Geology of the Ardenne Anticlinorium, in the Amberloup - La Roche-en-Ardenne - Houffalize sector. The faults of the La Roche Syncline and the overturned Taverneux Anticline.

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Abstract. The area included in the Amberloup - La Roche-en-Ardenne - Houffalize sector is located in the province of Luxembourg and belongs geographically to the Central Ardenne. The rocks are of Lower Devonian age. On the regional level, the region integrates southeast of the axial zone of the Ardenne Anticlinorium, northwest of the Neufchâteau Synclinorium. Geological mapping at the scale of 1 : 10 000 has identified numerous faults ignored on old geological maps at a scale of 1 : 40 000. The greater part of map-sheet Houffalize is modeled by the Houffalize Syncline, which extends into the lower third of map-sheet Wibrin. The detailed surveys of its northern flank and the transition zone to the La Roche Syncline in the northwest show that the intermediate structure does not correspond to a simple anticline known in the literature as Taverneux Anticline. During the Variscan orogeny, an anticline was effectively formed, then it overturned north and, finally, was segmented by longitudinal faults which, initially, were reverse faults, but some were reactivated as normal faults during a phase of relaxation.

Keywords : Stratigraphy, Lower Devonian, Variscan orogeny, fault, cleavage, geological mapping.

Résumé. **Géologie de l'Anticlinorium de l'Ardenne, dans le secteur Amberloup – La Roche-en-Ardenne – Houffalize (Belgique). Les failles du Synclinal de La Roche et de l'Anticlinal déversé de Taverneux**. La région comprise dans le secteur Amberloup - La Roche-en-Ardenne - Houffalize est située dans la province de Luxembourg et appartient géographiquement à l'Ardenne centrale. Le sous-sol est constitué de terrains d'âge dévonien inférieur. Sur le plan régional, la région s'intègre au sud-est de la zone axiale de l'Anticlinorium de l'Ardenne, au nord-ouest du Synclinorium de Neufchâteau. Des levés géologiques à l'échelle du 1 : 10 000 ont identifié de nombreuses failles ignorées sur les anciennes cartes géologiques à l'échelle du 1 : 40 000. La plus grande partie de la planchette d'Houffalize est modelée par le Synclinal d'Houffalize qui se prolonge dans le tiers inférieur de la planchette Wibrin. Les levés détaillés de son flanc nord et de la zone de transition au Synclinal de La Roche situé au nord-ouest, montrent que la structure intermédiaire n'épouse pas la forme d'un anticlinal simple connu dans la littérature sous le nom d'Anticlinal de Taverneux. Au cours de l'évolution de la déformation varisque, un anticlinal s'est effectivement formé, puis il s'est renversé vers le nord et enfin, a été tronçonné par plusieurs failles longitudinales normales qui, initialement, étaient des failles inverses, mais dont certaines ont rejoué en failles normales au cours d'une phase de relaxation.

Mots-clés : Stratigraphie, Dévonien inférieur, orogenèse varisque, faille, schistosité, cartographie géologique.

1. Introduction

The Amberloup - La Roche-en-Ardenne - Houffalize region was the subject of geological cartographic surveys at the scale 1 : 10 000, according to the rules of Hedberg (1996), in the context of the production of the geological map of Wallonia. It concerns three geological maps at a scale of 1 : 25 000 : Champlon - La Roche-en-Ardenne 60/1-2, Amberloup – Flamierge 60/5-6 and Wibrin - Houffalize 60/3-4, for which no structural tectonic synthesis has been achieved previously. Some surveys have been published with explanatory notes (Dejonghe, 2008b, 2012a,b; Dejonghe & Hance, 2001a,b, 2008). The Wibrin - Houffalize sector is yet unpublished.

Previous geological mapping in the study area has been conducted by Dumont (1853), Gosselet (1888), Stainier (1896a,b; 1900), Leblanc (1923), Asselberghs & Leblanc (1934), Asselberghs (1946) and Brühl (1966). These contributions are out of date. The most substantial contributions are those of Stainier (1896a,b; 1900) and Leblanc (1923). Respectively 117, 113 and 90 years elapsed since the publication of their work. A revision was necessary because scientific conceptions have largely evolved primarily in the field of stratigraphy. Also earlier publications virtually do not recognize faults in this region. A further aim of this work is to present a synthesis of the main structural accidents.

The study area is located in the Belgian province of Luxembourg and belongs geographically to the northern Ardennes. The main river that runs through is the Ourthe which has cut a steep-sided valley and results from the confluence of the western Ourthe and the eastern Ourthe. Land use is equally split between forests and meadows or fields. Woods generally overlay quartzitic and quartz-phyllitic (in French : quartzophyllade) substrates belonging to the Mirwart Formation and valley slopes. In the southwestern part of map-sheet Amberloup, in the region of the airfield at St-Hubert, the highest elevations are occupied by Venn, very wet swampy area, where weathered rocks and peat are developing.

Geologically, the study area is integrated in the axial zone of the Anticlinorium of the Ardenne which links the Rocroi Massif in the west with the Stavelot Massif in the north-east. Specifically, it is located in the relay box which forms the junction between two sections of the anticlinorium of different orientations. The basement consists mainly of rocks of Lower Devonian age.

2. Formations description - Lithostratigraphy

Asselberghs (1934, 1946, 1954), Godefroid et al. (1994), Bultynck & Dejonghe (2001) and Dejonghe et al. (2008), have described with more or less detail the formations exposed in this region. The previously used chronostratigraphic terminology is shown in Tables 1 and 2.

Except old and valley bottom alluvium, all formations are siliciclastic and belong to the Lower Devonian. A lithostratigraphic synthetic column is provided in Fig. 1.

Seven formations are present in the sector considered : St-Hubert, Mirwart, Villé, La Roche, Jupille, Pèrnelle and Pesche (Fig. 1). Each of these formations (except St-Hubert) contains dark blue gray phyllites, often largely dominant. The sandstones are present in variable and often minor proportions. These formations differ on lithological or paleontological criteria. Isolated outcrops are sometimes very difficult to assign to a specific formation. The lithostratigraphic correlation of the outcrops was based on more or less continuous cross-sections and sets of points of observation. The thicknesses of the formations are indicated in Table 3. Note that the relevant formations are formed in large part of pelitic materials whose flattening may be significant, either by post-depositional compaction or through tectonic action (schistosity). Thicknesses have therefore only a

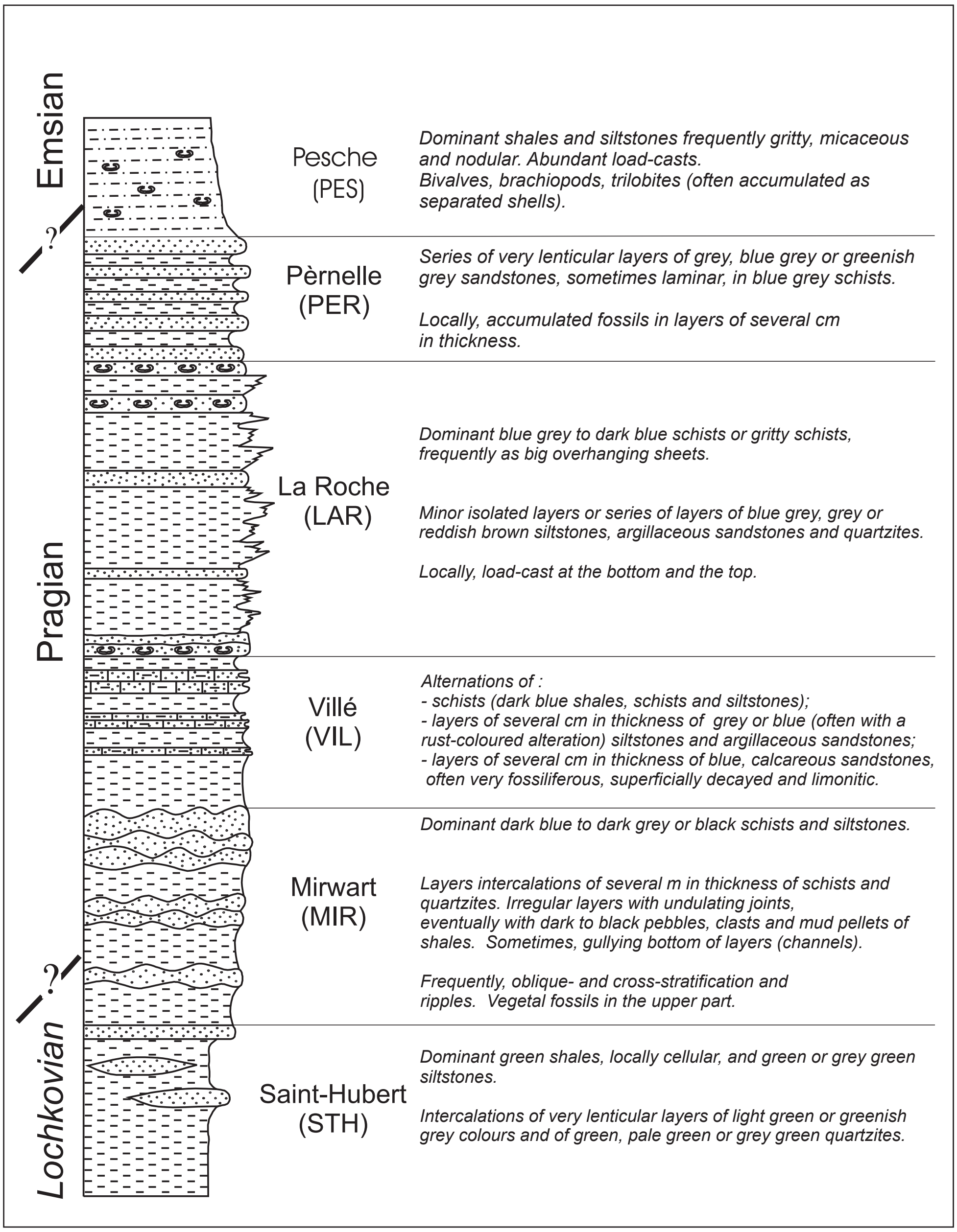

Figure 1. Lithostratigraphic column of geological formations.

relative value, different from the original thicknesses. The characteristics of the different formations are evoked briefly hereafter.

Saint-Hubert Formation

This formation is represented only on the SW part of map-sheet Amberloup. It is dominated by green shales, locally cellulous, and by green or green gray siltstones. The cellulous character results from the weathering of carbonated nodules in a pulverulent limonitic residue which disappears at the outcrop. This character is very typical for the formation. The rocks, always very altered, are strongly faded and the shales evolve to kaolinitic clays by their position in a Tertiary peneplain. Its thickness is not determinable on Amberloup map-sheet because the top of the formation does not crop out there.

Mirwart Formation

The depositional environment of the Mirwart Formation rocks was precised by Goemaere & Dejonghe (2005). The sub-environments represented by tidal channels and tidal sandy clayey areas stack up vertically. These environments, of very low relief, form extensive surfaces without barrier which are protected from influences of the open sea. The strong expansion of the tidal zone is a reaction to the Devonian transgression over flat surfaces that form flood plains and delta plains. Compared to current comparable environments, these series have unusual thicknesses in connection with a high and continuous rate of subsidence and a regular sedimentation. A well-developed fluvial system brings sediments from the Old Red Sandstones Continent through the alluvial and deltaic environments developed north of the study area. In short, the rocks of the Mirwart Formation reflect deposit under high energy conditions in very shallow water.

Villé Formation (Amonines and Longlier facies)

The Villé Formation delivered an abundant and diversified fauna including large specimens. More than 200 different species have been counted. On the map-sheet Wibrin - Houffalize, the recognition of the Villé Formation is however much more delicate than on the Champlon - La Roche-en-Ardenne map. This recognition is quasi impossible for the majority of the non-fossiliferous isolated outcrops. Indeed :

- the rocks of this formation are dark blue gray phyllites splitting in large sheets. They are component of thick series of several tens of meters in thickness which alternate with sandy or clayey-sandy levels, often of nodular aspect, slightly micaceous, possibly with undulating joints (current ripples), which reach several meters in thickness. These phyllites are identical to those of the Mirwart, La Roche, Jupille and Pèrnelle Formations. Only the presence of fossiliferous levels makes it possible to differentiate them;

- by places, the rocks are made up of alternations of several millimeters to several centimeters of light gray (sandier) and dark gray (more argillaceous) layers which confers a ribbon aspect to them;

Table 1. Relationship between stratigraphic units considered by various authors since 1896 for the Mirwart, Villé, La Roche, Jupille and Pèrnelle formations.

Formations → Authors↓	Mirwart	Villé	La Roche	Jupille + Pèrnelle
	Coblencian			
Geological map N°188 Stainier (1896b)	Cb1a – Assise d'Anor et de Bastogne. Phyllades noirs, grès noir, grès blanc dans la bande septentrionale. Quartzophyllades zonaires, grès stratoïdes, phyllades noirs dans la bande méridionale	Cb2a - Quarzophyllades, grauwackes, psammites et grès de Houffalize Cb2ac - Calcaire (très peu développé)	Cb2b - Phyllades à grands feuillets	
	Siegenian			
Leblanc (1923)	Sg1 - Siegenien inférieur (Taunusien)	Sg2a Siegenien supérieur (Hunsruckien)	Sg2b - Siegenien supérieur (Hunsruckien)	
Maillieux & Demanet (1929)	Grès d'Anor	Grauwacke du Bois de Saint-Michel	Grauwacke du Bois de Petigny	
Maillieux (1933 & 1941)	Sg2 - Grès d'Anor	Sg3 - Grauwacke de Saint-Michel (région S) Grauwacke des Ammonines (région E) (1933)	Sg4 - Grauwacke de Petigny	Sg5 - Grauwacke de Grupont (1940)
Asselberghs & Leblanc (1934)	Sg1 - Siegenien inférieur (Taunusien)	Sg2 - Siegenien moyen (Hunsruckien)	Sg3 - Siegenien supérieur (Hunsruckien)	
Asselberghs (1946)	S1 - Faciès d'Anlier	S2 - Faciès des Amonines	S3 - Faciès de La Roche et de Saint-Vith	
Godefroid (1979, 1982) Godefroid et al.(1982)	Anor	Villé (1982)	La Roche	Formation "B"
	Lochkovian pro parte - Pragian pro parte.	Pragian pro parte .		
Godefroid et al. (1994)	MIR - Mirwart	VIL - Villé	LAR - La Roche	PER - Pèrnelle
Dejonghe et al. (2008)				Jupille + Pèrnelle

- in the large majority of the cases, the fossiliferous beds do not present a carbonated character (no reaction to HCl 1/10 N). Crinoidic limestone beds observable on the map-sheet Champlon - La Roche-en-Ardenne are absent. Rocks making a light effervescence with HCl 1/10 N are always sandstones with very slightly carbonated cement;

- the presence of fossils is more discrete than on the map-sheet Champlon - La Roche-en-Ardenne. Fossils are rarely concentrated in beds of a few cm thick. Generally, they are diluted in sandstone levels of several meters in thickness. But shelly rocks of tempestite type are also present. The presence of fossils is rarer in phyllitic levels. Obviously, the fossils were moved mechanically under the action of waves or of currents;

- Asselberghs (1946, pp. 144-146) rightly distinguished the Amonines Facies (= typical Villé) from that of Longlier which grows rich in beds by quarzites and quartz-phyllites correlatively to a reduction by the carbonated levels. Compared to its stratotype located on the map-sheet Champlon - La Roche-en-Ardenne, the Villé Formation evolves to the east towards thickness increase accompanied by a clear reduction (even, a disappearance at many places) in its carbonated nature and finally, of a rarefaction and a dilution of its fossiliferous contents. One passes from the Ammonines Facies to the Longlier Facies. The latter can be seen from east of Maboge, in the Maboge-Bérisménil road cut.

La Roche Formation (La Roche and Saint-Vith facies)

On the map-sheet Champlon - La Roche-en-Ardenne, dark blue grey phyllite clearly dominates the La Roche Formation and the silty sandstone component is very incidental. On the other hand, on the map-sheet Wibrin - Houffalize, the silty sandstone component increases significantly in many places where the phyllites do not split into fine sheets but become more compact. It is not uncommon that the silty phyllite in sandstone incorporates millimeter to centimeter laminas and grey sandstone beds of several decimeters, especially at the base and at the top of the formation but also in the central part (see below). In laminar beds, bedding is sometimes flat, sometimes cross-bedded.

The notion of St-Vith Facies was introduced by Asselberghs in 1927 (p. 209). But it is in 1946 (pp. 179-186) that he clearly specified its peculiarities, making the distinction between La Roche and St-Vith facies. Concerning St-Vith facies, he wrote pp. 179-180: « … *vers le Nord et le NE, le siegenien supérieur acquiert un facies de caractère néritique plus accentué (...). Il caractérise (...) le bassin d'Houffalize et l'extrémité Est de celui de Laroche. Il renferme des phyllades et des quartzites. Les phyllades sont bleu noir, à grands feuillets.(...). Dans les phyllades, sont intercalés des paquets de 5 à 10 m de puissance de quartzite à ciment séricitеux, fins ou très fins, verts, gris ou même blanchâtres, facilement altérables et des quartzophyllades schisteux.(...). Dans ce facies, les roches sont très souvent criblées de cubes de pyrite qui peuvent atteindre 15 mm de côté.* ».

The La Roche Formation of Stainier (1994), characterized by the development of blue large sheets phyllite, only matches the lower part of the Laroche Facies of Asselberghs. The upper part of the La Roche facies, significantly more gritty, was assigned by Dejonghe & Hance (2001a,b) to the Pèrnelle Formation which is currently included to the Group of Jupille and Pèrnelle (Dejonghe et al., 2008).

In the Grand Duchy of Luxembourg, on sheet 8 Wiltz at 1 : 50 000 scale, Lucius (1949) describes the Upper Siegenian Sg3 as composed of compact, coarse-grained, poorly stratified shale, with rare clayey sandstone beds. He distinguishes a sandstone facies, called Bas-Bellain Shale, mapped under the acronym Sg3a. The Sg3 of Lucius (1949) corresponds to the La Roche, Pèrnelle and Jupille formations. One may also wonder if towards the Grand Duchy of Luxembourg, the distinction between these three formations is still possible, as indeed the sandstone facies becomes abundant.

Table 2. Summary of stratigraphic concepts.

Stages, this work	Formations, this work	Leblanc, 1923	Asselberghs, 1946
Lower Emsian/Pragian	Pesche	Lower Emsian Em1 pp	Lower Emsian Em1a
Pragian	Jupille + Pèrnelle	Siegenian Sg2b	Upper Siegenian S3
Pragian	La Roche	Siegenian Sg2b	Upper Siegenian S3
Pragian	Villé	Siegenian Sg2a	Middle Siegenian S2
Lochkovian/Pragian	Mirwart	Siegenian Sg1a	Lower Siegenian S1
Upper Lochkovian	Saint-Hubert	Gedinnian Gd pp	Gedinnian G2b

Grouping of the Jupille and Pèrnelle formations

Cartographic surveys in the Lower Devonian of the High-Ardenne spreading over more than 10 years led Dejonghe et al. (2008) to reconsider the status of the Pèrnelle Formation in High-Ardenne and introduce the concept of Jupille Formation to designate the strata between La Roche Formation at the base and Pèrnelle or Pesche formations at the top. Both Jupille and Pèrnelle formations are characterized by the abundance of lenticular beds, of some centimeters to some decimeters or even some meters in thickness, of grey, grey blue or greenish grey sandstone, sometimes laminar, sometimes clayey, and taking on exposed surfaces a shade of brownish to reddish alteration, or even limonitic. These beds can be grouped in packages of several meters in thickness and form gritty bars that emerge in outcrop. The sandstones are intercalated in the siltstones and blue grey phyllites similar to those of the La Roche Formation.

In places, load casts occur, some up to 50 cm long. The sandstone is locally quartzitic. It can sometimes be slightly carbonated.

In the study area, the thickness of the grouping of Jupille and Pèrnelle formations would thus considerably increase from north to south and, locally, from west to east.

Pesche Formation

The Pesche Formation is rich in bivalves, brachiopods and trilobites. The bivalves are particularly numerous in the shales. On the S and SE edges of Dinant Synclinorium, the fossils of this formation are characterized by piles of shells, disjointed, whole when they are small, but often broken and in all positions. The walls of these shells are often thin (< 1 mm).

3. Stratigraphic scheme

Leblanc (1923), Asselberghs & Leblanc (1934) and Asselberghs (1946), provide lists of macrofossils and indications to localize the places where these fossils have been found. The stratigraphy of the current geological maps relies strongly on this work.

Table 1 shows the evolution of concepts about series that were considered as mappable. To the attention of readers who will consult the former works, it is useful to summarize these conceptions as in Table 2.

The Lower Devonian is also widely exposed in the Grand Duchy of Luxembourg. Different names of formations are in use (Colbach, 2003) : the Radelange Formation (strictly equivalent to the Villé Formation), the Martelange Formation (corresponding to a part of the La Roche Formation) and the Grumelange Formation (which covers the grouping of Jupille and Pèrnelle formations as well as a part of the La Roche Formation).

4. Structural geology – Tectonics

A synthetic geological map is shown in Fig. 2. Major structures of this region are, from NW to SE, the Halleux Anticline, the La Roche Syncline, the Taverneux Faulted Zone and the Houffalize Syncline. This very simple scheme hides a tectonic complexity which is expressed by minor folds and by multiple longitudinal faults (strike-slip, reverse or normal). The asymmetric style of

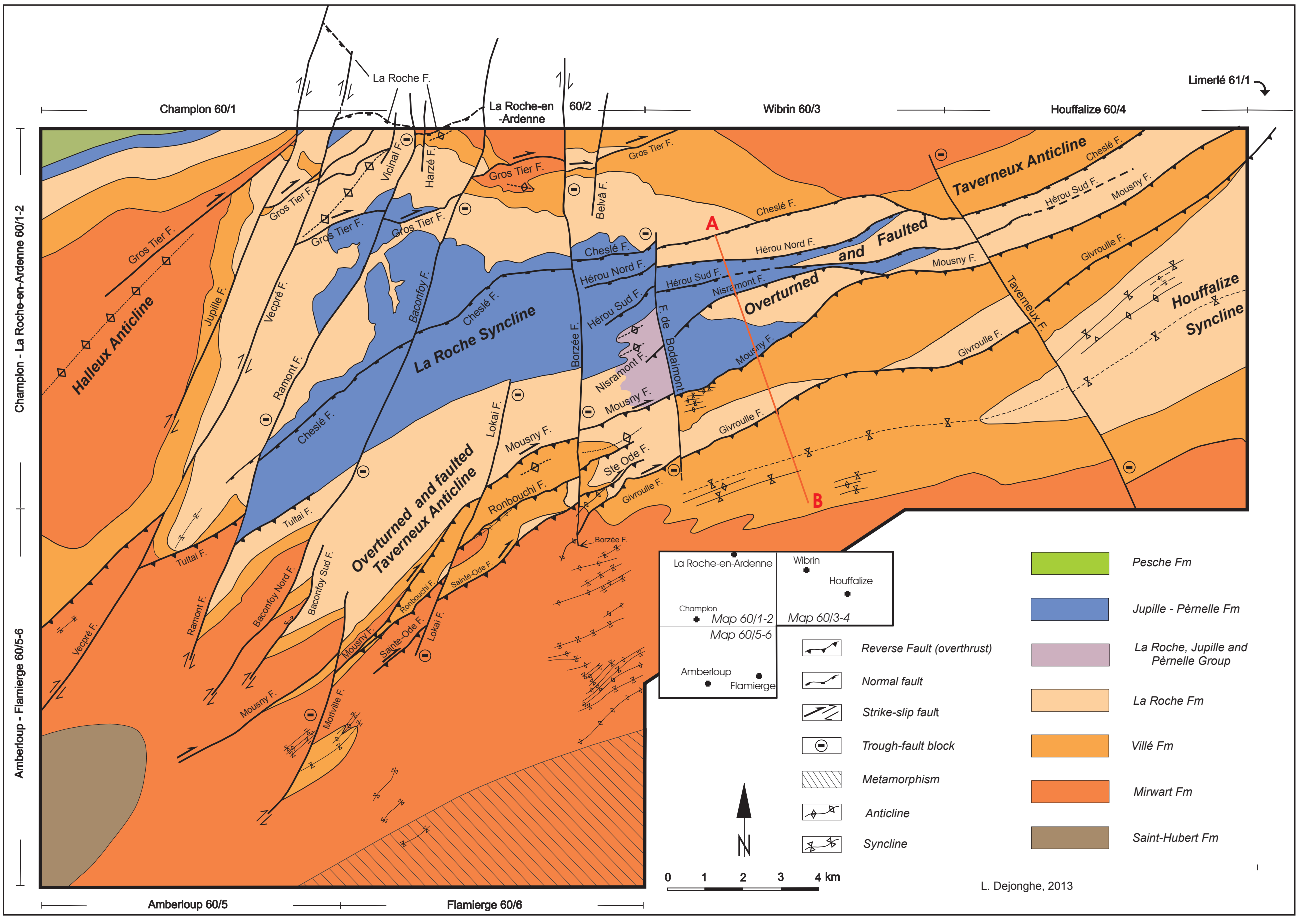

Figure 2. Synthetic geological map of the Amberloup - La Roche-en-Ardenne - Houffalize area (Belgium).

	Mirwart	Villé	La Roche	Jupille-Pèrnelle	Pesche
Hotton - Dochamps 55/8-9 Map Dejonghe (2008b)	1050	250-550	300-430	700	700-800
Champlon - La Roche 60/1-2 Map Dejonghe & Hance (2001a,b)	>700	250-300	350-800	150-600	
Amberloup - Flamierge 60/5-6 Map Dejonghe (2012a,b)	Faulted >1000	250-300	Faulted >1600	Faulted >500	
Wibrin - Houffalize 60/3-4 Map Dejonghe (Submitted)	>900	600-1000	Faulted >600	Faulted >1000	
Asselberghs (1954)	>1100	250-600	1500		
Godefroid et al. (1994)	300-700	30-230	215-450		160-400

Table 3. Thickness (in meters) of geological formations.

folding, characterized by folds where one of the sides is very elongated and deformed in flat undulations and the other is short and very steep or even reversed, is very characteristic for the region and is repeated at different scales of observation (some meters to several kilometers). All structures (folds and longitudinal faults) are cut by transverse faults either with vertical displacement or with strike-slip dextral component. The two most important delimit a wrench corridor that separates the Halleux Anticline and La Roche Syncline with a cumulative dextral throw of the order of 4 km (Dejonghe, 2008a).

4.1. The folds

The **Halleux Anticline**, whose core is formed by rocks of the Mirwart Formation, is symmetrical, with little inclined flanks, and its axis is oriented NE. It is a vast dome, whose eastern flank presents many undulations (e.g., Leblanc, 1931) and which can be termed as anticlinorium. See also Leblanc (1936).

The **La Roche Syncline** has an ENE oriented axis. The core is occupied by rocks of Jupille - Pèrnelle formations. Notwithstanding the faults that cut its southern flank, the La Roche Syncline is a fold of several kilometers wide, inclined to overturned to the NNW, and the southern flank of which is affected by small secondary knee folds or by wider undulations, through which reappear flat long limbs (in French : plateures). This fold is followed to the south by a large area affected by faults and secondary folds : the Taverneux Faulted Zone (see below) which separates the La Roche and Houffalize Synclines.

For Asselberghs (1946 p. 525), the Laroche Syncline, relayed by the Houffalize Basin, of which the core is also of Upper Siegenian age, are separated by the **Taverneux Anticline**. He considers this structure formed of Middle Siegenian fossiliferous quartz-phyllites as a significant isoclinal fold, overturned to the north, which disappears to the west of Houffalize. In fact, Asselberghs takes over the concept of Leblanc (1923), who provided a cross-section of the Bastogne Anticline and Houffalize Syncline, passing by the meridian of Houffalize. Between Taverneux and Houffalize, Leblanc draws a very tight overturned anticline. Our detailed surveys show that it has not, or, to speak more accurately, no more, an isoclinal fold pattern at Taverneux between La Roche and Houffalize synclines. In this area, there are rocky panels separated by faults (see point 3.2) which reflect the fragmentation of a former anticlinal fold.

The **Houffalize Syncline** is well characterized. In detail, it is affected by many small secondary folds that make it more akin to a synclinorium than to a simple syncline. To the east of the Houffalize meridian and the Taverneux Fault, if we restrict ourselves to the contact of Villé and La Roche formations, there the northern flank of the syncline is made up of undulating layers of moderate dip, while on the southern side, layers are steep or even reversed. To the west of the meridian of Houffalize and the Taverneux Fault, the structure of the syncline is more symmetrical. This latter syncline is always assigned by undulations (well observed in the valleys of the streams Mabompré and Bertogne).

To the east of map-sheet Wibrin-Houffalize, on the map-sheet Limerlé and further to the east crossing the Belgian-Luxembourg border, the Houffalize Synclinorium opens very clearly due to pitching. In addition, the St-Vith facies that characterizes the Laroche Formation takes more and more importance.

4.2. The faults

On maps previously drawn by Dumont (1853), Gosselet (1888), Stainier (1896a,b), Leblanc (1923), Asselberghs & Leblanc (1934) and Asselberghs (1946), either none, or only a few rare faults are drawn in the region. However, our detailed surveys show the existence of many brittle accidents, transverse and longitudinal, described below and positioned on Fig. 2 and the cross-section of Fig. 3.

4.2.1. The transverse faults

On the map-sheet Champlon - La Roche-en-Ardenne, faults are mainly oriented NNE (faults of Jupille, Vecpré, Ramont (= Stemby.), Baconfoy, Lokai). To the east, they are oriented NS (faults of Moriville, Borzée, Belvâ, Bodaimont). Further to the east, on the map-sheet Wibrin - Houffalize, their orientation becomes NW (Taverneux Fault). They cut the folded structures and the longitudinal faults and are strongly uprighted to a nearly vertical position. Some of these faults (Baconfoy, Ramont and Moriville) have been introduced by Asselberghs & Leblanc (1934). Note that the Ramont Fault is also designated by these authors and in the same work as Stemby Fault, but the name of Ramont prevailed. They recognize that these faults « *se présentent comme des failles d'effondrement ...* ». But they added « *que ces failles d'effondrement ne sont guère fréquentes en Ardennes et elles en compliqueraient la tectonique. Nous sommes plutôt tentés de croire qu'il s'agit de décrochement horizontaux...* ». Our detailed mapping surveys contradict this conclusion.

<u>Jupille, Vecpré, Vicinal, Ramont, Harzé, Baconfoy, Moriville, Lokai, Borzée and Belvâ faults</u>. From west to east, the Jupille, Vecpré, Vicinal, Ramont, Harzé, Baconfoy, Moriville, Lokai, Borzée and Belvâ faults are well represented on the Champlon - La Roche-en-Ardenne and Amberloup - Flamierge map-sheets. Their characteristics were commented by Dejonghe & Hance (2001) and Dejonghe (2012b). They are transverse faults, either dextral strike-slip faults (Jupille and Vecpré), or normal faults (Ramont, Baconfoy, Belva), or also with a double component, strike-slip and normal (Borzée). In fact, the map-sheet Hotton - Dochamps is cut by a dextral strike-slip corridor of N-S orientation, which is formed by the extension of the Vecpré and Jupille faults. This corridor is characterized by a throw around 3.6 to 4 km (Dejonghe, 2008a). It has the effect of a northward shift onto map-sheet Hotton of all formations and structures recognized to the east on map-sheet Dochamps. This important wrenching is even recognized on map-sheet Durbuy - Mormont located north of map-sheet Hotton - Dochamps. Its extension - more than 25 km - and its location at the western edge of the Stavelot Massif suggest that the basement of the latter may have locally slowed the northward thrust of the Dinant Nappe near the end of the Variscan orogeny. Part of this nappe lying west of the Stavelot Massif would have been advanced more far to the north than part of the nappe located south of the current area of outcrop of this Stavelot Massif.

Strike-slip transverse faults are likely of Late Variscan age while normal faults are likely post-Variscan in age. Those which present a double component, strike-slip and normal, are probably Late Variscan with a possible recurrent normal post-Variscan faulting.

<u>Bodaimont Fault</u>. This gently undulating fault, of NS to N10°W trend, was observed on a length of 6 km. It is located close to the

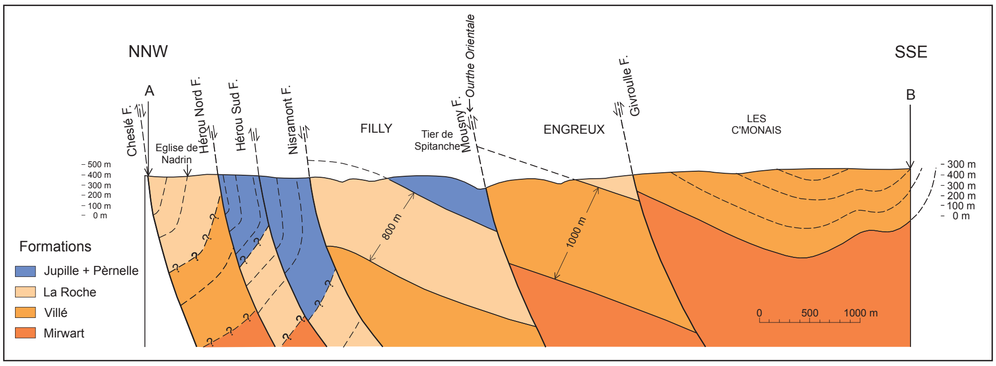

Figure 3. AB cross-section located in figure 2 showing the Taverneux Faulted Zone (Filly - Enfreux) and the Houffalize Syncline (Les C'Monais). Belgian Lambert (1972) coordinates of its edges : A : x = 243.870 ; y = 95.355 : B : x = 246.350 ; y = 88.180.

western edge of map-sheet Wibrin, between Derrière les Ecwârais and Les Haies de Compogne. It uplifts the east block from the west block.

Taverneux Faults. This fault of mean N35°W trend goes exactly in the centre of the village of Taverneux and is mapped for more than 10 km. It is characterized by block sinking which has led to significantly expand the area of outcrop of the La Roche Formation from west to east. It clearly shifts the Villé and Mirwart formations between Alhoumont and Wandebourci. It juxtaposes the La Roche and Villé formations around Taverneux. It does not seem to present strike-slip component.

4.2.2. The longitudinal faults

La Roche Fault. The La Roche fault was identified by Asselberghs (1931) along the road from La Roche to Vielsalm, north of La Roche-en-Ardenne. The La Roche Fault is interpreted as a thrust fault by Asselberghs & Leblanc (1934) and mapped over a length of 9 km.

Unlike the fault trace of Asselberghs (1931), Dejonghe & Hance (2001) have shown that this fault is barely exposed on map-sheet Champlon - La Roche-en-Ardenne. It is mainly located on map-sheet Dochamps. For Tricot (1954), it is a normal fault, steeping southward, interpretation which is most compatible with the fault trace by Dejonghe & Hance (2001a) : indeed, its southern lip always exposes younger rocks than its northern lip. Through displacements along the Jupille and Vecpré dextral strike-slip faults, the La Roche Fault is shifted more than 4 km northward on map-sheet Hotton.

The trace of the La Roche Fault, as proposed by Asselberghs & Leblanc (1934), in fact combines pieces of several different tectonic accidents. Its NNE section in the direction of Petit-Halleux is actually a transversal fault, the Vecpré Fault. The eastern segment, curving southward to Maboge is attributed to a longitudinal strike-slip dextral fault, the Gros Tiers Fault.

Gros Tiers Fault. The Gros Tiers Fault is sub-parallel to the La Roche Fault and cuts the northern flank of the La Roche Syncline. To the SW of Borzée, a geochemical prospecting by Sondag & Martin (1985) revealed that this fault coincides with lead and zinc anomalies. The area was the subject of complementary, geochemical and geophysical, studies which indicated that this accident has a strong inclination to the south (Ndayiragije, 1984; Michiels et al. , 1989). By displacements due to transverse faults, this fault connects to the fault that cuts off the tip of the Halleux Anticline. Depending on the axes of cutting, the Gros Tiers Fault presents apparent reverse or normal thrown. The more coherent interpretation is to see a dextral strike-slip fault with a thrown of the order of 1-2 km.

Cheslé, Hérou nord and Hérou sud faults. Three longitudinal faults oriented ENE cut out the core of La Roche Syncline. These are probably normal faults over which is superimposed a strike-slip movement. These faults are responsible for the repetition of the layers of Pèrnelle Formation forming the southern flank of La Roche Syncline and the increased width of their outcrop which exceeds 1500 m. These layers are sometimes in normal position, strongly tilted towards the NNW, sometimes reversed with an inclination of 70-85° to the SSE. A few knee folds interrupt this impressive series. The old edition of the geological map at 1 : 40 000 assigns steeply dipping layers at Hérou to an anticlinal core making the Cb2a layers (equivalent to the Villé Formation) reappear. This interpretation is contradicted by the north polarity of all steeply dipping layers as well as by the presence of fossiliferous levels very high in the Jupille - Pèrnelle Formation, or even in the overlying Pesche Formation (P. Stainier, personal communication).

The trace of the Cheslé Fault is obvious because it brings in contact formations of different compositions and layers of different directions and dips. On the Champlon - La Roche-en-Ardenne and Wibrin – Houffalize map-sheets , the throw of this normal fault is in the order of 600 to 700 m.

At Ollomont, Brumagne (1963, p. 157) reported the presence of a series of lenses of quartz veins with a thickness of 10 m that presumably corresponds to a portion of the Hérou nord Fault. He does however not draw a fault at this location but considers it as the crystallization of quartz in areas more cracked as in the core of an anticlinal fold. The throw of the Hérou nord normal fault was estimated at about 600 m on map-sheet Champlon - La Roche-en-Ardenne. It seems to increase on map-sheet Wibrin and exceeds 1000 m. Eastward, near the former mill of Wilogne, the Hérou nord fault seems to graft to the Cheslé Fault. The area north of the old mill of Wilogne is particularly complex. There, a small anticlinal flexure commented by Richter (1962) is very well observed. It could be in connection with the collapse of the south block of the Hérou nord Fault. The Hérou sud Fault was observed by Dejonghe & Hance (2001b, p. 24), at the bottom of the right side of the river Ourthe, to the north of Tier de Hérou. On map-sheet Wibrin, it could continue a little south of Cresse Ste-Marquerite. We extend it to the east, in the valley of the Eau de Martin Moulin, SSE of Flachon, where there is an abnormal contact between the Jupille and La Roche formations. On the map-sheet Houffalize, its eastern prolongation is suspected in the river Sommerain, to the NW of Wayonpré, where it changes from weak south dips to layers in reverse series, then to weak north dips. This is a normal fault whose local opening allowed the filling by milky quartz. Its thrown in the fault plane is of the order of 1000 m.

Nisramont Fault. On map-sheet Wibrin, between the dam of Nisramont and Achouffe, the Nisramont Fault separates two blocks of distinct features : a north block, where the layers of the Jupille Formation are very steep and reversed, and a south block, where the dips of the layers of the La Roche and Jupille formations are often less than 40°.

The question is to know whether it was only an inclined anticline or an inclined anticline also faulted along its axial plane. Directions measured on the layers located southeast of the dam of Nisramont, downstream from this dam to the confluence of the river Ourthe with the Filly stream, being not parallel, militate in favor of a fault. Its passage is observable on the left bank of the Ourthe, at 350 m downstream of the dam. Approximately 300 m to the WSW, Renier, Corin & Grosjean reported a large vein of milky quartz (archives of the geological survey of Belgium, observation of 22-25 August 1928). Briart (1873) had already « …*reconnu la présence d'un très fort filon de quartz…* ». He pointed out that « *Il y aurait donc eu cassure et disjonction du terrain en ce point, et la fente qui en aurait été le résultat, se serait remplie de quartz blanc*.». He still mentioned that the depression he observed there seemed extend to the east « *sur la* *colline de l'autre rive, et redescendre à nouveau sur le versant opposé où elle se trouve en face d'une vallée secondaire se prolongeant jusqu'au hameau de Filly.*». The geology around the dam of Nisramont was studied by Brumagne (1963). Page 157, he pointed out, at the level of the Nisramont bridge, a quartz vein of 1 m thick which may well also be in relation to the Nisramont Fault. In the Trou du Blanc Caillou, a milky quartz vein was mined. This vein appears to correspond to a Riedel fracture linked to the Nisramont Fault.

The Nisramont Fault is a reverse fault whose throw in the fault plane is about 1100 m. East of Achouffe, it merges with the Mousny Fault.

Tultai, Mousny, Ronchouchi, Sainte-Ode and Givroulle faults. Identified on Champlon - La Roche-en-Ardenne (Dejonghe & Hance, 2001a,b) and Amberloup - Flamierge (Dejonghe, 2012a,b) map-sheets, these reverse longitudinal faults of ENE trend crosscut folds that develop south of the La Roche Syncline with a dextral strike-slip component. When they cross sandstone or quartzophyllites facies, they are filled with milky quartz. Quartz veins can reach a thickness of several meters, as it is the case at Mousny, at a place called Les Blancs Cailloux. Quartz infilling is likely due to the strike-slip movement. The Sainte-Ode Fault does not seem to extend to the map-sheet Wibrin. On the contrary, surveys on the map-sheet Wibrin - Houffalize show that the Mousny and Givroulle faults are clearly present there and also act as reverse faults :

Due to the Mousny Fault, the Villé Formation is overlapping the La Roche and Jupille-Pèrnelle formations with a throw of about 1800 m on map-sheet Wibrin. On map-sheet Houffalize, the Mousny-Nisramont Fault has a throw in the order of 1200 m.

Due to the Givroulle Fault, the Villé Formation is overlapping the La Roche Formation. East of Taverneux, this fault only affects the Villé Formation and is therefore little constraint. Nevertheless, it could pass south of Rettigny where a very disturbed zone puts in contact the La Roche and Villé formations.

4.3. The schistosity

Schistosity is well marked only in some formations : it is the case of the La Roche, Jupille and Pèrnelle formations. In other formations, it is often poorly present. It passes from a penetrative cleavage (slaty cleavage or crystallization cleavage which redirects some minerals) to a dissolution cleavage (marked by the existence of planes that delimit volumes free of cleavage). Schistosity is axial plane, fan-like shaped, converging to the core of the synclines in more pelitic lithologies and towards the core of anticlines in more competent lithologies.

On the map-sheet Champlon - La Roche-en-Ardenne, folds are affected by a schistosity tilted towards the SE, SSE, or S. More often, the schistosity plane is subparallel to the stratification plane or cuts it obliquely. In the more pelitic lithologies, schistosity determines the cutting of the rock in more or less regular sheets. At the scale of the map-sheet, the schistosity does not present significant changes of attitude. However, it seems a little less inclined in the Halleux Anticline (many values ranging between 20 and 40 °and tilting towards the SE to SSE) than in the La Roche Syncline where the inclination is more often greater than 45°. This could correspond to the locally most competent character of the rocks of the Halleux Anticline.

On the map-sheet Amberloup - Flamierge, cleavage always presents a SE dip. On map-sheet Amberloup, the cleavage dips vary from 30 to 60 ° SE (in average 40° SE) and the cleavage strikes, from N40° to N60° (in average N50°E). On the map-sheet Flamierge, cleavage dips seem to be more inclined, with values comprised between 40 and 70°SE (in average 50°E) and cleavage strikes are very similar to those of the map-sheet Amberloup with values ranging from N30° to N70°E (in average, N45°E). A statistic by stereographic method on all of the stratification and cleavage measurements on Amberloup and Flamierge map-sheets shows that the cleavage is strictly axial plane (Fig. 4).

On the map-sheet Wibrin - Houffalize, folds are affected by a cleavage tilted from the SSE to the SE. Most often, the cleavage plane is sub-parallel to bedding plane or intersects it obliquely with an angle often between 0° and 20°. In the large majority of cases, its dipping is between 50 and 70° SSE to SE.

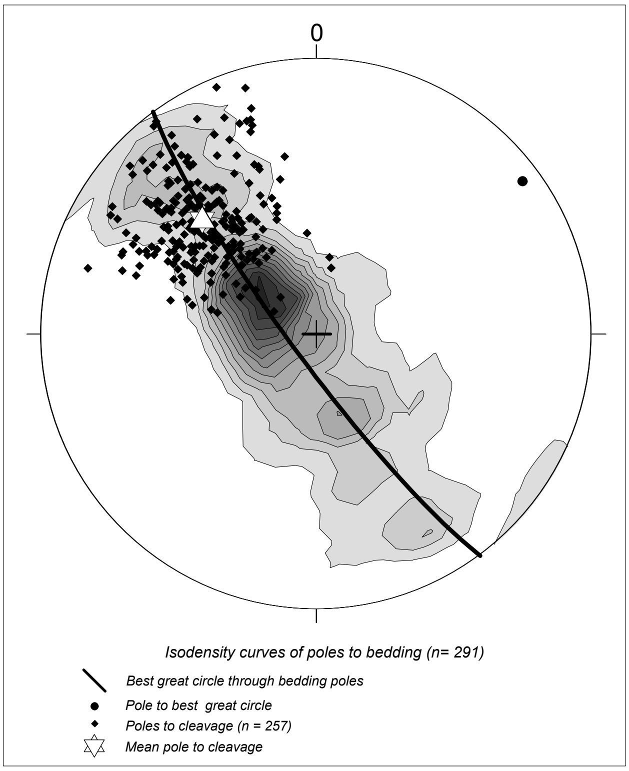

Figure 4. Stereogram of bedding and cleavage measurements for the Amberloup - Flamierge map.

Schistosity is sometimes very strongly developed and then also crosscuts sandstone beds where it is refracted. The phenomenon can be accompanied by boudinage of the beds. Interboudins milky quartz veins follow the planes of refracted cleavage and reach up to 15 cm thick. Before Dejonghe (2005) and Vanbrabant & Dejonghe (2006), the phenomenon of boudinage was practically not documented in this region. The introduction of the concept of boudinage is however due to Lohest and al. and dates back to 1908. Although Leblanc (1923, p. 326) draws a boudinated bed, he does not mention the phenomenon of boudinage. Similarly Asselberghs (1946, p. 452) speaks of "*quartzite en chapelets*", while however, taking over the drawing of Leblanc (1923), he mentions in the legend "*Quartzite boudiné du siegenien moyen*" (Ibid., p. 164, fig. 13). In the archives of the Geological Survey of Belgium, the existence of disturbed beds or of crumpled layers is frequently reported without link to the boudinage phenomenon. The boudinage phenomenon is remarkably illustrated to the east of the area, between Steinbach and Limerlé, in a former quarry equipped for the practice of sport. This former quarry is dug in La Roche Formation (St-Vith facies) where the dark blue grey phyllite incorporates, on the southeast flank of the quarry, a layer of grey coarse grained sandstone, about 1.5 m thick, very much boudinated. The visualization of the boudinage is remarkable there because the upper part of the boudinated sandstone bed is completely clear and shows a beautiful scalloped stratification plane. The sandstone is intersected by interboudins milky quartz veins, lenticular, of varying thicknesses, from a few mm to 8 cm thick (Fig. 5). For a reminder, Goscombe et al. (2004), unlike Kenis et al. (2002), consider that the terms "boudin" and "boudinage" are still applicable in high Ardenne.

4.4. The milky quartz veins

Veins of milky quartz, of several cm thick, in association with boudinage of sandstone beds, are not uncommon. In phyllites, these veins are also sometimes seen parallel to the schistosity, but they are infrequent. Milky quartz veins of some cm thick parallel to schistosity of phyllites and boudinated are however well developed northeast of Achouffe, in the valley of the Eau de Martin Moulin.

Other types of milky quartz veins ranging from a meter to several meters in thickness have been reported in some places :

Figure 5. Top of a boudinated bed in an old quarry located between Steinbach and Limerlé. Belgian Lambert (1972) coordinates of its center : x = 260.313 ; y = 94.608.

At Nadrin (Trou du Blanc Caillou), Renier described a quarry exploiting a quartz vein (archives of the Geological Survey of Belgium, description of 22-25 August 1928). This vein appears to correspond to a Riedel fracture grafted onto the Nisramont Fault. No observation is any more visible because the quarry is completely filled.

At Nadrin, upstream of the dam of Nisramont, in the Au Fays locality, Briart (1873), has « *reconnu la présence d'un très fort filon de quartz* ». Renier, Corin & Grosjean confirm the observation of Briart (1873) and report a « *gros filon de quartz laiteux* » (archives of the Geological Survey of Belgium, observation of 22-25 August 1928). Its location coincides with that of the Nisramont Fault.

Brumagne (1963, p. 157) reported the existence of veins of milky quartz in two places in the municipality of Nadrin : 1. downstream of the Nisramont dam, at the level of Nisramont bridge (quartz vein of 1 m thick which could also coincide with the Nisramont Fault) and 2. At Ollomont, a series of lenses of quartz veins with a thickness of 10 m which presumably correspond to a portion of the Hérou nord Fault.

In a thick rocky bar exposed over approximately 300 m on the left bank of the western Ourthe, southeast of La Nasse locality, several milky quartz veins folded in a complex way have been observed. In the hinges, their thickness may exceed 20 cm. Small veins are oblique to the main fracture as in the case of Riedel fractures. These veins illustrate the compression ratio of sediments during the development of the schistosity.

Abundant very large blocks of milky quartz, several exceeding 1 m, were observed between La Penne and Speche in the vicinity of the Bodaimont Fault.

5. Synthesis

The Amberloup - La Roche-en-Ardenne - Houffalize region is composed of terrains of Lower Devonian age (partially Lochkovian, Pragian and partially Emsian). They are predominantly composed of blue grey phyllite incorporating beds and swarms of sandstone and quartzite, with grey blue and greenish-grey colors. These sediments were deposited in a marine transgression on the Old Red Sandstone Continent which cropped out to the northwest and of which the Brabant Massif is a southern spur. This transgression began during the Late Pridoli - Early Lochkovian (around 426.0 Ma) and continued during the Emsian (around 397.5 Ma) and likely later (part of the succession has been eroded). During this period, the Ardenne-Rhine geosyncline will be fed by mainly siliciclastic sediments. It is also during the Middle Pragian that the maximum extension of this transgression will be achieved. The Mirwart Formation reflects shallow costal sedimentation, attested by abundant current ripples, channels, clasts of dark shales and plant debris (Goemaere & Dejonghe, 2005). On the other hand, the La Roche Formation corresponds to a sedimentation mainly made up of clay, more monotonous, in much deeper or quieter marine environment.

These rocks have been folded in synclines and anticlines following the shortening linked with the Variscan orogeny, the main phase of which dates back to the end of the Westphalian (around 310 to 305 Ma) but whose effects were felt up to 250 Ma ago. The accentuation of the folding caused spills of folds and shear of the upright short flanks of the secondary folds. Reverse longitudinal faults are likely coeval with the main phase of folding. The normal longitudinal faults appeared either early, in connection with the uprising of the chain, or later, during the relaxation phase that followed the folding. This latter interpretation is favored by Delvaux (1990). The transverse normal faults are probably post-Variscan in age.

During the Variscan orogeny, the Stavelot Massif seems to have acted as a shield which has hindered the spread of thrust movement to the north. This hypothesis explains the elbow observed in the axial plane of the Halleux Anticlinorium, near the SW termination of the Stavelot Massif, and the appearance of a dextral strike-slip corridor when blocking has been more marked at the level of the Stavelot Massif. Because of this corridor of dextral strike-slip, displacement of the nappe was more important to the west than to the east. Thrust faults may also have occurred after the blocking of the transverse deflection and would therefore constitute a final phase of shortening. This hypothesis is however not shared by authors who put forward that the Dinant nappe was already folded, thus lithified, and had likely a very similar competence to that of the basement.

Detailed surveys of the northern flank of Houffalize Syncline and the transition to the La Roche Syncline area show that the intermediate structure does not correspond to the shape of a simple anticline known in the literature as the Taverneux Anticline. During the evolution of the Variscan orogeny, an anticline actually formed, then overturned to the north. This anticline was then fragmented by reverse faults (of the SSE to NNW, Givroulle, Sainte-Ode, Ronbouchi, Mousny and Nisramont faults) and probably others who have been reactivated in normal faults during a phase of relaxation/extension (of the SSE to NNW, Hérou sud, Hérou nord and Cheslé faults). This structure is named the Faulted Zone of Taverneux (cross-section in Fig. 3).

In this region, landmarks are clearly related to the geological structure, e.g. the Cheslé Celtic fortifications , the Hérou viewpoint (which allows a good observation of the tight meandering of the Ourthe), the Hérou crest (steep cliffs, 80 to 90 meters high, as part of the Jupille Formation and barring the course of the river Ourthe on about 1400 m long. “Hérou” comes from “Herald” because it was from the top of the cliff that a herald proclaimed sentences of the Court of Nadrin), the feudal Castle of La Roche-en-Ardenne, the Nisramont dam (built on the Ourthe in 1958), Cresse Sainte-Marguerite, the Bernistap canal, etc.

6. Acknowledements

The author gratefully thanks Prof. Jacques Bellière and Pierre Stainier for their reviews and very helpful comments. The English version of the manuscript benefited from kind assistance of Michiel Dusar (Geological survey of Belgium).

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Manuscript received 22.03.2013, accepted in revised form 02.09.2013, available on line 15.09.2013.