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Dinantian in Campine Basin

Introduction of new formal lithostratigraphic units for the Dinantian in the Campine Basin

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David Lagrou & Ben Laenen

Flemish Institute for Technological Research (VITO), Boeretang 200, BE-2400 Mol, Belgium, david.lagrou@vito.be

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During systematic lithostratigraphic description of the deep subsurface of the Campine basin (Northern Belgium) it was found that certain stratigraphic intervals in deep boreholes, already identified and described as separated units by different authors, are not yet formally named. As one of the goals of the detailed stratigraphic study was to put all data in the Flemish web-based 'Databank Ondergrond Vlaanderen' (DOV), codes for the different lithostratigraphic units were needed. To have an accordance between DOV and the Belgium official stratigraphy, the newly proposed lithostratigraphic are submitted to the National Commission of Stratigraphy.

In borehole Turnhout 80 m of partly karstified limestones (breccia) are present (old codes V3c-b), for which we propose the name **(1) Loenhout Formation** and have incorporated it in the 'Carboniferous Limestone Group'. This Formation is well-known because of its excellent reservoir properties (it is currently in use as underground gas storage). The underlying **(2) Velp Formation** consists of compact bioclastic limestones which can be up to 100 m in thickness. The rocks of the **(3) Steentje-Turnhout Formation** are mainly massive (light) grey limestones and dolomites, varying in thickness (10 m to 400 m), probably due to paleotopography and block faulting. The **(4) Kessel Formation** (about 80 m thick) is only found in 2 boreholes. For sedimentological reasons it is assumed that the Kessel Formation only occurs between the paleo shoreline of the London-Brabant Massif in the west and the open marine limestones and reefs of the Steentje-Turnhout Formation to the east.

In borehole Geverik-1 (the Netherlands), below the Souvré Formation, a 500 m thick sequence of grey to dark-grey and black limestones, known as the **(5) Goeree Formation** in the Dutch stratigraphy (Van Adrichem Boogaert & Kouwe, 1994) are found. Despite the fact that the Goeree Formation is not yet found in Belgian boreholes, the large thickness found in borehole Geverik-1 suggests the Goeree Formation should be present to the north of Visé.

The **(6) Bosscheveld Formation** is a transitional unit between the clastics from the Devonian Condroz Group and the carbonates of the Carboniferous Limestone Group. The upper part mainly consists of mudstones and limestones. The lower part is more sandy and often rich in micas. In this part soil roots and plant remains are found. In the Dutch stratigraphy (Van Adrichem Boogaert & Kouwe, 1994) the Bosscheveld Formation is described as an informal unit because of the limited amount of data available.

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References:

Bless et al., 1976; Lagrou & Laenen, 2012; Paproth et al., 1983; van Adrichem Boogaert & Kouwe, 1994

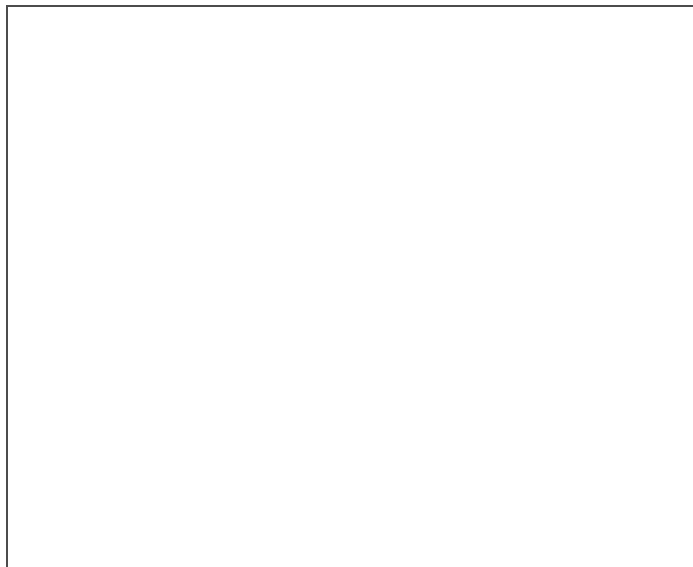


Figure 1: Lithostratigraphic correlation scheme for the Carboniferous in Flanders. (After Laenen 2003, modified by Lagrou, 2012)

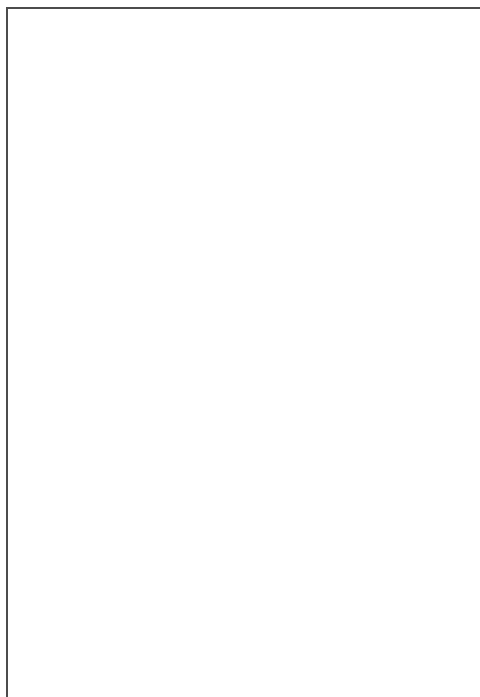


Figure 2: Legend of the lithostratigraphic logs corresponding to the stratotype boreholes of the newly introduced units. (From Laenen, 2003)

1. Loenhout Formation

Authors:Laenen, 2003.

Description: Pale, fossil bearing mudstones, bio- and lithoclastic wacke- to grainstones and boundstones. Locally thin, dark, clayey layers are present/are found. Four facies types are distinguished:

- 1- Fossil rich mud-, wacke- and boundstones, interpreted as reefs and locally alternating with peritidal limestones. The boundstones are found in the boreholes carried out around the gas storage site of Loenhout and in borehole 030W371 (KB170 – Poederlee).
- 2- Massive, fossil poor limestones. The colour varies from van grey to dark grey – black. Locally certain levels are silicified. Monotonous fossil content and sedimentology indicate a closed depositional environment.
- 3- Mostly pale, thickly bedded, bioclastic (brachiopods and crinoids) limestones and crypto-algae microbeccia deposited in shallow, open marine environment.
- 4- Thick layers of carbonate conglomerates and breccias. Microfossils showing that part of lithoclasts are reworked from older Dinantian Formations (Ardunian), but the matrix points to Holkerian- to Warnantian age.

Stratotype: Borehole 007E178 (KB129, Loenhout, Heibaart 1/1bis), X 172.343, Y 231.025, Z 23.4 m, 1962-1963. Total depth 1638,65 m. Loenhout Formation: depth range 1141-1320 m.

Borehole Heibaart-1 was abandoned for mechanical reasons at 1277 m (loss of drilling mud in karstic top Visean limestones) and drilling was continued at Heibaart 1-bis, 40 m to the north from the first hole.

Parastratotype: borehole 076E243 (kb131, Halen): 633 - 984 m, borehole 017E225 (KB120, Turnhout Zwemdok): 2186.6 - 2273 m.

Area: Loenhout Formation is found in the largest part of the Campine Basin.

Thickness: In the stratotype borehole the total thickness of the Loenhout Formation is about 180 m. However, thickness varies considerably between boreholes. This is due to sedimentological differences (the presence or absence of reef structures), differential subsidence and the degree of post-Dinantian erosion.

Age: Early Brigantian to Holkerian (Foraminifera zones: Cf6γ to Cf5, coral zones: CR7β/RC8 to CR6). Old codes V3b-c.

References: Bless et al., 1976; Bless et al., 1981; Delmer, 1962; Graulich, 1975; Muechez & Langenaeker, 1993; Muechez & Peeters, 1987; Muechez et al., 1987a; Muechez et al., 1987b; Muechez et al., 1991; Pirlet, 1967; Van Tongeren & Pagnier, 1987.

Table 1: List of boreholes in which top and base of Loenhout Formation was drilled (in m). Stratotype borehole is underlined.

Borehole	Location	Date	Top	Base	Thickness	
KB120	017 ^E 225	Turnhout	1952	2186,6	2273	86,4
<u>KB129</u>	007 ^E 178	Loenhout (Heibaart)	1962	1140	1306	166
KB131	076 ^E 243	Halen	1962	632	984	352
S02-02	NL, off shore	1983	2128	2390	262	

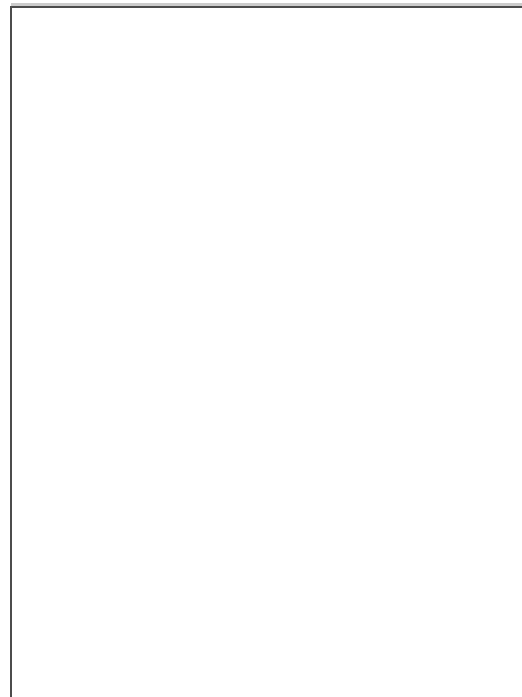


Figure 3: Litholog of Lower Carboniferous and Devonian sequence of borehole 007E178 (KB129, Heibaart 1/1bis), stratotype for the Loenhout Formation. (From Laenen, 2003)

2. Velp Formation

Authors: Laenen, 2003.

Description: Compact, bioclastic and pellet wacke- to grainstones. The colour varies from dark grey – black to light grey and brown grey. Locally clay rich levels occur. In the stratotype borehole the lowest 5 m consist of dark grey dolomites. Both in 076E243 (KB131, Halen) and in 059E146 (KB132, Booischoot) the Velp Formation can be subdivided in two sequences, separated by a clay rich zone below a breccias interval.

Stratotype: Borehole 076E243 (KB131, Halen Citrique), X 202.197, Y 181.886, Z 25 m, 1962. Velp Formation in depth range 984-1082 m. Named after the river Velp which flows through the village Halen, the location of the stratotype

borehole.

Thickness: In stratotype borehole KB131: 98m. The thickness of the Velp Formation varies significantly. Most probably because of erosion during Late Arundian and Holkerian. A maximum thickness of 131 m is found in borehole 059E146 (KB132, Booischot). In this borehole the Velp Formation has been eroded (angular unconformity) the Cretaceous. The Formation is cut by brecciated limestones of the Loenhout Formation. The transition is characterised by a sharp erosional contact. The base of the Velp Formation is characterised by a fine-grained, often clayey crinoide limestone-dolomite overlying a sequence of massive, pale oolitic limestones of the Steentje-Turnhout Formation or the clay and sand rich deposits of the Kessel Formation.

Area: The Velp Formation is only found in boreholes in the western part of the Campine Basin. There are no data available for the eastern part of the basin. In borehole 108W359 (KB192, 's Gravenvoeren) and Heugem 1/1a time equivalent deposits of the Berneau Formation are found.

Age: Late Arundian – Early Holkerian (Foraminifera zones: Cf4y- δ ; coral zones: RC5).

References: Bless et al., 1981a; Bless et al., 1980b; Bless et al., 1976; Conil et al., 1991; Graulich, 1968; Langenaeker, 2000; Muechez & Langenaeker, 1993; Muechez et al., 1987a; Muechez et al., 1991; Pirlet, 1967; Poty, 1991.

Table 2: Selection of boreholes in which the Velp Formation was drilled (in m). Stratotype borehole is underlined.

Borehole		Location	Date	Top	Base	Thickness
KB120	017E225	Turnhout	1952	2273	2306,5	33,5
KB129	007E178	Loenhout, Heibaart	1962	1306	1332	26
<u>KB131</u>	076E243	Halen	1962	984	1082	98
KB132	059E146	Booischot	1963	438,5*	523,6	85,1
KB38	044W011	Kessel	1903	572	623	51

* top Carboniferous

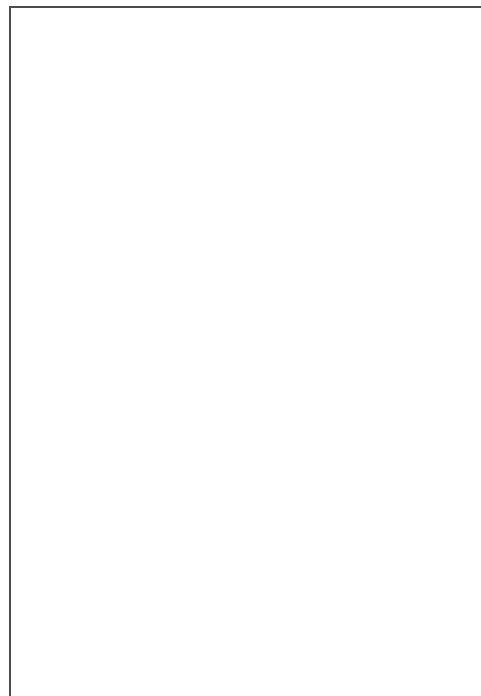


Figure4: Litholog of Lower Carboniferous and Devonian sequence of borehole 076E243 (KB131, Halen), stratotype for the Velp Formation. (From Laenen, 2003)

3. Kessel Formation

Authors: Bless et al., 1976; Paproth et al., 1983; Laenen, 2003.

Description: Alternating beds of massive, grey to redbrown limestones with clayey, nodular limestone layers, red,

calcareous sandstones and red, mottled and black claystones. Locally dolomite layers are present. In the upper part of the stratotype section and in the interval between 660 m and 675 m different beds with plant remains are found. In borehole 059E146 (KB132, Booischot) root soils and even thin coal layers are present. In the zones with plant remains the lithology is mainly dominated by mottled claystones, marls and mica and calcareous sandstones.

Stratotype: borehole 044W011(KB38, Kessel-bij-Lier), X 169.096, Y 206.659, Z 8 m, 1903. Kessel Formation in depth range 622-703,6 m (TD). Named after the village Kessel in the vicinity of Lier, the location of the stratotype borehole.

Thickness: The Kessel Formation has a total thickness of about 80 m (minimal 81,6 m in stratotype borehole 044W011 (Kessel-bij-Lier) and 76 m in borehole 059E146 (Booischot). The contact with the underlying limestones of the Steentje-Turnhout Formation is sharp. Where the Kessel Formation is not in direct contact with the Cretaceous, paleosoils are present beneath the crinoidal limestone and dolomite layers at the base of the Velp Formation.

Area: It is impossible to give a detailed picture of the occurrence of the Kessel Formation, because it was only found in two boreholes. For sedimentological reasons it is assumed that the Kessel Formation only occurs between the paleo shoreline of the London-Brabant Massif in the west and the open marine limestones and reefs of the Steentje-Turnhout Formation to the east.

Age: Late Arundian to Chadian. Foraminifera zones: Cf4 α - δ ; coral zones: RC5 to RC4 β .

References: Bless et al., 1976; Bless et al., (1980a; Conil et al., 1991; Delmer, 1962; Langenaeker, 2000; Muechez et al., 1987b; Paproth et al., (1983b; Pirllet, 1967; Poty, 1991.

Table 3: List of boreholes in which the Kessel Formation was drilled (in m). (Stratotype borehole is underlined)

Borehole		Location	Data	Top	Base	Thickness
KB132	059E146	Booischot	1963	523,6	600	76.4
<u>KB38</u>	<u>044W011</u>	Kessel	1903	623	<704 *	<81

* Total depth

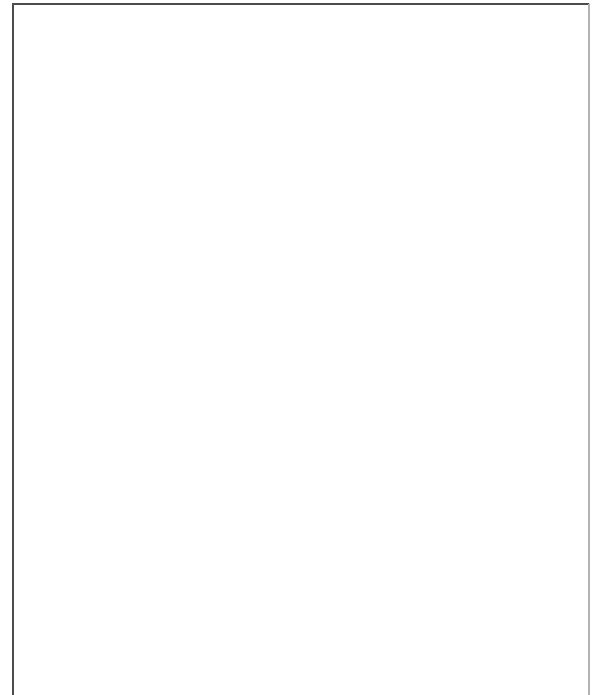


Figure5: Litholog of Lower Carboniferous and Devonian sequence of borehole 044W011 (KB38, Kessel-bij-Lier), stratotype for the Kessel Formation. (From Laenen, 2003)

4. Steentje-Turnhout Formation

Authors: Laenen, 2003.

Description: Massive grey to light grey limestones and dolomites, locally karstified and with brecciated beds. In the stratotype borehole 3 lithological units can be distinguished:

1. Pale, massive, oolitic limestones with locally breccias levels at the top (2306,5 m - 2390 m)
2. Fine grained, grey to dark grey limestones with clayey beds, locally rich in crinoids in the middle (2390 m - 2563,3 m)
3. Algal boundstones with intercalations of bioclastic wacke to grainstones at the base (2563,3 m - 2706,55 m)

Stratotype: borehole 017E225 (KB120, Turnhout Zwemdok), X 190.573, Y 223.829, Z 29,6 m, 1952. Steentje-Turnhout Formation in depth range 2306,5-2705,55 m. Named after the old fire station of Turnhout, close to the location of the stratotype borehole.

Area: The Steentje-Turnhout Formation is present throughout the Campine Basin, but the distribution and thickness is influenced by block faulting or tectonics.

Thickness: The thickness of the Steentje-Turnhout Formations varies significantly. It appears that the formation is absent or of minimal thickness in the Heibaart region (borehole 007E178), while in the stratotype borehole it has a thickness of roughly 400 m. The differences in thickness are probably due to the differences in paleotopography and block faulting. Where younger deposits of the Carboniferous Limestone Group are present, the top is characterised by mottled marls and sandy carbonate rocks of the Kessel Formation or with finegrained, often clayey crinoids limestone or dolomites of the base of the Velp Formation. Elsewhere an unconformity separates this Formation with the base of the Cretaceous. The massive limestones of the Steentje-Turnhout Formation lay conformably over the dolomites of the Vesder Formation. The contact is discrete. It is also characterized by an abrupt change in the pattern of the gamma well log.

Age: Early Arundian to Chadian (Foraminifera zones: Cf4 α - β ; coral zones: RC5 to RC4).

References: Bless et al., 1976; Bless et al., 1980a; Bless et al., 1981a; Delmer, 1962; Graulich, 1968; Graulich, 1975; Langenaeker, 2000; Muech & Langenaeker, 1993; Muech et al., 1987b; Muech et al., 1991; Paproth et al., 1983b; Poty, 1991.

Table 4: List of boreholes in which the Steentje-Turnhout Formation was drilled (in m). (stratotype borehole is underlined)

Borehole	Location	Date	Top	Base	Thickness
<u>KB120</u>	017E225 Turnhout Zwemdok	1952	2306.5	<2706,55*	<400,05
KB129	007E178 Loenhout, (Heibaart)	1962	1332	1422 (or 1458)**	90 (or 126m)**
KB131	076E243 Halen	1962	1082	1165	83
KB132	059E146 Booischoot	1963	602	641	39

* Total depth

** see litholog KB129 (Fig. 3)

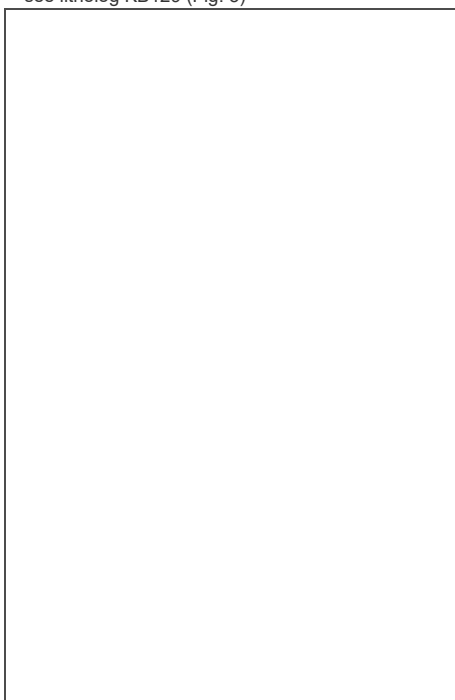


Figure 6: Litholog of Lower Carboniferous and Devonian sequence of borehole 017E225 (KB120, Turnhout, Zwemdok), stratotype for the Steentje-Turnhout Formation. (from Laenen, 2003)

5. Goeree Formation

Authors: Van Adrichem Boogaert & Kouwe, 1994.

Description: A sequence of grey to drak-grey and black limestones, thin- to thick-bedded and often partly silicified. The limestone beds often grade into calcareous and/or silicified black shales or black cherts toward the top. Very thin beds of tuffaceous rock occur, predominantly in the upper part of the Formation.

In borehole Geverik-1 the Formation gradually changes into silicified shales and carbonates of the overlying Souvré Formation. The boundary is set at the top of the last massif limestone-dolomite layer. The transition is gradual. Geophysical well logs can help to determine the boundary, which is characterized by a pronounced gamma ray peak and a drop in the velocity of the acoustic log. The base the Goeree Formation gradually changes into pale, massif carbonate rocks of the Visé Formation. The boundary is set by color of the rocks. As for the upper boundary, the lower boundary is also sharp, shown by an abrupt flattening in the gamma ray log.

Stratotype: borehole S02-02, X 97.727, Y 283.209, Z 36.0 m, 1983. Goeree Formation in depth range 1883-2123 m. Named after western part of the island Goeree-Overflakkee in the province of South Holland (the Netherlands).
Parastratotype: borehole Geverik-1: 992-1492 m.

Area: Not yet found in Belgian boreholes, but the large thickness in borehole Geverik-1 the Goeree Formation is supposed to be present to the north of Visé (Bless et al., 1980b).

Thickness: in stratotype borehole S02-02: 240 m. In borehole Geverik even 500 m.

Age: Late Visean (V3a-V3c; late Holkerian to Brigantian (Van Adrichem Boogaert & Kouwe, 1994)
Brigantian to Asbian (Foraminifera zones: Cf7 to Cf6γ locally possibly Cf6α/β), conodont zone: CC5 (*bilineatus*) (Laenen, 2003)

References: Bless et al., 1980b; van Adrichem Boogaert & Kouwe, 1994; Van Tongeren & Pagnier, 1987.

Table 5: List of boreholes in which the Goeree Formation was drilled (in m).

Borehole	Location	Date	Top	Base	Thickness	
S02-02	The Netherlands	1983	1883	2123	240	
GVK-01	Geverik-1	The Netherlands	1986	992	1492	500

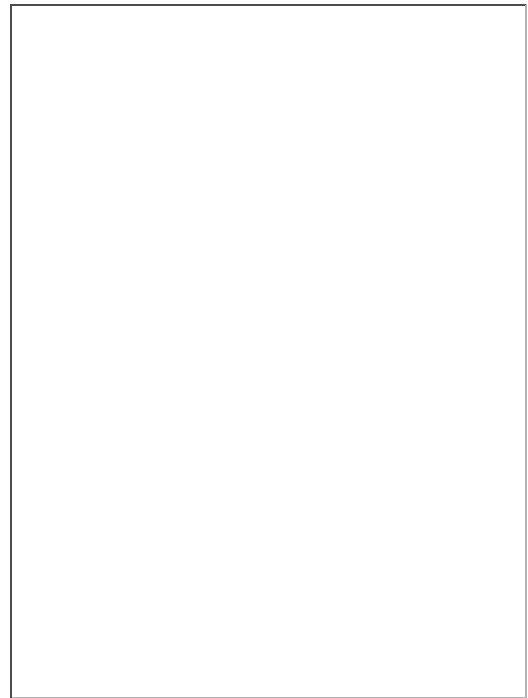


Figure 7 : Litholog of Lower Carboniferous and Devonian sequence of borehole S02-02, stratotype for the Goeree Formation. (From Laenen, 2003)

6. Bosscheveld Formation

Authors: Van Adrichem Boogaert & Kouwe, 1994 (informal unit).

Description: The Bosscheveld formation is a transitional unit between the clastics from the Condroz Group and the carbonates of the Limestone Group. The upper part mainly consists of mudstones and limestones and are rich in crinoids, brachiopods and corals. The lower part is more sandy and often rich in micas. In this part soil roots and plant remains are found. In the lithostratigraphic subdivision of Laenen (2003) of borehole Kastanjelaan-2 the Bosscheveld Formation is covered by mudstones of the Pont d'Arcole Formation (Carboniferous Limestone Group). The base is formed by a transitional zone of dominant grey siltstones to green, red, mica bearing, silt- and sandstones of the Evieux Formation. In Van Adrichem Boogaert & Kouwe (1994) the Formation is described as interbedded dark-grey, partly calcareous mudstones, fine-grained sandstones and limestones, often nodular. Locally, red colours occur.

Stratotype: Well Kastanjelaan-2, X 242.550, Y 172.650, Z 51,5.0 m, 1981. Bosscheveld Formation in depth range 400-483.5[1]m. Named after the Bosscheveld quarter of the town of Maastricht in the province of South Limburg (the Netherlands), where the well Kastanjelaan-2 was drilled (Bless et al., 1981).

Area: The Bosscheveld Formation consist of shallow marine sediments deposited in a sheltered, low energy depositional environment, which probably has only limited extent in Flanders. This transitional unit was possibly found in borehole Heibaart 1/1bis, but is missing in Booischoot, where the Steentje-Turnhout Formation resting on the Evieux Formation. The distribution is probably controlled by block faulting.

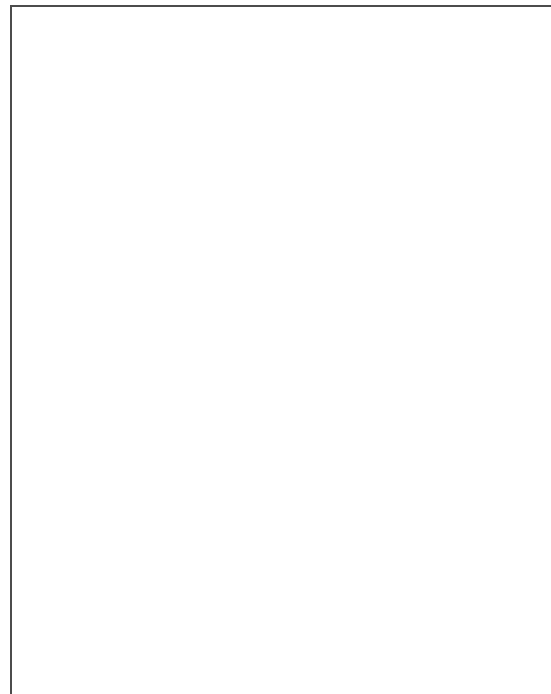
Thickness:in borehole Kastanjelaan-2 the Bosscheveld Formation is 83,5 m thick.

Age: Hastarian to Late Fammennian (Conodont zones: *Siphonodella duplicata* Zone to *Palmatolepis expansa* Zone).

References:Becker et al., 1974; Bless et al., 1981a; Labofina, 1976; Langenaeker, 2000; Muchez & Langenaeker, 1993; Piérard, 1963; van Adrichem Boogaert & Kouwe, 1994.

Table 6: List of boreholes in which the Bosscheveld Formation was drilled (in m).

Borehole	Location	Date	Top	Base	Thickness	
<u>KSL-02</u>	Kastanjelaan	The Netherlands	1983	400	483,5	83,5



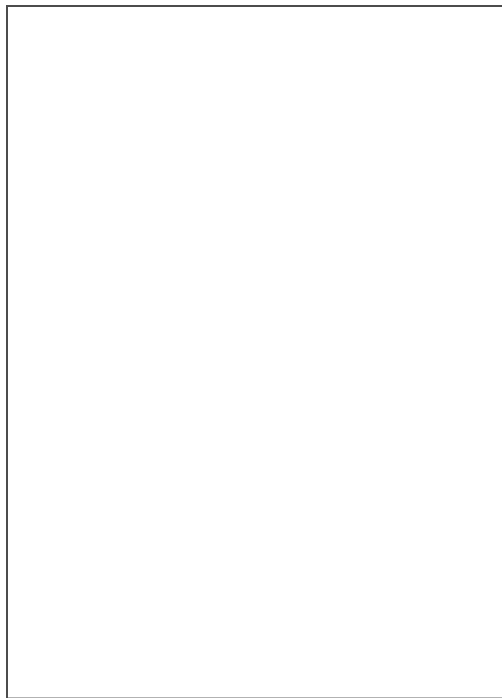


Figure 8: Litholog of Lower Carboniferous and Devonian sequence of borehole Kastanjelaan-2, stratotype for the Bosscheveld Formation. (From Laenen, 2003)

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[1] In contrast with Van Adrichem Boogaert & Kouwe (1994) the claystones between 382 m en 400 m and the variegated mica bearing silt- and sandstones at the base of the Kastanjelaan-2 well are not included in the Bosscheveld Formation, but respectively allocated/assigned to the Pont d'Arcole and Evieux Formation (Laenen, 2003).