapearance of the tectonic barriers, the material was winnowed and transported basinward (to the S-SW) by the W.B.C. A time-space relationship of the different Upper Devonian oolitic ironstone levels with highly explosive synsedimentary volcanism (Dreesen, 1982) would evoke the possibility of tsunamis transporting ferruginous ooids over very large shelf areas (Dreesen, 1986)*

Block-tilting also intermittently blocked the transport of siliciclastics from the north-eastern source by the W.B.C. Beyond these tectonic barriers (Fraipont High and the one on which the Baelen-reef structure was located), subtidal limestones formed over a large part of the shelf area (eastern part of the Dinant Synclinorium); however, some sectors of the sedimentary basin "escaped" from the transgressive pulse producing the limestones (such as the area around Crupet in the Namur Syncline). These limestones bear a micro-fauna depicting protected marine conditions; later on they were reworked as clasts becoming embedded in a sandy matrix and giving rise to the characteristic nodular sandy limestones of the Souverain-Pré Formation.

The northern limit of the Bioul-Crupet-Hoyoux-Ourthe-Vesdre-Eupen tectonic blocks more or less

* DREESEN, R., 1986 (in press). Event stratigraphy of the Belgian Famennian (Uppermost Devonian, Ardenne Shelf). *In :* A. Vogel (ed.) : The Rhenish Massif. Earth Evolution Sciences, Berlin.

matches the partition between the later Dinant and the Namur tectonic units and parallels the Midi-Eifel thrust-fault. Presumably, the Dinant Synclinorium has been displaced over the autochtonous Namur structure over at least a dozen Km during the Asturian phase. The similitude of depositional environments on both sides of the Midi fault (when comparing those preserved in the Namur Syncline, to those of the northern flank of the Dinant Synclinorium) could suggest that a maximum shortening of the original depositional basin has been reached during Famennian times. Particularly the Crupet High (sedimentary phases 1 and 2) was limitating the northern parts of the Bioul-Crupet and part of the Hoyoux blocks.

The quasi-permanent asymmetrical tilting of these blocks has also controlled the buildup and later westward extension of the barrier system. Eventually, during sedimentary phase 11 (coinciding within the deposition of the alluvial Evieux strata), a permanent "Condroz ridge" appeared (Paproth, Dreesen & Thorez, 1986, Fig. 8), separating the two future tectonic units, the Namur Syncline and the Dinant Synclinorium. The existence of such an emerged "ridge" or high is emphasized a.o. by the exceptionally well-preserved plants found in the nearby Bocq valley at the time the latter area received alluvial deposits. Low levees and a narrow, small floodplain bordering the southern flank of the "Condroz ridge" provided propitious environmental conditions for the growth of *Archaeopteris* and *Condrusia* (Goemaere, 1984). Their delicate branches, with still attached sporanges only can have been transported over a very short distance into the Bocq valley. These structures would have not survived indeed long transport with high-energy hydrodynamic conditions (as for the W.B.C.). The "Condroz ridge", is also indicated in the Hoyoux valley (Royseux, Chabofosse and Modave), at the same stratigraphical level as a local elongated emerged high that separated the back-barrier-barrier system from the later alluvio-lagoonal depositional environments : there polycyclic paleosoils with several dolcrete horizons developed; they ended with dolomite and sulphates and only occupied a narrow stream channel (with a width of about 20 m from one level to the other) oriented perpendicularly to the "Condroz ridge".

The existence of the Crupet High and of the later Condroz ridge, rather early in the sedimentation history of the "Psammites du Condroz", does not preclude absolutely that the shortening of the paleobasin was completed during the Upper Famennian times. A simple comparison of facies appears rather dangerous as a definitive clue for attesting that the two tectonic units, the Namur Syncline and the Dinant Synclinorium, were at their minimum distance. Lateral variation of facies and, thus, of environments, is a rule in the "Psammites du Condroz" (as depicted i.e. in Fig. 8). Should the Dinant Nappe have become displaced by several dozens of Km (as suggested by data from northern

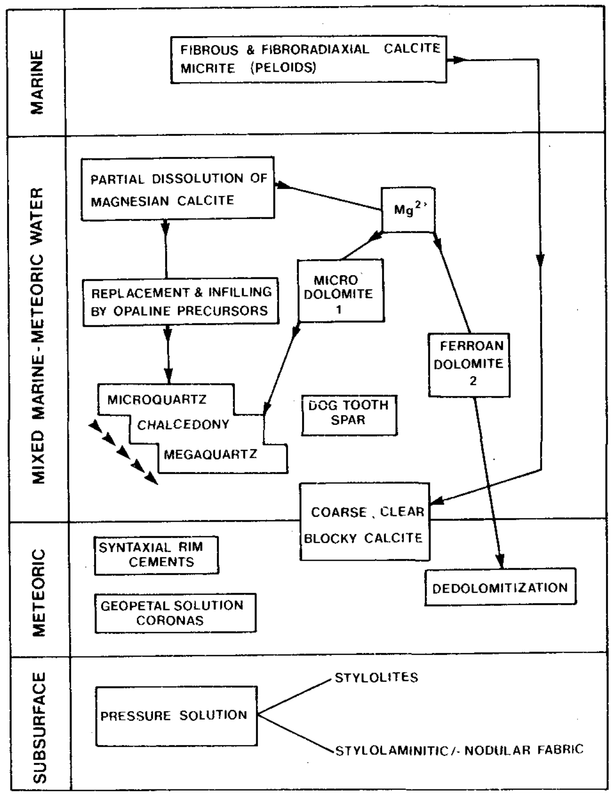

Figure 35
Successive diagenetic stages and diagenetic events observed within the Baelen limestone complex.

France, Epinois borehole), it would imply that a completely masked depositional area exists beneath the Dinant Nappe and escapes, consequently, all paleogeographic reconstruction. Such a masked area could have been occupied by a laterally extended lagoon of which the series observed (over 40 m) in Streupas could only be an edge portion.

The Upper Famennian in the Namur Syncline is either missing (by post-erosion or by non-deposition) or weakly developed, and shows sedimentary features which resemble, at the best, the more inshore environments found on the northern flank of the Dinant Synclinorium. In Huy, the Upper Famennian developed about 200 m thick red sandstones overlying the Esneux Sandstones. The exact age and the real environmental significance of this series within the general paleogeographic reconstruction of the "Psammites du Condroz" on the Condroz Platform, require further study. Thus a pure comparison of the facies as exposed on both sides of the Midi Overthrust appears insufficient to ascertain an accurate estimation of the shortening.

The Stavelot block seems to have been tilted rather permanently, with its northern flank levelled during several sedimentary phases (Thorez *et al.*, in preparation). As a consequence, the Vesdre paleobasin (Fig. 33) has become several times isolated, being limited

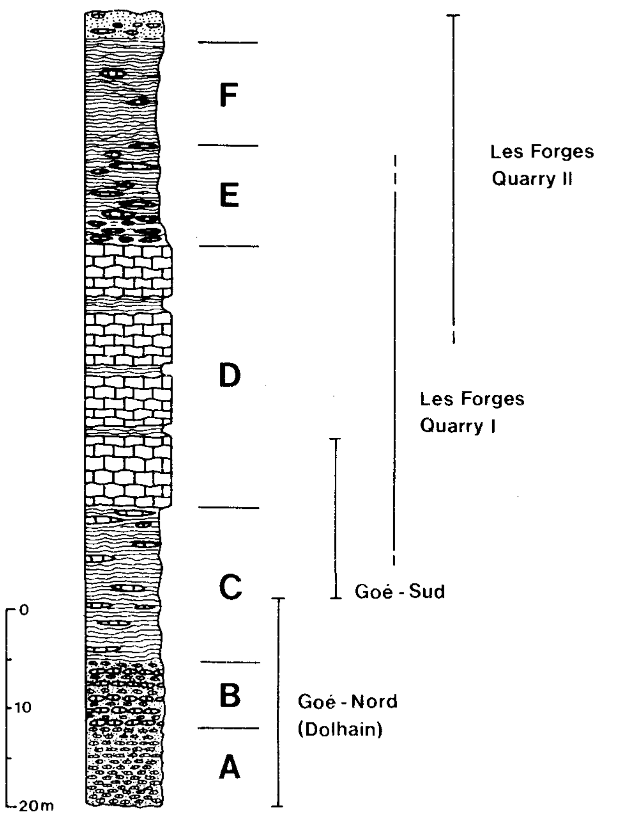

Figure 36
Compiled columnar section, lithological units and stratigraphical position of the studied section within the Baelen limestone complex.

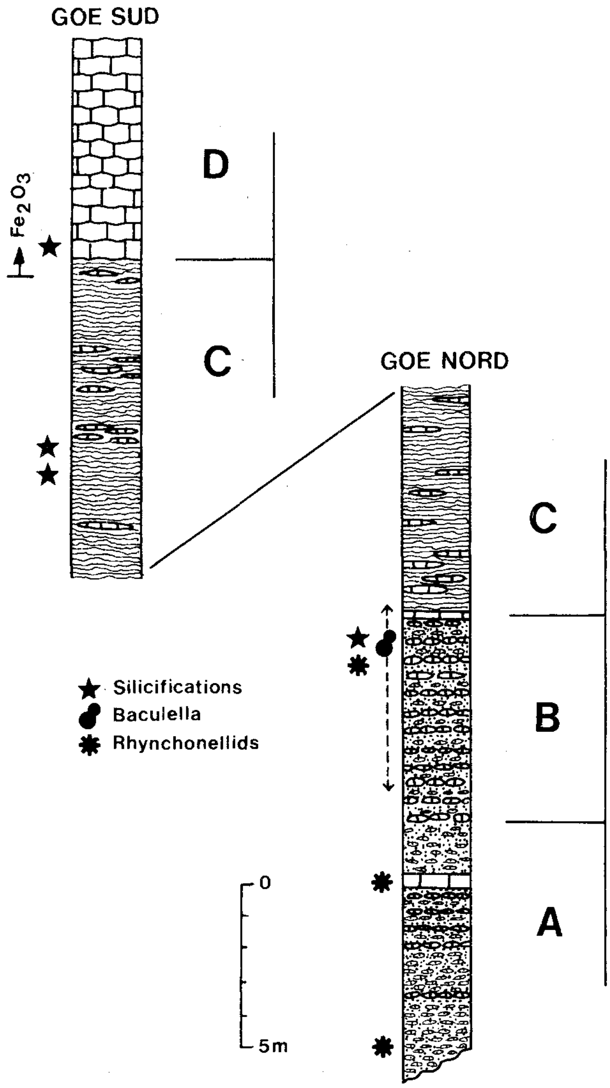

Figure 37
Detailed columnar section and lithological units at Goé-Nord and Goé Sud (sections on both banks of the Vesdre meander, North of Goé).

to the South by the Stavelot block, to the East by the Verviers-Trier lineament, and to the West by the temporary Fraipont High (which corresponded to the boundary between the Vesdre and the Hoyoux-Ourthe blocks). The tectonically controlled depositional system favoured lagoonal conditions particularly for the genesis of oolitic ironstones; under rather protected marine conditions a blanket of crinoidal limestone was formed that later on became crumbled and redistributed as a nodular limestone facies (Souverain-Pré Formation).

From the different paleogeographic maps relative to the eleven sedimentary phases it also appears that the irregularly reactivated block-tilting in the Dinant Synclinorium controlled : the progradation of the "Psammites du Condroz"; the changes of the coast-line; the general progradation of the more inshore environments; the progressive retreat of the Souverain-Pré nodular limestone through time and space. Thus the regional tectonosedimentary events have clearly dominated the paleogeography in the area, particularly in the eastern part of the Dinant Synclinorium and in the Vesdre and Namur Synclinoria.

Even if the problem of the Midi Overthrust remains, with the lack of arguments about the environments possibly masked beneath the Dinant Nappe, there is no evidence for a major worldwide event affecting the shallow Condroz Shelf and the adjacent Cornwall and Rhenish Basins. However, by the end of the Famennian, a glaciation in South America produced a global climatic change (Paproth, Dreesen & Thorez, 1986; Streel, 1986, fig. 8). This glaciation might have caused a global narrowing of the warm climatic belt, and also the characteristic and sudden Famennian regression by a worldwide fall of the sea level. The latter process would have favoured the progradation of siliciclastics according to the here reconstructed paleogeography. Regression, tectonics, sea level change are possibly intimately connected in this case. However, whereas the first two could be easily demonstrated in the investigated area, clues for the latter are still lacking or to be demonstrated.

10. - THE "MARBRE ROUGE A CRINOIDES DE BAELEN" IN THE VESDRE SYNCLINORIUM

As already referred to before, an exceptional reefoid structure occurs in the Vesdre area : the "Marbre Rouge à Crinoïdes de Baelen". This heterogenous carbonate complex is the only massive carbonate deposit, and the only reef-analogous structure observed so far within the late Devonian of the Ardenno-Rhenish Massif.

Its location is linked to the presence of a deep-seated transversal fault (the so-called Verviers-Trier dislocation of Dvořák, 1973) which is part of the chess-board-like block-tilting mentioned above. This lineament runs parallel to the analogous NNW-SSE synsedimentary faults deduced in the eastern part of the Dinant Synclinorium (Fig. 33) and in the Rheinisches Schiefergebirge (Paproth, Dreesen & Thorez, 1986, Figs. 4, 5).

Detailed sedimentological-paleontological analysis (Dreesen & Flajs, 1984; Dreesen *et al.,* 1985) has emphasized its reef-analogous character and also the role of subsiding movement during its growth. The observed diagenetic features (Fig. 35) point to a gradual uplift and a possible emersion of this buildup after its deposition.

This particular carbonate episode coincided with a transitory transgressive event, a "migration" of plurilocular Foraminifera (Tournayellidae-Endothyridae) (Bouckaert, Conil & Thorez, 1966), and a temporary waning detrital influx. Its cyclic lithological aspect (Fig. 36) reflects differences in siliciclastics and in the degree of early cementation.

The Baelen limestone complex is subdivided into six succeeding lithological units (Fig. 37) which can be best observed in the Goé and Baelen-Les Forges sections (Figs. 37, 38 and 39). The transition to the underlying micaceous silt- and sandstones is gradual and encloses a mineralized hardground which is coeval with oolitic ironstone level IV located at the very base or slightly below the Souverain-Pré limestone according to conodont data (Dreesen *et al.,* 1985).

The different lithological units of the Baelen limestone complex are characterized by one or more primary carbonate microfacies (Fig. 40). 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 often gradual. The calcareous, micaceous sandstone contains allochems as well. The overlying "argillaceous" heterogeneous 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 (very locally);

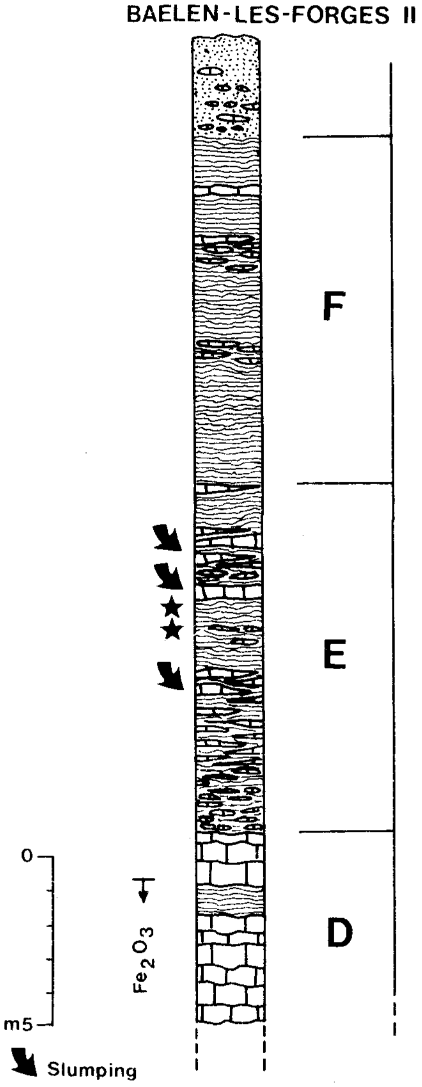

Figure 38
Detailed columnar section and lithological units at Baelen-Les Forges.

- crinoidal wacke/packstones, grading into grainstone/rudstones, often displaying graded bedding (reverse and normal), and even cross-bedding.

These microfacies alternate and grade into each other, whereas a strong compaction produced iden-supported to stylocumulate diagenetic fabrics (resulting in "secondary" packstones, grainstones and rudstones). The central unit, D, the core of the complex, consists essentially of the same, but "purer" (exempt of siliciclastics) microfacies types with a higher frequency of *stromatactis* peloidal and spiculitic mudstones. Spar cementation is here pervasive, the lime mud is almost free of detrital grains, so that compaction only produced a strong packing and a relatively weak stylolitization. Iden-supported or stylocumulate fabrics

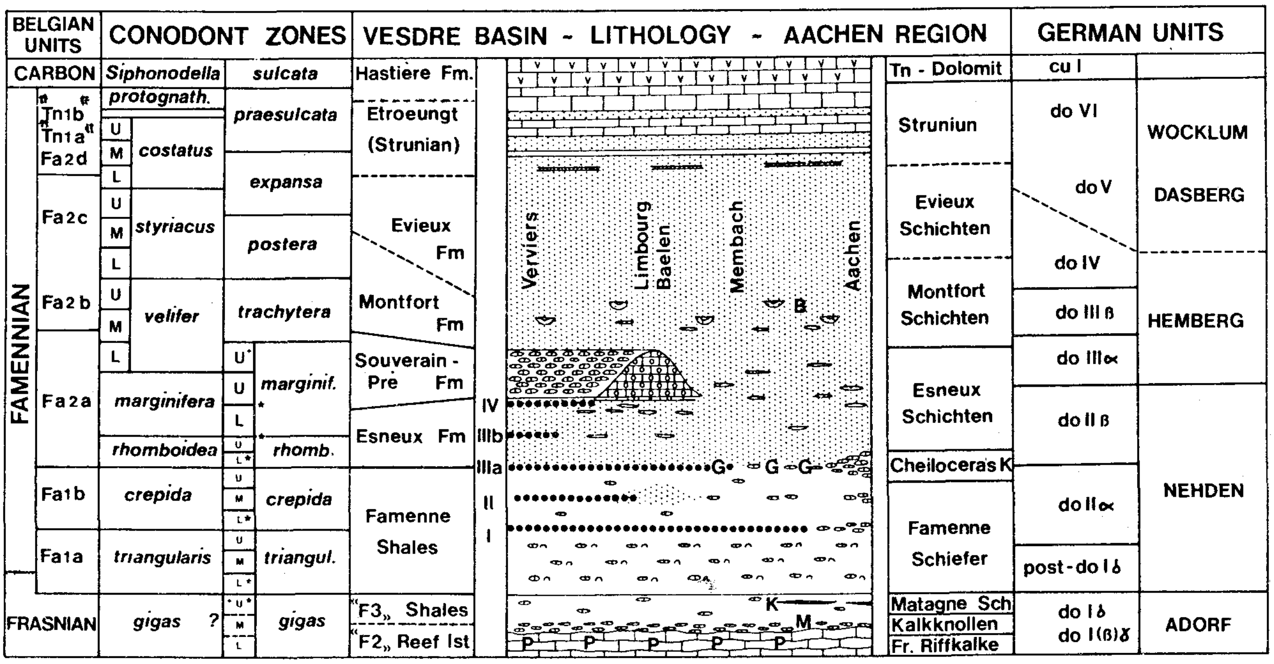

Figure 39.- Stratigraphical correlation scheme of the late Upper Devonian in the Verviers-Aachen region; Roman ciphers refer to oolitic ironstone levels of Dreesen (1982). Asterisks represent condensed conodont zonal intervals. M : *Manticoceras;* P : *Phillipsastrea;* G : *Cheiloceras;* K : Kellwasser-type limestones; B : Ball-and pillow structures. (after Dreesen *et al.*, 1985).

are absent or restricted to short, deeply red-stained "argillaceous" intervals.

Microfacies and ecological arguments point to a reef mound environment for the Baelen complex : it represents a low-diversity algal-sponge-crinoidal carbonate buildup, which grew on a shoal in an open marine shelf just below or at wave base (Dreesen & Flajs, 1984; Dreesen *et al.*, 1985).

The dominant microfacies (actually under-represented due to intense pressure solution) consists of algal, spiculitic and cryptalgal mudstones or wackestones (biomicrites) alternating with crinoidal packstones, grainstones, rudstones (coarse biosparites, encrinites), and subordinate algal bindstones and floatstones.

Probably the bulk of the lime mud has been produced and/or fixed by non-skeletal algae *in situ.* Piles of crinoidal debris and/or a hardground could have formed the basis for organic lime mud accumulation. When rates of clastic deposition were low, carbonate production could have taken place on tectonically-controlled offshore submarine shoals. Crinoids, sponges and dasyclads might have formed a suitable trapping and baffling agent, by diminuishing the local current velocities, so that the lime mud banks developed as self-propagating systems. Subsequently, their skeletal debris have been fixed by encrusting algae. Early-diagenetic (synsedimentary) marine cementation of the numerous cryptalgal and *stromatactis* cavities resulted in the stabilization of the lime mud and the consolidation of the algal mud-mound.

These algal-sponge mudstones have been deposited in a "quiet" environment, below wave base, but still within the photic zone, as suggested by the relative abundance of Issinelids (Dasycladacean green algae). A well-preserved, silicified smooth-shelled and spinous ostracode fauna from one algal mudstone/floatstone level (unit B) reflects relatively deep, or more likely quiet, open shelf conditions. The frequent but irregular interstratification of coarse, poorly-sorted crinoidal packstones, grainstones and rudstones within the algal mud mound would suggest that the mound intermittently reached the wave base, or that the mound had been affected by (storm) wave activity.

These encrinites often display graded, reverse-graded and even exceptionally cross-bedding, whereas slumping and brecciation affect the encrinites in the upper units (E-F) of the Baelen limestone complex. The former sedimentary structures as well as the relative poor sorting of the encrinites, and the mass accumulation of large, often undissociated crinoid stems (locally with calyx), suggest rather low energy conditions. It is also possible that the crinoid ossicles have been picked up and transported over short distance by storm waves or currents around and in between the growing reef mounds. Otherwise, the slumping and brecciation phenomena might indicate a considerable relief for this mound or tectonic movements (or earthquakes).

The crinoidal pack/grainstones contain broken plurilocular foraminifera, intraclasts, girvanellid on-

	Basal Bioclastic Wackestone	Algal/ Cryptalgal Mud/Wackestone	Spiculitic/ Stromatactis Mud/Wackestone	Crinoidal Packstone/ Grainstone	Top Bioclastic Wackestone
Crinoids	VF	F	F	VF	VF
Brachiopods	VF	R	R	F	F
Bryozoans	F	VR	R	F	F
Gastropods	F	VR	VR	F	F
Thick-shelled Ostracods	VF	–	–	F	F
Thin-shelled Ostracods	–	VF	F	–	–
Pluriloc.Foraminifera	–	R	–	VF	F
Agglut.Foraminifera	–	R	–	–	–
Parathuramminacea	–	R	–	R	F
Issinella	–	VR	R	F	R
Girvanellids	F	R	–	F	F
Kamaena	R	R	–	R	R
Baculella	–	VF	–	–	–
Rhodophyceae	VR	–	–	–	–
Spicula	–	VF	VF	–	–
LF-fabrics	–	VF	VF	–	–
Stromatactis		–	VF	–	–
Stromatolitic crusts	R	–	–	–	–
Conodonts	VF	R	VR	F	F

VF: very frequent;R: rare; VR: very rare; F; frequent

Figure 40. – Microfacies types and distribution of micro-organisms within the Baelen limestone complex.

coids and cortoids, vermetid gasteropods, fenestellid and encrusting bryozoans, Bisphaerids and Issinellids, all of which indicate rather shallow subtidal conditions at or just above wave base. The lenticular crinoidal wackestones just above the Baelen limestone complex contain calcispheres and Umbellinaceans, suggesting even shallower, more restricted or protected shelf environments. The close association of both mudstones and grainstones within the Baelen mound points to an alternating deposition below and above wave base. The original thickness of the Baelen complex may have exceeded some 150 m. This would indicate an important rate of subsidence, possibly related to the vertical movements along a deep-seated fault.

No clear evidence exists for the exact bathymetrical position of the Baelen reef mounds. Environmental interpretation of mudmounds and related carbonate buildups merely depends on the nature and the ecology of *in situ* living organisms as well as on the relationship with the enveloping and coeval lateral sediments. In contrast to the "deeper water mudmounds", the Baelen mounds are characterized by the absence of typical pelagic organisms, by the higher frequency of green algae, and by the shallower water aspect of the coeval sediments.

Furthermore, it is suggested that very shortly after or even during the growth of the Baelen mounds, and *during* their supposed temporary emersion, Souverain-Pré type nodular limestones were deposited under more protected shelf conditions within the backmound area (at least within the Vesdre Synclinorium). Baelen-type mounds are unknown within the Dinant Synclinorium, although proto-mounds or incipient crinoidal debris reefs episodically grew on shoals which appear to be aligned with or corresponded to fault-block sutures (for instance the Ciney-Pessoux-Haversin line, Fig. 33).

CONCLUDING REMARKS

In the Vesdre area, the "Psammites du Condroz" exhibit a distinct alluvial signature as provided by the study of Soumagne and Soiron boreholes, and an alluvio-lagoonal environment particularly near Trooz (South of Liège). The deposition was influenced by the Booze-Val-Dieu High. The alluvial source of the "Psammites du Condroz" seems well to be located to the NNE of the Condroz Platform (Paproth, Dreesen & Thorez, 1986). Moreover, the Vesdre area was permanently influenced by the passage of detrital material through the "Vesdre Corridor", and transported by longshore currents of the W.B.C.

Bad and/or incomplete exposures characterize the Upper Famennian in the Namur Syncline except in certain localities (i.e. Huy). This situation is due either to the lack of deposition along the edges of the London-Brabant High, or because of post-Variscan erosion. The southernmost part of the Dinant Synclinorium also lacks well-preserved Upper Famennian sections. This is partly due to post-Variscan (Tertiary) erosion, too. However, some isolated data have been obtained from boreholes (i.e. Tohogne) or local outcrops (i.e. Custinne). As a consequence, most of the paleogeography of the "Psammites du Condroz" has been obtained through the detailed study of the numerous outcrops and quarries in the sole eastern part of the Dinant Synclinorium, and completed by data obtained from the neighbouring area, the Vesdre Synclinorium.

The interplay of the paleogeography, paleoclimate, paleohydrodynamics and paleotectonics within the Ardenno-Rhenish geosyncline has produced a very attractive subject of study, and a model of complex progradational deposits which, within all their physical, chemical and biological aspects, reveals a rather intricate evolutionary history of the sedimentation at different scales of the accumulation. The detailed paleogeographic reconstruction would not have been possible without the pluridisciplinary work so far achieved in the Dinant Synclinorium where the "Psammites du Condroz" are the best exposed. It is the rhythm of the sedimentation at different but integrated scales, from a single bed through minor and major rhythms, to Formations, which forms the real "Ariadne tread" for unravelling the geologic history and thus emphasizes the quotation by Robertson (1948) : "Any law expressing the order in which different types of sediments are deposited is of the greatest value, not only in correlation but also in the interpretation of the sequence in terms of the physical conditions under which the sediments were laid down".

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