

IVORIAN

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(7 figures)

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ABSTRACT. The Ivorian Substage is the upper division of the Tournaisian. Its base, emended in this paper, corresponds to the first appearance of the conodont *Polygnathus communis carina* in the Yvoir railway station section. Its top is defined by the base of the Moliniacian Substage which corresponds now to the base of the Viséan. The Ivorian is characterized by a rich and diversified conodont fauna throughout and by a diversification of the foraminifers in its upper part. It is therefore very well zoned and precisely correlated across the Franco-Belgian Basin and beyond. Its upper boundary is marked by a drastic reduction of the conodont fauna and the disappearance of selected Tournaisian foraminiferal taxa. Ivorian sedimentation reflects the evolution of the Namur-Dinant Basin from a homoclinal ramp in the early Tournaisian to a broad shelf of regional extent in the late Tournaisian. Waulsortian buildups started growing in the distal part of the ramp during early Ivorian and formed a discontinuous barrier over the southwestern part of the Dinant Sedimentation Area. Distal peri-Waulsortian facies are dominated by cherty crinoidal wacke- to packstones, thick-bedded crinoidal packstones, grainstones and dolostones. An oolitic grainstone, the Avins Mbr of the Longpré Fm, caps the Ivorian succession in the inner shelf. Proximal peri-Waulsortian facies are cherty crinoidal wacke- to packstones and purplish blue, poorly fossiliferous wacke- to packstones.

KEYWORDS: Ivorian, Upper Tournaisian, Belgium, Lithostratigraphy, Biostratigraphy, Sequence Stratigraphy, Palaeogeography.

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1. Name

Ivorian (English), Ivoriaan (Dutch), Ivorium (German), Ivorien (French).

2. Age

The Ivorian substage lasted about 6 Ma – 348 Ma to 342–342.5 Ma – according to Menning *et al.* (2000, 2001), but the age of the base of the Viséan (on top of the Ivorian) is placed at 345.3 +/- 2.1 Ma in the Geological Time Scale of Gradstein *et al.* (2004). These dates should be taken with caution, however, as data are scarce and poorly constrained biostratigraphically.

3. Authors

Conil *et al.*, 1977, p. 368 and tab. 1. « L'Ivorien commence à 0,45 m au-dessus de la base du Calcaire d'Yvoir. La coupe de la gare d'Yvoir, située vis-à-vis de la coupe de la route, sur l'autre rive, offre un parfait parallélisme dans tous les détails sédimentaires. »
Emend, this paper.

4. Historical type area

The name of the substage is derived from the village of Yvoir, on the right bank of the Meuse River, between Namur and Dinant, in the Dinant Sedimentation Area (S.A.) (Fig. 1 ; Hance *et al.*, 2001). The Ivorian succession is very well exposed on both banks of the river (Fig. 2). The stratotype of the substage emend is the section exposed in the abandoned quarries located immediately south of the Yvoir railway station.

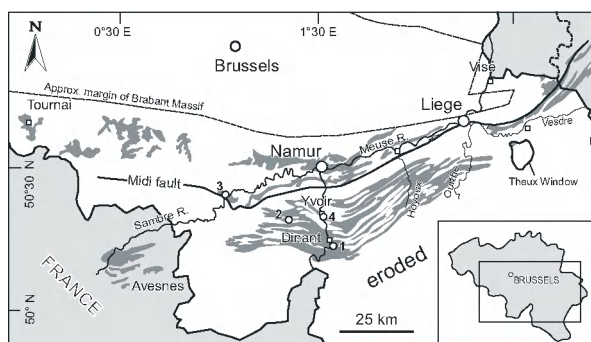


Figure 1. Location of Ivorian sections mentioned in the text. 1. Bayard; 2. Denée drillhole; 3. Landelies; 4. Yvoir. The shaded areas represent Lower Carboniferous outcrops.

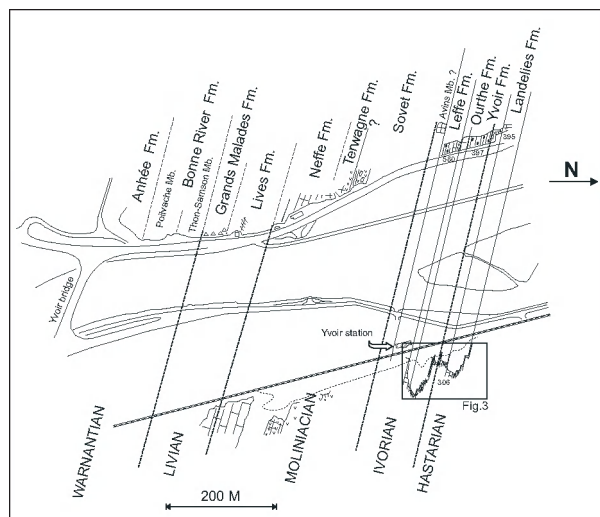


Figure 2. Lithostratigraphy of the Ivorian stratotype in the Yvoir railway station section on the right bank of the Meuse River and correlation with the section on the left bank of the river.

5. Historical background

The Tournaisian at Yvoir has been extensively studied for more than a century. Dupont (1882–1883) introduced the term “Calcaire d’Yvoir” as upper subdivision of his “Assise des Ecaussines”. Conil (1960, 1968) gave a detailed description of the railway station section (Fig. 3). Groessens (1973, 1975) published the conodont distribution from sections on both sides of the Meuse River, and precisely located the last occurrence of the siphonodellids and the first appearance of *Polygnathus communis carina*. The quality of the exposure and the detailed conodont data led Conil *et al.* (1977) to define an Upper Tournaisian Ivorian substage at Yvoir, along the Dinant road, on the left bank of the Meuse, 800 m downstream from the Yvoir bridge. They placed the base of the Ivorian at the bottom of a 75 cm thick calcareous shale (bed 134) overlying the first cherty bed of the Yvoir Fm, which yields the last *Siphonodella*. *Polygnathus communis carina* enters 2.3 m above the boundary (bed 140; Groessens, 1975)

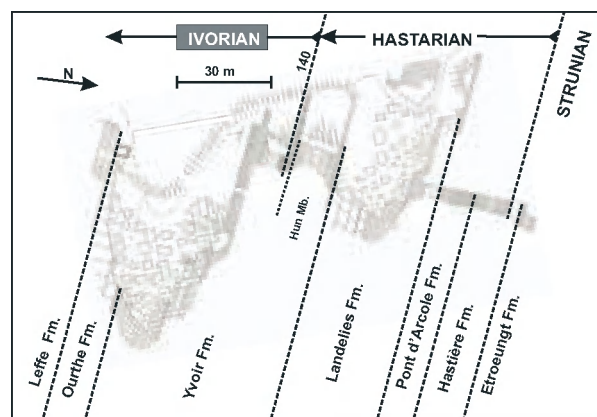


Figure 3. Stratigraphy of the Ivorian lectostratotype (after Conil, 1960).

Paproth *et al.* (1983) include in the boundary stratotype the abandoned quarries just south of the Yvoir railway station, which offer good exposures on the right bank of the Meuse River.

The lithological criterion proposed by Conil *et al.* (1977), although useful locally, is unsatisfactory for a chronostratigraphic boundary as it does not correspond to a recognizable biostratigraphical level. We propose here to relocate the base of the Ivorian to the base of bed 140 in the railway station section where *Polygnathus communis carina* enters (Groessens, 1975). The upper boundary of the Ivorian is constrained by the first appearance of the foraminifer *Eoparastaffella simplex* at the base of the overlying Moliniacian in the Salet road section (Devuyt *et al.*, this volume). The beds below *E. simplex*, corresponding to the Cf4α1 Zone of Conil *et al.* (1991) and originally assigned to the Moliniacian, are now put in the Ivorian.

6. Description

In the type area, the substage encompasses from bottom to top :

- 40 m: the Yvoir Fm (sensu Poty *et al.*, 2002), except its lower Hun Mbr and the first 3 m of the upper member (Yvoir s.s.; Fig. 3) Dominant facies are dark limestones (mainly packstones) with thin crinoidal and shelly layers. Chert nodules are abundant at 5 levels. A 6 m thick argillaceous unit is included in the lower part of the upper member.
- 15.65 m: the Ourthe Fm consisting of crinoidal rudstones (= Formation du Petit-Granit du Bayard in Groessens, 1973).
- 35 m: the Leffe Fm and its transition to the Sovet Fm (± 35 m).

The lithological column of the Ivorian lectostratotype is given in figures 5–6. For more detailed descriptions, see Conil (1960, 1968) and Groessens (1973, 1975).

7. Lithology

The lithology of the lectostratotype is shown in figure 6 along with its correlation to the holostratotype and other reference sections. In the Ourthe and Hoyoux valleys (Condroz S.A.), the Ivorian succession is respectively 213 and 240 m thick, distributed between the thin-bedded cherty crinoidal packstones of the Yvoir Fm, except its partly dolomitic Hastarian lower part, respectively 57 and 49 m thick, the crinoidal thick-bedded rudstones of the Ourthe Fm (40 and 29 m), the thin-bedded cherty crinoidal packstones of the Martinrive Fm (38 and 27 m) and crinoidal dolostones (Flémalle Mbr) and oolitic grainstone (Avins Mbr) of the Longpré Fm (78 and 135 m). The last two formations are laterally equivalent of the Leffe Fm, consisting of well stratified, purplish-blue wacke- to packstones, generally including cherts

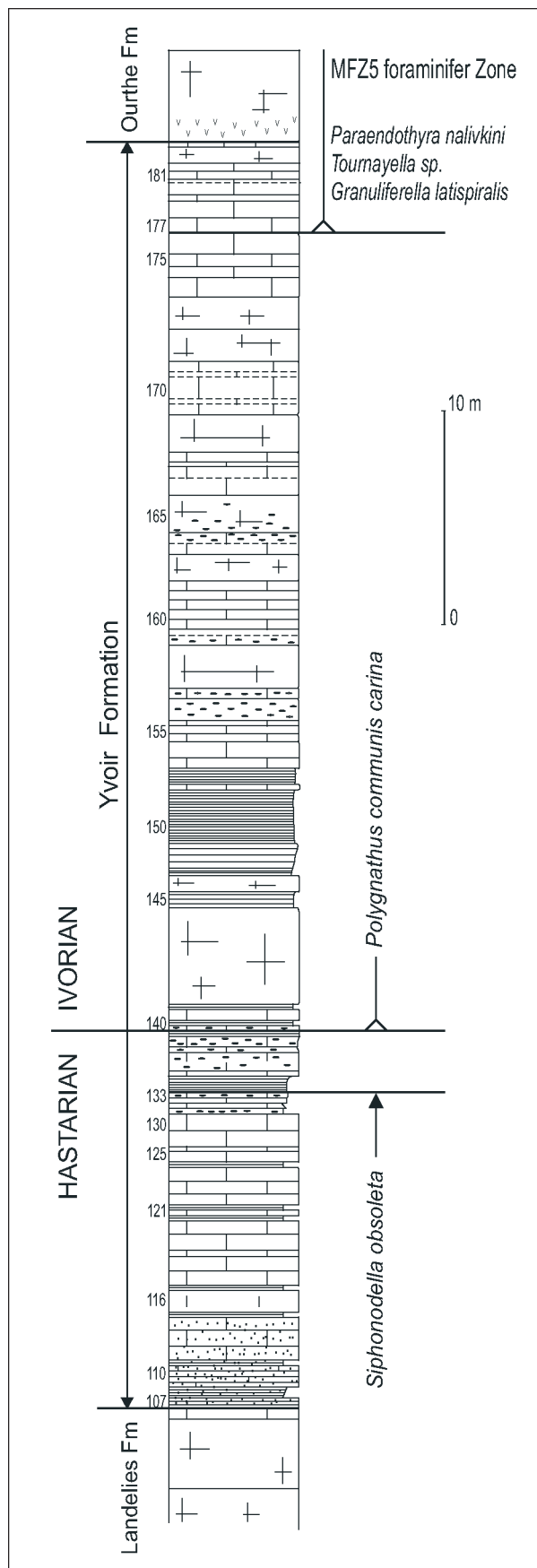


Figure 4. Lithological column of the Ivorian at the Yvoir railway station section (modified from Groessens (1973)).



Figure 5. Base of the Ivorian in the lectostratotype, Yvoir railway station section.

nodules and poorly fossiliferous. In the southern part of the Dinant S.A., the Ivorian starts with the Bayard Fm, overlain by the thick Waulsortian sequence (locally more than 300 m thick).

In the western part of the Namur S.A., the Yvoir Fm and overlying Ourthe and Martinrive Fms are not found. The succession there starts with the crinoidal dolostones of the upper member of the Engihoul Fm (15 m) followed by the crinoidal rudstones and oolitic limestones of the Longpré Fm (30 m).

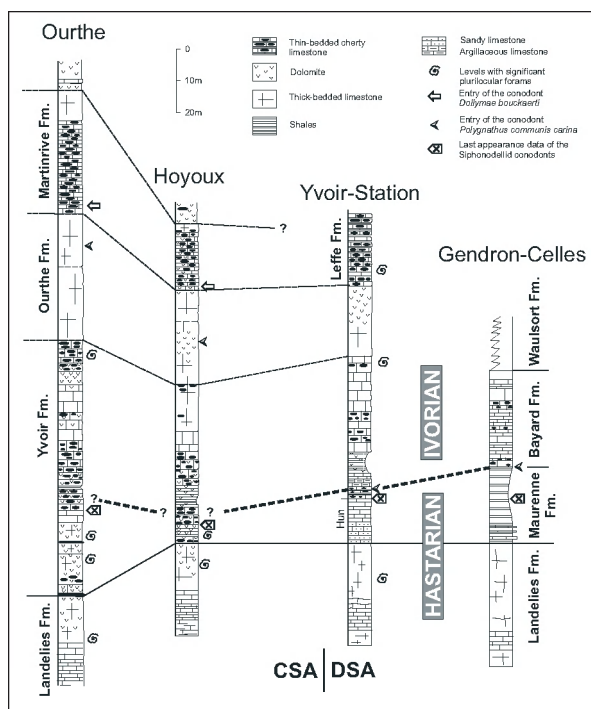


Figure 6. Correlation of the Ivorian succession between the Condroz S.A. and the Dinant S.A.

In the Avesnois South S.A., the succession starts with the crinoidal dolostones of the Grives Fm (107 m) unconformably resting on the Landelies Fm. The oolitic grainstones of the Godin Fm (68 m) marks the end of the Ivorian (Mansy *et al.*, 1989).

In the Saint-Ghislain borehole (Hainaut S.A.; Groessens *et al.*, 1982), the position of the top of the Ivorian is uncertain and included between a depth of 2851 m, where the first undoubted Viséan foraminifer association is found, and a depth of 2927 where the conodont *Scaliognathus anchoralis europensis* was recorded. Its base is at 4002 m just above black shales which yield the last siphonodellid conodonts. Correcting for an average dip of 15°, the thickness of the substage ranges between 1038 and 1112 m.

8. Sedimentology and palaeogeography

During the Ivorian, the basin architecture evolved from a ramp setting, prevailing since the latest Devonian, to a shelf (Hance *et al.*, 2001). Inner ramp/shelf facies occurred in the Namur-Condroz S.A. and in the Avesnes South S.A. in northern France (Fig. 2) whereas outer ramp/shelf facies were restricted to the Dinant S.A. and bordered to the south by a discontinuous barrier of Waulsortian buildups. The slope break separating the inner and outer shelf facies prograded southward and reached the Ciney-Yvoir area during the earliest Viséan (Hance *et al.*, 2001). The Ivorian succession comprises the third-order sequences 3 (except its lowermost part which belongs to the Hastarian), sequence 4 and the first meters of sequence 5 of Hance *et al.* (2001).

9. Palaeontology

9.1. Foraminifers

The Ivorian correlates with zones MFZ5 to MFZ8 (Devuyt & Hance, in Poty *et al.*, in press) (Fig. 7). The Yvoir and Ourthe Fms and their lateral Waulsortian equivalents are almost devoid of plurilocular foraminifers, except for isolated occurrences in the upper part of the Yvoir Fm where the MFZ5 Zone (= Cf2 of Conil *et al.*, 1991) is identified. The late Ivorian Longpré Fm and top Waulsortian lateral equivalent are characterized by a progressively richer fauna with some diagnostic elements (MFZ6–MFZ8 = Cf3–Cf4α1 of Conil *et al.*, 1991) but dolomitization hampers detailed correlations. The basinal equivalent, the Leffe Fm, has an impoverished foraminiferal association but a few tempestites bring shallow-water elements into the basin in the latest Ivorian (Lees, 1997; Poty *et al.*, in press).

9.2. Conodonts

The Ivorian is characterized by a rich conodont fauna. It correlates with conodont zones CC2 (*Polygnathus*

communis carina), CC3 (*Scaliognathus anchoralis*) and the lower part of CC4 (*Mestognathus praebeckmanni* Subzone) (Groessens in Conil *et al.*, 1991). The *M. praebeckmanni* Subzone has only local value as the index taxon is reported from the Upper *G. typicus* Zone in Moravia (= upper part of CC2 Zone; Kalvoda, 2002).

9.3. Rugose corals

The base of the Substage corresponds approximately to the base of the RC3 Coral Zone of Poty (1985; in Conil *et al.*, 1991) and its top to the RC4β1 – RC4β2 boundary (Fig. 7; Poty in Poty *et al.*, in press). Corals are common in relatively shallow-water facies (Yvoir Fm, Ourthe Fm, Martinrive Fm and Longpré Fm in the CSA) but are very rare in the deeper-water facies (Leffe Fm). The Waulsortian facies yields almost exclusively numerous representatives of the genus *Amplexus* which has no stratigraphical value.

9.4. Other fossils

Macrofossils are abundant in the Ivorian, including mainly the crinoids, brachiopods, and bryozoans. Associations are more diverse in the Yvoir Fm than in the underlying Hastarian Landelies and overlying Ourthe Fms (Conil, 1960).

The productid brachiopod *Levitusia humerosa* was previously considered as a guide for the early Viséan (see synthesis in Brunton, 1979), as it occurs in the oolitic facies of the Avins Mbr (upper part of the V1a in the old Belgian terminology). This unit is now assigned to the late Ivorian by Hance *et al.* (2001).

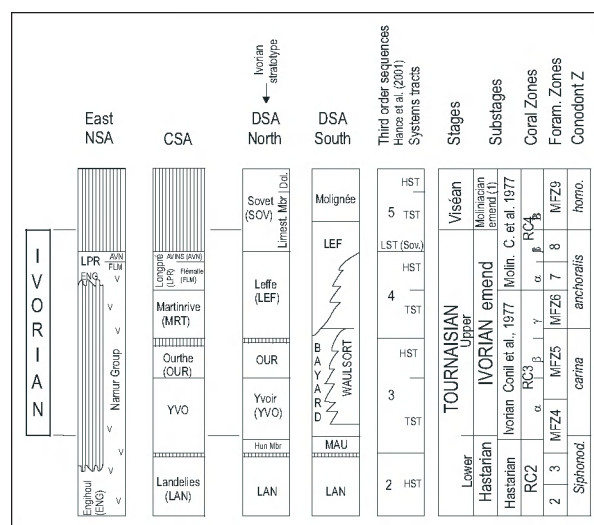


Figure 7. Stratigraphy of the Ivorian Substage in southern Belgium. (1) in Hance *et al.*, in press. LST, lowstand systems tract; TST, transgressive systems tract; HST, highstand systems tract; FSST, falling stage systems tracts (sensu Plint & Nummedal, 2000).

10. Chronostratigraphy

Figure 7 gives the main chronostratigraphic elements. More details about the stratigraphical correlations outside Western Europe are given in Poty *et al.* (in press).

11. Geochronology

There is no radiometric date available for the Ivorian in Belgium. The only date available around the base of the Ivorian is from a tuff level in the Rußschiefer of Thuringia, Germany (352 $\pm$ 8 Ma) but the litho- and biostratigraphical control on its position is poor (Menning *et al.*, 2001). See Hance *et al.* (this volume) for a discussion of the dates available for the base of the Viséan (top Ivorian).

12. Structural environment

The type area is included in the Dinant "Synclitorium", included in the Ardennes Allochthon, and forms the northern flank of the Namurian "Anhée Syncline". The bedding is almost vertical (85° to the south). The succession is repeated by the Yvoir Fault, located a short distance north of the type section. This fault coincides with the boundary between the CSA and the DSA and might therefore be synsedimentary, reactivated during the Variscan Orogeny (Hance *et al.*, 2001).

13. Reference sections in Belgium

The Ivorian is documented by numerous sections including:

In the DSA: Yvoir, both banks of the River Meuse (Conil, 1960, 1968; Groessens, 1973, 1975); Dinant-Bayard (Groessens & Noël, 1977; Conil *et al.*, 1988.); Denée drillhole (Conil *et al.*, 1981).

In the CSA: Hoyoux and Ourthe Valleys (Groessens, 1975)

In the NSA: Landelies (Mamet *et al.*, 1970; Groessens, 1975; Groessens *et al.*, 1976)

14. Main contributions

Conil (1960), Conil *et al.* (1977), Groessens (1973, 1975), Paproth *et al.* (1983), Hance *et al.* (2001), Poty *et al.* (in press).

15. Remarks

Note that the succession between 2927 and 3653 m in the Saint-Ghislain well is characterized by a foraminiferal fauna belonging to the MFZ7-MFZ8 Zones of Devuyt

& Hance (in Poty *et al.*, in press) and is here assigned to the late Ivorian and not to the Moliniacian, as proposed by Groessens *et al.* (1982). The *Scaliognathus anchoralis* conodonts found at 2927m therefore do not need to be reworked (Groessens *et al.*, 1982) but are in agreement with a late Tournaisian age.

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