

Ostracods and lithofacies of the Devonian-Carboniferous boundary beds in the Avesnois, North of France

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Abstract

Seven major carbonate microfacies are defined in the Devonian-Carboniferous (D-C) transitional strata (90 m) of the Bocahut quarry (Avesnes "basin"), and ten levels ranging through the Epinette, Etroeuungt, Avesnelles and Hastière formations are recognized. The "bathymetric" sequences range from open marine spiculite, below the storm wave base to semi-restricted lagoon. A standard sequence records a shallowing-upward trend, from environments below the storm wave base to strongly eroded supratidal pre-evaporitic environments. Faunal components (echinoderms, brachiopods...) point to an open marine domain for the first six microfacies. Except for the "black" mudstones of microfacies containing rare algae, the environment is located within the dysphotic-euphotic zone.

Ostracods are abundant and diversified throughout the studied section. Sixty-six species are identified and belong to an assemblage of the Eifelian ecotype indicating oxygenated shallow marine environments generally between storm and fair-weather wave bases. The absence of some platycopid ostracods at the base of the Hastière Formation could be related to the hiatus observed between the Avesnelles and Hastière formations. That hiatus probably corresponds to the Hangenberg Event; however, its effect on the distribution of ostracods was very reduced.

Ostracods and sedimentology show that the Bocahut quarry displays the most complete succession presently known through the D-C transition in Northern France (Avesnes "basin") and Southern Belgium (Dinant basin) although it is far from being continuous.

Two new species are described: *Sacclatia? advena* nov. sp. and *Healdianella dorsosulcata* nov. sp.

Key-words: Ostracods - Sedimentology - Devonian-Carboniferous boundary - Avesnois - France

Résumé

La carrière Bocahut (Avesnes-sur-Helpe) entame depuis quelques années les couches de la limite Dévonien-Carbonifère (D-C) qui dans l'Avesnois étaient actuellement mal exposées. Sept familles de microfaciès carbonatés (séquence standard MF1 à MF7) sont déterminées et leur succession enregistre une diminution progressive (MF1 à MF6) de la profondeur d'eau depuis des milieux de rampe externe silico-carbonatée (une soixantaine de mètres d'eau) jusqu'aux environnements carbonatés de rampe interne de faible profondeur, parfois soumis à une diagenèse vadose. Le microfaciès 7 est érosif et traduit une diminution brutale de la tranche d'eau avec remaniement important

de faciès lagunaires semi-restreints. Les variations de salinité sont la règle depuis des saumures hypersalines de reflux jusqu'aux milieux saumâtres. L'étude des microfaciès permet de reconnaître dix niveaux dans les formations d'Epinette, d'Etroeuungt, d'Avesnelles et d'Hastière. Les variations bathymétriques vont des faciès de lagon semi-restreint jusqu'au marin ouvert franc, spiculitique situé sous la zone d'action des tempêtes. Excepté le sommet ponctuel de la Formation d'Avesnelles où le milieu devient temporairement dysoxique à anoxique, l'environnement général est oxygéné, de faible profondeur. La distribution des organismes est liée aux variations de l'énergie (vagues de tempêtes ou houle permanente), dans un système de rampe, ou aux fluctuations de salinité, dans celui de plate-forme. La transition des formations d'Avesnelles et d'Hastière est marquée par une brutale baisse eustatique qui érode une partie inférieure de la Formation d'Hastière. A cette évolution correspond l'installation temporaire d'une plate-forme semi-restreinte.

Les ostracodes sont abondants et diversifiés dans la série étudiée. Soixante-six espèces sont identifiées et elles appartiennent à l'écotype de l'Eifel. Les différents assemblages indiquent des milieux marins francs bien oxygénés généralement entre la zone d'action des vagues de beau temps et de tempêtes. Les milieux les moins profonds sont situés dans la Formation d'Hastière, comme l'atteste la présence d'abondants Paraparchitacea et Aparchitacea. Aucune association d'ostracodes typiques de milieux mal oxygénés ou lagunaires n'est présente dans la coupe étudiée, bien que de tels environnements aient été ponctuellement mis en évidence au cours de l'analyse sédimentologique. Seule l'absence de quelques espèces d'ostracodes appartenant aux Platycopida à la base de la Formation d'Hastière, pourrait témoigner de l'hiatus observé à la limite entre les formations d'Avesnelles et d'Hastière. Celui-ci pourrait correspondre à l'événement Hangenberg, qui n'aurait par conséquent quasi aucune influence locale sur la distribution des ostracodes.

Les ostracodes et la sédimentologie montrent que la carrière Bocahut expose la succession la plus complète connue à ce jour au niveau de la limite D-C dans le nord de la France ("bassin" d'Avesnes) et le sud de la Belgique (Bassin de Dinant), bien qu'elle soit loin d'être continue.

Deux nouvelles espèces sont fondées: *Sacclatia? advena* nov. sp. et *Healdianella dorsosulcata* nov. sp.

Mots-clefs: Ostracodes - Sédimentologie - Limite Dévonien-Carbonifère - Avesnois - France

Introduction

We know little about ostracods from the Devonian-Carboniferous (D-C) transition in the western extremity of the Dinant Synclinorium. In the Avesnes "basin", 29 ostracod species have been reported by LETHIERS (1974a,b) from the Etroeuungt Formation of the du Parc quarry and of the Avesnelles trench. MILHAU *et al.* (1997) and MISTIAEN *et al.* (1998) reported several ostracod spe-

cies from the same beds. But up to now, and except for some *Cryptophyllus*, no ostracods have been recorded from the Avesnelles and Hastière formations in that region.

In the Dinant basin (Belgium), some ostracod species have been reported from the Etrœungt and Hastière formations by KUMMEROW (1939), ROME & GOREUX (1964), ROME (1971, 1977), BECKER & BLESS (1974a,b), and COEN (1985). Some of these species have been revised by LETHIERS (1975) and COEN (1995).

The goal of our paper is to complete the inventory of ostracods occurring close to the D-C boundary in the western extremity of the Dinant Synclinorium. A second objective is to see if the distribution of these ostracods is influenced by the Hangenberg Event responsible for the disappearance of numerous ostracods in Thuringia (Germany), and in the Holy Cross Mountains (Poland).

The Bocahut quarry - General setting

The Bocahut quarry is located about 2 km south-west of Avesnes-sur-Helpe in the Avesnes "basin" (western part of the Dinant Synclinorium), North of France (Fig. 1). This quarry has been active for a long time, and in the 19th century was known as the "old Godin quarry". Today the quarry shows four main excavations (numbered from 1 to 4 in MANSY *et al.*, 1988) located to the west of a new excavation (or "new quarry") started in 1999. A new truck trench recently built between the old and new quarries, exposes transitional D-C strata. These strata present no economic interest due to their high clay content. We have sampled this new continuous succession (GPS: N 50°07'510; E 3°53'504) which is around 90 m thick.

The section exposes the top of the Epinette Formation, the Etrœungt Formation, the Avesnelles Formation, and the Hastière Formation. The bathymetric sequences deduced from the sedimentological analysis range from open marine environments, below storm wave base, to lagoonal environments. However, the exact position of the D-C boundary in the Avesnois (CONIL *et al.*, 1990), is not precisely known. Until now, no conodont data are available from the Bocahut quarry and neither *Siphonodella praesulcata*, nor *S. sulcata*, has been recognized in the western extremity of the Dinant Synclinorium (CONIL *et al.*, *ibid.*).

Rock and facies analysis (A. Pr at)

Two hundred forty samples for thin sections were collected for sedimentological analysis. The section is composed of a series of thin to medium well-bedded, clayey limestones at the base and coarser and thicker limestones towards the top where several conglomeratic beds are present. Microfacies analysis (MAMET & PR AT, in press) indicates ten levels ranging through the Epinette, Etrœungt, Avesnelles and Hasti re formations. The

"bathymetric" sequences (eustatism, subsidence, salinity) range from open marine spiculite, below the storm wave base to semi-restricted lagoon. A standard sequence of 7 microfacies records a shallowing-upward trend (MAMET & PR AT, in press) from environments below the storm wave base to strongly eroded supratidal pre-evaporitic environments.

Microfacies description

Open marine below the storm wave base

Microfacies 1 (MF1)

Clayey and silty mudstones with a few bioclasts composed of crinoids, brachiopods, bryozoans, ostracods, and

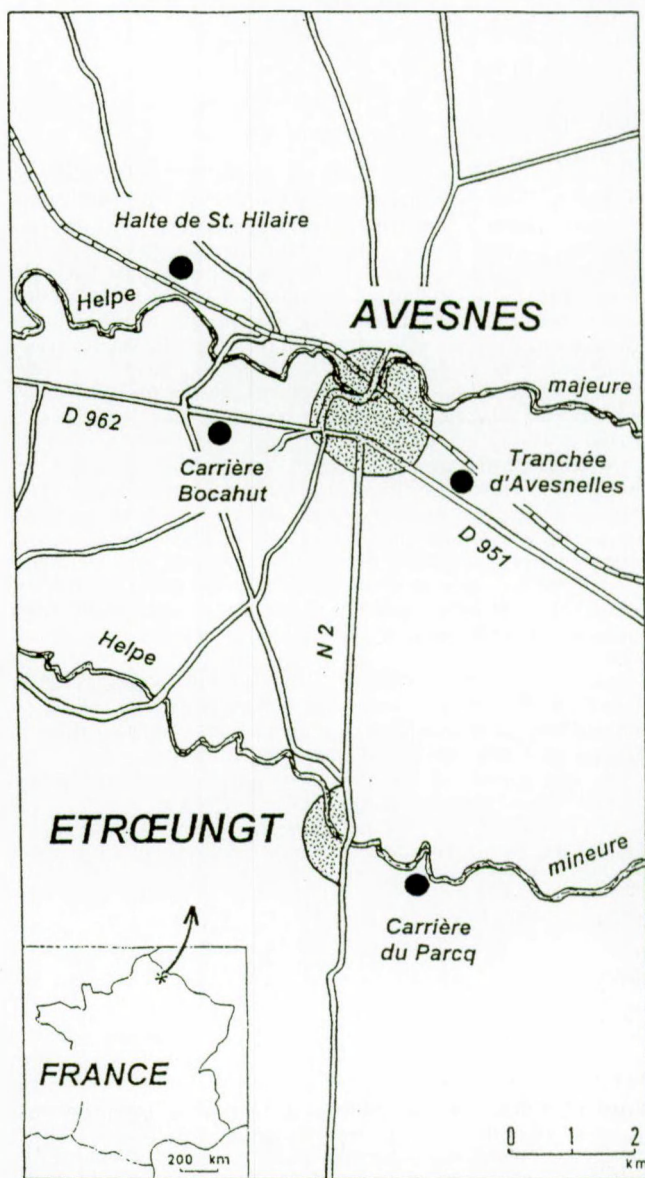


Fig. 1 — Geographic location of the Bocahut quarry, west of Avesnes-sur-Helpe (from MISTIAEN *et al.*, 1998).

rare algae (*Girvanella*, kamaenids, issinellids). The matrix is burrowed (Pl. 6, Figs. 2, 3) and contains fine-grained organic matter fragments. The greyish to brownish mudstones are mainly associated with levels 1 and 2 (Fig. 2 in MAMET & PRÉAT, in press). Black mudstones rich in fine-grained pyrite, organic matter fragments and sponge spicules (Pl. 1, Fig. 1) are also present in level 7 (*Ibid.*). They constitute the darkest facies of the series. Thin shells of brachiopods and bivalves are well preserved. The matrix is completely or partly recrystallized with a peloidal clotted fabric. These dark mudstones are sometimes bioturbated. They are only associated with levels 6, 7, and the spiculitic facies is only present at the top of level 7.

Open marine near the storm wave base

Microfacies 2 (MF2)

Clayey and silty burrowed wackestones with various bioclasts (abundant echinoderms, bryozoans, ostracods, mollusks, brachiopods, a few foraminifers and algae (Pl. 1, Figs. 5, 6). These organisms are present as large fragments inside millimetric laminae (up to 3 mm thick), or within small lenses (Pl. 1, Fig. 4). Bioturbation figures are well developed at the centimetric scale and contain a recrystallized fine-grained homogeneous microspar. These figures have often obliterated the primary laminations. The micritic matrix is rich in fine-grained organic matter fragments (same type as those of MF1) and echinoderm bioclasts are sometimes pyritized. Pressure solution processes are more accentuated in the clayey facies inducing a packstone texture to the sediment.

Open marine within the storm wave base

Microfacies 3 (MF3)

Clayey and silty wackestones and packstones with diversified bioclasts (Pl. 1, Figs. 7, 8, see previous facies). By comparison with MF2, there is an increase of the number of foraminifers, a sporadic presence of coral (*Rugosa*) and stromatoporoid fragments, and a development of algae (issinellids, kamaenids and *Girvanella*). The bioclasts display a bimodal distribution, one centered around 2-3 mm and the other around 0,5 mm (Pl. 1, Fig. 6), the latter being present also in the previous facies. Bioturbation is particularly intense and has destroyed most of the bioclastic laminations. However, a few of them are preserved, are thicker than in the previous facies, and reach up to 5 mm. They also contain larger bioclasts, (echinoderms, brachiopods, bryozoans) often found elongated within the bedding.

Microfacies 4 (MF4)

Laminar bioclastic packstones with coarse echinoderm bioclasts (Pl. 7, Figs. 1, 2). Coral and stromatoporoid fragments, and plurilocular foraminifers (*Endothyridae*, *Tournayellidae*) are more abundant. Laminations are thicker (Pl. 7, Fig. 1) and more frequent. They are centimetric (up to 3 cm), sometimes cross-bedded and graded.

Their lower parts are rich in millimetric brachiopod and echinoderm fragments, while their upper parts contain foraminifer and algal bioclasts (100 to 200 μm). The thickest levels are multiple as indicated by strong grain size variations (Pl. 7, Fig. 1). The "amalgamated" laminae are plane without erosional figures. Bioturbation and pressure solution are poorly developed, and the silty fraction is absent. Rare *Bisphaera* (*Incertae sedis*) and a few micritized grains are present. The micritic matrix is sometimes recrystallized in to a homogeneous fine-grained calcitic microspar.

Microfacies 5 (MF5)

Coral (*Rugosa* and *Tabulata*) and stromatoporoid packstones and floatstones with various bioclasts (echinoderms, brachiopods, bryozoans, foraminifers, ostracods and mollusks). The fragments of bioconstructors are poorly sorted and angular. The matrix is rich in algae (issinellids and kamaenids, Pl. 7, Figs. 3, 4). Crinoidal fragments remain abundant (Pl. 7, Fig. 5). Bioturbation figures are rare and the micritic matrix is often recrystallized into a homogeneous fine-grained calcitic microspar.

Open marine within the fair-weather wave base

Microfacies 6 (MF6)

Echinoderm ("encrinites"), stromatoporoid and coral grainstones and rudstones with various bioclasts (see previous facies). Algae are less abundant than plurilocular foraminifers, which form specific levels (Pl. 7, Fig. 6). Lamination size is variable. Discontinuities are plane without erosional figures. Alignments of molluscan shells highlight a strong oblique stratification (shell lag). The syntaxial cementation is well developed around the echinoderms. The matrix is partly or totally recrystallized in a homogeneous fine-grained calcitic "greyish" microspar or replaced by continuous or discontinuous large areas of coarse "white" calcite. The sediment is therefore transformed into a "false-grainstone". Calcite also fills irregular enterolithic-like cavities while calcitic microspar and large calcite crystals replace bioclasts (mollusks, echinoderms, corals, stromatoporoids). This is observed for the first time in the succession (see microspar of microfacies 4 and 5) and these replacements highlight the "false-grainstone" texture of the former "normal" grainstones (or rudstones). Bioturbation figures are exceptional and typical stylolites appear for the first time.

Restricted semi-evaporitic lagoons

Microfacies 7 (MF7)

Oolitic grainstones with millimetric- to centimetric-sized microbreccia (Pl. 7, Fig. 8), bioclasts (echinoderms, brachiopods, mollusks, foraminifers) and microconglomerates composed of polygenic packstone and grainstone microbreccia. These packstones and grainstones are oolitic (Pl. 7, Fig. 7), oncoidic, peloidal or contain micritized grains, bahamites and various lumps. The micro-

breccia are perforated and do not contain reworked fragments of the six previous microfacies (MF1 to MF6). Grains frequently display cross-bedding and the shells (brachiopods, mollusks) form umbrella cavities. Cementation consists of a first isopachous lamellar calcite phase followed by a drusy or syntaxial second phase. An asymmetric calcite cement is sometimes present. Irregular fenestral and geopetal cavities infilled with vadose silt and peloid mudstones are also observed. Due to the abundance of the fenestrae, the sediment sometimes becomes a loferite.

Microfacies and paleoenvironmental interpretations








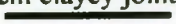












Omnipresent faunal components (echinoderms, brachiopods...) point to an open marine domain for the first six microfacies. Except for the "black" mudstones of microfacies that contain rare algae, the environment is located within the dysphotic-euphotic zone in relatively shallow-waters. The textures of the sediments (mudstones to rudstones) associated with the different characteristics of the laminae permit an estimation of palaeobathymetry and the position of the storm (SWB) and fair-weather (FWWB) wave bases (EINSELE & SEILACHER, 1982, AHR, 1989). The laminar levels, which are absent (MF1), thin and rare (MF2), of intermediate thickness despite the bioturbation (MF3), and finally thick and frequent (MF4), contain the same bioclasts. Their size and the complexity of the biotic assemblages increase with the lamination thickness. Bioturbations vary in the opposite direction and disappear in MF5 and MF6. Moreover, the lamination types vary along the microfacies standard sequence displaying erosional cross-bedding, amalgamation in MF5 and MF6, and being plane in the other microfacies.

These characteristics suggest a mixed siliciclastic carbonate ramp system whose sedimentation is determined by the respective SWB and FWWB positions (WRIGHT & BURCHETTE, 1998). Microfacies one (MF1) without bioclasts is located below the SWB, sedimentation takes place in "deep" water at the base of the dysphotic zone and is the result of decantation. Thin bioclastic laminae without erosive surfaces in MF2 are interbedded with open marine sediments (bioturbated micrites, open marine fauna) and interpreted as distal tempestites (d/SWB); layers of moderate thickness in MF3 represent intermediate tempestites (i/SWB), and the thicker bioclastic levels of MF4 represent proximal tempestites (p/SWB). In this general context, the background sedimentation is a decantation of clayey and carbonate muds in quiet environments (AIGNER, 1985). Bioturbation processes are predominant and disappear progressively in microfacies 5 and 6 where energy is high (erosional laminations or high sedimentation rates). In such conditions crinoidal meadows, algal banks, stromatoporoid and coral "bioconstructions" are destroyed and exported in the offshore or reworked in the FWWB. These microfacies are similar to those reported by PRÉAT & KASIMI

(1995) in the Belgian-French Middle Devonian or by SEBBAR *et al.* (2000) in the Algerian Carboniferous (Tindouf basin).

The weak development of restricted facies suggests a mixed ramp setting where bioconstructions are small. By comparison with the present day average depths of the SWB and FWWB, we can assume that MF1 and MF2 belong to an outer ramp around a depth of 60 m, MF3 and MF4 a mid ramp below the FWWB (i.e. deeper than 25-30 m), the *in situ* reworked bioconstructions (MF5 *pro parte*) being located at the outer-mid ramp transition where the energy increased. The MF5 and MF6 stacking by progradation? filled the available space and the sediments represent an inner ramp setting near a vadose environment (pendant cements, loferites) temporarily invaded by hypersaline brines ("false grainstone") or brackish waters (palissadic cements). Only the ostracods and *Earlandia minima*, a foraminifer, survived in these highly stressful environments and can be very abundant in MF5 and MF6. These facies display the strongest diagenetic alteration (repetitive dissolutions, microsparitisation, (de)dolomitization...). Finally the MF7, only present in the lower part of the Hastière Formation, indicates for the first time littoral sedimentation reworking a carbonate platform (oolites, bahamites, oncoids...). The Avesnelles/Hastière transition indicates therefore a major evolution in the sedimentary system from an "open" ramp to a "restricted" platform. The composition of the microbreccia in the Hastière Formation suggests that the sea level drop has only affected the Hastière Formation (an eroded unknown lower part).

Legend of figure 2

	bioclasts		silty limestone
	ostracods		dm shale
	sponge spicules		mm clayey joints
	paleoberesellids (large and small)		cm clayey joints
	brachiopods		erosional contact
	bioclastic lenses		peloids
	crinoidal lenses		oolites
	crinoids		microbreccia
	rugosa		burrows
	stromatoporoids		pyrite

AVESNES-SUR-HELPE

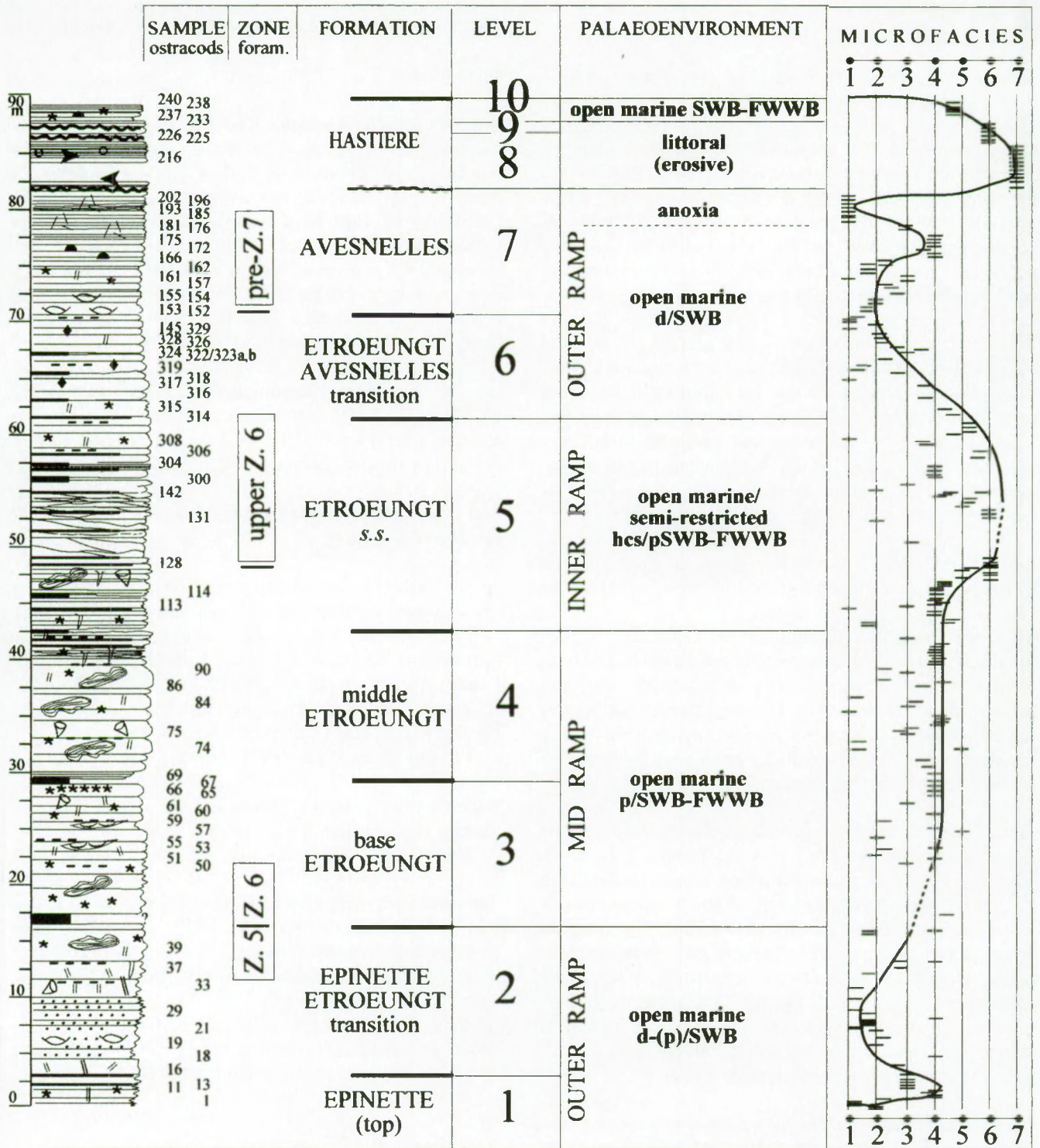


Fig. 2 — Lithological column of the new Bocahut quarry outcrop located west of Avesnes-sur-Helpe. Other columns indicate the position of sedimentological and ostracod samples, the foraminiferal zonation (MAMET, 1974), the names of formations, the level succession from 1 to 10, the paleoenvironmental interpretation and the microfacies evolution. Abbreviations: d = distal, p = proximal, SWB = normal storm wave base, FWWB = normal of fair-weather wave base, hcs = hummocky cross-stratification, Z = Zone (from MAMET & PRÉAT, in press).

Sedimentary evolution

Based on the interpretation of the lithologic curve (MAMET & PRÉAT, in press), the series can be subdivided in ten local levels showing the following evolution (Fig. 2):

Level 1 (L1): top of the Epinette Formation (seen over 4 m), and level 2 (L2): Epinette/Etroeungt transition (12 m).

Open marine (normal salinities) shelf facies within the storm wave base and the photic zone. Despite the fact that the tempestites are mainly distal, the presence of a few proximal tempestites point to a shallow environment located between SWB and FWB. The facies are composed of clayey mudstones and wackestones (mainly MF1 to MF3). The fauna is marine.

Level 3 (L3): base of Etroeungt Formation (13 m), and Level 4 (L4): middle part of Etroeungt Formation (12 m).

These levels represent the continuation of the preceding ones with progressive increase of proximal tempestites. MF3 and MF4 (wackestones and packstones) become dominant toward the top where abundant peloids, foraminifers and *Bisphaera (Incertae sedis)* appear. Macrofauna (stromatopores, corals, crinoids....) is diversified.

Level 5 (L5): upper part of the Etroeungt Formation or Calcaire d'Etroeungt sensu stricto (GOSSELET, 1860) (19 m).

MF4, MF5 and MF6 are dominant and contain bacterial micritized grains, lagoonal peloids and lumps mixed with open marine organisms (corals, brachiopods, etc) and various algae (*Girvanella*). This regressive level shows the transition from an open marine environment within the storm wave base (hummocky cross stratification) to a shallow semi-restricted lagoon.

Level 6 (L6): Etroeungt/Avesnelles transition (10 m); and Level 7 (L7): Avesnelles Formation (10 m).

The Etroeungt/Avesnelles transition is progressive with alternation of the preceding levels (4 and 5) and more open marine facies (MF1) still in the photic zone. The latter are composed of clayey mudstones and wackestones rich in pyrite. Despite the intensity of bioturbation, a few distal tempestites are preserved. The top of the Avesnelles Formation is black (Calcaire noir des Avesnelles), rich in sponge spicules ("spiculites") and contains very rare algae. The environment is temporarily anoxic.

Levels 8 (L8) and 9 (L9): Hastière Formation (4 m and 1 m).

These levels are discordant and composed in their lower part of microconglomerates reworking various shallow-water packstones-grainstones (with peloids, lumps, micritized grains, dolomitic burrows, bahamites....). The upper part is composed of packstones-grainstones containing brachiopods and crinoids. These facies are the most littoral and represent strong erosion of semi-restricted lagoons.

Level 10 (L10): Hastière Formation (2 m).

Open marine facies with normal salinities. The environment is the same as that of levels 2, 3 and 4.

Ostracods of the Bocahut quarry (J.-G. Casier)

Introduction

Fifty-six samples (samples CI 1 to CI 240) collected on the east flank of the Bocahut trench, have been selected for the study of ostracods during the sedimentological analysis (Fig. 2). Seventeen additional samples (samples CI 300 to CI 329) have been selected directly on the opposite flank of the trench. About 6,500 carapaces and relatively few valves of generally well-preserved ostracods have been extracted by the hot acetolysis method (LETHIERS & CRASQUIN-SOLEAU, 1988). No ostracods have been found in samples CI 60, CI 65, CI 304, CI 306, CI 308, CI 316, CI 326 and CI 193. Ostracods are very abundant in samples CI 225, CI 226, CI 237, CI 238 and CI 240. Ostracods are not determinable in samples CI 21, CI 37, CI 59, CI 84, CI 128 and CI 185. Sixty-six ostracod species are identified (Table 1).

List and systematic placement of species occurring in the Bocahut quarry

Order Palaeocopida HENNINGSMOEN, 1953
Suborder Palaeocopina HENNINGSMOEN, 1953

Superfamily Kirkbyacea ULRICH & BASSLER, 1906

Family Amphissitidae KNIGHT, 1928

– *Amphissites* sp. A (Pl. 1, Fig. 1 a, b).

Family Kirkbyidae ULRICH & BASSLER, 1906

– *Villozona?* sp. indet. (Pl. 1, Fig. 2).

Superfamily Aparchitacea JONES, 1901

Family Aparchitidae JONES, 1901

– *Sacclatia? advena* nov. sp. (Pl. 1, Fig. 3a,b).

Superfamily Youngiellacea KELLETT, 1933

Family Youngiellidae KELLETT, 1933

– *Youngiella calvata* (GREEN, 1963) (Pl. 1, Fig. 5a,b).

– *Youngiella?* nov sp. A (Pl. 1, Fig. 6a,b).

Superfamily Primitiopsacea SWARTZ, 1936

Family Graviidae POLENOVA, 1952

– *Coryellina grandis* ROBINSON, 1978 (Pl. 1, Fig. 4a,b).

– *Parapribylites?* sp. (Pl. 1, Fig. 7).

Superfamily Hollinacea SWARTZ, 1936

– Hollinacea indet. (Pl. 1, Fig. 8).

Suborder Paraparchiticopina GRAMM in GRAMM & IVANOV (1975)

Superfamily Paraparchitacea SCOTT, 1959

Family Paraparchitidae SCOTT, 1959

- *Shishaella nana* ROME, 1977 (Pl. 1, Fig. 9a,b).
 - *Shemonaella* sp. A (Pl. 1, Fig. 10a,b).
 - *Shemonaella?* sp. B (Pl. 1, Fig. 11).
 - *Shivaella?* cf. sp. 2 OLEMPKA, 1997 (Pl. 1, Fig. 12).
 - *Samarella* sp. A (Pl. 1, Fig. 13a,b).
 - *Samarella?* sp. B (Pl. 1, Fig. 14a,b).
 - *Paraparchites* sp. (Pl. 2, Fig. 1a,b).
- Family Coelonellidae SOHN, 1971
- *Coelonella* sp. A (Pl. 2, Fig. 2a,b).

Suborder Platycopina SARS, 1866

Superfamily Kloedenellacea ULRICH & BASSLER, 1908

Family Knoxitidae EGOROV, 1950

- *Knoxiella* aff. *bastachica* (BUSCHMINA, 1970) sensu CASIER & LETHIERS, 2001 (Pl. 2, Fig. 3a,b).
- *Knoxiella* sp. A (Pl. 2, Fig. 4a,b).
- *Amicus* cf. *complanatus* (KUMMEROW, 1939) (Pl. 2, Fig. 6a,b).
- *Amicus?* sp. (Pl. 2, Fig. 5).
- Kloedenellacea indet. (Pl. 2, Fig. 7a,b).

Superfamily Cytherellacea SARS, 1866

Family Cavellinidae EGOROV, 1950

- *Cavellina* sp. A (Pl. 2, Fig. 8a,b).

Order Podocopida SARS, 1866

Suborder Metacopina SYLVESTER-BRADLEY, 1961

Superfamily Healdiacea HARLTON, 1933

Family Healdiidae HARLTON, 1933

- *Cribroconcha* sp. A (Pl. 2, Fig. 9a,b).
- *Healdia* sp. A (Pl. 2, Fig. 10a,b).

Suborder Podocopina SARS, 1866

Superfamily Bairdiocypridacea SHAVER, 1961

Family Bairdiocyprididae SHAVER, 1961

- *Healdianella lumbiformis* LETHIERS & FEIST, 1991 (Pl. 2, Fig. 11a,b).
- *Healdianella dorsosulcata* nov. sp. (Pl. 2, Fig. 12,13).
- *Healdianella* sp. A (Pl. 2, Fig. 14a,b).
- *Elliptocyprites lorangeri* LETHIERS, 1981 (Pl. 2, Fig. 15, 16).
- *Praepilatina* sp. A, aff. *adamczaki* OLEMPKA, 1979 (Pl. 3, Fig. 1a,b).
- *Bairdiocypris* sp. A, aff. *rudolphi* (KUMMEROW, 1939) (Pl. 3, Fig. 2a,b).
- *Bairdiocypris* sp. B (Pl. 3, Fig. 3a,b).
- *Bairdiocypris* sp. 32 BECKER & BLESS, 1974 (Pl. 3, Fig. 4a,b).
- *Bairdiocypris* sp. indet.

Family Pachydomellidae BERDAN & SOHN, 1961

- *Ampuloides* nov. sp. A (Pl. 3, Fig. 5a,b).
- *Micronewsomites elatus* (LETHIERS, 1978) (Pl. 3, Fig. 6a,b).
- *Microcheilinella* cf. *buschminae* OLEMPKA, 1981 (Pl. 3, Fig. 7a,b).

- *Microcheilinella* sp. sensu OLEMPKA (1979) (Pl. 3, Fig. 8a,b).
- *Microcheilinella* sp. A (Pl. 3, Fig. 9a,b).
- *Microcheilinella* sp. B (Pl. 3, Fig. 10a,b).
- Pachydomellidae indet. (Pl. 4, Fig. 1a,b).

Superfamily Bairdiacea SARS, 1888

Family Acratiidae GRÜNDEL, 1962

- *Famenella angulata perparva* LETHIERS & FEIST, 1991 (Pl. 4, Fig. 2a,b).
- *Acratia bidecliva* LETHIERS & FEIST, 1991 (Pl. 4, Fig. 3a,b).
- *Acratia* aff. *sagittaeformis* LETHIERS & CASIER, 1999 (Pl. 4, Fig. 4a,b).
- *Acratia* cf. *cooperi* GRÜNDEL, 1962 (Pl. 4, Fig. 5).
- *Acratia* sp. A, aff. *rostrata* ZANINA, 1956 (Pl. 4, Fig. 6a,b).

Family Bairdiidae SARS, 1888

- *Bairdia (Bairdia) feliumgibba* BECKER, 1982 (Pl. 4, Fig. 7a,b).
- *Bairdia (Bairdia)* sp. B, aff. *feliumgibba* BECKER, 1982 (Pl. 4, Fig. 8a,b).
- *Bairdia (Bairdia)* sp. B BLUMENSTENGEL, 1979 (Pl. 4, Fig. 9a,b).
- *Bairdia (Bairdia)* sp. C (Pl. 4, Fig. 10a,b).
- *Bairdia (Bairdia) hypsela* ROME, 1971 emend LETHIERS, 1975 (Pl. 4, Fig. 11a,b).
- *Bairdia (Rectobairdia) fusiformis* ROME, 1971 (Pl. 4, Fig. 12a,b).
- *Bairdia (Rectobairdia)* sp. 120 BECKER & BLESS, 1974 (Pl. 5, Fig. 1a,b).
- *Bairdia (Rectobairdia) venterba* GRÜNDEL, 1961 (Pl. 5, Fig. 2).
- *Bairdia (Rectobairdia)* cf. *plebeja* REUSS, 1854 (Pl. 5, Fig. 3).
- *Bairdia (Rectobairdia) extenuata* NAZAROVA, 1951 (Pl. 5, Fig. 4a,b).
- *Bairdia (Orthobairdia?) romei* LETHIERS, 1974 (Pl. 5, Fig. 5a,b).
- *Bohlenatia?* sp. A (Pl. 5, Fig. 6a,b).
- *Bairdianella* sp. A, aff. *cuspis* BUSCHMINA, 1970 (Pl. 5, Fig. 7, 8).
- *Bairdiocypris robusta* KUMMEROW, 1939 (Pl. 5, Fig. 9a,b).
- *Bairdiocypris* sp. A, aff. *robusta* KUMMEROW, 1939 (Pl. 5, Fig. 10a,b).
- *Bairdiocypris* cf. *quasielongata* BUSCHMINA, 1968 (Pl. 5, Fig. 11a,b).
- *Bairdiocypris* sp. B, aff. *nanbiancunensis* (WANG, 1988) in CASIER & LETHIERS, 2002 (Pl. 5, Fig. 12a,b).
- *Bairdiocypris* sp. C (Pl. 5, Fig. 13a,b).
- *Bairdiocypris subvirga* BUSCHMINA, 1979.

Order Eridostraca ADAMCZAK, 1976

- *Cryptophyllus* sp. A, aff. *cordiformis* ROME & GOREUX, 1964 (Pl. 5, Fig. 14).
- *Cryptophyllus* sp. B, aff. *inflatus* ROME & GOREUX, 1964 (Pl. 5, Fig. 15).

Description of two new species

The types are deposited in the collections of the Department of Palaeontology (Section Micropalaeontology) of the Royal Belgian Institute of Natural Sciences (IRScNB n° b...).

Genus *Saccelatia* KAY, 1940

Type-species: *Aparchites arrectus* ULRICH, 1894.

Saccelatia? advena nov. sp.

(Pl. 1, Fig. 3a,b)

Derivation of the name - From the Latin *advena* = foreign, probable root of the name Avesnes.

Types - Holotype: Carapace. CI225. IRScNB n° b4107. L = 0.68 mm; H = 0.37 mm; W = 0.34 mm. (Pl. 1, Fig. 3a,b).

Paratype A: Carapace. CI225. IRScNB n° b4108. L = 0.38 mm; H = 0.21 mm; W = 0.18 mm.

Paratype B: Carapace. CI225. IRScNB n° b4109. L = 0.64 mm; H = 0.34 mm; W = 0.33 mm.

Paratype C: Carapace. CI225. IRScNB n° b4110. L = 0.37 mm; H = 0.19 mm; W = 0.18 mm.

Locus typicus - Bocahut quarry, Avesnes-sur-Helpe (Nord), in the Ardennes, France.

Stratum typicum - Hastière Formation, Tournaisian.

Material - About 160 valves and carapaces.

Diagnosis - The new species is smooth and elongate and belongs questionably to the genera *Saccelatia*. The hinge line is long, straight and strongly incised, and the carapace without lateral tubercles.

Description - In lateral view, the carapace is small and slightly preplete. The dorsal margin is long and straight or very slightly convex close to the anterior third of the carapace. The posterior border is slightly more rounded than the anterior one. The ventral border is regularly rounded. The cardinal angles measure 130°. The valves are sub-equal. The maximum length is at mid-height or just above, and the maximum height is at anterior two fifth of the length. The admarginal ridges extend from one cardinal extremity to the other. In dorsal view, the hinge line is long, straight, and incised. The carapace is regularly bi-convex except close to the extremities where the surface between the admarginal ridges are concave. The maximum width is at mid-length. A circular muscle scar is occasionally visible. No lateral tubercles and no polymorphism have been observed. The surface of the valves is smooth.

Comparison - *Saccelatia kakisaensis* LETHIERS, 1981, and *Saccelatia* n. sp. A LETHIERS, 1981 from the Famennian of Canada are reticulated.

Occurrence - The species is known only from the Hastière Formation in the Bocahut quarry (samples CI225, CI226, CI238, CI240).

Genus *Healdianella* POZNER, 1951

Type - species: *Healdianella darwinuloides* POZNER, 1951.

Healdianella dorsosulcata nov. sp.

(Pl. 2, Fig. 12, 13)

Derivation of the name - Allusion to the dorsal depression present along the hinge line on the left valve.

Types - Holotype: Carapace. CI225. IRScNB n° b4111. L = 0.52 mm; H = 0.30 mm; W = 0.22 mm. (Pl. 2, Fig. 12).

Paratype A: Carapace. CI225. IRScNB n° b4112. L = 0.55 mm; H = 0.30 mm; W = 0.19 mm. (Pl. 2, Fig. 13).

Paratype B: Broken carapace. CI226. IRScNB n° b4113. L = 0.53 mm; H = 0.30 mm; W = 0.21 mm.

Paratype C: Carapace. CI225. IRScNB n° b4114. L = 0.53 mm; H = 0.27 mm; W = 0.21 mm.

Locus typicus - Bocahut quarry, Avesnes-sur-Helpe (Nord) in the Ardennes, France.

Stratum typicum - Hastière Formation, Tournaisian.

Material - 42 valves and carapaces.

Diagnosis - *Healdianella dorsosulcata* nov. sp. displays a long narrow dorsal depression along the hinge line on the left valve. The contact between the posterior border and the dorsal border of the right valve is slightly angular.

Description - In lateral view, the carapace is small, and kidney-shaped. The dorsal border is slightly curved except at 2/5 of the length where the curvature is more accentuated. The ventral border is concave, practically parallel to the dorsal border, and consequently with the maximum of curvature close to the 2/5 of the length. The anterior and posterior borders are regularly arched. The contact between the posterior border and the dorsal border of the right valve is slightly angular. The maximum length is at mid-height but the maximum height is nearly constant from 1/4 to 3/4 of the length. The anterior extremity of the carapace is more or less pinched along the anterior border. The postero-dorsal border of the right valve is nearly straight forming an obtuse angle with the posterior border. The left valve overreaches the right valve along the dorsal margin, and overlaps slightly the entire free border. A long and narrow dorsal depression is present along the hinge line on the left valve. On corroded specimens, the depression shows the crenellation of the hinge. In dorsal view, the carapace is elongate-elliptic with the anterior extremity pinched and the posterior extremity rounded. The surface of valves is smooth.

Comparison - *Healdianella dorsosulcata* nov. sp. resembles *H. alba* LETHIERS, 1981, from the upper Devonian of Canada, and *Healdianella lumbiformis* LETHIERS & FEIST, 1991 from the Late Devonian of the Montagne Noire, Southern France. However, *H. dorsosulcata* is larger, more elongated and the dorsal overreach is more important.

Occurrence - The species is only known from the Hastière Formation in the Bocahut quarry (samples CI225, CI226, CI237, CI238, CI240).

Palaeoecology of ostracods

Ostracods are abundant and diversified in the Bocahut quarry. Sixty-six species are identified (Table 1). They belong exclusively to the Eifelian ecotype (BECKER *in* BANDEL & BECKER, 1975), and more precisely to the Assemblage III of CASIER (1987) (Fig. 3). This assemblage is indicative of well-oxygenated shallow to moderately "deep" marine environments. No ostracod assemblage characteristic of true lagoonal environments (Fig. 3, assemblage 0), indicative of poor oxygenated (Fig. 3, assemblage V) or of deep water (Fig. 3, assemblage IV) conditions have been found.

At the top of the Epinette Formation and in the Epinette/Etroeungt transition (levels 1 and 2 of the sedimentological analysis, Fig. 2), the abundance of ostracods is variable: rich in samples CI 13, 18, 29, 33; poor in

samples CI 1, 19, 21, 39. The assemblage is dominated by podocopids indicative of well-oxygenated marine water, and the presence of Kloedenellacea and Paraparchitacea indicates a shallow marine environment. However, the abnormal abundance of instars in some samples shows that part of this fauna has been transported close to storm-wave base.

In the Etroeungt Formation (levels 3, 4 and 5), except in the rich samples CI 50, 53, 75, 86 and 142, ostracods are extremely rare; they are even absent in CL 60, 65, 304, 306, 308. Ostracods do not show evidence of transport, and are dominated by podocopids indicative of very well oxygenated water conditions. *Bairdia* (*B.*) *hypsel* ROME, 1971 emend LETHIERS, 1975, *Healdianella lumbiformis* LETHIERS & FEIST, 1991, *Bairdia* (*R.*) *extenuata* NAZAROVA, 1951, and *Microcheilina* sp. sensu OLEMPKA, (1979) are among the most abundant species. This fauna indicates a marine environment between storm and fair-weather wave bases. However, the absence of ostracods in some samples at the top of the Etroeungt Formation, is possibly linked to brief periods of restricted water conditions as displayed by the sedimentological analysis.

In the Etroeungt/Avesnelles transition (level 6), ostracods are scarce, while podocopids predominate.

At the base and middle part of the Avesnelles Formation (level 7), *Cryptophyllus* is frequent, and several species belonging to the Platycopina and the Paraparchitacea appear. These species are indicative of a shallowing of the environment. However in the top of the Aves-

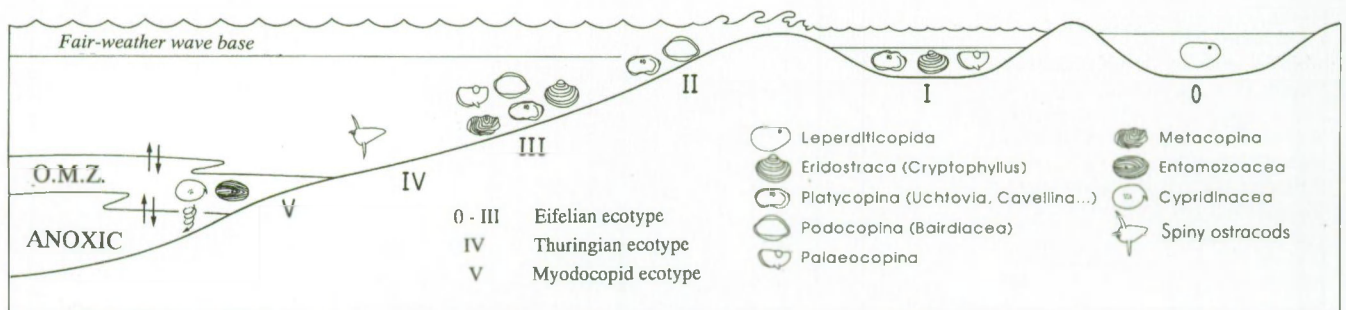


Fig. 3 — Ostracod assemblages recognized in the Upper Paleozoic. Assemblage 0: poorly diversified assemblage characterized by leperditicopids or platycopids; indicator of lagoonal environments. Assemblage I: more diversified assemblage with cryptophilloids, platycopids, palaeocopids, metacopids and rare podocopids; indicator of semi-restricted water conditions. In this assemblage, a few species occur generally in great individual abundance and the number of podocopids increases with the increase of marine influence. Assemblage II: assemblage characterized by heavy shelled and frequently broken carapaces of adult podocopids and platycopids; indicator of agitated marine environments above fair-weather wave base. Assemblage III: very diversified assemblage containing all the major groups of ostracods; indicator of marine environments below fair-weather wave base or below storm wave base. In this assemblage the abundance of filter-feeding metacopids and paleocopids compared to deposit-feeding podocopids is related to the oxygen content of the bottom waters. Assemblage IV: assemblage characterized by spiny palaeocopids, podocopids and metacopids; indicator of calm, probably deep and (or) colder environments = Thuringian ecotype (BECKER *in* BANDEL & BECKER, 1975). Assemblage V: rich in entomozoids and (or) cypridinoids; indicator of hypoxic water conditions = Entomozoid ecotype (BECKER, *ibid.*) = Mydocopid ecotype (CASIER *et al.*, 1995). Assemblages 0 to III belong to the Eifelian ecotype (BECKER, *ibid.*) except that they are not restricted to reef environments. Assemblage III also includes the Malvinokaffric ecotype (LETHIERS *et al.*, 2001). Mixed assemblages III-IV, III-V and IV-V may occur. OMZ = minimum oxygen zone (After CASIER, 1987 and CASIER *et al.*, 1995).

CARRIERE BOCAHUT	Epinette Form.			Epinette - Etroeungt transition					Etroeungt Formation																			
	11	13	16	18	19	29	33	37	39	50	51	53	55	57	61	66	67	69	74	75	86	90	113	114	131	142	300	
<i>Acratia bidecliva</i>	X			X			X					?									X							X
<i>Cryptophyllus</i> sp. A, aff. <i>cordiformis</i>	X																				X							
<i>Bairdiocypris</i> sp. 32		X																										
<i>Knoxiella</i> sp. A		X		X			X																					
<i>Bairdiocypris</i> cf. <i>quasielongata</i>		X				X																	X					
<i>Shemonaella</i> sp. A		X													X							?						
<i>Microcheilinella</i> sp. A		X		X																	X			X	X			
<i>Bairdiocypris</i> sp. B, aff. <i>nanbiancunensis</i>		?	X	X			X		X				?				X				X	X			X	X		
<i>Bairdia</i> (<i>Bairdia</i>) sp. A		?					X																					
<i>Bairdia</i> (<i>Bairdia</i>) <i>hypsel</i>		X	?	X	?		X				?	X									?			?		X		
<i>Healdianella lumbiformis</i>		X		X		X	X			X		X								?	X	X			X	X		X
<i>Bairdianella</i> sp. A, aff. <i>cuspis</i>		X		X		X			?												X	X	?	X	X			
<i>Bairdia</i> (<i>Rectobairdia</i>) <i>extenuata</i>		X		X		X				X		X		X	X			X			X	X		X	X		X	
<i>Microcheilinella</i> cf. <i>buschminae</i>		X			?		?					X									X	?		X		X		
<i>Healdia</i> sp. A				X																								
<i>Criboconcha</i> sp. A				X			X																					
<i>Bairdia</i> (<i>Rectobairdia</i>) <i>venterba</i>				X			?							X										X				
<i>Youngiella calvata</i> (GREEN, 1963)				X			X	?																		X		
<i>Acratia</i> aff. <i>sagittaeformis</i>				X																								
<i>Micronewsomites elatus</i>				X																								
<i>Bairdia</i> (<i>Rectobairdia</i>) sp. 120				X																								?
<i>Amicus</i> cf. <i>complanatus</i>				X																	?		X					
<i>Microcheilinella</i> sp.				X		X	X			X		X						X	X		X	X	X			X	X	
<i>Bairdiocypris robusta</i>				?		?							?				X	X			X	X			X		X	
<i>Paraparchites</i> sp.						X																			X		X	
<i>Pachydomellidae</i> indet.							X																					
<i>Bairdiocypris subvirga</i>							X																					
<i>Hollinacea</i> indet.							X																					
<i>Cryptophyllus</i> indet.							X																					
<i>Kloedenellacea</i> indet.							X																					
<i>Bairdia</i> (<i>Bairdia</i>) sp. B aff. <i>feliumgibba</i>							X														?			X				
<i>Bairdia</i> (<i>Orthobairdia</i> ?) <i>romei</i>							?																				X	
<i>Bairdiocypris</i> sp. A, aff. <i>robusta</i>										X											X	?				X	X	
<i>Acratia</i> sp. A, aff. <i>rostrata</i>											X		X								X	X		X		X	X	
<i>Bairdiocypris</i> sp. B																X										X	X	
<i>Coelonella</i> sp. A																					?	X						
<i>Bairdiocypris</i> sp. A, aff. <i>rudolphi</i>																					X	X		X				
<i>Shishaella nana</i>																					X	X		X			X	
<i>Praepilatina</i> sp. A, aff. <i>adamczaki</i>																							X					
<i>Bairdia</i> (<i>Rectobairdia</i>) cf. <i>plebeja</i>																									?			
<i>Bairdia</i> (<i>Rectobairdia</i>) <i>fusiformis</i>																									X			
<i>Cryptophyllus</i> sp. B, aff. <i>inflatus</i>																									X		X	
<i>Youngiella?</i> nov. sp. A																											X	
<i>Acratia</i> cf. <i>cooperi</i>																												?
<i>Famenella angulata perparva</i>																												
<i>Villozona?</i> sp. indet.																												
<i>Bairdiocypris</i> sp. C																												
<i>Shivaella?</i> cf. sp. 2																												
<i>Ampuloides</i> nov. sp. A																												
<i>Bairdia</i> (<i>Bairdia</i>) <i>feliumgibba</i>																												
<i>Parapribylites?</i> sp.																												
<i>Cavellina</i> sp. A																												
<i>Knoxiella</i> aff. <i>bastachica</i>																												
<i>Amicus?</i> sp.																												
<i>Healdianella</i> sp. A																												
<i>Bairdia</i> (<i>Bairdia</i>) sp. C																												
<i>Microcheilinella</i> sp. B																												
<i>Samarella?</i> sp. B																												
<i>Sacclatia?</i> <i>advena</i> nov. sp.																												
<i>Healdianella dorsosulcata</i> nov. sp.																												
<i>Amphissites</i> sp. A																												
<i>Shemonaella?</i> sp. B																												
<i>Coryellina grandis</i>																												
<i>Samarella</i> sp. A																												
<i>Bolhenatia?</i> sp. A																												
<i>Elliptocyprites lorangeri</i>																												

Table 1 — Distribution of ostracods through the Devonian-Carboniferous transition in the Bocahut quarry.

nelles Formation (upper part of level 7, above sample CI 181) the rarity or even the absence of ostracods is possibly related to an anoxia period as indicated by the sedimentological analysis.

Finally in the Hastière Formation (levels 8 and 9), the shallowing reaches a maximum with the blooming of Paraparchitacea (6 species) and Aparchitacea (3 species). The appearance of *Samarella* sp. A, *Samarella?* sp. B, *Shemonaella?* sp. B, *Sacclatia advena* nov. sp., and *Coryellina grandis* ROBINSON, 1978, in sample CI 225, is the most important change in the fauna. These ostracods are indicative of shallow and perhaps semi-restricted water conditions (Fig. 3, assemblage I), while in this case the abundance of podocopids indicates a very strong marine influence.

Ostracods and the Hangenberg Event

Several faunal "events" occurred during the Late Devonian, and the Hangenberg Event close to the D-C boundary is believed to be one of the most dramatic (HOUSE, 1985; WALLISER, 1984, 1996). This event corresponds to the Hangenberg Shale in the Middle *praesulcata* conodont Zone, and coincides with the disappearance of numerous ammonoids (HOUSE, 1993; BECKER, 1993), conodonts (GIRARD, 1996) and trilobites (FEIST, 1991). Important biotic changes near the D/C boundary refer also to reef ecosystems (WEBB, 1996) and crinoids (GLUCHOWSKI, 2002). The causes and consequences of the Hangenberg Event were recently reviewed by CAPLAN & BUSTIN (1999).

In order to document the effect of the Hangenberg Event on the distribution of ostracods, we have recently published two papers on ostracods associated with the D-C boundary series in the Montagne Noire, Southern France (CASIER *et al.*, 2001, 2002). There we have shown that the number of species disappearing during the Hangenberg Event is less important in the Montagne Noire than in other deeper successions setting in Thuringia and Rheinisches Schiefergebirge (BLUMENSTENGEL, 1993; BECKER & BLUMENSTENGEL, 1995; BECKER, 1999), and in the Holy Cross Mountains of Poland (OLEMPKA, 1997).

The distribution of ostracods in the Bocahut quarry (Table 1) confirms this statement. No dramatic disappearance of ostracods is recorded. The entry and the disappearance of the greatest part of ostracod species can be explained by progressive changes of the environments displayed by the palaeoecological and sedimentological analyses. The absence in the Hastière Formation of some platycopids belonging to the genera *Cavellina* and *Knoxella*, and occurring briefly in the Avesnelles Formation, is intriguing because the environment is normally favourable for these species in the Hastière Formation. However, this absence may be linked to the hiatus displayed by the sedimentological study close to the Avesnelles-Hastière formations boundary. This hiatus, more important in Belgian sections (VAN STEENWINKEL, 1988), is

probably related to the Hangenberg Event. Although the Eifelian ecotype ostracods play a rather modest part in biostratigraphy (BECKER, 2000), the study in progress of ostracods present in the "Pont-rail" section close to Anseremme in Belgium (Dinant basin), will probably clarify the influence of the Hangenberg Event on ostracods.

Conclusions

Analysis of the seven recognized carbonate microfacies permits recognition of ten levels ranging through the Epinette, Etroeungt, Avesnelles and Hastière formations. The "bathymetric" sequences range from open marine spiculite, below the storm wave base to semi-restricted lagoon. Faunal components (echinoderms, brachiopods...) point to an open marine domain for the first six microfacies. The textures of the sediments (mudstones to rudstones) associated with the different characteristics of the laminations permit establishment of a palaeobathymetry related to the storm (SWB) and the fair-weather (FWWB) wave bases in a ramp depositional setting. Interpretation of these microfacies associations permits to recognition of different environments within outer-, mid- and inner ramp settings. The series containing these six microfacies represents a mixed silico-carbonate ramp depositional system. The outer-ramp is composed of marly brownish (Epinette Formation, levels 1 and 2) or blackish (Avesnelles Formation, levels 6 and 7) mudstones, the mid-ramp succession is built up by frequent alternations of burrow-mottled to laminar bioclastic wackestones, and the inner-ramp by crinoid bioclastic packstones and grainstones interbedded with coquinoïd (various shells, stromatoporoids, corals) floatstones and rudstones. The thickness of the stacked inner to outer-ramp sediments is several tens of metres. Shallow-water facies are well developed indicating a progressive decrease in accommodation space (reduced sea-level rise or higher sedimentation rate). These conditions allowed the development of thin "back-barrier" sediments in the Hastière Formation (peritidal environments, microfacies 7). Microfacies 7 suggests a semi-restricted platform where salinity fluctuations from hypersaline brines to brackish waters were the rule. The transition of the Avesnelles/Hastière formations is marked by an abrupt sea level drop and sedimentation of carbonate microconglomerates records an important erosive phase. The "true" thickness of the Hastière Formation is therefore unknown.

Ostracods are abundant and very diversified close to the D-C boundary, and 66 species belonging to the Eifelian ecotype (BECKER *in* BANDEL & BECKER, 1975) are identified. The assemblages are generally indicative of well-oxygenated marine environments between storm and fair-weather wave bases. A very shallow-water ostracod assemblage characterized by abundant species of Paraparchitacea and Aparchitacea, has been found in the Hastière Formation. These ostracods are indicative of

very shallow and maybe semi-restricted water conditions, while the presence of numerous podocopids attests to a strong marine influence. No ostracods indicative of true lagoonal or of poorly oxygenated water have been found whereas such environments have occasionally been displayed in the sedimentological analysis.

The absence of some platycopids at the base of the Hastière Formation may be related to the hiatus between the Avesnelles and Hastière formations. If this gap corresponds to the Hangenberg Event, its influence on the distribution of the ostracod fauna was very reduced. The sedimentological analysis and the study of ostracods show that the hiatus between the Avesnelles and Hastière formations is brief and that the Bocahut quarry displays

the most complete succession known through the D-C transition in North of France (Avesnes "basin") and South of Belgium (Dinant basin), although it is far from being continuous (MAMET & PRÉAT, in press).

Acknowledgments

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Explanation of Plates

The types are deposited in the collections of the Department of Palaeontology (section Micropalaeontology) of the Royal Belgian Institute of natural Sciences (IRScNB n° b...). The thin sections are deposited in the Department of Earth Sciences and Environment of the University of Brussels (Préat n° Cl...). Cl = sample number (see Fig. 2 for the stratigraphic position). Dev = Devonian. Carb = Carboniferous.

PLATE 1

- Fig. 1 — *Amphissites* sp. A. Cl 237. Hastière Formation. IRScNB n° b4115. Carapace. a. Left lateral view. b. Dorsal view. x120.
- Fig. 2 — *Villozona?* sp. indet. Cl 145. Etroeungt/Avesnelles transition. IRScNB n° b4116. Left lateral view of a carapace. x80.
- Fig. 3 — *Sacclatia? advena* nov. sp. Cl 225. Hastière Formation. IRScNB n° b4107. Holotype. a. Left lateral view. b. Dorsal view. x80.
- Fig. 4 — *Coryellina grandis* ROBINSON, 1978. Cl 225. Hastière Formation. IRScNB n° b4117. Carapace. a. Right lateral view. b. Dorsal view. x70.
- Fig. 5 — *Youngiella calvata* (GREEN, 1963). Cl 33. Epinette/Etroeungt transition. IRScNB n° b4118. Carapace. a. Right lateral view. b. Dorsal view. x100.
- Fig. 6 — *Youngiella?* nov sp. A. Cl 240. Hastière Formation. IRScNB n° b4119. Carapace. a. Right lateral view. b. Dorsal view. x90.
- Fig. 7 — *Parapribylites?* sp. Cl 175. Avesnelles Formation. IRScNB n° b4120. Left valve. x60.
- Fig. 8 — Hollinacea indet. Cl 33. Epinette/Etroeungt transition. IRScNB n° b4121. Carapace in right lateral view. x100.
- Fig. 9 — *Shishaella nana* ROME, 1977. Cl 240. Hastière Formation. IRScNB n° b4122. Carapace. a. Right lateral view. x65. b. Dorsal view. x70.
- Fig. 10 — *Shemonaella* sp. A. Cl 61. Etroeungt Formation. IRScNB n° b4123. Carapace. Right lateral view. b. Dorsal view. x60.
- Fig. 11 — *Shemonaella?* sp. B. Cl 225. Hastière Formation. IRScNB n° b4124. Carapace. Right lateral view. b. Dorsal view. x100.
- Fig. 12 — *Shivaella?* cf. sp. 2 OLEMPKA, 1997. Cl 175. Avesnelles Formation. IRScNB n° b4125. Left valve. x50.
- Fig. 13 — *Samarella* sp. A. Cl 226. Hastière Formation. IRScNB n° b4126. Carapace. a. Left lateral view. b. Dorsal view. x70.
- Fig. 14 — *Samarella?* sp. B. Cl 225. Hastière Formation. IRScNB n° b4127. Corroded carapace. a. Left lateral view. b. Dorsal view. x80.

PLATE 2

- Fig. 1 — *Paraparchites* sp. Cl 29. Epinette/Etroeungt transition. IRScNB n° b4128. Carapace. a. Left lateral view. b. Dorsal view. x40.
- Fig. 2 — *Coelonella* sp. A. Cl 157. Avesnelles Formation. IRScNB n° b4129. Carapace. a. Lateral view. b. Dorsal view. x80.
- Fig. 3 — *Knoxiella* aff. *bastachica* (BUSCHMINA, 1970) sensu CASIER & LETHIERS, 2001. Cl 175. Avesnelles Formation. IRScNB n° b4130. Carapace. a. Left lateral view. b. Dorsal view. x70.
- Fig. 4 — *Knoxiella* sp. A. Cl 33. Epinette/Etroeungt transition. IRScNB n° b4131. Carapace. a. Left lateral view. b. Dorsal view. x100.
- Fig. 5 — *Amicus?* sp. Cl 175. Avesnelles Formation. IRScNB n° b4132. Lateral view of a valve. x100.
- Fig. 6 — *Amicus* cf. *complanatus* (KUMMEROW, 1939). Cl 18. Epinette/Etroeungt transition. IRScNB n° b4133. Carapace. a. Right lateral view. b. Dorsal view. x100.
- Fig. 7 — Kloedenellacea indet. Cl 226. Hastière Formation. IRScNB n° b4134. Carapace. a. Right lateral view. b. Dorsal view. x100.
- Fig. 8 — *Cavellina* sp. A. 175. Avesnelles Formation. IRScNB n° b4135. Carapace. a. Left lateral view. b. Dorsal view. x70.
- Fig. 9 — *Cribroconcha* sp. A. Cl 18. Epinette/Etroeungt transition. IRScNB n° b4136. Broken carapace in right lateral view. x80.
- Fig. 10 — *Healdia* sp. A. Cl 18. Epinette/Etroeungt transition. IRScNB n° b4137. Carapace. a. Right lateral view. b. Dorsal view. x77.5.
- Fig. 11 — *Healdianella lumbiformis* LETHIERS & FEIST, 1991. Cl 29. Epinette/Etroeungt transition. IRScNB n° b4138. Carapace in right lateral view. x100.
- Fig. 12 — *Healdianella dorsosulcata* nov. sp. Cl 226. Hastière Formation. IRScNB n° b4111. Right lateral view of the Holotype. x80.
- Fig. 13 — *Healdianella dorsosulcata* nov. sp. Cl 225. Hastière Formation. IRScNB n° b4112. Dorsal view of Paratype A. x80.
- Fig. 14 — *Healdianella* sp. A. Cl 181. Avesnelles Formation. IRScNB n° b.4139. Carapace. a. Right lateral view. b. Dorsal view. x77.5.

- Fig. 15 — *Elliptocyprites lorangeri* LETHIERS, 1981. CI 225. Hastière Formation. IRScNB n° b4140. Carapace in right lateral view. x77.5.
 Fig. 16 — *Elliptocyprites lorangeri* LETHIERS, 1981. CI 225. Hastière Formation. IRScNB n° b4141. Carapace in dorsal view. x80.

PLATE 3

- Fig. 1 — *Praepilatina* sp. A, aff. *adamczaki* OLEMPKA, 1979. CI 225. Hastière Formation. IRScNB n° b4142. Carapace. a. Right lateral view. x80. b. Dorsal view. x90.
 Fig. 2 — *Bairdiocypris* sp. A, aff. *rudolphi* (KUMMEROW, 1939). CI 237. Hastière Formation. IRScNB n° b4143. Carapace. a. Right lateral view. b. Dorsal view. x60.
 Fig. 3 — *Bairdiocypris* sp. B. CI 66. Etroeungt Formation. IRScNB n° b4144. Carapace. a. Right lateral view. b. Dorsal view. x50.
 Fig. 4 — *Bairdiocypris* sp. 32 BECKER & BLESS, 1974. CI 13. Epinette Formation. IRScNB n° b4145. Carapace. a. Right lateral view. b. Dorsal view. x60.
 Fig. 5 — *Ampuloides* nov. sp. A. CI 225. Hastière Formation. IRScNB n° b4146. Carapace. a. Right lateral view. b. Dorsal view. x97.5.
 Fig. 6 — *Micronewsomites elatus* (LETHIERS, 1978). CI 18. Epinette/Etroeungt transition. IRScNB n° b4147. Carapace. a. Right lateral view. b. Dorsal view. x100.
 Fig. 7 — *Microcheilinella* cf. *buschminae* OLEMPKA, 1981. CI 225. Hastière Formation. IRScNB n° b4148. Carapace. a. Right lateral view. b. Dorsal view. x100.
 Fig. 8 — *Microcheilinella* sp. sensu OLEMPKA (1979). CI 225. Hastière Formation. IRScNB n° b4149. Carapace. a. Right lateral view. b. Dorsal view. x80.
 Fig. 9 — *Microcheilinella* sp. A. CI 114. Etroeungt Formation. IRScNB n° b4150. Carapace. a. Right lateral view. b. Dorsal view. x100.
 Fig. 10 — *Microcheilinella* sp. B. CI 225. Hastière Formation. IRScNB n° b4151. Carapace. a. Right lateral view. b. Dorsal view. x80.

PLATE 4

- Fig. 1 — Pachydomellidae indet. CI 33. Epinette/Etroeungt transition. IRScNB n° b4152. Carapace. a. Right lateral view. b. Dorsal view. x77.5.
 Fig. 2 — *Famenella angulata perparva* LETHIERS & FEIST, 1991. CI 181. Avesnelles Formation. IRScNB n° b4153. Carapace. a. Right lateral view. b. Dorsal view. x100.
 Fig. 3 — *Acratia bidecliva* LETHIERS & FEIST, 1991. CI 18. Epinette/Etroeungt transition. IRScNB n° b4154. Carapace. a. Right lateral view. b. Dorsal view. x87.5.
 Fig. 4 — *Acratia* aff. *sagittaeformis* LETHIERS & CASIER, 1999. CI 225. Hastière Formation. IRScNB n° b4155. Broken carapace. a. Right lateral view. b. Dorsal view. x70.
 Fig. 5 — *Acratia* cf. *cooperi* GRÜNDEL, 1962. CI 154. Avesnelles Formation. IRScNB n° b4156. Right lateral view of a corroded carapace. x80.
 Fig. 6 — *Acratia* sp. A, aff. *rostrata* ZANINA, 1956. CI 113. Etroeungt Formation. IRScNB n° b4157. Carapace. a. Right lateral view. b. Dorsal view. x125.
 Fig. 7 — *Bairdia* (*Bairdia*) *feliumgibba* BECKER, 1982. CI 237. Hastière Formation. IRScNB n° b4158. Carapace. a. Right lateral view. b. Dorsal view. x60.
 Fig. 8 — *Bairdia* (*Bairdia*) sp. B, aff. *feliumgibba* BECKER, 1982. CI 114. Etroeungt Formation. IRScNB n° b4159. Carapace. a. Right lateral view. b. Dorsal view. x60.
 Fig. 9 — *Bairdia* (*Bairdia*) sp. B BLUMENSTENGEL, 1979. CI 176. Avesnelles Formation. IRScNB n° b4160. Carapace. a. Right lateral view. b. Dorsal view. x50.
 Fig. 10 — *Bairdia* (*Bairdia*) sp. C. CI 225. Hastière Formation. IRScNB n° b4161. Carapace. a. Right lateral view. b. Dorsal view. x80.
 Fig. 11 — *Bairdia* (*Bairdia*) *hypselae* ROME, 1971 emend LETHIERS, 1975. CI 18. Epinette/Etroeungt transition. IRScNB n° b4162. Carapace. a. Right lateral view. b. Dorsal view. x40.
 Fig. 12 — *Bairdia* (*Rectobairdia*) *fusifformis* ROME, 1971. CI 216. Hastière Formation. IRScNB n° b4163. Carapace. a. Right lateral view. b. Dorsal view. x60.

PLATE 5

- Fig. 1 — *Bairdia (Rectobairdia)* sp. 120 BECKER & BLESS, 1974. CI 18. Epinette/Etroeungt transition. IRScNB n° b4164. Carapace. a. Right lateral view. b. Dorsal view. x70.
- Fig. 2 — *Bairdia (Rectobairdia) venterba* GRÜNDEL, 1961. CI 114. Etroeungt Formation. IRScNB n° b4165. Right lateral view of a broken carapace. x67.5.
- Fig. 3 — *Bairdia (Rectobairdia) cf. plebeja* REUSS, 1854. CI 237. Hastière Formation. IRScNB n° b4166. Right lateral view of a carapace. x60.
- Fig. 4 — *Bairdia (Rectobairdia) extenuata* NAZAROVA, 1951. CI 157. Avesnelles Formation. IRScNB n° b4167. Carapace. a. Right lateral view. b. Dorsal view. x90.
- Fig. 5 — *Bairdia (Orthobairdia?) romei* LETHIERS, 1974. CI 142. Etroeungt Formation. IRScNB n° b4168. Carapace. a. Right lateral view. b. Dorsal view. x60.
- Fig. 6 — *Bohlenatia?* sp. A. CI 225. Hastière Formation. IRScNB n° b4169. Carapace. a. Right lateral view. b. Dorsal view. x80.
- Fig. 7 — *Bairdianella* sp. A, aff. *cuspis* BUSCHMINA, 1970. CI 226. Hastière Formation. IRScNB n° b4170. Right lateral view of a carapace. x80.
- Fig. 8 — *Bairdianella* sp. A, aff. *cuspis* BUSCHMINA, 1970. CI 225. Hastière Formation. IRScNB n° b4171. Dorsal view of a carapace. x100.
- Fig. 9 — *Bairdiacypris robusta* KUMMEROW, 1939. CI 226. Hastière Formation. IRScNB n° b4172. Carapace. a. Right lateral view. b. Dorsal view. x50.
- Fig. 10 — *Bairdiacypris* sp. A, aff. *robusta* KUMMEROW, 1939. CI 216. Hastière Formation. IRScNB n° b4173. Carapace. a. Right lateral view. b. Dorsal view. x80.
- Fig. 11 — *Bairdiacypris cf. quasielongata* BUSCHMINA, 1968. CI 13. Epinette Formation. IRScNB n° b4174. Carapace. a. Right lateral view. b. Dorsal view. x90.
- Fig. 12 — *Bairdiacypris* sp. B, aff. *nanbiancunensis* (WANG, 1988) in CASIER & LETHIERS, 2002. CI 18. Epinette/Etroeungt transition. IRScNB n° b4175. Carapace. a. Right lateral view. b. Dorsal view. x70.
- Fig. 13 — *Bairdiacypris* sp. C. CI 152. Avesnelles Formation. IRScNB n° b4176. Carapace. a. Right lateral view. b. Dorsal view. x97.5.
- Fig. 14 — *Cryptophyllus* sp. A, aff. *cordiformis* ROME & GOREUX, 1964. CI 152. Avesnelles Formation. IRScNB n° b4177. Broken valve. x55.
- Fig. 15 — *Cryptophyllus* sp. B, aff. *inflatus* ROME & GOREUX, 1964. CI 142. Etroeungt Formation. IRScNB n° b4178. Broken valve. x80.

PLATE 6

- Fig. 1 — Blackish spiculitic mudstone. The micrite matrix is slightly recrystallized in a very fine-grained calcite microspar. Presence of a few sponge spicules, microbivalves and fine-grained black fragments of organic matter. Préal n° C1201/417, sample CI 201, microfacies 1, level 7, Avesnelles Formation, scale bar = 390 µm.
- Figs. 2, 3 — Heavily burrowed clayey silty wackestone with crinoidal fragments and small-sized organic matter debris. Presence of a lighter fine-grained calcite microspar in the burrows (upper part of Fig. 2) and well-defined burrows (all parts of Fig. 3). Fragments are displaced by the bioturbation processes. Préal n° C13/28 (Fig. 2) and C13/30 (Fig. 3), sample CI 3, microfacies 1, level 1, Epinette Formation, scale bar = 950 µm (Fig. 2) and 155 µm (Fig. 3).
- Fig. 4 — Clayey silty wackestone with millimetric-sized crinoidal lenses due to bioturbation (see text). Fragments of bryozoans, ostracods and issinellids are also present in the lenses. Préal n° C12/9, sample CI 2, microfacies 2, level 1, Epinette Formation, scale bar = 950 µm.
- Fig. 5 — Bioclastic (mollusks, paleosiphonoclad algae, crinoids) wackestone layer in a clayey silty mudstone. The bioclastic layer is interpreted as a distal tempestite (see text). Préal n° C174/211, sample CI 74, microfacies 2, level 4, middle Etroeungt Formation, scale bar = 390 µm.
- Fig. 6 — Clayey silty wackestone with reworked crinoid fragments in a bioturbation area. This latter shows a very fine-grained greyish calcite microspar. Préal n° C12/11, sample CI 2, microfacies 2, level 1, Epinette Formation, scale bar = 390 µm.
- Fig. 7 — Microsparitized bioclastic (ostracods, paleosiphonoclad algae and crinoids) wackestone-packstone layer in a clayey wackestone. Very small foraminifers (see blackish bioclasts appearing as "peloids") are present in the layer. Préal n° C113/71, sample CI 13, microfacies 3, level 1, Epinette Formation, scale bar = 390 µm.
- Fig. 8 — Lower part of a thick (centimetric) bioclastic (gastropod in the lower right corner, crinoids, small issinellids as tiny regular circles) packstone layer (upper part of the photograph) in a clayey silty wackestone (lower part of the photograph). Préal n° C136/132, sample CI 36, microfacies 3, level 2, Epinette/Etroeungt transition, scale bar = 390 µm.

PLATE 7

- Fig. 1 — Bioclastic (crinoidal and paleosiphonoclad fragments) packstone centimetric (up to 2 cm) layer in a clayey mudstone rich in very small fragments of organic matter (not visible here). The bioclastic layers interpreted as a proximal tempestite (see text) display oblique stratification and gradation (three sublevels are partly visible). The base of the photograph is the stratigraphical base. Préat n° C170/202, sample CI 70, microfacies 4, level 4, middle Etroeungt Formation, scale bar = 950 μm .
- Fig. 2 — Bioclastic (crinoids, bryozoans, ostracods, foraminifers) packstone-grainstone layer (up to 1,5 cm thick) in a homogenous clayey mudstone (not visible here). Préat n° C137/143, sample CI 37, microfacies 4, level 2, Epinette/Etroeungt transition, scale bar = 390 μm .
- Figs. 3, 4 — Bioclastic (paleosiphonoclad algae, echinoderms, brachiopods and ostracods)(bafflestone)-packstone. The millimetric laminae (Fig. 4) are partly bioturbated (Fig. 3). Préat n° C1225/323 and 322, sample CI 225, microfacies 5, level 9, Hastière Formation, scale bar = 390 μm .
- Fig. 5 — Crinoidal and algal (small kamaenids) packstone. The crinoids are partly altered showing pitting. Pressure solution seams are well developed. Préat n° C157/177, sample CI 57, microfacies 5, level 3, Etroeungt Formation, scale bar = 950 μm .
- Fig. 6 — Medium-grained crinoidal foraminiferal grainstone. Cement is syntaxial around crinoidal fragments. Préat n° C1127/469, sample CI 127, microfacies 6, level 5, Etroeungt Formation, scale bar = 390 μm .
- Fig. 7 — Oolitic recrystallized packstone. Oolites are partly or totally micritized and cemented by a very fine bladed calcite phase. An echinoderm fragment is present and partly micritized. Matrix is strongly recrystallized in a homogeneous medium-grained calcite microspar. Préat n° C1221/341, sample CI 221, microfacies 7, level 8, Hastière Formation, scale bar = 155 μm .
- Fig. 8 — Microconglomeratic packstone-grainstone with a centimetric peloidal grainstone microbreccia (only part is visible) and various subangular to subrounded lumps. Micrite matrix strongly recrystallized in a homogeneous medium-grained calcite microspar and remaining voids filled with a syntaxial calcite cement. Préat n° C1217/345, sample CI 217, microfacies 7, level 8, Hastière Formation, scale bar = 950 μm .

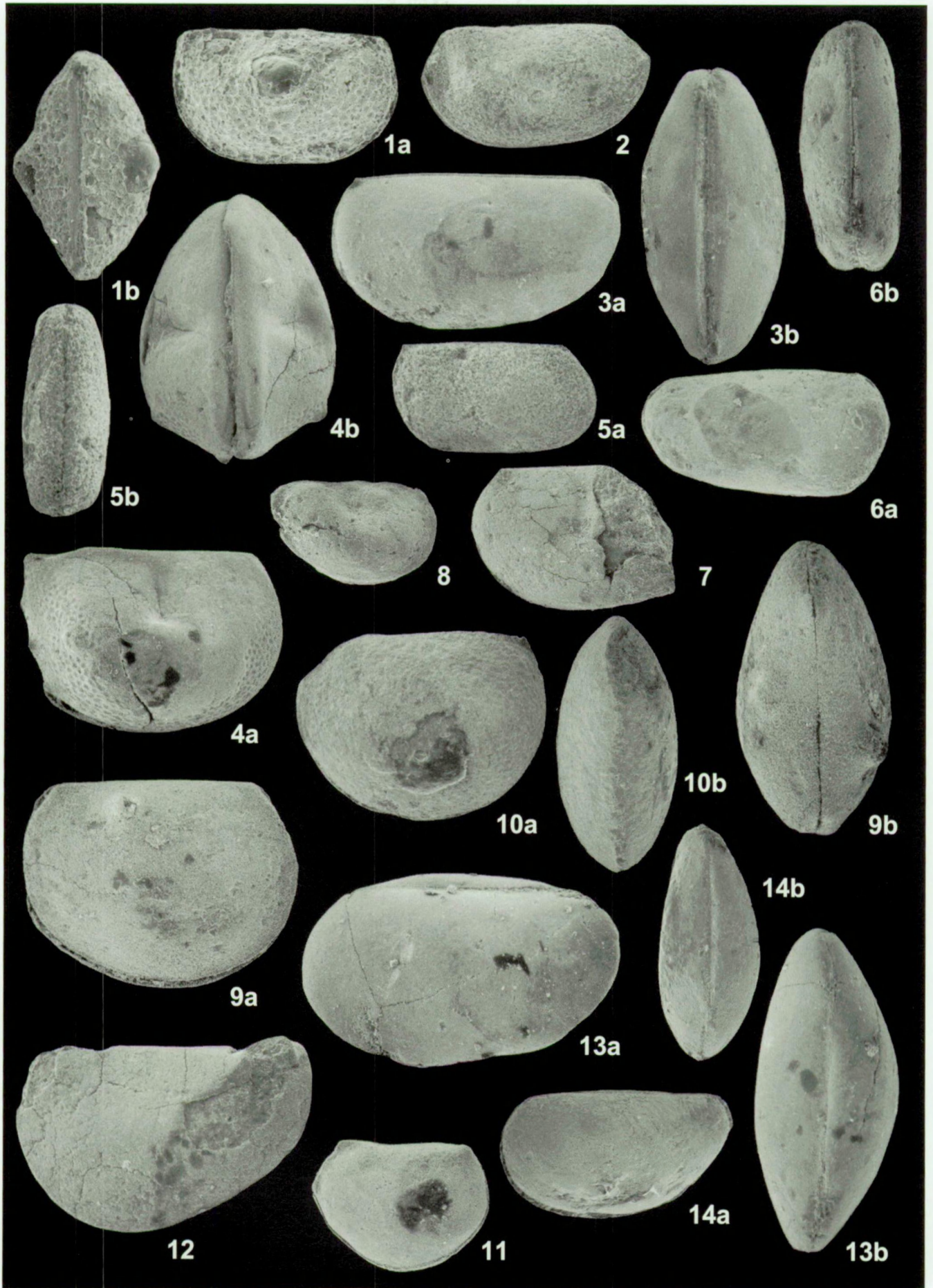


PLATE I

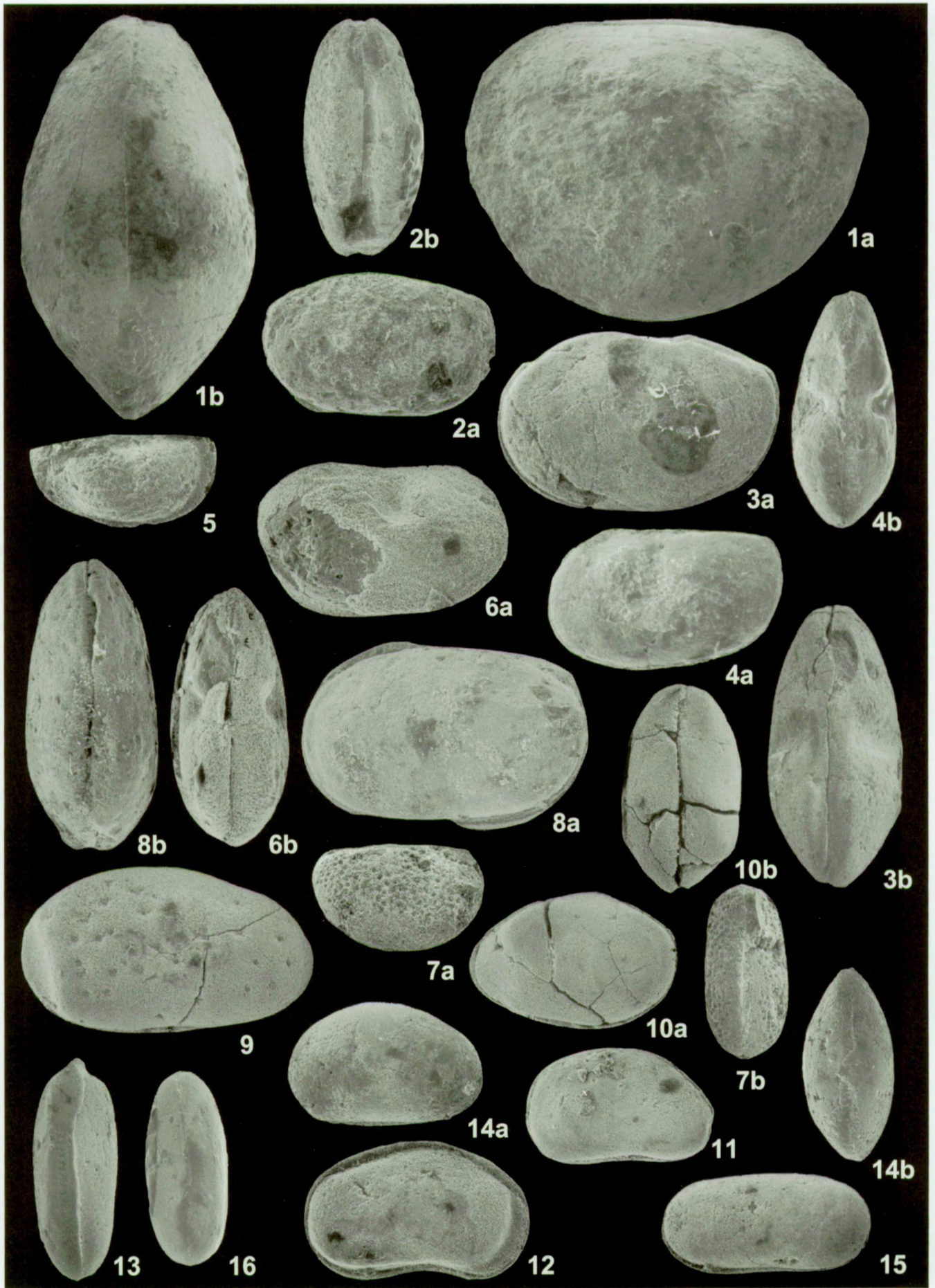


PLATE 2

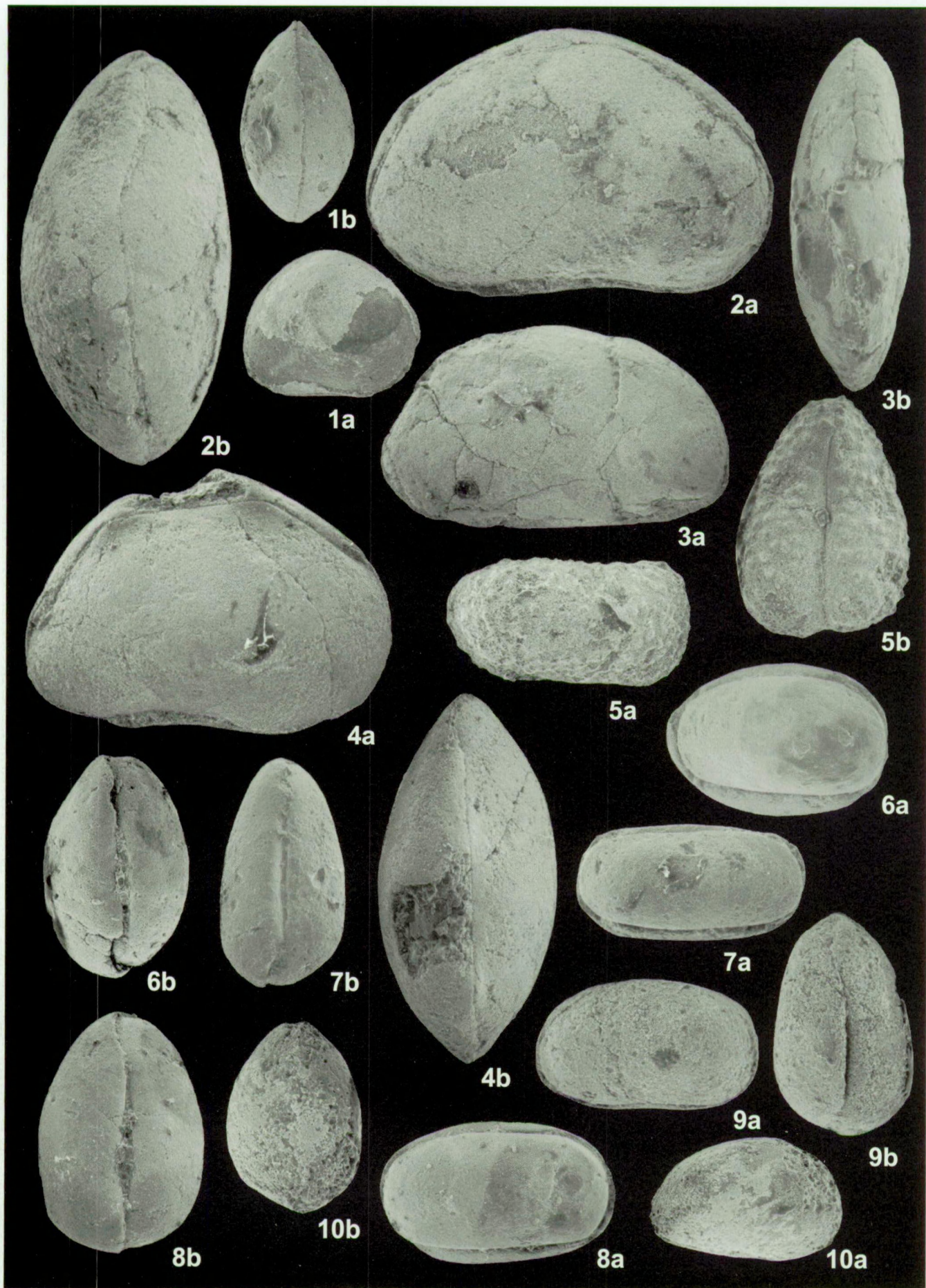


PLATE 3

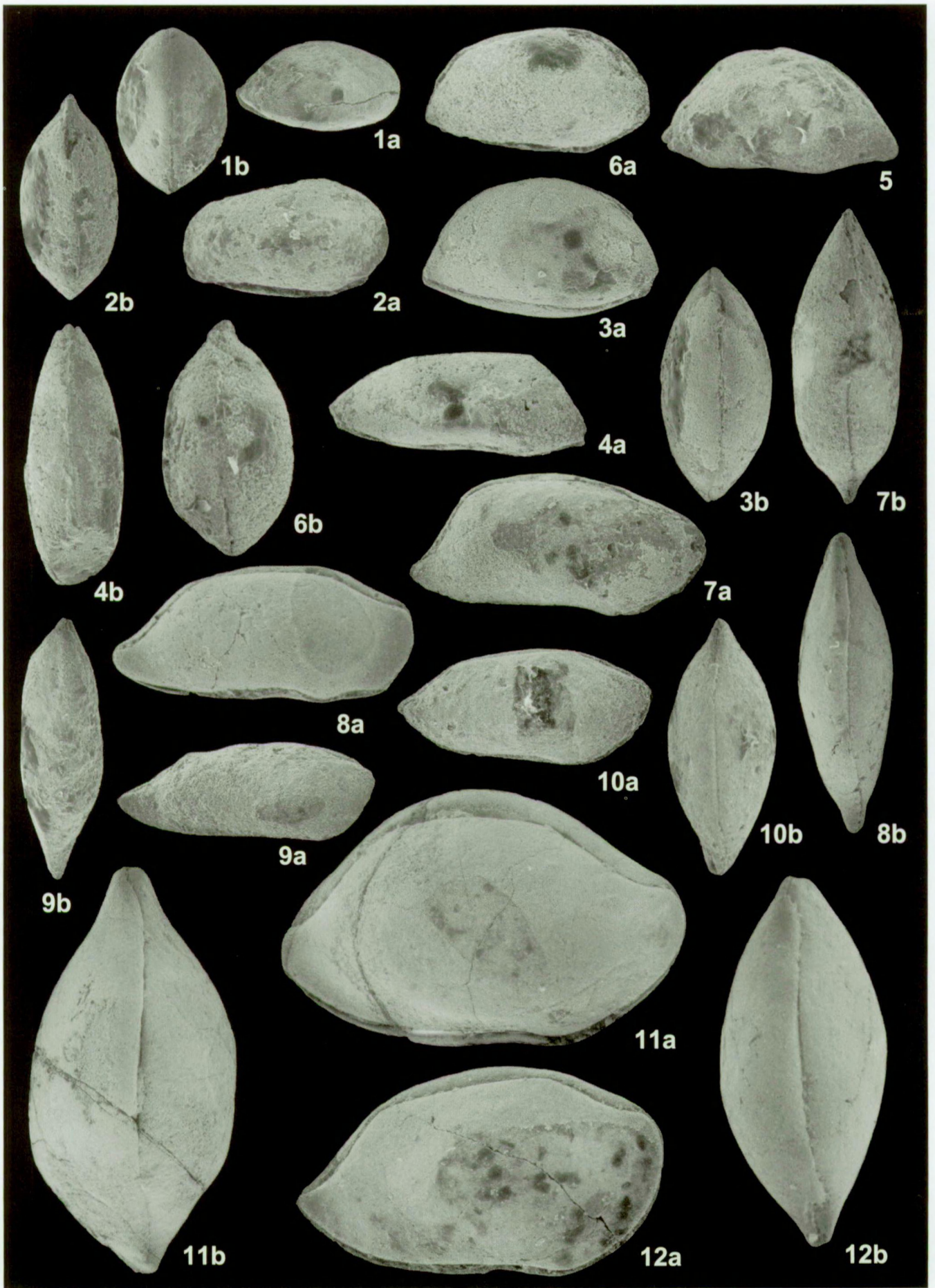


PLATE 4

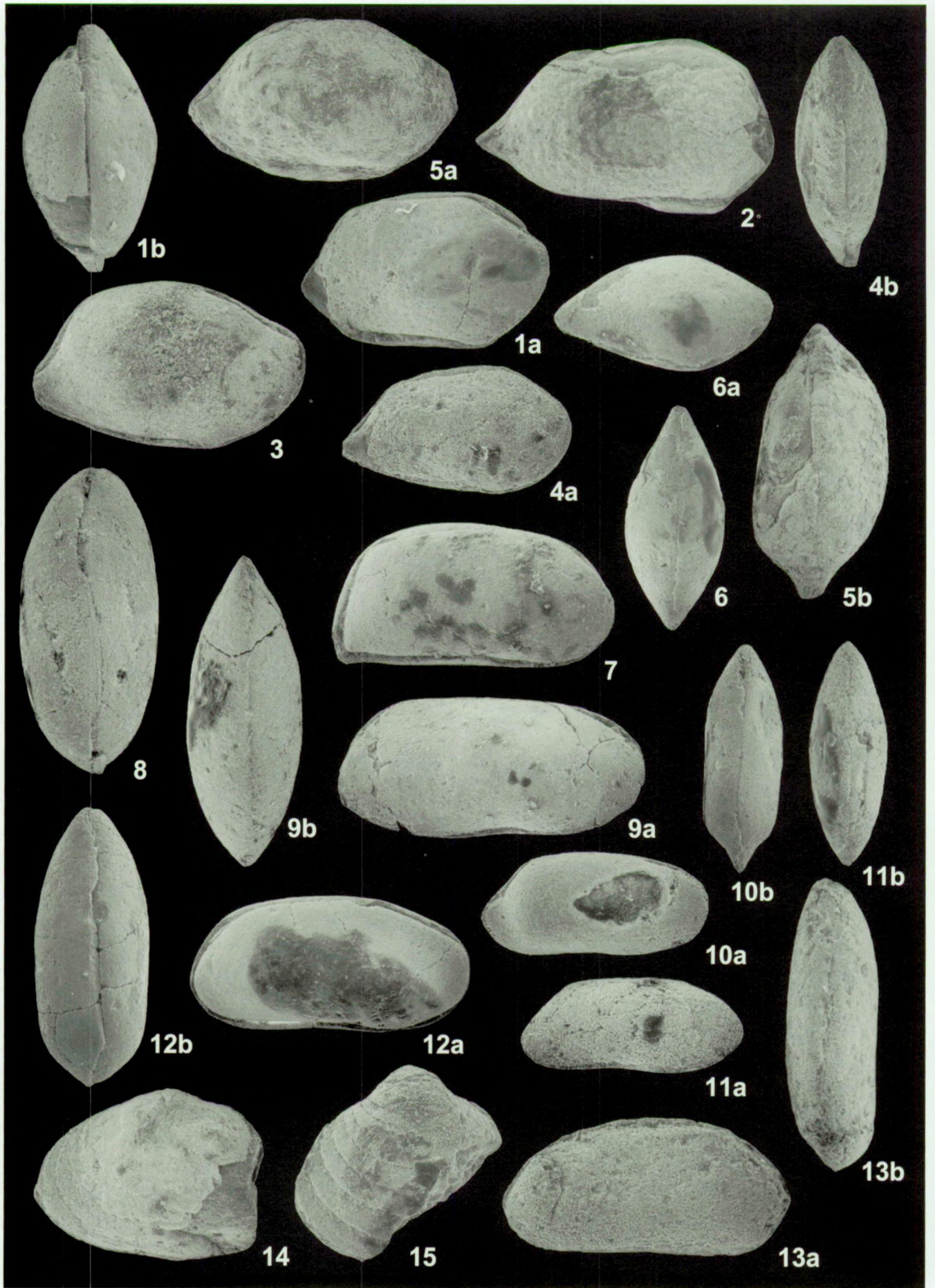


PLATE 5

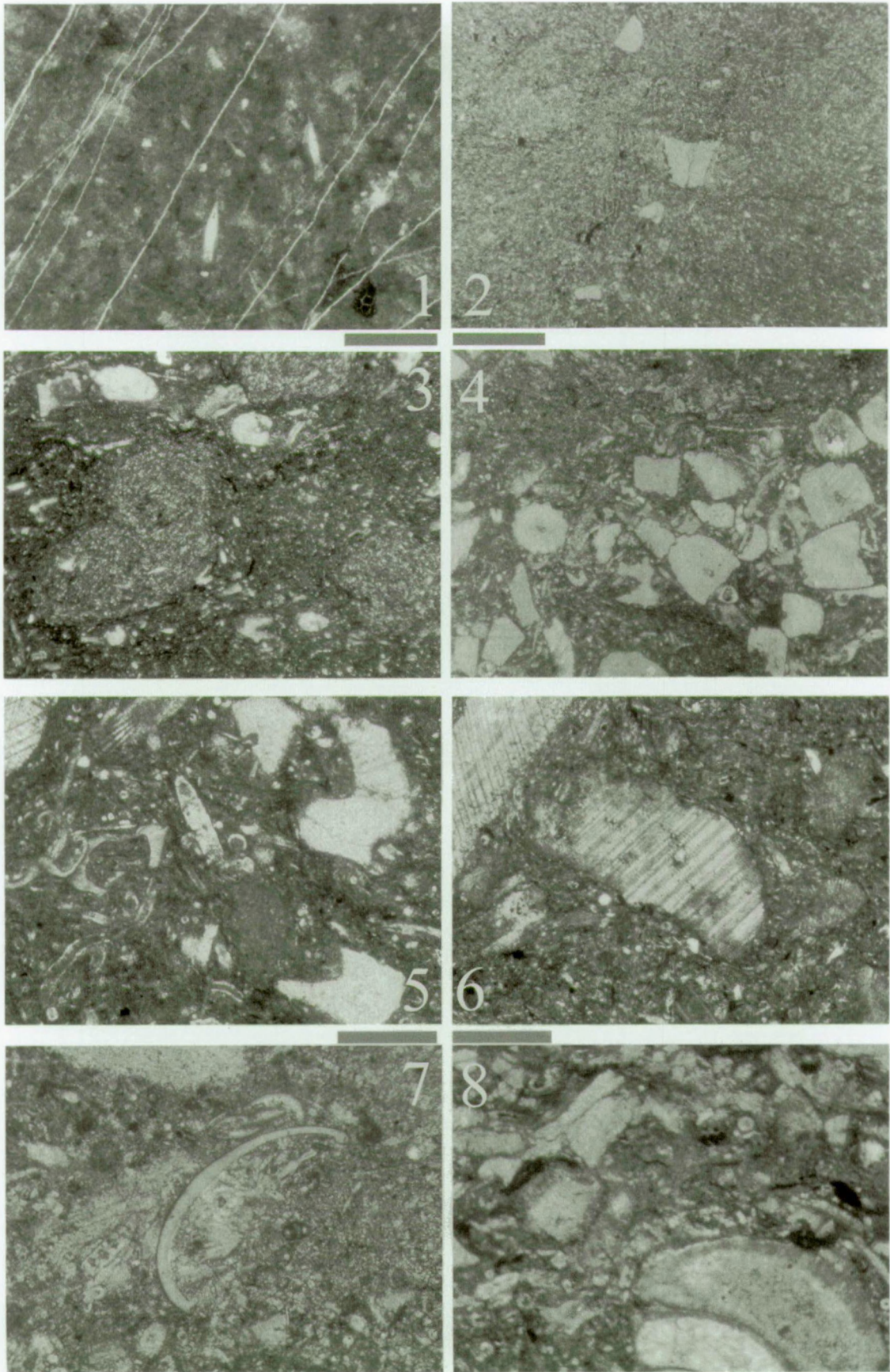


PLATE 6

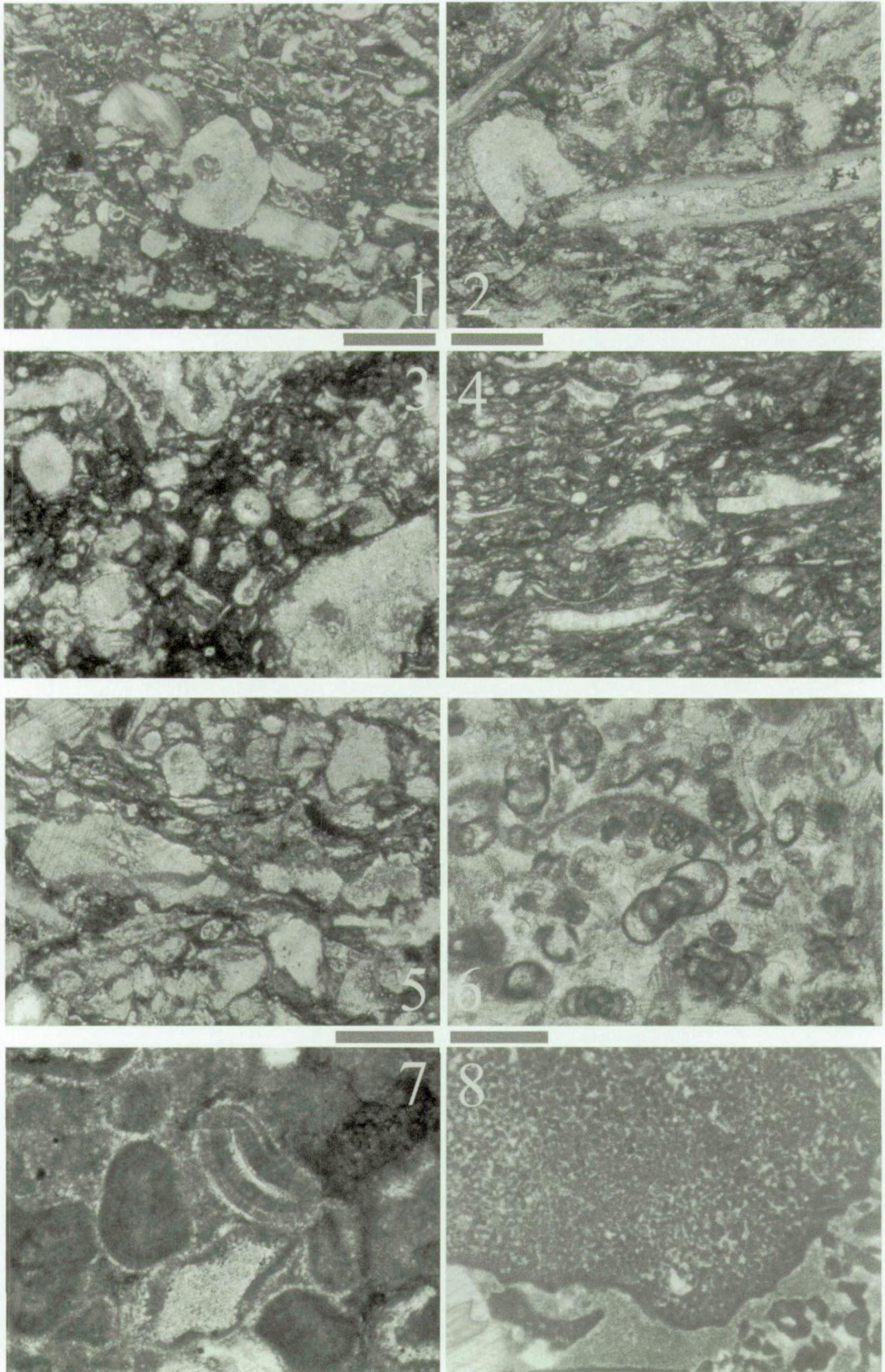


PLATE 7

