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COMPARISON OF THE DIAGENETIC EVOLUTION OF THE LOWER VISEAN BELLE ROCHE BRECCIA AND THE MIDDLE VISEAN GRANDE BRECHE

by

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ABSTRACT

In the Visean of southern Belgium two evaporite-related dissolution limestone breccias occur, i.e. the lower Visean Belle Roche breccia and the middle Visean Grande Brèche. Both show a similar paragenetic sequence. However, the importance of the diagenetic processes in both breccias was different.

The Belle Roche breccia is characterized by an intense early diagenetic dissolution of the evaporites and the infilling of the cavities by a sedimentary matrix. This early dissolution can be related to the extensive development of paleosols in the Lower Visean and the associated meteoric water circulation. In the Grande Brèche, late diagenetic dissolution of the evaporites was more important than the early diagenetic dissolution phase.

In the Belle Roche breccia and in the Grande Brèche late diagenetic brecciation was related with fracturing and tectonism. The fractures were pathways along which fluids circulated in the deeper subsurface. This circulation initiated the dissolution of evaporites in the burial realm.

KEY WORDS

Limestone breccia, diagenetic evolution, evaporites, fracturing, southern Belgium, Viséen.

RESUME

Deux brèches calcaires liées à la dissolution d'évaporites sont connues dans le Viséen du Sud de la Belgique : la brèche de la Belle-Roche dans le Viséen inférieur et la Grande Brèche dans le Viséen moyen. Les deux niveaux bréchiques présentent une séquence paragénétique globalement similaire bien que l'importance relative des processus diagénétiques varie d'une brèche à l'autre.

Une dissolution intense des évaporites au cours de la diagenèse précoce et le remplissage des cavités par une matrice sédimentaire caractérisent la brèche de la Belle Roche. Cette dissolution précoce résulte de la circulation de fluides météoriques associés à l'émersion des niveaux contemporains du Viséen inférieur comme l'indique le développement de paléosols. C'est par contre un processus de dissolution des évaporites essentiellement attribuable à une phase diagénétique tardive qui explique la formation de la Grande Brèche.

Une nouvelle bréchification tardi-diagénétique se produit dans la brèche de la Belle Roche comme dans la Grande Brèche. Cette bréchification est liée à la fracturation et à la tectonique, les fluides ayant circulé en profondeur à la faveur du réseau de fractures et y ayant provoqué la dissolution d'évaporites déjà soumises à l'enfouissement.

MOTS CLES

Brèche calcaire, évolution diagénétique, évaporites, fracturation, Sud de la Belgique, Viséen.

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1. INTRODUCTION

In Belgium, the stratigraphy of the Dinantian and especially the micropaleontology has been extensively studied by Conil and co-workers. This resulted in a detailed litho- and biostratigraphical subdivision of the Dinantian (Conil *et al.*, 1981 ; Paproth *et al.*, 1983 ; Conil *et al.*, 1990). This subdivision forms an excellent framework for further sedimentological and diagenetic studies. Within this framework (Fig. 1), two Visean evaporitic dissolution limestone breccias have been studied.

The oldest breccia (the Belle Roche breccia) has a lower Visean age (Conil, 1967). The youngest one (the Grande Brèche) is of middle Visean age (Bouckaert *et al.*, 1961 ; Conil & Pirlet, 1970). The importance of early diagenetic dissolution in the formation of these breccias has been documented (Mamet *et al.*, 1986 ; Jacobs *et al.*, 1982 ; Swennen *et al.*, 1990). Especially in the Belle Roche breccia, major brecciation took place soon after deposition. Several authors suggested that brecciation has also occurred late in the diagenetic history (Pirlet, 1972 ; Rouchy *et al.*, 1987 ; Swennen *et al.*, 1990). For the Grande Brèche, however, no general agreement exists on the origin of these diagenetic processes. Recently, a paragenetic sequence of brecciation and cementation periods has been independently reconstructed for the two Visean breccias (De Putter & Herbosch, 1990 ; Peeters, 1990 ; Muchez *et al.*, 1992).

The aim of this study is to compare the paragenetic sequence of the Visean evaporitic dissolution collapse breccias and to discuss the importance of fracturing for late stage dissolution and brecciation.

2. GEOLOGICAL SETTING

The lower Visean Belle Roche breccia is present in the Vesder Massif and in the eastern part of the Dinant synclinorium (Fig. 2). In the eastern part of the Vesder Massif (Walhorn), a breccia occurs above a sedimentary conglomerate (Vogel *et al.*, 1990). In the western part of this area (Bai-Bonnet) and in the eastern part of the Dinant synclinorium (Belle Roche) only a limestone breccia has been recognized (Swennen *et al.*, 1990 ; Peeters *et al.*, 1992). The depositional environment became more restricted upwards in the stratigraphy (Walhorn) and westwards (Bai-Bonnet, Belle Roche ; Peeters *et al.*, 1992). The major part of the limestone fragments has a lagoonal origin, suggesting a subaqueous, lagoonal origin of the evaporites.

The middle Visean Grande Brèche occurs in the Namur and Dinant synclinoria (Fig. 1). At St-Ghislain (Namur synclinorium), thick evaporite sequences are preserved in the subsurface (Dejonghe *et al.*, 1976 ; Groessens *et al.*, 1982). They are interpreted as subaqueous deposits (Rouchy *et al.*, 1984 ; De Putter *et al.*, in press). However, also in the Grande Brèche, lateral facies variations occur. For example at Corenne, the sediments and evaporites have been deposited in the inter- to supratidal zone of a sabkha environment (De Putter & Herbosch, 1990).

3. METHODS

Hundred thin sections have been examined by conventional and cold cathodoluminescence petrography. Although various trace and rare earth elements are capable of influencing calcite luminescence (Machel, 1985), it is well known that the major control is the manganese and iron concentration and the Mn/Fe ratio (Mason, 1987 ; Hemming *et al.*, 1989). Manganese (Mn^{2+}) is the most important activator and iron (Fe^{2+}) the main inhibitor of luminescence (Sommer, 1972 ; Pierson, 1981 ; Fairchild, 1983).

In this paper cathodoluminescence petrography is only used as an advanced petrographic tool to reconstruct the paragenetic sequence and to identify different diagenetic phases which formed under the same physico-chemical conditions. No interpretations have been made concerning the physico-chemical conditions themselves.

4. DIAGENETIC EVOLUTION OF THE BRECCIAS

4.1. Petrography

4.1.1. The Belle Roche breccia

After lithification and development of thin veins, the limestones were intensely brecciated (Fig. 3). The early development of the veins is indicated by their restriction to the fragments. The cavities between the fragments became filled with clasts, peloids, ooids, pseudomorphs after evaporites, ostracods and foraminifers (Plate I, 1, 2). The matrix has a micritic to sparitic texture. The fragments and the micritic to sparitic matrix are cross-cut by stylolites (Plate I, 3).

Red luminescent dolomites are associated with these stylolites. They formed as a replacement of the matrix (Plate I, 4) and as a cement in fractures. Sometimes the fragments are completely dolomitised. The dolomites are cross-cut by fractures (Plate I, 5). The latter have been cemented by non-ferroan, dull orange-brown luminescent calcites (Plate I, 6, 7). Calcite

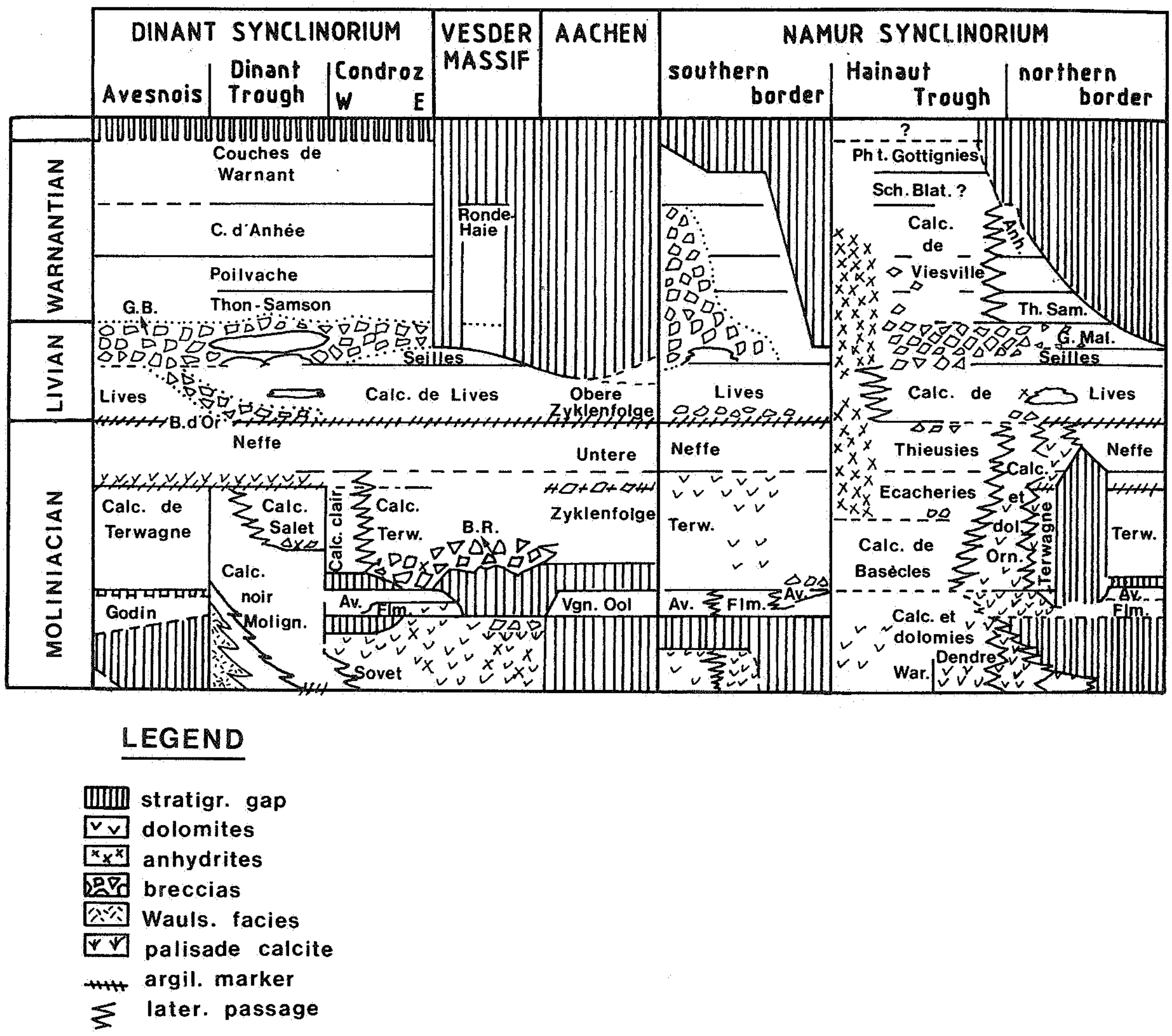

Figure 1. Lithostratigraphic position of the Belle Roche breccia (B.R.) and the Grande Brèche (G.B. ; after Paproth *et al.*, 1983).

pseudomorphs after evaporites may also show a dull orange-brown luminescence. The fractures can be traced into larger dissolution cavities. From petrographical observations alone, it is not clear if these fractures represent only one stage of fracturing or several distinct periods. After the non-ferroan dull orange-brown cementation phase, another fracturing period occurred. This period was followed by the precipitation of ferroan, bright yellow or orange-yellow zoned luminescent equigranular to blocky calcites (Plate I, 8). These calcites fill small cavities (100 µm - cm) and veins (µm - mm). The same bright yellow luminescence is observed in some calcite pseudomorphs after evaporites.

4.1.2. The Grande Brèche

The paragenetic sequence of the Grande Brèche is based on the investigation of the Corenne borehole. Since lateral facies variations are present, generalization of the data is unallowed, especially the results of the early diagenesis. However, intermediate and late diagenetic processes which are often related to the tectonic setting and evolution of the basin are thought to be representative for the Dinant synclinorium. Further research will be carried out to verify to which extent this generalization can be made.

After lithification, Livian limestones have been brecciated to a limited extent (Fig. 3). This minor brecciation phase caused the development of angular fragments surrounded by non-luminescent calcites. The fragments show a fitted fabric (Plate II, 1). The fragments and the non-luminescent calcites are cross-cut by stylolites (Plate II, 2). The stylolites are themselves cross-cut by large fractures. Associated with these fractures are dissolution cavities. Both give the limestone its typical brecciated aspect. The fractures and the cavities have been subsequently filled with non-ferroan, dull orange-brown luminescent calcites (Plate II, 3). In the Grande Brèche, several periods of fracturing have been recognized. Stylolitisation also occurred later in the diagenetic history. They cross-cut the non-ferroan, dull orange-brown vein cements. The stylolites are post-dated by another generation of calcitic vein cements (Plate II, 4). The latter calcites are ferroan and bright yellow luminescent (Plate II, 2).

4.2. Comparison between the diagenetic evolution of the Belle Roche breccia and the Grande Brèche

The comparison between the diagenetic evolution of the Belle Roche breccia and the Grande Brèche is given in figure 3. The precursors of both breccias were lithified and were brecciated early in the diagenetic history. Brecciation, however, was more intense in the lower Visean than in the middle Visean limestones. In the middle Visean only thin fractures with a non-luminescent calcite cement are present. In the lower Visean, large cavities were created during this early stage. They were subsequently filled with a sedimentary micritic matrix with peloids, ooids, ostracods and foraminifers.

The difference in the early diagenesis can be - however not necessarily - related to the general sedimentological setting. During the early Visean several important continental phases occurred. They are represented by well developed, thick paleosols. The paleosols are present just above the Belle Roche breccia (Swennen *et al.,* 1988 ; Maes *et al.*, 1989 ; Peeters *et al.,* 1993) and as fragments within the breccia (Peeters *et al.*, 1992). Isotopic evidence indicates that during these continental periods, meteoric waters could have penetrated the subsurface and dissolved the evaporites (Muchez *et al.*, 1992). Also, in the middle Visean, exposure surfaces have been recognized (De Putter & Préat, 1989). Numerous emergence phases, indicated by the dissolution of the limestones and by the presence of meniscus cements, are related to the rhythmic sedimentation. The occurrence of only a few, badly developed glaebules and the absence of other typical features of paleosol development, however, indicate a limited exposure time for each emergence phase.

In the Belle Roche breccia and the Grande Brèche a second brecciation period was associated with the development of fractures, which post-dated stylolitisation. The fractures and the cavities have in both cases been filled with non-ferroan, dull luminescent calcites. Although these characteristics do not prove a common formation period, it does at least indicate a similar mechanism. The second brecciation period was more important in the middle Visean than in the lower Visean. The difference between both breccias is though to be due to the absence of an important, early diagenetic evaporite dissolution phase in the middle Visean strata. So, thick anhydrite sequences were preserved in the deeper subsurface and were dissolved after stylolitisation.

The veins with a bright yellow luminescence are omnipresent. Minor dissolution of evaporites associated with this fracturing period has only been recognized in the lower Visean.

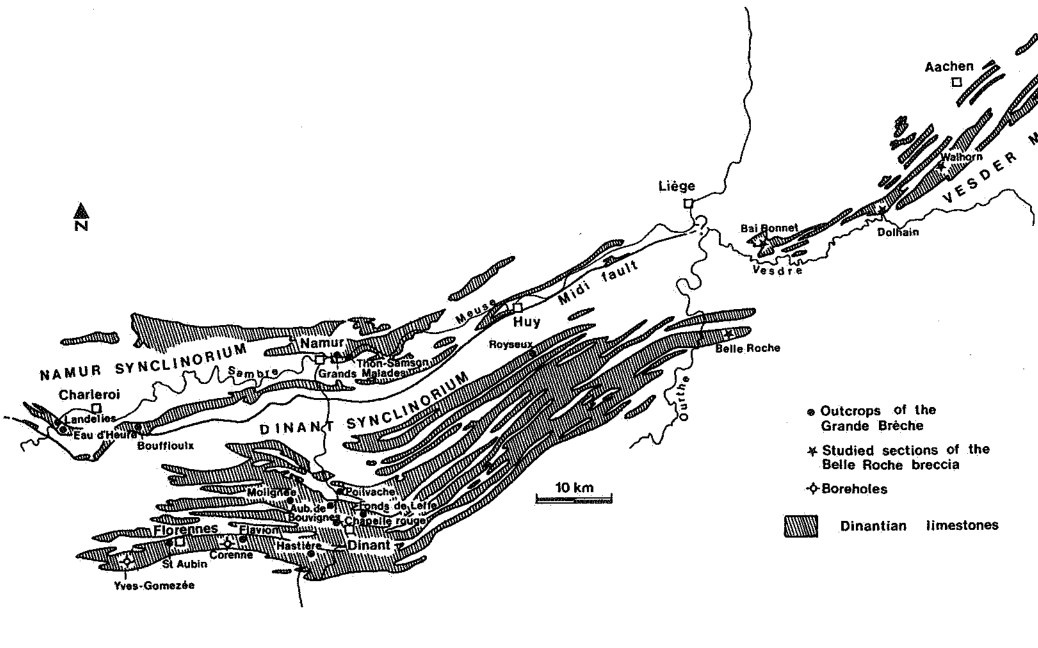

Figure 2. Geological map of the Dinantian in south Belgium and the position of the investigated outcrops and boreholes.

5. DISCUSSION

A common feature of the Visean breccias is the late diagenetic dissolution. In both cases this dissolution is related with the development of fractures. The fracturing allowed the circulation of fluids undersaturated in evaporitic minerals in the deeper subsurface. In the Grande Brèche, several fracturing periods have been recognized. Dating of these periods from the present data is impossible. In the Dullière quarry near Charleroi, fracturing of the Grande Brèche was caused by stresses generated during Variscan tectonism (De Putter & Mercier, in press). In the Belle Roche breccia at its type locality, major fracturing was probably associated with the Sudetic orogenic phase (Swennen *et al.,* 1990). The importance of the migration of fluids during the Carboniferous in the deeper subsurface of northern Belgium has been described by Muchez *et al.* (1991). Even during the present time, the dissolution of the Visean evaporites in southern Belgium continues due to the migration of fluids in the subsurface (de Magnée *et al.,* 1986).

6. CONCLUSION

The two Visean breccias have a comparable paragenetic evolution (Fig. 3). However, the importance of the diagenetic processes is different in both breccias. In the lower Visean Belle Roche breccia, early

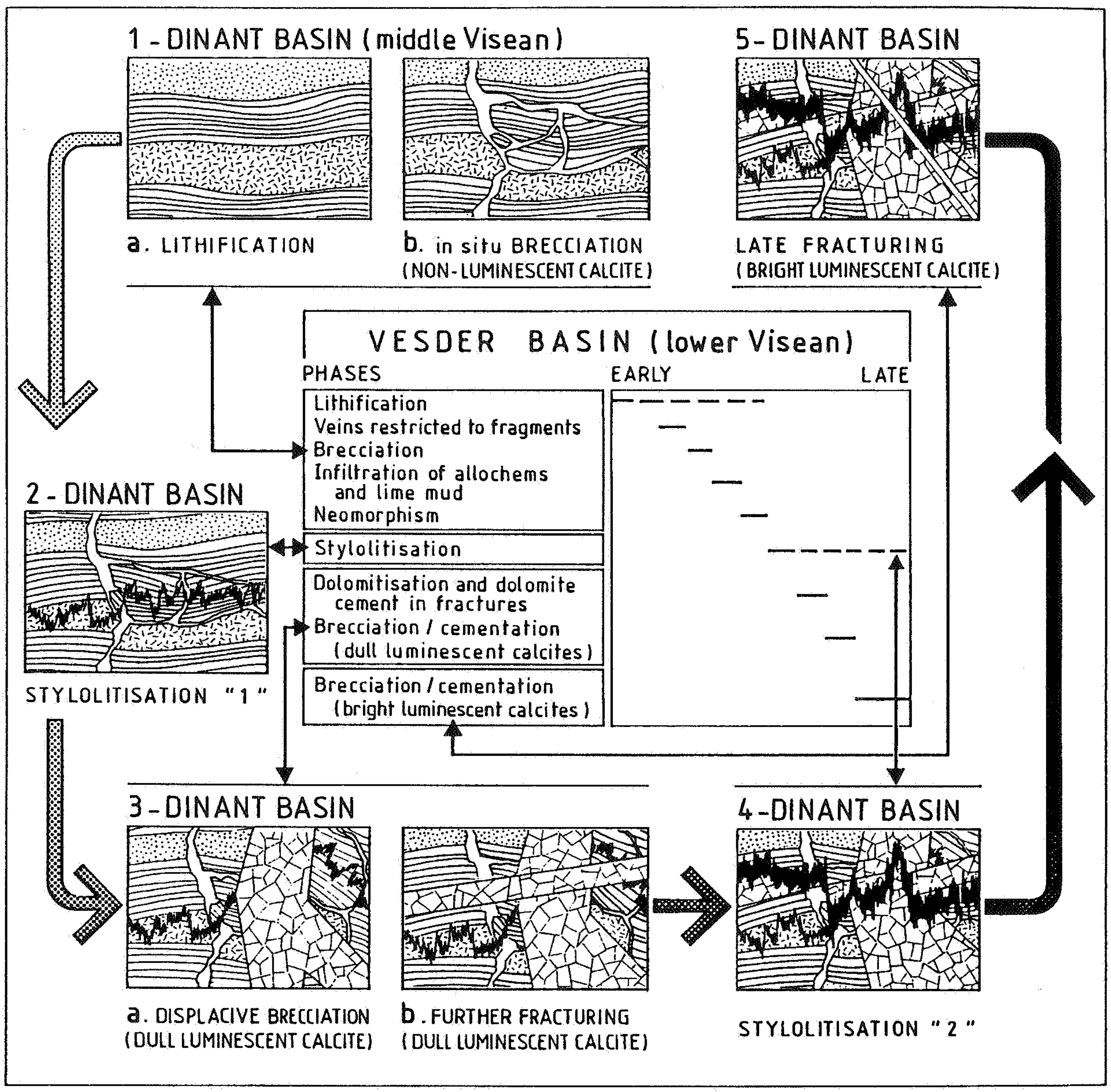

Figure 3. Comparaison of the diagenetic evolution of the Belle Roche breccia and the Grande Brèche (partly after De Putter & Herbosch, 1990 ; Muchez *et al.*, 1992).

diagenetic dissolution of the evaporites was very important. This dissolution is probably related the emergence periods during the lower Visean. In the middle Visean Grande Brèche, dissolution in the burial realm was more important. This was due to the preservation of evaporites in the deeper subsurface.

In both breccias, the late diagenetic dissolution of the evaporites is associated with fracturing of the limestones. The fractures were the pathways for the migration of fluids in the deeper subsurface. If a detailed knowledge of the sedimentological and tectonic evolution of an evaporite-limestone sequence exists, the diagenetic evolution of this sequence can be generally modelled and predicted.

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REFERENCES

BOUCKAERT, J., DELMER, A. & OVERLAU, P., 1961 - Stratigraphie du Viséen moyen et supérieur et du Namurien inférieur dans la région de Basècles-Blaton (Tranchée du Mont des Groseillers). *Mém. Inst. Géol. Univ. Louvain,* **22**: 239-255.

CONIL, R., 1967 - Problèmes du Viséen inférieur dans le Condroz. *Ann. Soc. géol. Belgique,* **90**: B413-429.

CONIL, R. & PIRLET, H., 1970 - Le calcaire carbonifère du synclinorium de Dinant et le sommet du Famennien. Colloque sur la stratigraphie du Carbonifère, Liège, avril 1969. *Congr. & Colloque U.Liège,* **55**: 167-177.

CONIL, R., LYS, M., RAMSBOTTOM, W., NAUM, C., GERARD, R., HANCE, L. & VIESLET, J.-L., 1981 - Contribution à l'étude des foraminifères du Dinantien d'Europe occidentale. *Mém. Inst. Géol. Univ. Louvain,* **31**: 255-275.

CONIL, R., GROESSENS, E., LALOUX, M., POTY, E. & TOURNEUR, J., 1990 - Carboniferous guide foraminifera, corals and conodonts in the Franco-Belgian and Campine basins : their potential for widespread correlation. *Cour. Forsch. Inst. Senckenberg,* **130**: 15-30.

DEJONGHE, L., DELMER, A. & GROESSENS, E., 1976 - Découverte d'anhydrite dans les formations anté-namuriennes du sondage de Saint-Ghislain. *Bull. Acad. roy. Belgique,* séance du 10 janvier 1976, 80-83.

de MAGNEE, I., DELMER, A. & CORDONNIER, M., 1986 - La dissolution des évaporites du Dinantien et ses conséquences. *Bull. Soc. belge Géol.,* **95**: 213-220.

DE PUTTER, Th. & PREAT, A., 1989 - Sédimento-diagénèse de séquences émersives de type "shallowing-upward" dans la "Grande Brèche" calcaire du Viséen supérieur de Belgique. *C.R. Acad. Sc. Paris,* **309**: 1827-1831.

DE PUTTER, Th. & HERBOSCH, A., 1990 - Le V3a du Sondage de Corenne (Synclinorium de Dinant, Belgique) : 110 mètres de Brèche Grise. *Ann. Soc. géol. Belgique,* **113**: 247-265.

DE PUTTER, Th. & MERCIER, E., in press - La brèche rouge de Landelies (Massif de la Tombe) : Grande Brèche (Livien supérieur, ex-"V3a") ou brèche post-viséenne ? *Mém. Inst. géol. Univ. Louvain.*

DE PUTTER, Th., ROUCHY, J.-M., GROESSENS, E., HERBOSCH, A., KEPPENS, E. & PIERRE, C., in press - Sedimentology and palaeoenvironment of the upper Visean anhydrite series of the Franco-belgian basin. *Sed. Geology.*

FAIRCHILD, I.J., 1983 - Chemical controls of cathodoluminescence of natural dolomites and calcites: new data and review. *Sedimentology,* **30**: 579-583.

GROESSENS, E., CONIL, R. & HENNEBERT, M., 1982 - Le sondage de St-Ghislain. *Mém. Expl. Cart. géol. min. Belgique, Serv. Géol. Belgique,* **22(1979),** 137 p.

HEMMING, N.G., MEYERS, W.J. & GRAMS, J.C., 1989 - Cathodoluminescence in diagenetic calcites : the roles of Mn and Fe as deduced from electron probe and spectrophotometric measurements. *J. Sed. Petrology,* **59**: 404-411.

JACOBS, L., SWENNEN, R., VAN ORSMAEL, J., NOTEBAERT, L. & VIAENE, W., 1982 - Occurrences of pseudomorphs after evaporitic minerals in the Dinantian carbonate rocks of the eastern part of Belgium. *Bull. Soc. belge Géol.,* **91**: 105-123.

MACHEL, H., 1985 - Cathodoluminescence in calcite and dolomite and its chemical interpretation. *Geosc. Canada,* **12**: 139-147.

MAES, K., PEETERS, C., MUCHEZ, Ph., SWENNEN, R. & VIAENE, W., 1989 - The occurrence of paleosols in the Lower Visean of the Walhorn section (Vesder basin, E-Belgium). *Ann. Soc. Géol. Belgique,* **112**: 69-77.

MAMET, B., CLAEYS, Ph., HERBOSCH, A., PREAT, A. & WOLFOWICS, Ph., 1986 - La Grande Brèche viséenne (V3a) des bassins de Namur et de Dinant (Belgique) est probablement une brèche d'effondrement. *Bull. Soc. belge Géol.,* **95**: 151-166.

MASON, R.A., 1987 - Ion microprobe analysis of trace elements in calcite with an application to the cathodoluminescence zonation of limestone cement from the Lower Carboniferous of South Wales, U.K. *Chem. Geol.*, **64**: 209-224.

MUCHEZ, Ph., VIAENE, W.A., KEPPENS, E., MARSHALL, J.D. & VANDENBERGHE, N., 1991 - Vein cements and the geochemical evolution of subsurface fluids in the Visean of the Campine Basin (Poederlee borehole, Belgium). *J. Geol. Soc. London*, **148**: 1005-1117.

MUCHEZ, Ph., PEETERS, C., VIAENE, W. & KEPPENS, E., 1992 -Stable isotopic composition of an evaporitic dissolution breccia in the Lower Visean limestones of SE Belgium. *Chem. Geol., **102**:* 119-127.

PAPROTH, E., CONIL, R., BLESS, M.J.M., BOONEN, P., CARPENTIER, N., COEN, M., DELCAMBRE, B., DEPRYCK, Ch., DEUZON, S., DREESEN, R., GROESSENS, E., HANCE, L., HENNEBERT, M., HIBO, D., HAHN, G., HAHN, R.,HISLAIRE, O., KASIG, W., LALOUX, M., LAUWERS, A., LEES, A., LYS, M., OP DE BEECK, K., OVERLAU, P., PIRLET, H., POTY, E., RAMSBOTTOM, W., STREEL, M., SWENNEN, R., THOREZ, J., VANGUESTAINE, M., VAN STEENWINKEL, M. & VIESLET, J.L., 1983 - Bio- and lithostratigraphical subdivision of the Dinantian in Belgium, a review. *Ann. Soc. géol. Belgique*, **106**: 185-239.

PEETERS, C., 1990 - De genese van breccies, palisade calcieten en paleosols uit het Onder-Viseaan ten zuidoosten van het Brabant Massief en hun implikaties voor de paleogeografie. *Ph. D. thesis, K.U.Leuven*, 228 p.

PEETERS, C., MUCHEZ, Ph. & VIAENE, W., 1992 - Paleogeographic and climatic evolution of the Moliniacian (lower Visean) in southeastern Belgium. *Geol. Mijnbouw*, **71**: 39-50.

PEETERS,C., SWENNEN, R., NIELSEN, P. & MUCHEZ, Ph., 1993 - Sedimentology and diagenesis of the Visean carbonates in the Vesder area (Verviers synclinorium, E-Belgium). *Zentralbl. Geol. Paläont.*, **1992/5**: 519-547.

PIERSON, B.J., 1981 - The control of cathodoluminescence in dolomite by iron and manganese. *Sedimentology*, **28**: 601-610.

PIRLET, H., 1972 - La "Grande Brèche" viséenne est un olisthostrome : son rôle dans la constitution du géosynclinal varisque en Belgique. *Ann. Soc. géol. Belgique*, **95**: 53-134.

ROUCHY, J.-M., GROESSENS, E. & LAUMONDAIS, A., 1984 - Sédimentologie de la formation anhydritique viséenne du sondage de Saint-Ghislain (Hainaut, Belgique) : implications paléogéographiques et structurales. *Bull. Soc. belge Géol.*, **93**: 105-145.

ROUCHY, J.-M., LAUMONDAIS, A. & GROESSENS, E., 1987 - The Lower Carboniferous (Visean) evaporites in Northern France and Belgium : depositional, diagenetic and deformational guides to reconstruct a disrupted evaporitic basin. *Lect. Notes Earth Sci.*, **13**: 31-67.

SOMMER, S.E., 1972 - Cathodoluminescence of carbonates. 1. Characterization of cathodoluminescence from carbonate solid solutions. *Chem. Geol.*, **9**: 257-273.

SWENNEN, R., PEETERS, C., MUCHEZ, Ph., MAES, K. & VIAENE, W., 1988 - Sedimentological and diagenetic evolution of Dinantian carbonates (dolomitization, evaporite solution collapse breccias, paleosols and palisade calcites). *In :* Herbosch, A. (Ed.), *Int. Assoc. Sediment., 9th Eur. Meet. Exc. Guidebook, Leuven. Min. Econ., Aff., Belg. Geol. Survey, Brussels.* 77-97.

SWENNEN, R., VIAENE, W. & CORNELISSEN, C., 1990 - Petrography and geochemistry of the Belle Roche breccia (Lower Viséan, Belgium) : evidence for brecciation by evaporite dissolution. *Sedimentology*, **37**: 859-878.

VOGEL, K., MUCHEZ, Ph. & VIAENE,W., 1990 - Collapse breccias and sedimentary conglomerates in the Lower Visean of the Vesdre area (E-Belgium). *Ann. Soc. géol. Belgique*, **113**: 359-371.

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PLATE 1

Figure 1. Dolhain. Cavities between the fragments have been filled with ooids (a) and clasts (b). The latter float in a microsparitic matrix. Scale bar is 375 μm.

Figure 2. Bai Bonnet. Breccia matrix with peloids (a) and broken shells (b). Scale bar is 440 μm.

Figure 3. Bai Bonnet. Stylolites (arrows) cross-cut the micritic to microsparitic matrix. Scale bar is 440 μm.

Figure 4. Bai Bonnet. Dolomite crystals (d) partly replace the breccia matrix. Scale bar is 375 μm.

Figure 5. Bai Bonnet. Dolomite (d) cross-cut by calcite fractures (c).

Figure 6. Bai Bonnet. Fracture in the breccia is cemented by blocky calcites. Scale bar is 100 μm.

Figure 7. Cathodoluminescence photograph of figure 6. The first fracture filling calcites have a dull orange luminescence (a). After this cementation, a second period of fracturing and dissolution occurred. The resulting cavities have been cemented by bright yellow luminescent calcites (b). Dedolomitized crystals (c) also show this bright yellow luminescence.

Figure 8. Bai Bonnet. Orange-yellow zoned luminescent calcites fill fractures (a) and occur as pseudomorphs after evaporites (b). Scale bar is 100 μm.

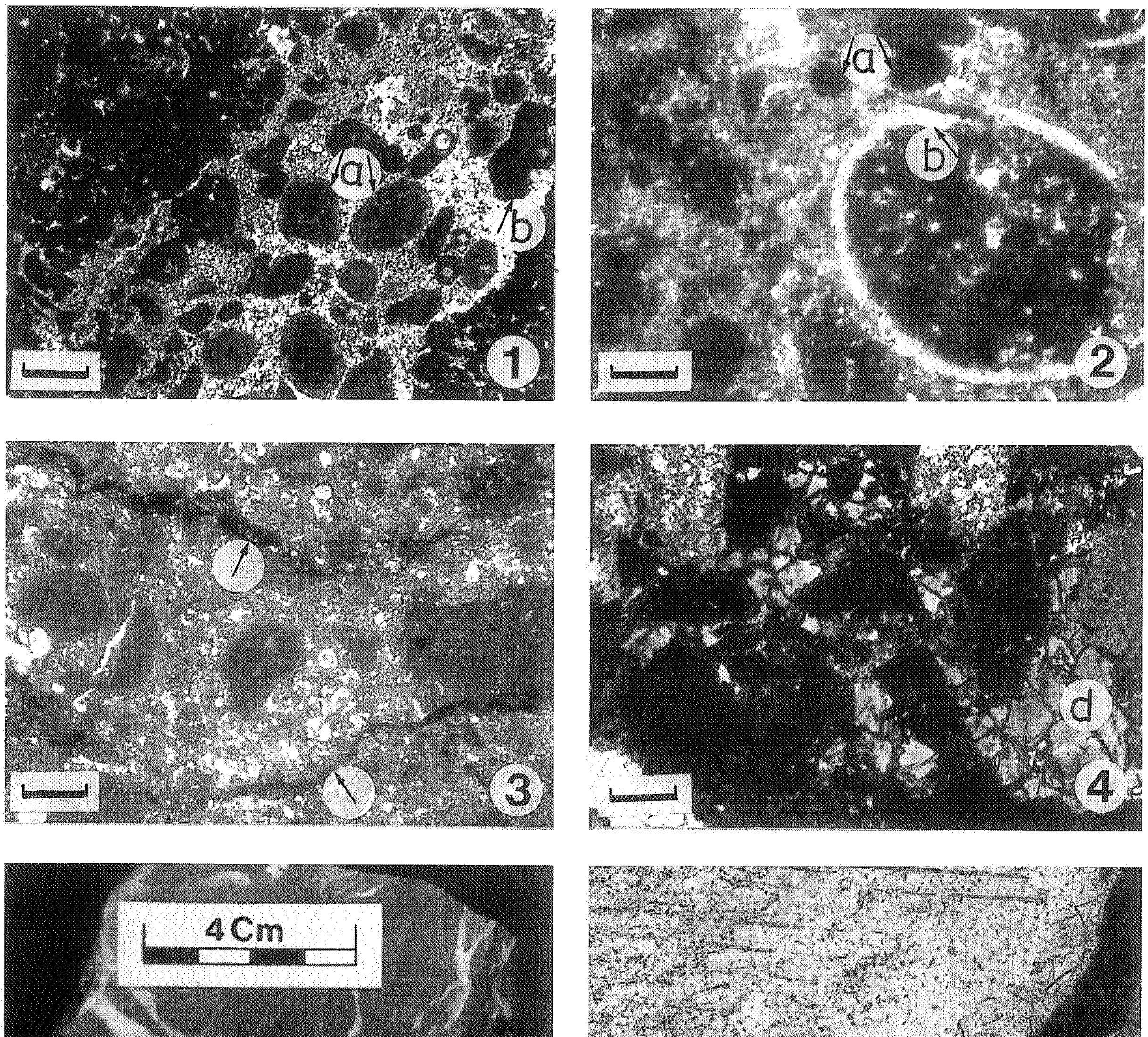
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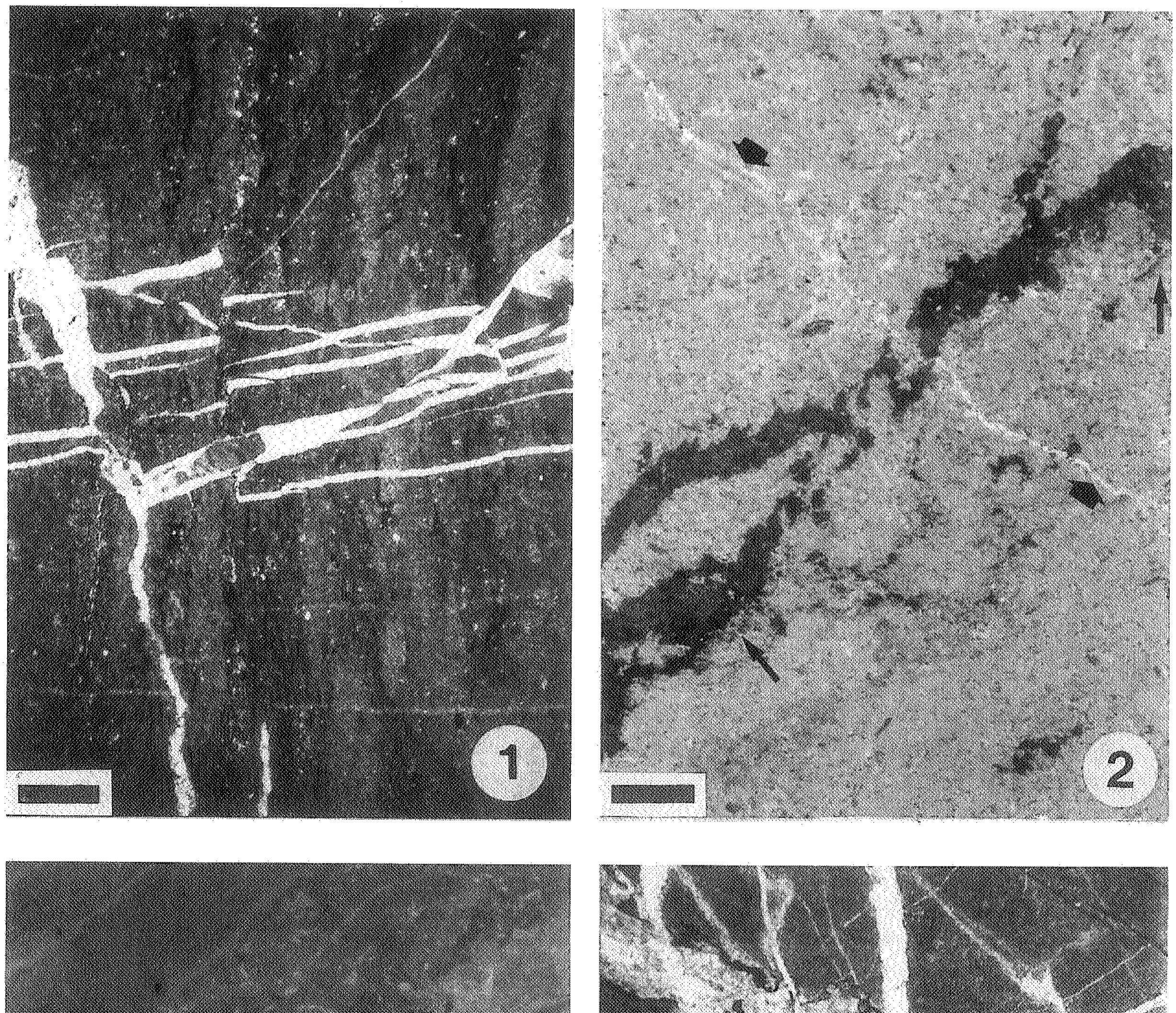
PLATE 2

Figure 1. Fragments of the Grande Brèche showing a fitted fabric. Corenne borehole, 33 m. Scale bar is 300 μm.

Figure 2. Cathodoluminescence photograph showing non-luminescent calcites (dark) cross-cut by stylolites (thin arrows). A thin late bright yellow luminescent fracture is indicated by thick arrows. Corenne borehole, 55.25 m. Scale bar is 100 μm.

Figure 3. Cathodoluminescence photograph showing a fracture filled by dull orange-brown luminescent calcites (a). A pseudomorph after anhydrite is filled by earlier non-luminescent calcite (b). Corenne borehole, 55.25 m. Scale bar is 100 μm.

Figure 4. Calcite vein post-dating styolites (b), while another vein pre-dates the stylolites (a). Corenne borehole, 55.25 m. Scale bar is 350 μm.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