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COLLAPSE BRECCIAS AND SEDIMENTARY CONGLOMERATES IN THE LOWER VISEAN OF THE VESDRE AREA (E-BELGIUM)

by

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(4 figures and 2 plates)

ABSTRACT.- Based on their lithological and petrographical features two carbonates rudites have been distinguished in the lower part of the Lower Visean (Lower Moliniacian) of the Walhorn quarry.

The lowermost carbonate rudite, the dolomitic Vesdre Breccia Member, is an evaporitic solution-collapse breccia, that consisted primarily of a number of shallowing upward sequences deposited in a sabkha environment. Dolomite pseudomorphs after anhydrite nodules still form a major portion of this breccia.

The upper carbonate rudite is mainly a limestone conglomerate of sedimentary origin. This interpretation is based on the presence of large, rounded, polymict carbonate fragments and the presence of marine biota and oolites in the conglomerate matrix. The conglomerate unit represents a shallowing upward sequence. The macroscopic features of the conglomerate fragments indicate that the transport occurred in a short lived, highly energetic environment. The possible depositional environments are discussed.

RESUME.- Dans le Moliniacien inférieur, deux types de rudites carbonatées ont été distingués dans la carrière de Walhorn. Cette distinction est basée sur une étude minéralogique, lithologique et génétique.

Le premier, situé dans la partie inférieure représente une brèche dolomitique d'effondrement par dissolution d'évaporites. La brèche consiste en cinq «shallowing upward» séquences, qui ont été déposées dans un milieu de type sabkha. Des dolomies pseudomorphes de nodules anhydritiques sont des constituants importants de la brèche.

La partie supérieure de la rudite est principalement formée par un conglomérat d'origine sédimentaire. Cette interprétation est basée sur la présence de grands fragments poligènes arrondis, d'une faune marine et de présence d'oolites dans la matrice. Cette unité conglomératique représente une «shallowing upward» séquence. Les caractéristiques macroscopiques des fragments indiquent que le transport s'est passé dans un milieu énergétique et fut de courte durée. Les processus de transport possibles sont discutés.

1.- INTRODUCTION

This paper presents the results of a sediment petrographical study of the Lower Visean carbonate beds exposed in the Walhorn quarry, located in the Vesdre Basin in eastern Belgium. This quarry was the subject of many recent studies (Jacobs *et al.,* 1982; Swennen, 1986; Swennen *et al.,* 1981, 1982, 1988; Maes *et al.,* 1989) as it is one of the most complete and representative Visean exposures of the basin. The purpose of the study was to gain a better insight into the processes resulting in the formation of the breccias and conglomerates exposed there. A general location map of the village and of the quarry is given in the figures 1A and 1B respectively.

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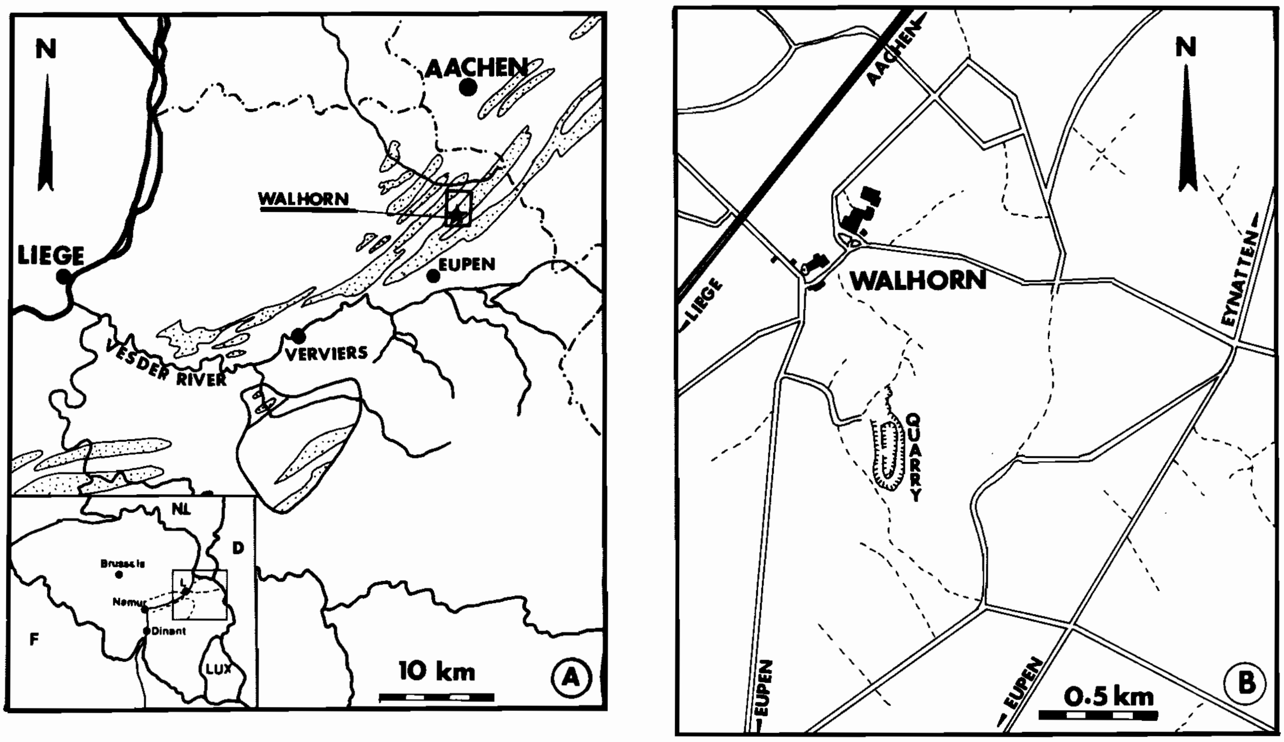

Fig. 1.- a) General location of the Walhorn village. b) Detail map showing the location of the studied quarry.

2.- THE DOLOSTONE BRECCIA

2.1.- LITHOLOGICAL AND SEDIMENT PETROGRAPHICAL FEATURES OF THE DOLOSTONE BRECCIA

The lowermost portion of the studied sequence consists of a dolostone breccia (fig. 2), named the Vesdre Breccia Member by Jacobs *et al.* (1982), who defined it as the dolostone breccia occurring above the Palisade Calcite Member. The breccia is about 12,5m thick and is interrupted by several continuous dolostone beds. Jacobs *et al.*(1982) interpreted this breccia as an evaporitic collapse breccia, based on the presence of slump and collapse structures, breccia fragments with a fitted fabric and fragments showing crumbled edges. A new exposure at a deeper level in the quarry reveals several interesting features supporting this interpretation. Moreover, as the degree of weathering is less at this lower outcrop, a greater amount of sedimentological detail is visible.

2.1.1.- Macroscopic description

The base of the studied section (fig. 2) consists of a thick blue-gray palisade calcite. An undulating boundary separates a 5m thick palisade calcite bed from a 0.4m thick dolostone bed, which occurs immediately under the first breccia bed. This dolostone bed includes a 0.2m thick stromatolite. The breccia beds consist of blue-grayish to whitish fragments (0.1 to 40cm large) in a blue-grayish to whitish matrix (Pl. I: 1). Upon weathering both turn into various shades of beige or brown and become crumbly and monotonous in color, consequently obscuring the breccia characteristics. The breccia matrix commonly shows flow textures (Pl. I: 2). In the larger fragments and in the continuous dolostone beds, white dolomitic nodules are present, showing cauliflower, enterolithic (Pl. I: 3) and chickenwire structures (Pl. I: 4). The breccia fragments often show a jigsaw puzzle structure (Jacobs *et al.*, 1982). It is sometimes possible to piece two adjacent fragments together again. The breccia beds are fragment-supported and their upper boundary is usually distinct. A transitional dolostone bed separates the dolostone breccia from the limestone conglomerate.

Several dedolomitized zones, characterized by a rusty brown weathering color, cross-cut the breccia beds. Unbrecciated beds between the breccia beds are common and consist of a lithology similar to that of the breccia fragments. One type of unbrecciated bed not found as breccia fragment are bluish palisade calcite beds, showing a similar general macroscopic succession as found by Swennen *et al.* (1981). These calcites always underlay a thin brown dolomitized stromatolite (not shown in fig. 2).

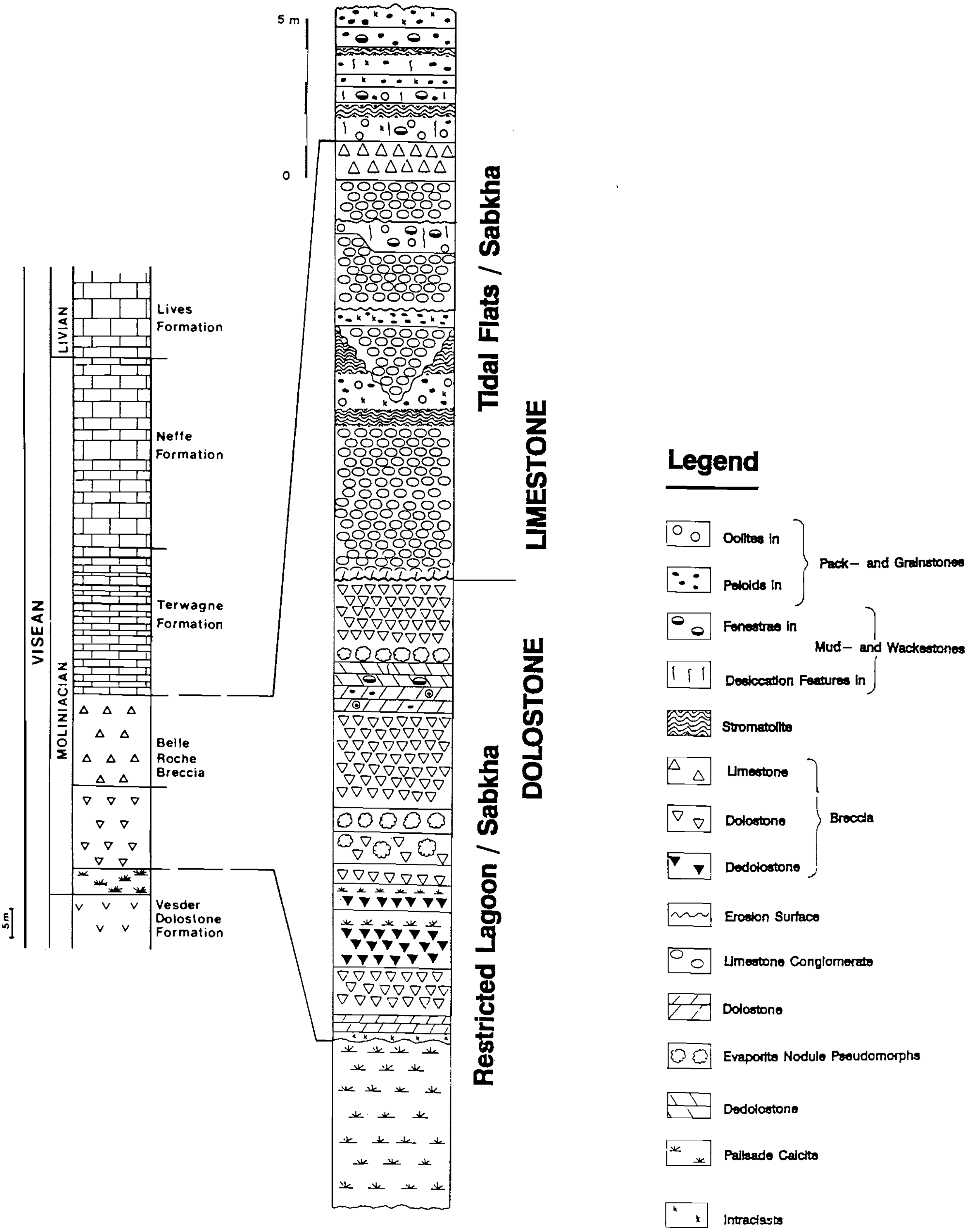

Fig. 2.- Schematic lithostratigraphic log of the studied interval section.

2.1.2.- Microscopic description

Microscopically the breccia consists mainly of dolomicrite fragments, often recrystallized to dolomicrosparite, in a matrix of clear xenotopic and hypidiotopic dolosparite (Pl. I: 5). The fragments are rich in dolosparite pseudomorphs after selenite, anhydrite, gypsum and halite (Pl. II: 1). They rarely contain foraminifer, peloid and fenestrae relicts. Desiccation features are common. Minor fragment types include dolosparites, sometimes with peloid relicts. Other dolomite types found include saddle dolomite, frequently found in the Vesdre Breccia Member as a diaclase filling cement, associated with fluorite. The bad state of preservation and paucity of the fossil found in the dolostone breccia preclude their use for biostratigraphy.

2.2.- INTERPRETATION OF THE DOLOSTONE BRECCIA

Several features indicate that the xenotopic dolosparite nodules were primarily anhydrite nodules, diagenetically altered to dolosparite:

- lath-shaped protrusions out of the nodules (Pl. II: 2);
- enterolithc and chickenwire structures are typical of evaporite nodules (Shearman, 1978);
- the cauliflower shape of the nodules;
- gypsum relicts in the center of the nodules.

Upon a closer examination of the breccia a rough succession in the fragments is noticeable. A similar succession is reflected in the unbrecciated beds. Thus a schematic sequence of the dolostone beds prior to brecciation can be reconstructed (fig. 3). Upon comparing this sequence with an ideal sabkha sequence (e.g. Shearman, 1978) we can assign a depositional environment to the different subunits of the measured sequence (fig. 3). At least five sabkha cycles, interpreted to be shallowing upward sequences are present in the studied dolostone brecia. The base of the recognized sequence is formed by peloid and intraclast-rich grainstones and by stromatolites. The latter probably originated in the intertidal zone, although a subtidal origin can not be excluded (Tucker, 1985). The stromatolite is followed by evaporite-rich dolomicrite with loose evaporitic crystals floating in the dolomicrite, and by supratidal nodular, enterolithic and chicken wire-structure anhydrite, which succeed each other in different permutations. The whole is capped by a supratidal marsh type deposit, present only in the uppermost sequence. The position and the origin of the palisade calcite in this sequence is discussed below.

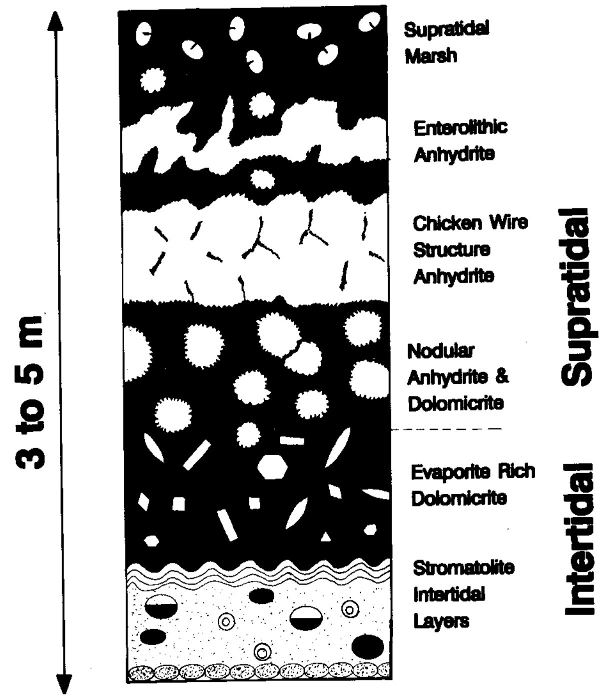

Fig. 3.- Reconstructed ideal sabkha sequence, as it would look prior to brecciation.

The dolomite breccia is interpreted as having a solution collapse origin based on the following characteristics:

- variable fragment size;
- anglular, oligomict fragments;
- association with evaporites;
- dolomicrite fragments;
- jigsaw puzzle structure and crumbled edges of the fragments (cfr. Stanton, 1966).
- evaporitic flow structures in the matrix.

The brecciation occurred between deposition of the sequence and the deposition of the next sequence. The beds were deposited in cycles in a sabkha environment. At the top of each cycle percolating meteoric or marine water, undersaturated in evaporites, dissolved a part of the evaporites, thus creating instability of the interlaying dolomicrite beds, resulting in brecciation.

2.3.- FEATURES OF THE PALISADE CALCITE

The origin of the palisade calcite is still a point of discussion and beyond the intended scope of this article. Still a few observations are made here concerning the appearance of this calcite. Typical of this lithology is the occurrence of calcite rosettes (Jacobs *et al.*, 1982) of varying size (usually between 1 to 5cm). The thickness of the palisade calcite beds decreases upwards in the stratigraphic profile. In other words the thickness of the lower bed (5 m) is larger than the thickness of the middle bed (60 cm), which in turn is larger than the upper bed (30 cm). As the forementioned sequences represent shallower and shallower sedimentation upwards in the profile, this would seem to imply that the precursor of the palisade calcites was deposited in an intertidal to subtidal environment. However, a more detailed study of the palisade calcite is needed for confirmation.

A spatial relation exists between the position of the palisade calcites, or their precursor, and the dedolomites. The dedolomites occur below the palisade calcites and the degree of dedolomitization decreases as the distance away from the calcites increases (see below).

3.- DEDOLOMITES

3.1.- LITHOLOGICAL AND SEDIMENT PETROGRAPHICAL FEATURES OF THE DEDOLOMITES

3.1.1.- Macroscopic description

Many dedolomitization zones cross-cut the Vesdre Breccia Member. Most of these run more or less stratiform. One, not discussed in this article, runs symmetrically around a diaclase. The zones are characterized by a yellowish to rusty color of iron oxides and hydroxides. Often dolostone breccia fragments present in these zones have a dedolomitized outer rim and a partially dedolomitized dolomicritic inner core. They immediately underlie either a palisade calcite bed or a bed consisting entirely of evaporite nodule pseudomorphs. The degree of dedolomitization rapidly decreases from total dedolomitization immediately beneath the beds to minor dedolomitization of the matrix further below. Above the beds only minor dedolomitization occurs.

3.1.2.- Microscopic description

Microscopically the dedolomites are characterized by a yellow-brown grumulous, micritic calcite, showing signs of being secondary after dolomite. All primary textures have been obliterated. Often dolosparite crystals have a dedolomite outer rim, while the core remains untouched or has an iron hydroxide coating.

3.2.- INTERPRETATION OF THE DEDOLOMITES

Two dedolomite beds immediately underlie two palisade calcite beds, the third is associated with a bed consisting entirely of evaporite nodule pseudomorphs. Two facts suggest a relationship:

- the degree of dedolomitization rapidly diminishes from total dedolomitization immediately beneath the palisade beds and the bed consisting of evaporite nodule pseudomorphs to minor dedolomitization of the matrix further beneath the beds. Above the beds only minor dedolomitization occurs.
- the stratigraphic nature of the dedolomites: the dedolomite zone parallel the dip and trend of the beds with which they are associated.

The dedolomitization process could have involved the dissolution of gypsum and anhydrite. Evamy (1967) suggested the following dedolomitization reaction:

$$CaSO_4 + CaMg(CO_3)_2 \rightarrow 2CaCO_3 + MgSO_4$$

The surface ions necessary for this reaction are supplied through the oxidation of pyrite or the dissolution of gypsum/anhydrite (Evamy, 1967). Although the beds are rich in pyrite, none of this pyrite shows any sign of being oxidized, except in the dedolomitized beds themselves. The upper stratigraphic dedolomite bed is associated with a 0.7 m thick bed of evaporite nodule pseudomorphs showing chicken-wire structure.

An indication for the origin of the sulfate ions is the pseudomorphosed evaporitic bed overlying the largest portion of the dedolomites. The relationship between the palisade calcite and the dedolomites remains unclear. If the precursor of the palisade calcites were originally a calcium sulphate mineral the pseudomorphosis of this mineral could have been the supplier of the sulphate necessary to drive the above mentioned reaction. Otherwise the process of palisade calcite formation might have locally oxidized some pyrite to produce dedolomitization. Both possible dedolomitization methods remain hypothetical, due to the unclear origin of the palisade calcite.

A logical sequence of events for the dolostone breccia would therefore be:

1) deposition of dolomicrites and evaporites in a sabkha.
2) dissolution of a large part of these evaporites resulting in the collapse of part of the dolostone beds.
3) cementation of the collapse breccia by xenotopic/hypidiotopic dolosparite.
4) pseudomorphism/dissolution of the remaining evaporites, releasing sulfate ions. The reaction of the sulfate with the dolomite would be most intense nearest the source, i.e. immediately underneath the evaporite-rich beds. Due to dilution, the dedolomitization is less farther away.

4.- LIMESTONES

4.1.- LITHOLOGICAL AND SEDIMENT PETROGRAPHICAL FEATURES OF THE LIMESTONE CONGLOMERATES

Above a 40 cm thick, secondarily dedolomitized transition bed, in erosive contact with the underlying dolostone breccia, a 13 m thick, discontinuous limestone conglomerate unit occurs (fig. 2). Occasionally the conglomerate is interrupted by massive beds. Typically it contains rounded fragments (Pl. II: 3) and occasional «broken rounds» (Pl. II: 4; sensu James, 1980) which can be fit into each other. The fragments are polymict and their sizes range from 0.1 to 40 cm. The conglomerates may occur in channel-like structures (Pl. II: 5). The underside of the deposit seems to be in erosive contact with the underlying beds. Current marks and scour marks are present on the underside, paralleling the long axis of the channel-like structures. The current marks are usually of the subparallel, meandering rill type (Fairbridge & Bourgeois, 1978).

The top of the infilled channel-like structures is more or less planar to wavy and the sediments above the conglomerates usually show intertidal features: desiccation cracks, stromatolites, fenestrae,... Six channel-like structures were recognized in the exposure, though only three are exposed in their deepest parts. They cut through sub- to interdidal sediments or through other channel-like structures. Tectonism influenced the conglomerates as indicated by a transversal fault through the quarry and by the presence of tension qashes. These observations limit the interpretation of the U-shaped channel-like structures. However, detailed mapping of the conglomerate by Vogel (1987) showed lateral and vertical variations of the lithofacies along U-shaped structures.

The matrix of the conglomerates is volumetrically limited. Often it is heavily stylolitized or missing. If present it consists of lime sand, with varying amounts of intermixed micrite. The lime sand consists mainly of ooids and calcispheres, and to a lesser extent of foraminifers, aggregate grains, algal lumps and grapestones. Sometimes a normal gradation of the fragments is noticeable, although it is relatively uncommon. The grading is noticeable as a diminution of fragment size a vertical distance of 50 cm.

The conglomerate fragments themselves are very divers. Volumetrically the most important fragments are oolitic and peloidal packstones and grainstones (Pl. II: 6) and mudstones with fenestrae. Also present are bioclastic grainstone fragments, evaporitic mudstone fragments algal mudstone fragments, wackestone with calcisphere fragments, dolostone breccia fragments and dolostone and limestone paleosol fragments, although they are all volumetrically unimportant.

The beds the channel-like structures cut through, are not exposed in the lower portion of the conglomeratic sequence. An estimation of the dimensions of the lower channel-like structures suggests that they were at least 20 m wide and 4.5 m deep. Due to compaction and stylolitization and the dip of the beds these estimates may be on the conservative side. The beds the uppermost channel-like structures cut through are exposed, as the dimensions of these structures are smaller (~2 m deep and ~5 m wide). The beds they cut throug range from peloidal, calcisphere and ostracod-rich packstones, to well burrowed wackestones, to mudstones and stromatolites. Usually a channel-like structure is topped by mudstones, stromatolites and wackestones with the same intertidal characteristics as in the beds they cut through. Above the conglomerates there is a limestone breccia. The limestone breccia mainly has mudstone fragments with evaporite pseudomorphs after halite, anhydrite and gypsum, floating in a sparite matrix. This matrix locally contains well developed ooids, which apparently have been sucked in after the breccia formation. This breccia has been interpreted by Jacobs *et al.* (1982) and Swennen (1986) as an evaporitic solution-collapse breccia.

Above this breccia occur tidal flat deposits with bioclastic packstones, oolitic grainstones, peloidal and pellitic packstones, mudstones and wackestones with fenestrae, stromatolites and paleosols (Maes *et al.,* 1989).

4.2.- INTERPRETATION OF THE LIMESTONE CONGLOMERATES

The large, rounded fragments of polymict origin, the presence of marine fossils in an oolitic matrix and the current and scour marks all suggest that the conglomerates have a marine sedimentary origin (see also Blount & Moore, 1969). They were deposited by highly energetic flowing water as indicated by the large fragments (up to 40 cm) which were transported and rounded. Lower Visean conglomerates of sedimentary origin are also present in the Namur synclinorium (Pirlet, 1967b) and in the Visé area (Pirlet, 1967a; Poty, 1982).

The ooids in the matrix and in the conglomerate fragments are usually fairly large and concentric with a coat larger than 0.1 mm. These ooids were probably formed on an oolitic shoal located nearby, as abundance and good preservation state of the ooids in the matrix testifies. Although sometimes gradation of the fragments is present, as imbrication of the fragments, sedimentary structures are usually absent.

Most modes of transportation and deposition of the conglomerates other than storms (turbidity deposition, transgression conglomerate) were judged to be less likely than a storm or tide origin, following reasoning analogous to James (1980).

A possible other origin for the conglomerates can be related to gravity induced processes. They can be divided into rockfall, slides and sediment gravity flows. Only the last two processes are considered here. Slides include both translational (glides) and rotational (slump) types (Varnes, 1978). Most authors fail to differentiate between these two (see Cook & Mullins, 1983), so no differentiation will be made. Typical features of glide deposits such as soft sediment folds or faults, exotic blocks and intraformational truncation surfaces (Davies, 1977) have not been recognized in the studied outcrop. This can be due to the limited exposure. However, it is unlikely that a slide can produce the mixing of the highly diverse fragments as the internal cohesion of slides confines mixing of lithologies to interlayering of the original deposits (Enos & Moore, 1983).

Sediment gravity flows are also considered to be less likely due to:

- the evidence of current activity from the current and scour marks;
- the depositional environment, which is situated on a large, tidal influenced flat surface;
- the impact evidence as indicated by the «broken rounds» that fit into one another;
- the mixing of the fragments which formed in a different depositional environment. Many of the conglomerate fragments as well as the matrix originated in a more basinward environment than the depositional environment. This indicates that the fragments and the matrix were transported, at least partially, in a coastward direction.

The limestone conglomerate probably represents infill of tidal channels by fragments eroded by storms (see also Ball, 1967; Shinn, 1983; Loucks & Anderson, 1985). Indications that these channels have a tidal origin are:

- the channels cut through subtidal and intertidal beds and through each other;
- the width and depth of the channel-like structures are roughly the same as their modern day equivalents (Shinn *et al.,* 1969, p 1206). The larger, stratigraphically lowermost channel-like structures were located farther away from the coast,than the stratigraphically higher, narrower channel-like structures, which were probably gullies located more coastward on the tidal flat;
- lag conglomerates are not uncommon in tidal channels (Matter, 1967, Shinn *et al.,* 1969, Shinn, 1983, Loucks & Anderson, 1985);
- paleocurrents indicate directionally variable flow in the different channel-like structures, as would be expected in meandering tidal channels.

The rounding implies prolonged abrasion in a high energy system. Tides and storms provide such a system. However, the massive bedding and «broken-rounds» that fit into one another argue for a rapid deposition. Boulder-size fragments can be transported by storms (McKee, 1959; Perkins & Enos, 1968).

The stratigraphically higher channel-like structures contain more intertidally derived fragments, while the lower ones contain more subtidal fragments. This could be due to a difference in erosional base (Shinn, 1969). The fact that point bar sediments with epsilon cross-bedding were not recognized may be attributable to the episodic nature of the sedimentation (see above), intense burrowing or the limited extent of the outcrop.

The broken rounds are created when a round conglomerate fragment is flung violently against an obstacle (cfr. James, 1980), resulting in two «broken-rounds» that fit into one another. Otherwise the broken round fragments would not be found close together and would not show sharp fractures. The broken rounds started out as a piece of limestone torn loose from an early lithified source, after which it was transported and rounded. Upon deposition it struck against the channel floor and broke in two. The two halves were not transported any further due to the short-lived nature of the event. The fact that the two halves are found next to each other, also implies a lack of reworking after deposition.

5.- FACIES MODEL

It is clear that on the whole the Walhorn section represents two important regressive sequences. This is noticeable in the stratification of the fragments in the dolomite breccia: in the lowermost breccia package only sub- and intertidal fragments are present, while in the uppermost package intertidal and supratidal deposits are represented. In the limestone layers the regression is also noticeable in the shallower origin of the fragments in stratigraphically higher layers, as well as in the shallower origin of the non-conglomerate layers stratigraphically higher up (e.g. conglomerates are capped by an evaporitic

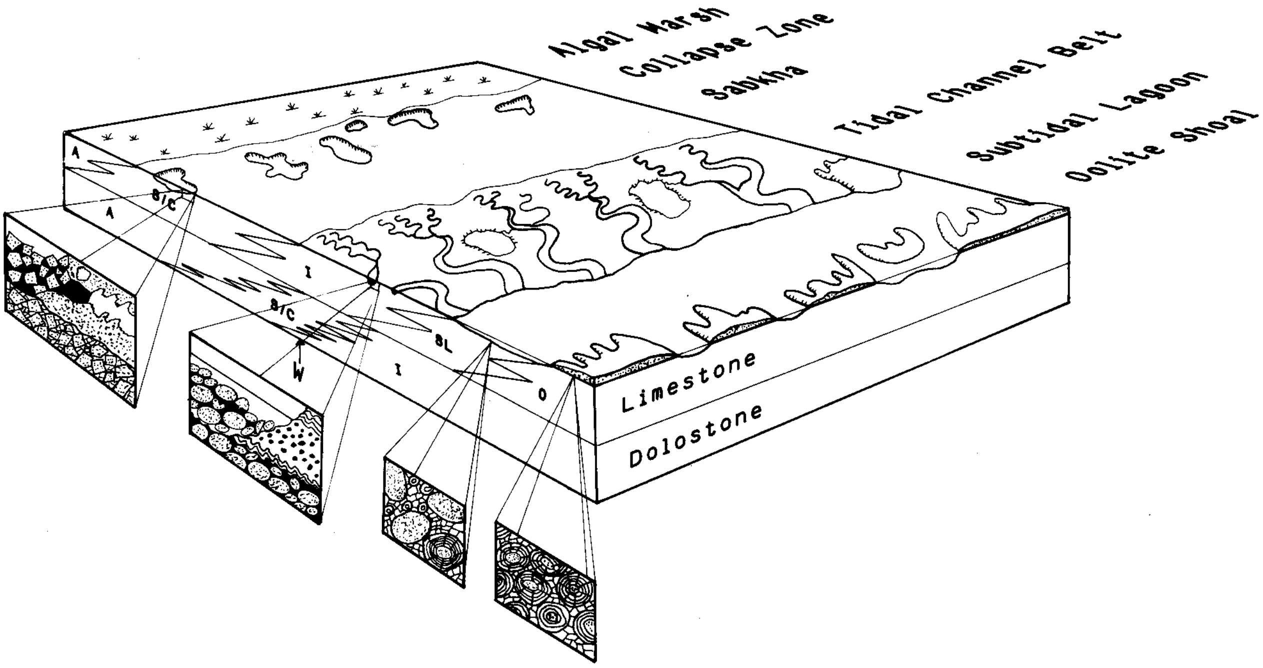

Fig. 4.- Hypothetical reconstruction of the paleodepositional environment of the area around Walhorn at the time of the formation of the last limestone sabkha sequence.
Abbreviations: A: Algal marsh; S/C: Sabkha/Collapse Zone; I: Intertidal zone; SL: Subtidal Lagoon; O: Oolite Shoal; W: Location of the Walhorn quarry.

collapse breccia). The reconstructed paleoenvironment is shown in figure 4 (after Multer, 1977, chapter 5; Hardie & Garrett, 1977; Reijers & Hsu, 1986, p. 156). Most landward there was a lagoon-sabkha in which water flow was restricted (evaporites, calcispheres), possibly due to the presence of an ooid shoal, although circumstantial evidence indicates that the Braibant-Halloy high was partly responsible (Hance, 1988).

Periodically, due to storm surges, the lagoon/sabkha water was replenished or the restrictiveness of the back shoal lagoon would temporarily disappear.This allowed short periods of deeper sedimentation to occur. As the storm breakthrough was closed off or when deposited sediment builded itself up, restricted hypersaline conditions were created and the lagoon turned into an evaporative environement. In this sabkha flat dolomicrites and evaporites were deposited. The evaporites were partly dissolved later due to meteoric water influx or the next marine influx of undersaturated marine water, resulting in brecciation of the underlying bed.

Thereafter a the tidal flat prograded locally over the sabkha/lagoon deposits. First there occurred sub- and intertidal deposition after which probably tidal channels cut through these layers, eroding any lagoonal sediments deposited on top of the dolostone breccia. They could not erode through the early lithified (Vogel, 1987) dolostone breccia, therefore the first channels found their base there. During storm surges or periods of breakthrough, strong currents went over a more local, nearby situated shoal, tearing off coarse rubble and depositing it in the channels as a lag.

6.- CONCLUSION

The sedimentary record in Walhorn shows a series of beds in which two large shallowing upward cycles, each consisting of several small-scale cycles, have been deposited. The depositional environment was influenced by a shoal, with a tidal flat/lagoon leeward of it. Lowermost in the studied section sediments deposited in a restricted lagoon/sabkha are present. At least five small scale shallowing upward cycles occur, in which deposition depth decreased from shallow subtidal to supratidal. Due to leaching of the supratidally deposited evaporites, interlying layers collapsed, resulting in a dolostone collapse breccia. With time the restricted lagoon/sabkha leeward of the shoal was replaced by tidal flat sedimentation in the Walhorn area. The latter is characterized by conglomerates, interpreted to be tidal channel lags, and various intertidal sediments (stromatolites, mudstones with fenestrae, ...).

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BIBLIOGRAPHY

BALL, M.M., 1967. Carbonate sand bodies of Florida and the Bahamas. *Jour. Sed. Petrology,* 37: 556-591.

BLOUNT, D.N. & MOORE, C.H., 1969. Depositional and non-depositional carbonate breccias, Chiantla Triangle, Guatemala. *Bull. Géol. Soc. Am.,* 80: 429-442.

COOK, H.E. & MULLINS, H.T., 1983. Basin margin environment. *In:* Scholle, P.A., Bebout, D.G. & Moore, C.H. (eds.): Carbonate depositional environment. *Am. Assoc. Petrol. Geol. Memoir,* 33: 539-617.

DAVIES, G.R., 1977. Turbidites, debris sheets, and truncation structures in Upper Paleozoic deep-water carbonates of the Sverdrup Basin, Arctic Archipelago. *In:* Cook, H.E. & Enos, P. (eds.): Deep-water carbonate environments. *Soc. Econ. Paleont. Min Spec. Publ.,* 25: 221-247.

ENOS, P. & MOORE, C.H., 1983. Fore-reef slope environment. *In:* Scholle, P.A., Bebout, D.G. & Moore, C.H. (eds.): Carbonate depositional environments. *Am. Assoc. Petrol. Geol., Memoir,* 33: 507-537.

EVAMY, B.D., 1967. Dedolomitization and the development of rhombohedral pores in limestones. *Jour. Sed. Petrology,* 37: 1204-1215.

FAIRBRIDGE, R.W. & BOURGEOIS, J., 1978. The encyclopedia of sedimentology. Dowden, Hutchinson & Ross, Inc., 901 p.

HANCE, L., 1988. Le Moliniacien du Synclinorium de Dinant (Belgique) de la région dinantaise à la valléé de l'Ourthe. *Mém. Inst. géol. Univ. Louvain,* 33: 1-99.

HARDIE, L.A. & GARRETT, P., 1977. General environmental setting. *In:* Hardie, L.A. (ed.): Sedimentation on the modern carbonate tidal flats of northwest Andros Island, Bahamas: 12-49.

JACOBS, L., SWENNEN, R., VAN ORSMAEL, J., NOTEBAERT, L. & VIAENE, W., 1982. Occurrences of gypsum pseudomorphs after evaporitic minerals in the Dinantian rocks of the eastern part of Belgium. *Bull. Soc. belge Géol.,* 91: B105-123.

JAMES, W.C., 1980. Limestone channel storm complex (Lower Cretaceous), Elkhorn Mountains, Montana. *Jour. Sed. Petrology,* 50: 447-456.

LOUCKS, R.G. & ANDERSON, J.H., 1985. Depositional facies, diagenetic terranes, and porosity development in Lower Ordovician Ellenburger Dolomite, Puckett Field, West Texas. *In:* Roehl, P.O. & Choquette, P.W. (eds.): Carbonate Petroleum Reservoirs: 19-37.

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

MATTER, A., 1967. Tidal flat deposits in the Ordovician of Western Maryland. *Jour. Sed. Petrology,* 37: 601-609.

McKEE, E.D., 1959. Storm sediments on a Pacific atoll. *Jour. Sed. Petrology,* 29: 354-364.

MULTER, H.G., 1977. Field guide to some carbonate rock environments. Kendall/Hunt publishing house, 425 p.

PERKINS, R.D. & ENOS, P., 1968. Hurricane Betsy in the Florida-Bahama area. Geologic effects and comparison with hurricane Donna. *J. Geol.,* 76: 710-717.

PIRLET, H., 1967a. Mouvements épeirogéniques dévono-carbonifères dans la région de Visé; la carrière de «La Folie» à Bombaye. *Ann. Soc. géol. Belg.,* 90: 103-117.

PIRLET, H., 1967b. Mouvements épeirogéniques au sein du Viséen inférieur V1 dans la partie centrale du synclinorium de Namur. *Ann. Soc. géol. Belg.,* 90: 255-260.

POTY, E., 1982. Paléokarsts et brèches d'effondrement dans le Frasnien moyen des environs de Visé. Leur influence dans la paléogéographie dinantienne. *Ann. Soc. géol. Belg.,* 105: 315-337.

REIJERS, T.J.A. & HSU, K.J., 1986. Manual of carbonate sedimentology: a lexiconographical approach. Orlando Academic Press, 302 p.

SHEARMAN, D.J., 1978. Recent anhydrite, gypsum, dolomite and halite from the coastal flats of the Arabian shore of the Persian Gulf. *Proc. Geol. Soc. London,* 1607: 63-64.

SHINN, E.A., 1969. Submarine lithification of Holocene carbonate sediments in the Persian Gulf. *Sedimentology,* 12: 109-144.

SHINN, E.A., 1983. Tidal flat environment. *In:* Scholle, P.A., Bebout, D.G. & Moore, C.H. (eds.): Carbonate depositional environments. *Am. Assoc. Petrol. Geol.,* 33: 171-210.

SHINN, E.A., Lloyd, R.M. & GINSBURG, R.N., 1969. Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas. *Jour. Sed. Petrology,* 39: 1202-1228.

STANTON, R.J., 1966. The solution brecciation process. *Bull. Géol. Soc. Am.,* 87: 843-848.

SWENNEN, R., 1986. Lithogeochemistry of Dinantian carbonates in the Vesdre Basin (Verviers synclinorium: E-Belgium) and its relations to paleogeography, lithology, diagenesis and Pb-Zn mineralizations. *Meded. Kon. Acad. Wet. Lett. & Sch. Kunsten België. Klasse Wet.,* 48: 66-108.

SWENNEN, R., VIAENE, W., JACOBS, L. & VAN ORSMAEL, J., 1981. Occurrence of calcite pseudomorphs after gypsum in the Lower Carboniferous of the Vesdre region. *Bull. Soc. belge Géol.,* 90: 231-247.

SWENNEN, R., BOONEN, P. & VIAENE, W., 1982. Stratigraphy and lithogeochemistry of the Walhorn section (Lower Visean, Vesder basin, E-Belgium) and its implications. *Bull. Soc. belge Géol.,* 91: 239-258.

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, 1988. Ministery of Economic Affairs, Belgian Geol. Survey: 77-97.

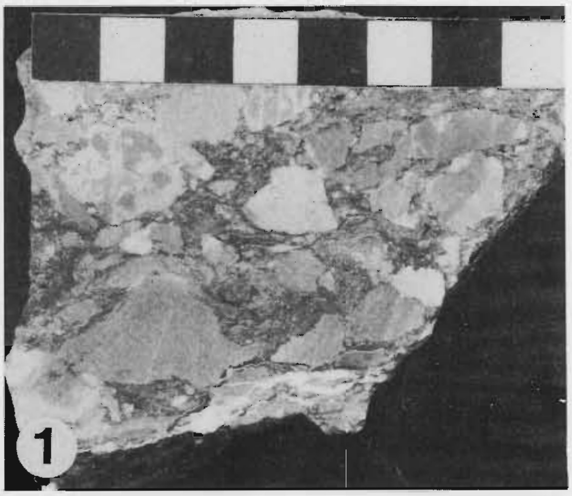
TUCKER, M.E., 1985. Shallow-marine carbonate facies and facies models. *In:* Brenchly, P.J. & Williams, B.P.J. (eds.): Sedimentology: recent developments and applied aspects. Blackwell Scientific Publications: 147-169.

VARNES, P.J., 1978. Slope movement types and processes. *In:* Schuster, R.L. & Krizek, R.J. (eds.): Landslides; analysis and control. Transportation Research Board, *Natl. Acad. Sci., Spec. Rept.,* 176: 11-33.

VOGEL, K.R., 1987. Sedimentpetrografie, diagenese en lithogeochemie van de dolomiet- en kalksteenbreccies ontsloten te Walhorn (Onder-Visean, bekken van de Vesder). Unpublished licenciate thesis, Katholieke Universiteit Leuven, 75 p.

PLATE I

1. Typical dolostone breccia occurrence, showing angular dolomicrite (partially recrystallized to dolomicrosparite) fragments is a dolosparite matrix.
2. Evaporitic flow textures in the dolostone breccia. Note the dark dolomicrite trails (a) in between the white trails of dolosparite (b), pseudomorphic after evaporites.
3. Enterolithic dolosparite texture (a), pseudomorphic after enterolithic anhydrite. Arrow indicates top of sample.
4. Chicken-wire structures in dolosparites, pseudomorphic after anhydrite.
5. Microscopic characteristics of the dolostone breccia, showing a dolomicrite to dolomicrosparite fragment in a clear xenotopic dolosparite matrix. Scale bar is 300 μm.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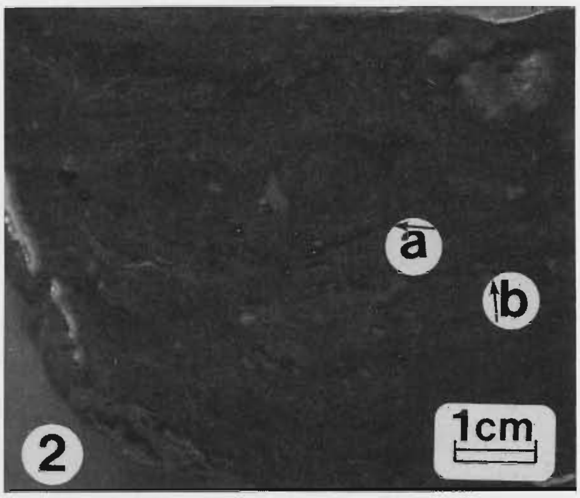
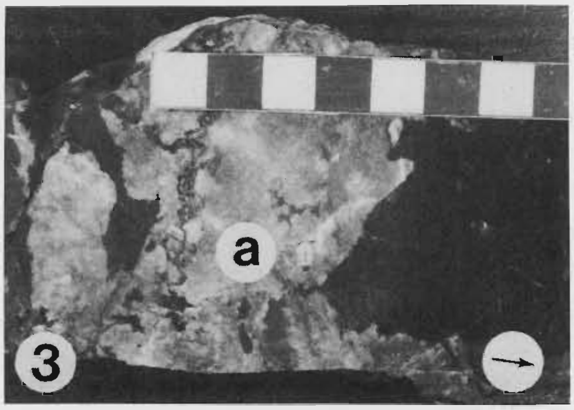

a
b
1cm
2


a
3


4

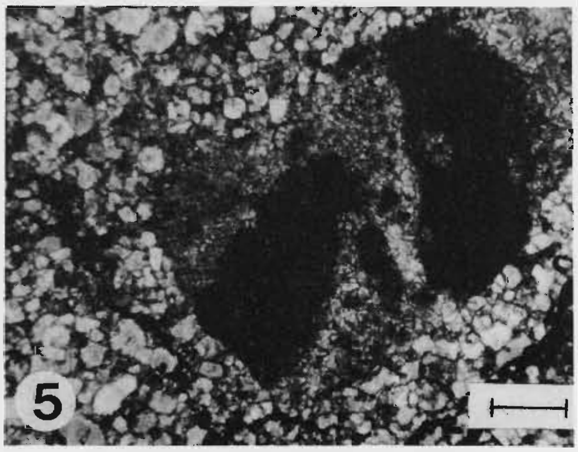

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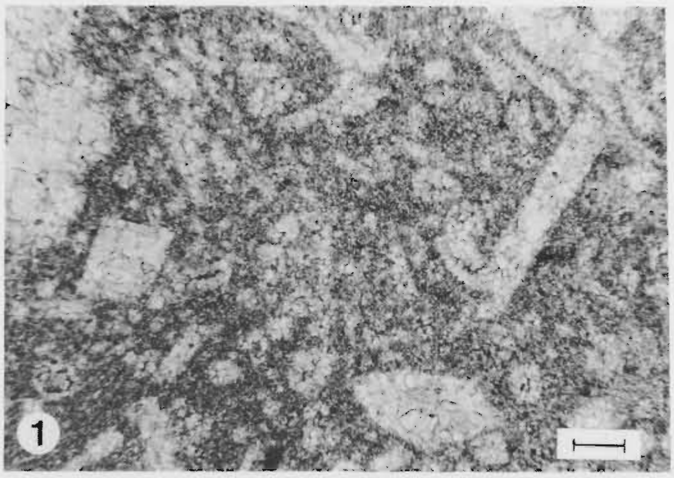
PLATE II

1. Photomicrograph of dolomite pseudomorphs after anhydrite (lath shapes) and gypsum (lozenge shapes) in a dolomitic matrix. Scale bar in 300 μm.
2. Photomicrograph of lath shaped dolosparite protrusions out of a dolosparite nodule, both pseudomorphic after anhydrite. Scale bar is 300 μm.
3. Rounded oolitic grainstone fragments in an oolitic matrix.
4. Two «broken rounds» in the upper part of the conglomerate unit.
5. Photograph showing a channel-like structure in the upper part of the conglomerate unit. This structure cuts through well banked subtidal deposits (upper left corner) and is topped by a stromatolite (right side of the picture). Scale bar is 70 cm.
6. Photomicrograph of the limestone conglomerate, showing an oolitic packstone fragment (a) in stylolitic contact with the ooid- and peloid-rich matrix. Scale bar is 250 μm.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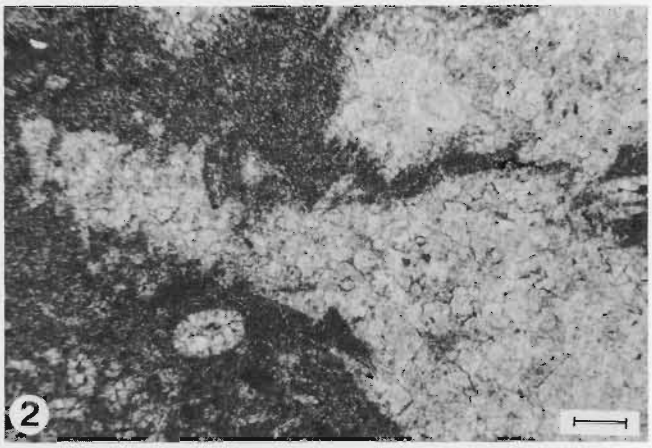
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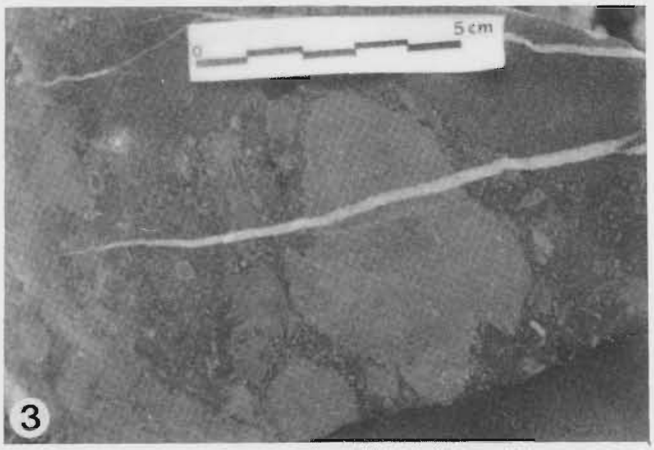
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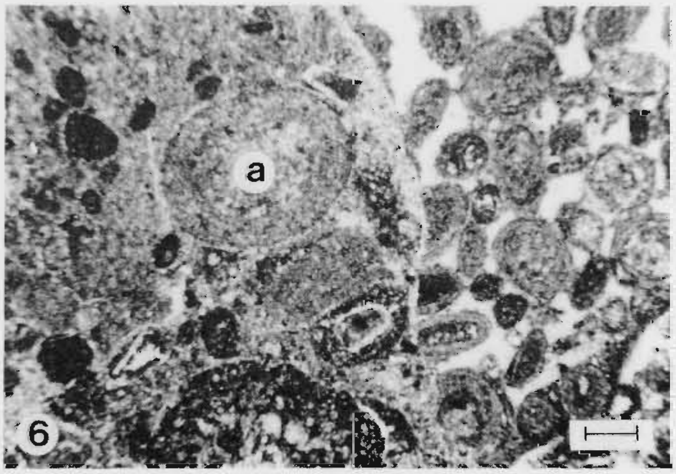
a
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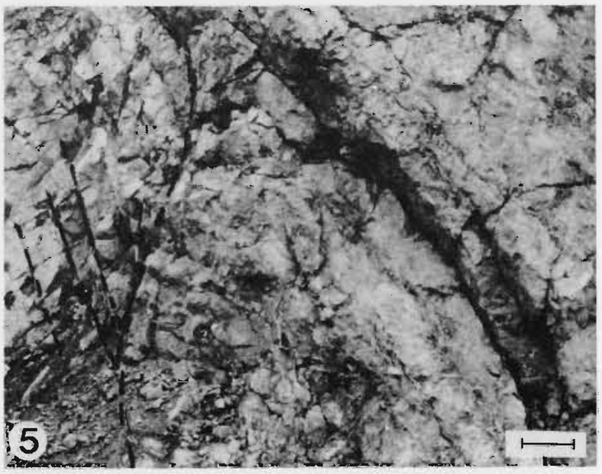
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