

# The Geological and Cultural Heritage of the Caledonian Stavelot-Venn Massif, Belgium

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**Abstract** The Stavelot-Venn inlier (also called as the Stavelot-Venn Massif) exposes a thick series of sedimentary rocks that have been intensely deformed and fractured by two succeeding orogenies (Caledonian and Hercynian). In addition, the Massif has been metamorphised into greenschists (at least at its southern border), subsequently cut by a large collapse structure (the Graben of Malmedy) and is still subjected to vertical tectonic movements. The geology of the Massif is quite distinct from that of the surrounding Devonian-Carboniferous strata. The rocks that built it, as well as their complex geological histories, created a particular landscape that is of great biological and geological interest; this has led to the creation of the High Fens Natural Park. Its subcrop encloses many peculiarities of regional, international or even global importance: e.g. manganese and molybdenum mineral deposits, slightly mineralised and ferruginous waters and sharpening stones made of ‘coticule’. The building stones extracted from the Massif (slates, quartzites) and from its borders (arkoses, sandstones) provide a characteristic look to the built environment and to other smaller heritage objects. Some relicts of the former mining activities have been used for touristic purposes (e.g. the slate quarry of Recht, the Museum of the Coticule); others have evolved into natural sanctuaries for rare or even exceptional faunas and floras, while some others have been deliberately abandoned to evolve freely. The conservation of the extensive peat bogs of the High Fens receives international attention and support. Clusters of ‘viviers’ (ramparted and closed remnants of Pleistocene lithalsas)

within this peat bog landscape are unique witnesses of subarctic conditions that ruled here during the youngest ice age. The cities of Spa and Chevron are true cities of water: the former is internationally renowned, having given its name to the famous and popular spa. The natural and geological heritage assets of the Stavelot-Venn Massif are thus multiple and interrelated: stunning landscapes, interesting former mining activities, exceptional ecosystems, excellent mineral waters and attractive local building stones. However, a holistic project integrating all of the latter components has still to be launched and is waiting for regional, national and international support. The Massif is well positioned between Belgium and Germany and covers different administrative units, offering excellent opportunities for creating a cross-border Geopark.

**Keywords** Coticule · Slate · Mineral waters · Stavelot-Venn · Geotourism · Geological heritage

## Introduction

The geology of Belgium has outstanding universal value because it forms the stage where a large part of Earth’s history has been elucidated. Geologists worldwide still use chronostratigraphic stage names coined in Belgium. Moreover, the classical Meuse River profile between the cities of Namur and Givet, displaying different facies for the Palaeozoic international stage names (Namurian and Givetian), is hailed as one of world’s first showcases of a geological succession in an orogenic belt (Lombard 1957).

Besides geosites and key sections linked to the above chronostratigraphic stages, Belgium also possesses emblematic natural heritage sites with a long history of human curiosity about their geological character (Dusar 2012). Exceptional finds unmatched elsewhere in the world, such

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as the Cran aux Iguanodons in Bernissart, are now showcased in the Natural History Museum in Brussels (Bultynck 1987; Godefroit et al. 2012). The recent morphological evolution, epeirogenic uplift followed by incised epigenetic rivers, exposed many more rock outcrops or allowed their exploitation, displaying more than 500 million years of geological history in a relatively limited territory (Dejonghe and Jumeau 2010).

Despite the overall presence of valuable geological heritage, Belgium has still no unique or uniform legal framework for its protection and conservation. After the regionalization of Belgium in 1980, the different regions or communities became responsible for protection and conservation measures and they apply different approaches to conservation and protection of geological heritage. Currently, geological sites and objects are protected by their incorporation within nature parks or reserves. Up to now, and despite the existence of many areas of outstanding geology and scenic landscapes in Belgium, no national or international geoparks have been officially appointed. However, several areas have already inventoried their geological heritage and geotouristic assets. They have demonstrated the intimate relationships between nature and culture, and they want to reach geopark status recognition, both nationally and internationally: e.g. the Cretaceous of the Mons Basin (Mortier & Baele 2012), the karstic area of Han-sur-Lesse area (Rekk et al. 2014) and the Stavelot-Venn Massif, described here. In 2011, the ‘Hoge Kempen Rural - Industrial Transitional Landscape’ in NE-Belgium has been officially put on the indicative list of World Heritage by UNESCO. The Hoge Kempen National Park (founded in 2004) bears a number of unique geological and geomorphological features witnessing of extreme global climate changes that once affected this area: from warm and humid tropical swamps to cold and dry permafrost conditions (Dreesen. 2006, 2012). With respect to the industrial and mining heritage in Belgium, many initiatives for conservation and development are already available, listed in the overview of geotouristic ‘attractions’ given by Dejonghe and co-workers (2009).

In this paper, we present the rich geodiversity of the Stavelot-Venn Massif, a particular geological unit in Eastern Belgium, and stress the strong ties between its fascinating geological history, scenery, natural environment, biodiversity, cultural traditions and local economic development. These complex interrelationships obviously produce a rich heritage that needs to be preserved in order to enhance local geotourism and ecotourism (Hose 2000, 2012). The main objective of this paper is to demonstrate the potential of the Stavelot-Venn Massif to become a cross-border geopark and eventually a member of the European Geopark Network, by establishing and implementing an integrated management tool that will foster the sustainable socio-economic development of the whole area.

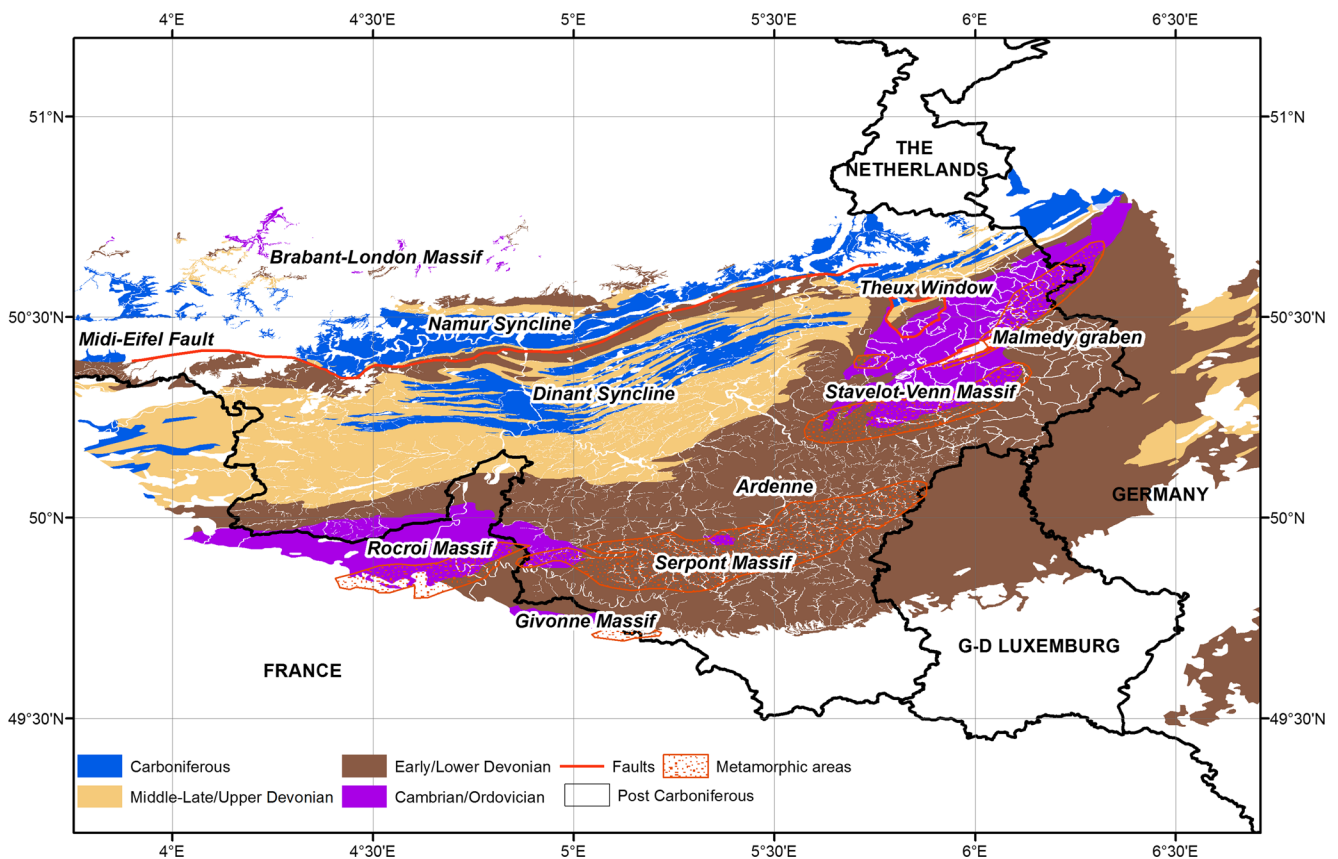
## Geological and Geographical Settings of the Stavelot-Venn Massif

In Belgium, Lower Paleozoic rocks crop out in six different areas (Fig. 1). The Stavelot Massif, *sensu stricto*, is the largest and the best exposed Lower Paleozoic inlier, traditionally called a ‘Massif’ in the Belgian geoscientific literature (Verniers et al. 2001). The inlier extends into Germany where it is better known as the Venn Massif. Its surface covers 1080 km<sup>2</sup> (length: 83 km, width: 25 km) in Belgium. The Belgian part of the SVM is located in Wallonia, and it is part of both the provinces of Luxemburg and Liège (Fig. 2). It belongs to the Walloon Region, but its German-speaking Community is a political independent Belgian entity (also called the ‘Eastern Cantons’) founded in the 1980s. Since 1994, this political entity has been entitled to decree regional laws, including directives for the protection of monuments and the conservation of the environment.

The SVM is characterized by a smooth highland (plateau), covered by forests, fens and small rural patches. It is incorporated within the allochthonous Variscan Ardenne nappe, together with three other entities (the Rocroi, Givonne and Serpont inliers). The Variscan Ardennes Allochthon, previously called the Dinant Nappe, has been thrust from the south over a distance of 10 to 100 km into its present position.

The SVM underwent two main deformation phases: the Caledonian and the Late Westphalian Variscan orogenies. The E-W trending Caledonian folds are overprinted by SW-NE striking Variscan tectonics. The Graben of Malmedy cuts the SVM in two and separates two complexly folded and faulted antiform structures. The NW flank of the SVM is characterized by a flat-lying thrust fault (Bless et al. 1990). To the north, a tectonic window called ‘Fenêtre de Theux’ exposes both Lower Paleozoic and Upper Paleozoic formations. Under the SVM, an important deep seismic reflector has been interpreted as the southward continuation of the well-known Midi-Aachen-Eifel Overthrust.

The basement of the SVM consists of a 2500 m thick siliciclastic sedimentary sequence ranging from the Early Cambrian through the youngest part of the Middle Ordovician (Figs. 3 and 4). The lithostratigraphic scale for the early Palaeozoic of the SVM formerly comprised the now disused Devillian, Revinian and Salmian stages. The ‘Salmian’ stage refers to the Salm River running through the southern part of the SVM. The SVM is unconformably overlain by Devonian rocks as a result of orogenic deformation caused by the collision of Avalonia, Baltica and Laurentia during the Late Ordovician through to the Early Devonian (Verniers et al. 2001). The first Devonian deposits on the SW flank of the SVM consist of conglomerates (Fépin Formation) surmounted by coarse sandstones (formerly erroneously known as ‘Arkose de Dave’ in spite of the lack of feldspars). The latter coarse sandstones were used for the



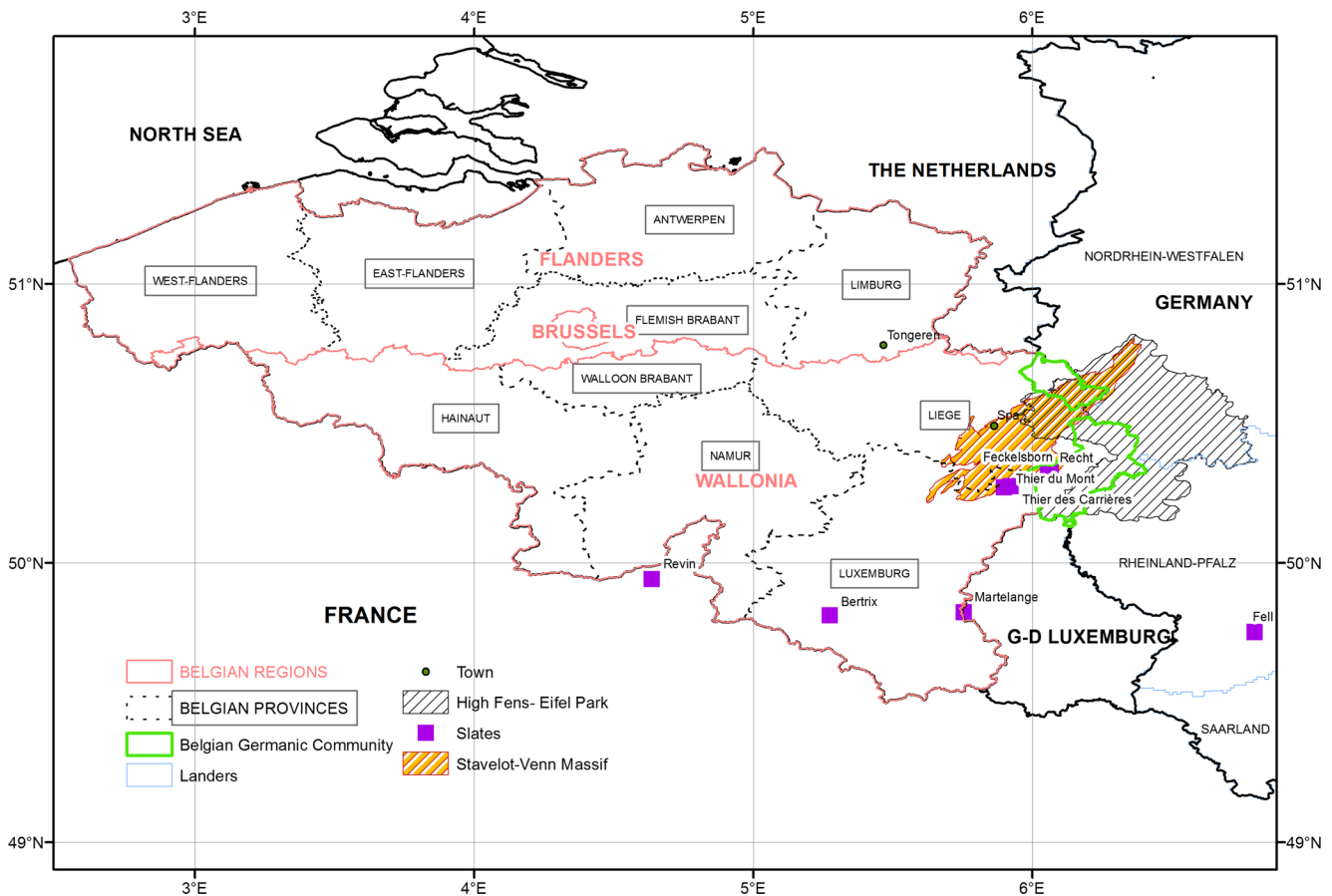
**Fig. 1** Geological map showing the location of the Lower Palaeozoic inliers (in purple). Limits of the metamorphic areas are taken from Fielitz and Mansy (1999)

manufacture of millstones during the Middle Ages and later on mostly as building stones and curb stones. The SVM encloses a few acid volcanic rocks (rhyolites and dacites) and exceptionally also intrusive magmatic rocks (diabases), all interbedded within Cambrian strata (Lamens et al. 1986). The Helle and the Lammersdorf sill-type granodioritic to dioritic intrusions (tonalities) are a few good examples. In the porphyry Cu-Mo mineralization linked to the tonalite intrusion of the Helle River, good pocket samples of molybdenite can still be found. Kramm (1976) related the high iron and manganese content of the Otré Formation to volcanic exhalations and interpreted the particular coticule beds as metamorphised volcanic tuffs (Fig. 3). However, this idea is still hypothetical because magmatic rocks are lacking in the latter formation.

The SVM is also divided in two metamorphic domains. The northern domain is characterized by an anchizonal Caledonian metamorphism (180–280 °C, 80–130 MPa), whereas the southern domain shows a Variscan greenschist-facies metamorphism (280–380°, 80–300 MPa) completely overprinting the lower-grade Caledonian metamorphism (Ferket et al. 1998). The Variscan metamorphism also affected the Early Devonian series located to the south of the SVM.

Since the Late Carboniferous (Variscan or Hercynian deformation), uplift and erosion affected the Ardennes-Rhenish area. Later on, a NE-SW-striking collapse structure called the Graben of Malmedy (2.5 to 0.5 km wide and about 22 km long) cut the SVM in half (see Fig. 4). The graben is of Permian age and has been infilled with reddish (continental-fluvial) conglomerate deposits forming the Malmedy Formation (thickness about 80 m in Stavelot and up to 210 m in Malmedy; Bultynck et al. 2001). Its middle member is predominantly composed of fossiliferous limestone clasts (indicating a Middle Devonian through to Lower Carboniferous, Tournaisian age), allowing local karst development. The probable provenance area for the limestone clasts is the western Eifel in W-Germany. Other pebbles are derived from the underlying Cambro-Ordovician basement. The latter conglomerates are well exposed in the Warche valley and in the cliffs near Malmedy. These rocks were also used as building stones in the past, giving a peculiar architectural touch to a geological environment otherwise made of grey quartzites and deep blue, green, black or purplish slates (from the Lower Paleozoic basement).

After a long period of non-deposition and erosion, the area was flooded by a Late Cretaceous marine transgression. Thin decalcified residual deposits of clay and flints, witnesses of



**Fig. 2** Outline of the Stavelot-Venn Massif and the High Fens – Eifel Park superposed on the administrative map of Belgium and neighbouring countries

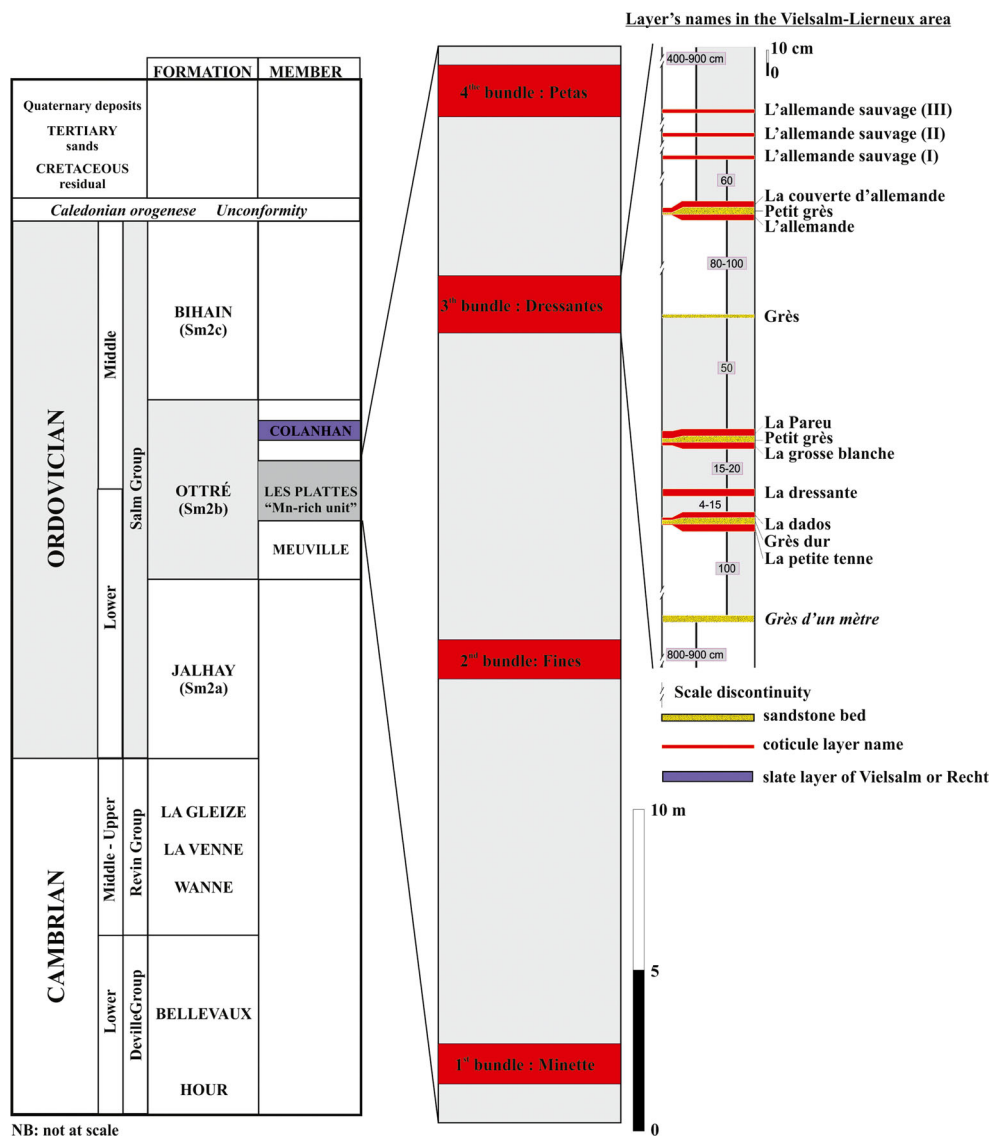
this event, are still present in the High Fens area. During the Early Eocene, the area was invaded by the sea again. As a result, thin layers of pebbles and sand were deposited in the SW-part of the High Fens. These layers occur on the top of the High Fens, covering the former residual Cretaceous flint-bearing clays, near Baraque Michel. Subsequently, in the same area, peat and gyttja (mud formed from the partial decay of peat) formed during the Quaternary.

**Peat Deposits and Lithalsas** The HF plateau, culminating at 694 m.a.s.l., has a relatively cool and humid climate favouring the development of peatlands with ombrotrophic bogs. The Cambro-Ordovician bedrock (mainly quartzites and slates) gave rise to clay-rich alteration layer. During the glacial episodes, loess accumulated but it survived only locally on the highest parts of the plateau. Peat soils cover 3750 ha, including 1000 ha of raised bogs protected since 1957 in a state nature reserve. The High Fens have a key position among the European peat deposits because they grew under both oceanic and continental influences. The average precipitation is about 1440 mm/year and the mean annual temperature over the High Fens averages 6.7 °C. Previous studies of the High Fens peat archives (using palynology) have demonstrated their potential for reconstructing regional vegetation changes.

Data from this area are important to improve our understanding of past climatic changes for this part of Europe (Damblon 1994; Strel et al. 2014). During the Boreal, peat-forming vegetation covered most of the High Fens area above 600 m, infilling depressions with up to 8 m thick peat deposits (Bless et al. 1990). Peat has been exploited since the sixteenth century as a combustible. The resulting disturbances of the substrate triggered the growth of a typical acidophilic (Ericaceae) flora that is extremely vulnerable and needs special protection.

In addition, clusters of so-called lithalsas (or mineral palsas \*)—permafrost mounds formed by ice segregation in mineral-rich soil that occur within the zone of discontinuous permafrost—are well preserved on the High Fens plateau. These particular structures, first interpreted as excavations made by prehistoric man and later as the remnants of pingos, formed in discontinuous permafrost conditions during the last ice age (Pissart 2003, 2009). They consist of circular to elongated peat bogs (so-called ‘viviers’) surrounded by rims (or ramparts) made of loose mineral material (see Fig. 5). The ramparts are the result of both mass wasting on the slopes of the mounds and toppling of inside material. The lithalsas formed on weathered Cambro-Ordovician quartzitic rocks and are associated with local hydrological conditions. Comparatively warm but extensive discontinuous permafrost,

**Fig. 3** Lithostratigraphic log of the Stavelot-Venn Massif highlighting the stratigraphic positions of the economically valuable raw materials (coticle and slates)

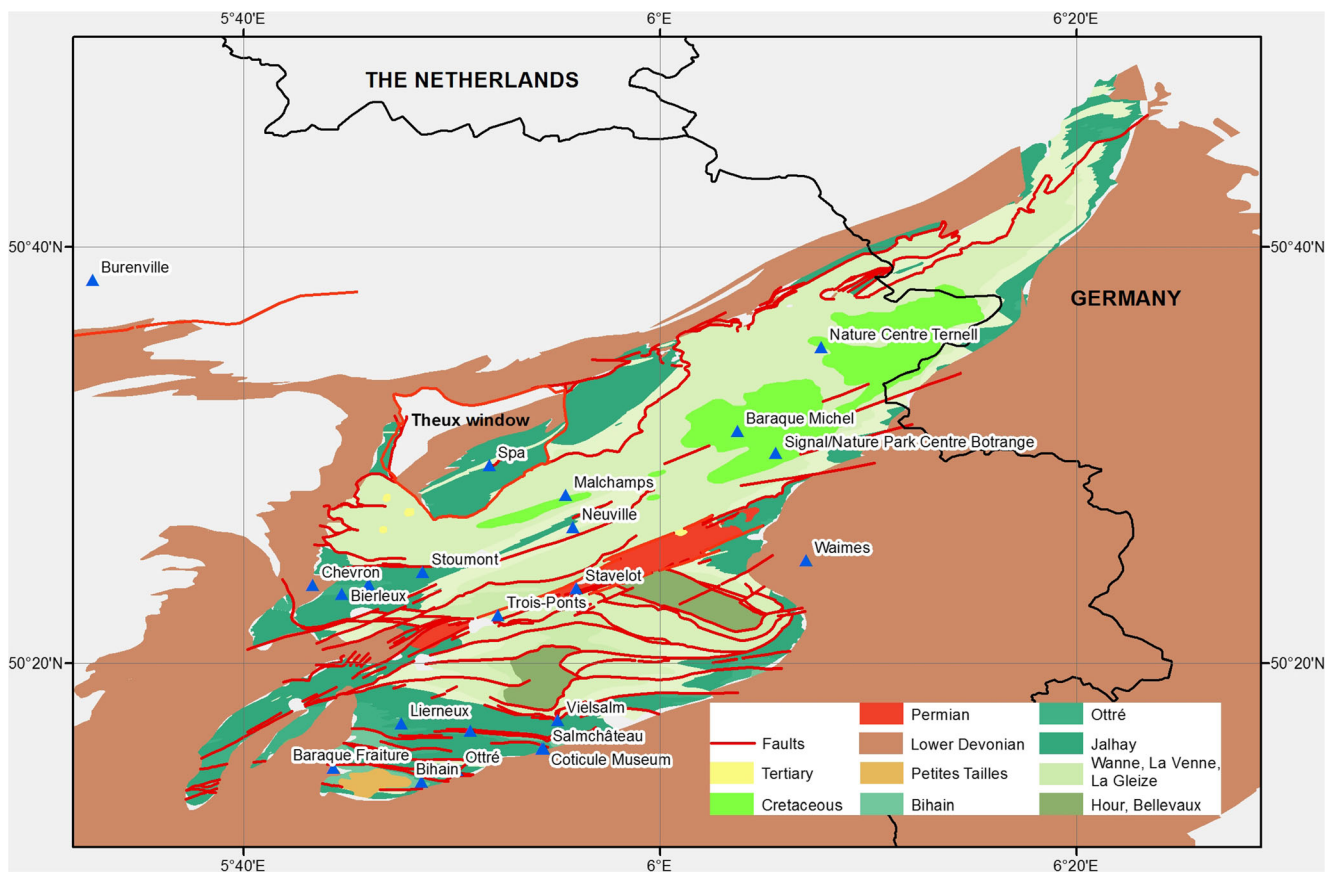


fine-grained sediments and available groundwater supply provide the prerequisite climatic and hydrogeological parameters for the development of lithalsas in permafrost terrain (Van Vliet-Lanoë, 2005; Wolfe et al. 2013). Forms identical to those viviers have been observed in northern subarctic Québec, Canada (Wolfe et al. 2013). <sup>14</sup>C dating of a peat layer preserved under a rampart, Alleröd volcanic ashes and palynological studies suggest that the viviers of the High Fens area formed during the Younger Dryas (Pissart 2003). Present-day lithalsas are solely known in subarctic Quebec and in Lapland. They form in the discontinuous permafrost zone, close to the tree line, i.e. in zones where the mean annual temperature ranges from -4 to -6 °C and where the average temperature of the warmest month is between +9 and +11.5 °C. Such climatic conditions are rarely encountered nowadays in periglacial regions. Remnants of lithalsas are also very infrequent. Such traces, dating from the Younger Dryas, have been

described only at elevations above 500 m.a.s.l. on the Belgian High Fens Plateau, around 250 m.a.s.l. in Wales and at sea level in Ireland. The climatic conditions during the Younger Dryas were similar to present-day conditions in subarctic Quebec, where numerous lithalsas still occur.

Finally, recent tectonic movements of the High Fens area along NW-SE directed fault zones, resulting from contemporary crustal movements, have been inferred from high-precision levelling data (Demoulin and Collignon 2000) and geomorphological features (Sougnéz and Vanacker 2011). The area appears to be continuously uplifting with a high mean rate of between 1 and 2 mm/year.

(\*) Palsas are low, often oval, frost heaves occurring in polar and subpolar climates, which contain permanently frozen ice lenses. They develop from ground water without additional hydrostatic pressure. Palsas are characteristically found in areas with discontinuous permafrost, and in such



**Fig. 4** Detailed geological map of the Stavelot-Venn Massif, modified after Geukens (1986)

areas, they may be the only reliable surface evidence of permafrost. Palsas occur particularly in bogs. Lithalsas are frost-induced raised land forms in permafrost areas with mineral-rich soils, where a perennial ice lens has developed within the soil.

### The High Fens, a Wealth of Water Resources

The High Fens are the largest nature reserve or park in Belgium, with an area of 4500 ha. Due to its topography, specific location and characteristic substrate, the area is

**Fig. 5** Lithalsas at Brackvenn, along the road from Eupen to Monschau. Aerial photograph by courtesy of E. Juvigné (Liège University)

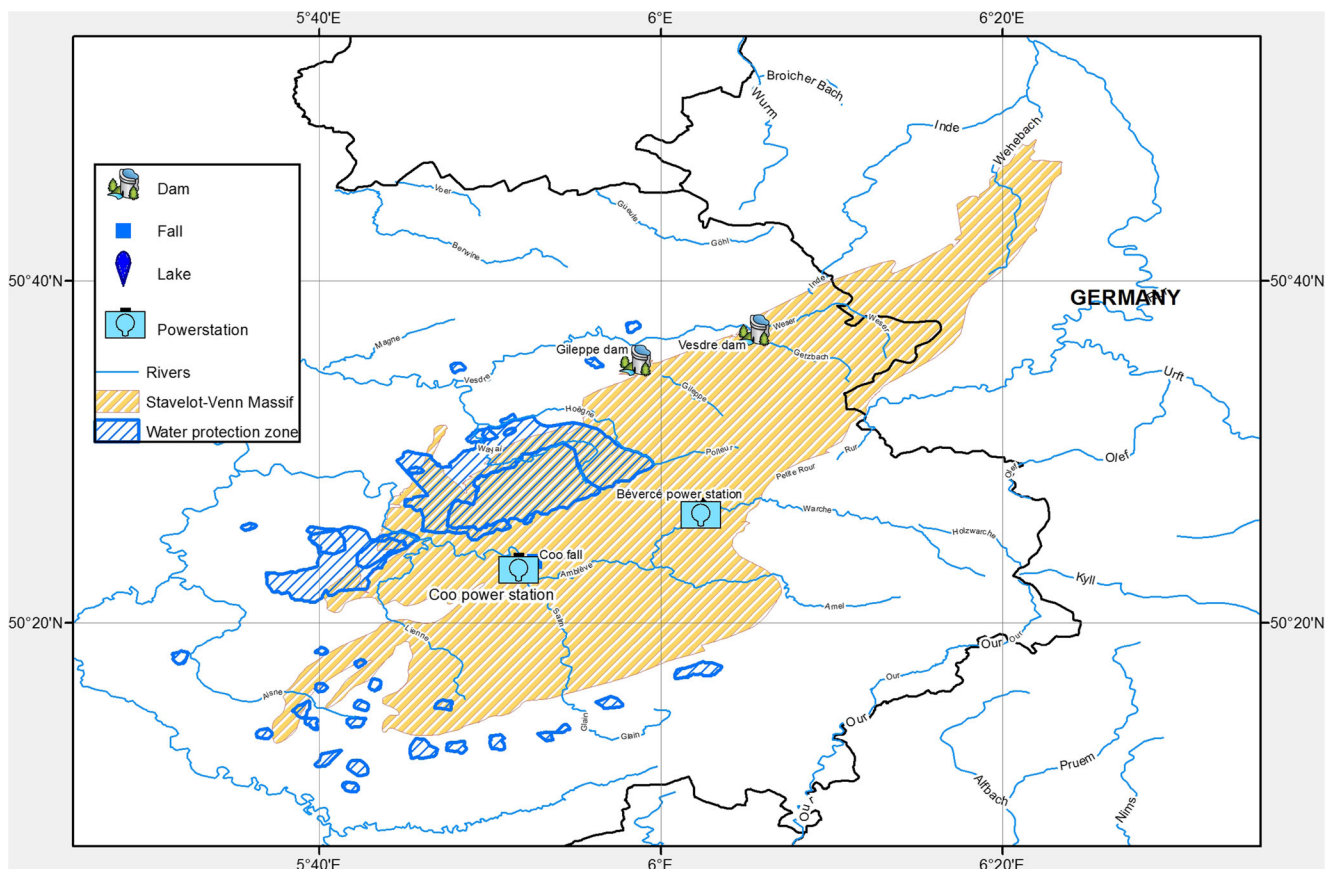


composed mainly of moorlands, peat bogs, low grass- and forest-covered hills. It has a subalpine climate with strong winds and fierce winters that can even become occasionally subarctic. The plateau intercepts clouds brought in by the prevailing Atlantic winds, resulting in abundant rainfall, averaging 1400 mm/year. However, underneath the fragile soils, the shallow bedrock and clays prevent infiltration of the water, thus creating ideal conditions for the development of moorlands, marshes and raised bogs. Water is the major landscaping element (Figs. 2 and 6) due to the presence of impervious bedrocks and high rainfall generating a large watering network. Consequently, several Belgian and German rivers have their sources here, fed by excess water draining off the high moors, including the Vesdre, Hoëgne, Warche, Gileppe, Eau Rouge, Amblève, Our, Kyll and Rur rivers.

The reserve is a rich ecological endowment for Belgium. It is covered with alpine sphagnum bogs both on the plateau and in the valley bottoms. Peat bogs, which are over 10,000 years old, bear unique subalpine flora, fauna and microclimate that are keys to the conservation endeavour of the park. In 1966, the European Council awarded a ‘certificate of preservation’ to the High Fens, for their high ecological value. The North Eifel Nature Park was subsequently founded in 1960, and in 1971, it merged with the Belgian ‘Parc Naturel des Hautes Fagnes’ to become the cross-border ‘Hohes Venn – Eifel

Nature Park’ (72,000 ha). Its emblem is the black grouse (*Tetrao tetrix*). While complementary, the reserve and park status are distinct: the first is dedicated to nature conservation, whereas the second is a combination of nature conservation and economic development. It is one of the most beautiful spots in Belgium and the place to be for cross-country ski during wintertime. Two important visitor centres are located in or near the fens: the Botrange Nature Park Centre and the Ternell Nature Centre. Each year, they attract thousands of visitors by offering guided nature tours, thematic exhibitions and various eco-educational activities. In Botrange, a permanent exposition called ‘Searching for lost landscapes of the Meuse-Rhine Euregion’ shows the development of the landscape of the High Fens. In Ternell, a geological trail (Geo-Pfad Ternell) allows visitors to explore and discover geological and geomorphological relicts and to reconstruct 600 million years of the geological history of the area.

Watercourses are important geopolitical and geohistorical boundaries. This is well proven by the River Helle. It bubbles from its spring not far from Botrange. In Roman times, the Helle marked the border between the administrative districts of Tongeren (*Civitas Tungrorum*) and Cologne (*Civitas Agrippinensium*). Before the French Revolution, the Helle marked the border between the Duchies of Limbourg and Luxembourg, and for many centuries, it has been the natural



**Fig. 6** Overall hydrographical map showing the most relevant places related to its water resources

separation between the bishoprics of Cologne (Köln) and Liège. From 1815 to 1920, it separated Prussia from the United Kingdoms of The Netherlands and their successor state, The Netherlands, followed by their regional successor, Belgium. Testimony to this fact can be found near one of the springs, the Fontaine Périgny, where the border stone ‘156 BP’ (BP: Belgium-Prussia) is still standing.

### ‘Coticule’ of Vielsalm: ‘The Best Whetstone in the World’

**Definition** Coticule is a very fine-grained highly Mn-bearing metamorphic rock, chiefly composed of crystals of spessartine (Mn-rich garnet, grain size: 1–5 up to 20  $\mu\text{m}$ , garnet content about 40 %, Fig. 9), a K-mica rich matrix and very fine grains of quartz (grain size below 1  $\mu\text{m}$ ). Similar rocks of about the same age can be found along the Appalachian and Caledonian fold belts (e.g. the ‘coticule’ occurrences of the Leinster Massif and in the Alps; Kennan & Murphy 1993). However, these are distinct from the Belgian coticule by their quartz-richer matrix and coarser garnet crystals. In the Belgian coticule, spots of andalousite or chlorite are present as well as red-stained parts (due to hematite) and thin crosscutting quartz veins. The spessartine grains are rounded, but crystal faces and edges can only be observed under the electronic microscope. Due to their small grain size, individual grains of spessartine are macroscopically not visible. Yellowish layers of coticule are interbedded with purplish or bluish hematite-stained garnet-bearing slates (Figs. 7 and 10). The colour of the coticule is generally pale yellow, but it can vary from very light green, to light orange or even light red, according to small compositional changes from one layer to another.

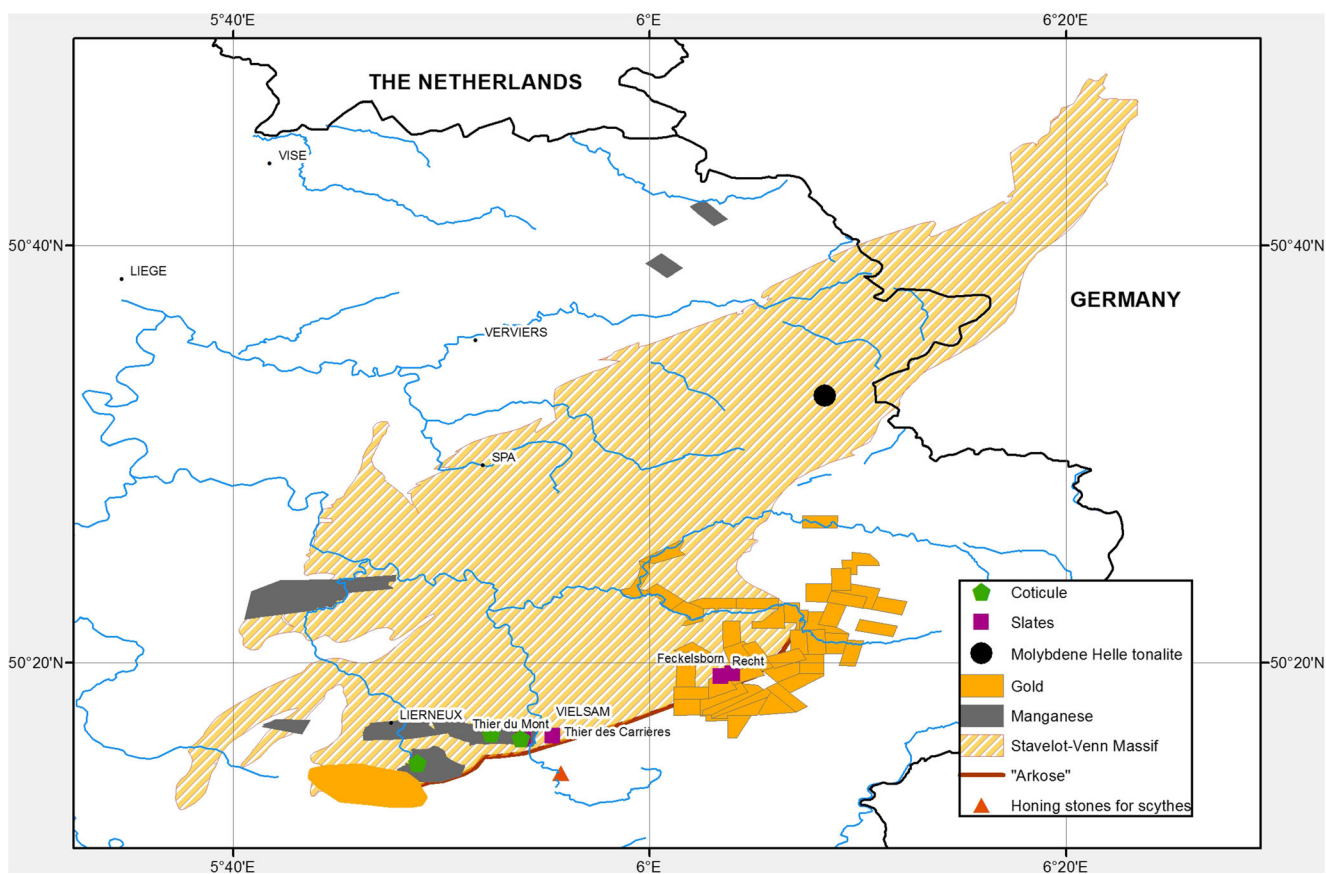
**Fig. 7** Cm-thick microfolded veins of yellowish coticule interbedded in purplish slates. Scale is given by the hammer (lower right part of the picture). Orange colours are due to iron oxo-hydroxides infiltrated in the fractures (open-air quarry of Liemeux)



**Geological Outline** Coticule only occurs in the vicinity of Vielsalm, Otré and Lierneux, and its occurrence is restricted to the Member of Les Plattes in the Formation of Otré (Llanvirnian, Ordovician; see Figs. 3, 4 and 8). The coticule occurs in very thin beds (<1 to 15 cm), but the thinnest beds have no commercial value. Coticule beds often occur in bundles next to each other with slate sequences in between, and they are strongly folded and faulted. Each bundle is characterized by a specific appearance (varying thickness, colour, size and distribution of the spessartine grains) and honing quality. Often, despite discontinuities induced by faults or strong folds, the specific bundle composition can be traced over short distances, resulting in a same rock type and hence a similar coticule quality.

**History** Although the use of whetstones already started in the Metal Ages (3500 BC to 52 BC), they are still distributed and used worldwide today. In Belgium, the oldest whetstones were made of fine-grained and well-sorted siltstones and sandstones. Sharpening any metallic cutting device requires a material applied repeatedly by contact. The surface irregularities of the blade must be removed to create a small angle V-profile to provide a high cutting ability. Various tools designed for different crafts (e.g. barbers, butchers), military purposes (swords), religious traditions (mainly for the Jewish community) and industrial uses all need to be sharp. The quality of the whetstone and the skills of the operator define the final cutting ability. The coticule of Vielsalm has been considered to be the world’s finest whetstone. Its first use dates back to 1536 and its industry bloomed between 1875 and 1925 but strongly declined after the Second World War. This was mainly due to competition from cheaper foreign synthetic honing materials and their impact on the European Jewish community, who were the biggest consumers of high-quality coticule tools for ritual use.





**Fig. 8** Map locating the different slate extraction areas, the coticule extraction sites as well as the main ore claims

**Extraction** Initially, coticule was extracted from trenches of the height of a man, following the strike and dip of the geological strata. Later on, the increasing demand for larger quantities and better quality required the extraction of deeper layers. The extraction depth first reached 5 to 6 m (extraction pits with small entrances, of about 1 m × 1 m), increasing afterwards to depths of 50 to 70 m. For the later deep extractions, more elaborate and better-structured shafts first had to be built. From the sixteenth to the eighteenth century, the extraction was carried out by small (2 to 3 person) family groups and was often located close to their homes. This resulted in a landscape with a vast disturbed surface, cut by tortuous trenches and covered with numerous heaps. When the surficial reserves were exhausted, the underground extraction started, resulting in more hazardous working conditions (e.g. crawling in small tunnels). These harsh conditions led to the reduction of the workers life expectancy to about 40 years. Additionally, water infiltration could seriously hamper all underground quarrying activities. Initially, water was removed by hand (with the help of buckets), later by hand-operated pumps and finally by steam-driven engines. The latter technique was possible in Vielsam from 1860 onwards, when a railway connection between Liège and Vielsalm facilitated coal transport. Finally, electrical centrifugal pumps replaced the steam powered ones.

During the ‘Dutch’ period (from 1814 to 1830), a legal mining administration was established. This legislation was based on the Napoleonic code, forcing the owners to better design their quarries and to implement structural safety regulations, especially for ventilation. Technological evolution, such as the availability of electrical power and associated new tools like the pneumatic hammer, improved not only the safety of the workers but also their productivity. From 1848, the use of explosives increased the digging speed of the galleries as well. Large rock slabs <100 kg were extracted and transported outside the quarry through small galleries (1.8 m width by 2 m height). Larger galleries were dug if the presence of more than one vein was suspected. Because of the interbedding of the coticule with slates, large amounts of waste material were produced and piled up near the entrances, forming large heaps. At the end of the nineteenth century, as extraction went deeper and galleries became longer, transport was accomplished by wagons whenever possible. At the surface, the waste material (slate) was removed from the coticule by specialized workers inside small cabins located near the shafts. They could produce 80 to 100 pieces per day. Because water was necessary for all further manufacturing steps, the prepared rock slabs were transported to the Salm River valley. In the beginning, the finishing was done in private

houses during winter period; later, it was carried out in workshops that were operating throughout the year.

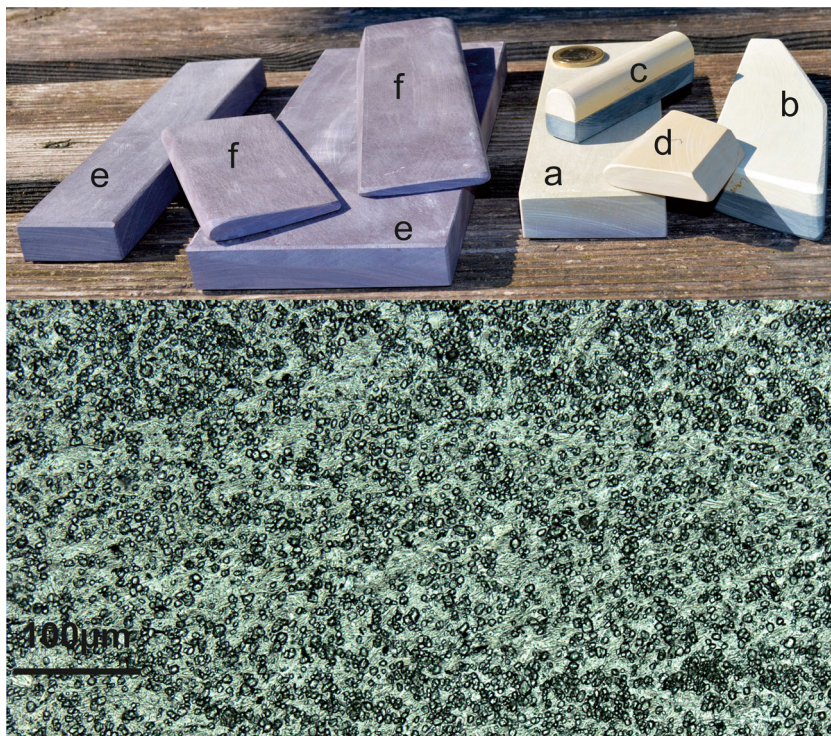
**Manufacturing Technology in the Workshop** The first step consists in cutting the raw materials into standard dimensions: initially, this meant manual sawing using a mixture of water and sand; since the 1950s, diamond discs have been used (Figs. 9 and 10). Secondly, the coticule is straightened on a polishing table using water and well-sorted fine sands. However, depending on the thickness of the coticule layer and on the quality and thickness of the overlying slate, different finishes can be applied: either the layer of slate in contact with the coticule is cut to the required size, or in the case of thicker coticule layers, smaller pieces are cut out longitudinally to standard heights. Four kinds of end products are available: parallelepipedic stones ('razor hones'), polygonal stones ('bouts', literally cuts), curved stones and multiform stones combining flat and rounded surfaces. The end products have two different layers, differing by colour and garnet density: an upper 'active' yellowish part made of coticule sensu stricto and a lower 'passive' purplish part made of slate. Coticules were always backed by a piece of slate, either naturally bounded or glued. The main reason was to reinforce the coticule part, where small cracks might lead to brittleness. Furthermore, during honing, a thicker whetstone is always easier to handle.

**Quality and Prices** The most valued coticules have a parallelepipedic shape, the price of which depends on their

dimensions (thickness/length/width, expressed in inches). For bicolored stones, the coticule layer has to represent 35 to 55 % of the total piece. The contact between the shale and the coticule can be natural or glued (formerly with bee wax and colophane; nowadays with artificial resin). The prices increase substantially with the dimension and the absence of visible faults (hematite-staining, pyrolusite dendrites, white andalousite-rich spots, cracks, excess glue, small variations in colour). Curved coticules are manufactured for tools with a curved cutting shape. They are more expensive as they require more skills and manufacturing time. The quality of the final product is mainly related to the absence of coarse quartz crystals (typically those greater than 5  $\mu\text{m}$ ) and the lack of agglomerated garnets. The ideal concentration of spessartine is between 20 and 40 %. Higher concentrations might lead to uneven polishing and scratches. The presence of black hematite patches in the coticule is unaesthetic, but it does not influence its sharpening properties. The colour—ideally light yellow—might turn slightly to reddish, however, without impact on the quality of the honing. Different qualities are thus produced, depending on the intrinsic mineralogical characteristics of the coticule layer, the extraction location and the natural variability of the material.

**Distribution and Marketing** As mentioned before, distribution was initially in the hand of individual salesmen who went door-to-door throughout Europe. As the reputation of the coticule spread, its demand subsequently increased with time, resulting in a more extensive commercial

**Fig. 9** Upper part: different products manufactured by the Ardennes Coticules company: a razor hone in coticule, b 'bout' in coticule, c gouge stone (rounded edges razor hone) in coticule, d multiform tool in coticule, e razor hone in Belgian Blue Whetstone and f multiform tool in Belgian Blue Whetstone. Lower part: well-sorted micrometric crystals of spessartine in a matrix composed of mica flakes and submicrometric grains of quartz. Coticule of Vielsalm, thin slide, PPL



**Fig. 10** Manual polishing of razor hones. Note the rectangular shape of the bicolour stones (coticle). Workshop of the late Prosper Burton, now owned by the Ardennes Coticle Company in Liemeux, the last company extracting, producing and selling coticle throughout the world



network. For instance, the product was shown at international exhibitions and world fairs, (e.g. the ‘World Fair’ of London in 1851, then known under the title the ‘Great Exhibition of the Works of Industry of All Nations’) stimulating its global demand on all continents. The fame of this product even attracted investors from outside of Vielsalm and Lierneux. However, the difficult extraction conditions, the high manufacturing costs and the intrinsic high durability of the product (the quality of the coticle was so good that a barber could use it for 50 years) resulted in restricted sales. Moreover, the introduction of cheaper alternatives and artificial products on the market, the lowering of production prices through automation and the poor efficiency of coticle extraction and production all hampered a continuous manufacturing. Nowadays, the last remaining extraction and manufacturing site in the region is the open pit of Thier del Preu (Petit-Sart, Lierneux), operated by the ‘Ardennes Coticle’ company. The same company also introduced a new series of honing stones including the Belgian Blue Whetstone (BBW) made of purple-blue slate rich in small garnets. The BBW is closely related to the coticle and is extracted together. Finally, Mn-rich clays are mined in the same quarry as well and mixed with clay paste to produce black ceramic products. The company plans the opening of an underground quarry to extract new veins of coticle.

Due to the international fame of the coticle, from the eighteenth century onwards, the nearby city of Bovigny produced honing stones for scythes made of very fine sandstones without garnets. The sandstones were extracted until around 1940 from Lower Devonian (Pragian) sandstone formations that crop out along the southern border of the SVM.

### The Roofing Slates of Vielsalm and Recht

Good-quality roofing slates were produced in Vielsalm and Recht, two cities located in the southern part of the Stavelot inlier (Fig. 11). The slates have different thicknesses: the thin ones (2–3 mm thick) were produced at Vielsalm, the thicker ones (thickness up to 1 cm, also called ‘Lauzes’) were manufactured in both Vielsalm and Recht. Besides roofing, slate had many other uses such as building stone (e.g. the so called ‘Imperial Ottrelite’) for outdoor walls, as well as door and window framing. Slates were also used for blackboards, billiard tables, toys, stone crosses, altars, sculptural figures, and various other household items. Geologically speaking, the purple slates of Vielsalm and the green slates of Recht, both containing ottrelite (a chloritoid), belong to the Colenhan Member of the Les Plattes Formation (Fig. 3).

### The Roofing Slates of Vielsalm

The high quality of the Vielsalm slates triggered a local economy. Their mechanical properties and weathering resistance were better than those of the competitors: density of 2.89 g/ml, 88 N/mm<sup>2</sup> longitudinal flexibility, 65 N/mm<sup>2</sup> transversal flexibility, water absorption of 0.22 %, negligible loss of weight under acid attack (without any change in colour or oxidation) and favourable chemical parameters (carbonate content <5 % and very low sulphide content). Indeed, the Vielsalm roofing slates remained unweathered after more than 200 years. Environmentally speaking, the main impact of slate extraction on the landscape was the production of waste heaps (exceeding 40 m in height) and the digging of deep (up to 60 m) open-air quarries (Figs. 8 and 12). Religious building roofs have been covered with slates (Bovy 1981) since the twelfth century. Roofing slates from the Salm area were used before the

**Fig. 11** Old slate roof made of typical thick purplish slates ('cherbains') extracted from the Vielsalm quarries. Two different shapes are used to cover the ridge tiles. Slates showing an arrowhead-shape are locally named 'lignolets'. This slate covering type is restricted to a small area around Vielsalm and Liemeux. The house in the background is built with sandstones whereas the windows are bordered by sawn and polished slate (village of Jevigné, Liemeux)



end of the fifteenth century. In 1657, a law prohibited the use of straw covered roofs because of the risk of fire. This law really boosted slate production. An extraction right had to be obtained first from the local lord who raised taxes. Since the French Revolution, the extraction rights vanished and new taxes appeared, leading to a gradual decline in extraction and a dramatic reduction in production. A slow recovery occurred during the nineteenth century due to liberalization of the market, easier concession acquisition and the availability of foreign investments. From 1866, a new railway connection between Vielsalm and Liège enlarged the market. However, in

1910, only 6 societies employing a total of 217 workers were left.

**Extraction Methodology** Although slate fragments have been found associated with human habitation from the Magdalenian (17,000–10,000 years BP, Paleolithic), the use of this material as building stone and as roofing slate began in Belgium during the Roman occupation (e.g. in the Roman camp of Vielsalm). Initially, slates were extracted from natural outcrops along incised valleys. Most probably, this extraction continued until the middle of the twentieth century, when its

**Fig. 12** Waste heap composed of slate fragments attracting specific vegetation (ferns, mosses...) containing rare species (see Remacle 2007). These places are protected and conserved to prevent natural colonization by the forest and the disappearance of a very rare biotope in Europe



production decreased progressively and ended in the 1970s. The first extractions started as usual in open-air quarries. Since the second half of the nineteenth century, underground quarries appeared. Here, slates were extracted by the classical room and pillar method, at different depths and using 1 up to 3 levels until a depth of 60 m, in order to reach the richest layers. In contrast with the underground extraction of coticule, large cavities were made to remove the slates; the galleries connected individual cavities located at short distances from each other for safety reasons. Underground water was evacuated by dewatering galleries. Due to the collapse of the deepest galleries, some cavities are flooded and no longer accessible. As for the coticule, the extraction technology and the environmental legislation evolved simultaneously. The extracted material was quite heavy, so it became necessary to prepare the material and to remove the refuse parts on the spot. In contrast with the coticule mines, the slate workshops were located in the immediate vicinity of the quarries because water was not required. The remaining hilly landscape, the open-air quarries and the subsequently generated ecosystem launched tourist activities in the area. However, parts of this hilly landscape have been levelled because of land reclamation and because some of the waste has been used as a fill in civil works, especially in road construction during the 1960s and 1970s.

**Distribution and Marketing** The market was mostly national with minor export to the neighbouring countries. However, episodically, the material was also exported to Austria and Italy. To the north, the market was limited by the Meuse; indeed, slates from the Belgian-French border (Revin, Fumay) were shipped over the Meuse to The Netherlands and into northern Belgium. The production fluctuated significantly with time due to the impact of transport costs and toll taxes. Because of the geometrical complexity of the underground quarries, the decreasing demands, the long extraction time, the lack of technological investments, the geographical isolation, and the competition from cheaper import products, the extraction of slate became gradually unprofitable. Consequently, the last quarry closed in 1968 at Vielsalm.

**Manufacturing Technology** Once the slabs reached the surface, waste parts were removed by hammer. The slabs were subsequently subdivided into smaller components according to the required sizes. This was done first with the help of hammer and chisel and later by using a diamond saw. The renowned Vielsalm slate had a constant thickness of 2 to 3 mm.

### The Recht Slate Quarry (Sankt-Vith)

The history of the quarry and its production can be found on the following website: <http://www.schieferstollen-recht.be>. The slate extraction in Recht started with open-air quarries

until it was proved that it would be more economical to go underground in order to reach richer deposits. This slate was extracted from underground cavities from the eighteenth to the early twentieth century. As in Vielsalm, the Recht slate is rich in chloritoid flakes. However, the slate of Recht differs from the slate of Vielsalm by its blue colour (so-called ‘bluestone’). Only thick slates (>5 mm thick) known as ‘cherbins’ were produced here, and only 20 % of the extraction was transformed into valuable commercial products. Heavyweight slate roofs required expensive supporting structures: this probably led to the closure of the quarries. Most roofing slates were manufactured by Tyrolean craftsmen when the territory still belonged to the Austrian empire. Two different levels were mined underground, and the excavation operated through blasting with black powder. Horizontal galleries were bored in order to reach the richer deposits and for dewatering purposes. The extraction area had a length of almost 100 m, and the largest excavation room (called ‘the cathedral’) reached 14 m in height.

The excavating technique was similar to the one used in the open-air quarries. The stone blocks (up to 750 kg) were transported out of the mine on railway tracks. The working conditions were tolerable, slightly cold (about 7 °C) but constant. However, humidity reached almost 100 %. The lower and upper shafts were connected by an aeration shaft, for keeping a constant airflow and to serve as an escape route for the miners. In the gallery, thin layers of yellowish-greenish coticule outcropped. Attempts to extract the coticule beds in Recht were unsuccessful due to their poor quality and due to the high extraction and processing costs. A gallery was extended in order to reach the Lower Devonian sandstones that were supposed to be enriched with gold, but the gold content was much lower than that of the local river deposits.

### Geoheritage, Geoconservation and Related Geotourism

These items are analogous to those already described for the coticule. Deep open-air quarries still present a risk for landslides, and remaining cavities may collapse with time. Moreover, unprotected entrances are prone to attract people who might proceed further into galleries that are no longer roof-supported and that could collapse suddenly. Nevertheless, for geotouristic purposes, specific underground quarries could still be maintained and made accessible to the public. After restoration, the Schieferstollen Recht (slate quarry) was made accessible for visitors. It is presently the second Belgian slate quarry that is accessible for tourist visits; the other one is located in Bertrix (‘Au Coeur de l’ardoise’—Domaine de la Morepire, Fig. 1).

Other underground slate quarries can be visited in Martelange (‘Schiefermuseum Uewermaartel’, ‘Musée vivant des ardoisières du Haut-Martelange’ in the nearby Grand-Duchy of Luxembourg) and in the Fell quarry (‘Besucherbergwerk Fell’) near Trier (Germany) (Fig. 1).

The latter three quarries extracted Early Devonian greyish black pelitic rocks. At Recht, visitors can admire the huge rooms carved in the rock for extracting slates. Visitors walk for about 800 m and cross a bridge offering them a nice panoramic view. During the visit, the geological characteristics of the area are explained. All details of the implemented extraction techniques are shown. The difficulties and related dangers for miners are described. Quarry operating details are well illustrated and also verbally depicted with the help of anecdotes. Like many of the other underground cavities, the slate quarry hosts bats during the winter period. A guided tour (90 min) called the ‘bluestone tour’ is offered to visitors, allowing them to discover the numerous uses of the Recht slates (church and farm roof slates, the workshop, funeral crosses, votive crosses, religious patrimony, watering place...) (Fig. 13).

### Manganese Ores in the non-Metamorphic Part of the Stavelot-Venn Massif

In Belgium, manganese ores were only mined in the SVM, mainly in the Lienne valley, and used as a desulfurization component in the manufacturing of cast iron. The Lienne river (see Fig. 8) crosses the Stavelot-Venn Massif from the south to the north. To the north of the city of Chevron, it cuts a folded syncline, formed by the strata of the Les Plattes Member (Sm2b, middle part of the Ottré Formation, 150–180 m thick). In the latter syncline, two distinct manganese-rich ore levels (iron- and manganese-rich carbonate nodules enclosed within purplish slates and quartzitic phyllites) were mined, with thicknesses of 0.50–0.70 m and 0.7–1.10 m. These ore-bearing strata are separated by a thick series (32 to 47 m) of quartzitic phyllites (‘quartzophyllades’) and slates. It is

noteworthy that of the three existing concessions (Moët-Fontaine, Werbomont-Bierleux and Bierleux), the second was owned by John Cockerill Ltd., the European leader in steel production (a large consumer of Mn). The ore is a complex mixture of Mn-rich carbonates (rhodocrosite and kutnahorite/kutnohorite) and Fe-Mn-rich oxides and silicates. The wall rocks are impregnated with Fe and Mn as well. After their discovery in 1845, the Fe-Mn ores were mined in trenches and in underground galleries in the Lienne River valley, between 1856 and 1935.

The impact of mining on the landscape and the entrances of the Meuville mine is still visible. The lower part of the Lienne basin supplied 180,000 tons of manganese ores between 1880 and 1934 (Liebert 1905; Dussart & Dussart 1991). During the first half of the nineteenth century, charcoal was used for the local foundries, provoking significant deforestation of broadleaf trees (0.25 ha of forest per ton of cast iron). Afterwards, conifers were planted, resulting in the current appearance of the area. At Malempré, all surficial traces of the former exploitation have now disappeared. The narrow gauge railway that connected the Rahier and Chevron mines has been transformed into a walking trail, where cast iron marks can still be observed. Only literature keeps up the memory of those unique Mn-ore exploitations in Belgium (Goemaere 2005; Bosmans 2005). Their underground extraction cavities also became winter residences for bats (Dussart & Dussart 1991). Others small concessions were operating at Lierneux and Bihain, but the low Mn content of the ores made them unsustainable and the mines closed down. The Ardennes Coticule Company mined two levels of clayey Fe-Mn-rich black slates (thin layers or lenses of MnO<sub>2</sub>) in the quarry of Lierneux for the manufacturing of black ceramic products.

**Fig. 13** Boggies located at every incoming road to the centre of the village of Recht, guiding the visitors straight to the slate mine entrance. A nineteenth century old funeral cross, made in ‘bluestone’ of Recht can be seen in the background. A nice ‘bluestone sightseeing tour’ is organized throughout the village allowing the discovery of the local interesting buildings, as well as various historical and religious small heritage objects



## World-Famous Minerals and new Mineralogical Type Localities

Hatert et al. (2002) listed all the minerals occurring in Belgium (about two hundred and sixty species, fourteen of which are unique to Belgium). Furthermore, Van der Meersche et al. (2010) published a book dealing with the minerals that have names derived from Belgian personalities or Belgian localities. Due to the early start of the extractive industry in Belgium (linked to the Industrial revolution), Belgian mineralogists were very active and described quite a number of new species. Fifty-four new mineral species have been named after Belgian mineralogists. Six new world mineral occurrences were identified in the southern (metamorphic) part of the Stavelot-Venn massif near Vielsalm: they were named after their discovery location or after famous mineralogists. Visitors can still admire all these particular mineralogical species at the Musée du Coticule in Salmchâteau (Vielsalm).

Some of the new minerals listed here are so unique and so rare that their authors did not want to give details about their exact occurrences, because of the fear of the depletion or destruction of the mineral deposits by collectors.

**Ardennite-As**— $(\text{Mn}^{2+}, \text{Ca})_4(\text{Al}, \text{Mg}, \text{Mn}^{3+})_6(\text{AsO}_4)(\text{SiO}_4)_2(\text{Si}_3\text{O}_{10})(\text{OH}, \text{O})_6$ —was described as a new mineral species in 1872 and refers to the Belgian Ardennes. The mineral was discovered at the localities of Bihain and Salmchâteau within the city of Vielsalm (Van der Meersche et al. 2010). One Ardennite-(V) occurrence was mentioned from Sparone (Locano valley, Italy) in 2007.

**Ottrelite**— $(\text{Mn}^{2+})\text{Al}_2\text{O}(\text{SiO}_4)(\text{OH})_2$ —is the manganese end-member of the chloritoid group and was discovered by Dethier in 1809, described 30 years later and accepted as a new species in 1978. Deep green crystals are common and can be collected in numerous outcrops near Otré and Vielsalm.

**Stavelotite-(La)**— $\text{La}_3(\text{Mn}^{2+})_3\text{Cu}^{2+}(\text{Mn}^{3+}, \text{Fe}^{3+}, \text{Mn}^{4+})_26(\text{Si}_2\text{O}_7)_6\text{O}_{30}$ —was first discovered in 2005 in the locality of Coreux (Salmchâteau) and refers to the town of Stavelot. It was found in a quartz vein cutting manganeseiferous metamorphic phyllites of Ordovician age (Bernhardt et al. 2005; Van der Meersche et al. 2010) but it was identified in thin sections only.

**Davreuxite**— $\text{Mn}^{2+}\text{Al}_6\text{Si}_4\text{O}_{17}(\text{OH})_2$ —was discovered in 1852 by the famous geologist André Dumont—who also discovered the concealed coal basin of the Campine—in quartz veins near Otré and Salmchâteau. The mineral was recognized as a new mineral species in 1984 (Fransolet et al. 1984). The name refers to the Belgian chemist and mineralogist Charles-Joseph Davreux (1800–1863).

**Grauliche-Ce**— $\text{CeFe}^{3+}_3(\text{AsO}_4)_2(\text{OH})_6$ —was discovered in 2002 as mm-sized aggregates on quartz crystals in the Hourt quarry of Grand-Halleux where Cambrian quartzites were exploited (Vielsalm). The mineral was dedicated to Jean-Marie Graulich (1920–2001), a mining engineer and

former head of the Geological Survey of Belgium who continued working on the Spa waters after his retirement.

**Vantasselite**— $\text{Al}_4(\text{PO}_4)_3(\text{OH})_3 \cdot 9\text{H}_2\text{O}$ —was discovered in 1987 (Fransolet 1987; Van der Meersche 2010) on mining dumps in quartz veinlets or schistosity planes in a quartzite quarry, north of Bihain (city of Vielsalm). The name honours René Van Tassel (1916–2013), Belgian mineralogist at the Royal Belgian Institute of Natural Sciences.

**Gold**—The gold rush in Belgium occurred between 1875 and 1920. Gold is found as granules of maximum 4 mm in bed load river sediments (De Rauw 1912; Dumont 1980; Hatert et al. 2002). Many heaps from placer mining have been recognized along creeks flowing along the southern border of the SVM.

- The Noir Ru creek, belonging to the Ourthe river basin, named ‘Martin-Moulin’.
- The Rolayi creek (Alias Petites Tailles or Pisserotte) and the creek of St-Martin (alias Bihain), tributaries of the Salm River basin.

Only one actual gold mine is known, near Baraque de Fraiture (Trô des Massotais), and was investigated some years ago, but it is not accessible to visitors. Native gold has also been discovered in quartz veins crosscutting the quartzites and quartzophyllades of the Salmian and Devillian formations of the SVM, in particular in the Hourt quarry, from which gold granulates have been extracted (Hanson et al., 2000).

Minerals first described from Belgium include: Ardennite-(As), ‘Bastonite’, Calclacite, Davreuxite, Delvauxite, Destinezite, Dewalquite → Ardennite-(As), Drugmanite, Ferristrunzite, Fraipontite, Graulichite-(Ce), Halloysite, Hopeite, Koninckite, Ottrelite, Pumpellyite-(Al), Richellite, Stavelotite-(La), Vantasselite, Viaeneite and Willemite. Descriptions and pictures are published by Van Der Meersche et al. 2010).

Significant minerals discovered in the Vielsalm area (101 species after Hatert et al. (2002), although 115 valid species are listed in <http://www.mindat.org>; Hanson & Dehove 2008): Albite, Apatite-(CaF), Altaite, Anatase, Andalusite, Anilite, Ardennite-(As), Ardennite-(V), Native Arsenic, Arsenopyrite, Azurite, Balyakinite, Beryl, Biotite, Bornite, Braunite, Brochantite, Cacozenite, ‘Carbonates group’ (siderite, calcite...), Cerusite, Chalcoalumite, Chalcocite, Chalcophyllite, Chalcopyrite, ‘Chlorite group’ (Clinochlore, Sudoite, Cookeite), ‘Chloritoid group’ (Chloritoid, Ottrelite), Cryptomelane, Cobaltite, Connellite, Covellite, Crandallite, native Copper, Cuprite, Davreuxite, Delafossite, Dickite, Digenite, Djurleite, Euclase, Ferrimolybdate, Florencite-(Ce), Gahnite, Galena, Goethite, native Gold, Graemite, Gypsum, Hausmannite, Hematite, Hollandite, Illite, Idaite, Ilmenite, Kanonaite, Kaolinite, Langite, Libethenite, Lithiophorite, Malachite and Pseudomalachite, Magnetite, ‘Manganese oxides’, Manganite, Marcasite, Melonite, ‘Al-Mica Group’

(Muscovite, Paragonite), Mimetite, Molybdenite, Monazite-(Ce), Nsutite, Olivenite, Orthose, Paratellurite, Pharmacosiderite, Piemontite, Plumbojarosite, Posnjakite, Pyrite, Pyrophyllite, Pyrrhotite, Pyrolusite, Quartz, Rhodochrosite, Rutile, native Sulphur, Spessartine, Spionkopite, Sphalerite, Stavelotite-(La), Strontiomelane, native Tellurium, Teineite, Tellurobismuthite, Todorokite, Torbernite and Metatorbernite, Tourmaline, Turquoise, Vantasselite, Variscite, Wardite, Wavellite, Wittichenite, Wulfenite, Xenotime-(Y), Yarrowite...

### Mineral Water as Geoheritage in the Stavelot-Venn Inlier

In Belgium, about 20 different trademarks of mineral waters (\*) exist, most of which are located in the southern part of the SVM. The most renowned ones are the weakly mineralised water springs of the cities Spa and Chevron, already known by the Romans (Fig. 6). The abundance and diversity of sparkling or still mineral water springs led to the denomination of ‘blue Ardenne’ for the area located in the northern part of the SVM, including the High Fens and the geologic window of Theux. The High Fens ecosystem and the underlying quartzitic bedrock provide a continuous source for the famous mineral waters described in this section.

(\*) By definition (Belgian Royal decree 8 February 1999), natural mineral water is water originating in an aquifer, which outflows or is directly pumped from the aquifer. It is characterized by its chemical and microbiological composition, which distinguishes it from drinking water, and its properties may not be altered.

### The Mineral Waters of Spa

The name of the city of Spa has become the generic term throughout the world for mineral springs and health resorts providing ‘thermal baths’.

**History** The Spa springs were first mentioned in the journals (*Naturalis Historiae*) of Pliny the Elder (77–79 AD). In his book, he mentioned ‘a famous fountain in which bubbles sparkle’. During the Middle Ages, the popularity of the Spa waters was reflected by the variety of legends stressing their medicinal and ‘magical’ properties. According to the local tradition, Spa is associated with the fame of Saint Remacle, a bishop and apostle of the Ardennes, builder of monasteries and churches and possessing the power to purify fountains. People came from around the world to take baths and to obtain relief from their illnesses. At the end of the Middle Ages, newly married bridegrooms used to bring their bride to the Sauvenière spring at Spa to drink the water in order to increase their fertility. This miraculous peculiarity is related to the

presence of an imprint of Saint Remacles’ foot left in the stone. It was sufficient for the young matron to place her foot in the imprint and to drink water from the spring to be assured of progeny. This superstition still survives until today. Indeed, the spring water is particularly rich in iron and it has been proven that an iron-deficiency (anaemia) hampers the menstrual cycle. The personal physician of Cardinal de la Marck, Prince-Bishop of Liège during the sixteenth century, strongly recommended the use of Spa waters in a manuscript that was translated into Latin, Spanish and Italian, spreading the name of Spa all over the world. The city of Spa gradually became more famous and attracted a lot of distinguished visitors including royal families, notorious artists and influential people who drank the water for its health benefits. The Tsar Peter the Great gave his name to one spring in the centre of Spa. The town became known as ‘the Cafe of Europe’ and the ‘place to be’. Nowadays, three springs still supply the water for the thermal baths or ‘Thermes de Spa’.

**Hydrogeology** A great number of springs near Spa are related to the existence of a thrust fault bordering the Theux Window to the south (Geukens 2007). In the high moors of Malchamps, rain water and snow melt waters are filtered through a series of deposits including Pleistocene/Holocene peaty deposits or/and colluvia, thin Cretaceous flint-bearing clay deposits and Tertiary sands, covering strongly folded, faulted and fractured Cambrian rocks (quartzites, phyllites and quartzo-phyllites). The Cambrian rocks are strongly weathered and deeply leached (over several dozens of metres). The water is filtered during percolation through all these layers, unable to take a mineral load. Eventually, it produces a water of high purity with very low sodium, magnesium and calcium content (Table 1). Underground waters re-emerge at different altitudes and locations in Spa. Different kinds of natural waters occur in Spa: they are qualified as ‘spring waters’, ‘mineral waters’ and ‘sprinkling mineral waters’. Their composition and properties vary depending on the nature of the subsoil, weathering/leaching depth, transfer time, infiltration depth and altitude of the emerging point (Fig. 14).

- The ‘Source’ water (Clairefagne). The rainwater that infiltrated in the high moors of Malchamps is filtered through Cenozoic sands, Cretaceous clays before reaching the top of Cambrian subcrop. This water is no longer bottled (Jobé 2014a).

- The ‘Spa Reine’ mineral water originates from rainwater that is filtered through the colluvium and the weathered Caledonian basement, eventually reaching a phreatic zone located in a fractured substratum. This water has a residence time ranging from 6 months to several years. The Spa Reine spring is located at an altitude of 440 m. Its catchment area is mainly the ‘Fagne de Malchamps’ which reaches a high point of approximately 600 m. This water is very poorly mineralised (the lowest sodium content of all European mineral waters) as



**Table 1** Hydrochemical analyses (partial data) from the waters of Spa (after Jobé 2014b) and Chevron (after Jobé 2014a)

Elements	Units	Spa			Chevron		
		Reine	Barisart	Marie-Henriette	Bru	Monastère	Love-My-Planet
pH		5.5	6	6.2	5.5	5.6	7
Conductivity	μSiems/cm	45	60	125	300	550	150
Ca <sup>2+</sup>	mg/l	4.5	5.5	11	21	68	17
Mg <sup>2+</sup>	mg/l	1.3	1.5	6.5	20	21	3.5
Na <sup>+</sup>	mg/l	3	5	7	8	12	11
SO <sub>4</sub> <sup>2-</sup>	mg/l	4	7.5	8.5	5	8	18
HCO <sub>3</sub> <sup>-</sup>	mg/l	15	18	70	180	330	70
Cl <sup>-</sup>	mg/l	5	5.5	5	4	5	5
CO <sub>2</sub>	g/l	–	–	3.8	4	3	–
Dry residue	mg/l	33	49				

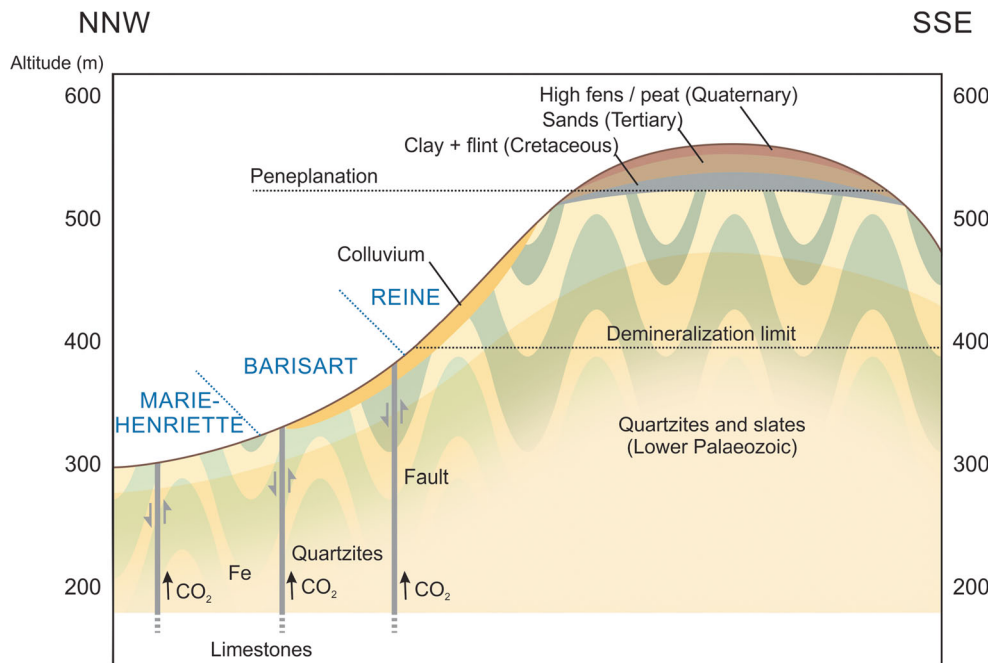
it flows only through leached bedrocks, resulting in a constant chemical composition throughout the year. The ‘Spa Reine’ waters are bottled and are the best-known and most widely distributed mineral waters in Europe.

- The naturally sparkling water named ‘Barisart’ shares the same source as the Spa Reine. However, as the spring is located about 400 to 440 m deeper, it has as a higher mineral content. The rainwaters infiltrate deeply into the unweathered bedrock and become enriched, particularly in iron and CO<sub>2</sub>. After a journey that can last for 20 years, they emerge due to the uplifting force of CO<sub>2</sub> bubbles, travelling through faults. Another well-known sparkling water is the ‘Spa Marie-Henriette Spring’ which has its source at greater depths. The presence of CO<sub>2</sub> probably results from the decomposition of carbonates present in beds located in the deeper subsurface, below thrust faults. It is mainly used for bathing and

showering. Its name is linked to H.M. Queen Marie-Henriette, wife of the Belgian king Leopold II, who died in Spa in 1902.

The first protective measures to guarantee the purity and cleanliness of the spring waters started in 1624 by ordinances. An ordinance compelled the citizens of Spa to repair any water adduction, drinking water distribution and discharge network, to avoid contaminations. In the eighteenth century, formerly established ordinances relating to hygiene were repeatedly re-enacted and steadily increased in severity through time. In 1989, a first European directive defining the protected hydrological perimeter of the Spa Waters was published as a Royal Decree. This area has been increased regularly, encompassing many springs in the Spa area. Presently, the monitoring area covers more than 13,100 ha and includes the whole hydrogeological catchment area.

**Fig. 14** Idealized cross section of the subcrop of Spa. Modified after Jobé (2014b)



## The Mineral Waters of Bru-Chevron

The Bru mineral water springs are located in Chevron (Stoumont) and are captured and bottled by the Spadel group. The Bru springs were already known by Pliny the Elder and located on the Roman military maps under the name of ‘Fontes Acidi’ (acid springs near the junction of the Amblève and Lienne rivers). They are natural sparkling waters, the fame of which results from their chemical composition, particularly their high iron content. These natural sparkling waters have been bottled by the monks of the Stavelot Abbey since the seventeenth century, and the bottles were brown to mask the red-coloured iron-rich residues at the bottom of the bottle (Fig. 15). Their hydrogeologic origin is complex. In fact, two different aquifers are exploited. The former is composed of partially captive underground waters (still waters named ‘Love My Planet’) stored in Early Devonian sandstones and Ordovician quartzites. The second aquifer occurs much deeper and is stored within calcareous rocks below the Midi-Eifel overthrust. The Bru and Abbey waters (Table 1) are naturally sparkling waters containing CO<sub>2</sub> (this originates from carbonate rocks, with a contribution from the mantle and atmospheric precipitation). These carbonated waters have an underground residence time of more than 50 years and travel upward through a complex fault structure (Jobé 2014b).

## Artificial Lakes and Geolandscaping

The artificial lake (surface: 6.2 ha; volume: 8 million m<sup>3</sup>) of Robertville (Malmedy) is located in the High Fens – Eifel Nature Park, about 5 km north of Waimès. It was constructed in 1928 for supplying drinking water to Malmedy and for

driving the power station in Bévécé. Lake Bütgenbach (120 ha) is an artificial lake created by the damming of the Warche river in 1932, not far from the German border. The Eupen Lake and the Vesdre Dam are located near Eupen and receive water from the High Fens. It is the third greatest water reservoir in Belgium (126 ha, 25 million m<sup>3</sup>). Lake Warfaaz (8 ha, 360,000 m<sup>3</sup>) is an artificial lake located near the city of Spa. The dam on the Wayai River was built in 1892, and the area is a tourist attraction offering water sports facilities.

The village of Coö (Trois-Ponts) is well known for its waterfall on the Amblève river. It has a 15-m drop, making it the highest waterfall in Belgium. The village of Coö, part of the Trois-Ponts community, also has a hydroelectric station. A closed arm of the Amblève river represents the lower basin of this reversible pumping/turbining storage power station. A leisure park is situated at the foot of the Coö waterfall, offering a magnificent view over the Amblève valley.

Lake Gileppe is one of the oldest artificial lakes in Europe and is a very nice tourist location. The lake is fed by the Gileppe River. The large water volume (26.4 million m<sup>3</sup>, area of 130 ha) constitutes an important drinking water reservoir. The Gileppe Dam was initially built for providing pure and acid water for the wool industry in Verviers. The dam was constructed with local green Lower Devonian sandstones extracted in local open-air quarries. The acidity of the water corroded the original nineteenth century lead pipes and poisoned the area. This water storage supplies the large volumes of drinking water required by the city of Liège area. To reduce its corrosiveness, this water is mixed with carbonated underground waters. Making use of the water head and a significant volumetric storage, a small hydroelectric power is in operation. The dam bears a monumental lion sculpture (13.5 m high

**Fig. 15** Natural ferruginous and carbon dioxide-rich springs are called ‘pouhons’ in Wallonie. Their high iron content produces a rusty colour by settlement. Sauvenière source of Spa. Image available on Wikipedia and released in the public domain. More annotated images of the springs of Spa can be found on the <http://photos.piganl.net/2009/spa/spa.html> website



and with a weight of 130 t) created by the Belgian artist Antoine-Félix Bouré and made of Jurassic sandstones from the Sûre valley (Grand-Duchy of Luxembourg). A 78-m high panoramic tower with a restaurant installed at the top offers a scenic view.

### Geoheritage, Geoconservation and Geotourism

One of the key issues for the described SVM is the conservation of underground quarries because shafts and galleries are degrading and might collapse with time. Moreover, immediate maintenance is impossible because of the technical complexity and the high costs involved. That is why we are essentially restricted to active ‘geowatching’ activities. In any case, potential surface damage through subsidence is almost unpredictable and also probably irremediable. Therefore, the risk areas should be mapped first, georeferenced by the authorities and appropriately marked in the field. A GIS database has already been set up, not only to define risk areas but also to generate an integrated surface/subsurface overview. However, this is a very time-consuming work requiring data acquisition from various sources (e.g. federal and regional archives, scientific data, etc., Devleeschouwer et al. 2006). Modified landscapes, e.g. due to the occurrence of waste heaps, are less prone to hazards except potential landslides. The most hazardous relicts are the old shafts that are still open or of which the filling is deteriorating. This is especially the case when they are concealed by vegetation. Access to abandoned underground quarries is prohibited. Presently, there is still subsidence/collapse risk due to poorly documented or undocumented drainage galleries extending far beyond the area of the underground extraction sites. Additionally, vertical aeration shafts are no longer fenced.

### Geocultural Heritage of the SVM

In order to preserve the industrial past of coticule mining, a museum was erected at Vielsalm in 1983 in a former manufacturing workshop. This museum is now a top tourist attraction, retracing the geology and the history of coticule exploitation and manufacturing from its beginnings. Demonstration of razor stone manufacturing is still going on in order to keep this tradition alive. It is considered as a ‘heritage for the future’ and belongs to the so-called ‘Denkmäler der Zukunft’ by the Rheinlandpfalz natural heritage specialists.

The local anthropogenically disturbed landscape and the resulting ecosystems need to be protected and conserved as valuable witnesses of the long-lasting mineral exploitation of this particular area. Walking tours should be set up to enhance public awareness of the local history, in combination with a visit to the museum. A statue of Saint Clement (Fig. 16), the



**Fig. 16** In all slate mines (including those of Recht) and other quarries of Belgium, France and Germany, Saint Barbara is the patron saint of the quarry workers. Surprisingly, Saint Barbara is replaced by Saint Clement (martyr and fourth pope) in Vielsalm, as patron saint of both the coticule and the slate quarry miners. A big statue of Saint Clement made of concrete is erected in the village of Regné (Vielsalm), at the base of the coticule mining fields

patron saint of the quarry workers, is erected near the former exploitations of Regné. Furthermore, many maps of the underground galleries need to be preserved as well as other general records and files that also represent fine historical art products. These documents (mostly drawings) are not only of direct use for GIS-applications but they also illustrate the historical evolution of the extraction technologies and give a good overview of the evolution of the quarries. Unfortunately, coticule mine shafts are no longer accessible but an open-air quarry is still operating and has been adapted for visitors.

With time, a characteristic evolution can be observed of both the landscape and the flora and fauna of formerly exploited areas. Stacks of waste rocks deposited during extraction and subsequent processing have led to a disturbed surface. This particular landscape attracts a recolonising-type of flora, which evolves with time: it starts with lichens on the bare rocks, followed by bryophytes and ferns and ends with

angiosperms (flowers, beech and finally oak trees). Abandoned mine cavities and galleries have become good winter refuges for bats.

### Geodiversity and Geoheritage Within the Stavelot-Venn Massif: Its Main Assets

It has been demonstrated in the previous chapters that different sites of the Stavelot-Venn Massif area are of great interest to both geologists and naturalists. They combine rare and original geological and mineralogical features, unique natural sceneries and manmade landscapes inherited from a long-lasting geological history but overprinted by human activities exploiting its natural resources.

The following assets are witnesses of the important and broad geodiversity and of the unique geoheritage and related geotouristic potential of the Stavelot-Venn Massif (SVM).

The SVM area represents a key region for the detailed observation of Cambrian to Ordovician rocks that were affected by two succeeding orogenies: the Caledonian and the Late Westphalian Variscan deformation phases. Tectonic structures such as the ‘Theux Window’ and the ‘Graben of Malmedy’ are quite exceptional, witnessing of the complexity of the structural geology of the studied area.

The high Mn and Fe content of the Ordovician rocks and their related mineralogical diversity attracted prospectors and mineral collectors for centuries. The latter diversity strongly varies from North to South, according to the intensity of Variscan metamorphism. The area has a worldwide geoscientific importance due to its richness in unique Mn, REE or As-rich mineral species and its potential for new mineralogical discoveries.

For many centuries, the Vielsalm-Lierneux area delivered honing rock of exceptional quality, easily identifiable by its yellow and violet colour and its very soft touch: the coticule. It can be considered as the best whetstone worldwide. The extraction and manufacturing of both the coticule and the associated slates continue, keeping alive a great geocultural tradition.

Clusters of particular closed and ramparted periglacial structures in the High Fens area (lithalsas and viviers) are quite unique geomorphological features for this part of Europe. They represent a very special boreal-type ecosystem adding to the magnificent natural scenery and attractiveness of the area. Furthermore, the extensive peat bog landscapes of the High Fens plateau and their exceptional ecosystems deserve particular attention.

The hydrogeological system of the SVM generated numerous springs producing still and sparkling waters with very low mineral content. Moreover, some of those mineral waters are iron-rich and have curative qualities. The waters of the main springs are bottled and marketed worldwide. The numerous drinking fountains constitute an additional architectural

heritage. The mineral water resources are protected by predefined perimeters published in the Official Journal, according to regional Belgian decrees. The SVM possesses an extensive fluvial network and various artificial water storages (lakes), providing sport and other leisure facilities.

The use of local arkoses, slates and conglomerates as building stones adds to the regional look and personality of the villages in the SVM area. These villages also display many other uses of these rock types, including funeral monuments, items of religious worship, carved decorative artefacts and household items.

The SVM is the backbone of a huge natural park: the ‘Hohes Venn - Eifel Nature Park’. It results from the merging of the German North Eifel Nature Park with the Belgian ‘Parc Naturel des Hautes Fagnes’ and constitutes an important protected natural area. Visitor centres in the Nature Park attract thousands of visitors each year.

The Botrange Nature Park Centre (Malmedy) lies in the heart of the ‘Hautes-Fagnes-Eifel’ nature reserve. Its infrastructure and its various activities blend in smoothly, providing an extensive programme for discovering the natural treasures of the park. A comprehensive and varied environmental education programme is offered to school classes and groups of people of all ages. Various topics are covered in the form of games, educational walks or environmental and ecological studies. The permanent exhibition ‘*In the search of the lost landscapes of the Euregio Meuse-Rhine*’ describes the making of the High Fens landscape. In the geological part of the exhibition, the visitor is taken down a ‘time-tunnel’ to learn about the changes that once affected the plateau and that were caused by continental drift over the last 500 million years. The second part of the exhibition describes the evolution of the landscape due to human impact.

The Ternell Nature Centre and Regional Centre for Environmental Initiation has a permanent exhibition (show-cases and dioramas) on minerals and stones from the region, local mammals, birds and trees from the adjacent forests. Guided tours organized by nature guides and special packages arranged for school classes help visitors to discover the particular flora and fauna of the nearby high moors (in particular that of the so-called ‘Brackvenn area’ which features a cluster of the unique ramparted traces of lithalsas (viviers). Additional visitor centres highlight other geocultural assets of the SVM, such as the mineral water resources, e.g. the educational centre and bottling company of the Spa waters (L’Eaudyssée de Spa), the Forest and Water Museum in the Estate of Bérinzenne and the Natural Park of Springs (initiated by the towns of Spa and Stoumont, an additional trigger for stimulating tourism in the so-called ‘Pays des Sources’ area).

Socio-economic aspects are also in support of the geoconservation strategy of the SVM. A geopark could indeed be created on the basis of three different but complementary thematic roads, called ‘man and raw materials’, ‘man and

water’ and ‘man and heritage’. The first is materialized by a road trip along the diverse natural mineral resources such as coticule, slates, Fe-Mn ores, rare minerals, lithalsas and peat bogs, combined with a visit of the Salmchâteau Museum and the old slate quarry in Recht. The water road constitutes the second pathway leading from the High Venn to the springs of the Spa-Chevron area, including visits to several streams, artificial dams and rivers. The third, ‘building stone road’ would be directly linked with the natural stones extracted in the area (not only within the SVM but also at its immediate borders) displaying the particular character or ‘soul’ of the Ardennes villages. A visit to the Vielsalm Life and History Museum, contained in a nice eighteenth century house, will complete this particular road trip.

The region has a great geotouristic potential, in particular because of its location at the crossroad of several neighbouring countries. Their citizens are well aware of all their local natural and cultural attractions and their associated leisure potentials, including historical museums and a refurbished slate quarry.

### Protecting Geoheritage in Belgium: The Need for ad hoc Measures and Legislation

Outcrops and former quarries that have been educationally and ecologically re-designed are becoming tourist attractions that can trigger geotourism and generate economic benefits. However, most current reclamation scenarios for quarries and pits do not take into consideration the value of geoheritage. As a consequence, many unique geosites will be or have already been lost, due to the lack of an appropriate management and ad hoc regulations.

A legal framework for the conservation or protection of geological heritage is still lacking in Belgium, while it exists for archaeological heritage. Raising public awareness is necessary, and it is becoming a condition sine qua non for the conservation of our vulnerable geological heritage. Combining natural and geological heritage (biotopes and geosites), or coupling natural to cultural history (urban geology), are possible pathways.

Public awareness of geological heritage can surely stimulate respect for and protection of geological heritage. This awareness, in turn, can be generated by combining nature and geology values and by linking them to cultural-historical aspects. Sustainable conservation of heritage can only succeed when barriers between the different forms of heritage are overcome. The link with cultural-historical heritage can also be demonstrated by looking at natural rocks, out of their natural context, in historical buildings and monuments: through ‘urban geology’ geodiversity becomes evident and recognizable. This is the objective of several volunteer geotouristic initiatives, such as the geologic walking and biking tours in

Flanders and Wallonia (Ek et al. 2004; Dreesen, 2012; Rekk et al. 2014).

Unfortunately, geoheritage is orphaned at the institutional level in Belgium. Its representative institutions have split competences for geoheritage, e.g. as embedded in nature reserves or as part of mining heritage. Furthermore, geoheritage initiatives are developed in near-isolation.

In the absence of a clear framework of geoheritage concepts in Belgium, creative use is being made of denominations, such as ‘geopark’ or its translations, without reference to the internationally accepted standard definition. Moreover, these institutions lack the structural support for assessment of geoconservation issues by a stable and influential organization. Decisions for protection are made ad hoc, but there is no ranking of sites and no thematic approach (Dusar 2012). On the other hand, the visitor management and stakeholder cooperation of the National Park Hoge Kempen (NPHK) is reminiscent of the European Geopark Network (EGN).

After the regionalization of Belgium (1980), the different regions and/or communities became responsible for the inventory and conservation of heritage objects, including landscapes (natural, artificial or ‘cultural’ ones), historical gardens, trees and sites of particular biological, botanical or zoological interest (Dusar 2012). In the Walloon Region, the administrative pattern is codified in the Walloon Code for land development, heritage, urbanism and energy, which is frequently updated. It (CWATUPE) gives precise definitions of the different heritage objects. Numerous categories have been distinguished including natural or artificial outcrops, active or abandoned quarries, etc. The reasons for their importance are quite diverse: they include places of purely geological interest (for stratigraphy, sedimentology, petrology or palaeontology) with reference sections (stratotypes) but also important places for the history of geology or industry (industrial archaeology *sensu lato*, showing for example the evolution of extraction techniques). Even industrial reasons are considered such as the protection of reserves for the production of dimensional stones. Many examples can be given, but a general reflection about a global strategy for the conservation of these ‘geological sites’ is lacking. In the last couple of years, several nature reserves have been created and protected in Wallonia, but these are essentially related to exceptional biotopes, not because of the presence of particular geosites or landscapes.

Since 2011, the Walloon Region has also implemented the Habitats and Birds Directive of the European Commission through the extensive ecological network ‘Natura 2000’. Six areas of the High Fens have been designed as ‘Natura 2000’ conservation zones. Moreover, several projects within the High Fens area have been funded in the past few years, by European LIFE and LEADER initiatives. In 2013, one of those projects has even been awarded the ‘best of best natural LIFE projects’ by the European Commission: it concerns the restoration and preservation of different natural habitats and

exceptional habitats present within the peat bogs or high moors of the High Fens area.

Some abandoned quarries or mines, including former slate mines in the study area, have been protected thanks to the European directives (translated into Belgian and regional laws) giving protection to bats.

So far and as already mentioned above, no national or regional laws or directives have been established specifically aiming at protecting and conserving geological sites, geological objects or landscapes. Nevertheless, sites with particular or exceptional geological, geomorphological and cultural values have already been identified and inventoried by different authors in the recent past throughout Belgium (e.g.: Dejonghe et al. 2009; Dejonghe & Jumeau 2007; Dreesen 2012; Duser & Dreesen 2012; Goemaere, 2007; Goemaere, 2010; Mortier 2013)..

## Conclusion

The Stavelot-Venn-Massif has a great geoheritage potential in combination with all its assets as a cross-border natural park, the High Fens-Eifel Nature Park. The rich and complex geological history of this particular inlier, covering more than 500 million years of earth history, created various natural resources that were extracted for the benefit of the region and of its inhabitants: particular minerals, local building stones, unique whetstones and famous mineral waters. In addition, their exploitation has created new environments and habitats allowing the development of highly specialized and vulnerable ecosystems. All of the geological, geomorphological, hydrogeological and ecological features of this particular area and their complex interrelationships provide a unique appeal. The interrelationships represent the core of a potential new geopark, the development of which will require a holistic approach that integrates all the natural assets and the already existing (geo-) touristic infrastructure. However, in order to initiate and implement geoconservation initiatives in this particular area, it is mandatory to have an ad hoc legal framework first, taking into account the complexity of the administrative legal competences.

The inventory and quality assessment of the geoheritage potential of the Stavelot-Venn Massif is the first important step in a long process of successive protection, conservation and implementation measures. The authors hope therefore that this paper will contribute to the awareness of all people in the area and to the motivation of the decision makers of this particular part of the Meuse-Rhine Euregion.

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