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OCCURENCES OF PSEUDOMORPHS AFTER EVAPORITIC MINERALS IN THE DINANTIAN CARBONATE ROCKS OF THE EASTERN PART OF BELGIUM

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ABSTRACT. - Pseudomorphs after evaporitic minerals have been found in Visean (Lower Carboniferous) limestones in the Vesder basin and in the eastern parts of the Dinant and Namur basins.

Beside the palisade calcite pseudomorphs after gypsum (SWENNEN et al., 1981), three types of pseudomorphs are recognized :

1) lozenge-shaped calcite pseudomorphs after gypsum, occurring as scattered crystals in micritic limestones or as a gypsum "silt",
2) lath-shaped calcite pseudomorphs after anhydrite and
3) square-shaped calcite pseudomorphs probably after halite.

In the Vesder and Dinant basins, these pseudomorphs are present in the Ourthe Breccia Formation (V1b). It is believed that this Ourthe Breccia formed as a collapse breccia after the dissolution of interlayered evaporitic beds. This brecciation occurred before the deposition of the overlying oölitic limestones of the Neffe Formation (V2a).

In the Namur basin, pseudomorphs have been found in thin layered supratidal limestone conglomerates and breccias on top of regressive sequences in the Terwagne (V1b) and Neffe (V2a) Formations and in algal mats of the Lives and Namêche Formation (V2b).

In the Vesder basin, two new members are defined on top of the Vesder Dolostone Formation : a palisade calcite member and a Vesder breccia member.

The occurrence of these pseudomorphs give new evidence for evaporitic sedimentation conditions during Visean time. They allow us to obtain a better insight in the different phenomena of the Visean strata such as fibrous calcites, dolomitization and dedolomitization, disconformities, conglomerates and breccias. They provide new data for a paleogeographical reconstruction.

INTRODUCTION.

Recently palisade calcite beds occurring in the Vesder basin have been interpreted as calcite pseudomorphs after gypsum (SWENNEN et al., 1981). Since the recognition of evaporitic sedimentary conditions is very important in a paleogeographical reconstruction, a more detailed study was carried out on the Visean strata in the eastern part of Belgium. As a result, pseudomorphs after evaporitic minerals have been found, until now, in eleven sections of the Vesder basin and in the eastern parts of the Dinant and Namur basins (Figure 1).

The detailed sedimentpetrographical study involved about 350 acetate peels and 70 oriented thin sections. The classifications of Elf-Aquitaine (1975), based on FOLK (1959, 1962) and DUNHAM (1962), have been used.

GENERAL STRATIGRAPHY.

The general litho- and chronostratigraphy of the Tournaisian-Visean boundary in the Vesder basin and in the eastern parts of the Dinant and Namur basins is given in Figure 2.

Ir the Vesder basin, the main carbonate unit of the Tournaisian consists of

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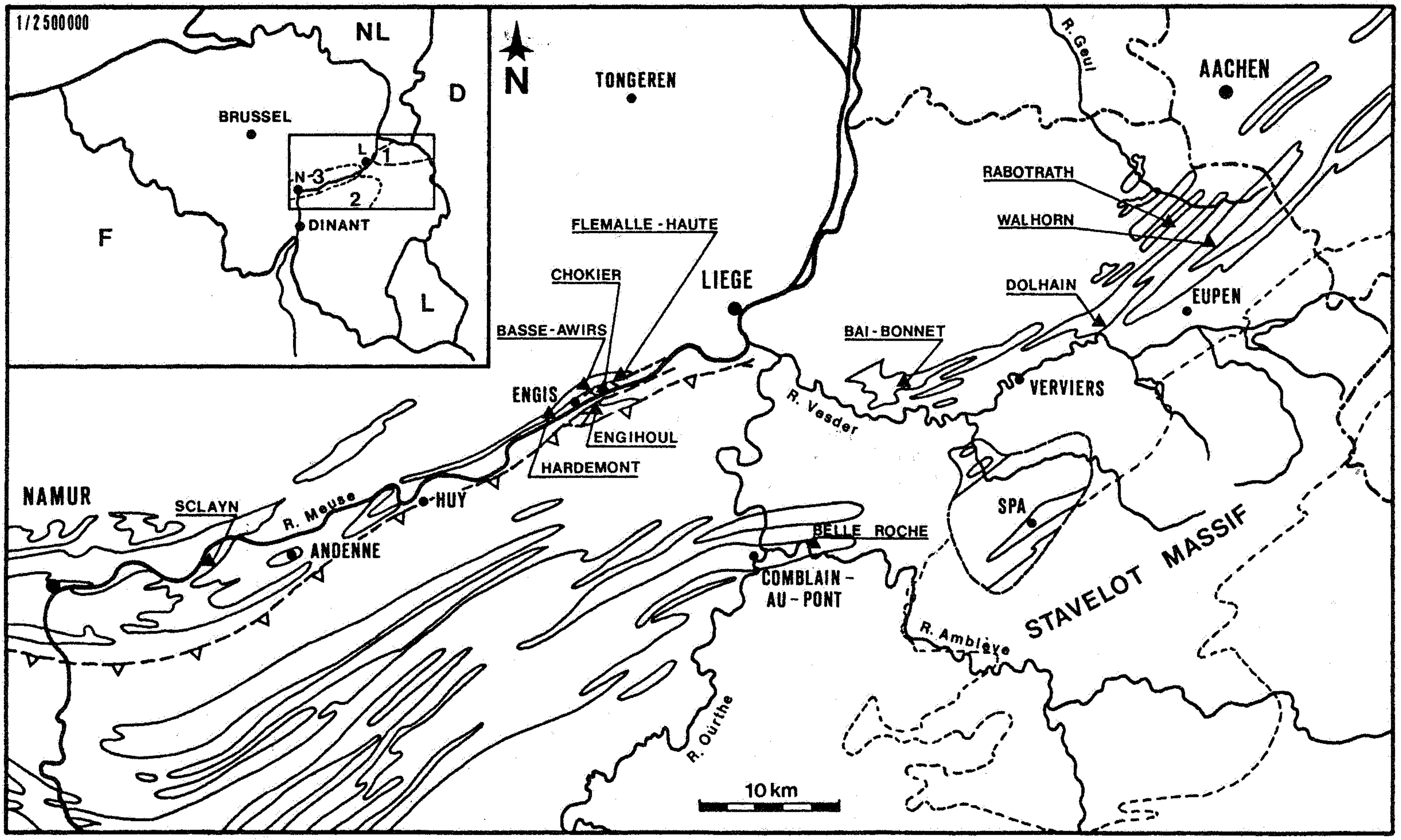


Figure 1: Localization of the studied sections.

(▲: section, 1. Vesder basin, 2. E-Dinant basin and 3. E-Namur basin) the Vesder Dolostone Formation (BOONEN, 1978). It is composed of brown to brown-grey dolostones characterized by the occurrence of cherts, geodes and crinoïds. A Lower Visean age is presumed for the uppermost part of this Formation. On top of these dolostones, grey banded palisade calcide beds are present. They are overlain by a grey-brown dolostone breccia and a grey limestone breccia. The latter is lithologically identical to the Ourthe Breccia of the eastern part of the Dinant basin (VARLAMOFF, 1937). Above the breccias, an important succession of limestones - characterized by oölites, pellets and intraclasts - is present. These limestones of the Neffe Formation (V2a) are probably equivalent to the Vaughanites oölitic limestones in the Aachen region (KASIG, 1980).

In the eastern part of the Dinant basin, the Upper Tournaisian Martinrive Formation (Tn3c) is composed of black bituminous and chert-rich limestones. The overlying Visean Sovet Formation (V1a) consists of brown-grey dolostones with some fine-grained limestone intercalations at the top. This Formation is characterized by the occurrence of crinoïds, which are very abundant at the base of the unit, and calcite geodes. The Sovet Formation is overlain by a grey limestone breccia - the Ourthe Breccia (V1b) - and by grey oölitic and intraclastic limestones of the Neffe Formation (V2a).

In the eastern part of the Namur basin, the Upper Tournaisian Namur Dolostone Formation shows similar lithological characteristics as the Vesder Dolostone Formation of the Vesder basin and as the Sovet Formation of the eastern part of the Dinant basin. Light grey columnar calcite, occurring as beds and lenses, is locally present at the top of these dolostones. The contact of the dolostones with the columnar calcite has been recognized as an erosion surface, and is sharp. They are overlain by grey crinoidal limestones (V1a; MALPICA, 1973) which are described as "Encrinite de Chokier" or "Encrinite de Flémalle". The Terwagne Formation (V1b) starts with grey to grey-brown oölitic and intraclastic limestones which are covered by algal mats and by grey limestone conglomerates. The top of the Terwagne Formation consists of grey intraclastic, pelletoidal and oölitic limestones. The Neffe Formation (V2a) with brown-grey to dark grey intraclastic and oölitic limestones is characterized in its middle part by 5.6 meters of light to dark grey limestone breccias. The rythmic limestones of the Namêche and Lives Formation (V2b), which starts with an algal sequence, contain black chert nodules in its upper part.

NEW MEMBERS OF THE VESDER DOLOSTONE FORMATION IN THE VESDER BASIN.

At the top of the Vesder Dolostone Formation, we can recognize 2 distinct horizons which are hereby called the "palisade calcite member" and the "Vesder breccia member". These new members are defined in the Walhorn section (Figures 1, 2 and 3).

1. THE PALISADE CALCITE MEMBER.

Definition.

The palisade calcite member consists of grey to blue-grey limestones characterized by coarse-grained, fibrous radiating calcite crystals up to 2 centimeters long. In some beds, a conglomeratic to pseudobreccoid character can be distinguished. Macrofossils are not present.

The contact of this member with the underlying dolostones and the overlying dolostone breccia are sharp.

The total thickness of this palisade calcite member is 4.8 meters in the Walhorn section, which is until now the only section in the Vesder basin where this member is outcropping.

Sedimentpetrographical characteristics and interpretation.

An accumulation of several successions consisting of three subunits could be distinguished : (A) an intraformational conglomerate containing fragments of calcite rosettes eroded from subunit C, (B) a grumelous microsparite-micrite layer and (C) the palisade calcite which is composed of vertically oriented conical calcite rosettes. The latter are interpreted as calcite pseudomorphs after gypsum (SWENNEN et al., 1981). The successions are deposited in an environment ranging from intertidal to supratidal and restricted. A Lower Visean age is presumed for this member.

2. THE VESDER BRECCIA MEMBER.

Definition.

This member is composed of grey to brown dolostone fragments of different sizes (1 mm up to 30 cm) cemented by a brown-grey fine-grained dolomite.

The lowest 10 cm of the member is characterized by a dolostone conglomerate containing elongated, flattened dolostone pebbles.

This conglomerate is overlain by a real dolostone breccia. Small scale slump and collapse structures are present (Plate 1A). In the dolostone breccia and on top of it, several coloured dedolomitization zones are recognized.

This member overlies the palisade calcite member in the Walhorn section. In other places, where the palisade calcite member is lacking, the Vesder breccia member is in contact with the Vesder dolostone. The effective thickness of the Vesder breccia member in the Walhorn section is about 11 meters, since a fault between the lowest limestone breccia and the uppermost breccia zone occurs (Figure 3).

In other sections, the Vesder breccia member - if present - is very reduced in thickness.

Sedimentopetrographical characteristics and interpretation.

The detailed lithological succession of the Vesder breccia member as it outcrops in the Walhorn section is shown in Figure 3.

Three dolostone breccia zones (A_1, A_2 and A_2') which have similar sedimentpetro-

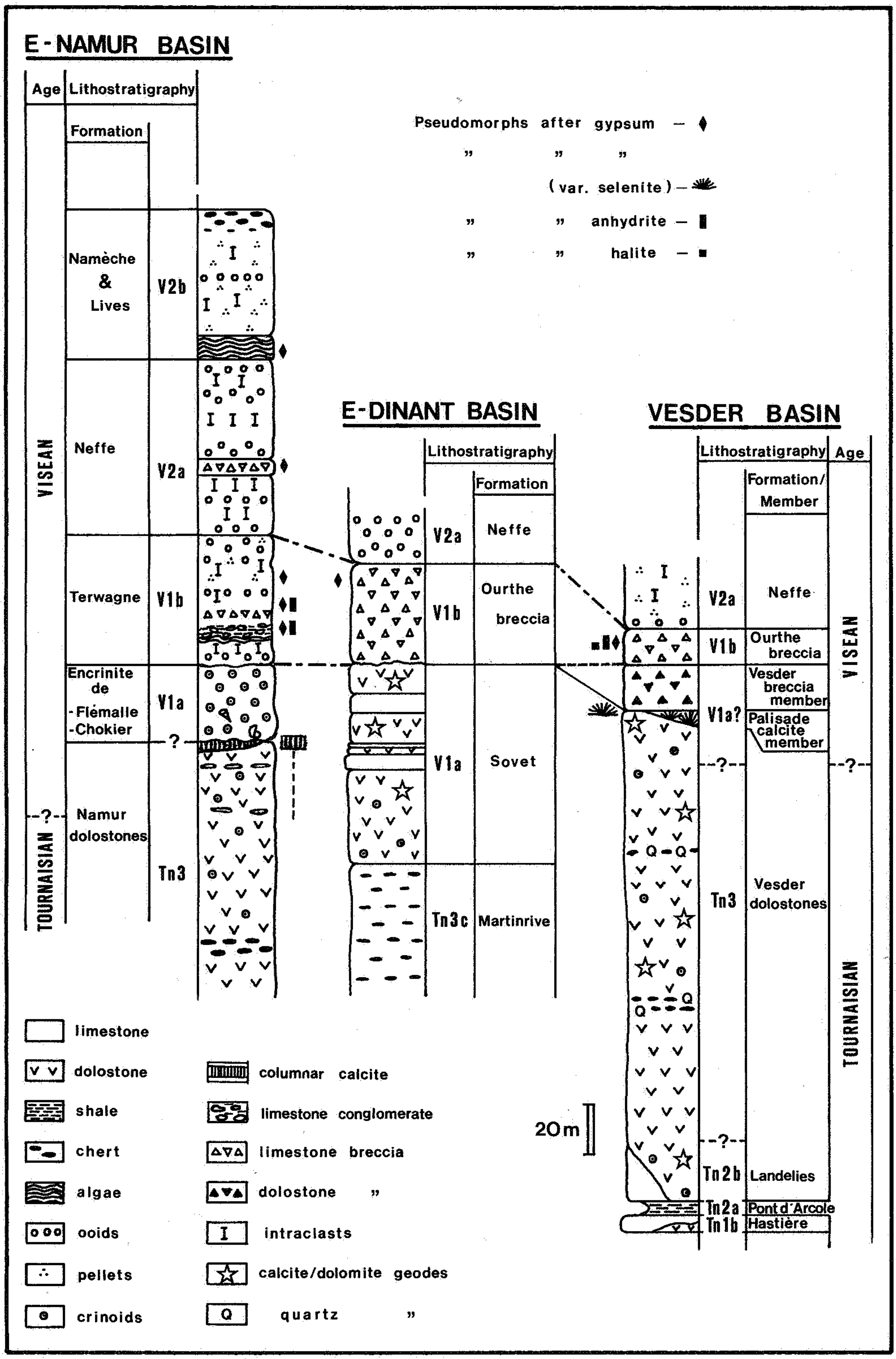


Figure 2 - Lithostratigraphy of the Dinantian near the Tournaisian-Visean boundary in the eastern part of the Namur and Dinant basins and in the Vesder basin.

graphical characteristics, are recognized.

The black-grey to dark brown dolostone breccia fragments varies in lenght from 1 mm to 20 cm, their average being 4 cm. Exceptionally, 30 cm pieces are present. Fragments with sharp borders as well as rounded fragments occur. Typical are fragments with apparent crumbled edges. Locally, broken breccia fragments - still fitting into each other - are present. The grain size distribution in the fragments is homogeneous, but may grade from dolomicrite to dolosparite. Sometimes, the anhedral dolomite grains have a dark center. Birdseye structures, with geopetal infillings, have been found. Detritical quartz grains, up to 3% of the fragments, are common. Locally iron oxides-hydroxides are found.

The colour of the dolostone breccia matrix is beige, light brown to silver-grey. The grain size distribution of the matrix is heterogeneous. Small and large, often rounded, dolosparite grains are inbedded in a dolomicrite mud. It has the appearance of a reworked dolomite sand. The most peculiar feature of the matrix are collapse and slump structures (Plate 1A). The matrix often seems to be swallowed between the fragments.

The hanging wall of the breccia units is characterized by dedolomitization zones (B_1, B_2 and B_2'). Petrographical and textural criteria which served to determine dedolomitization are cited by SHEARMAN et al. (1961), EVAMY (1967), FOLKMAN (1969) and others.

The recognized dedolomitization zones have a yellow brown to rusty, locally purple, colour. These zones have a thickness of a few decimeter up to two meters. Since the breccia character is preserved, these strata originate from the underlying dolostone breccias. The dedolomitized crystals are often composed of a calcite rim, with a dolomite center. The largest dolomite crystals are less dedolomitized. The calcite is monocrystalline and is in optical continuity with the dolomite center. Most of the dedolomitized crystals are covered by iron hydroxides. In the largest crystals, these iron hydroxides occur sometimes as thin lineaments paralled to the cleavage planes.

The occurrence of birdseye structure in the dolostone fragments and the high amounts of detritical quartz indicate a supra- to intertidal sedimentation environment of the original carbonate phase.

Few interpretation about the dolomitization process and the genesis of this dolostone breccia were proposed in the past. BRIEN (1904) concluded that the dolomitization of the dolostone breccia was accomplished before the formation of the overlying limestone breccia since he observed few reworked dolostone fragments in the overlying limestone breccia. This argument and the occurrence of dolostone fragments with a grain size distribution totally different from that of the dolostone matrix exclude a late-diagenetic dolomitization process. The latter would homogenize the grain size distribution of the breccia and wipe out the recognized breccia textures (contrast fragment-matrix, flow and collapse structures, etc.). Furthermore, the occurrence of dolomicrite fragments suggests that the dolomitization of the dolostone breccia occurred early in the diagenetic history.

Geochemical data of this dolostone breccia (SWENNEN et al., 1982b : in press) indicate a positively anomalous behaviour for Na ($\bar{X}$ = 427 ppm, σ = 165 ppm) and for Sr ($\bar{X}$ = 207 ppm, σ = 48 ppm). Such high concentrations are interpreted by VEIZER and DEMOVIČ (1974), VEIZER et al. (1978) and KRANZ (1976) as indicative for an early-diagenetic dolostone. The high Na content may point to a hypersaline nature of the dolomitizing solutions.

From the described sedimentpetrographical features, we can conclude that during brecciation, the dolostone acted partly as a consolidated (fragments) and partly as an unconsolidated matter (dolomite sand). The occurrence of broken breccia fragments indicates several brecciation phases. These characteristics point to a collapse origin for this breccia. A similar evaporitic collapse dolostone breccia with flow structures and with fragments showing apparent crumbled edges, was described by STANTON (1966).

The presence of dedolomitization is becoming increasingly recognized. VON MORLOT (see CAYEUX, 1937, p. 429) was the first to describe dedolomitization by the equation :

$$CaSO_4 + CaCO_3.MgCO_3 \underset{\text{dolomitiz.}}{\overset{\text{dedolomitiz.}}{\rightleftharpoons}} 2\ CaCO_3 + MgSO_4$$

Several authors supplied the sulphate ions by solutions leaching gypsum and/or anhydrite beds (SHEARMAN et al., 1961; LUCIA, 1961 and GOLDBERG, 1967). Other authors, like EVAMY (1963) and FOLKMAN (1969), obtained these sulphate ions through the oxidation of pyrite. Laboratory dedolomitization processes were described by DE GROOT (1967). He concluded that effective dedolomitization is favoured by a high rate of water flow to remove Mg^{2+} and keep the Ca^{2+}/Mg^{2+} ratio constantly high, a CO_2 partial pressure lower than 0,5 atmosphere and a temperature below 50°C. Thus in nature, dedolomitization is a near surface process. This evidence was well recognized in field relationships by SHEARMAN et al. (1961), GOLDBERG (1967), CHAFETZ (1972) and others.

In our case the dedolomitization zones, which occur on top of the dolostone breccia subunits, indicate paleosurfaces. The erosion of the upper part of the dolostone collapse breccia, which probably outcropped during a long period, and the high Ca^{2+}/Mg^{2+} waters, derived from the dissolution of the gypsum beds, caused dedolomitization. This process occurred several times. The rusty colour of these dedolomites is caused by their association with iron hydroxides. Geochemical data (SWENNEN et al., 1982 (b), in press) show that the dedolomitized zones of the Walhorn section are enriched in Fe, Mn, Zn, Pb and Ni in comparison with the dolostone breccia, The Sr, Na, and Org C concentrations of the

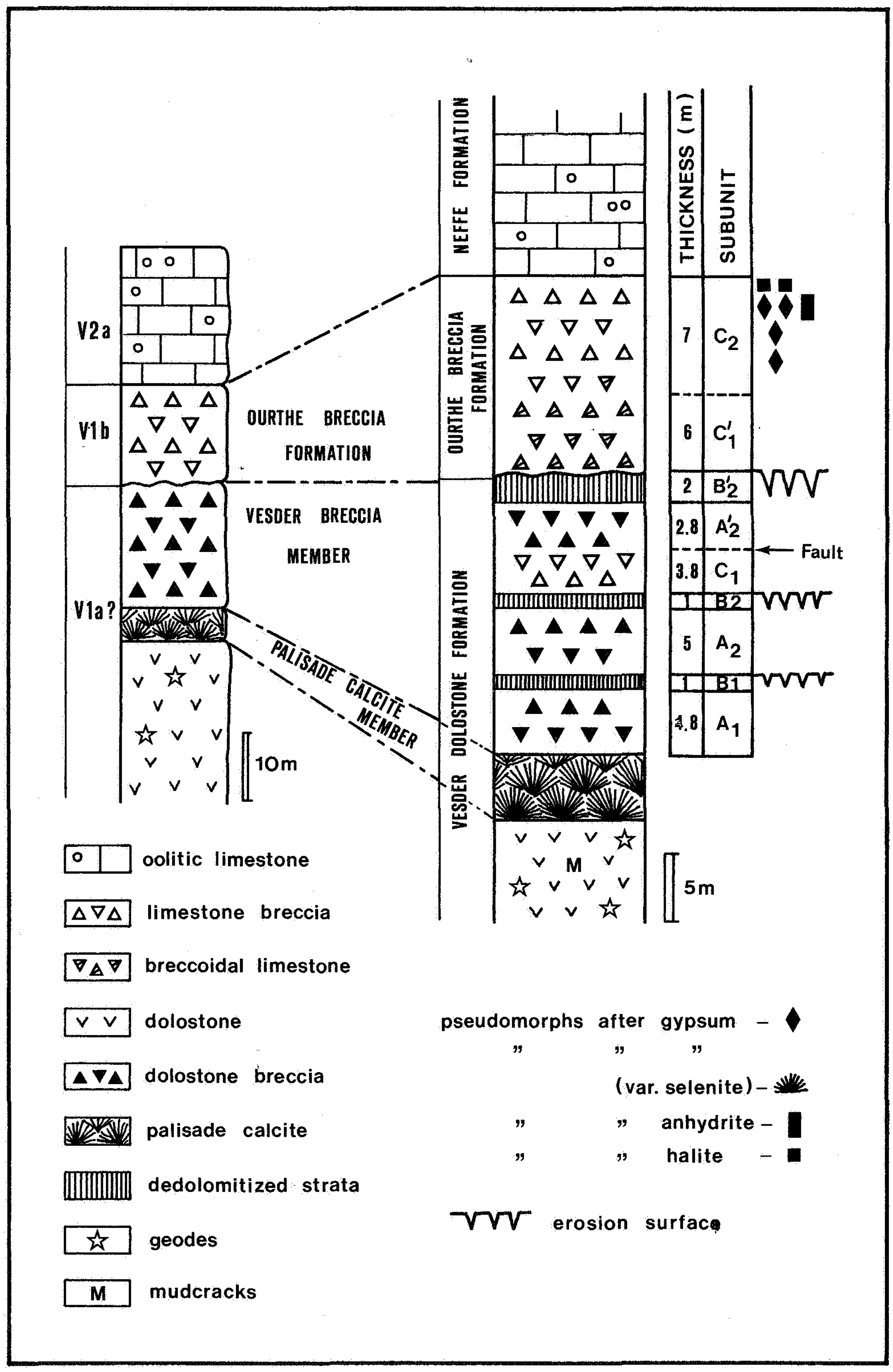


Figure 3 - Detailed lithology of the Lower Visean carbonates in the Walhorn section (Vesder basin).

studied dedolomites, compared with the data of under- and overlying strata show low to very low concentrations in these zones (Sr: $\bar{X}$ = 112 ppm, σ = 67 ppm; Na: $\bar{X}$ = 92 ppm, σ = 59 ppm; Org C: $\bar{X}$ = 0.061%; σ = 0,060%). Similar low Sr concentrations were reported by SHEARMAN and SHIRMOHAMMADI (1969) and MAGARITZ and KAFRI (1980).

3. LITHOSTRATIGRAPHICAL POSITION OF THE NEW DEFINED MEMBERS.

The palisade calcite member and the Vesder breccia member are included in the Vesder Dolostone Formation since 1) the fragments of the Vesder breccia member display mostly identical lithological features as the underlying dolostones of the Vesder Dolostone Formation, 2) on top of the Vesder breccia member a thick dedolomitization zone occurs, indicating a paleosurface and 3) the carbonates of the Vesder Dolostone Formation, the palisade calcite and the Vesder breccia are interpreted as successive paleogeographical events. This evolution is also reflected in their geochemistry (SWENNEN et al., 1982 (b); in press).

TYPES OF CALCITE PSEUDOMORPHS.

Besides the palisade calcite pseudomorphs after gypsum (SWENNEN et al., 1981), three types of calcite pseudomorphs are recognized in the Visean limestones :
1. lozenge-shaped calcite pseudomorphs,
2. lath-shaped calcite pseudomorphs and
3. square-shaped calcite pseudomorphs.

1. THE LOZENGE-SHAPED CALCITE PSEUDOMORPHS. (PLATE 1B, 2, 3A and 4B).

The euhedral, lozenge-shaped calcite grains range in size from 50 μm up to 2 mm. They have often a discoid, lenticular shape. Typical are rounded obtuse angles. The length-width ratio varies between 2.0 and 3.5. The crystal angles were measured on 60 specimens. Mean obtuse and sharp angle values are about 136° and 43° respectively. The lozenge-shaped pseudomorphs are filled by microsparitic and sparitic calcite crystals. The largest pseudomorphs often show a micritic infilling in their center (Plate 2A). Sometimes twins of lozenge-shaped calcite pseudomorphs occur.

In the literature, identical lozenge-shaped crystals were described as pseudomorphs after gypsum. BHATT (1975, Fig. 3a), KERR and THOMPSON (1963), WEST (1964, Fig. 1 and 6), and BLUCK (1965, Fig. 1c and 2c) recorded the occurrence of calcite pseudomorphs after gypsum euhedral from different stratigraphic levels. Analogous lenticular gypsum crystals were described by SHEARMAN (1963, 1978) and BUTLER (1969) from recent sediments along the Arabian coast, by MASSON (1955) from the Laguna Madre in Texas, by ILLING et al. (1965) from the intertidal zone of Qatar, and more recently by LOGAN et al. (1970, 1974) and ARAKEL (1980) from Western Australia.

2. THE LATH-SHAPED CALCITE PSEUDOMORPHS (PLATE 5).

Lath-shaped and square-shaped cross-sections of different calcite crystals indicate pseudomorphs after an orthorhombic mineral. These pseudomorphs are up to 1200 μm long. They are composed of different calcite crystals. Their end faces are often unsharp.

The morphological similarity of these pseudomorphs with the crystal description given by HOLLIDAY (1970, Fig. 2) and MURRAY (1964, Fig. 8), suggests that these calcite crystals are pseudomorphs after anhydrite.

3. THE SQUARE-SHAPED CALCITE PSEUDOMORPHS (PLATE 3B).

These calcite crystals have a square-shaped cross-section. As perfect squares are present, these crystals are calcite pseudomorphs after a cubic mineral. The calcite phase is mostly monocrystalline. The size distribution is homogeneous and varies around 80 μm. These cubic crystals are probably pseudomorphs after halite. Similar pseudomorphs were recently described in Belgium by LECLERCQ (1980) from V2b-V3a limestones. Recent occurrences of halite in the sabkhas around the Arabian coast were mentioned by SHEARMAN (1963), BUTLER (1969) and ARAKEL (1980). They reported that halite mainly occurred in limited concentrations in the top half-inch of the sabkha.

OCCURRENCES OF THE CALCITE PSEUDOMORPHS AND SEDIMENTPETROGRAPHICAL CHARACTERISTICS OF THE HOST ROCKS.

A. VESDER BASIN.

In the Vesder basin, the three types of calcite pseudomorphs have been found in the Lower Visean Ourthe Breccia (V1b) in four sections (Figure 1 and 3).

This Ourthe Breccia is characterized, in its lower part, by breccoidal fine-grained limestones with a vague bedding. These are overlain by a limestone breccia without bedding planes. In the Walhorn section (Figure 3), these units are respectively 6 and 7 meters thick. On top of the Ourthe Breccia a gradual contact with the overlying oölitic limestones of the Neffe Formation (V2a) occurs.

Sedimentpetrographical characteristics and interpretation.

The breccoidal limestones are composed of packstones and/or mudstones containing micritic pellets and intraclasts. Some pisolites are present. Calcispheres, sometimes appearing as nuclei of the micritic intraclasts, and ostracod fragments are abundant. The mudstones are characterized by the occurrence of birdseye structures with geopetal infillings.

The fragments of the overlying limestone breccia have identical characteristics as the breccoidal limestones. Fragments range in length from 1 mm to 20 cm. Sharp-bordered fragments as well as rounded pebbles occur. The fragment pieces often fit into each other. Locally, well-rounded pisolitic micritic intraclasts occur.Calcite pseudomorphs after gypsum occur in the micritic fragments. At the base of the breccia they are rare but near the top they can become a major component. Also square-shaped cross-sections of calcite pseudomorphs probably after halite have been found.

The breccia matrix is microsparitic. Thick-walled calcispheres are common.

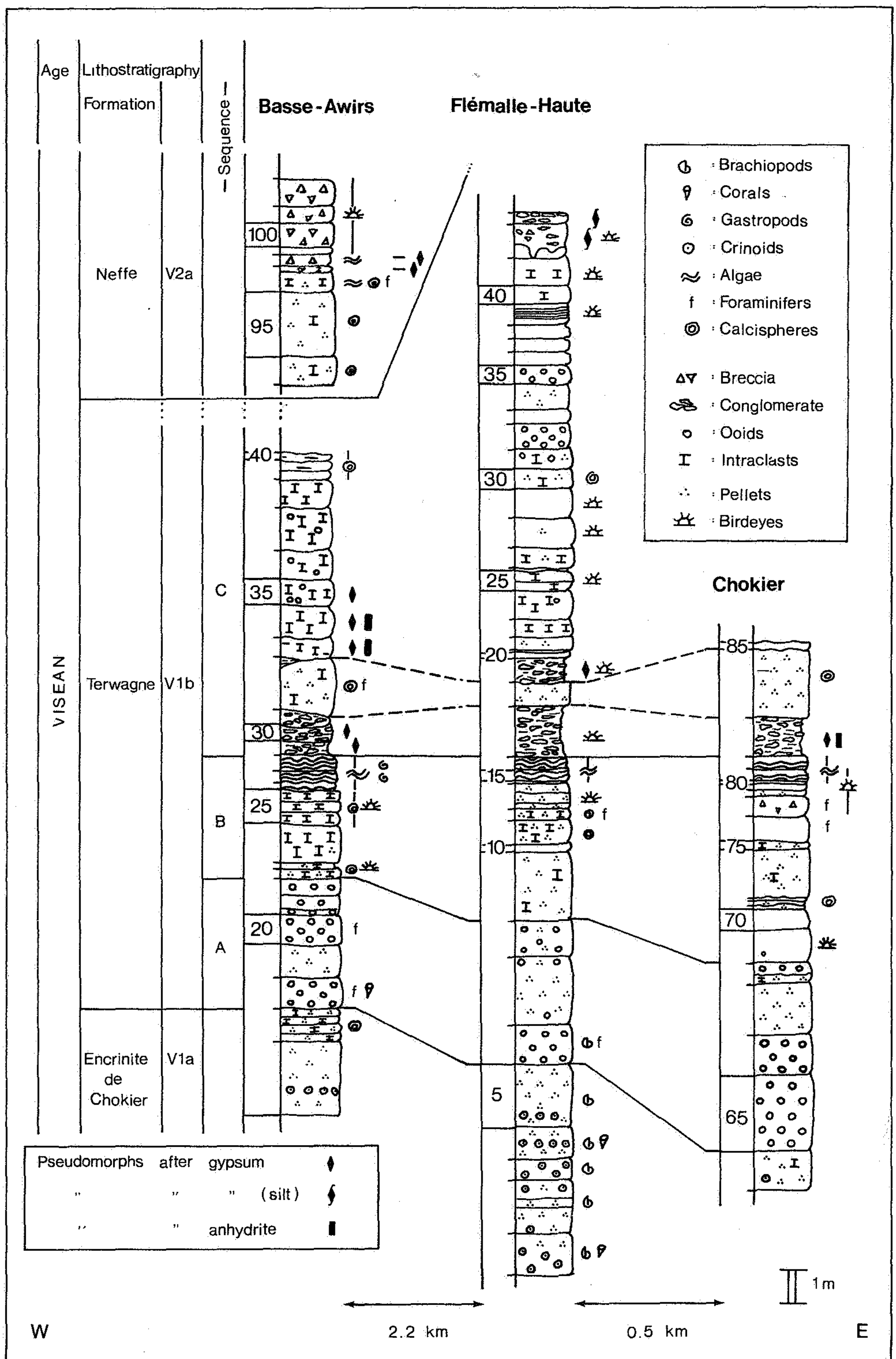


Figure 4 - Lithological correlations of the lower part of the Terwagne Formation (V1b) in the Basse-Awirs, Flémalle-Haute and Chokier sections.

Lath-shaped calcite pseudomorphs after anhydrite as well as discoid calcite pseudomorphs after gypsum are present in the clay-rich matrix parts.

The described breccoidal limestones and the breccia fragments themselves, containing micritic pellets, intraclasts, pisolites and birdseye structures, are probably deposited in an inter- to supratidal sedimentation environment. Several features of this limestone breccia, such as the more or less continue stratigraphic development, the heterogeneous distribution of sharp-bordered to rounded fragments, the absence of bedding planes, the inter- to supratidal sedimentation conditions of the fragments, fragments fitting well into each other, the occurrence of pseudomorphs after gypsum, anhydrite and probably halite, indicate an evaporitic collapse origin for this breccia. Several of these features are also described from an evaporitic solution breccia from SW Montana (MIDDLETON, 1961).

The limestone breccia occurs at several places in the Vesder basin e.g. Bai-Bonnet, Dison, Dolhain, Hergenrath and partly in Soiron and Eynatten (for references see BOONEN, 1981). Concerning its biostratigraphical position, only Pachysphaerina pachysphaerica which also occur in the underlying palisade calcite member, could indicate a Visean age (CONIL and LYS, 1968). In analogy with the Ourthe Breccia (V1b) of the eastern part of the Dinant basin, a Lower Visean age may be presumed for the two top members of the Vesder Dolostone Formation and for the Ourthe Breccia Formation of the Vesder basin.

B. DINANT BASIN.

The Lower Visean carbonates are well exposed in the Belle Roche Quarry in the most eastern part of the Dinant basin (Figure 1). In this section the lower part of the Sovet Formation (V1a) is formed by a brown-grey sparitic dolostone with abundant crinoids. The amount of crinoids decreases towards the top of the Formation where the dolostone are characterized by the occurrence of abundant calcite geodes and where three light grey micritic limestone intercalations occur. Recent works in the quarry revealed large slump structures in the Sovet Formation. The uppermost bed is characterized by ripple-marks. There exists a sharp contact between the Sovet Formation and the overlying Ourthe Breccia Formation.

The Ourthe Breccia is about 42 m thick in the Belle Roche Quarry and shows no stratification. The Ourthe Breccia Formation is built up of grey limestone fragments varying in size between 2 and 20 cm. The fragments of the breccia are very angular and sometimes fit well into each other.

In the lowest part of the Ourthe Breccia, light grey dolostone fragments occur. Some fragments are characterized by calcite veins which are restricted to the fragments and do not pass through the matrix. Fluorite crystals occurring in small calcite veins, are present all over the breccia unit. The cement/fragment ratio of the breccia varies strongly.

Sedimentpetrographical characteristics and interpretation.

Five different types of breccia fragments are present :

1. grey micritic limestone fragments which occur all over the breccia unit. Some fragments contain calcispheres. These breccia fragments are often characterized by parallel calcite veins. Lozenge-shaped calcite pseudomorphs after gypsum have been found in these micritic limestone fragments on top of the breccia unit (Plate 3A). These pseudomorphs are scattered over the fragments or are concentrated in clusters;
2. grey pelmicritic limestone fragments which are only found at the base of the unit;
3. grey oömicritic limestone fragments occurring over the breccia unit but more abundantly towards the top. These fragments contain about 80 % of micritic oöids. Fossils have not been found;
4. small black shaly limestone fragments, without any fossils, occurring sporadically and
5. grey dolomicrite - dolomicrosparite fragments without fossils.

The matrix of this breccia is sparitic. However, in the lowest part sometimes a dolomicrosparite matrix is present.

The occurrence of calcite pseudomorphs after gypsum in the Ourthe Breccia shows that these limestones were deposited in a hypersaline sedimentation environment. The calcite veins in the fragments show that these fragments were partly consolidated before brecciation.

The different characteristics of the Ourthe breccia allows us to reconstruct the diagenetic history of this breccia : after a cyclic deposition of limestone- and gypsum beds a consolidation of the limestone beds occurred. Sometimes, during short periods the Mg/Ca ratio of the brines were high enough for dolomite formation. Different calcite vein systems developed. Due to fresh water influence a dissolution of the interlayered gypsum occurred. The limestone layers collapsed, forming a porous, not cemented breccia. Later on, cementation occurred, forming the sparitic breccia matrix.

C. THE NAMUR BASIN.

THE EASTERN PART OF THE NAMUR BASIN.

In the eastern part of the Namur basin, calcite pseudomorphs after evaporitic minerals have been found in the Terwagne Formation (V1b), the Neffe Formation (V2a) and the Namèche and Lives Formation (V2b).

I. The Terwagne Formation (V1b)

The Terwagne Formation is composed of about 45 m of grey to grey-brown oölitic, pelletoidal and intraclastic limestones (Figure 2). Some grey limestone conglomerates overlying algal mats are present. Figure 4 shows lithological correlation of the lower part of the Terwagne Formation in the Basse-Awirs, Flémalle-Haute and Chokier sections. The sections of

Hardêmont and Engihoul, which are not indicated, also fit very well into this scheme.

Three sedimentological sequences are considered :

A. grey-brown oölitic limestones (oösparite/grainstone) with one intercalated fine-grained limestone bed (pelsparite/packstone). The oölitic beds contain 40 to 70 % of oöids with an average size of 350 μm. Foraminifers are common in this unit. Some brachiopods and solitary corals occur in the lowest bed;

B. grey intraclastic limestones with birdseye structures (pelintramicrite/mudstone and pelintramicrosparite/wackestone) with on top of it fine laminated algal mats. Calcispheres are abundant while ostracods and small foraminifers are common. Gastropods occur often in the algal mats; and

C grey limestone conglomerates, intraclastic-, oölitic- and micritic limestones.

The oölitic (A) and intraclastic (B) sequences are becoming slightly thicker to the east.

Only the lower part of unit C, which is characterized by the occurrence of calcite pseudomorphs after evaporitic minerals, is further discussed here (Figure 4).

Sedimentpetrographical characteristics and interpretation.

In the different considered sections, the base of sequence C is characterized by limestone conglomerates which show similar sedimentpetrographical features. These conglomerates contain about 30% of small, up to 2 cm long, well rounded limestone fragments. Two types of fragments are present : grey algal laminite, with identical features as the underlying algal mats and grey to grey-brown micrite/mudstone, with scattered lozenge-shaped calcite pseudomorphs after gypsum. Furthermore 30 % of the rock consists of ellipsoidal micrite intraclasts and of proto-oöids. The dark grey clayey micrite cement (40 % of the rock) contains about 2 % of rounded detritical quartz grains and a lot of bioclasts : calcispheres, ostracods, small foraminifers, gastropods, brachiopods with algal envelopes and algae. Clusters of lozenge-shaped calcite pseudomorphs after gypsum and lath-shaped calcite pseudomorphs after anhydrite are sometimes present in the cement.

A biomicrosparite/wackestone bed with calcispheres, algae and foraminifers separates these conglomerates from the overlying, mostly intraclastic, limestones.

In the Basse-Awirs section, 3 intraclastic limestone beds (33, 34 and 35) contain calcite pseudomorphs after gypsum and anhydrite. The beds 33 and 34 consist of grey clayey intramicrites/mudstones. The well rounded intraclasts contain about 10 % of lozenge-shaped calcite pseudomorphs after gypsum. The clayey lime cement contains lath-shaped calcite pseudomorphs after anhydrite (Plate 5). These beds are overlain by intraoömicrosparite/packstone to grainstone beds (33 - 37). The intraclasts of bed 35 contain calcite pseudomorphs after gypsum while scattered calcite pseudomorphs after anhydrite are present in the cement.

In the Flémalle-Haute section, the limestone conglomerates (17 and 19) are overlain by grey micritic limestones with pellets, oöids and intraclasts. Several beds contain birdseye structures. Algae, calcispheres, ostracods and gastropods are abundant.

Two limestone breccia beds (42 and 43) occur in this section. The first bed (Plate 4A) consists in its lower part of a grey micrite/mudstone (a) characterized by abundant birdseye structures and calcispheres. The upper part of this bed is composed of grey angular limestone fragments (b) in a grey-brown fine grained conglomeratic cement (c). The size of the fragments varies strongly but can be up to 20 cm. They consist of alternating laminae of micrite/mudstone and peloömicrosparite/packstone with 70 % of proto-oöids. Ostracods, gastropods and algae occur. The cement of the limestone breccia consists of well sorted lozenge-shaped calcite crystals with an average size of 25 μm (Plate 4B). This calcite "silt" is interpreted as calcite pseudomorphs after gypsum. Some algae and spherolitic nodules are present. There exists a disconformity (d) between the lower part and the upper part of bed 42.

The second breccia bed is characterized by grey banded limestone layers and lenses in a fine grained conglomeratic limestone cement. These layers and lenses are brecciated but the fragments fit well into each other. Both the fragments and the conglomeratic cement show similar characteristics as the first described bed.

We can conclude that a regression started at the base of the Terwagne Formation. Low intertidal oölitic limestones (Figure 4, sequence A) evolue to middle and high intertidal intraclastic and algal limestones (sequence B) which are followed by supratidal sediments (sequence C) characterized by birdseye structures. In this supratidal sequence several sedimentary conglomerates and breccias occur which are characterized by calcite pseudomorphs after gypsum and/or anhydrite. This indicates evaporitic sedimentation conditions in a sabkha-like sedimentation environment.

II. The Neffe Formation (V2a)

The Neffe Formation consists of about 40 m of brown-grey intraclastic and oölitic limestones. In the Basse-Awirs section the middle part of this Formation is characterized by 5.6 m of limestone breccias (Figure 2 and 4). The breccias are overlying pelintramicrosparitic beds which contain about 10 % of calcispheres.

Sedimentpetrographical characteristics and interpretation.

The first two breccia beds (97 and 98) consist of angular fragments up to 2.5 cm long in a microsparitic cement. Oömicrosparite and micrite fragments occur. They are characterized by up to 30 % of lozenge-shaped calcite pseudomorphs after gypsum. Oöids, sometimes as oöidaggregates, and bioclasts are also present in the microsparitic cement. A micritic bed (B 99) with 15 % of birdseye structures separates these two beds from the overlying limestone breccias (98 - 106). However, in the latter, which show similar sedimentological characteristics as the above described breccia, no calcite pseudomorphs after evaporitic minerals have been found.

As in the Terwagne Formation these breccia beds are overlying oölitic and intraclastic limestones. These breccias, which are deposited in a supratidal sedimentation environment, occur on top of a regressive sequence.

III. The Namêche and Lives Formation (V2b).

The rythmic limestones of the Namêche and Lives Formation start with an algal sequence. In the Basse-Awirs section, this sequence is about 8.70 m thick and consists of laminated algal limestones.

Sedimentpetrographic characteristics and interpretation.

The laminae of algal micrite are accentuated by small layers of elongated intraclasts, pellets and oöids. The first algal bed of this sequence is characterized by upstanding lozenge-shaped calcite pseudomorphs after gypsum which break through the algal laminae. These pseudomorphs can be compared with the algal mat gypsum or intertidal zone gypsum of SCHREIBER (in DEAN and SCHREIBER, 1978).

THE CENTRAL PART OF THE NAMUR BASIN.

In the central part of the Namur basin, only the Sclayn section (Figure 1) is considered.

In this section, a channel-like feature in the dolostones is filled by conglomerates and breccias of V1 age (PIRLET, 1967). The latter are composed of limestone and dolostone blocks up to 70 cm long. These blocks are cemented by a clayey micritic lime containing ooïds and a large amount of scattered euhedral dolomite crystals.

Sedimentpetrographical characteristics and interpretation.

A detailed sedimentpetrographical study of these breccias revealed five different types of fragments :

1. brown-grey to grey oömicrosparite to sparite. Oöid aggregates and small amounts of crinoïds, with rim cement and micritized walls are present,
2. beige dolomicrosparite,
3. small, black micrite-microsparite characterized by irregular brown clay spots,
4. grey algal micrite and
5. brown to grey, well-rounded micrite which contain 30 to 70 % of small and large lozenge-shaped calcite pseudomorphs after gypsum as well as square-shaped calcite pseudomorphs probably after halite.

The latter are present at the base of the channellike structure. The calcite pseudomorphs after gypsum occur as clusters or as scattered individuals in the fragments as well as in the cement.

The first four types of fragments originate from limestone beds which occur laterally of the channel. This indicates a short transport of these fragments. Until yet, no lateral equivalent is found for the small well rounded fragments with calcite pseudomorphs. Probably they are transported from farther away.

PALEOGEOGRAPHICAL IMPLICATIONS.

At the time of sedimentation the three regions (i.e. Dinant, Vesder and Namur) belonged to the same basin : the so-called Dinant-Namur basin which is bordered to the N by the Brabant Massif. To the E of the basin two shoals were present : the "Booze-Le Val Dieu" and the presumed "Aachener" shoal. To the W, the Jeumont shoal is supposed, separating the W part of the Namur basin. This basin is characterized by an evaporitic environment as demonstrated by the St-Ghislain borehole (BLESS et al., 1980; SWENNEN et al., 1982, fig. 3). Generally speaking, the Dinantian is characterized by a shallow shelf-environment, the Namur and Vesder regions lying nearer to the coast than the Dinant region.

The described lithological and sedimentpetrographical features allow us to propose an idealized sedimentation model in the NE part of the Namur-Dinant basin during Upper Tournaisian and Lower Visean time (Figure 5).

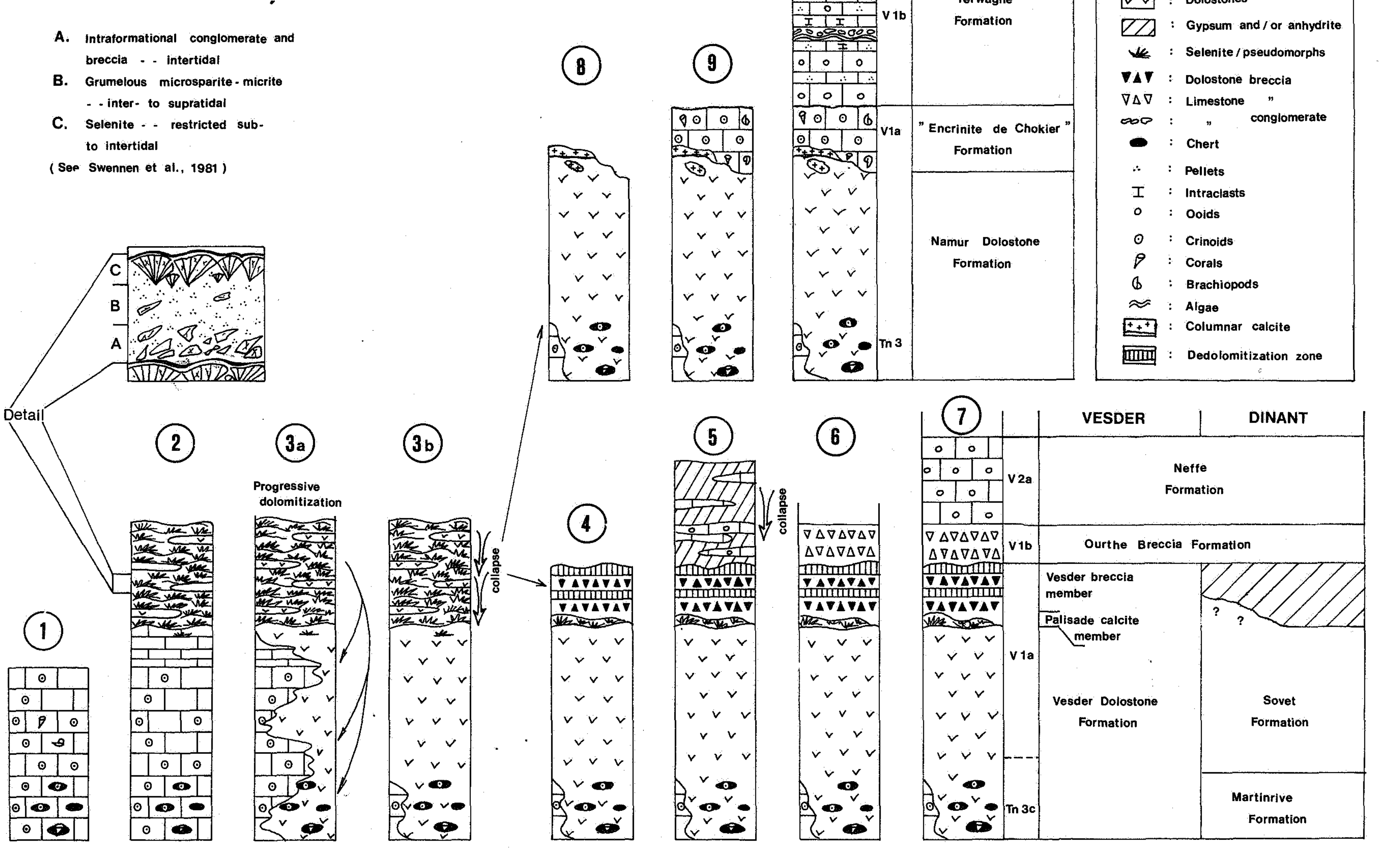
1. During Upper Tournaisian and Lower Visean time, crinoidal limestones were deposited in a subtidal environment. Early in the diagenetic history smaller parts of the limestone were replaced by silica producing mostly black chert lenses and nodules with silicified fossils (crinoids, foraminifers, corals, etc.).

2. Gradually the sedimentation environment changed from subtidal to evaporitic. This is especially pronounced in the most NE part where evaporitic sequences are characterized by rhythmic deposition of fibrous gypsum (SWENNEN et al., 1981). Typical are the gypsum rosettes with conical crystals which are deposited in an environment varying from intertidal to supratidal and restricted. Some carbonate intercalations are probably present in this evaporitic sequence.

3. ab. The deposition of this gypsum induced a progressive dolomitization of interlayered limestone beds as well as of the underlying crinoidal- and chert-rich limestones. This explains the decreasing thickness of the dolomitized strata (Sovet, Namur and Vesder Dolostone Formations) from the NE to the SW away from the evaporitic basin (SWENNEN et al., 1982, fig. 2). A similar dolomitization model has been described in detail by Deffeyes et al. (1965) from the Netherland Antilles. It is to be noticed that the majority of the original sedimentological features as well as most of the fossils of these limestones disappeared by this dolomitization process. Therefore the chert nodules, preserving the fossils, can indicate the age of these dolostones.

4. Later on, the gypsum beds are dissolved by fresh water influence. This process caused an angular, unsorted and unbedded dolostone collapse breccia (E-Vesder ba-

FIGURE 5: TENTATIVE RECONSTRUCTION OF THE SEDIMENTOLOGICAL EVENTS DURING THE LOWER DINANTIAN IN THE EASTERN PART OF BELGIUM.



sin; Walhorn section). Dedolomitization occurs in and on top of this collapse breccia. These dedolomitization zones are due to exposure at surface conditions and to high Ca/Mg waters, derived from the dissolution of the gypsum. This explains also the scarcity of outcrops of the Vesder breccia and the palisade calcite member, since these dedolomitization zones indicate paleosurfaces and stratigraphical gaps. This collapse process occurred at least 2 times. Relicts of the original gypsum beds are preserved as pseudomorphs in the Vesder basin (Walhorn section).

5. In the E Dinant and Vesder basins a new evaporitic sequence started characterized by limestone intercalations, gypsum, anhydrite and possibly halite.

6. A new influx of water, possibly at the beginning of a new transgressive phase, caused the dissolution of the evaporitic layers forming a limestone collapse breccia (Ourthe Breccia).

7. Eventually, oölitic limestones were deposited all over the Dinant and Vesder basin (V2a).

8. In the E-part of the Namur basin, on top of the Namur dolostones, an other sedimentological succession developed. Erosion and possibly karstification occurred. Here on top of the Namur dolostones a columnar calcite spar developed, displaying some similar characteristics with the previously mentioned palisade calcite rosettes of the Vesder basin. However, it is still a matter of discussion if these columnar calcites are pseudomorphs after gypsum, or if they are speleothers (karst stuffing). The time of the possible formation of such speleothers is also unclear. Further research is needed to solve these problems.

9. On top of the columnar calcite spar, a crinoidal facies developed (Encrinite de Chokier) which is possibly an intertidal bioclastic accumulation with reworked fossils.

10. Gradually, a regression leads to the deposition of intertidal and supratidal sabkha-like sediments with algal mats and micritic limestones with birdseye structures. Collapse of small evaporitic sequences gave rise to small breccia beds. Several small regressions occurred during VIb time. Small breccia beds with pseudomorphs after gypsum are also present in the V2a. During V2b time, more homogenous sedimentation conditions were present all over the Namur basin resulting in the deposition of rhythmic limestones. Algal mat gypsum sometimes occur.

From this tentative sedimentation model, it is clear that the Vesder basin is the eastern sedimentological prolongation of the Dinant basin. It also seems that in the Dinant and Vesder basins another sedimentological succession developed in comparison with the Namur basin during Lower Visean time.

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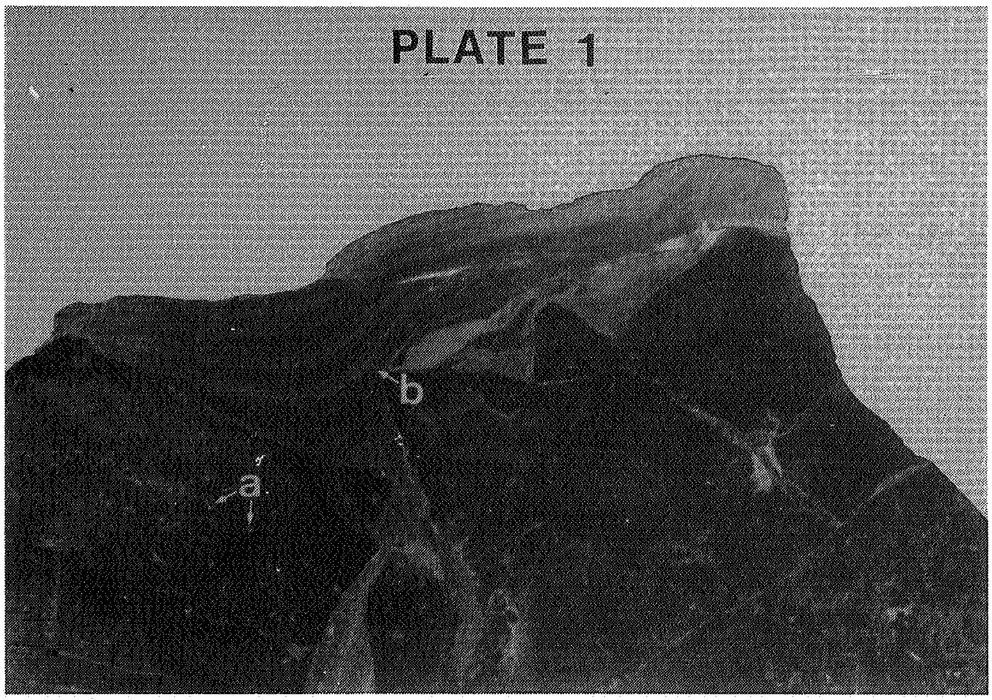
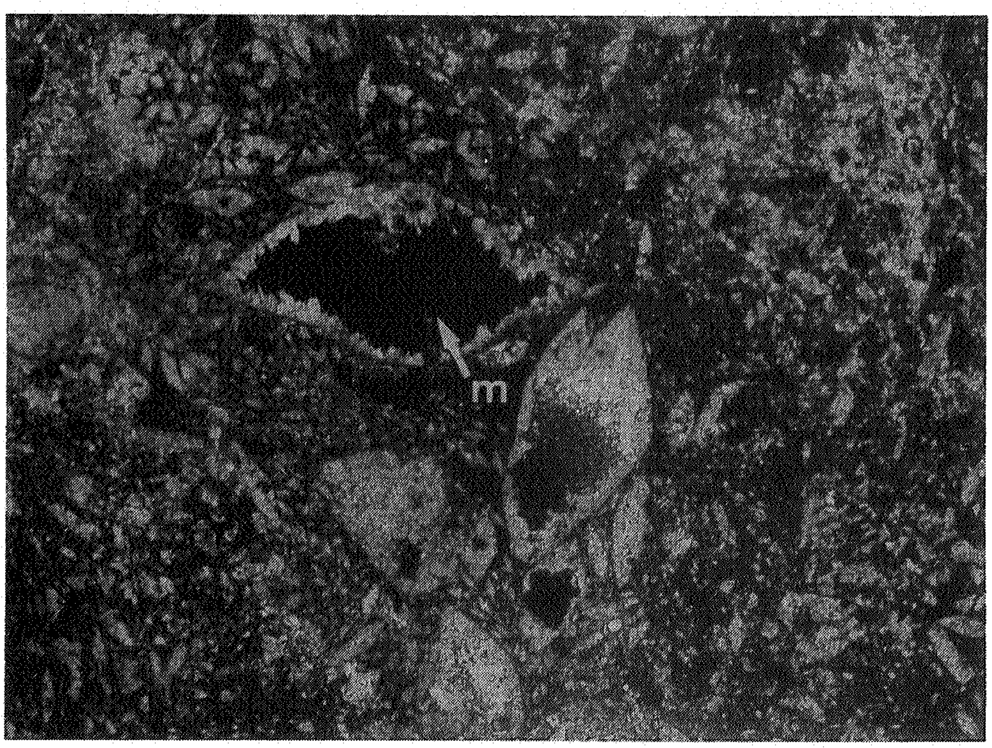
(A)



A. Dolostone breccia of the Vesder breccia member.
Dark angular dolostone fragments with relicts of birdseye structures (a).
Light coloured breccia matrix with collapse structures (b).
The impression arises that the matrix is swallowed between the fragments.
Walhorn section - Vesder basin.
Enlargement : 1x

(B)



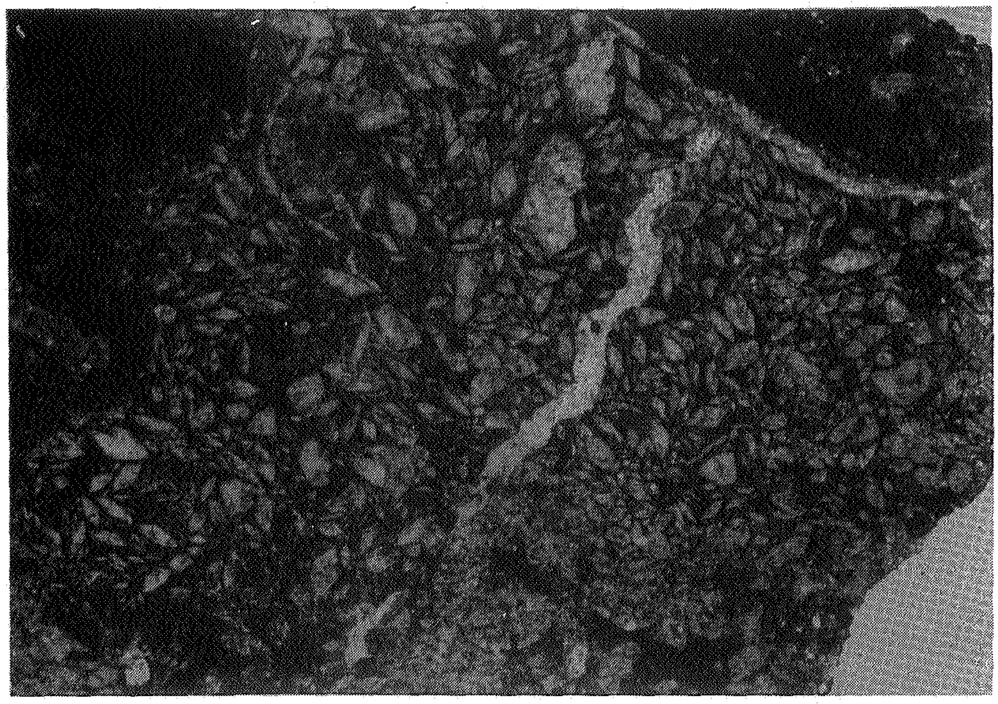
B. Lozenge-shaped calcite pseudomorphs after gypsum.
The large crystals often show a micritic infilling (m).
Ourthe Breccia Formation (V1b).
Walhorn section - Vesder basin.
Enlargement : 28x

PLATE 2

Lozenge-shaped calcite pseudomorphs after gypsum.
Ourthe Breccia Formation (V1b)
Walhorn section - Vesder basin.
Enlargement : 28x

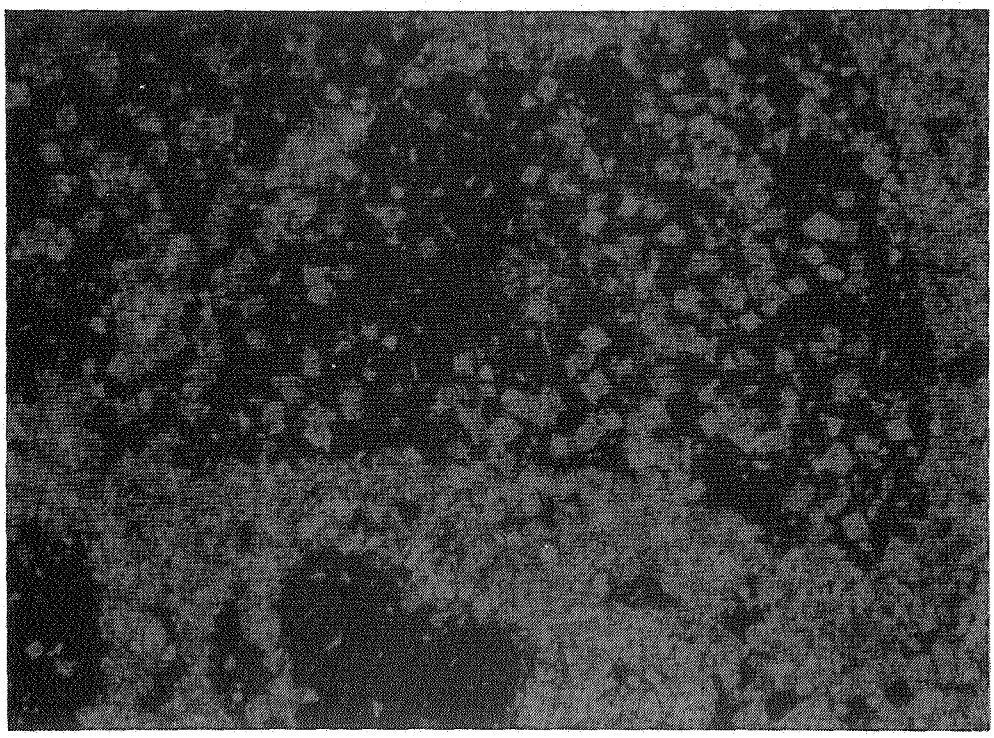
PLATE 3

(A)



A. Lozenge-shaped calcite pseudomorphs after gypsum.
Ourthe Breccia Formation (V1b).
Belle Roche Quarry - Dinant basin.
Enlargement : 14x

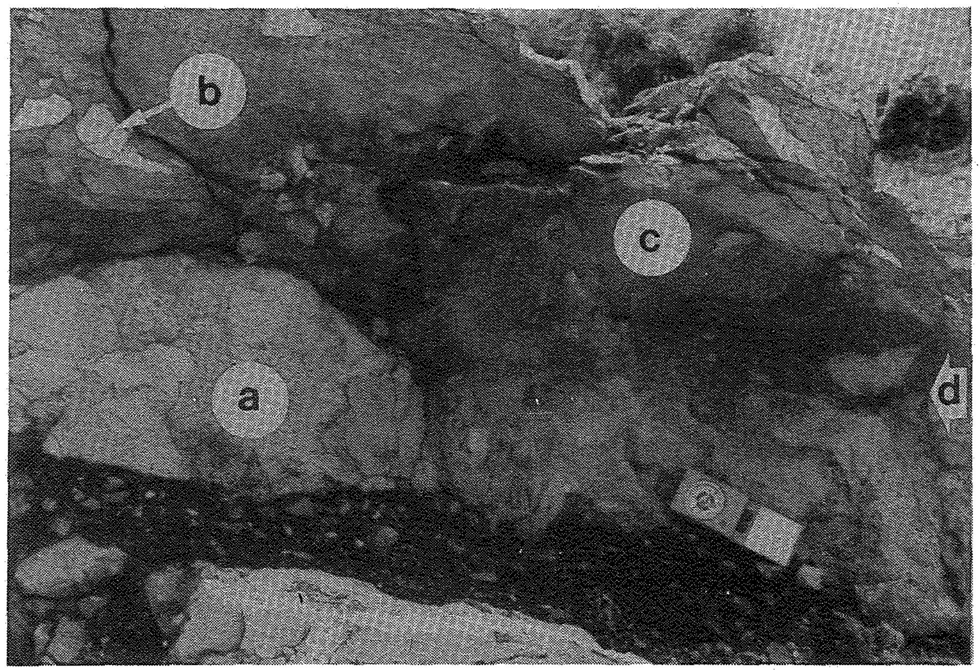
(B)



B. Calcite pseudomorphs probable after halite.
Ourthe Breccia Formation (V1b).
Walhorn section - Vesder basin.
Enlargement : 28x

PLATE 4

A



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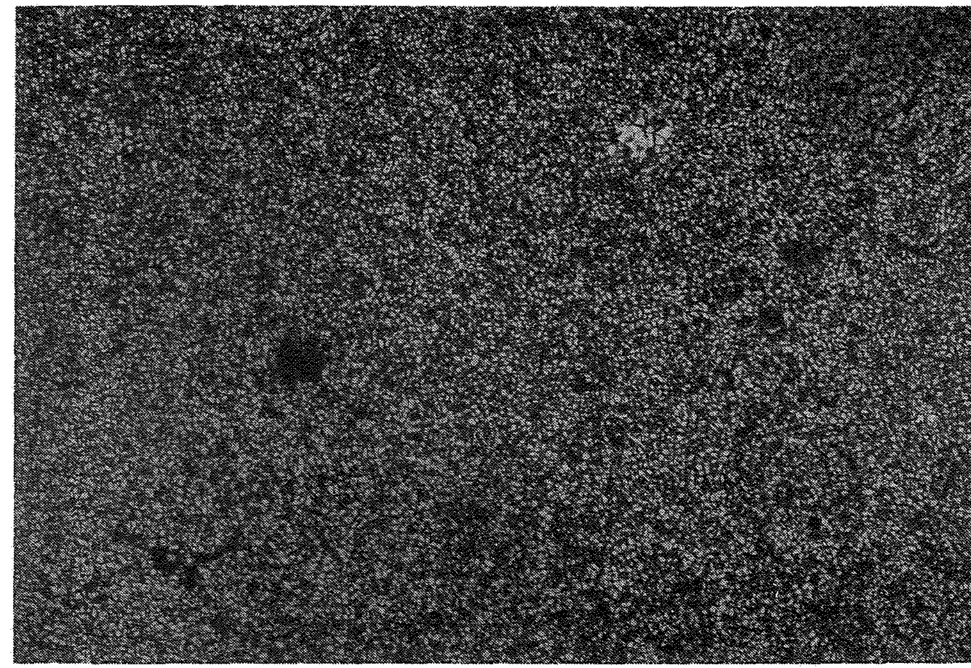
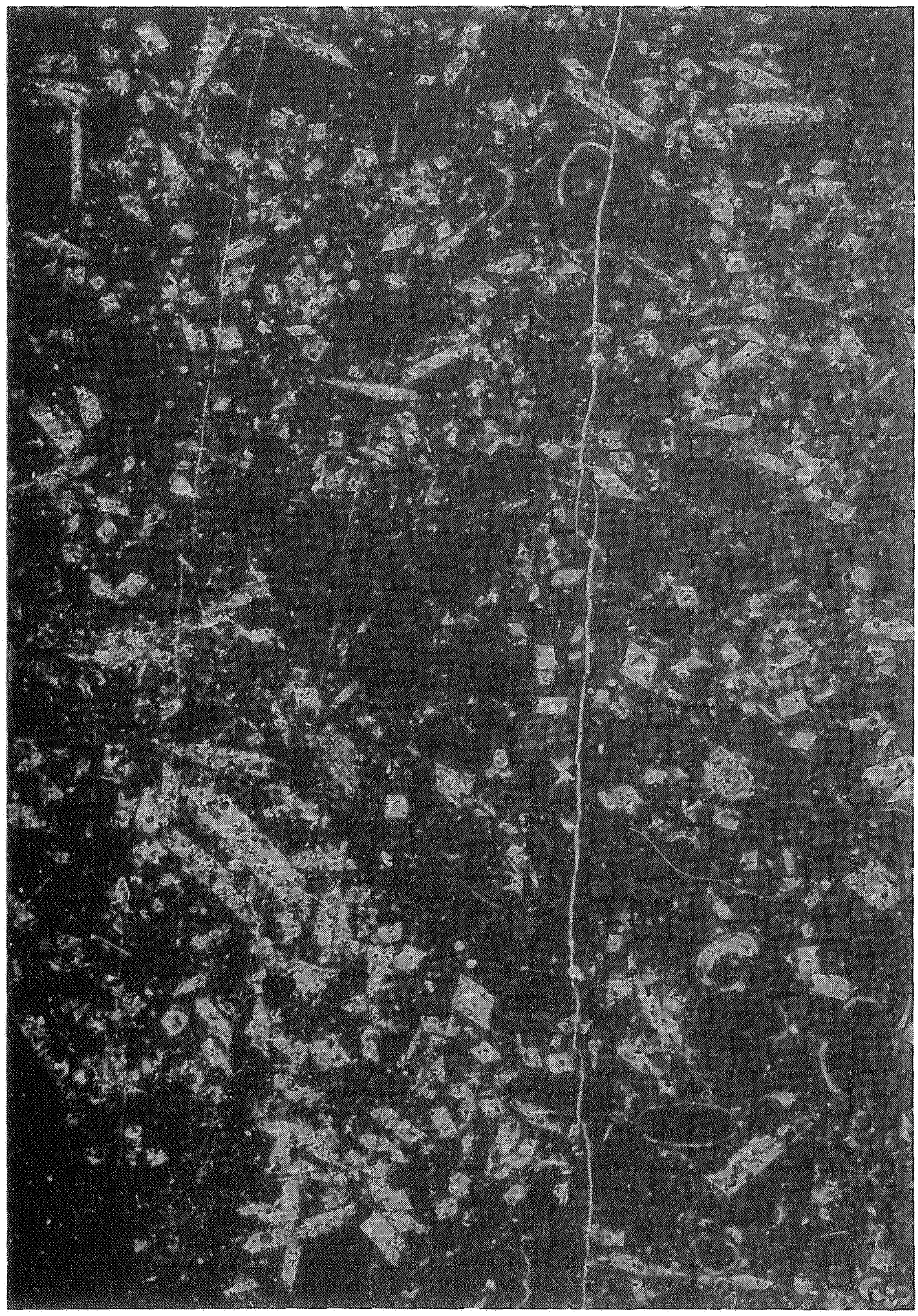


A. A limestone breccia bed which consists in its lower part of a light grey micrite mudstone (a) characterized by abundant birdseye structures and, its upper part of light grey angular limestone fragments (b) in a grey-brown fine-grained calcite cement (c). The fragments consist of alternating laminae of micrite / mudstone and peloömicrosparite / packstone.
There exists a disconformity (d) between the lower and the upper part of the breccia bed.
Terwagne Formation (V1b).
Flémalle-Haute (Fh 42) - Namur basin.
Enlargement : 0,1x

B. The cement (c) of the upper part of the limestone breccia (Plate IV A) consists of a well-sorted "silt" ($\pm$ 25 μm) of lozenge-shaped calcite pseudomorphs after gypsum.
Terwagne Formation (V1b).
Flémalle-Haute section (Fh 42) - Namur basin.
Enlargement : 28x

PLATE 5



Lath-shaped calcite pseudomorphs after anhydrite.
Terwagne Formation (V1b).
Basse-Awirs section - Namur basin.
Enlargement : 28x

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