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Paleogeographic and climatic evolution of the Moliniacian (lower Visean) in southeastern Belgium

C. Peeters,[1] Ph. Muchez[1,2] & W. Viaene[1]
[1] Fysico-chemische geologie, Katholieke Universiteit Leuven, Celestijnenlaan 200C, B-3001 Heverlee, Belgium; [2] Senior Research Assistant, National Fund for Scientific Research, Belgium

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Abstract

A detailed biostratigraphical subdivision of the lower Visean (Moliniacian) in southeastern Belgium is not possible. Therefore correlations are based on the facies evolution. Based on these correlations, the paleogeographical evolution during the early Visean can be reconstructed.

During the early Moliniacian, open marine subtidal limestones were deposited. Near the coast, these sediments were subsequently dolomitized and intense karstification took place under humid conditions. Basinwards, algal laminites formed in the intertidal zone. The continental interval was followed by open marine sedimentation above wave base. At the end of the early Moliniacian, beginning of the middle Moliniacian, the depositional environment became shallower. A second continental interval occurred near the Brabant Massif and a sabkha developed further to the south (i.e. basinwards) in a semi-arid to arid climate. The subsequent transgressive trend was very gradual. Middle Moliniacian sedimentation occurred in an evaporitic lagoonal and intertidal setting. The peritidal sediments contain numerous paleosol horizons, which formed under semi-arid conditions. Upper Moliniacian limestones, were deposited on a shallow open marine shelf.

The paleolatitudinal position of Euramerica during the early Visean was close to the equator and normally a humid climate must have been present. The recognized semi-arid intervals are due to the large Gondwana landmass situated south of the equator, deflecting rains away from Euramerica.

Introduction

The lower Visean in southeastern Belgium belongs to two structural basins: the autochthonous Namur basin and the allochthonous Vesder basin (Fig. 1). The Aachen area in western Germany forms the eastern part of the Vesder basin. The Midi-Eifel overthrust separates the two units. During early Visean times the two units belonged to the same shelf, bordered to the north by the Brabant Massif, a former landmass, creating nearshore and restricted sedimentation conditions. In spite of the excellent biostratigraphic data available in southern Belgium, correlation of the lower Visean strata in the southeastern part, based on fossils, is almost impossible (Swennen & Viaene 1985). Moreover, lithological correlations are hampered by extensive dolomitization, brecciation and by important lateral facies variations (Jacobs et al. 1982). Hence only the evolution of the changing facies allows adequate correlations and a detailed reconstruction of the paleogeography.

The aim of this study is to reconstruct the paleogeography and the climatic evolution in the early

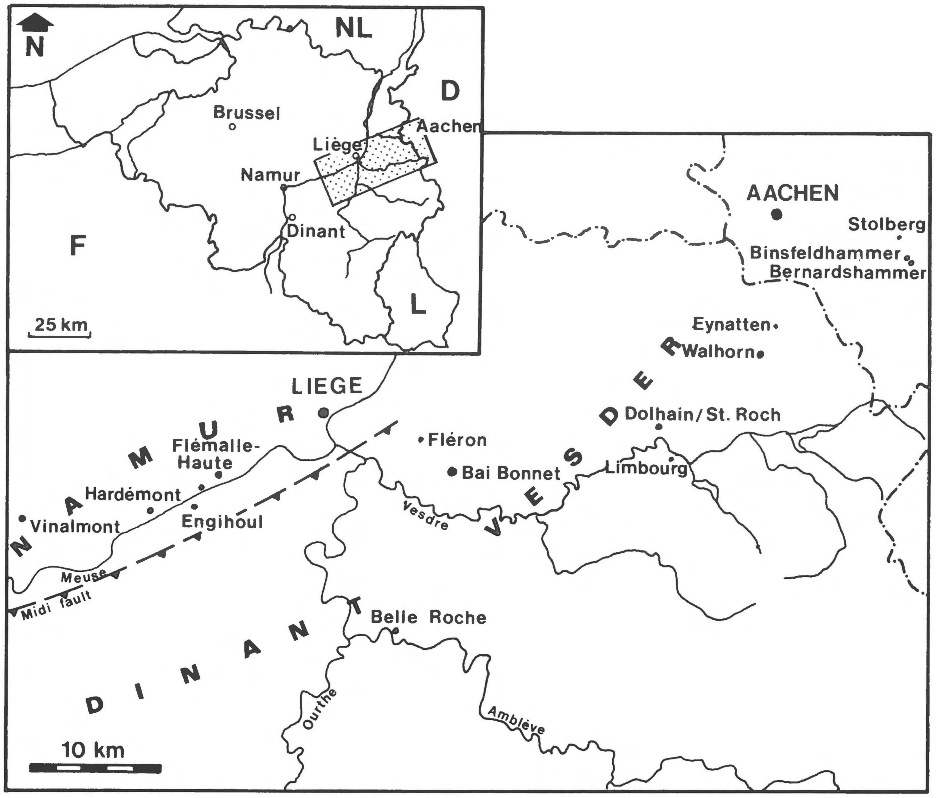

Fig. 1. Situation map of the investigated outcrops in southeastern Belgium and west Germany.

Visean in southeastern Belgium. The investigated outcrops are given in Fig. 1: Binsfeldhammer and Bernardshammer in the Aachen area, Walhorn, Dolhain and Bai-Bonnet in the Vesder basin and Flémalle-Haute, Chokier, Engihoul and Hardémont in the Namur basin.

Facies patterns and evolution

The investigated Visean interval in the studied basins is shown in Fig. 2. According to the general biostratigraphy used in Belgium, the interval comprises the Moliniacian, subdivided in the foraminifer zones Cf4α, β, γ and δ (Paproth et al. 1983). The facies differs largely between the Vesder area and the Aachen and Namur areas. The Aachen and Namur area are similar and are discussed together.

Namur and Aachen area

The upper part of the dolomitized carbonates in the Namur area has an early Moliniacian age (Conil et al. 1988). They contain an open-marine biota (crinoids, corals, brachiopods) and an original pack- and grainstone texture may still be recognized. The texture and the fauna indicate an open-marine shallow subtidal sedimentation environment. The top of the carbonates is intensely karstified (Pirlet 1970). Karst pockets (Fig. 3A) are filled with non-dolomitized crinoidal limestones of the overlying unit and palisade calcites of speleothem origin (Kasig 1980, Swennen et al. 1981). In the Aachen area, these karst features are found directly on top of dolostones dated as Cf2 in age (Kasig 1980). Wether the lowermost Moliniacian was deposited and subsequently eroded or not deposited at all in this area remains to be established.

The continental karst interval is followed by lower Moliniacian (Malpica 1973, Viel 1984) bioclastic

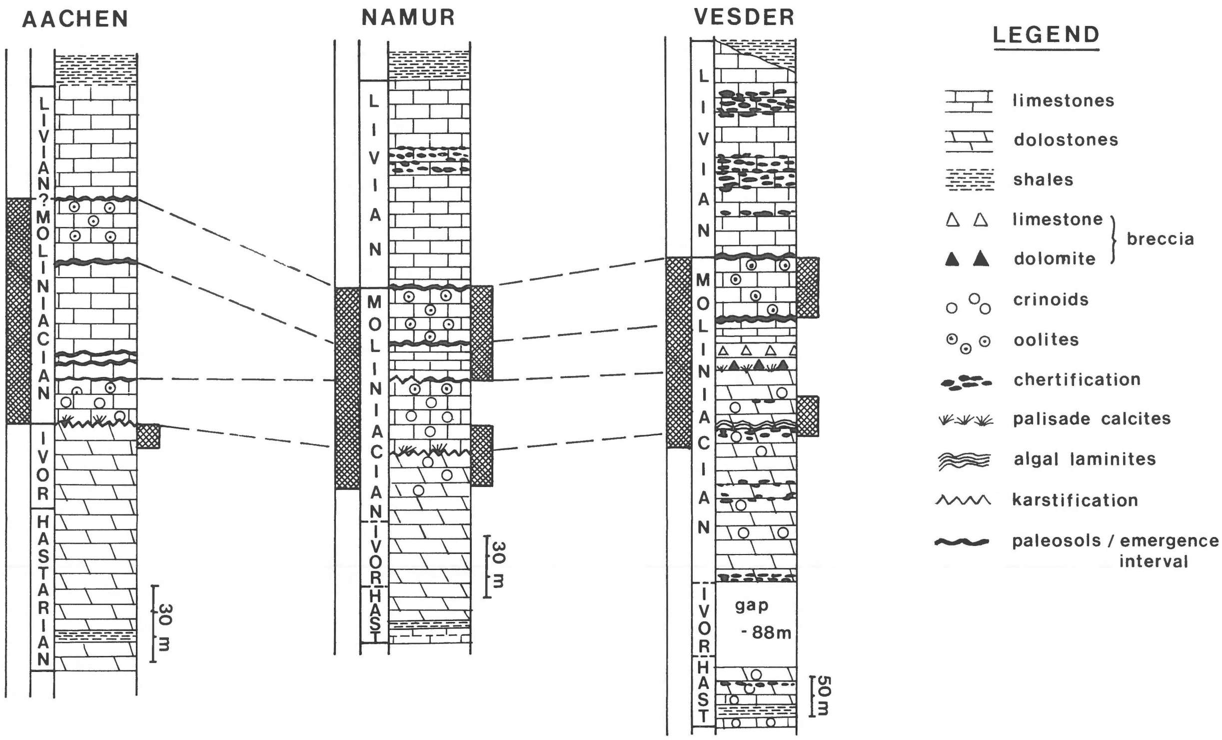

Fig. 2. General stratigraphic logs of the Lower Carboniferous in the Namur, Vesder and Aachen area. Hast: Hastarian, Ivor: Ivorian (after Kasig 1980, Conil et al. 1988, Swennen et al. 1988, Peeters 1990). The shaded area to the left of the logs represents the investigated interval, the shaded area to the right indicates the biostratigraphically dated parts of the investigated interval.

(corals, crinoids) grainstones and by oolitic grainstones (Fig. 3B). The latter may already have a middle Moliniacian age (Hance 1988). On top of the grainstones a continental erosion surface is present in the Namur basin (Conil & Lys 1968). In more southern parts of Belgium (Dinant basin) the presence of alveolar textures (sensu Klappa 1980) and stalactitic vadose cements (sensu Purser 1980) in the upper part of this grainstone confirm an emergence phase (Hance 1985, 1988).

After this interruption, middle Moliniacian sedimentation (Conil 1973, Paproth et al. 1983) occurred on a tidal flat. Peritidal sediments range from bioclastic wackestones, packstones and grainstones (Fig. 3C) to intertidal fenestral mudstones (Fig. 3D) and paleosols (Swennen et al. 1988). The peritidal sequence is capped by a paleosol (Fig. 3E), characterized by the abundance of rhombic calcites. Under cathodoluminescence, a complex zoned pattern becomes obvious in these calcites (Fig. 3F). This pattern indicates repeated carbonate saturation and leaching, reflecting the prominent wetting and drying phases (Wright & Peeters 1989).

The upper Moliniacian strata consist of open marine subtidal grain-supported limestones (Monty 1964, Hance 1982), mainly deposited above wave base.

In the Moliniacian of the Namur and Aachen area three main cycles can be recognized (Fig. 4). The first ends at the karstic surface capping the dolostones, the second at the emergence interval on top of the oolitic grainstones and the third probably at the top of the subtidal, grain-supported limestones (for the latter see Paproth et al. 1983), which is also an emergence interval, namely the Banc d'Or.

Vesder area

The upper part of the massive crinoidal dolostones

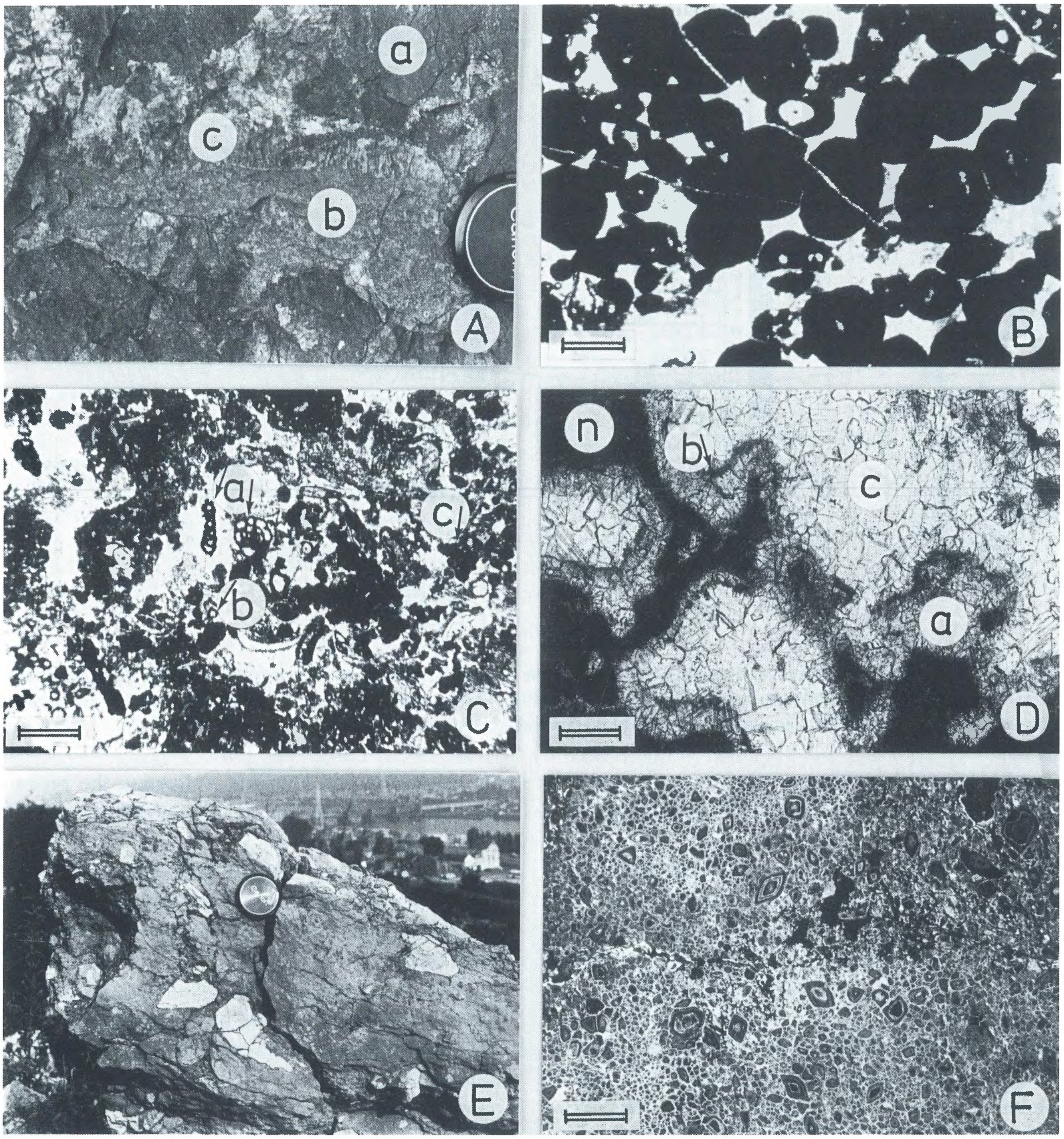

Fig. 3 (A) Karstified dolostone (a). Karst-pockets are filled with non-dolomitized crinoidal limestone (b) and palisade calcites (c). Chokier, lower Moliniacian. Width of lens cap is 6 cm. (B) Oolitic grainstone. Bernardshammer, lower Moliniacian. Scale bar is 300 μm. (C) Bioclastic packstone with forams (a), calcispheres (b) and pellets (c). Flémalle-Haute, middle Moliniacian. Scale bar is 300 μm. (D) Fenestral mudstone with needle-fibre calcite (n), brown fibrous to blocky cement (a), micritic rim (b) and clear blocky calcites (c). Hardémont, middle Moliniacian. Scale bar is 200 μm. (E) Paleosol horizon capping the Middle Moliniacian peritidal sediments. Flémalle-Haute, middle Moliniacian. Width of lens cap is 6 cm. (F) Cathodoluminescence microphotograph of euhedral rhombic calcite crystals in a pseudospar-microspar groundmass. Bernardshammer, middle Moliniacian. Scale bar is 300 μm.

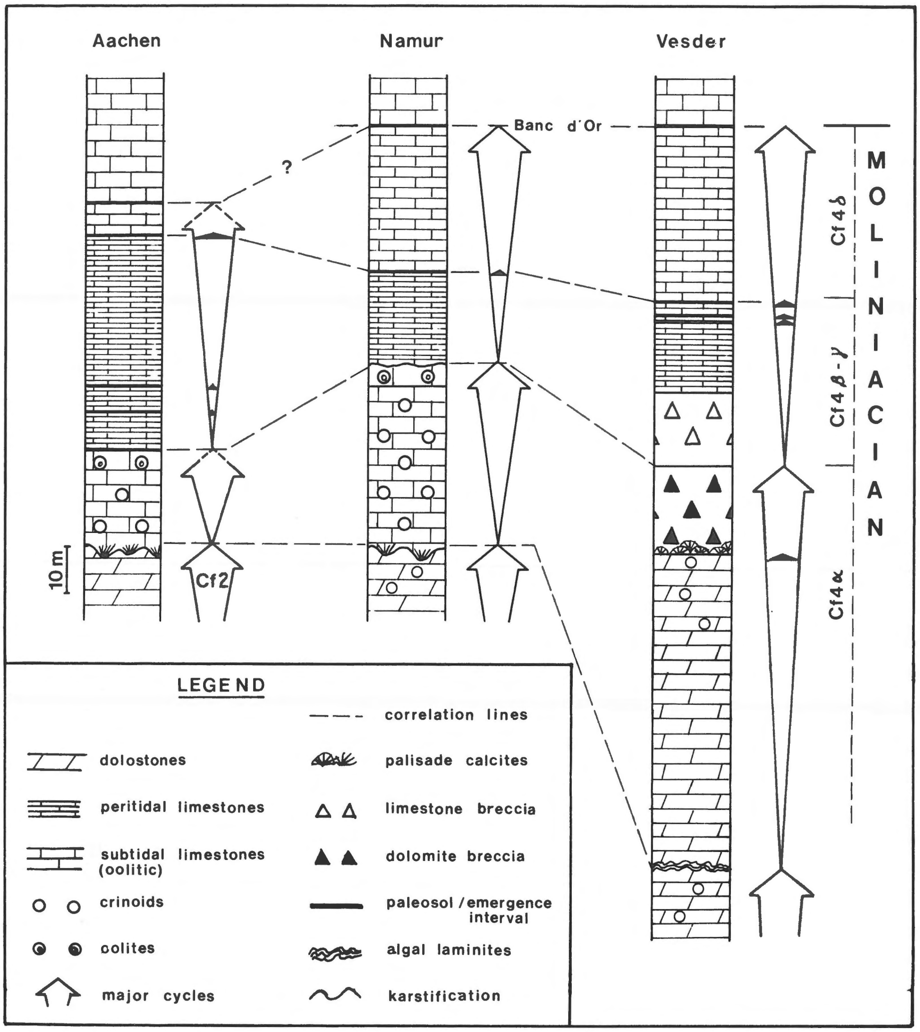

Fig. 4. Summary logs of the Moliniacian with the major cycles present in the Aachen, Namur and Vesder area.

are of early Moliniacian age (dated by R. Conil in Swennen 1986) and reflect subtidal sedimentation conditions. In the upper part of these dolostones, algal laminites are present, indicating an intertidal environment (Swennen & Viaene 1986). Above the dolostones, a horizon dominated by palisade calcites occurs. The crystals have a maximum length of 3 cm and a width of 2 mm. Individual crystal clusters give rise to hemispherical fan-shaped crystal arrays (Fig. 5A). The palisade calcites formed through a process of aggrading neomorphism. However, a displacive growth underneath a thin sediment cover can not be excluded for a certain number of them (Peeters et al. in press). The palisade horizon is followed by a dolomite breccia (Fig. 4). Characteristic in the dolomite unit are dolomitized anhydrite nodules (Fig. 5B) with typical enterolithic and chickenwire structures (sensu Shearman 1978) and relicts of evaporitic minerals in the center of the nodules. Vogel et al. (1990) showed that the dolomites were deposited in a sabkha environment and that the breccia has an evaporitic solution-collapse origin. The latter interpretation is based on the variable fragment size, the association with evaporites (Fig. 5C), the dolomite fragments, the jigsaw puzzle structure and crumbled edges of the fragments (cfr. Stanton 1966) and the flow structures in the matrix. Above

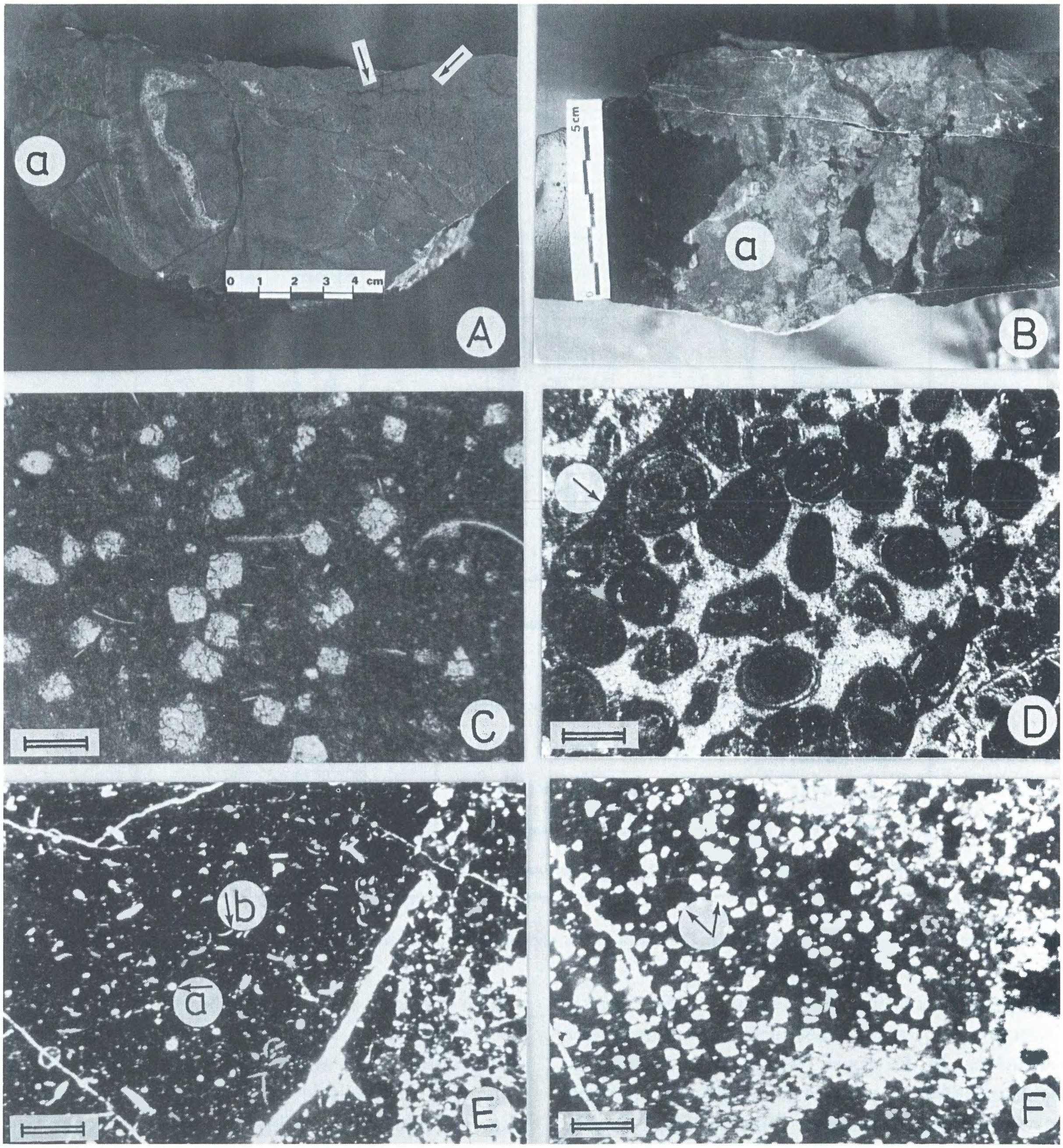

Fig. 5. (A) Hemispherical fan-shaped crystal array (a) above mudstone with desiccation cracks (arrows). Walhorn, lower Moliniacian. (B) Dolomitized anhydrite nodules (a). Walhorn, lower Moliniacian. (C) Dolomite pseudomorphs after evaporites in a dolomitic matrix. Walhorn, lower Moliniacian. Scale bar is 300 μm. (D) Oolitic grainstone fragment in the conglomerate at Walhorn, middle Moliniacian. Fragment is surrounded by a micritic rim (arrow). Scale bar is 140 μm. (E) Bioclastic wackestone with calcispheres (a) and ostracods (b). Walhorn, middle Moliniacian. Scale bar is 1 mm. (F) Micritic limestone fragment with numerous calcite pseudomorphs after evaporites (arrows). Walhorn, middle Moliniacian. Scale bar is 400 μm.

the dolomite breccia, a supratidal horizon is present.

The lower part of the middle Moliniacian is represented by a limestone conglomerate or breccia. In the eastern part of the Vesder basin (Walhorn) a breccia occurs above a conglomerate. The polymict conglomerate mainly consists of fragments of oolitic and peloidal packstones and grainstones (Fig. 5D), wackestones with calcispheres (Fig. 5E) and algal mudstones. The matrix is volumetrically limited. Typical in the matrix are ooids and calcispheres and to a lesser extent foraminifers, aggregate grains and algal lumps. These features suggest that the conglomerate has a marine sedimentary origin (Vogel et al. 1990). The upper part of the limestone breccia has mudstone fragments with evaporitic pseudomorphs (Fig. 5F) after halite, anhydrite and gypsum, floating in a sparite matrix. This breccia has been interpreted by Jacobs et al. (1982) and Swennen et al. (1990) as an evaporitic solution-collapse breccia.

In the western part of the Vesder basin (Bai-Bonnet) only a limestone breccia has been recognized in the lower part of the middle Moliniacian. The breccia can be classified as a mosaic to rubble breccia (sensu Morrow 1982). The fragments are polymict:

- wackestones with calcispheres and ostracods,
- intraclastic wackestones with algae, peloids, calcispheres, ostracods, vermiform gastropods and forams,
- peloidal, bioclastic packstones (the biota consists of shell hash, ostracods, forams and algae),
- laminated mudstones,
- calcretes with primitive glaebules and desiccation cracks,
- fragments composed of pseudomorphs after evaporitic minerals; pseudomorphs are mainly lozenge-shaped (Fig. 6A), but also lath- and square-shaped forms are present.

The matrix consists of micrite, microsparite or sparite (Fig. 6B) with ostracods, forams, peloids, pseudomorphs after evaporites and sporadic ooids with radial cortices. The latter represent a lagoonal environment (Strasser 1986).

The limestone fragments with a restricted biota also indicate lagoonal sedimentation conditions. The glaebules and the desiccation cracks formed under temporarily continental conditions. Brecciation occurred due to the dissolution of a large part of the not yet pseudomorphosed evaporites (Swennen et al. 1990).

In the area between Walhorn and Bai-Bonnet, at Dolhain, a dolomite and limestone breccia are present. The dolomite breccia is identical to the one found in Walhorn. In the limestone breccia, some characteristics also found in the fragments and matrix of the conglomerate at Walhorn occur: oolitic grainstone fragments and ooids in the matrix. So the environment became more restricted upwards in the stratigraphy (Walhorn) and westwards (Bai-Bonnet).

Above the limestone breccia, peritidal sediments similar to those in the Namur and Aachen area occur. In the Dinant area, to the west of the Vesder area, these peritidal limestones have a middle Moliniacian age (Paproth et al. 1983). Three paleosol horizons have been recognized (Maes et al. 1989). The youngest caps this peritidal sequence and is characterized by rhombic calcites. Bioclastic and oolitic packstones and grainstones were deposited on an open marine shelf during the late Moliniacian (Swennen et al. 1982, Swennen 1986).

In the Moliniacian of the Vesder area at least two and probably three major cycles can be recognized (Fig. 4). A first cycle could have ended within the dolostone unit, as indicated by the intertidal conditions of the algal laminites. However, a distinct boundary as in the Namur and Aachen areas has not been recognized. The second cycle is represented by the crinoidal dolostones, the palisade horizon and the dolomitic evaporite solution-collapse breccia. This breccia originally formed in a sabkha environment and is capped by a brecciated supratidal marsh deposit. As in the Namur and Aachen areas, the third cycle of subtidal limestone deposition ended with the Banc d'Or, which is situated at the transition between the Moliniacian and overlying Livian (Paproth et al. 1983).

Paleogeographic reconstructions

Within the Moliniacian four lithologies have been

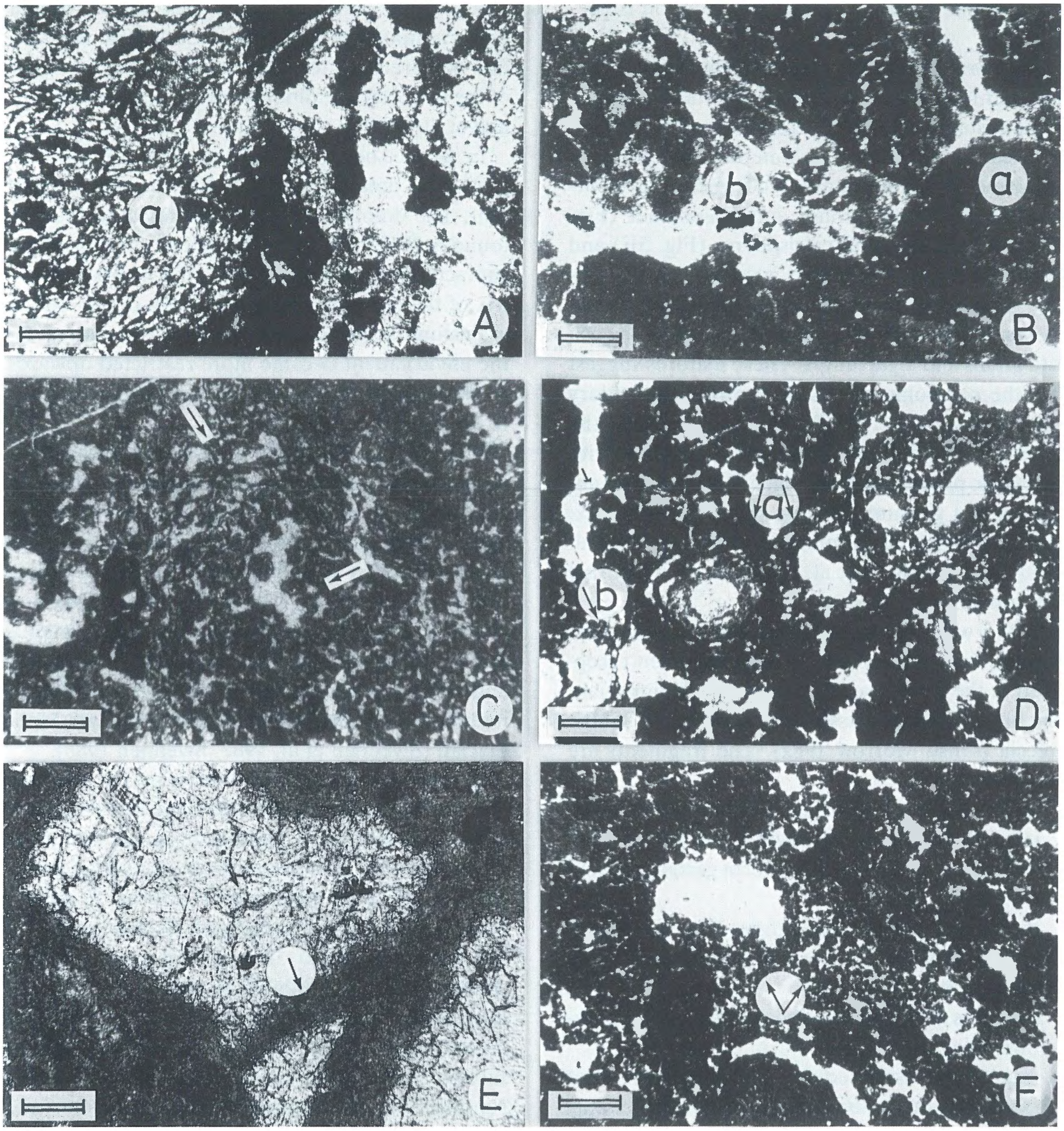

Fig. 6. (A) Lozenge-shaped calcite pseudomorphs after gypsum in a mudstone fragment (a). Bai-Bonnet, middle Moliniacian. Scale bar is 300 μm. (B). Breccia with fossiliferous mudstone fragments (a) in a micritic to sparitic matrix (b). Bai Bonnet, middle Moliniacian. Scale bar is 300 μm. (C) Alveolar texture (arrows) in paleosol horizon. Walhorn, middle Moliniacian. Scale bar is 300 μm. (D) Root (a) and cellular textures (b). Hardémont, middle Moliniacian. Scale bar is 300 μm. (E) Needle-fibre calcite crystals (arrow) in paleosol capping peritidal sequences at Hardémont, middle Moliniacian. Scale bar is 100 μm. (F) Sorted pellets (arrow) showing a coated dropping fabric. Bernardshammer, middle Moliniacian. Scale bar is 300 μm.

accurately dated (see above). These lithologies are the lower Moliniacian dolomites (dated at Flémalle-Haute and at St. Roch near the Dolhain quarry), the bioclastic grainstones at the top of the lower Moliniacian (dated at Flémalle-Haute), the middle Moliniacian peritidal sediments (dated in the Namur and Dinant areas) and the upper Moliniacian open-marine limestones (dated at Vinalmont and at Walhorn). This stratigraphical framework is the basis for a more detailed correlation (Fig. 4) based on the similar evolution of the sedimentation pattern in the Namur, Vesder and Aachen areas. This correlation is used for paleogeographical reconstructions (Fig. 7).

During the early Moliniacian (Fig. 7A) a uniform sedimentation of open-marine limestones took place in the Namur and Vesder areas and possibly also near Aachen. After dolomitization, these strata were intensely karstified in the Namur and Aachen areas (Fig. 7B). In the Vesder basin sedimentation continued, and algal laminites were deposited. Thereafter, uniform open marine sedimentation was reinstalled (Fig. 7C). At the end of the early Moliniacian – beginning middle Moliniacian, the environment became shallower and an emergence interval occurred in the nearshore areas. Further to the south deposition took place in a sabkha environment (Fig. 7D). During the following transgressive phase, sedimentation evolved from middle Moliniacian peritidal and restricted (Fig. 7E) towards late Moliniacian open marine subtidal conditions (Fig. 7F).

Climatic evolution

Evidence for the nature of the early Visean paleoclimate comes from sedimentation conditions, paleokarsts and paleosols. Intensely karstified carbonates, like the early Moliniacian dolostones, are today found in regions of high rainfall, e.g. the tropical and subtropical areas of Puerto Rico (Monroe 1966, Ireland 1979). In this view, the dolomitization which predated the karstification, may be related to the water circulation in the mixing-zone of meteoric and marine water. Only during a humid regime this dolomitization would have been effective. Early Visean mixing-zone dolomitization in Great Britain, under humid conditions, has already been described by Hird et al. (1987) and Searl (1988).

The top of the oolitic grainstone of the lower Moliniacian is characterized by alveolar textures, pointing to continental modification. To the south, sedimentation occurred in a sabkha environment. Sabkhas form today under an arid to semi-arid climate such as in the Persian Gulf. In South Wales, to the west of the investigated area, oolitic grainstones at the top of the lower Moliniacian are capped by a mammillated paleokarst surface and a paleosol with alveolar textures (Wright 1982). This continental horizon formed under arid conditions (Wright 1988), corresponding to the observations in southeastern Belgium.

The paleosols in the middle Moliniacian contain alveolar textures (Fig. 6C), root traces (Fig. 6D), needle fibre calcites (Fig. 6E) and a dropping fabric (Fig. 6F). The needle fibre calcite is the product of calcite precipitation within fungal mycelial bundles (Callot et al. 1985). In present day soils they only accumulate under a semi-arid climate (Phillips & Self 1987). The abundance of evaporites in the middle Moliniacian is in agreement with these semi-arid conditions. In summary, a climatic shift from humid to semi-arid is evident in the early Visean.

The paleolatitudinal position of Belgium during the early Visean was close to the equator (Scotese et al. 1979). Normally this equatorial zone would have been a region of humid or wet climate (Rowley et al. 1985). However, from the evidence just presented, a semi-arid climate prevailed during the middle Moliniacian. Additional evidence is present in the literature (Wright 1980, 1988, Besly 1987, Hird & Tucker 1988). In order to explain this equatorial aridity, Van der Zwan et al. (1985) suggested that the early to middle Visean paleoclimatic equator was offset 10° N, leading to a drier climate over what is now western Europe. This difference in equatorial position could have been due to a difference in heat-budget, because of the large size of the Gondwana landmass. A low pressure zone would have been present above this landmass (Wright 1990). During the winter this cell would have de-

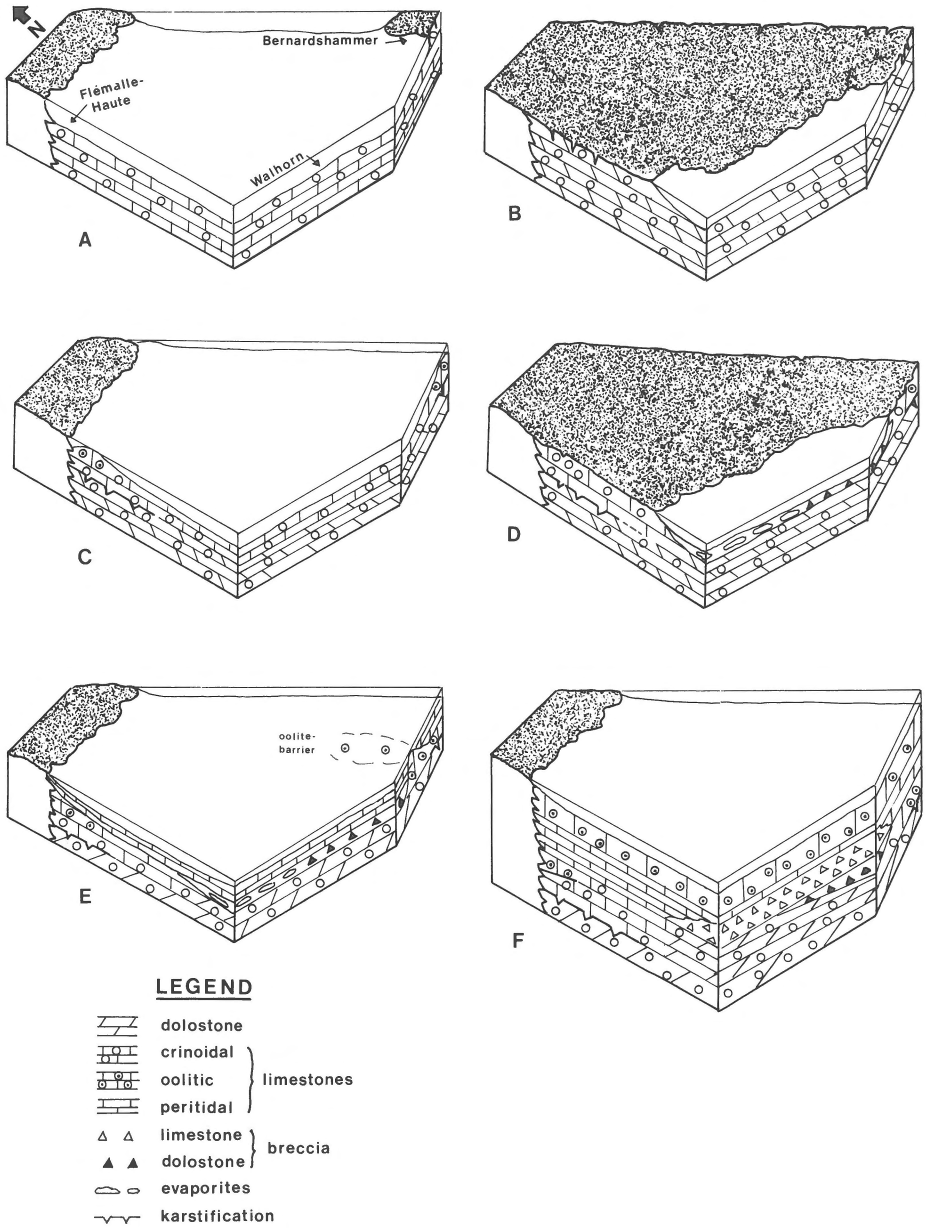

Fig. 7. Early Visean paleogeographic reconstructions of southeast Belgium (A) Earliest Moliniacian: open marine, subtidal environment (crinoidal limestones), possibly no deposition near Aachen; (B) Karstification interval within the early Moliniacian; (C) Late early Moliniacian: open marine, subtidal environment (crinoidal and oolitic limestones); (D) End early Moliniacian- beginning middle Moliniacian: continental environment in the Namur and Aachen area, hypersaline conditions in the Vesder area (evaporites); (E) Middle Moliniacian: peritidal and restricted depositional environment (lagoonal sediments, paleosols); (F) Late Moliniacian: open marine, subtidal environment (oolitic limestones).

flected rains over northern Gondwana, causing aridity over southern Euramerica.

Conclusion

In nearshore depositional successions, such as during the early Visean in southeastern Belgium, biostratigraphy is hampered due to the restricted sedimentation conditions. Lithostratigraphy is hindered by rapid facies variations, irregular, non-stratified dolomitization, erosion, brecciation and depositional gaps. Correlations based on the evolution and interpretation of facies, however, are applicable in these nearshore settings. Insight in the facies evolution allows a detailed reconstruction of the paleogeography.

The reconstruction of the paleoclimate in southeastern Belgium shows a trend from humid to semiarid or arid conditions during the earliest Visean. Similar trends during the Visean have been recognized in other areas. Large-scale correlations based on paleoclimatic criteria may become more important in the future.

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