Ferrantia

The geology of the Éislek area (North of Luxembourg)

Lithostratigraphy, tectonics and mineral resources of the Lower Devonian within the Wiltz Synclinorium

Léon Dejonghe

94 2026

Page de couverture:
1. Merkholtz, gros bancs de grès exploités en carrière.
2. Stubach, figures de charge.
3. Weiswampach, réfraction de la schistosité.

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Contents

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Léon Dejonghe

Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium
13 Jenner street, B1000 Brussels, Belgium
ldejonghe@naturalsciences.be

Keywords: geological mapping, Lower Devonian, lithostratigraphy, tectonics, mineral resources, Luxembourg, Éislek, Wiltz Synclinorium.

Abstract

The north of Luxembourg, known as the Éislek (Oesling), extends to the SE of the Belgian Ardenne and continues eastwards into the German Eifel, through the Rhenish shield. The subsoil mainly consists of Lower Devonian-age terrain (Pragian and Emsian, from -413.02 Ma ± 1.91 Ma to -393.47 ± 0.99 Ma), including the Mirwart, Villé, Kautenbach-Troisvierges, Jupille, Our, Clervaux and Wiltz formations, listed in order from oldest to most recent.

At the regional scale, the studied area is located:

- In the SE of the axial zone of the Ardenne Anticlinorium drawing a marked elbow shape. To the west, it corresponds to the E-W axis of the Rocroi Massif, whilst to the east, it aligns with NE-SW axis of the Stavelot Massif.

- At the level of the Neufchâteau - Wiltz - Eifel Synclinorium.

This publication summarizes the geological mapping work conducted at a scale of 1:10,000 over the period 2011-2025.

Schlüsselwörter: geologische Kartierung, Unterdevon, Lithostratigraphie, mineralische Rohstoffe, Tektonik, Großherzogtum Luxemburg, Éislek, Synklinorium von Wiltz.

Zusammenfassung

Lithostratigraphie, Tektonik und mineralische Rohstoffe des Unterdevons im Synklinorium von Wiltz

Der Norden des Großherzogtums Luxemburg, Éislek (Oesling) genannt, erstreckt sich geografisch südöstlich der Belgischen Ardenne und reicht im Osten bis zur Eifel, zum Rheinischen Schiefergebirge. Der Untergrund besteht hauptsächlich aus Böden aus dem unteren Devon (Praguium und Ems, von -413.02 Ma ± 1.91 Ma bis -393.47 ± 0.99 Ma), zu denen die Formationen von Mirwart, Villé, Jupille, Kautenbach-Troisvierges, Our, Clervaux und Wiltz gehören.

Auf regionaler Ebene befindet sich das untersuchte Gebiet:

- Im SE der axialen Zone des Ardenne-Antiklinoriums, das eine ausgeprägte Ellbogenform aufweist. Im Westen entspricht es der Ost-West-Achse des Rocroi-Massivs, während es im Osten mit der Nordost-Südwest-Achse des Stavelot-Massivs übereinstimmt.

- Auf der Höhe des Synklinoriums Neufchâteau - Wiltz - Eifel.

Die vorliegende Veröffentlichung ist eine Zusammenfassung der geologischen Kartierungsarbeiten im Maßstab 1:10 000, die im Zeitraum 2011-2025 durchgeführt wurden.

Mots clés: cartographie géologique, Dévonien inférieur, lithostratigraphie, tectonique, ressources minérales, Grand-Duché de Luxembourg, Éislek, Synclinorium de Wiltz.

Résumé

Lithostratigraphie, tectonique et ressources minérales du Dévonien inférieur dans le Synclinorium de Wiltz

Le nord du Grand-Duché de Luxembourg, dénommé l'Éislek (Oesling), s'étend géographiquement au SE de l'Ardenne belge et se prolonge vers l'est, dans l'Eifel allemand, par le Massif schisteux rhénan. Le sous-sol est constitué principalement de terrains d'âge dévonien inférieur (du Praguien et de l'Emsien, de -413.02 Ma ± 1.91 Ma à -393.47 ± 0.99 Ma), comprenant les formations de Mirwart, Villé, Kautenbach-Troisvierges, Jupille, Our, Clervaux et Wiltz, citées dans l'ordre de la plus ancienne à la plus récente.

Sur le plan régional, l'Éislek s'intègre:

- Au SE de la zone axiale de l'Anticlinorium de l'Ardenne matérialisée à l'ouest, par l'axe ouest-est du Massif de Rocroi et à l'est, par celui du Massif de Stavelot qui prend une orientation SW-NE.

- Au niveau du Synclinorium de Neufchâteau - Wiltz - Eifel.

La présente publication constitue la synthèse des travaux de cartographie géologique effectués à l'échelle de 1:10 000 pendant la période 2011-2025.

1 Introduction

The present work constitutes a synthesis of the geological mapping devoted to the Lower Devonian of the Éislek region (north of Luxembourg) over the period 2011-2025. The field survey was carried out at a scale of 1:10,000, and the maps were published by the Geological Survey of Luxembourg at a scale of 1:25,000. The region encompasses five geological sheets shown in Figure 1: Troisvierges Nr 1 (Dejonghe 2018), Wiltz Nr 2 (Dejonghe 2021a), Clervaux Nr 3 (Dejonghe 2020a), Esch-sur-Sûre Nr 4 (Dejonghe 2024a), and Diekirch Nr 5 (Dejonghe & Wagner in progress). Each sheet is associated with an explanatory note published in the series Bulletins du Service géologique du Luxembourg: Troisvierges (Dejonghe 2019), Wiltz (Dejonghe 2021b), Clervaux (Dejonghe 2020b), Esch-sur-Sûre (Dejonghe 2024b), and Diekirch (Dejonghe & Wagner in progress).

Previously, the area was mapped by Lucius (1948a, 1949a). A small portion of the Lower Devonian also appears on the Redange sheet Nr 7 by Colbach (2003).

There are several reasons for updating the Lucius maps of 1948a and 1949a. On the one hand, the topographic background has changed (e.g., modernizations in the road network, new buildings, different extents of woods, crops, and grasslands, improved survey accuracy due to a more detailed basic topographic document and satellite surveys, etc.). On the other hand, geological concepts have evolved. The primary difference is that the old geological maps were based on the principle of chronostratigraphic bedding ("assises" in French), relying on ages generally determined by the fossils present, whereas modern mapping is based on
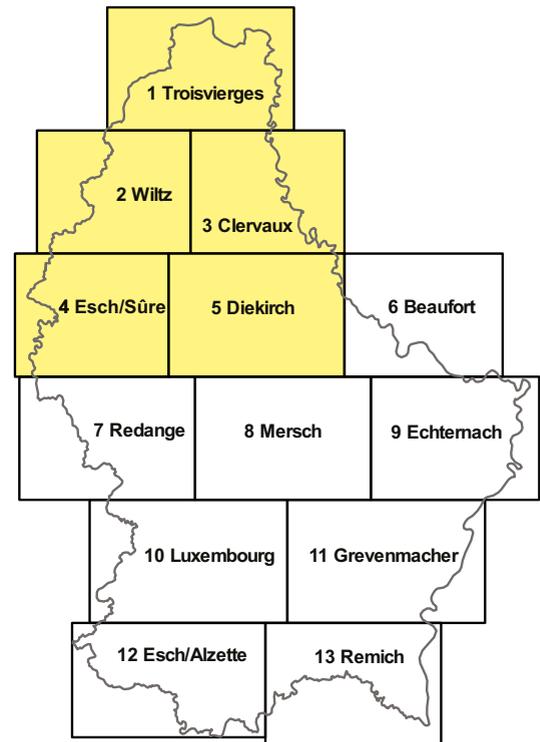

Figure 1: Subdivision outline of the geological maps of Luxembourg, with those relating to Éislek highlighted in yellow.

lithostratigraphic formations, according to the rules of Hedberg (1976) and the International Commission on Stratigraphy (1994), where the lithological composition is paramount. Figure 2 summarizes the differences between the two approaches.

In the past, assises 1, 2, and 3 were mapped, consisting of rocks of the same age but not necessarily of the same lithological nature. Today, formations 1, 2, and 3 are mapped, consisting of rocks of the same type, though their age may vary.

Lithostratigraphic units (formations) divide a lithostratigraphic column into sets of layers with the same properties. The relative age of each formation is determined by its position: a formation is older than the layer above it and younger than the layer below it. This follows the principle of superposition. Formations therefore reflect the geological time scale in each region.

In fact, the stratigraphic subdivisions proposed by Lucius (1948a, 1949a, 1950a) were more closely aligned with lithostratigraphy than with chronostratigraphy. However, they were partially challenged by Furtak (1965) and Konrad & Wachsmut (1973), as some of them could not be identified in the field.

One of the main challenges in modern mapping is defining geological formations. Geologists must select sets of geological layers (strata) from the region's lithological column based on their composition (lithology) and their spatial and temporal relationships (stratigraphy). Formations are the fundamental lithostratigraphic units in geological mapping. They can be subdivided into members or grouped into larger units. Formations are generally named after locations where they are well exposed due to visible and accessible outcrops.

The first significant contribution to the geological subdivision of the Éislek was made by Gosselet (1885). These subdivisions were later adapted by various authors, including Asselberghs (1912, 1913, 1927, 1932, 1941, 1946) and Lucius (1913, 1937, 1940, 1948a, 1949a, 1950a).

Since 2011, geological mapping of the Éislek has been conducted using modern techniques, leading Dejonghe et al. (2017) to redefine the lithostratigraphic framework. This framework was further refined as various maps of the Éislek were developed. The most recent version is presented in Figure 3. Since geological formations extend beyond borders, correlations with formations used in the western neighbouring country, Belgium, are also shown in this figure.

The lithostratigraphy of the Lower Devonian in Belgium has been documented in detail by Denayer & Mottequin (2024). The stratigraphic correlations with the Moselle and the Eifel can be found in Figure 1 of van Viersen & Müller (2024: 91).
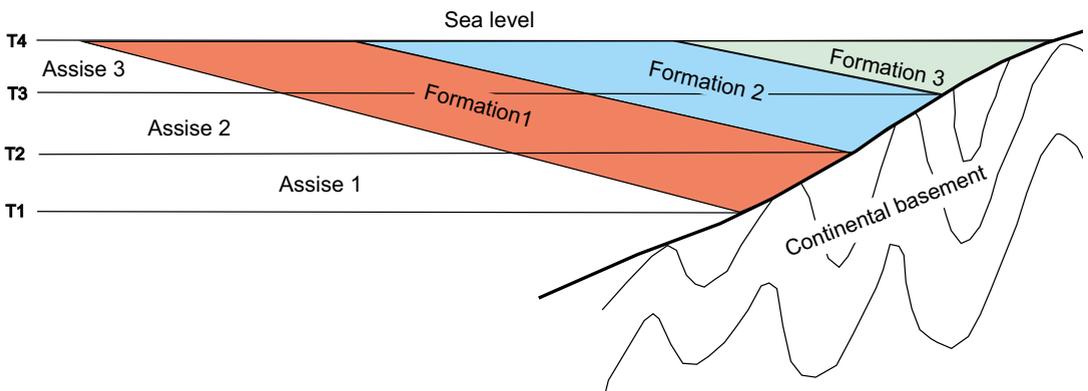
Figure 2: Schematic illustration of ancient and modern cartographic concepts. T1 to T4 correspond to successive periods of time; the coloured zones represent rocks of different types (e.g., brown for shale, blue for sandstone, and light green for limestone). During the period T1-T2, only shales were deposited in the sedimentation basin. Between T2 and T3, both shales and sandstones were deposited. In the interval T3-T4, different types of rocks (limestone, sandstone, and shale) were deposited depending on their distance from the shore.
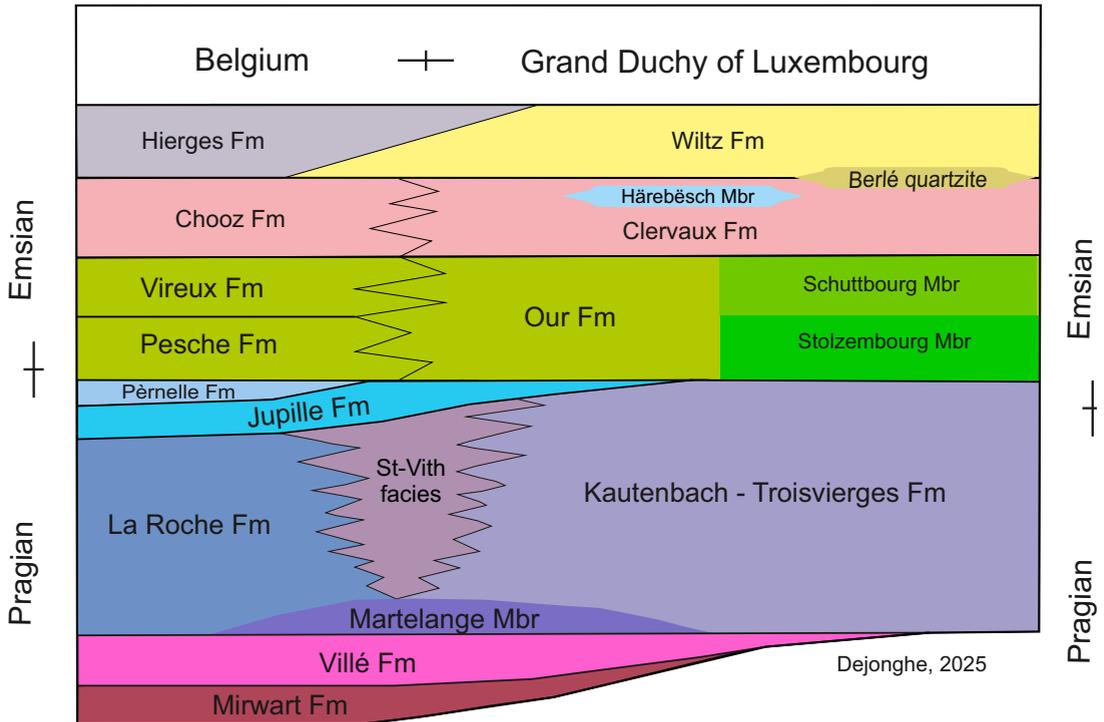
Figure 3: Synthetic lithostratigraphic framework showing the relationships between the geological formations in Belgium and Luxembourg. Correlations follow the biostratigraphic synthesis of Jansen (2016), based on the study of brachiopods. Thicknesses are not to scale. Fm: Formation; Mbr: Member.

To facilitate the interpretation of older publications, Table 1 compares the terminology previously used by Lucius (1949a, 1950a) with the current terminology (Dejonghe et al. 2017).

These formations belong to the Pragian, which spans the time interval from 413.02 Ma ± 1.91 Ma to 410.62 Ma ± 1.95 Ma, and to the Emsian, which extends from 410.62 Ma ± 1.95 Ma to 393.47 ± 0.99 Ma (International Commission on Stratigraphy, December 2024).

In French, the word "schiste" describes a sedimentary rock composed of clay-sized and silt-sized particles that splits along planes of cleavage. As the word "schist" refers in English to a distinctly metamorphic rock, we have chosen to translate the French term "schiste" as "shale." When the rock is extremely fine-grained with a pronounced cleavage, the French term "phyllade" is commonly used; we will refer to it as "phyllite." The term "slate" (French: phyllade ardoisier) refers to a clay-rich rock with a highly pronounced foliation cleavage, making it suitable for quarrying as slate or its by-products. In older French literature, the term "quartzophyllade" is frequently used but difficult to translate into English. It generally describes a mixed rock characterized by millimetre- to centimetre-scale alternations of shales (or phyllites) and sandstones (or quartzites).

Except for the Clervaux Formation, which has distinctive lithological characteristics, including the presence of olive-green and variegated rocks, each of these formations contains dark blue-grey shales and phyllites, which often predominate. Grey sandstones and quartzites are present in varying proportions typically forming a minor component in the lower and upper sections of the lithological column but becoming increasingly significant in the middle part. These formations are distinguished based on fossil criteria and lithological proportions.

Table 1. Comparison of stratigraphic terminologies used by Lucius (1949a, 1950a) and Dejonghe et al. (2017).

Lucius (1949a, 1950a)		Dejonghe, Colbach & Goemaere (2017)	
Emsian	E3 – Wiltz shales q – At the basis, Berlé Quartzite	Emsian	Wiltz Formation (WIL) --------------- Berlé Quartzite (BER)
	E2 – Clervaux variegated layers		Berlé Quartzite (BER) --------------- Clervaux Formation (CLE)
	E1b – Schuttbourg quartzophyllades Frequent intercalations in shales and phyllites of quartzites and quartzophyllades in fairly strong banks E1a – Stolzembourg shales Well stratified rocks. Quartzophyllades and rare quartzite beds.		Our Formation (OUR) Schuttbourg Member (SCH) --------------- Stolzembourg Member (STO)
Upper Siegenian	Sg3 – Compact, coarse, poorly stratified shale with rare banks of clayey sandstone Sg3s – Sandstone facies: Bas-Bellain shale ------------------------------- Sg3a – local slate facies at the base	Upper Pragian	Kautenbach-Troisvierges Formation (KAT) --------------- Martelange Member (MTL)
Middle Siegenian	Sg2 – Sandstone and sandstone shale, compact	Middle Pragian	Villé Formation (VIL)
Lower Siegenian	Sg1 – Blue, black and grey quartzophyllade	Lower Pragian	Mirwart Formation (MIR)

On an isolated outcrop, it is very difficult, if not nearly impossible, to determine which formation the rocks belong to. For the geological mapping of the Éislek, lithostratigraphic correlations of outcrops were established using continuous, sufficiently extensive sections and clusters of adjacent observation points.

2 Geographical and geological frameworks

Luxembourg consists of two natural regions, as shown in Figure 4 (Muller 1980: 51):

- A northern part, called the Éislek (also spelled Islek, Eisleck, Oesling, or Ösling - 32% of the total area), which some translate as "wasteland," and is geologically linked to the Ardennes and Southern Eifel.

- A southern region, the Guttland (also spelled Gutland or Gudland - 68% of the total area), characterized by more fertile land, often water-logged, and which is part of the eastern edge of the Paris Basin.

These two geographical regions also correspond to a geological distinction: the Éislek is made up of terrains from the Lower Devonian (older than 393 million years), while the Guttland consists of terrains from the Triassic and Jurassic periods (younger than 252 million years). The Éislek region is geographically part of the Ardennes-Eifel group (Belgian Ardenne in the NW, Rhenish Massif in the NE). It is an area where the plateaus are dominated by meadows and fields, and where the valleys are generally wooded. The density of outcrops is uneven, being scarce on the plateaus and sometimes quite significant in the valleys.
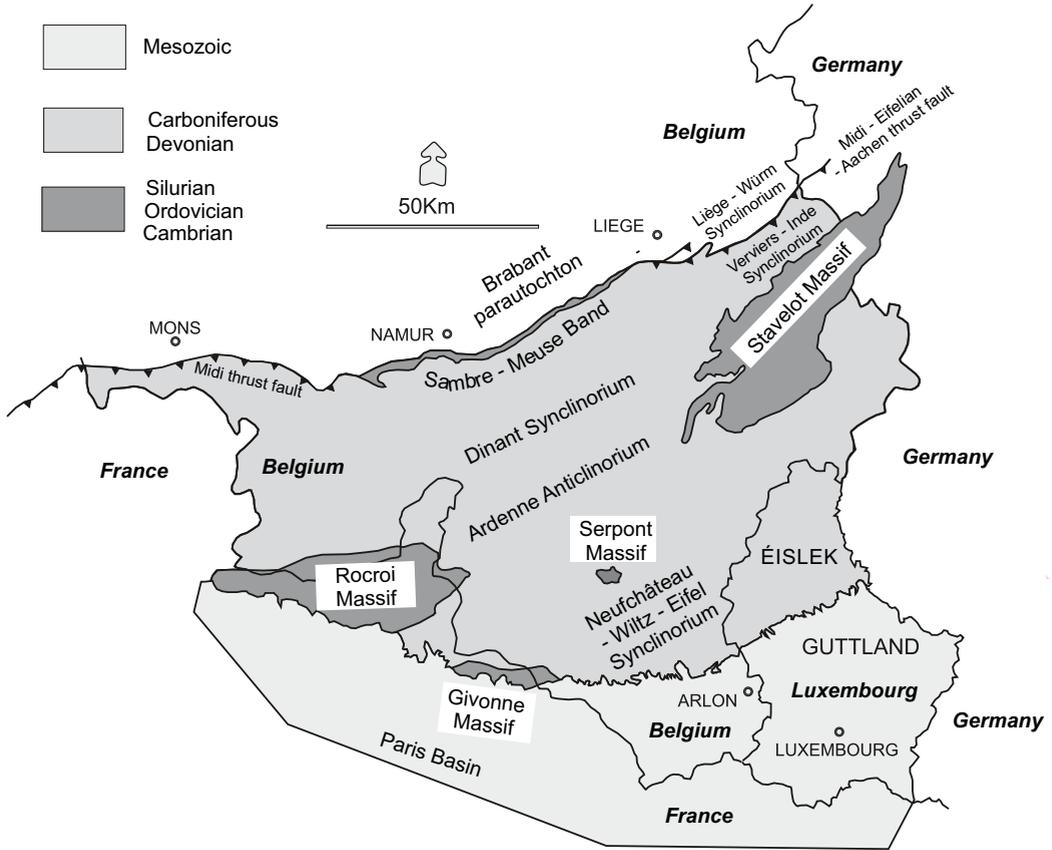
Dejonghe, 2023

Figure 4: Main structural units of Belgium, Luxembourg and France.

The geological history of Luxembourg can be summarized as follows:

- Deposition of a sedimentary series from the Cambrian to Silurian periods, present only at depth; however, this Caledonian basement outcrops in the Belgian Ardenne, in the inliers that occupy the heart of the anticlinal zones: namely, the Givonne, Rocroi, and Stavelot Massifs, and the small Serpont Massif (Fig. 4). Caledonian rocks also exist in the Hunsrück-Taunus region, but they are relatively rare and not always well exposed.

- Caledonian folding followed by erosion and peneplanation.

- Unconformable deposition of a sedimentary series from the Devonian to Carboniferous periods on this Caledonian basement.

- Variscan folding (also called Hercynian folding) followed by erosion and peneplanation. Only the Lower Devonian is exposed in outcrop in the Éislek.

- Discontinuous deposition (in time and space), unconformably on this Variscan basement, of Mesozoic and Cenozoic sediments, which remained unfolded and mostly in a sub-horizontal position.

- After erosion, only the Triassic and Jurassic remain in outcrop in the Guttland, discordant with some Permian and Lower Devonian.

The structuring by Variscan tectogenesis at the end of the Westphalian period consisted of a shortening in a general SSE-NNW direction with folding of the Paleozoic formations into a series of successive composite synclines and anticlines,

cut by numerous longitudinal thrust faults. This folded ensemble is part of the Rheno-Hercynian zone of the Variscan tectogeny in Europe, of which it constitutes the northernmost part.

This summary provides an overview of the geological history of Luxembourg, highlighting the major events and formations that have shaped its current landscape.

3 Lithostratigraphic units

Seven formations are distinguished in the Lower Devonian of the Éislek. They are named, from bottom to top: Mirwart, Villé, Kautenbach-Troisvierges (including the Martelange Member at the base), Jupille, Our (divided into two members, Stolzembourg at the base and Schuttbourg at the top), Clervaux (including the Härebësch Member), and Wiltz. The Berlé Quartzite is located at the boundary between the Clervaux and Wiltz formations (Tab. 1, Fig. 3).

Regarding the paleontological works related to the stratigraphy of the Lower Devonian in this area, the pioneering works of Leblanc (1923), Asselberghs & Leblanc (1934), and Asselberghs (1941, 1946) must be mentioned. They provide lists of macrofossils and the localities where they were found. The paleontological investigations of Asselberghs (1946) are summarized on pages 326-346 and are often referenced in the lists of fossils detailed by Lucius (1950a: 54-62).

Other authors who have carried out paleontological studies in this field include: Kräusel & Weyland (1930), Solle (1937), Lippert (1937, 1939), Asselberghs (1941, 1946), Schultz (1968), Steemans (1989), Blieck et al. (1998), Steemans & Brasseur (1999), Delsate et al. (2004), Franke (2006a,b,c, 2010, 2012, 2016, 2024a,b,c), Franke & Wenndorf (2024), Basse & Franke (2006), Basse et al. (2006), Poschmann & Franke (2006), Müller & Alberti (2010), Plusquellec & Franke (2010), Becker & Franke (2012), Müller & Franke (2012), De Baets et al. (2013), Jansen (2016), Capel et al. (2024), Markus et al. (2024), van Viersen (2025), van Viersen et al. (2025) and the authors of volume 91 of Ferrantia (Ben Thuy & Christian Franke publishers, 2024).

In summary, these studies indicate that the rocks of the Mirwart, Villé, and Kautenbach-Troisvierges formations are primarily of Pragian age, while those of the Stolzembourg and Schuttbourg units, as defined by Lucius (1949a, 1950a), are mainly of Lower to Middle Emsian age. The Clervaux shales are predominantly of Middle Emsian age, whereas the Berlé Quartzite and Wiltz shales belong to the Upper Emsian units.

In modern terminology, the term Middle Emsian is no longer in use. The Emsian is now subdivided into two intervals: the Lower Emsian and the Upper Emsian. However, the term Middle Emsian has been employed by several authors cited in this text. In such cases, the term has been retained in order to preserve the original meaning intended by the authors.

For the stratigraphy and paleontology of the Devonian period in the Ardennes-Rhenish Massif zone, see Ziegler (1982), Ribbert (2008), and Jansen (2016).

Correlations between the different siliciclastic units of the Eodevonian were made based on brachiopods and, incidentally, conodonts. Jansen (2016: 33) specifies that biostratigraphic correlations between the Ardennes and the Rhenish Massif are possible (the meaning of the abbreviations is mentioned by Jansen, 2016):

" Based on the range of *Mult. solitarius*, the upper part of the Mirwart Formation ("Grès d'Anor") and the Villé Formation ("Grauwacke de Saint-Michel") at the southern flank of the Dinant Synclinorium are correlated with the Rhenish middle Siegenian; representatives of an early morphotype of *Acr. primaevus*, *Mau. gosseleti* and *Fasc. sedgwicki* support this assignment. According to Godefroid et al. (1994), *Acr. primaevus* and *Pro. personata* reach into the overlying La Roche Formation and would still prove a Siegenian age of this unit; the latter species was reported up to its upper boundary. The middle-upper Siegenian boundary may be located near the boundary between the Villé and La Roche formations as the typically middle Siegenian species *Mult. solitarius*, *Mau. gosseleti* and *Din. papilio* disappear at this level. Accordingly, the upper Siegenian could be represented by a lower part of the La Roche Formation.

However, the lower Emsian species *Arduspirifer antecedens* (Frank, 1898) and *Ard. latestriatus prolatestriatus* Mittmeyer, 1973b have been reported from a low level within the La Roche Formation, which do not fit to the occurrences of *Pro. personata* and *Acr. primaevus* here (Godefroid et al. 1994); a scrutiny of these taxa may shed new light on this problem. Occurrences of *Mau. gosseleti*, an early morphotype of *Acr. primaevus* and *Pro. personata* suggest a mid-Siegenian age of the Solières Formation ('Grès et Schistes de Solières') on the northern flank of the Dinant Synclinorium (see Maillieux 1931; Godefroid & Stainier 1982; material restudied by the author). "

In the following sections, the locations of geological observation sites are denoted by a letter followed by a number: L for the Troisvierges sheet, W for the Wiltz sheet, C for the Clervaux sheet, E for the Esch-sur-Sûre sheet, and D for the Diekirch sheet. These points are mapped on 1:10,000-scale topographic maps available at the Geological Survey of Luxembourg. In the appendices, readers will find a correspondence table linking these acronyms to their coordinates in the WGS84 system, enabling easy identification on the Luxembourg geoportal (https://map.geoportail.lu).

S1 represents the cleavage plane, S0 the stratification plane, and D1 the joint plane. Measurements are presented as oriented dips. For instance, S1 = 42→157 indicates a cleavage dip of 42° in the direction of 157° clockwise from the north.

3.1   Mirwart Formation - MIR

The term was introduced by Stainier (1994a). The type locality is situated in Belgium, along the railway section crossing Mirwart. Coordinates WGS84: 5.26E/50.06N.

This formation occurs only in a small area of the Éislek, on the Troisvierges and Wiltz sheets. Just to the west, in Belgium, it consists of irregular alternations of dark blue phyllites, shales, and siltstones with argillaceous sandstone layers, as well as sequences of sandstones and quartzites in light grey, beige-grey, and green-grey hues. Generally, the thicker sandstone and quartzite sequences create

well-exposed outcrops. However, this does not imply that these rock types are predominant within the formation (Dejonghe, 2013).

Goemaere & Dejonghe (2005) described the paleoenvironments of this formation at Flamierge, a Belgian locality close to the Belgian–Luxembourg border. Distinctive sedimentological structures pointed out that the very fine sands, coarse-grained silts and muds originated in a tidal flat environment. Tidal channels, mud flats, mixed flats and sand flats sub-environments are vertically stacked. Mud/sand flats represented extended surfaces with very low relief areas without any sandy barrier to protect tidal flat from the open sea. These large surfaces are an answer to the transgression over large flood- and delta plain flat environments.

For more information, see: Asselberghs (1946), Stainier (1994a), Godefroid et al. (1994), Goemaere & Dejonghe (2005), Jansen (2016), Dejonghe et al. (2017).

3.2   Villé Formation - VIL

The formation was named by Godefroid & Stainier (1982). Its type locality lies in Belgium, along the La Roche-en-Ardenne to Houffalize road, where outcrops are abundant. However, its extent is very limited in Éislek due to the eastward and northeastward dip of the layers. Its presence has only been recorded near the Belgian border on the Troisvierges, Wiltz, and Esch-sur-Sûre sheets.

The rock types of the Villé Formation are very similar to those of the Mirwart, Jupille, and Our formations but are distinguished by the relatively frequent occurrence of fossiliferous sandstone layers. More than 200 different species have been described, including crinoids, brachiopods, bivalves, trilobites, tentaculites, and corals (Asselberghs 1946: 147-157).

In the La Roche-en-Ardenne area, the cement of the fossiliferous sandstones is clearly carbonate-based (reacting to 0.1 N HCl). At outcrops, these rocks are generally weathered and consist of a brownish limonitic residue. Toward the east, the carbonate cement gradually disappears, and fossils are dispersed within thicker layers (up to a few metres). Fossils often appear as internal moulds (Fig. 5).

Figure 5: Radelange. Rock debris belonging to the Villé Formation. The fossils, mainly crinoids, appear only as internal moulds.

Shells were reworked into sand-bearing beds by wave and current action, possibly during storms (tempestites). A Pragian age has been determined by Godefroid et al. (1994).

The Villé Formation has also been referred to as the Radelange Formation (d2R) by Colbach (2003) in sheet Nr 7 (Redange). However, due to the lack of high-quality outcrops and the now-established correlation with Villé, the term Radelange should be abandoned in favour of Villé.

For more information, see: Asselberghs (1946), Godefroid & Stainier (1982), Godefroid et al. (1994), Bultynck & Dejonghe (2001), Jansen (2016), Dejonghe et al. (2017).

3.3 Kautenbach-Troisvierges Formation – KAT

The terminology was introduced by Gosselet (1885) and later refined by Dejonghe et al. (2017). The type localities, showing characteristic outcrops, are situated around Troisvierges railway station and in the hamlet of Kautenbach, 5 km east of Wiltz.

In the **Troisvierges area** (Fig. 6), blue grey-phyllites predominate. They split into fine sheets that may contain pyrite cubes (up to 1 cm). In some places, the phyllites are silty to sandy and slightly micaceous. Locally, they contain beds (occasionally lenticular) of light grey or greenish-grey sandstones, sometimes argillaceous and/or slightly micaceous. These sandstone beds are often cut by milky quartz veins that do not extend into the surrounding phyllites. Additional distinctive features may include a quartzitic nature, abundant pyrite cubes (mainly in sandstone beds), oblique stratification, and wavy bedding. Load casts are rare.

In the **Kautenbach area**, blue-grey shales are widely exposed and reach a total stratigraphic thickness of 1,350 m, greater than in the Troisvierges area. Furthermore, access to these outcrops is unrestricted. Blue-grey shales predominate at the base and may contain light grey sandstone laminae and argillaceous sandstone beds (up to 10 cm thick), which highlight the stratification. These beds become increasingly abundant higher in the stratigraphic column. Near the top, they can occur as metric series of beds, often cut by milky quartz veins. Thus, the Kautenbach area exhibits a more

Figure 6: Troisvierges, near the railway station. Point L29. Phyllites of the Kautenbach-Troisvierges Formation.

pronounced sandy character than Troisvierges. Fossils are rare and consist mainly of brachiopods and bivalves. A Pragian age is likely (Godefroid et al., 1994).

The Kautenbach-Troisvierges Formation is interpreted as a lateral variation of the Laroche Formation (Stainier, 1994b) under its so-called St-Vith facies (see Fig. 3). This facies was introduced by Asselberghs (1927: 206) and further defined in 1946 (ibid.: 179-186). Colbach (2003) referred to it as the Grumelange Formation (d2G) in the geological Redange map, but this term should now be abandoned. Godefroid et al. (1994: 54) suggested that the Laroche Formation is probably Pragian in age.

On the Diekirch map, a fossil site located approximately 2.3 km ESE of Heiderscheid church has been known since 2006 as the Réideschbaach fossil fauna. It contains trilobites studied by Basse & Franke (2006) and Basse et al. (2006). Additionally, the pleurodictyform reported at this site by Basse & Franke (2006) was re-examined by Plusquellec & Franke (2010) and redefined. These authors attribute the fossils to the basal part of the Lower Emsian.

In 2021, under the aegis of the Musée national d'histoire naturelle Luxembourg, an excavation using a mechanical digger was carried out in the valley of the river Fél. Since the fossils from the Réideschbaach fauna had been collected from alluvium rather than an in-situ rock outcrop, one of the objectives of the 2021 campaign was to reach the in-situ rock beneath the alluvium and locate the original fossiliferous layer. The lithological log presented by Hellemond & Vellekoop (2024 figs. 7 and 8) shows a very limited fossiliferous level within a predominantly pelitic lithology. It is reasonable to question whether this limited level provided the rich fossil assemblage discovered in the alluvial deposits. But the excavation did yield new fossil samples, which were studied in detail. The results were published in Ferrantia (2024, vol. 91, Ben Thuy & Christian Franke, eds.).

The age inferred from this fossil assemblage corresponds to the lower part of the Lower Emsian.

Hellemond & Vellekoop (2004) questioned the formation from which these fossils originate but did not determine whether the fossiliferous site belongs to the Kautenbach-Troisvierges Formation or the Our Formation (Stolzembourg Member).

According to the geological maps of Lucius (1949a, b), the excavation site lies within the Upper Siegenian (Sg3), which is extensively represented southeast of Heiderscheid. Our surveys place it within the Kautenbach-Troisvierges Formation, equivalent to Lucius' Sg3, which we identified over a radius of more than 1,500 m around the excavation site. Moreover, the lithological log drawn by Hellemond & Vellekoop (2004: fig. 3) is predominantly pelitic, suggesting that the age of the Kautenbach-Troisvierges Formation should be extended to include part of the Lower Emsian.

For more information, see: Gosselet (1885), Asselberghs & Leblanc (1934), Asselberghs (1946), Lucius (1950a), Godefroid et al. (1994), Stainier (1994), Bultynck & Dejonghe (2001), Jansen (2016), Dejonghe et al. (2017).

3.4 Martelange Member – MTL

Martelange is a village in Belgium, located precisely on the Belgian–Luxembourg border. The corresponding locality on the Luxembourg side is called Rombach-Martelange.

The Martelange Member (MTL), identified by Brichant (1927), is found at the base of the Kautenbach-Troisvierges Formation (KAT) and consists of blue-grey slates (Fig. 7). These slates were locally quarried for roofing tiles and similar purposes, primarily in the Martelange-Perlé area and near Asselborn (Emeschbaach), approximately 30 km to the northeast. A smaller slate quarry was also present about 20 km north of Martelange, in the Niederwampach-Schimpach region. Exploitation of this slate level is detailed in section 9.

Foliation cleavage (phyllitic cleavage) is highly pronounced. The member is highly lenticular and can locally disappear entirely. The geological setting and underground mining of this unit were

Figure 7: Wolwelange, place called Leekoll, outcrop along the cycle track, NNW side. Point E232. Summit of the Martelange Member. Blue-grey phyllites breaking into thin sheets corresponding to the cleavage planes (S1mean = 42 →157). Joint brittle fractures (diaclases): D1mean = 67→345. The yellow part of the hammer handle is 13.5 cm long.

described by Asselberghs (1924) and Lucius (1947b, 1950a).

Brichant (1927: M8) refers to the Assise de Martelange (Sg2b), which he assigns to the Upper Hunsrückian (an earlier equivalent of the Upper and Middle Siegenian or, more recently, the Middle Pragian). Lucius (1947b, 1950a), who provides a detailed description of the Martelange-Perlé and Asselborn slate phyllite mines, assigns them to the Upper Siegenian (Sg3), corresponding to the Kautenbach-Troisvierges Formation.

For more information, see: Asselberghs (1924, 1946), Brichant (1927), Lucius (1947b, 1950a), Mayérus (1953), Belanger (1992), and Dejonghe et al. (2017).

3.5   Jupille Formation - JUP

Jupille is a small village in Belgium, located between Hotton and La Roche-en-Ardenne in the Ourthe Valley. The abundance of sandstone beds at the top of the Pragian justified the introduction of the Jupille Formation in eastern Belgium by Dejonghe et al. (2008). This formation, well represented in the Ourthe Valley, extends as far as Luxembourg on the Troisvierges sheet, although it is significantly bevelled in this direction.

The formation consists of abundant lenticular beds (a few centimetres or decimetres, sometimes metres thick) of green, blue-green, or greenish-grey sandstones. These are sometimes laminar and occasionally argillaceous. A limonitic alteration is commonly observed on the periphery of fractured blocks. Occasionally, the beds form several-metre-thick series, creating large outcrops that have frequently been exploited. Sandstone beds are interlayered with blue-grey siltstones and phyllites, like those of the La Roche and Kautenbach-Troisvierges formations. Grey micaceous sandstones with tool marks, current ripples, lenticular and oblique stratifications, and wavy bedding are also present. Load casts up to 50 cm in length have been observed. All intermediate rock types between pure sandstone and pure quartzite are found within the formation. The rock's cement can also be very slightly carbonated. Fossils were described by Asselberghs (1946: 181-184).

The Pèrnelle Formation, which lies above the Jupille Formation in Belgium, is included in the palynological biozone Su of the uppermost Pragian (Steemans, 1989). This datum provides a stratigraphical constraint on the Jupille Formation.

For more information, see: Dejonghe et al. (2008), Dejonghe et al. (2017).

3.6   Our Formation - OUR (Stolzembourg Member - STO and Schuttbourg Member - SCH)

This formation, introduced by Dejonghe et al. (2017), is named after the Our River, which forms part of the German–Luxembourg border, where the relevant rocks are widely exposed. Stolzembourg is a village in the Our Valley, while Schuttbourg is a castle located in the Clerve Valley, north of Kautenbach.

Lucius (1949a, 1950a) identified petrographic differences between the lower and upper parts of this series, justifying its subdivision into two sections. He stated that:

> The lower part (E1a), corresponding to the schiste de Stolzembourg, is dominated by shales, phyllites, and mixed quartzite-phyllite rocks of dark colors, with thin and infrequent quartzitic sandstone intercalations. Stratification is almost entirely obliterated by cleavage.

> The upper part (E1b), forming the quartzophyllades de Schuttbourg, exhibits clear stratification due to the presence of thick quartzitic sandstone beds frequently intercalated within shales and phyllites.

Although Dejonghe et al. (2017) acknowledge that the lithology of the lower part of this series differs significantly from the upper part, they argue that Lucius's (1949a, 1950a) subdivision is difficult to apply in the field due to the progressive nature of lithological variations. Consequently, an accurate stratigraphic boundary marked by a distinct reference bed cannot be established. Instead, Lucius's subdivisions should be regarded as facies variations within the Our Formation. This perspective is supported by Furtak (1965) and Muller (1980: 586-587).

Konrad & Wachsmut (1973) take this argument even further, suggesting that clear boundaries cannot be drawn between the Kautenbach-Troisvierges Formation, the Stolzembourg Member, and the Schuttbourg Member, and that they should all be grouped into a single unit. While Dejonghe et al. (2017) adopt the views of Furtak (1965) and Muller (1980), they do not fully embrace the position of Konrad & Wachsmut (1973). To facilitate the interpretation of older studies, they propose subdividing the Our Formation into two members - Stolzembourg at the base and Schuttbourg at the top (Fig. 3) -, while acknowledging that the boundary between these two members remains highly subjective.

In the **Stolzembourg Member**, the argillaceous nature of the rock is predominant. The rocks range from silty to sandy and consist of dark grey to dark blue-grey shales or coarse-grained phyllites. Shales and phyllites transition imperceptibly into argillaceous and weakly micaceous dark grey to dark blue-grey sandstones. Occasionally, very compact sandstone layers, typically ranging in thickness from a few centimetres to a few decimetres (and sometimes a few metres), are observed. Current ripples and load casts might also be observed.

In the **Schuttbourg Member**, shales and phyllites contain frequent interbedded sandstones and quartzites, typically ranging in thickness from 10 to 30 cm. These beds occur either in isolation or in sets exceeding 20 m in thickness, often making them suitable for quarrying (notable sites include Heinerscheid, Holler, Lieler, Sassel, Weiswampach, Clervaux, Untereisenbach, Consthum (Fig. 8), Merkholtz (Fig. 9), Roullingen, etc.). Locally, this rock type is referred to as "Hassel."

In the **Our Formation**, the sandstones are mostly grey to greenish and noticeably lighter in colour than the surrounding shales and phyllites. As their argillaceous and micaceous content increases, the sandstones darken progressively. In some areas, laminar textures (Fig. 10) and even ribbon-like structures can be observed. In the latter case, the rock consists of alternating layers of grey sandstone and dark grey argillaceous sandstone, a lithology historically referred to as "quartzophyllade" in French. Undulating sedimentary joints (current ripples) are rare, and beds are typically bounded by planar surfaces, though occasionally they appear lenticular. The thickest sandstone beds are often traversed by milky quartz veins, but no evidence of boudinage has been observed.

Figure 8: Consthum, site known as Pënzerhuuscht, point C649. Views of the Rinnen quarry, which exploits the sandstone beds of the Schuttbourg Member (situation as of 27/03/2017).

Figure 9: Merkholtz, point W466. Abandoned quarry where grey sandstone beds of the Schuttbourg Member were extracted. The sandstone layers are several decimetres thick (situation as of September 2019).

In certain locations, load casts (also known in English literature as "ball and pillow" structures and in French literature as "pseudonodules") are present (Figs 11, 12, 13). These structures result from the gravitational sinking of sandstone masses into a more clay-rich substrate and may be associated with the subaqueous sliding of water-logged sediments.

Macar & Antun (1950) provided a detailed description of these structures in the Lower Emsian at various sites in the Éislek region. They noted that load casts tend to occur more frequently at the base than at the top of the Our Formation (ibid.: B124). Similarly, Dejonghe (2020b: 15) observed load casts in this formation on the Clervaux sheet, with a higher concentration towards its base. However, on the Troisvierges and Wiltz sheets, load casts have been documented both at the base and at the top of the Our Formation (Dejonghe, 2019: 19-20; 2021b:

19). Additionally, on the Esch-sur-Sûre sheet, load casts appear frequently at various stratigraphic levels within the Stolzembourg Member but are much rarer in the Schuttbourg Member (Dejonghe, 2024b). On the Diekirch sheet, they have been identified in the upper part of the Stolzembourg Member and at a single location within the Schutt-bourg Member.

While these structures may, in some cases, have been triggered by earthquake-like events, they do not serve as precise stratigraphic markers. However, their presence strongly suggests that they are more characteristic of the Our Formation than of the Kautenbach-Troisvierges Formation. Moreover, they provide valuable indicators for determining bed polarity.

In the Steffeshausen quarry, located at Burg-Reuland in Belgium, near the Belgian–Luxembourg border, De Baets et al. (2013) identified ammonoids
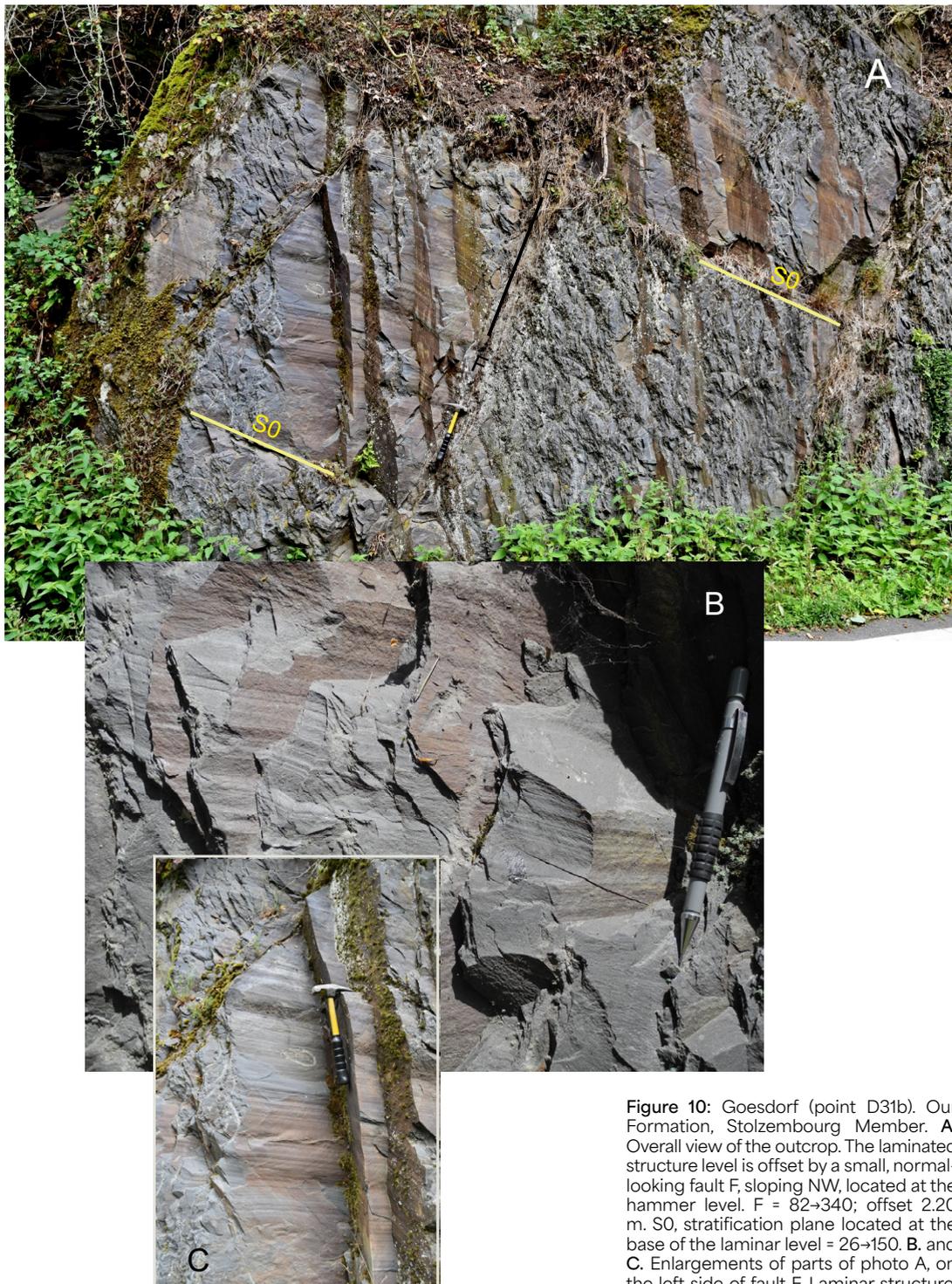
Figure 10: Goesdorf (point D31b). Our Formation, Stolzembourg Member. **A.** Overall view of the outcrop. The laminated structure level is offset by a small, normal-looking fault F, sloping NW, located at the hammer level. F = 82→340; offset 2.20 m. S0, stratification plane located at the base of the laminar level = 26→150. **B.** and **C.** Enlargements of parts of photo A, on the left side of fault F. Laminar structure. B: the mechanical pencil is 14 cm long. C: the hammer is 35 cm long.

Figure 11: Büderscheid, point E46c. Our Formation, Stolzembourg Member. Load casts are present over a stratigraphic thickness of 3 m at the level of the scale bar. S0 = stratification.

in the Our Formation. This discovery confirms the marine nature of the formation and suggests a Lower Emsian age (corresponding to Singhofen or Vallendar in the German classification). Later, Hellemond et al. (2019) completed the assembly of marine fossils.

The discovery of a psammosteid heterostracan in the Schuttbourg Member by Delsate et al. (2004) marks the second confirmed occurrence of a vertebrate in Luxembourg's Lower Devonian and represents the first recorded instance of a psammostoid heterostracan in the Ardennes Massif. However, the age attributed to the Schuttbourg Member has been debated. The authors note that while it is often assigned to the upper part of the Lower Emsian (E1b, according to Lucius 1949a, 1950a, 1955), the fossil assemblage from the relevant locality (a quarry southeast of Merkholtz) suggests a Middle to Upper Emsian age (E2 to E3, following Lucius 1948, 1949a, 1950a). Traditionally, these beds have been associated with the Clervaux and Wiltz formations.

Capel et al. (2024) have re-evaluated the flora from the rocks of the Rinnen quarry at Consthum (Schuttbourg Member), also assigning it a Middle Emsian age. In modern chronostratigraphic terminology, this is equivalent to the Lower Emsian.

Based on the latest palaeontological studies, the Our Formation likely spans the Lower to Middle Emsian transition in the sense of Lucius (1950a).

For further information, see: Asselberghs (1946), Lucius (1950a), Godefroid et al. (1994), Bultynck & Dejonghe (2001), Jansen (2016), Dejonghe et al. (2017).

Figure 12: Eschdorf, point E105. Our Formation, Stolzembourg Member. In a former quarry west of Eschdorf, load casts layers were extracted together with adjacent sandstone beds. The image shows two load casts levels: the lower one, at hammer height, and the upper one, of which only the base is visible at the top of the photograph. S0 = stratification. The hammer is 35 cm long.

Figure 13: Eschdorf, point E105. Our Formation, Stolzembourg Member. Close-up of a large load cast located at the extreme left of Figure 12 (partially obscured by a tree). The hammer is 35 cm long.

3.7   Clervaux Formation - CLE

Although it is well known that geological formations can be diachronous and vary laterally in thickness, some confusion arises when comparing different stratigraphic interpretations of the Clervaux Formation in Luxembourg and Germany. For German authors, the "Klerfer Schichten," "Klerf Schichten," or "Klerf Formation" do not correspond exactly to the same stratigraphic level as the "Clervaux Formation" defined in Luxembourg (see, for example, Landesamt für Geologie und Bergbau Rheinland-Pfalz, 2005: 36-39; Ribbert 2008: 288, or for a broader discussion, Franke 2006b: 54-57). The German perspective is summarized in Lithostratigraphische Einheiten Deutschlands (Ribbert 2007).

In Germany, the Klerf Formation encompasses a broader time frame than the Clervaux Formation as defined here and therefore also includes the period corresponding to the Our Formation. Since the term Schistes rouges de Clervaux (Clervaux Red Shales) was originally defined by Gosselet (1885: 269), priority is given to its primary usage. The German use of the same locality name (Clervaux) for two different lithostratigraphic units is unfortunate, even though both units (one in Luxembourg, the other in Germany) share the same facies. This issue has been further clarified by Dejonghe et al. (2017: 39). See also Godefroid's nomenclatural note on the term Clervaux in Delsate et al. (2004: 23).

The defining characteristic of this formation is its coloration. The Clervaux layers consist of a mixture of shales, very fine-grained sandstones (micro sandstones), siltstones, and coarse-grained sandstones in various colours: predominantly light or pale green (olive-green), as well as burgundy (wine-red to reddish) (Fig. 14) and variegated shades. The rocks are sometimes micaceous and laminated, locally clay rich. Quartzites are generally greyish white. The pale green shales have a soft, talc-like texture. The burgundy coloration can be subtle, appearing only on stratification joints, laminations, cleavage planes, or joint brittle fractures (diaclases), sometimes forming irregularly shaped spots.

In simplified terms, the burgundy and variegated colours are most prominent in the shales and siltstones, the olive-green hue is characteristic of clayey to highly clayey sandstones, and the grey coloration is typical of pure sandstones.

In certain areas, the rock contains irregularly shaped limonitic bodies measuring a few millimetres in size. Some of these limonitic structures exhibit faint ribbing, suggesting they may be fossil remnants. These limonitic bodies, likely altered calcretes, are a distinctive feature of the formation. The outer surfaces of the sandstone blocks are occasionally coated with limonite, and in some cases, the limonite pigmentation extends throughout the entire sandstone mass.

Lithological variations occur rapidly, likely due to shifts in sedimentation zones, including marine, coastal, and continental environments. Asselberghs (1932: 9) initially suggested that the Clervaux beds corresponded to a regression. However, in 1941, he refined his assessment, stating that the maximum regression took place in the lower part of the Clervaux shales, which he dates to the Middle Emsian. A subsequent transgression began in the Middle Emsian and continued beyond the Clervaux period, persisting into the Upper Emsian with the deposition of the Berlé Quartzite and the Wiltz shales (Asselberghs 1941: 78).

Franke (2006b) identified both marine and continental fauna characteristic of the formation. Through facies studies, he sought to document and establish the nature of the Clervaux beds as part of a river-dominated delta. He interpreted the simultaneous deposition of fauna from stagnant water areas within the delta plain and from marine shallow-water environments at the delta front, the prodelta, and reoccupied areas with pioneer populations. The emergence of an estuarine system during this time is highly probable and was confirmed by Michel et al. (2010). Their sedimentological study, based on facies analysis and magnetic susceptibility of the Clervaux Formation in the Wiltz Synclinorium (Himmelbaach quarry), proposed a tide-dominated marginal-marine depositional model consisting of three facies: tidal channels, tidal flats, and tidal sand ridges.

Although Franke (2006a) identified the characteristic fauna of the Clervaux Formation in Luxembourg and the Eifel, fossils are relatively rare in Belgium and the Grand Duchy. However, a fossiliferous deposit near Wiltz enabled Asselberghs (1941: 75-78) to determine an Emsian age for this formation. Michel et al (2010) place this formation in the Middle Emsian, while Franke (2006a) dates it to the Lower Emsian.

For further details, see: Gosselet (1885, 1888), Leidhold (1913), Asselberghs (1941, 1946), Lucius (1950a), Faber (1982), Franke (2006b), Michel (2012), Jansen (2016), Dejonghe et al. (2017).

Figure 14: Dorscheid, Point C13b. Clervaux Formation. Burgundy shales. S1 = cleavage. The mechanical pencil is 13 cm long.

3.8 Härebësch Member - HAR

Härëbesch is a location in Weidingen, in the city of Wiltz. The Härebësch Member, part of the Clervaux Formation, was introduced by Dejonghe (2021b). It consists of a thick sequence of grey (occasionally greenish or light olive-green) sandstone to quartzite, forming massive multi-decimetre to metre-scale, or even multi-metre beds. The sandstone can be coarse-grained or laminated, with thin clayey inter-layers that are typically olive-green.

These rocks were historically quarried in large extraction sites along the Wiltz River, east of Wiltz (Figs 15 and 16), as well as in a series of smaller quarries in the Himmelbaach Valley.

The littoral nature of this geological member, resembling a tidal flat deposit, is evidenced by the following observations:

- Desiccation polygons

- Current ripples (either unidirectional or interference ripples)

- Oblique stratifications

- Lenticular banks with erosional features

- Worm tracks, horizontal burrows, and more generally, bioturbation

- Plant debris

- Nodular calcretes

The term calcrete refers to a pedogenetic carbonate soil concretion that forms in climates with distinct wet and dry seasons. These features are often associated with vertic structures (also known as paleovertisols in French) and typically develop on alluvial plains.

For further details, see Maquil et al. (1984) and Dejonghe (2021b).

Figure 15: Quarry in Weidingen (site W246a) where sandstone from the Härebësch Member was extracted. The best stratification planes are highlighted in yellow. Black line: fault.
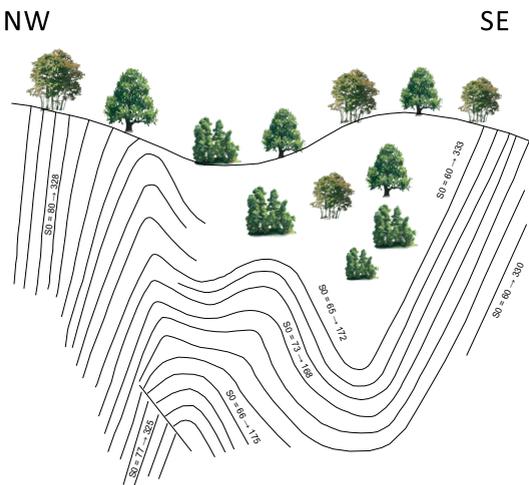
Figure 16: Diagram of the quarry strata shown in Figure 15, indicating the orientation of dips (S0).

3.9 Berlé Quartzite - BER

Berlé is a small village located between Bastogne and Wiltz. The term "Berlé Quartzite" was first introduced by Gosselet (1885), who referred to the "quartzites (plural) de Berlé." The characteristic rock is a white or yellowish quartzite, occurring in massive beds ranging in thickness from a few decimetres to several metres, separated by shale interlayers. This quartzite forms a lenticular level with an average thickness of 10 m, though it may be absent in some areas. Where it has been quarried, Lucius (1950a: 21) reported a thickness of 2-5 m south of Harlange and 10-15 m further east.

Stratification joints are sometimes cup-shaped, and cupules corresponding to internal fossil moulds have been observed by Dejonghe (2020b: 22–23). In some areas, limonitic bodies are present, often lacking a defined contour and only rarely preserving

fossil outlines. Additionally, quartzite in certain locations is veined with milky quartz. At Obereisenbach, Dejonghe (2020b: 23) noted the presence of cylindrical burrows filled with black clayey rock in the central part of some quartzite beds, creating a stark contrast with the white quartzite (Fig. 17).

The stratigraphic position of the Berlé Quartzite has been debated by several authors, including Asselberghs (1932: 6, 14–15) and Lucius (1950a: 21). Some studies have placed it at the top of the Middle Emsian, within the Clervaux Formation (e.g., Asselberghs 1932; Lucius 1947a; Muller 1980), while others have assigned it to the base of the Upper Emsian, at the bottom of the Wiltz Formation (e.g., Gosselet 1885; Lucius 1950a). Minten (1997) considers it a diachronous unit, occurring simultaneously at the top of the Clervaux Formation and the base of the Wiltz Formation. At Obereisenbach, Dejonghe (2020b: 23) observed the Berlé Quartzite precisely at the boundary between the Clervaux and Wiltz formations.

However, this level is not consistently visible at the Clervaux-Wiltz formation boundary, raising questions about its lateral continuity. Like Michel (2012: 9, 184), we believe it represents a discontinuous lenticular deposit. While Lucius, when preparing his 1949 map, likely had access to more outcrops of the Berlé Quartzite than are observable today, the continuity he assigned to it on that map does not seem to reflect geological reality. In some areas where he indicated its presence, geological evidence suggests that it does not actually exist (Dejonghe 2021b: 46).

Furthermore, the question of whether the Berlé Quartzite represents a single stratigraphic unit remains open. It appears that multiple levels of white quartzite with Berlé facies occur within the Clervaux Formation. Faber (1982) and Dürkoop (1992) suggest that the upper part of the Clervaux Formation contains decimetre-thick beds of massive quartzite, referred to as precursor quartzite or Vorläufer-Quarzit. However, in most cases, the Berlé Quartzite has been observed near the boundary between the Clervaux and Wiltz formations, making it a valuable stratigraphic marker at the transition between the Middle and Upper Emsian in Lucius's (1948a, 1950a) terminology.

Jansen (2016) established the Berlé Quartzite as a geological formation, placing it at the base of the Upper Emsian and correlating it with other formations in the Rhenish Massif. He refined the classification of brachiopod species specific to this level, designating it as the Berlé event, characterized by a sudden intensification of marine transgression. This event was preceded by a regression at the top of the Lower Emsian (Vallendar age level). However, this distinctive level does not meet the minimum thickness of 30 m required to qualify as a formation (Hedberg 1976) but could be classified as a member of a formation.

The quartzite contains numerous fossil moulds described by Asselberghs (1912: M60-61, 1946) and Leidhold (1913). However, Franke (2016) conducted the most detailed faunal study, providing numerous illustrations of the benthic fauna, primarily composed of brachiopods and bivalves. His research demonstrated that at the onset of the Upper Emsian, one-third of all recorded species were newly appearing.

Michel (2012) proposed a model in which the Berlé Quartzite represents tidal sand ridges, laterally transitioning into the flaser-bedded sandstones at the top of the Clervaux Formation. This lateral facies transition supports the interpretation that the Berlé Quartzite is a lenticular deposit. It is a prominent landscape feature and a highly resistant rock, valued both as a building material and for its refractory properties. Measurements of the illite crystallinity index by Michel (2012) indicate that the Berlé Quartzite has undergone varying burial conditions depending on the region.

Dejonghe (2020b: 22-25) provides detailed observations of its occurrences on the Clervaux geological map sheet. Notably, at Obereisenbach (point C285e), along the N10 road, it outcrops over a stratigraphic thickness of approximately 8 m, with well-exposed contacts with the Clervaux and Wiltz formations. On the Wiltz sheet, the abundance, length, and width of mining trenches between Berlé and Roullingen suggest that the Berlé Quartzite was particularly well-developed in this area. Additional occurrences are detailed by Dejonghe (2021b: 27-28).

For further references, see: Gosselet (1885), Leidhold (1913), Heuertz (1933), Asselberghs (1932, 1941, 1946), Lucius (1950a), Faber (1982), Maquil

Figure 17: Obereisenbach, point C285e. Berlé Quartzite containing cylindrical burrows a few millimetres in diameter, filled with black clayey rock. The black part of the mechanical pencil located at the bottom left of the photo has a diameter of 8 mm.

et al. (1984), Dürkoop (1992), Franke (2006a), Michel (2012), Jansen (2016), Dejonghe et al. (2017), Dejonghe (2020a,b).

3.10 Wiltz Formation - WIL

The type locality of this formation is the city of Wiltz. Gosselet (1885) referred to the schistes de Wiltz. Indeed, the formation primarily consists of shale, which can be locally silty or resemble sandstone. In some cases, the rock gradually transitions into a highly clay-rich sandstone. Depending on the location, the rock exhibits varying shades of grey - sometimes with a slight violet tint on certain fracture planes - as well as greenish-grey and blue-grey hues. The shale is characterized by a pronounced transverse cleavage, often breaking into thin sheets and sometimes resembling phyllite.

In certain areas, the shale contains nodules of fine-grained, massive sandstone with no internal structure. These nodules, typically bluish-grey, measure about 10 to 15 cm in length and 3 to 5 cm in thickness. Locally, they may also consist of iron-rich sandstone (Lucius 1950a: 20) or spherosiderite concretions (Muller 1980: 587). The core of these nodules sometimes alters into a purplish residue. Some nodules form around a light grey nucleus, a few centimetres in diameter, with no distinct shape; these nuclei effervesce in 1/10N HCl.

Inside the Wiltz Formation, stratification is usually difficult to discern due to the rock's strong foliation. The elongated nodules are generally reoriented along the foliation planes. When numerous and closely spaced, their alignment can help identify the stratification plane, particularly at the base of the formation.

Fossiliferous beds, particularly rich in *Spirifer arduennensis*, are common, especially in the lower part of the formation (Asselberghs 1946: 61) (Fig. 18). The faunal assemblage of the Wiltz Formation has been studied by Leidhold (1913), Lucius (1950a: 60), and in greater detail by Franke (2010, 2012) and Müller & Franke (2012), covering lamellibranchs, brachiopods, gastropods, cephalopods, trilobites, crinoids, and more.

The correlation between the Wiltz Formation in Luxembourg and the Hierges Formation in Belgium has been discussed by Franke (2010: 9,11), who writes:

"Lithologisch ähneln die Wiltz-Schichten den weiter westlich gelegenen Schistes de Hierges in Belgien, besonders südlich von Couvin am linken Ufer der Eau Noire (Fundpunkt siehe Godefroid et al. 1994: 82), deren unterste Schichten stratigraphisch etwa gleiches Alter anzeigen. Weiter östlich gibt es in dieser Form wenig konkrete kompatible Vergleichsmöglichkeit. Dort finden sich petrographisch ähnliche Sedimente erst in stratigraphisch jüngeren Schichten, die wie im Sauerland bis ins Mittel-Devon reichen können. Eine denkbare Erklärung bietet die Theorie der Heraushebung der Manderscheider Schwelle (Lippert & Solle 1937), mit der die Trennung größerer Meeresbecken seit dem Beginn des Ober-Emsiums erklärt werden könnte, die letztendlich auch durch diese Arbeit faunistisch besser untermauert werden kann."

Although the Hierges and Wiltz lithological units are of relatively similar age, as indicated by their faunal content, they should be distinguished by an inclined boundary line (Fig. 3). According to Jansen (2016), the top of the Hierges Formation appears to be slightly younger than that of the Wiltz Formation. The Wiltz layers were likely deposited under paleogeographic conditions much farther from the mainland (more distal) than the Hierges Member of Bois-Chession, which exhibits a distinctly coastal (proximal) character.

During the Late Emsian transgression, the Wiltz Formation would have represented a distal marine environment, whereas the Hierges Formation would have corresponded to a coastal marine setting. Franke (2010: 5) describes the Wiltz zone as

"(…) une aire de sédimentation vaste et assez stable, caractérisée par des eaux peu profondes, proximale à distale, du plateau continental ardenno-rhénan, montrant de nombreuses ressemblances faunistiques avec d'autres régions de la mer varisque de l'Emsien supérieur."

Based on the study of brachiopods, the Hierges Formation - considered the lateral equivalent of the Wiltz Formation - is dated to the Upper Emsian (Jansen 2016: 43-44; Franke 2010: 9, 11).

For further information, see: Gosselet (1985, 1888), Asselberghs (1941, 1946), Leidhold (1913), Lucius (1950a), Blieck et al. (1998), Franke (2010, 2012), Müller & Alberti (2010), Müller & Franke (2012), Michel (2012), Jansen (2016), Dejonghe et al. (2017), Dejonghe (2020a,b).

Figure 18: Bockholtz (Point C45), Wiltz Formation. Clay-rich sandstone with partially limonitized fossils. The mechanical pencil is 13 cm long.

3.11 Superficial formations

On the plateaus, Devonian formations are generally covered by loess of varying thicknesses, sometimes reaching several metres. Additionally, the upper part of the Devonian layers is often altered. This phenomenon, associated with erosion surfaces, was studied by Demoulin et al. (2018).

Lucius (1950a: 164-165) described the weathering of Devonian rocks in Éislek, which can be particularly pronounced on the plateaus. The weathering can extend several metres in depth and is characterized by rock discoloration and leaching, as well as the transformation of shales into clays (e.g., china clay) and sandstones/quartzites into sands. Shale formations exhibit the most significant alteration. Weathering is especially pronounced at the Belgian–Luxembourg border, between Marvie and Bras (Belgium), where the extension of this weathered zone into Luxembourg is identified by a specific acronym (crossbar) on the Wiltz geological map.

The geometry, age, and geodynamic implications of paleo-weathering and paleo-surfaces extending from northern and eastern France to Belgium and Luxembourg were addressed by Quesnel (2003). Following the Variscan orogeny, these regions experienced four episodes of emergence, evidenced by paleo-weathering. These episodes, marked by major unconformities, correspond to four phases of vertical lithospheric deformation: from the Permo-Triassic to the Jurassic, the Lower Cretaceous, the Paleogene, and the Neogene–Quaternary.

The periglacial conditions that prevailed during the Quaternary are well documented in Luxembourg (Riezebos 1987) and Belgium (see, for example, Pissart 1995). During the Pleistocene, the Ardennes Massif underwent various periglacial processes, including intense frost weathering, which led to the accumulation of bedded rock debris and the formation of slope deposits known as "grèzes litées." This term, introduced by Guillien (1964), refers to a type of surface formation consisting of scree resulting from frost action.

In Luxembourg, deposits of grèzes litées have been described in detail by Nyssen et al. (2016) on the Wiltz geological map sheet, specifically in Enscherange (point W46), and on the Clervaux sheet in Rodershausen (point C239). In these locations, the bedrock consists of shale belonging to the Wiltz Formation.

In Enscherange, the grèzes litées layer, formed from shale debris eroded from the local bedrock, is considered by Nyssen et al. (2016) to be the most significant known outcrop of this type in north-western Europe. When the Enscherange quarry was still active for brick production, Riezebos (1987) recorded a thickness of up to 20 m of grèzes litées (much of which is now concealed by a scree slope). This deposit is overlain by a solifluction layer, which contains shale debris, up to 0.20 m in length, in its lower part. The entire sequence is capped by a Holocene soil. The absence of a loess signature in the grèzes litées is likely due to the minimal loess deposition in the area (Paepe & Vanhoorne, 1967).

At Enscherange, a dense mineral analysis conducted by Nyssen et al. (2016) identified the signature of a tephra, characterized by the presence of titanite, brown amphibole, and augite. These minerals appear in both the overlying soil and the underlying solifluction lobe, where the upper layer of grèzes litées has been reworked (likely through infiltration from the overlying soil). This tephra has been linked to the Laacher See eruption, dated to 12,900 years BP, which is documented in numerous periglacial deposits across the Rhenish and Ardennes massifs. Consequently, the Enscherange grèzes litées are older than 12,900 years BP.

At Rodershausen, based on radiocarbon dating of charcoal found in the cryoturbation layer beneath the grèzes litées, Riezebos (1987) suggested a maximum age of approximately 50,000 years BP. Nyssen et al. (2016), who also commented on the timing of these deposits, place their formation in the Late Pleistocene.

In various soils across the Éislek region, volcanic ash residues from the Eifel, identified by the presence of hornblende and augite, have also been reported (Jean Thein, personal communication).

For soil mapping in Luxembourg, refer to Marx & Flammang (2018).

3.12 Alluvia

Modern alluvial deposits formed by rivers consist of a mixture of silt, clay, sand, and pebbles. Generally, coarser components (pebbles and sand) are found at the base, while finer materials (clay and silt) accumulate at the top. These deposits are particularly significant in the valleys of major rivers, where their

thickness ranges from a few decimetres to several metres. Additionally, the flanks of the main valleys contain remnants of ancient terraces. The terraces in the Our valley were studied by Wiese (1969).

3.13 Adapting stratigraphic boundaries

Considering the most recent biostratigraphic data from Luxembourg (2024), which highlight the diachronic nature of certain formations and members, the lithological formations diagram of the Lower Devonian in Éislek has been adapted accordingly (see Fig. 19).

4 Thicknesses of the lithostratigraphic units

The thicknesses of various Lower Devonian formations and members in the Ardennes region, as reported in the literature, are summarized in Table 2. The data have been compiled from Asselberghs (1946: 189, 224, 250, 275), Lucius (1950a: 21), Konrad & Wachsmut (1973: 4-6), Furtak (1965: 287, 290-292), Minten (1997), and Bultynck & Dejonghe (2001: 42-44).

A few comments are warranted regarding this table. Asselberghs (1946: 357) cites Fourmarier's estimate that the maximum thickness of the Lower Devonian in the Neufchâteau Synclinorium (see Fig. 4) is 9,000 m. However, Asselberghs takes a more conservative stance, proposing a figure roughly half that of Fourmarier's. In pages 367-371 and plate 4 of his annexes, he discusses thickness variations of the Lower Devonian in Belgium and adjacent regions. A general trend shows an increase in thickness from north to south, peaking in the central part of the Neufchâteau Basin. South of this area, thicknesses decrease, suggesting the presence of a structural high in that direction.

Lucius (1950a) supports Asselberghs' (1946) data. However, Konrad & Wachsmut (1973) report higher thickness values, while Furtak (1973) provides even greater estimates, with figures averaging two to three times those of Asselberghs and Lucius - at least 12,800 m according to Furtak. He notes, however, that these values are based on detailed cross-sections. He also reports that the thickness of the units he designated as A to C decreases from 12,400 m to at least 8,300 m toward the northeast, while the Clervaux facies thickness increases from 400 m to 1,400 m toward the east.
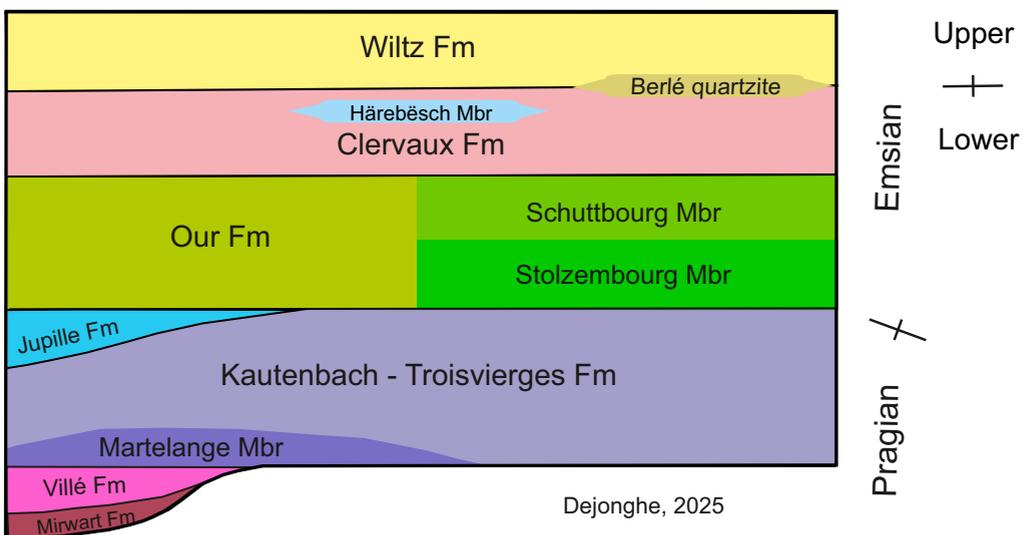
Éislek - Grand Duchy of Luxembourg

Figure 19: Diagram of Lower Devonian rock formations in the Éislek. Fm = Formation. Mbr = Member.

Using geological cross-sections for each geological map of Éislek, Dejonghe (2019, 2020b, 2021b, 2024b) and Dejonghe & Wagner (in progress) have determined the thicknesses of formations and members (Tab. 3). The total thickness of all formations ranges from 4,100 to 6,000 m, aligning with the estimates of Asselberghs, Lucius, and Konrad & Wachsmut (op. cit.), though slightly higher.

Table 2: Thicknesses (in metres) of Lower Devonian formations in the Ardennes region (adapted from Dejonghe et al., 2017, with modifications).

Éislek Formations	Asselberghs (1946) Neufchâteau Synclinorium	Lucius (1950a) Eisleck	Konrad & Wachsmut (1973) South Eisleck	Furtak (1965) Eisleck s.l.	Minten (1997) SW Eisleck	Bultynck & Dejonghe (2001) Dinant Nappe	Belgium Formations
Wiltz	± 150	± 250	200		> 250	160 - 330	Hierges
Berlé	0 -30	2 - 5 to 10 - 15	< 15	400 - 1400	10 - 15		
Clervaux	20-400	200 - 400	600		400	320-800	Chooz
Our (Schuttbourg)	750	750		2800 -6000	500 - 600	80 - 400	Vireux
Our (Stolzembourg)					± 500	160 - 800	Pesche
Jupille	400 -1500	500 - 1500	3500	3300 - 3700	1500	< 1000	Jupille + Pèrnelle
Kautenbach-Troisvierges						215 - > 800	La Roche
Villé	400 - 500			2200 - 2700	400	30 - 300	Villé
Mirwart	650 - 1000					300 - 1000	Mirwart
Total (m)	2220 - 4330	1702 - 2915	4315	8700 - 13800	3665	1265 - 5430	Total (m)

Table 3: Thicknesses (in metres) of Lower Devonian formations and members in Éislek and southeastern Belgium.

Membre (Mbr) - Formation (Fm)	SE Belgium	Troisvierges	Clervaux	Wiltz	Esch/Sûre	Diekirch
Wiltz (Fm)	Hierges, Wiltz > 300	0	700 - 800	> 500	> 150	0
Berlé (Mbr)	Traimont unknown	0	0 - 15	0 - 15	0 - 5	0
Härebësch (Mbr)	0	0	0	300 - 350	0	0
Clervaux (Fm)	Chooz 200 - 300	200 - 400	500 - 800	500 - 800	550 - 600	0
Schuttbourg (Mbr)	Pesche-Vireux 400 - 800	1100	2200	1000	900	> 500
Stolzembourg (Mbr)		1400 -1500		600	500 - > 900	> 3000
Jupille (Fm)	1000	0 - 250	0	0	0	0
Kautenbach-Troisvierges (Fm)	La Roche 800	1350 - 1500	2200	> 1000	> 1500	> 1450
Martelange (Mbr)	0 -150	0 - 700	0	0 - 100	0 - 150	0
Villé (Fm)	600 - 1000	500	0	750	> 500	0
Mirwart (Fm)	900 - 1050	unknown	0	weak	0	0
Total Lower Devonian	4200 - 4850	4550 - 5950	5600 - 6015	4650 - 5115	4100 - 4705	> 4950

Detailed measurements indicate significantly greater values on the Clervaux sheet, reflecting an overall increase in formation thickness toward the east.

Additionally, the Stolzembourg Member exhibits a marked thickening on the Diekirch sheet. There, systematic measurements of strata dips, particularly in the valleys of the Our, Stool, Blees, and Millebaach rivers, consistently indicate a NNW dip. Even accounting for minor local flexures, the thickness of the Stolzembourg Member is estimated to exceed 3,000 m. This thickening is surprising. It is represented on section BB' of Figure 37, showing a relatively constant NNW dip. However, both to the west (Fig. 37, section AA') and to the east (Fig. 35, section CC'), the layers are folded and do not have such a large thickness.

5 Folding

The fundamental structural characteristics of the Lower Devonian of Éislek have been described by Lucius (1913, 1950b, 1955), Furtak (1965), Bintz et al. (1973: 135-140), Michot (1980: 575-576), and Muller (1980: 586-587).

The major structural units affecting the Palaeozoic formations of southeastern Belgium and northern Luxembourg are, in the northwest, the Ardenne Anticlinorium (also referred to as the Givonne, Bastogne, Oesling, or Éislek Anticlinorium, depending on the author) and, in the southeast, the Neufchâteau Synclinorium (also known as the Wiltz, Eifel, or Oesling Synclinorium) (Fig. 4).

The Ardenne Anticlinorium transitions to the NNE into the Houffalize Synclinorium. In Belgium, to the east of the Wibrin-Houffalize sheet, on the Limerlé sheet, and further east, crossing the Belgian–Luxembourg border on the Troisvierges sheet, the Houffalize Synclinorium clearly widens due to its plunge. Additionally, the St-Vith facies, which characterizes the Laroche Formation, becomes increasingly extensive, justifying the introduction of the Kautenbach-Troisvierges Formation concept (Dejonghe et al. 2017) (Fig. 3, item 3.3). The Ardenne Anticlinorium weakens north of Bas-Bellain, and its extension may correspond to the Stubach Anticline (Dejonghe 2018).

Among the Éislek folds, determining a single dominant structure is challenging. Some folds are more prominent than others, but none extend across the entire region (see Figs 20 to 24). The youngest formation, the Wiltz Formation, occupies the central part of Éislek and is shaped by multiple folds. It is framed by stratigraphically older folded formations - Clervaux, Our, and Kautenbach-Troisvierges, in order of increasing distance from the Wiltz Formation. This structural pattern supports the concept of the Wiltz Synclinorium as the dominant structural unit of Éislek.

On the Troisvierges map, fold hinge lines pitch to the northeast at angles ranging from a few degrees to about 20° (Dejonghe 2019: 26). On the Clervaux map, however, there is little to no plunge which, when present, is oriented westward or southwestward (Dejonghe 2020b: 29). On the Wiltz map, plunge directions vary between NE and SW, though a predominant NE trend appears to emerge (Dejonghe 2021: 33). On the Esch-sur-Sûre sheet, most folds show minimal plunge, except on the NW side, where they dip eastward. On the Diekirch sheet, fold plunges are extremely shallow. These variations in plunge direction and intensity were already noted by Brichant (1927: M25-26) in the Belgian region adjacent to Luxembourg and by Furtak (1965). In short, in Éislek, hinge line plunges vary from SW to NE, both between different geological sheets and within individual maps.

Across all the geological sheets of Éislek, the primary folds are accompanied by secondary folds along their flanks, some extending only a few kilometres along their axial surfaces. The cross-sections detailed in the figures 35, 36, 37 and 40 indicate that most folds are relatively upright and symmetrical, though some display a slight or pronounced NW inclination (NW vergence). Conversely, on the Clervaux sheet, between the Reiteschberg and Dasbourg faults near Dasbourg-Pont, three anticlinal folds extend over a 2 km distance, with axial surfaces dipping NW and folds inclined SE (SE vergence) (Fig. 37). Refer to the comment about the Reiteschberg fault at section 8.1 for an explanation of the reason behind this vergence.

Each geological sheet provides fold names and structural descriptions in its explanatory notes. Structural sketch maps displaying fold and fault names for each geological sheet are presented in Figures 20 to 24.
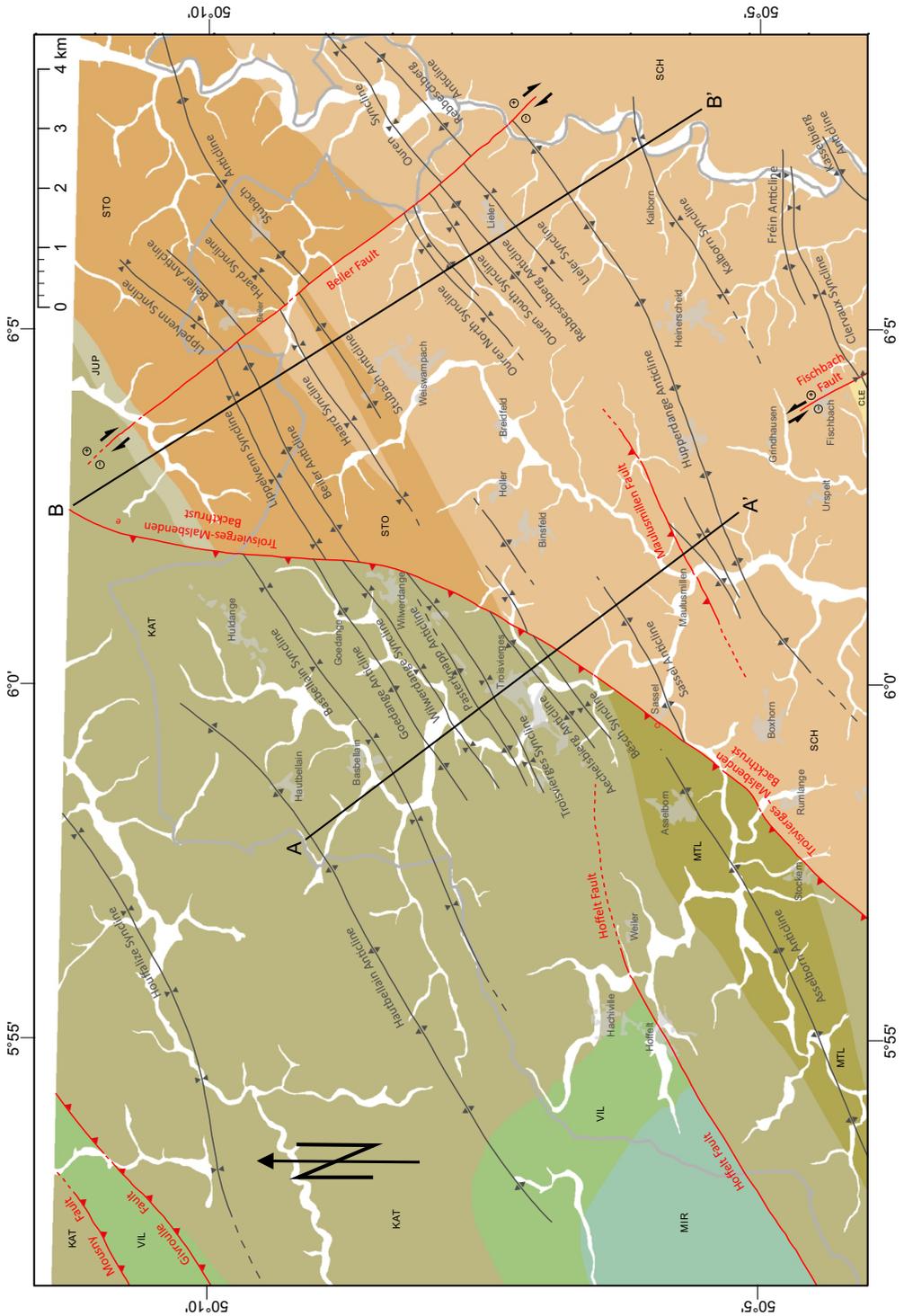
Figure 20: Structural sketch map showing the names of folds and faults related to the Troisvierges sheet. Adapted from Dejonghe (2019: 24), with modifications. Legend in Figure 25.
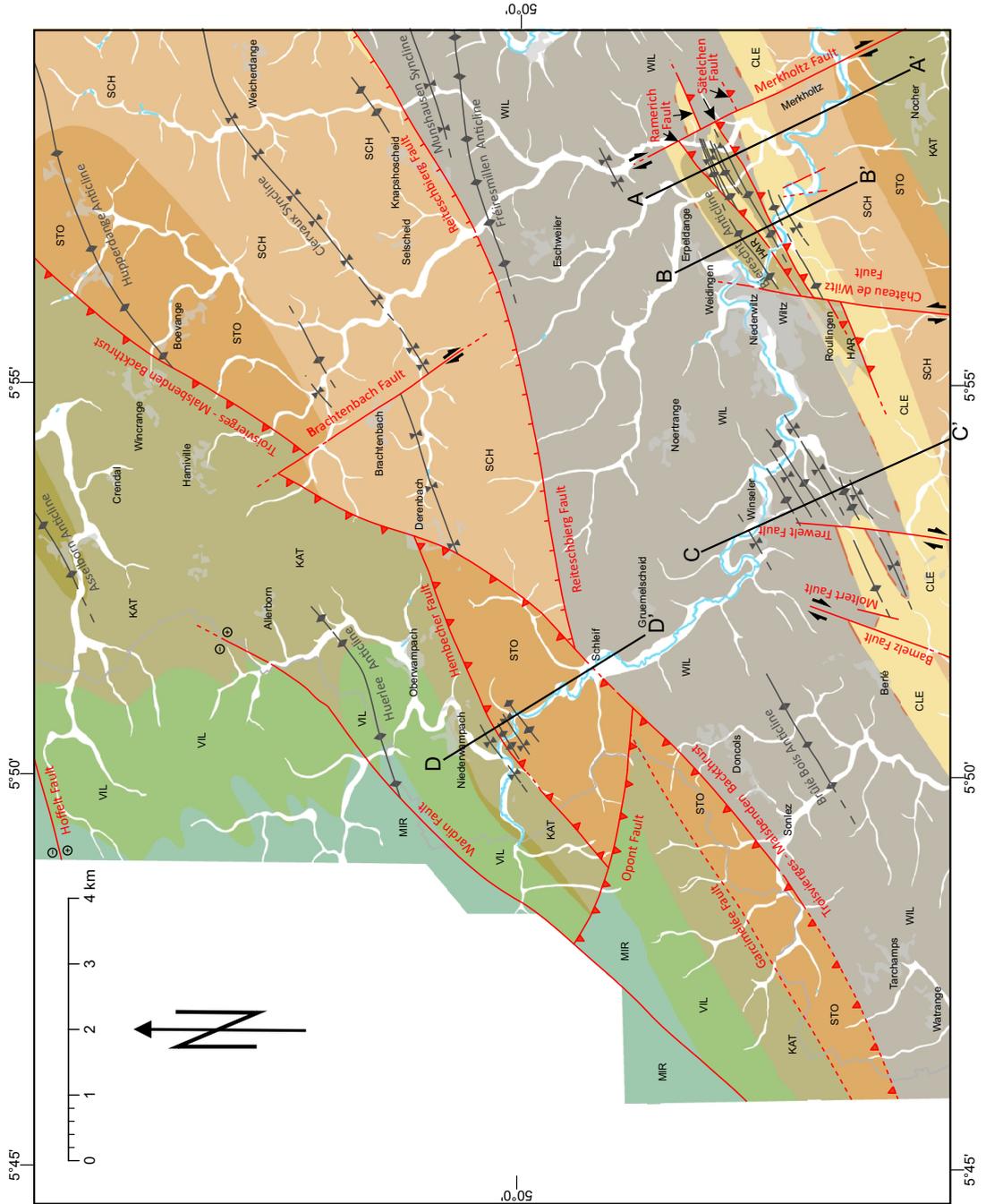
Figure 21: Structural sketch map showing the names of folds and faults related to the Wiltz sheet. Adapted from De-jonghe (2021: 34), with modifications. Legend in Figure 25.
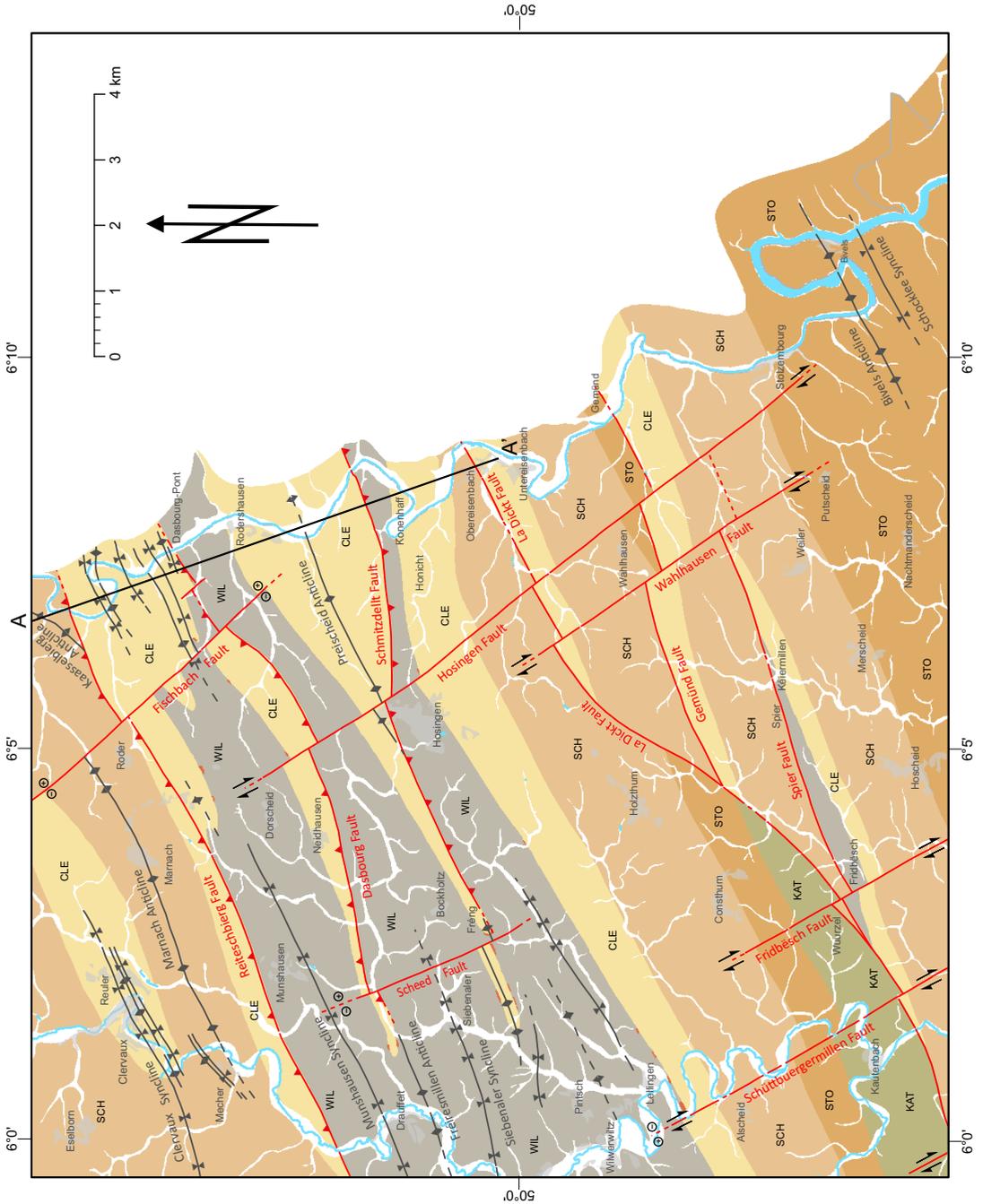
Figure 22: Structural sketch map showing the names of folds and faults related to the Clervaux sheet. Adapted from Dejonghe (2020: 28), with modifications. Legend in Figure 25.
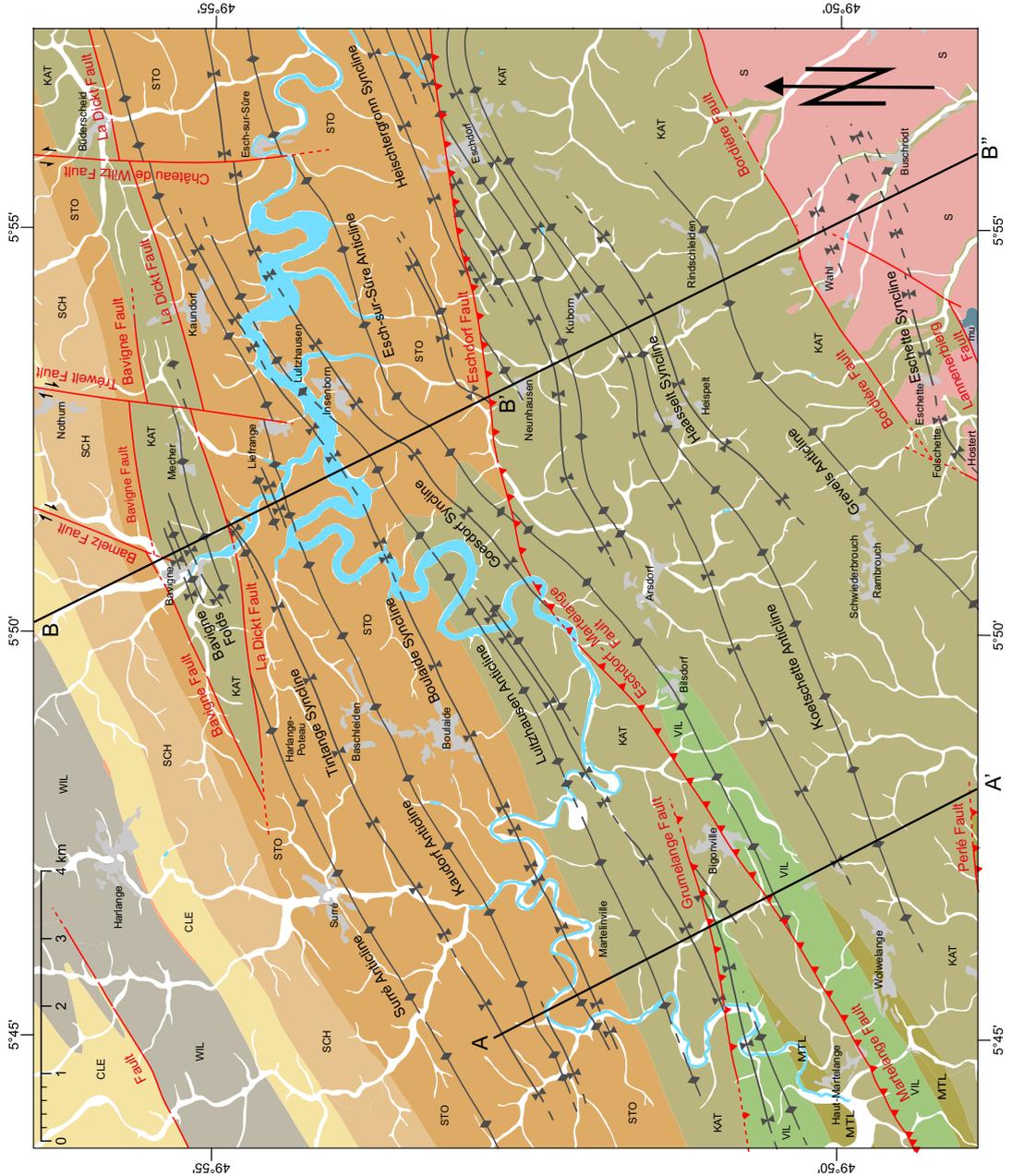
Figure 23: Structural sketch map showing the names of folds and faults related to the Esch-sur-Sûre sheet. Adapted from Dejonghe (2024: 36), with modifications. Legend in Figure 25.
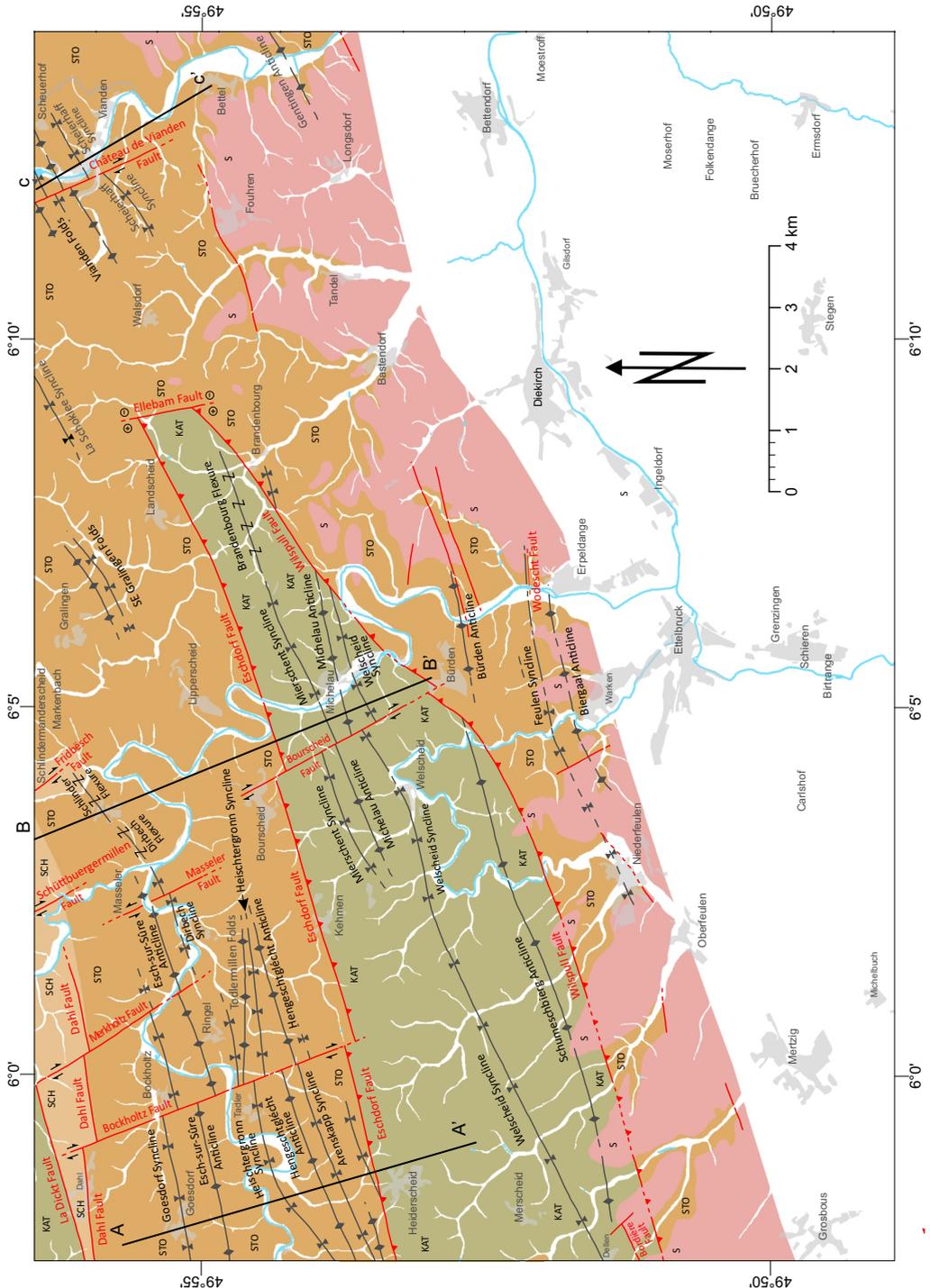
Figure 24: Structural sketch map showing the names of folds and faults related to the Diekirch sheet. The Lower Devonian–Buntsandstein boundary is reproduced from Lucius (1949b), as are the faults within and at the northern end of the Buntsandstein. Legend in Figure 25.
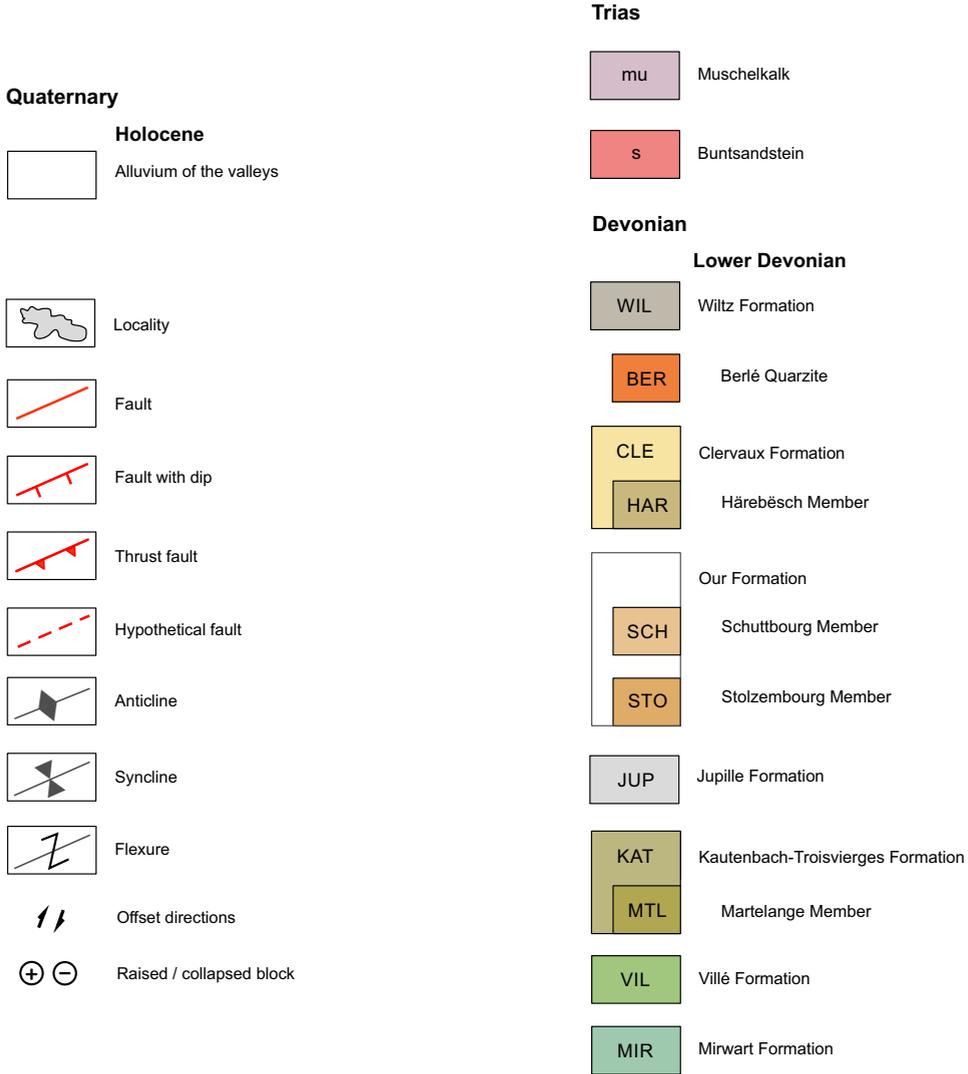
Trias

| mu | Muschelkalk |
| s | Buntsandstein |

Devonian

Lower Devonian

WIL	Wiltz Formation
BER	Berlé Quarzite
CLE	Clervaux Formation
HAR	Härebësch Member
	Our Formation
SCH	Schuttbourg Member
STO	Stolzembourg Member
JUP	Jupille Formation
KAT	Kautenbach-Troisvierges Formation
MTL	Martelange Member
VIL	Villé Formation
MIR	Mirwart Formation

Quaternary

Holocene

| | Alluvium of the valleys |

	Locality
	Fault
	Fault with dip
	Thrust fault
	Hypothetical fault
	Anticline
	Syncline
	Flexure
	Offset directions
⊕ ⊖	Raised / collapsed block

Figure 25: Legend for Figures 20 to 24.

The geological cross-sections in Figures 35 to 37 and 40 illustrate the morphology of the folds, whether wide open or narrow, and their vergence.

On the Wiltz map, a tectonic ramp (Figs 26 to 28) is present in Eschweiler, at a location known as Brantbierg (point W262c) (Dejonghe 2021b: 36-38). The rocks belong to the Clervaux Formation and consist of grey sandstone beds, sometimes exhibiting a limonitic pigment, alternating with layers of light grey (discoloured) shale. Some sandstone beds display oblique stratification with a tangential base,

indicating that the layers are in a normal position. The layers above a thick, massive, yellowish bed have a low dip (S0 = 26→332). However, in a very localized area, these layers are folded into a sharp, tight fold corresponding to a tectonic ramp (on the NW flank, S0 = 80→348; on the SE flank, S0 = 75→168) (Fig. 28).

The core of the fold contains a several decimetres thick bed of variable thickness, which is affected by a small fault at the hinge. This bed and the surrounding layers originate from a level above the

ramp surface that has been disrupted (not shown in Figure 28). The formation of this fold appears to have occurred in two stages, which would explain the complex structure of its core.

Stereographic analyses of stratification measurements were conducted for each Éislek map using the Stereonet program by R.W. Allmendinger et al. (2013), version 11.4.4. The stratification plane patterns are highly consistent across all sheets. As an example, Figure 29 illustrates the stratification measurements for the Esch-sur-Sûre sheet (N = 556 measurements).

It is important to note that this dataset encompasses multiple structural units, including several synclinal and anticlinal folds separated by faults. Therefore, the conclusions drawn from this study should be interpreted with caution. The primary takeaway is that most of the measurements correspond to planes with a mean orientation of N68°E.

6 Cleavage

The cleavage in the Luxembourg Ardenne was examined by Mosar (1987) using optical microscopy and an X-ray texture goniometer. He concluded that the cleavage formed contemporaneously with Variscan folding, exhibiting predominantly steep southward dips and a pronounced fan shape at the core of the folds (cleavage fan).

According to Bintz (in Waterlot et al., 1973: 139),

> "la schistosité des roches dévoniennes de l'Oesling est presque exclusivement un clivage de fracture dans le sens de P. Fourmarier (1964), clivage mécanique où les phénomènes de métamorphisme avec leurs effets de recristallisation ne jouent pratiquement aucun rôle."

In their view, a flow cleavage accompanied by mineral dissolution and recrystallization within the cleavage plane occurs only in the Martelange-Perlé region.

Figure 26: Eschweiler, Brantbierg (point W262c). Tectonic ramp fold in the Clervaux Formation. The photograph highlights the regularity and low dip of a massive yellowish bed beneath the fold. Stratification is marked with a yellow line.

Figure 27: Eschweiler, Brantbierg (point W262c). Close-up view of the fold shown in Figure 26. At its base, the distance between the fold flanks is approximately 2.5 m.
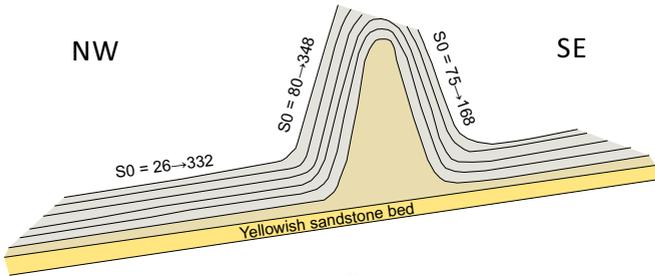

Figure 28: Diagram illustrating the photograph in Figure 26. Tectonic ramp fold. The simplified drawing does not depict the origin of the rocks located at the core of the tight anticline ramp fold.
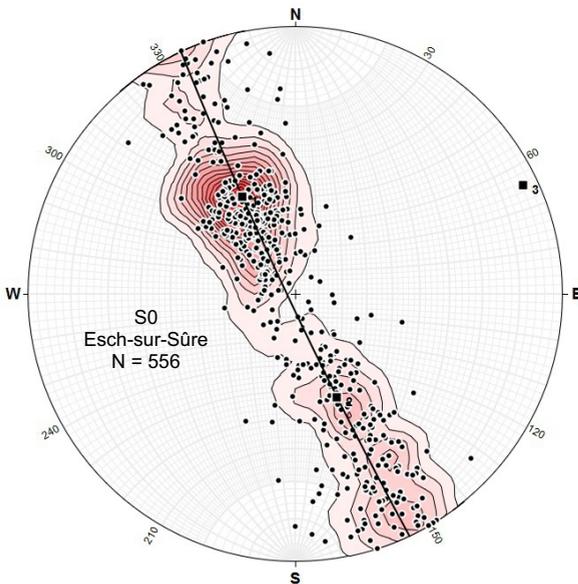

Figure 29: Stereogram of the poles of the stratification planes (black circles) for all 556 measurements conducted on the Esch-sur-Sûre sheet, with angles preserved. The black line represents the best-fitting great circle passing through the pole's axes. 1, 2, and 3 denote Bingham axes. Adapted from Dejonghe (2024b).

However, this perspective does not appear entirely accurate, as cleavage reorients certain quartz nodules, causing them to elongate and flatten within the cleavage plane. This phenomenon inherently induces recrystallization. It is particularly common in the Wiltz Formation (see section 3.10), where it complicates stratification identification. In fact, stratification can only be correctly determined when numerous nodules are aligned within the same plane, where their orientation, regardless of reorientation, remains parallel to the stratification plane.

The interaction between cleavage and sandstone beds varies. In some areas, such as northwest of Bildsdorf (Fig. 30), cleavage is well developed in the shales of the Kautenbach-Troisvierges Formation but does not significantly affect the embedded sandstone beds. Conversely, in many locations depending on the rock type, cleavage is refracted within the sandstone beds, as observed in Wahl (Fig. 31), forming step-like patterns in Weiswampach (Fig. 32) or displaying a sigmoidal shape in Clervaux (Fig. 33) (the S-shaped structure forms when the boundary between layers

of differing natures is not well marked). Within sandstone banks, cleavage transforms into a spaced disjunctive cleavage (fracture cleavage), causing strong fragmentation (Fig. 31).

As a complement to Figure 29, Figure 34 illustrates the stereographic distribution of poles of cleavage planes on the Esch-sur-Sûre sheet (N = 517 measurements). Two distinct subpopulations of steeply dipping cleavage planes are clearly visible: one predominantly oriented SE and the other NW. The cleavage distribution exhibits a fan-shaped pattern relative to the axial plane. The best-fitting great circles passing through the pole axes of both the stratification and cleavage planes are nearly parallel, with the following characteristics (expressed in right-hand rule (RHR) direction/dip notation):

- Stratification: 154.7° / 86.8°
- Cleavage: 336.5° / 89.7°

In most cases, the cleavage direction is either sub-parallel to the stratification or intersects it obliquely at an angle typically ranging from 0 to 20°.

Figure 30: Bildsdorf, point E411. Blue-grey shale of the Kautenbach-Troisvierges Formation with well-defined cleavage (red lines, S1 = 65→162). The shale contains sandstone beds up to 20 cm thick, which are either unaffected or only slightly affected by cleavage. The 35 cm hammer handle is aligned parallel to the stratification plane (yellow line, S0 = 35→153).
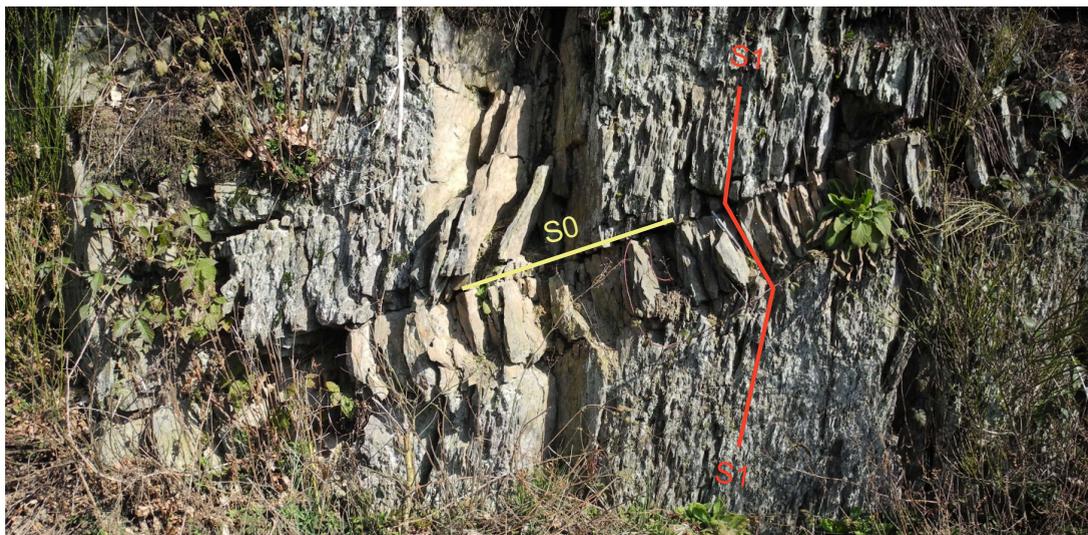
Figure 31: Wahl, point E368. Kautenbach-Troisvierges Formation. Well-developed cleavage (red lines) in blue-grey shale (S1 = 80→340), refracted within the grey sandstone bed (S1 = 70→160), causing fragmentation. The sandstone bed is 19 cm thick. The stratification (yellow line) is oriented S0 = 20→325.

Figure 32: Weiswampach, between points of coordinates WGS84: 6.07168E/50.13577N and WGS84: 6.07203E/50.13555N. Our Formation (Schuttbourg Member). Alternating layers of grey-blue shale and grey sandstone (S0 = stratification, yellow line) refract the cleavage (red lines, S1) in both step-like and sigmoidal patterns, depending on the rock type. The hammer handle is 35 cm long.

Figure 33: Clervaux, point C348c. Clervaux Formation. Greenish shale with localized sandstone components that induce a sigmoidal refraction of the cleavage. S0 represents stratification (yellow line), while S1 indicates schistosity (red line). The hammer handle is 35 cm long.
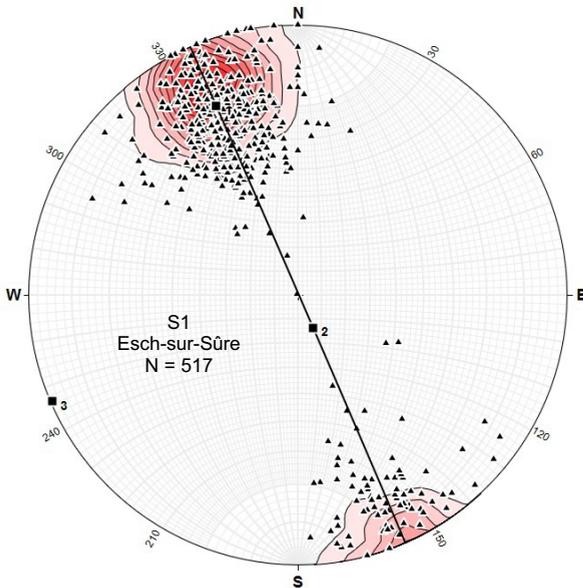

Figure 34: Stereogram of the poles of the cleavage planes (black triangles) for all 517 measurements carried out on the Esch-sur-Sûre sheet, with angles preserved. The black line represents the best-fitting great circle passing through the pole's axes. 1, 2 and 3 denote Bingham axes. Reproduced from Dejonghe (2024b).

7 Metamorphism

Metamorphism refers to all transformations that a rock undergoes in the solid state due to temperature (T), pressure (P), the nature of mineralized fluids, or the chemical composition of the rock. It is accompanied by the formation of specific minerals. Based on the intensity of these parameters, different metamorphic zones and isograds (curves of equal metamorphic grade) have been defined:

- Anchizone: Represents the transition between diagenesis and true metamorphism (T = 100-200°C; P = 1 kbar).

- Epizone: Corresponds to low-grade metamorphism, with an upper limit around T = 500°C, defined by the biotite isograd.

- Mesozone: Represents medium-grade metamorphism, with an upper limit around 650°C, marked by the sillimanite isograd.

- Catazone: Corresponds to high-grade metamorphism, with temperatures exceeding 700°C, often leading to partial melting.

By studying rock fabrics using optical microscopy and X-ray texture goniometry, Mosar (1987) determined that metamorphic intensity in the Éislek region ranges from deep diagenesis to epizonal metamorphism. Upper Emsian rocks exhibit anchizonal to slightly epizonal metamorphism, while Middle and Lower Emsian rocks show anchizonal and epizonal metamorphism. In contrast, Pragian (Siegenian) rocks display a clear epizonal metamorphic grade. Overall, the metamorphic intensity in Éislek is classified as very low to low.

Mosar (1987) demonstrated that the anchizonal and epizonal metamorphism, as studied through illite crystallinity, coincides with the development of Variscan rock cleavage in Devonian rocks. He suggested that the higher metamorphic intensity in Pragian rocks compared to Emsian rocks initially points to burial metamorphism. However, the stronger metamorphic intensity observed in the southern Luxembourg Ardenne compared to the north could also be attributed to higher heat flow in the south. Mosar (ibid.: 241) proposed that a combination of both factors is likely.

The extension of the Bastogne metamorphic zone (Belgium) into Luxembourg was studied by Antun (1971). He reported the presence of biotite in the Longvilly area and noted (ibid.: 159):

" L'isograde de la biotite monte donc jusqu'au sommet du Siegenien moyen et pénètre en territoire luxembourgeois sans cependant s'y poursuivre fort loin. ".

Additionally, Amory (1992) conducted a study on the crystallinity of illite in Martelange slates. She classified the Martelange region within the epizone, indicating that the rocks experienced metamorphism at temperatures of at least 350°C (ibid.: 40). She also concluded that alteration does not appear to have affected the illite crystallinity.

8 Faults

The similar lithological characteristics of the geological formations make fault identification challenging. However, based on detailed surveys of the various Éislek geological sheets, several faults were identified, described, and justified in the explanatory notes of the geological maps by Dejonghe (2019, 2020b, 2021b, 2023b, 2024b) and Dejonghe & Frank (in progress). These faults are illustrated in Figures 20 to 24, 35 to 37, and 40 and are briefly summarized below, from NW to SE.

8.1 Longitudinal faults

Mousny and Givroule Faults (Fig. 20). Identified in Belgium on the Champlon - La Roche-en-Ardenne map (Dejonghe & Hance 2001a, b) and the Amberloup - Flamierge map (Dejonghe 2012a, b), these faults intersect the folds developing south of the La Roche Syncline, with a dextral strike-slip component. They are also present on the Wibrin-Houffalize sheet (Dejonghe 2024c, d), although their strike-slip component can no longer be confirmed. In Luxembourg, they appear only over short distances in the northwestern corner of the Troisvierges map.

Hoffelt Fault (Fig. 20). In the Hoffelt area, this fault places the Kautenbach-Troisvierges Formation in anomalous contact with the Mirwart and Villé formations, which have significantly different stratification orientations. Its extension towards the northeast remains uncertain.

Troisvierges-Malsbenden Backthrust (Figs 20, 21, 35, 36). The Malsbenden Fault, first described in 1963 by Breddin in the North Eifel (Urft region), was extended south-westward by Furtak in 1965 to the St. Vith and Troisvierges region. He characterized it as a north-dipping fault and defined it as the Troisvierges-Malsbenden "Großüberschiebung" (major overthrust) (Furtak, 1965: 322-328). He wrote:

> "Le terrain analysé est traversé par un charriage de direction SW-NE pour lequel est proposé le nom de " Grand Charriage de Troisvierges - Malsbenden ". Il sépare des suites de couches (complexe B = argileux et C = gréseux) avec schistosité différemment développée et par suite à déformation interne différente." (Furtak, 1965: 276).

Indeed, Furtak (1965) notes the presence of distinct lithological units on either side of this structure:

- To the southeast, predominantly sandstone layers (his complex C), belonging to the Stubach Anticline. The southern limb extends over approximately 5,500 m, while the northern limb is barely exposed, spanning only about 250 m.

- To the northeast, mainly pelitic layers (his complex B), which form nearly symmetrical folds around Troisvierges and are part of the Bastogne Anticline.

As the Stubach Anticline predominantly outcrops on the southeastern flank and is significantly reduced on the northeastern flank, Furtak concludes that a major structural disturbance exists between units B and C. He locates this disturbance approximately 1300 m south of Troisvierges.

Furthermore, he confirms the presence of this thrust fault through observations in the Maulusmillen area, where he identifies a recumbent fold with an axial plane slightly inclined to the north (Fig. 35, section AA'). He interprets this fold as a concomitant feature of the Troisvierges-Malsbenden thrust. The weight of the overlying rock masses would have induced secondary folding in the steeply south-dipping layers of the Stubach Anticline. This overburden likely caused deformation of the Troisvierges-Malsbenden Fault by flattening it and leading to the subsidence - and, in some places, overturning - of the underlying layers. Since cleavage is also folded at this location, this super-

imposed folding is thought to have occurred during the final phase of internal deformation.

The Troisvierges-Malsbenden thrust fault has sometimes been described as a backthrust, meaning a thrust fault that develops due to movement in the opposite direction of the main thrusting event. It is also referred to as an antithetic fault, a fault whose displacement occurs in the opposite direction of a larger associated fault, reacting to its obstruction.

To the southwest, Lambert & Bellière (1976) and Jongmans & Cosgrove (1994) extend the Troisvierges Fault southeast of Bastogne. Beugnies (1986: 61) briefly mentions this fault and hypothesizes that it connects to the Opont Fault, which he traces across Belgium over 93 km. However, Cambier & Dejonghe (2012: 182) question this connection, citing differences in fault characteristics: the Opont Fault dips southward and exhibits dextral and normal displacement, whereas the Troisvierges-Malsbenden Fault is a backthrust with a north-dipping reverse displacement.

Its extension on the Wiltz sheet (Fig. 21) is less well-constrained than on the Troisvierges sheet. Nevertheless, several observations support its existence:

- The anomalous contact between the Kautenbach-Troisvierges and Our formations, along with the truncation of the Hupperdange Anticline near Lullange, Boevange, and Wincrange (Fig. 21).

- At Schleif, the absence of the Schuttbourg Member and the Clervaux Formation beneath layers of the Wiltz Formation (Fig. 36, section DD').

Maulusmillen Fault (Figs 20, 35): To the southeast of Maulusmillen, on the country road towards Blumer, there is a rather abrupt transition from overturned to normal layers. This is due to a weakly northward-dipping fault, which is likely related to the Troisvierges-Malsbenden Backthrust.

Hembecher Fault (Figs 21, 36): Between Winseler and the Belgian border, the former railway line, now redesigned as a cycle path, provides numerous outcrops. At Schleif (Fig 36 section DD), it intersects the Troisvierges-Malsbenden Backthrust. To the northwest of this backthrust, over a length of more than 1 km, the layers of the Stolzembourg Member
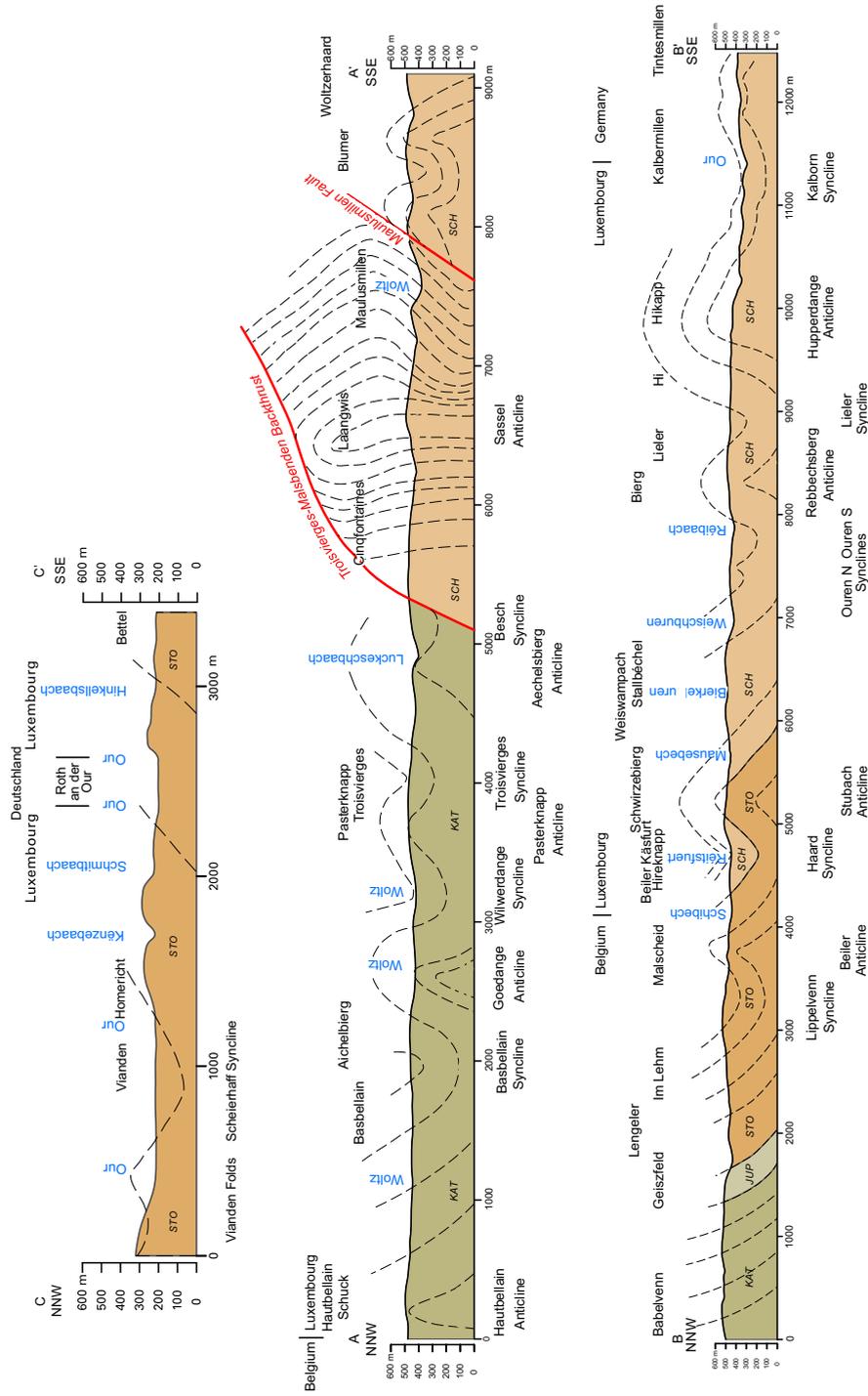
Figure 35: Upper part: section CC' located on Figure 24 (Diekirch map structural diagram); Lower part: sections AA' and BB' located on Figure 20 (Troisvierges map structural diagram). Reproduced from Dejonghe (2018), modified. Legend in Figure 25.
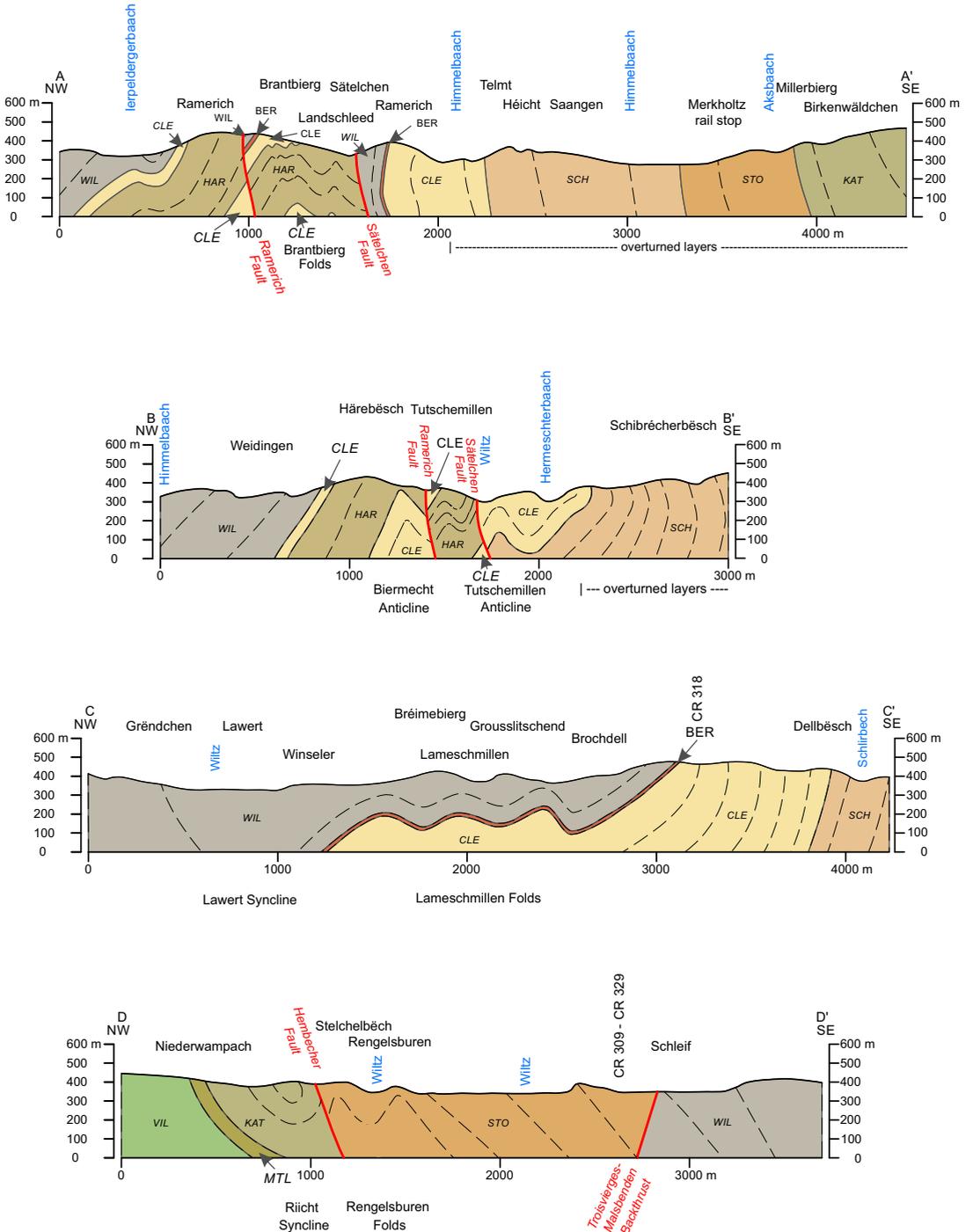
Figure 36: Geological cross-sections AA', BB', CC', and DD' from the Wiltz sheet, located on Figure 21. Reproduced from Dejonghe (2021a), with modifications. Legend in Figure 25.

dip evenly to the southeast. Further northwest, these layers are folded into two anticlines (the Rengelsburen Folds). To the northwest of the latter, the Kautenbach-Troisvierges Formation is exposed via a series of reversed layers. These tectonic features (folds to the southeast, overturning to the northwest) are related to a southeast-dipping fault, which caused the thrusting of the southeast panel onto the northwest panel. Dejonghe (2021: 36; 41) calls this the Hembecher Fault. It is responsible for the amputation of a large part of the overturned flank of the Riicht Syncline and explains the reduced thickness of the Kautenbach-Troisvierges Formation in this region.

Reiteschbierg Fault (Figs 21, 22, 37): Several reasons support the existence of this fault in the Our valley, 1750 m to the northwest of Dasbourg-Pont (Fig. 37, section AA'):

- To the north, the gently dipping layers of the Our Formation form the Kaaselbierg Anticline, the axial surface of which disappears in the Reiteschbierg region, colliding with the Clervaux Formation.

- To the south, the layers of the Clervaux Formation are exposed in a reverse series with a dip of around 70° NNW. Additionally, to the south of this fault, the Clervaux Formation is affected by three anticlinal folds whose axial planes dip 20 to 30° to the NNW over a length of two kilometres up to the Dasbourg Fault.

At this location, the SSE vergence of the folds in the Clervaux Formation suggests a NNW dip of the fault plane. Further west, the folds around the Reiteschbierg Fault become more regular. Therefore, the fault has been depicted with a moderate dip to avoid prematurely determining its behaviour.

To the northwest of Munshausen, the Clervaux Formation is present, but its thickness is greatly reduced compared to its eastern extension, due to truncation by the Reiteschbierg Fault (Fig. 22). Since the Reiteschbierg Fault clearly intersects the Kaaselbierg Anticline, it is considered an out-of-sequence fault.

On the Wiltz sheet (Fig. 21), its western extension is supported by the anomalous contacts of the Wiltz and Our formations in the Knaphoscheid area, where the Clervaux Formation is missing. Except

at its western end, the Reiteschbierg Fault generally coincides with an unnamed fault drawn by Lucius on his 1949 map.

Opont Fault (Fig. 21). A comprehensive history of the Opont Fault is provided by Cambier & Dejonghe (2012: 179-183). This fault was first introduced by Asselberghs (1944), who described it as extending nearly 30 km within the Ardennes Anticline Zone. It dips slightly southward. On the Wiltz sheet, the Opont Fault is offset by the Wardin Fault on its western side, while on the eastern side, it terminates at the Troisvierges-Malsbenden Backthrust.

La Garcimèlée Fault (Fig. 21). This is a highly speculative fault, proposed to account for the thinning of the Kautenbach-Troisvierges Formation. It may correspond to the Hembecher Fault, located southwest of the Opont Fault.

Dasbourg Fault (Figs 22, 37). The anomalous contact between the Wiltz Formation to the south and the Clervaux Formation to the north, which is clearly visible in the Our valley, supports the existence of the Dasbourg Fault. It appears to dip north-westward. In the Dasbourg-Pont area (Fig. 37, section AA'), Lucius had already mapped a northwest-dipping fault on his 1949 geological map, although he placed it slightly further south. The Dasbourg Fault can be traced from Dasbourg-Pont to approximately 1 km east of Drauffelt (near the locality of Bocholtz). Along this path, the Dasbourg fault is intersected by the Fischbach, Hosingen and Scheed transverse faults (Fig. 22). Further southwest, the lack of lithological contrast within the Wiltz Formation does not justify its continued trace, and it appears to dissipate within the axial zone of the Fréiresmillen Anticline.

Schmitzdellt Fault (Figs 22, 37). In the Our valley, north of Konenhaff and Honicht, a transition occurs from the Wiltz Formation (in an overturned sequence) in the southeast to the Clervaux Formation (in its normal position) in the northwest (Fig. 37, section AA'). These formations are separated by the Schmitzdellt Fault, which most likely dips southward due to the regional overturning of strata toward the southeast. The Clervaux Formation, which is well-developed in the east (with an outcrop width of 2,000 m in the Our valley), gradually thins westward to only about 200 m near Freng. This reduction in thickness can also
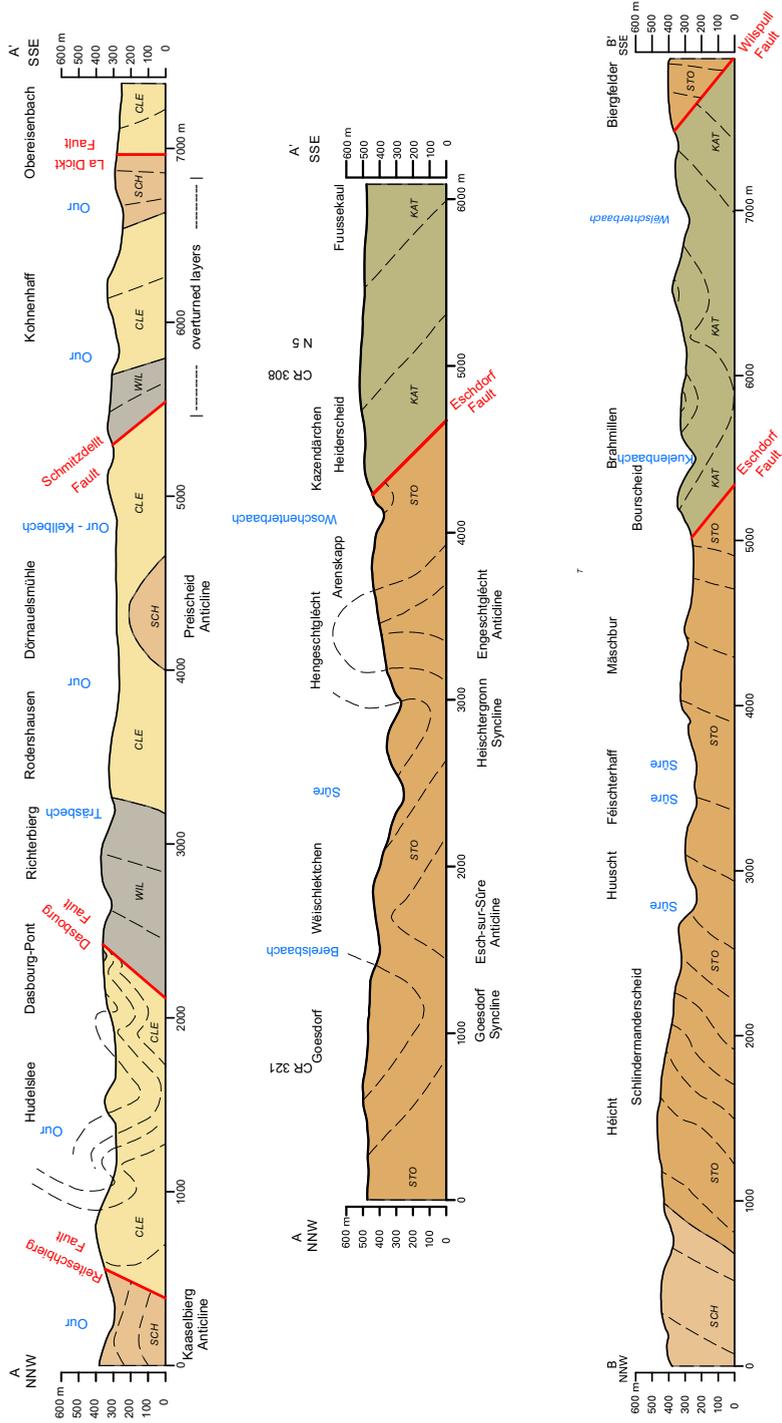
Figure 37: Upper part: section AA' located on Figure 22 (Clervaux structural diagram); Lower part: sections AA' and BB' located on Figure 24 (Diekirch structural diagram). Reproduced from Dejonghe (2020a), with modifications. Legend in Figure 25.

be attributed to the westward plunge of the Preis-cheid Anticline.

Ramerich Fault (Figs 21, 36). In the Wiltz valley near Weidigen, northeast of Wiltz, an anticline is present within the Härebësch Member of the Clervaux Formation (the Biermecht Anticline) (Fig. 36, section BB'). The southeastern flank of this anticline exhibits significantly thinner layers compared to the northeastern flank. Moreover, the geological map indicates strong bevelling of the Clervaux Formation at this location. The southeastward dip of the Ramerich Fault is attributed to its proximity to the Sätelchen Fault, both of which are interpreted within the same context of SE - NW thrust stress.

Sätelchen Fault (Figs 21, 36). In the Himmelbaach valley, the transition from the Härebësch Member to the Wiltz Formation is observed. The thickness of the Wiltz Formation decreases westward, ultimately disappearing in the Wiltz valley. The Sätelchen Fault likely dips to the southeast, as indicated by the steep to slightly overturned bedding in the SE part of the Härebësch Member, which reflects a thrust-related deformation from SE to NW.

La Dickt Fault (Figs 22, 23, 24, 37, 40). In several locations, this fault explains the anomalous contact between various formations. To the SSE, E, and NE of Kautenbach, an anomalous contact is observed between the layers of the Kautenbach-Troisvierges Formation to the NW and the Our and Clervaux formations to the SSE, E, and NE (Fig. 22). Additionally, in the Our valley, between Untereisenbach and Obereisenbach, crossing the La Dickt Fault from SE to NW results in a transition from normal layers of the Clervaux Formation to overturned layers of the Our Formation (Schuttbourg Member) (Fig. 22, Fig. 37, section AA').

This fault is significant as it cuts across the entire Clervaux sheet in a SW-NE direction, intersecting the dominant WSW-ENE orientation of the layers. In certain areas, such as the Schlenner valley, SE of Consthum, the fault disrupts both the orientation and dip of the layers. The La Dickt Fault intersects the Gemünd and Bavigne faults, indicating that it formed after these longitudinal faults (out-of-sequence fault). However, it predates the transverse faults described below.

The La Dickt Fault may be associated with the Troisvierges-Malsbenden Backthrust. It has been represented as a vertical fault in Fig. 37, section AA' and Fig. 40, section BB' to avoid making assumptions about its true nature. Its extension into the Esch-sur-Sûre sheet is supported by observations SSE of Büderscheid. Specifically, at the locality known as Bideschtermillen (point E51), the Kautenbach-Troisvierges and Our formations exhibit an anomalous contact.

To the west, this fault extends south of Bavigne (Fig. 23). However, farther west, in the Harlange-Poteau and Surré region, the scarcity of outcrops prevents confirmation of its continuity, and it has therefore been represented with dashed lines.

Gemünd Fault (Fig. 22). In the Our valley, S, SE, and W of Gemünd (Germany), all layers are in a normal position without significant variation in dip. They are oriented NW, with dips ranging from 37° to 87°, predominantly between 50° and 70° NW. The transition from layers of the Clervaux Formation (to the SE) to those of the Stolzembourg Member of the Our Formation (to the NW) is anomalous, as the Clervaux Formation is stratigraphically younger than the Our Formation. This contact occurs along the steeply dipping Gemünd Fault.

Spier Fault (Fig. 22). The Spier Fault is inferred from the anomalous contact between the Wiltz Formation (to the SE) and the Schuttbourg Member of the Our Formation (to the NW) in the vicinity of Fiederbierg, Spier, and Keiermillen. East of the Walhausen Transverse Fault, its trace becomes uncertain as it traverses the Our Formation (Schuttbourg Member), where no distinctive marker levels can be identified. To the west, in Wuurzel, it is believed to be connected to the La Dickt Fault.

Bavigne Fault (Figs 23, 40). This fault has a limited lateral extent and is only observed in the Bavigne area. There, the overturned layers of the Stolzembourg Member transition into normal and folded layers of the Kautenbach-Troisvierges Formation (Fig. 40, section BB'). The thickness of the Stolzembourg Member is somewhat reduced, reaching a maximum of 300 m, whereas it measures approximately 500 m to the northwest of the La Dickt Fault and more than 900 m to the southeast of this fault. Based on stratification measurements conducted in both formations and given that the Kautenbach-

Troisvierges Formation does not stratigraphically overlie the Stolzembourg Member, a fault contact must be assumed. To the west, it is intersected by the La Dickt Fault.

Grumelange Fault (Figs 23, 40). This fault was first introduced by Brichant (1927) and later studied by Lucius (1948a, 1953) and Belanger (1992), who attributed only a relatively small extent to it (1,700 m). Its existence is justified by the presence, near Grumelange, of layers belonging to the Villé Formation situated above layers of the Kautenbach-Troisvierges Formation (Fig. 40, section AA'). Although it is a minor fault, we have included it in our study because the axial surface of the small syncline in the Villé layers, located to the north above the Kautenbach-Troisvierges Formation, terminates at this fault.

Eschdorf Fault (Figs 23, 24, 37, 40). This fault is necessary east of Eschdorf, as the Kautenbach-Troisvierges Formation (with moderate south-eastward dips) is in anomalous contact with the Stolzembourg Member (which exhibits very steep north-westward dips). Its presence is further confirmed north of Neuhausen, where the Our and Kautenbach-Troisvierges formations show significantly different dip directions (Fig. 40, section BB'B'').

North and NNE of Bilsdorf, in the vicinity of the Misère Bridge (Pont Misère, Misärsbrék), numerous outcrops are found in the Sûre Valley. From north to southwest of the Misère Bridge, the layers of the Kautenbach-Troisvierges Formation display dips between 10° and 30° SE. In contrast, along the CR 309 road, southeast of the Misère Bridge, the layers of this formation initially dip very steeply before becoming folded. The differences in tectonic style northwest and southeast of the Misère Bridge justify the presence of the Eschdorf Fault at this location. The fact that the layers are highly folded to the southeast but remain relatively undisturbed to the northwest suggests that this fault originated from a thrust movement from SE to NW and therefore dips toward the southeast.

On the Diekirch geological sheet (Fig. 24), the Eschdorf Fault has been extended as far as Bourscheid. To the southeast, the strata belong to the Kautenbach-Troisvierges Formation, which is in anomalous stratigraphic contact with the Stolzembourg Member to the north-northwest. East of the

transverse Bourscheid Fault, the Eschdorf Fault continues northward, passing near the feudal castle of Bourscheid (Fig. 37, sections AA' and BB').

Dickeschbur (Eschdorf) Fault (Fig. 38). To the east of Eschdorf, at the location known as Dickeschbur (point E99d), a major fault is present in the central section of a 330 m-long outcrop on the western side of the N 15 (Fig. 38). The cross-section of this outcrop was described by Maquil et al. (1984: 65), and Dejonghe (2024a, b) who referred to it as the Dickeschbur Fault.

In the southern part of the outcrop, which belongs to the Kautenbach-Troisvierges Formation, the strata dip consistently, often between 25° and 35° south. As they approach the fault, they take on an anticlinal structure. As shown in Figure 38, where the stratification planes are highlighted in yellow, the anticline exhibits different shapes at the base and top of the outcrop, indicating a disharmonic fold. On the northern side of the fault, the strata of the Stolzembourg Member maintain a similar regularity as in the south, with dips generally between 20° and 40° south.

The fault zone is framed on both its northern and southern sides by slightly irregular yet sharply defined, nearly parallel surfaces F1 and F2, on which no slickensides are observed. The infill zone is 9.7 m wide parallel to the road (approximately 8 m perpendicular to planes F1 and F2). It consists of soft to loosely consolidated rock, composed of greenish-weathered blue-grey shale and fragments of burgundy shale. In some more cohesive areas, sandstone layers with convoluted bedding display a series of small, tightly folded S-shaped structures. Some blocks are coated with a thin white film, likely dickite.

On both sides of the fault - particularly in the south - the burgundy coloration overlays the rock's original hue. Hematitic impregnation is evident, penetrating several millimetres into the periphery of blocks, forming patches, bands parallel to stratification planes, and streaks along cleavage planes.

Below the photograph in Figure 38, a schematic cross-section illustrates the length of the outcrop. The section's origin (point A) is at the northern edge of a short, curved road leading to a farm at Dickeschbur (coordinates in the WGS84 system: 5.95909E/4988756N, orientation of the road: N25°W). The numbers correspond to measured dips along this section. A minor fault is present at
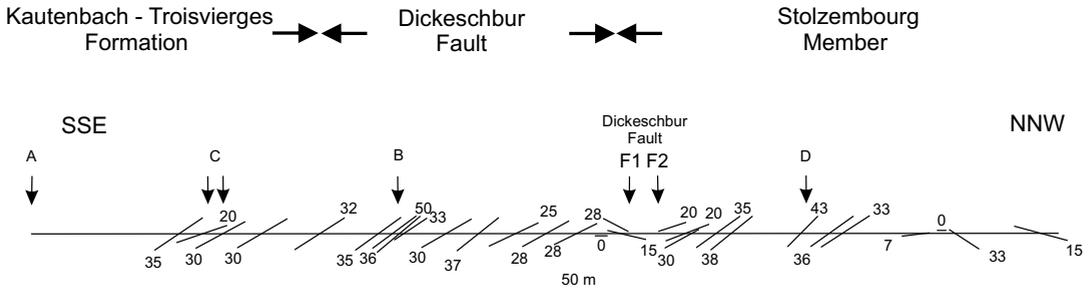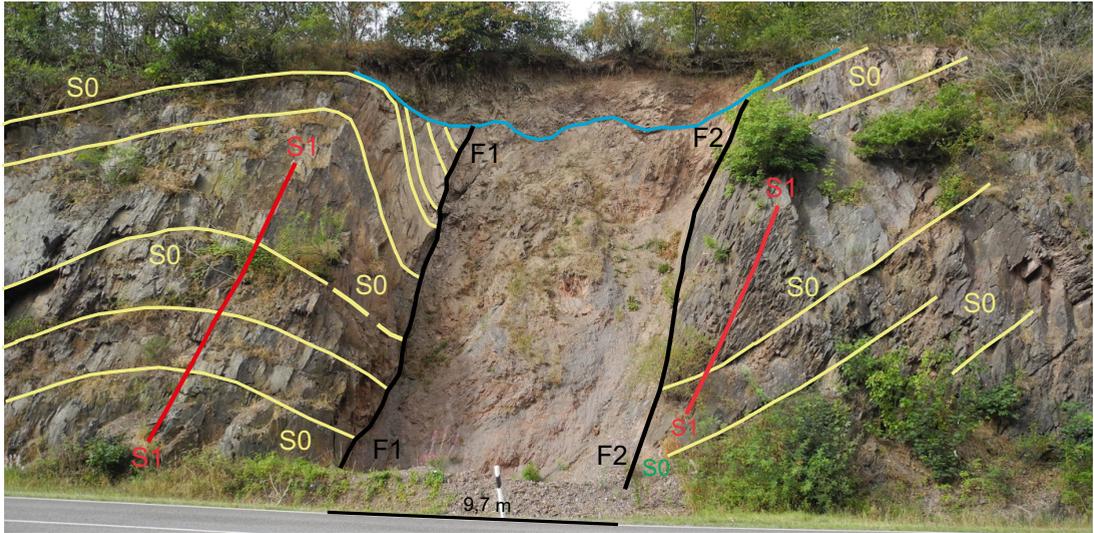
Figure 38: Eschdorf, point E99d – Dickeschbur Fault photographed on September 9, 2020. Yellow lines S0: stratification planes; Red lines S1: cleavage planes; Black lines F1 and F2: fault planes; Blue line: base of the colluvium covering the fault zone F1-F2. Measured dips at the foot of the outcrop on both sides of the fault: S0 (south): 28→243; S0 (north): 20→210. Fault zone boundary planes (measured at the foot of the outcrop): F1 (south), 86 to 90→173 to 174; F2 (north), 76 to 78→168 to 170. Below the photograph, a 330 m-long schematic cross-section illustrates the outcrop's extent. Point A is at the northern edge of the short, curved road leading to a farm at Dickeschbur, oriented N25°W. The numbers indicate measured dips along this section. A minor fault is observed at point B. At point C, a depression filled with red rock colluvium is noted. At point D, a load cast level is present.

point B. At point C, a depression filled with red rock colluvium is observed. At point D, a load cast in a layer approximately 1 m thick is identified.

Based on its characteristics and location, Dejonghe (2024a, b) associates the Dickeschbur Fault with the Eschdorf Fault. Interestingly, this fault is less prominent on the eastern side of the N15. This could be due to either a corner opening of the fault surface or a structure produced by a pull-apart mechanism (Fig. 39).

Martelange Fault (Figs 23, 40). South of Martelange and Rombach-Martelange, at a location known as Fockeknapp, the layers of the Villé Formation overlie those of the Stolzembourg
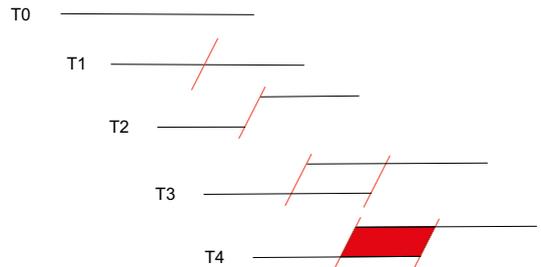

Figure 39: Eschdorf, point E99d. Chronology of the pull-apart Mechanism. T0: Formation of the Eschdorf Fault; T1: Development of a small transverse fault; T2: Minor displacement along the transverse fault; T3: Creation of an open space through longitudinal movement along the Eschdorf Fault; T4: Infill of the open space by trapping overlying sediments. These events were not necessarily sequential but likely occurred continuously over time.

Member. It was here that Brichant (1927) first introduced the concept of the Martelange Fault. Asselberghs (1946: 494) linked the Martelange Fault to the Herbeumont Fault in Belgium, estimating the latter to be 75 km long (ibid.: 490). He further noted that, according to Quiring (1933: 225), the Herbeumont Fault extends into the Éislek region via the Sauer-Uberschiebung, which crosses both the Éislek and the Eifel before continuing beyond the Triassic cover of Bitburg, reaching approximately 100 km east of Martelange.

Lucius (1947b: 104) described the Martelange Fault as a longitudinal reverse fault and later suggested (Lucius 1951: 181) that, in the Martelange-Perlé region, the Herbeumont thrust splits into multiple faults (Perlé, Martelange, and Grumelange), forming distinct thrust slices. Belanger (1992) included the Martelange Fault in her structural analyses. We have correlated the Martelange Fault with the Eschdorf Fault.

In summary, the Martelange-Eschdorf Fault (Figs 23, 24, 40) is a major geological structure that extends from Belgium through a large part of Luxembourg to Germany.

Perlé Fault (Figs 23, 40). The Perlé Fault was first introduced by Brichant (1927) and later taken up by Lucius (1948a, 1953), Belanger (1992), and Colbach (2003). This fault is significant because, to the NNW of the former slate quarries of the Perlé band (see 9.2.), the Villé Formation is present; farther north, the stratigraphic succession shifts back to the Kautenbach-Troisvierges Formation, which dips SSE. However, the eastern extension of this fault on the Esch-sur-Sûre sheet remains uncertain. It has been represented as a dashed line due to the lack of evidence supporting its continuation to the east.

Lannenerbierg Fault (Fig. 23). This fault is depicted on the Redange map by Colbach (2003). It corresponds to a major lineament trending N67°E, which is clearly visible in the LIDAR imagery (Digital Elevation Model – detailed version). It extends for approximately 1 km on the Esch-sur-Sûre map. In 1981, a gravimetric profile measuring about 600 m in length was conducted between Hostert and Folschette, crossing this structure (Götze & Schmidt 1981). The results indicate a fault displacement of approximately 50 m. According to Dittrich & Norbisrath (2006), this is a normal

marginal fault. At its eastern end, the N67°E lineament is bounded by another N30°E lineament, which may correspond to a diagonal fault.

Bordière Fault (Figs 23, 40). Although Lucius originally described a marginal flexure between the Lower Devonian and the Triassic, Wagner (1982), in his doctoral thesis, argued that this flexure does not exist. Instead, he proposed that the structure be classified as a fault, which he named the Bordière Fault (personal communication) (Fig. 40, section B'B"). Running parallel to the Lannenerbierg Fault, it likely has a displacement of a similar magnitude and extends into the Lower Devonian.

Dahl Fault (Fig. 24). The presence of this fault is justified by the progressive disappearance of the Schuttbourg Member on the Diekirch sheet.

Wilspull Fault (Figs 24, 37). In the Michelau-Bürden-Wilspull region, southeast of the Welscheid Syncline, the stratigraphic orientations of the Kautenbach-Troisvierges and Our formations are inconsistent. Furthermore, since all strata in this region dip northward and NNW, a stratigraphic contact between these formations would imply that the Kautenbach-Troisvierges Formation overlies the Our Formation, which is geologically impossible. A fault must therefore be inferred (Fig. 37, section BB').

A similar reasoning applies further east, near the ruins of the former feudal castle of Brandenbourg. Here, the orientations of the Kautenbach-Troisvierges and Our formations differ significantly (Kautenbach-Troisvierges: predominantly N80 - 85°E; Our: predominantly N45°W), yet all strata dip northward and NNW. This structural incompatibility further supports the necessity of a fault.

The Wilspull thrust fault truncates the eastern extension of the Michelau Anticline, the Welscheid Syncline, and the Schumeschbierg Anticline (out-of-sequence fault). Southwest of Bürden, this fault is less constrained, but we have extended it south of Dellen to delineate a structural panel of rocks trapped within two thrust faults (the Eschdorf and Wilspull faults).

Wodescht Fault (Fig. 24). North of Erpeldange-sur-Sûre, there is a beautiful outcrop along the N27, measuring over 300 metres in length, with walls reaching heights of around 20 metres. On the south
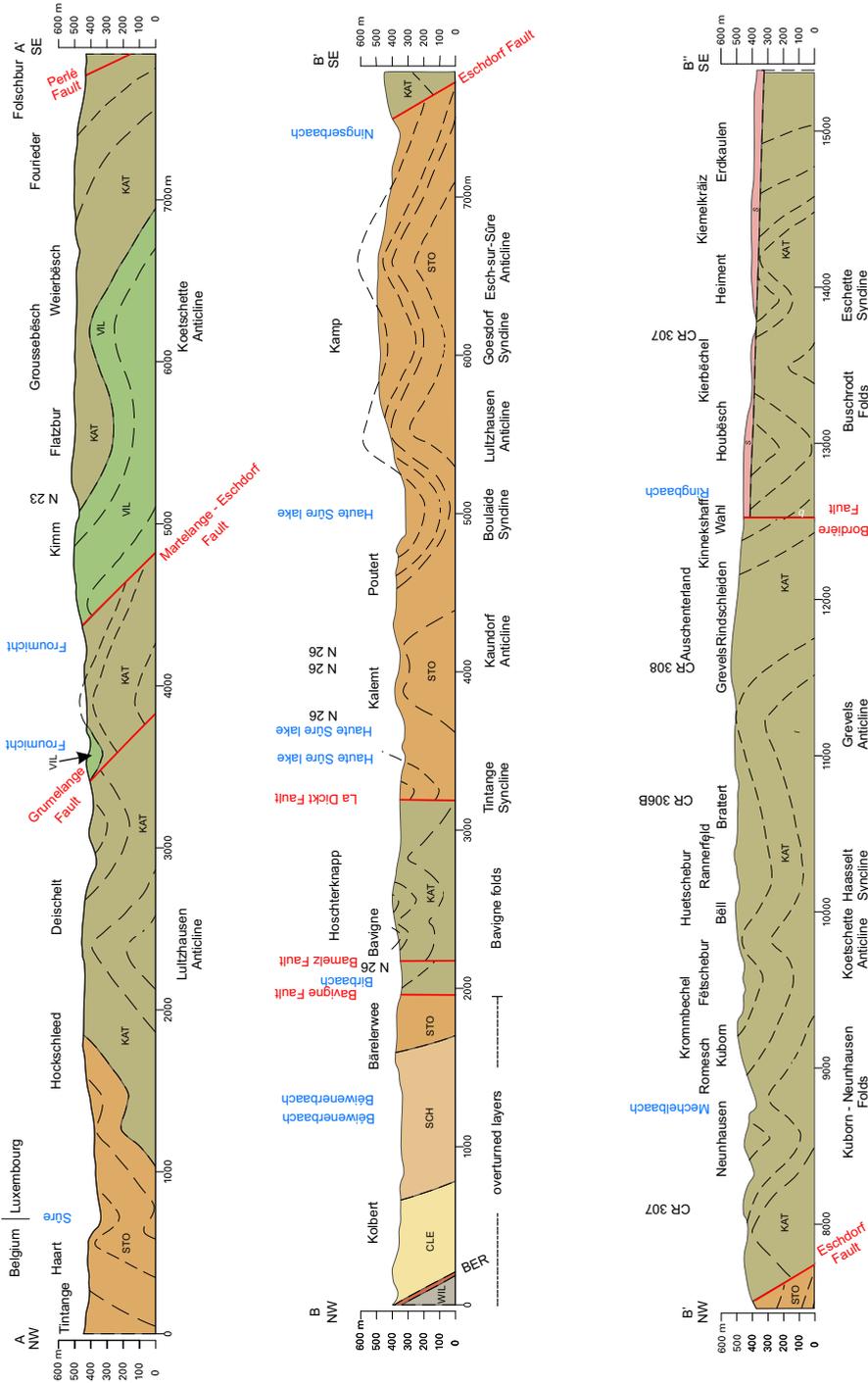
Figure 40: Geological cross-sections AA' and BB'B" from the Esch-sur-Sûre sheet, as indicated in Figure 23. The BB'B" section, though rectilinear and continuous, is divided into two parts: one (above) to the northwest and the other (below) to the southeast, separated by the Eschdorf Fault. Reproduced from Dejonghe (2024a), with modifications. Legend provided in Figure 25.

side, up to a recessed section about ten metres long coinciding with a wooded area (D334d), the layers dip southwards. Immediately to the north of this outcrop gap, the layers form a small syncline before resuming regular dips towards the S-SE to the northern end of the outcrop. This outcrop gap therefore likely marks the trace of a minor fault, as the small syncline is not followed southward by a corresponding anticline, which would otherwise suggest an association with a minor S-shaped fold developed on the flank of a major fold.

8.2 Transverse faults

Beiler Fault (Fig. 20). On the Troisvierges sheet, a transverse fault running N40°W through a point 400 m southwest of Beiler Church is supported by the following observations:

- In Lengeler, the Jupille Formation at Geissfeld is displaced southward in the former railway trench, northeast of the old Lengeler railway station.

- In the Beiler Käsfurt area, the Schuttbourg Member is present within a syncline to the west of the fault (Haard Syncline) but absent to the east.

- Between Ouren and Lieler, the fold axes are offset by the fault.

Fischbach Fault (Figs 20, 22). A transverse fault oriented N25°W cuts across the eastern end of the Clervaux Syncline on the Troisvierges sheet and continues south-eastward onto the Clervaux sheet. It results in an uplift of the eastern compartment.

Wardin Fault (Fig. 21). Primarily located in Belgium near the Belgian–Luxembourg border, the Wardin Fault intersects small sections of Luxembourg territory in two locations. It is well known in the Longvilly region, where it coincides with a lead-zinc vein that was historically mined (see section 9.5). Between Longvilly and Allerborn, the fault juxtaposes the Villé Formation layers to the northwest with those of the Kautenbach-Troisvierges Formation to the southeast. On the Wiltz sheet, it trends N45°E and bends northward at its eastern end, whereas west of Luttrebois, it shifts to N80°E.

According to Beugnies (1986: 39), later cited by Philippo & Kronz (2007: 104), the fault exhibits a vertical displacement, causing the eastern block to subside by 300 m. However, between Wardin and Luttrebois (Belgium), it acts as a sinistral strike-slip fault, shifting the eastern block 1,600 m north-eastward. In the field, it is marked by numerous quartz veins, often associated with Fe (Marvie, Wardin) and Pb-Zn mineralizations (Longvilly - Allerborn).

The variation in fault displacement characteristics across different locations remains unresolved. It is likely that the fault has two components: a normal faulting component and a sinistral strike-slip component, with varying amplitudes depending on the location. While no genetic conclusions can be drawn, it is worth noting that the Wardin and Troisvierges faults on the Wiltz sheet share a very similar orientation.

This is a late-stage fault, as it displaces the Opont Fault. Although it follows the bedding direction, its behaviour resembles that of a diagonal fault. This interpretation is also supported by Beugnies (1986: 38–39, 41).

Brachtenbach Fault (Fig. 21). The axial surface of the Clervaux Syncline is displaced along the Brachtenbach Fault, which is oriented N40°W and exhibits a dextral displacement of approximately 500 m.

Bamelz, Tréwelt, and Moltert Faults (Figs 21, 23, 40). East of Berlé, the white Berlé quartzite layer (see section 3.9.) was extensively mined in the past, as evidenced by elongated depressions containing white quartzite blocks at Bamelz, Hielschend, Gehälach, and Huuscht. These mining areas are roughly parallel and offset. Since these features cannot be explained by folding alone, the presence of diagonal faults trending NNE (the Tréwelt Fault at N5°E and the Bamelz Fault at N20°E) must be considered, both acting as dextral strike-slip faults.

Additionally, between Bamelz and Moltert, there are elongated depressions measuring approximately 200 m in length, oriented differently from those at Bamelz, Hielschend, Gehälach, and Huuscht. If these depressions indeed correspond to former Berlé Quartzite extraction sites, the Moltert Fault must be interpreted as a sinistral strike-slip fault. However, the mining origin of the depressions between Bamelz and Moltert remains uncertain, as they may have been excavated during the Ardennes Offensive of 1945 for military purposes. If this were the case, the Moltert Fault would not exist.

Château de Wiltz Fault (Figs 21, 23). At the level of Wiltz Castle, a fault oriented N7°E juxtaposes the Härebësch Member in the east with the Wiltz Formation in the west. East of Roullingen, it displaces the stratigraphic contact between the Clervaux and Our formations. It thus appears to act as a sinistral strike-slip fault with a slight uplift of the eastern block.

Merkholtz Fault (Figs 21, 24). On the Wiltz sheet, the layers of the Clervaux Formation, including those of the Härebësch Member, are clearly identified to the ENE of Wiltz, in the valleys of the Wiltz, Himmelbaach, and Kirel rivers. However, their northeastward extension is problematic, as the Wiltz Formation appears relatively quickly east of the Kirel River. Their disappearance is attributed to fold plunging. However, in certain locations, the Clervaux Formation is in direct lateral contact with the Wiltz Formation, without evidence of folding or plunging. Furthermore, NW of Merkholtz, the Berlé Quartzite layer and the Clervaux Formation are offset. These observations suggest the presence of a transverse fault oriented N25°W - the Merkholtz Fault -, which primarily exhibits dextral movement in the NW-SE direction. The folds observed west of the Merkholtz Fault could be attributed to a greater compressional force affecting the western block compared to the eastern block. This fault extends south-eastward into the Diekirch sheet, where it offsets the axial surfaces of the Goesdorf Syncline and the Esch-sur-Sûre Anticline.

Several transverse faults are represented on various maps (Troisvierges, Clervaux, Diekirch, Figs 20, 22, 24). From west to east, these include the **Schüttbuergmillen Fault**, the **Fridbësch Fault**, the **Scheed Fault,** the **Wahlhausen Fault**, the **Hosingen Fault,** and the **Fischbach Fault**. Some of these faults are inferred from NW-SE offsets in the formations. Most exhibit a dextral strike-slip component, while others (such as the Fischbach and Scheed Faults) are dominated by vertical displacement. It is also possible that both components act simultaneously, with varying intensities across these faults.

Lannenerbierg Fault (Fig. 23). This fault is represented on the Redange map by Colbach (2003). It corresponds to a major N67°E-oriented lineament, clearly visible in the LIDAR image (Digital Elevation Model – detailed version). It extends for approximately 1 km on the Esch-sur-Sûre map. It is believed to be a normal marginal fault (Dittrich & Norbisrath, 2006). At its eastern end, the N67°E lineament is bounded by another N30°E lineament, which may correspond to a diagonal fault.

Bockholtz Fault (Fig. 24). This fault, visible on the Diekirch sheet, systematically offsets the axial surfaces of the folds within the Stolzembourg Member due to dextral (right-lateral) displacement.

Masseler Fault (Fig. 24). This short fault (approximately 1,500 m) is not well-constrained. We have attributed a sinistral (left-lateral) displacement to it, in response to the offset of the axial surface of the Dirbech Syncline on the Diekirch sheet.

Bourscheid Fault (Fig. 24). On the Diekirch sheet, the folds within the Kautenbach-Troisvierges Formation (including the Welscheid Syncline, Michelau Anticline, and Mierschend Syncline), as well as the Eschdorf Longitudinal Fault, are displaced along the transverse Bourscheid Fault, which acts as a dextral (right-lateral) fault. This fault aligns with the Schüttbuergmillen Fault, and both exhibit dextral offsets. However, due to the absence of any tectonic structures along the 3 km stretch between these two faults, their continuity cannot be confirmed.

Ellebam Fault (Fig. 24). Bounded to the northwest by the Eschdorf Fault and to the southeast by the Wilspull Fault, the band of land belonging to the Kautenbach-Troisvierges Formation outcrops over 4.4 km at the western end of the Diekirch map. However, its width, which is 5.6 km to the NW, gradually decreases towards the NNE. At Brandenbourg, it narrows to just 1.2 km. As this formation disappears further east, we have delimited it with the short Ellebam transverse fault. The eastern block has subsided relative to the western block.

Château de Vianden Fault (Fig. 24). On the Diekirch sheet, the axial surfaces of the four Vianden folds are displaced along this transverse fault, which acts as a sinistral (left-lateral) fault.

8.3 Other faults

On the Diekirch sheet, faults within or at the northern end of the Buntsandstein were introduced by Lucius (1949b). They are shown in Figure 24 but are not discussed in this work.

A nearly vertical fault, parallel to the stratification, can be observed north of Clervaux (Fig. 41). At this

location (point C355), the layers are almost vertical, facilitating bedding-parallel slip. In this case, the infill between two sandstone beds - separated by an open space of 1.20 to 1.5 m, depending on the location - consists of bluish-grey clay incorporating fragments of curved sandstone banks Almost vertical slickensides are present on the sandstone bed on the northern side. This fault does not affect the stratigraphic thickness of the series or the geological mapping.

A different type of bedding-parallel slip can also be observed at Rodershausen (Fig. 42), where the base of the upper beds fold above the slip plane. This structure is comparable to a miniature tectonic ramp.

In certain locations, such as Michelau (Fig. 43), small faults can be found, but their impact on geological mapping is negligible.

- Fault F1 (70→337) brings grey-blue siltstones (to the NW) into contact with sandstone layers (to the SE), where several decimetres thick beds are truncated in a wedge shape. At the fault contact, cleavage is affected by a small kink.

- Fault F2 (43→152) is located behind the electric pole. This fault causes an upturn in schistosity at its contact whose shape implies that it is due to a reverse fault.

As these faults deform the schistosity, they must be late in their development.

Some small faults may be accompanied by significant alteration of the surrounding rocks (Fig. 44). This is the case at Goesdorf (point D50), where a subvertical fault separates two panels:

- To the SSW: the rock is composed of unaltered dark grey-blue clayey sandstone.

- To the ENE: the rock is highly fragmented, altered, and coloured by a reddish haematitic pigment.

This small fault does not affect the depiction of the geological features on the geological map.
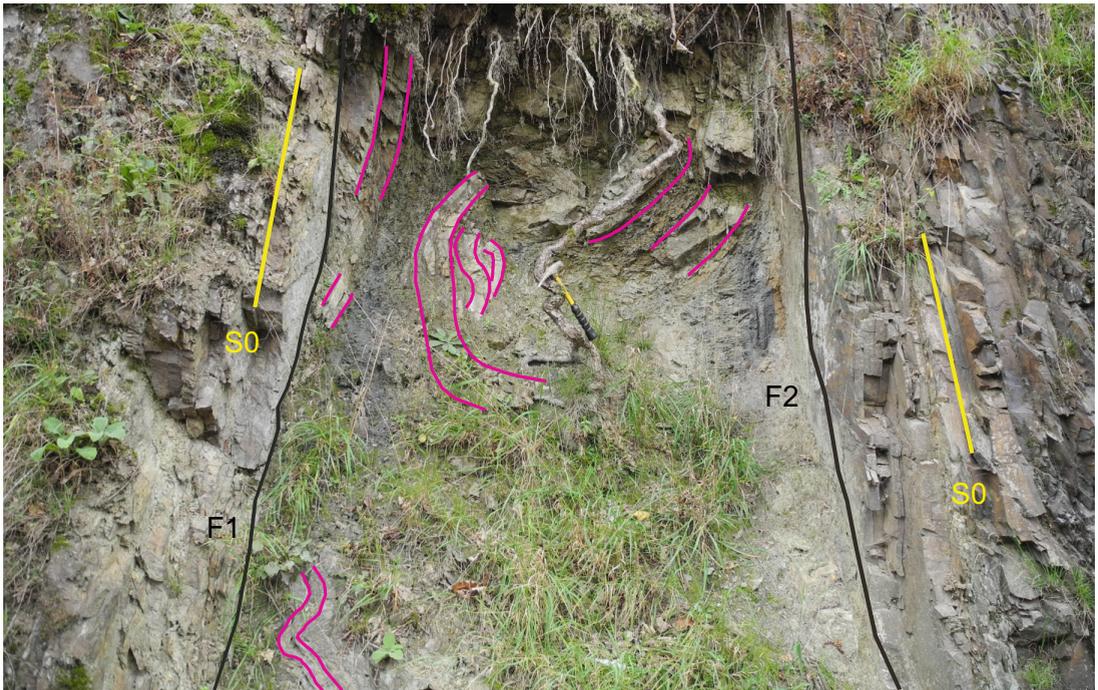

Figure 41: Clervaux (point C355), Our Formation, Schuttbourg Member. Almost vertical fault corresponding to bedding-parallel slip, leading to an opening between the stratigraphic surfaces of the beds. The clay infill contains fragments of curved sandstone beds. Certain curved stratification planes are highlighted in red. F1 and F2: fault walls. S0: stratification. The hammer is 35 cm long.

Figure 42: Rodershausen (point C199). Mini tectonic ramp at the hammer's position. Below the hammer: white to grey quartzite with irregular clasts of very dark grey shale (Berlé quartzite). Above the hammer: slipped beds showing slight folding at the ramp surface contact. The hammer is 35 cm long. S0: stratification; R1: mini tectonic ramp.
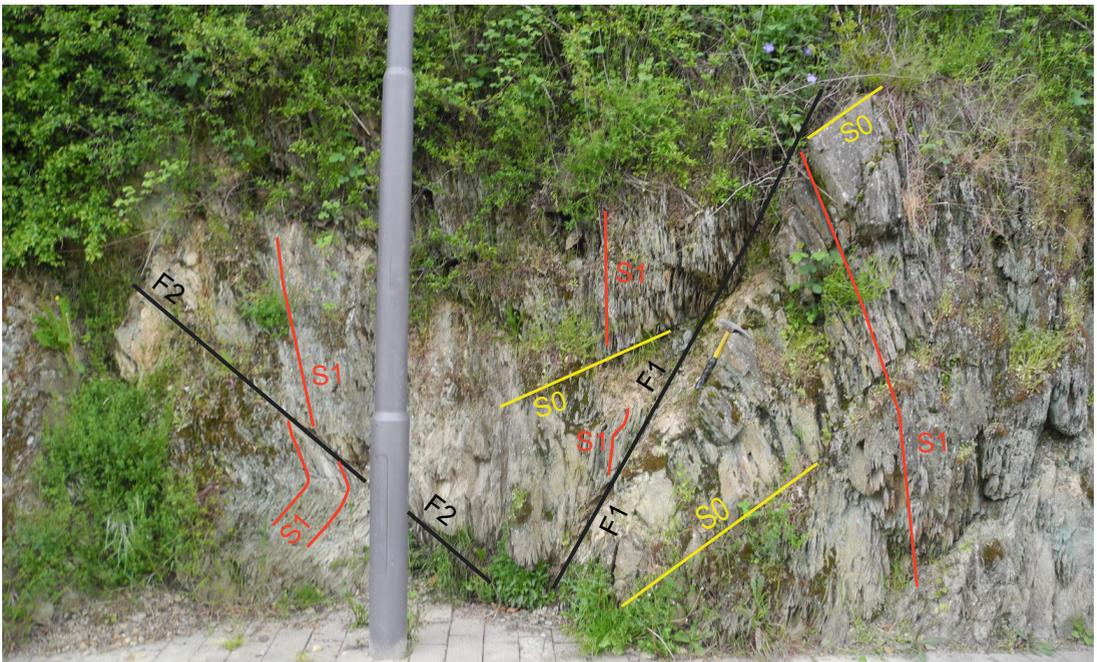

Figure 43: Michelau (point D138a-4). The photograph shows two small faults (F1 and F2) in the Kautenbach-Troisvierges Formation. S0: stratification; S1: cleavage. The hammer handle is 35 cm long.

Figure 44: Goesdorf (point D50-05). Subvertical fault F1 in the Our Formation, Stolzembourg Member. Fragmentation and alteration of the surrounding rocks led to their consolidation with wire mesh to prevent debris from falling onto the CR 361 road. A haematitic pigment is also visible on the right of the fault line, extending over approximately 50 cm in thickness. The hammer handle is 35 cm long

9 Mineral resources

This chapter only concerns rocks and minerals that have been mined. Although charcoal like layers have been mentioned (Asselberghs1946: 226-227; Lucius 1950a: 18; Muller 1980: 587), they have never been mined in Luxembourg.

9.1 Sandstone and quartzite

In the past, large quarries were established in the Our Formation to extract sandstone and quartzite, forming layers several metres thick (sometimes exceeding 20 m), primarily for construction purposes. These layers are locally referred to as "Hassel sandstone."

On the **Clervaux sheet**, at a site known as Pënzerhuuscht (point C649) (Fig. 8), the Rinnen company continues to extract a blue-grey sandstone known for its high strength (28 KN/cm²) and strong resistance to aggressive acids. The company supplies crushed stone for road construction, wall cladding slabs, stair treads, quarry stones, paving stones, floor slabs, gabions, and cyclopean stone blocks (data from 2019). More technical details on the rock from the Rinnen quarry can be found at www.rinnen.lu/carriere/. Other quarry operations also existed north of Clervaux (point C353).

On the **Troisvierges sheet**, although aggregate production continues at some former quarry sites, such as in Sassel and Holler, bedrock extraction is no longer a permanent activity (as of 2014/2015). However, temporary quarrying still occurs in certain locations, including Sassel (point L212) and Lieler (point L143). In the past, large quarries extracted sandstone and quartzite in thick layers (sometimes exceeding 20 meters) in areas such as Heinerscheid (points L168, L169, L170, L172, L173), Holler (point L98), Lieler (points L129, L130, L143), and Sassel (points L212, L213, etc.).

On the **Wiltz sheet**, sandstone and quartzite layers several metres thick (sometimes exceeding 10 m, and in some cases significantly more) were quarried at various locations, including west of Merkholtz

(points W12, W31, W35, W464, W465, W466), southeast of Roullingen (point W203), southeast of Doennange (point W127), and south of Hamiville (point W475).

On the **Esch-sur-Sûre sheet**, within the Schuttbourg Member, sandstone and quartzite layers several metres thick (sometimes over 20 m) were quarried, for example, 1,350–1,480 m WSW of Nothum church (point E8, located in Berlé, with four former quarries spanning 150 m in length). Additionally, 1,080–1,100 m NNW of Surré church (point E223a), quarrying extended over approximately 20 m. However, old quarries in the Schuttbourg Member are far less common on the Esch-sur-Sûre sheet than on the northern sheets of Wiltz and Clervaux. In the Stolzembourg Member, a large quarry was opened in Boulaide at a site known as Bauscheltermillen (point E306). Smaller, older quarries are also found in the area, such as in Esch-sur-Sûre (point E78a), northwest of Liefrange (point E21b), and northeast of Liefrange (points E498, E499, etc.).

On the **Diekirch sheet**, the Schuttbourg Member is not well developed and contains no old quarries. However, the Stolzembourg Member hosts several old, mostly small quarries.

9.2 Slate

Slate in the Martelange area has been exploited for several centuries. Asselberghs (1924: 1067) mentions that a memoir written in 1650 by a priest named Kuborn already refers to slate production in Martelange. However, Mayérus (1953: 15) cites the date as 1750. Given their significance in the geological composition of the Martelange Member, the locations of underground slate mining sites are depicted in Figure 45.

In Belgium, minor slate mining operations existed west of Wisembach (Jeanty and Anc. Nanquette), and an exploratory gallery was reported east of Radelange (Asselberghs, 1924: 1070). However, the most significant slate mining sites in this region are located further south, arranged in three parallel SW-NE trending bands (Fig. 45):

- A northwestern band extending just over two kilometres (1,450 m in Belgium; 660 m in Luxembourg), including the slate mines of Martelange and Rombach-Martelange (from SW to NE: Nanquette, Tornaco, Kuborn, Donner, Augustus, Adolf, and Angelsberg).

- A central strip, 1.25 km in length, encompassing the slate mines of Haut-Martelange and Wolwelange (from SW to NE: Hilda, Marguerita, Nanquette, Laura, Johanna, and Hoffmann).

- A southeastern strip, 1 km long, containing the slate mines of Perlé (from SW to NE: Karl-Eduard, Carolus, and Hemmer).

These three bands effectively define the extent of the Martelange Member within the Martelange area.

As a general rule, the mining method used in most slate quarries in the Ardennes involved excavating large underground chambers. Access to the slate formations was gained through inclined shafts positioned near the rock face. The unaltered, compact rock, unaffected by atmospheric agents, was typically reached at an average depth of around 20 m. Extraction proceeded by creating a series of adjacent, independent interior chambers measuring 12 to 14 m in length along the foliation plane. These chambers were separated by consolidation pillars 5 to 7 m thick. The mining technique employed was known as "underhand stoping" ("gradins droits" in French), where extraction progressed downward within each chamber. As the mining front advanced, the chambers were backfilled. However, at Martelange, mining was conducted in descending steps of 4 m, with waste materials removed to the surface. Consequently, the chamber height continuously increased. Voisin (1987: 79) notes that chamber Nr 1, the oldest and most extensively mined, reached a height of 75 m and a horizontal width of 70 m.

Further details on extraction and block splitting techniques are provided by Mayérus (1953: 17) and Voisin (1987). In 1943, the slate quarry employed 700 workers in the Martelange area (Mayérus, 1953: 16).

The Donner slate mine at **Martelange and Rombach-Martelange** was particularly significant, producing approximately 12 million slates per year. In 1946, it employed between 250 and 300 workers. The phyllite was extracted over a thickness of 50 m (mainly 30 m at the base, with an additional 20 m upper reserve zone). Mining extended 200 m parallel to the foliation, reaching a vertical depth exceeding 150 m (Voisin, 1987: 78-79). By 1924,
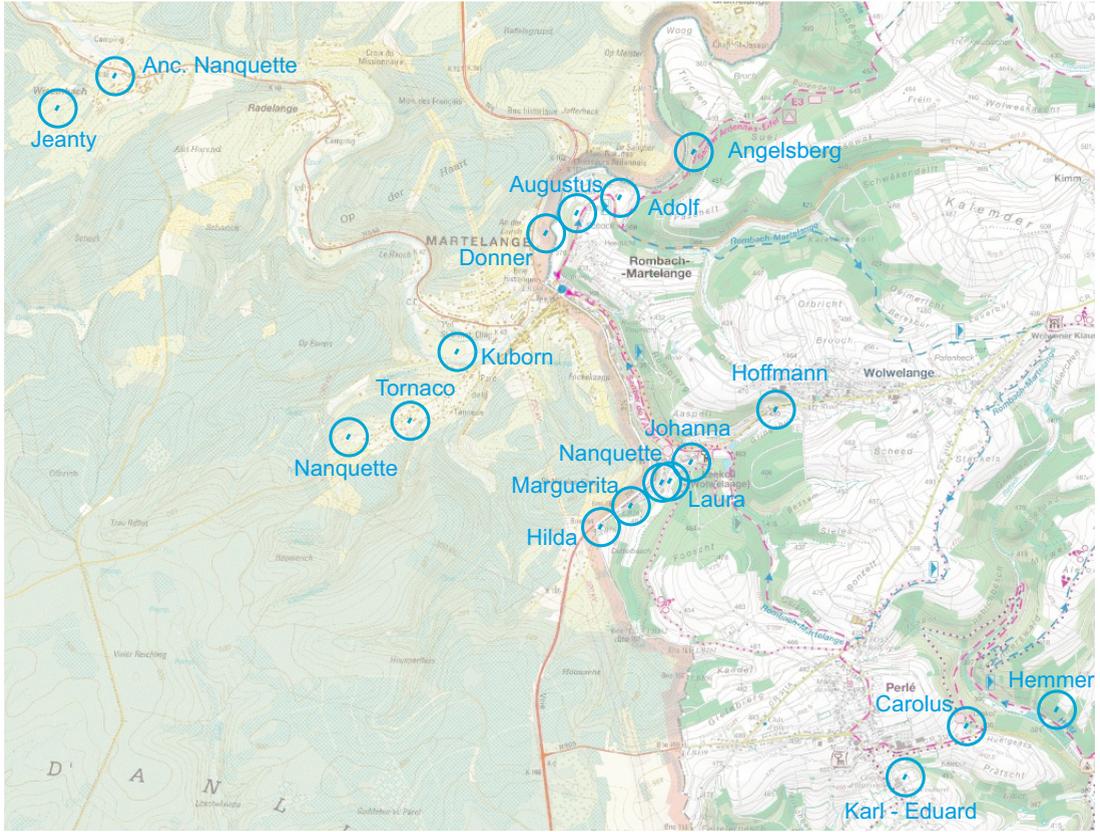
Figure 45: Map showing the locations of former slate mining operations in the Martelange area. Adapted from a document by the Geological Survey of Luxembourg, dated 1999.

around ten chambers, each 12 to 14 m wide, were separated by 7 m thick pillars.

At the end of the 18th century, the first underground mines were established in **Haut-Martelange.** By the late 19th century, over six million roofing slates were produced annually. The largest slate mines, Laura and Johanna, were situated next to each other. In 1946, Johanna employed 300 workers, 75 of whom worked underground. In 1945, the mine produced 5.5 million slates, but during more favourable periods, annual production ranged from 10 to 12 million slates, with approximately two-thirds exported. By 1946, operations had reached a vertical depth of 138 m and included 12 chambers.

Around 1900, the Haut-Martelange site employed 600 workers. Four years later, the site was equipped with a power plant that generated electricity using efficient steam engines. During World War I, mining operations continued, as the German occupiers

deemed the industry essential. However, from the 1930s onward, global economic downturns led to stagnating sales. During World War II, some workshops even expanded their workforce, a strategy used by employers to shield Luxembourgish workers from forced labour in German camps. After 1960, the decline of the Luxembourg slate industry accelerated due to the introduction of alternative roofing materials and the import of cheaper slate. Ultimately, in 1986, the last slate company in Luxembourg ceased operations.

In the **Perlé r**egion, slate phyllite was exploited along a stretch of 1,200 m. The slate-bearing zone, measuring between 50 and 70 m in thickness, gradually thins out towards the east as tectonic faults become more numerous, rendering further extraction unprofitable. Mining operations reached a vertical depth of 80 m (Lucius 1953: 202).

Slate phyllite was also mined at **Emeschbaach,** located 1,400–1,500 m west of Asselborn Church. This site is also known as the Demesbaach or Asselborn slate quarry. Research and excavation began in 1868 at a location where earlier extraction had already taken place. Between 1883 and 1904, and again from 1918 to at least 1947, slate was extracted first from open-cast quarries and later from underground mines. However, the slate-bearing layers were less substantial than those in Martelange, and significant dewatering requirements limited the expansion of mining activities. Detailed accounts of this slate mining operation can be found in Lucius (1947b: 108-111; 1950a: 30-33).

Approximately 1,700 m southwest of Emeschbaach, at a site known as **Kéimich** an excavation about 10 m in diameter and 5 m deep is visible. A metal plate blocking an underground entrance suggests the presence of past research or extraction activities.

Slate phyllite was also mined underground 900 - 1,000 m east-southeast of the church of Benonchamps, in the municipality of **Niederwampach-Schimpach,** near the Belgian–Luxembourg border (point W449). Remnants of old buildings and mine entrances are still present at this location. The site is sometimes referred to in literature as the **Benonchamps** slate quarry. According to Philippo & Kronz (2007: 103), the mine was opened in the late 1900s but was abandoned shortly thereafter. The presence of quartzophyllades in the rock made extraction particularly challenging.

Beyond the slate bands discussed above, Lucius (1847: 111) mentions the remains of an old slate quarry in **Folschette**, located on the western slope of a wooded hill known as "op der Schock," between Eschette and the area called Kesselbaach. Egloffstein (1988: 20) also refers to this former slate quarry west of Eschette (WGS84 coordinates: 5.87682E/49.82398N). After being abandoned for a century, operations briefly resumed in 1855 but were abandoned again in 1859. Further investigations in 1924 did not yield significant results. Given its geological setting, it is unlikely that this site belongs to the Martelange Member, as it is not located at the base of the Kautenbach-Troisvierges Formation.

9.3 Copper

Lucius (1948b: 207-228 and 1950a: 35-46) and, more extensively, Philippo et al. (2007) have provided detailed accounts of the history of the Stolzembourg copper mine, referencing both published and unpublished works by various authors.

This deposit is situated in the Klangbaach valley at a site known as Golddell (formerly Goldberg) at point C474 (Figs 46, 47). The main vein, the only one to have been mined, has been identified over a length of 500 m and a depth of 197 m from the top of the old workings. Two additional, smaller veins were identified 80 m and 400 m east of the main vein, respectively (Lucius 1948b: 207). Other occurrences have been documented in the area by Philippo et al. (2007), including the Fléssen gallery, Riedgerbësch gallery, SEO gallery, and a prospecting gallery along the Klangsbaach.

According to Dumont (1848), mining at Stolzembourg began in the early 17th century on the northern slope of the Goldberg. The first concession was granted on 14 June 1717 (Philippo et al. 2007: 12). Subsequently, the mine experienced numerous periods of exploitation alternating with periods of inactivity. The most prosperous mining periods occurred around 1856, 1882, 1901, and 1938. The last mining operations by the company Neu & Stauder took place between 1939 and 1944.

The Stolzembourg copper-bearing veins fill fractures trending NS or NNW-SSE, dipping at an average angle of 60° westward, and are slightly offset by minor ENE-WSW faults (Fig. 47). They intersect the shales and sandstones of the Our Formation, which dip at approximately 50° NNW. The mined vein, with a thickness ranging from 0.10 to 1.80 m, had a gangue mainly composed of ankerite $\{Ca(Fe,Mg,Mn)CO_3\}_2$ or dolomite $\{Ca(Mg,Fe,Mn)CO_3\}_2$.

Calcite ($CaCO_3$), siderite ($FeCO_3$), kaolinite $\{Al_4(Si_4O_{10})(OH)_8\}$, quartz ($SiO_2$), and barite ($BaSO_4$) were present in minor amounts. The copper ore consisted almost exclusively of chalcopyrite ($CuFeS_2$) mixed with some possibly copper-bearing pyrite (FeS_2). In addition to these primary minerals, Philippo et al. (2007: 64-65) also reported the presence of cubanite ($CuFe_2S_3$), sphalerite (ZnS), galena (PbS), and, in the cementation zone, covellite (CuS) and digenite (Cu_9S_5), along with 23 other newly formed minerals from the supergene
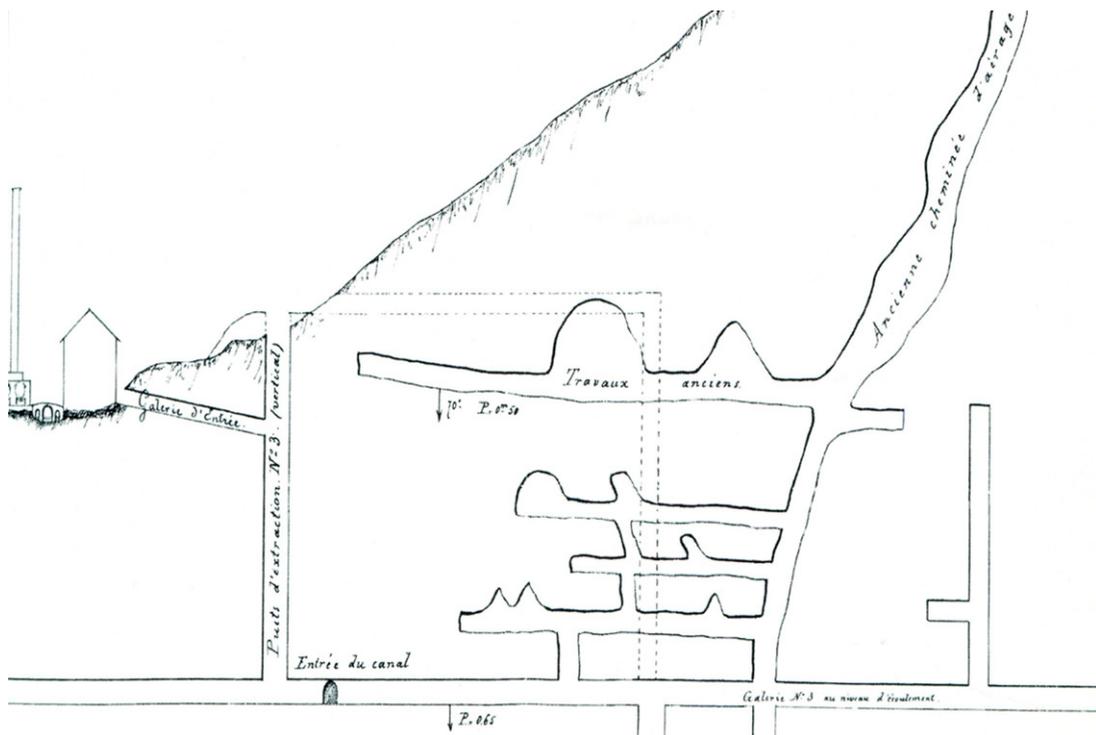
Figure 46: Stolzembourg, point C474. Old workings in the Stolzembourg mine in Goldberg. Reproduced from Philippo et al. (2007: 13; Fig. 2.2).
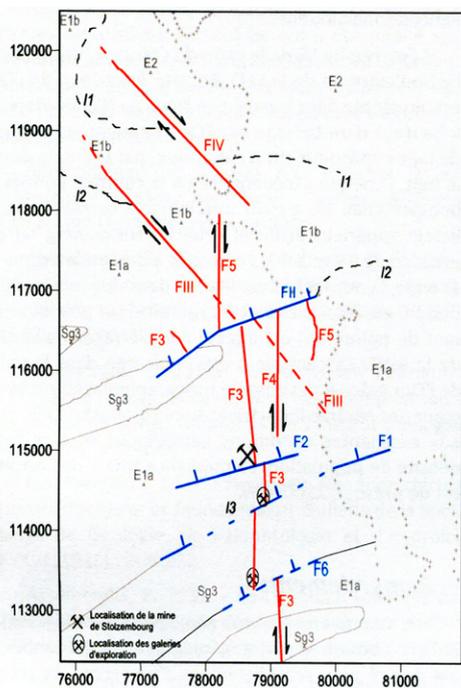

Figure 47: Stolzembourg, point C474. Location of the Stolzembourg copper-bearing veins based on geological data and geophysical surveys. The figure shows the displacement of the NS or NNW-SSE-trending mineralized vein by secondary transverse faults. Sg3: Upper Siegenian. E1a and E1b: Lower Emsian. E2: Middle Emsian. F1, F2, F3, F4, F5, F6, FIII, and FIV: faults. Reproduced from Philippo et al. (2007: 86, Fig. 8.10).

zone. The study of fluid inclusions in the gangue minerals indicates a formation temperature of around 150°C, classifying it as a low-temperature hydrothermal vein.

Adjacent to the wall and roof of the light-coloured section of the vein, there was often a zone referred to as "red shale," which could reach a thickness of up to 1 m. According to Schreurs in Philippo et al. (2007: 52), it consists of angular fragments of shale in a matrix of quartz and carbonates with chalcopyrite disseminated throughout. The copper content in these red shales is estimated at 2.2% by weight, and Schreurs (1981) describes them as "red ore".

The bulk of the copper ore occurred in tabular lenses (referred to as columns or ore shoots), ranging from a few centimetres to 0.30 m in thickness (occasionally reaching 0.50 m) and extending up to 5 m in length (exceptionally 10 m). These columns were oriented along the vein and dipped 60 to 70° to the north. As only the richest columns were mined, the extracted ore had an average copper grade of 14-18% by weight (sometimes higher, especially during the mining periods of the 18th and 19th centuries). It is estimated that more than 250 tonnes of copper metal were extracted.

In summary, the Stolzembourg vein and the mineral occurrences in the region belong to the same family of dextral strike-slip mineralized faults, offset by recurrent ENE-WSW faulting.

The book by Konen & Scheffen (2015: 117-135) contains numerous illustrations of the mine, the museum, and the galleries that were accessible at that time (see 12.2.).

9.4 Antimony

The antimony mine formerly exploited in the territory of Goesdorf has been described by Lucius (1948b), Nies (2005), and Philippo & Hanson (2007). The name of the locality, Goesdorf, originates from Gieszdorf, which translates to village of the smelters in English. On old topographical maps, the mine is located in an area called Weissenstein, meaning white stone, referring to the accumulation of milky quartz blocks that constitute the gangue of the mineralization.

A historical account of the mine's exploitation was established by Philippo & Hanson (2007: 113-121). The first known extraction of ore from Goesdorf is believed to date back to Roman times. It is also likely that the lords of Esch-sur-Sûre operated the mine until their dynasty disappeared around 1300. The first recorded concession was granted in 1354, followed by several others over the centuries, the last one being issued between 1934 and 1938 (to Ries, Hirt, and Cambier). Mining operations were highly irregular, and the mine definitively closed in 1938.

The deposit consists of quartz veins trending approximately east-west (N80°E), about two metres thick, dipping at 75°S. These veins are hosted within the Stolzembourg Member of the Our Formation, which forms a syncline at this location. The primary ore mineral is stibnite (Sb_2S_3), embedded in a palisade-like quartz (SiO_2) gangue, characterized by prisms perpendicular to the vein walls. Other primary minerals include pyrite (FeS_2), sphalerite (ZnS), and various carbonates. The mineralization is of low-temperature hydro-thermal origin (approximately 200°C). Supergene alteration minerals include valentinite (Sb_2O_3) and its polymorph senarmontite (Sb_2O_3), along with sulphur (S), stibiconite {$Sb^{3+}Sb^{5+}_2O_6(OH)$}, and gypsum ($CaSO_4 \cdot 2H_2O$). In reality, the primary and alteration mineral paragenesis at Goesdorf is more complex, containing additional minerals in trace amounts. Philippo & Hanson (2007: 132-142) provide a detailed description of the 34 mineral species they identified at the site.

The mine was accessed through three small historical shafts, which led to mining levels at depths of -16 m and -26 m. A later main venti-lation and extraction shaft, reaching a depth of 72 m, provided access to mining galleries at depths of -30 m, -60 m, and -70 m. Additionally, a 279-metre-long drainage gallery extended from the base of the main shaft towards the south-southwest, diverting water seepage into the valley. Figure 48, reproduced from Philippo & Hanson (2007: 119, Fig. 4), presents both plan and cross-sectional views of the different mining levels.

The results of a geochemical survey conducted by Fomino (1994) for Ni, Co, Cu, Pb, and Sb in oriented quartz outcrops, as well as those of a gravimetric survey carried out in 2005 by Bornain for the Musée national d'histoire naturelle Luxembourg, have been discussed by Philippo & Hanson (2007: 125-127).
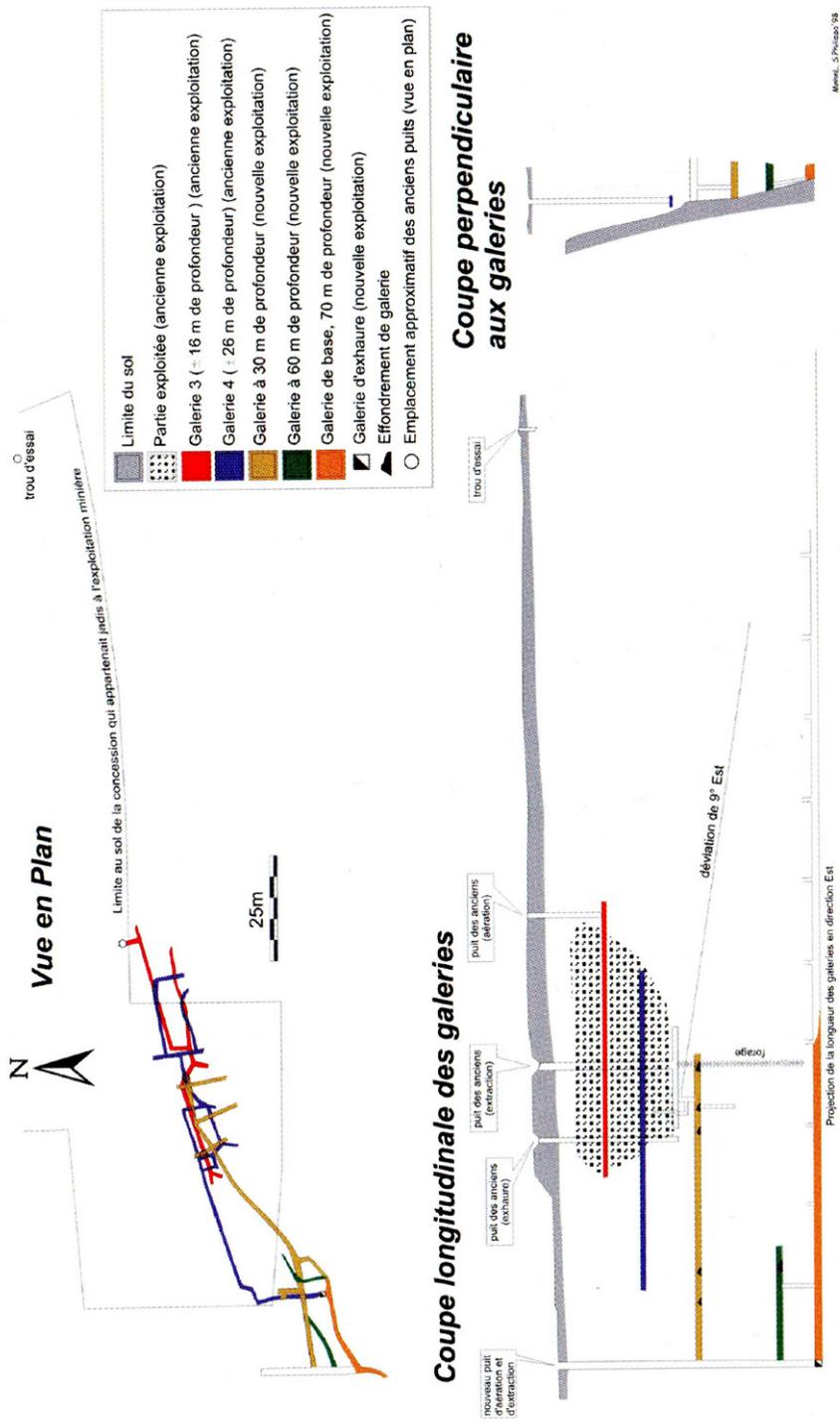
Figure 48: Plan and cross-sectional views of the different mining levels in the Goesdorf mine. Reproduced from Figure 4 of Philippo & Hanson (2007), based on Lucius (1948).

At point E381, an educational panel on mineralization has been installed near the site of the former extraction shafts and smelter. This panel displays a plan of the mining galleries and is accompanied by a large metal plate indicating the vein's orientation and dip characteristics. The outlet of the drainage gallery, designed to evacuate mine water from the base of the main extraction shaft, remains clearly visible at point E382.

9.5 Lead-zinc

In 1819, while draining a muddy area, an inhabitant of Allerborn uncovered a 600 kg block of galena (PbS) at a location known as Chiffontaine. A decree from the Dutch government, dated 26 August 1826, granted a lead concession over an area of 5,213 hectares. Mining operations began on 2 July 1827, approximately 1.3 km northeast of Longvilly Church. The galena was sold as "alquifoux" (the contemporary commercial French term for merchant galena) to potters, who used it in the ceruse process ($2PbCO_3.Pb(OH)_2$) to glaze their pottery.

The ore deposit was described by Lucius (1950a: 51-53) and Legrand (1970). The vein is vertical, ranging in width from 5 to 35 cm. It is hosted within the Wardin Fault (see 8.2.). The sulphides (galena - PbS, pyrite - FeS_2, and sphalerite - ZnS) are found within a gangue of quartz (SiO_2) and calcite ($CaCO_3$). In the surface oxidation zone, pyromorphite ($Pb_5(PO_4)3Cl$), limonite ($Fe_2O_3.nH2O$), and calamine (zinc-oxide mineral compound) are present.

From 1847 to 1865, a 2,240-metre-long gallery was excavated. The central part of the gallery is located at coordinates 5.85072N/50.03126 (WGS84). Mining operations were abandoned in 1873 but resumed in 1877, with the mine reaching a depth of 110 m. Around 1880, the area known as Chiffontaine was renamed La Mine, following the construction of housing for 200 workers and the establishment of a school. Starting in 1832, the ore was washed and sorted to separate galena, sphalerite, and pyrite. From the galena, an average of 30 grams of silver per ton was recovered. The mine was ultimately abandoned in 1901, by which time the extraction level had reached a depth of 172 m, with pumps operating at -185 m. Between 1827 and 1864, production is estimated at 1,000 tons, while from 1864 to 1902, production totalled 5,330 tons (Legrand, 1970: 3).

Moërynck (1984) published a history of its exploitation and research following its closure. A map of the workings from 1881 to 1898, reproduced from Moërynck (1984: 29), is shown in Figure 49. The site was also the subject of a surface geochemical survey (Sondag et al., 1972: 413-424; Sondag & Martin, 1974: 1-18; Sondag et al., 1974: 219-222).

The mine site hosts a calamine grassland, as described by Graitson (2005: 104). A geological trail with educational panels is in the area surrounding the former Longvilly-Allerborn mine site. The mine has also been documented with excellent photographic images by Konen & Scheffen (2015: 107-115).

9.6 Berlé Quartzite

The Berlé quartzite has been exploited for road paving and the production of refractory materials (Lucius, 1955: 34). Its characteristics are described in section 3.9.

9.7 Milky quartz

Located 900 meters south of the church of Sonlez, at a site called La Blanche Pierre (point W123), there is an excavation measuring up to 25 m long and 10 m wide, with a maximum depth of about 4 m. The excavation is elongated in a N50°E direction. This area is known for a milky quartz vein, as indicated by the toponymy, which was exploited in the past. The vein shares the same orientation as the axial surface of the Brûlé Bois Anticline (Fig. 21) and is likely connected to the external part (extrados) of this anticline
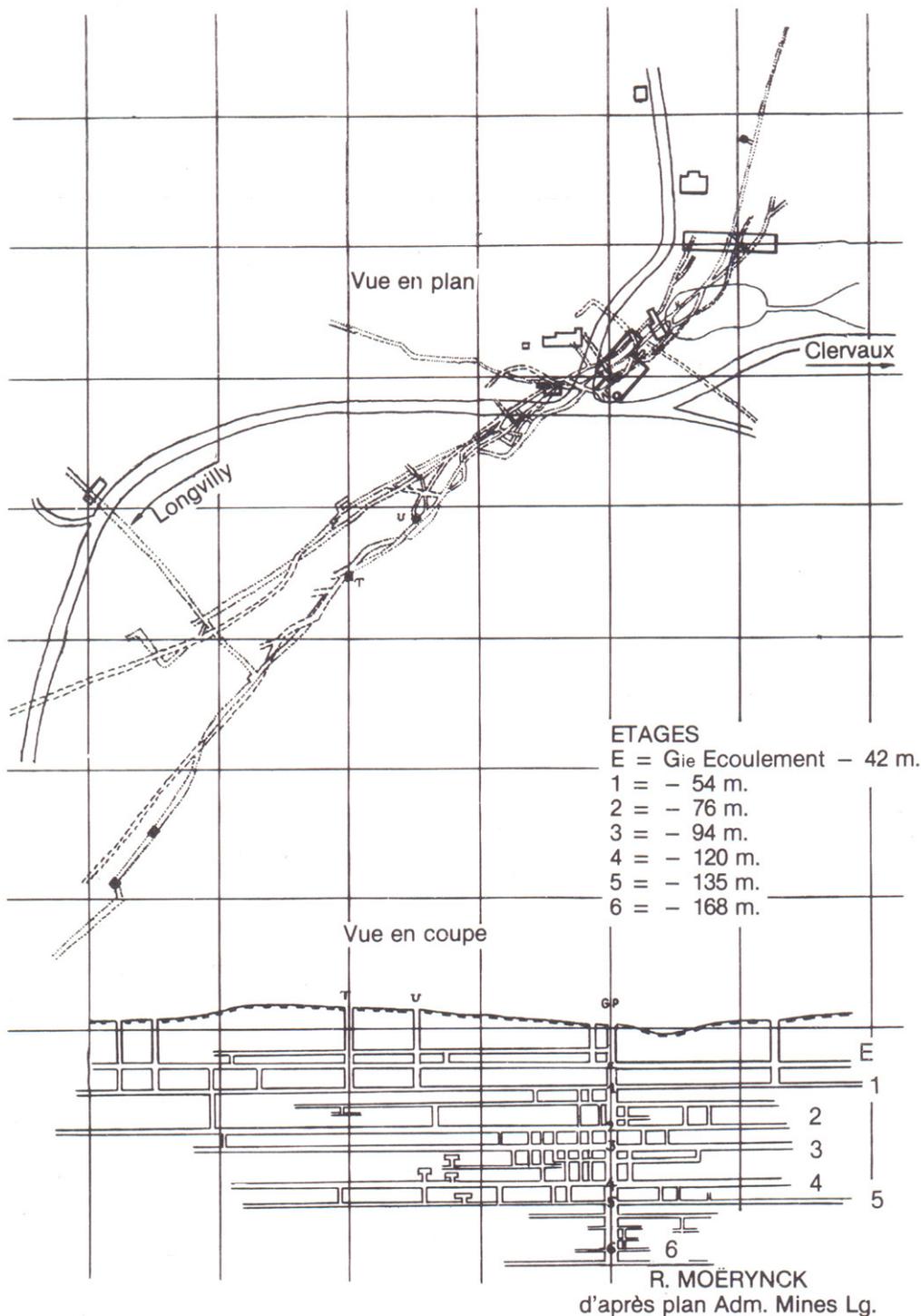
Figure 49: Plan of the workings from 1881 to 1898 at the Longvilly-Allerborn lead-zinc mine. Reproduced from Moërynck (1984: 29).

10 Mineralogy

10.1 Luxembourgite

During the construction of a new gallery for the SEO (Société Électrique de l'Our) in Bivels, a scientific collaborator from the Musée national d'histoire naturelle Luxembourg, Jean-Baptiste Burnet, observed heavily weathered shale samples in the gallery's rubble. These samples showed fine mineralized veinlets, up to 1 cm thick, containing dolomite, siderite, and very fine needles of an unknown mineral. Scanning electron microscope (SEM) analyses revealed that the mineral contained copper, bismuth, silver, lead, selenium, and traces of sulphur. Further electron microprobe and X-ray diffractometer analyses confirmed the mineral as a new species, named luxembourgite by Philippo et al. (2019). Its formula is $AgCuPbBi_4Se_8$.

10.2 Barite

A small barite lode is observable to the south of Bivels along the Our river (point C210).

10.3 Minerals of the quartz veins

The mineralogy of the quartz veins in the Schimpach area was studied by Philippo & Kronz (2007). The mineralogical assemblage includes hematite (Fe_2O_3), moganite (SiO_2), chlorite $\{(Mg,Fe,Al)_5(Al,Si)_3O_{10}(OH)_8\}$, and a rare mineral, gravegliaite $(Mn_2SO_3 \cdot 3H_2O)$, which, in 2007, was only the second known occurrence worldwide.

10.4 Alluvial minerals from the Wiltz River

Philippo & Kronz (2007) reported the discovery of garnets (spessartine - almandine), pyrite (FeS_2), rutile (TiO_2), zircon $(ZrSiO_2)$, and gold (Au) during an alluvial prospecting survey of the Wiltz River in the Schimpach region. The gold, the first recorded occurrence of its kind in Luxembourg in 2007, was found in placer deposits as flakes smaller than a millimetre. Its primary source is believed to be in the Bastogne region (Belgium).

11 Hydrology

The rocks of the Lower Devonian formations, predominantly consisting of shales and siltstones, with lesser amounts of sandstones and quartzites, are not conducive to the formation of significant groundwater aquifers. The clayey and silicic rocks exhibit very low permeability, and groundwater circulation beyond the altered and fractured zone near the surface is minimal. Some shallow private boreholes tap into this fractured zone, typically to supply individual farms. Where springs are exploited, the flow rates are often less than 100 m^3/day, generally providing water to single homes. These flow rates are insufficient to meet the needs of communities, especially in the summer.

Before the construction of the Esch-sur-Sûre dam, most of the drinking water in the Guttland area was sourced from the Luxembourg Sandstone (Lower Jurassic). Michel Lucius (Fig. 50), the founder and first head of Luxembourg's geological survey from 1936 onward, alerted the authorities to the risks of over-exploiting a single aquifer and advocated for the combined use of surface water, particularly from the Esch-sur-Sûre dam, which was built between 1953 and 1958 on the Sûre River. The Haute-Sûre reservoir created by the dam is currently the largest drinking water reservoir in Luxembourg, with a capacity of 60 million m^3. The lake spans 19 km in length and floods 380 hectares of land. Its catchment area covers 428 km^2, with two-thirds located in Belgium and one-third in Luxembourg and is entirely situated on Palaeozoic rocks.

The main dam includes a hydroelectric power station and is accompanied by six secondary dams designed to regulate flooding of the Sûre River and retain silt. These include two dams upstream, at Bavigne and Pont-Misère, and four downstream. The lake provides raw water to the treatment plant of the Syndicat des Eaux du Barrage d'Esch-sur-Sûre (SEBES), which was built in the 1960s. After treatment, the drinking water is pumped back to the main reservoir at Eschdorf. A new treatment plant was commissioned in 2023. Located near the main reservoir, with a nominal capacity of 110,000 m^3 per day, and divided into two separate treatment processes, it replaces the old plant. The Esch-sur-Sûre dam now supplies drinking water

Figure 50: Michel Lucius (foreground) and Jacques Bintz (former director of the Luxembourg Geological Survey) inspect construction work on the Esch-sur-Sûre dam around 1956. Source: Archives of the Administration des Ponts et Chaussées.

to 70% of Luxembourg's population. Additionally, electricity is generated by several turbines with a total output of 13 MW, installed on the main and secondary dams.

To the northwest of Vianden, a power station owned by SEO (Société Électrique de l'Our) is situated in the Our valley, at the site of a dam on the Our River. During periods of low electricity consumption, such as at night, the power station's surplus energy is used to pump water from the lower basin of the dam to an artificial upper basin at Niklosbierg, where it is stored. During periods of high electricity demand, the stored water is released into turbines to generate electricity, providing valuable peak load power, which is also fed into the German RWE grid. The power station was established in the Our valley due to its favourable topography, excellent geological conditions, and low population density. The total capacity of the turbines is nearly 1300 MW.

12 Places of geological, touristic or historical interest

12.1 Slate museum (Haut-Martelange)

Since January 1, 2019, the Johanna industrial site in Haut-Martelange, as described in section 9.2, has been transformed into a museum. The chambers of the former slate underground quarry have been adapted to a depth of 42 m, allowing visitors to explore them. The underground trail, inaugurated in 2022, takes visitors on a journey through the extraction chambers, enhanced with atmospheric lighting and audiovisual projections. The Slate Museum aims to raise public awareness of the trade and lifestyle of the former Martelange slate quarry workers, while also promoting rural tourism. It is managed by a non-profit organization, established in 2018 by the Luxembourg State, the Commune of Rambrouch, and Les Amis de l'Ardoise. For more information, visit https://www.ardoise.lu.

12.2 Stolzembourg copper mine and Stolzembourg museum (Putscheid)

To preserve the memory of the Stolzembourg copper mine, as detailed in section 9.3, the municipality of Putscheid, which includes Stolzembourg, has dedicated a museum to this heritage (Koffergrouf). A 2.5 km thematic trail (Mir gin op d'Grouf), leading from the museum to the former mine site, offers insights into the geological features of the rocks surrounding the mine. Remains of the surface installations are still visible at the former mine site. Additionally, part of the underground galleries is now open to the public. Full details of these initiatives can be found at www.stolzembourg.lu.

12.3 Meuse-Moselle canal tunnel (Hoffelt)

Supported by William I of the Netherlands, the Meuse-Moselle Canal is part of a 19th-century construction project aimed at opening Luxembourg by linking the Meuse basin to the Rhine via the Ourthe and Moselle basins, facilitating the transport of goods by small crafts. The hill on the Belgian–Luxembourg border posed a significant obstacle, which was to be overcome by tunnelling through the rocks of the Mirwart Formation. Work began in 1827. Under Dutch rule, large-scale work camps were set up in Belgium, a few kilometres east of Tavigny, in the village of Bernistap (also spelled Bernistape), and in Luxembourg, west of Hoffelt. When Belgium declared its independence in 1830, the Dutch withdrew, along with their capital, which accelerated the cessation of the project. Indeed, the growing ease of road and rail transport made the canal less necessary. The independence of Luxembourg in 1839 brought the project to a definitive halt. The two entrances of the canal were never connected. The planned tunnel for the Meuse-Moselle Canal was to be 2,528 m long and located 60 m beneath the hill crest. However, the tunnel collapsed just over four hundred metres from the Belgian entrance. To the west of Hoffelt, a 700-metre-long trench remains as a vestige of this ambitious endeavour.

12.4 Path of remembrance (Wiltz)

The woods to the southwest of Wiltz were the site of fierce fighting during the Ardennes Offensive in the winter of 1944-1945 (Battle of the Bulge), which claimed the lives of thousands of American and German soldiers. Near the Schumann crossroads, a monument and a footpath (known as the Sentier du Souvenir in French) commemorate these events. Along the Path of Remembrance, you can observe elongated trenches where soldiers sought shelter. These trenches were once part of the quarrying areas for the Berlé quartzite (see section 3.9). A bomb crater, where 157 German soldiers were temporarily buried after the fighting, is known as the Mass Grave (Tombe Commune in French).

12.5 Mausen Chapel (Rambrouch)

Located at Rambrouch (point E327), in the grey-blue shale of the Kautenbach-Troisvierges Formation (see section 3.3), the Mausen Chapel was dug by Aloyse Mausen, a resident of Folschette, as an act of gratitude (Fig. 51). Locally, it is known as the Mausen Cave (Grotte Mausen in French). In the early hours of December 16, 1944, Hitler's Wehrmacht launched its final assault. This counteroffensive, led by German Field Marshal von Rundstedt, advanced with surprising speed. As the danger closed in on Folschette and the situation grew increasingly dire, Aloyse Mausen vowed that if the village was spared, he would carve a chapel out of the rock in the Dillebaach Valley. On December 22, 1944, American General Patton's forces halted the German advance to the south, saving Folschette. Mausen kept his promise and dug the chapel that now bears his name.

12.6 Déck Lay rock (Eschdorf)

This outcrop, located at point E118, is part of the Kautenbach-Troisvierges Formation (see section 3.3). A plaque on the rock commemorates an event during the counteroffensive led by German Field Marshal von Rundstedt: on Christmas night, December 25, 1944, thirty inhabitants of Eschdorf sought shelter under the overhanging part of the rock.

12.7 St Pirmin spring (Kaundorf)

The mound of St. Pirmin, known as Përmesknupp, lies between Kaundorf and Büderscheid. This designated site has held cultural and historical significance for centuries and remains a place of Christian pilgrimage today. According to legend, in the 8th century, the Benedictine monk Pirminus blessed the spring here, which now bears his name. The spring is believed to have curative properties, particularly for children's ailments. The site was already a place of veneration during Roman times.

12.8 Esch-sur-Sûre castle

Esch-sur-Sûre Castle stands on a rocky promontory on the northern flank of an anticline in the Stolzembourg Member of the Our Formation (see section 3.6). Attractive load-cast structures are visible at various locations on the outcrops surrounding the promontory. The exact founding date of the castle is uncertain, and only ruins remain today. However, it is believed to be the oldest fortified castle in Luxembourg. Only its monumental dungeon (with walls 1.55 to 1.70 m thick) and its small chapel, dating from the Romanesque period, have been restored.

12.9 Lucius Museum (Reimberg)

The Lucius Museum, which offers insights into Luxembourg's geology, is housed in the birthplace of geologist Michel Lucius (1876–1971) (Fig. 50), the father of Luxembourg geology and the first head of the Luxembourg Geological Survey. The building is a typical example of 19th and 20th-century rural architecture. It was converted into a museum between 2004 and 2006 by the Service des Sites et Monuments.

12.10 Brandenbourg castle

Overlooking the picturesque village of Brandenbourg, the ruins of the former feudal castle rise on an imposing rocky outcrop at an altitude of 329 m, while the Blees valley lies 261 m above sea level. The history of Brandenbourg Castle dates to the 9th and 10th centuries, with a simple wooden fort guarding

Figure 51: Rambrouch, point E327. Grotte Mausen photographed on September 28, 2021. The chapel is carved into the grey-blue schist of the Kautenbach-Troisvierges Formation. The hammer, with its handle parallel to the schistosity plane (S1moy = 69→148), measures 35 cm in length.

this important site. In the 12th century (the first mention of a lord of Brandenbourg dates to 1138), stone buildings were erected, including the formidable dungeon that still watches over the ruins today. Over the centuries, the castle has expanded and evolved, with new towers, an extended chapel, and defensive walls, reflecting changing architectural needs and trends. Information panels allow visitors to explore most of the monument freely. Along the signposted route, visitors can also admire the superb rock outcrops of the Kautenbach - Troisvierges Formation (see section 3.3), some of which are gunned or bolted. For more information, visit https://www.visitluxembourg.com/fr/attraction/chateau-de-brandenbourg.

13 Conclusion: geological overview

The geological formations of the Éislek belong mainly to the Lower Devonian and, over a small area to the SE, to the Triassic. More specifically, these Lower Devonian rocks are Pragian to Emsian in age (from -413.02 Ma ± 1.91 Ma to -393.47 ± 0.99 Ma).

Seven formations are distinguished in the Lower Devonian of the Éislek (Fig. 19). They are named, from bottom to top: Mirwart, Villé, Kautenbach-Troisvierges (including the Martelange Member at the base), Jupille, Our (divided into two members, Stolzembourg at the base and Schuttbourg at the top), Clervaux (including the Härebësch Member), and Wiltz. The Berlé Quartzite is located at the border of the Clervaux and Wiltz formations (Tab. 1, Figs 3 and 19). Except for the Clervaux Formation, these formations consist of blue-grey phyllites, shales, and siltstones, incorporating layers of

grey, blue-grey, and greenish-grey sandstones and quartzites with thicknesses ranging from a few decimetres to a few metres. In the Clervaux Formation, variegated, burgundy, and olive-green rocks are prominently represented. The boundary between the Kautenbach-Troisvierges and Our formations is more apparent in the northern part than in the southern part of the Éislek.

These sediments were deposited during a major marine transgression on the Old Red Sandstone Continent, which outcropped to the NW, with the Brabant Massif forming a southern spur. This transgression took place at the end of the Pridoli and the beginning of the Lochkovian (around -419.0 Ma). During this transgression, the Ardenno-Rhenan geosyncline was primarily fed by arenaceous sediments. During the Lochkovian and Pragian periods, fluctuations in sea level provide evidence of transgression-regression oscillations (Fig. 52).

The Emsian is a period dominated by transgression. However, a regressive episode occurred in the lower part of the Clervaux Formation, and it is highly probable that an estuary was established at this time. Transgression then resumes in the upper part of the Clervaux Formation, with a marked intensification during the deposition of the Berlé event, continuing into the deposition of the Wiltz Formation.

These rocks were folded into synclines and anticlines, which were subsequently displaced by longitudinal faults during the Variscan orogeny, the main phase of which dates from the end of the Westphalian period (around 310 to 305 million years ago), although its effects were felt until around 250 million years ago. These longitudinal faults were later intersected by diagonal and transverse faults, probably linked to the opening of the Rhine graben.
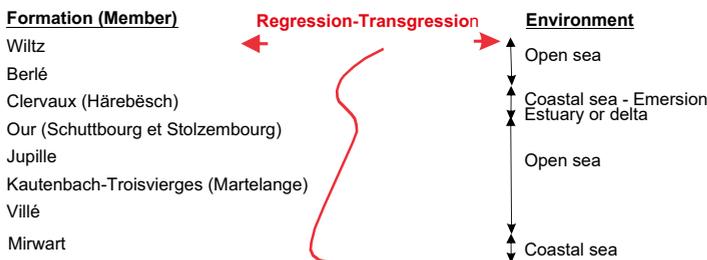

Figure 52 : Diagram illustrating the evolution of transgression and regression movements in the Luxembourg Basin during the Eodevonian period.

Regionally, the area is part of:

- The southeast of the axial zone of the Ardenne Anticlinorium, marked to the west by the west-east axis of the Rocroi Massif, and to the east by the axis of the Stavelot Massif, which trends SW-NE.

- The Neufchâteau - Wiltz - Eifel Synclinorium.

In the Triassic period (Middle Buntsandstein), coarse conglomeratic deposits were laid down in the valleys of a platform clearly separated from the Eifelian Trench. These sediments originated from the continent located to the NW at that time and were transported via a network of braided rivers.

For a geological summary of the region to the west, in Belgium, between Houffalize and Laroche-en-Ardenne, see Dejonghe (2013). For the regions to the east and NE, in Germany, Boy et al. (2005: 35-39) have summarized the main stratigraphic units considered.

Acknowledgments

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Appendices

Appendix 1. WGS84 coordinates of field observation points cited in the text, located on the Troisvierges sheet.

Acronym	Longitude	Latitude
L29	5.99001E	50.12054N
L98	6.04877E	50.12174N
L129	6.12902E	50.12133N
L130	6.12888E	50.12080N
L143	6.11375E	50.11225N
L168	6.09380E	50.09583N
L169	6.09472E	50.09534N
L170	6.09587E	50.09511N
L172	6.09867E	50.09501N
L173	6.10420E	50.09426N
L212	6.00939E	50.09668N
L213	6.00569E	50.09712N

Appendix 2. WGS84 coordinates of field observation points cited in the text, located on the Wiltz sheet.

Acronym	Longitude	Latitude
W12	5.96907E	49.96491N
W31	5.95659E	49.96122N
W35	5.96670E	49.96007N
W46	5.97752E	49.9551N
W123	5.82579E	49.95610N
W127	5.95993E	50.05782N
W203	5.93114E	49.94968N
W246a	5.94784E	49.96633N
W262c	5.96143E	49.97299N
W449	5.82197E	50.00068N
W464	5.97162E	49.96219N
W465	5.97224E	49.96332N
W466	5.97235E	49.96445N
W475	5.90472E	50.02904N

Appendix 3. WGS84 coordinates of field observation points cited in the text, located on the Clervaux sheet.

Acronym	Longitude	Latitude
C13b	6.05944E	50.04057N
C45	6.04632E	50.00948N
C199	6.10860E	50.04581N
C210	6.19237E	49.95580N
C239	6.12987E	50.04057N
C285e	6.12929E	50.01778N
C348c	6.02966E	50.05443N
C353	6.02536E	50.05775N
C355	6.02224E	50.06329N
C474	6.15042E	49.96782N
C649	6.03110E	49.97560N

Appendix 4. WGS84 coordinates of field observation points cited in the text, located on the Esch-sur-Sûre sheet.

Acronym	Longitude	Latitude
E8	5.86201E	49.93887N
E21b	5.8731E	49.91229N
E46c	5.91709E	49.93310N
E51	5.94212E	49.93250N
E99d	5.95766E	49.89015N
E78a	5.94363E	49.90898N
E105	5.90704E	49.88550N
E118	5.90666E	49.88050N
E223a	5.77030E	49.91043N
E232	5.75284E	49.82262N
E306	5.79454E	49.88229N
E327	5.86073E	49.82371N
E368	5.90121E	49.82154N
E381	5.95794E	49.92205N
E382	5.95684E	49.91979N
E411	5.80655E	49.86496N
E498	5.89059E	49.91444N
E499	5.89465E	49.91675N

Appendix 5. WGS84 coordinates of field observation points cited in the text, located on the Diekirch sheet.

Acronym	Longitude	Latitude
D50	5.96442E	49.90994N
D138a	6.09063E	49.89835N
D334d	6.11269E	49.86965N

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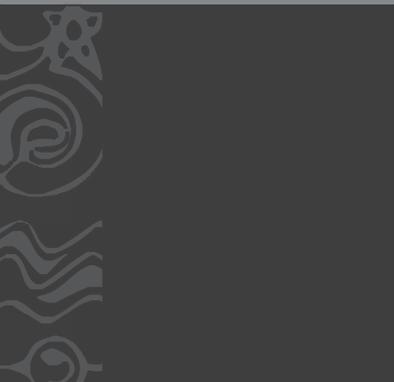
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