Management of abandoned slate and coticule underground quarries by means of GIS, Vielsalm, Belgium

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Abstract: In 2004, the Geological Survey of Belgium (GSB) launched the first Belgian program of computerized management of underground workings in the commune of Vielsalm (south-eastern part of Belgium).

Located in the southern part of the Caledonian Stavelot-Venn Massif, the commune of Vielsalm is built upon rocks of the Salm Group (Ordovician age - Tremadoc to Llanvirn: 495 - 465 Myrs). Rare minerals and famous rocks (slate veins and coticule) lie within these metamorphic formations. From the 15th century to the end of the 20th century, the commune of Vielsalm was the centre of an extractive industry.

The slate veins and coticule were initially exploited in open pits and later, starting from the middle of the 19th century, in underground workings. Around 30 concessions of roofing slate and coticule were active in the commune of Vielsalm. The exploitation of the coticule in trenches evolved to underground workings through the excavation of many shallow shafts from which a superimposed system of sinuous galleries followed the layers of coticule. Initially the slate vein was extracted in open pits. Then galleries between 150 and 450 m long were dug into the hillside until they reached the slate vein layers. The maximum depth of a slate vein mine could reach 60 to 70 m due to several superimposed exploited levels. The lower levels are generally flooded today. The dewatered galleries and their exits are not well known.

The GIS application made by the GSB with ESRI ArcView 8.3 products is a utility tool for country planners and also a management tool of the territory for legal authorities. This GIS application highlights the limits of risk zones classified by the horizontal projection of the underground galleries at the surface. The observed average density corresponds to one shaft or gallery entrance per hectare in the exploited zones.

Résumé: En 2004, le Service Géologique de Belgique (SGB) a lancé le premier programme belge de gestion informatisée d'anciennes carrières souterraines sur le site pilote de Vielsalm (sud-est de la Belgique).

Située dans la partie méridionale du Massif de Stavelot, la commune de Vielsalm repose sur des terrains attribués au Groupe de la Salm d'âge Ordovicien (Tremadoc à Llanvirn : 495 - 465 Ma). Ces formations métamorphiques recèlent des phases minérales particulièrement rares et des matériaux prestigieux (ardoise et coticule). Du XV^{e} à la fin du XX^{e} siècle, la commune de Vielsalm fût le siège d'une véritable industrie extractive.

L'ardoise et le coticule furent initialement extraits à ciel ouvert puis, à partir du milieu du XIX^{e} siècle, en souterrain. Au total, 30 concessions environ ont été dénombrées. L'extraction du coticule par tranchées évolua ensuite vers une exploitation souterraine par le creusement de nombreux puits peu profonds amenant à un système étagé de galeries méandriformes suivant les lits de coticule. L'extraction de l'ardoise diffère. Les carriers creusèrent tout d'abord des fosses à ciel ouvert, puis des galeries à travers-bancs à flanc de coteau, de 150 à 400 mètres de long jusqu'à atteindre les veines ardoisières exploitées par chambres. La profondeur maximale d'une ardoisière peut atteindre 60 à 70 mètres en plusieurs niveaux superposés. Aujourd'hui, les niveaux inférieurs sont généralement inondés. Les galeries d'exhaure ainsi que leurs orifices de sortie sont pratiquement inconnus.

L'application SIG développée par le SGB au moyen du logiciel ESRI ArcView 8.3 constitue un outil de gestion du territoire mais aussi d'aide à la décision pour les autorités compétentes (collectivités territoriales). L'application SIG délimite des zones à risques encore inconnues jusqu'à présent par la projection horizontale en surface des galeries souterraines. Les zones exploitées présentent une densité moyenne d'environ un puits ou entrée de galerie par hectare.

Keywords: Metamorphic rocks, abandoned mines, underground mining, geographic information systems.

INTRODUCTION

Slate vein and coticule mining constituted an essential activity during the industrial revolution and an important phase of the development of the country before the First World War. Today, the Belgian mining activity is almost extinct except for some limited, local exploitation. The development of the mines in the short to mid-term was established to guarantee an optimal output, profitability and security during the exploitation. Up until recently, the behaviour of the mine after its abandonment and the future consequences on the environment were not considered. The questions relating to the "post-mine" behaviour of the underground exploitations concern almost all the natural resources which were extracted from the subsurface deposits in Belgium. Some phenomena and disorders were observed and are known historically but there is an important gap in the awareness of processes that may be active today in the known and unknown underground workings.

In 2004, the Geological Survey of Belgium (GSB) launched the DB-ARCO programme (a French acronym meaning ‘a database about slate vein and coticule’). It concerned the creation and the development of a GIS (Geographical Information System) tool that could centralize dispersed data of different types and facilitate the management of the abandoned underground workings located in the municipality of Vielsalm. The are three main issues: country planning, especially the identification of potential collapse risk zones; the preservation of natural (flora and fauna) biodiversity; and the conservation of the industrial and cultural heritage. The programme has evolved from an early stage focussed on the Vielsalm commune, to other areas since mid-2005 where slate vein underground workings are known in Belgium.

The main purpose of this paper is to present a geomatic approach used in the Vielsalm commune to manage old archives describing the underground workings of the slate veins and coticule in the Vielsalm commune. The geological setting, the exploitation method and the geological risk described in Vielsalm will be compared to a basin located in the south of Belgium (Aise Valley, Bertrix, Belgian Ardennes).

GEOGRAPHICAL AND GEOLOGICAL SETTING

Geography

The studied area is located in the Vielsalm commune in the south-eastern part of Belgium (Province of Luxembourg). Vielsalm lies at an average altitude of 360 m and is surrounded by three hills reaching 530-550 m. The Salm River, flows along the Salm Valley between these hills, where quarries and underground exploitations are known.

Slate veins have been exploited in several places near the villages of Ottré-Bihain, Vielsalm and Salmchâteau. In this paper, we will focus on the slate veins exploited in and around Vielsalm. Slate veins have been intensively mined in two main deposits located in the northern and southern parts of “Thier des Carrières” hill, between the villages of Vielsalm and Salmchâteau on the eastern side of the Salm River. Other exploitations are known on the opposite side of the Salm River. Coticule deposits are found, on the “Thier de Regné”, “Thier del Preu” and “Thier du Mont” hills, near the villages of Salmchâteau, La Comté, Grand Sart, Bihain and Lierneux, on both sides of the N89 road between Salmchâteau and Baraque de Fraiture (Figure 1).

Geology

The Vielsalm area is located in the Caledonian Stavelot-Venn Massif, the best-exposed Lower Paleozoic inlier in the Variscan Ardennes Allochton (previously termed the ‘Dinant Nappe’) in Belgium. The Ardennes in southern Belgium consists of an allochtonous domain that was thrusted onto an autochtonous unit during the Variscan orogeny. Rocks from the Early Cambrian up to the Middle Ordovician age correspond to the oldest rocks present in this allochton. They were deformed during the Caledonian orogenic phase. During the Devonian and Carboniferous, an extensional basin was formed in the stable continental shelf platform in the south of the Lower Old Red Sandstone with sedimentary deposits related to transgressive-regressive cycles. As a result, Lower Devonian to Upper Carboniferous sediments unconformably overlie the Caledonian inlier. All these strata were subsequently deformed during the Late carboniferous Variscan orogeny. The Hercynian metamorphism (360-420°C; 2-3 Kbar), which characterizes the Stavelot-Venn Massif, is probably due to burial and/or tectonic loading of sheets (Ferket, Muchez, Schroyen & Sintubin 1998). The Lower Paleozoic are composed of Cambro-Ordovician sedimentary (slate, siltstone, sandstone, black shale) and rare magmatic (rhyolite and dacitic) rocks (Lamens & Geukens 1984, 1985, Lamens 1986). The deposits are Ordovician in age and correspond to the Salm Group, which has been subdivided into three stratigraphical formations (respectively, from base to top, Jalhay, Ottré and Bihain formations). As shown on the geological map (figure 1), the slate vein (S) and coticule (C) deposits have been mined in the Ottré Formation. The Ottré Formation (230 m thick) is composed of red siltstone, slate, and red slate alternating with 1-15 cm thick yellowish coticule beds and violet chloritoid-rich slate. These sedimentary rocks are enriched in iron and manganese (which have been mined in the Lienne valley). This formation is sliced by several thrust faults and bordered to the east by the Lower Devonian sedimentary series (Lochkovian and Pragian rocks), which overlie an angular unconformity (Figure 1).

Slate vein and coticule: definitions

Slate is a dense, fine-grained fissile rock formed by low-grade regional metamorphism of pelitic sediment (shale and mudstone). Slate is characterized by a single, perfect cleavage (‘slaty cleavage’), enabling it to split into parallel-sided sheets. The cleavage may be parallel to, or at a low angle to the primary sedimentary bedding. Fossils may be preserved but are invariably distorted. Folds are often apparent in the field. True slate is hard and compact and does not undergo appreciable weathering. Slate is generally dark grey, green or black in color, and individual grains cannot be distinguished with the naked eye. Specific mineral components are responsible for the various colors: carbon and manganese (black), hematite (red and purple), chlorite and ferrous iron oxide (green) for example. Slate is a term commonly used for any ‘flat rectangular’ roofing product. Slate has been used in Europe for hundreds of years with surviving examples dating back to the 8th century. In the following text, we use the terms ‘slate’ and ‘slate vein’ to distinguish the surrounding rocks (called in the Belgian literature “quartzophyllades”) from those found in veins, exploited in underground workings or used as roofing products.

Coticule is a very fine-grained metamorphic rock mainly composed of spessartine garnet (micrometric size), mica and quartz. They are typically very rich in manganese (up to 24 wt% MnO), poor in iron (less than 1 wt% FeO or Fe_2O_3), and are generally very rich in garnet (> 40 wt%) and rather poor in quartz (< 30 wt%) (Lamens 1986). Coticule is a natural abrasive stone used to sharpen and hone razor, surgery and knife blades. Similar rocks, also of Lower Ordovician age, occur in Wales, Ireland, Norway, New England, Massachusetts, Newfoundland and Nova Scotia (Kennan & Kennedy 1983). They differ from the Belgian coticule by their mineralogical composition (they are typically a near-pure quartz-garnet rock) and by a coarser-grained facies. The origin of the coticule veins in the Stavelot-Venn Massif is suggested to be deposition, by density currents, of a fine carbonate mud in a basinal setting. Calcium has been replaced by manganese, probably post-burial, and spessartine has formed during metamorphism (Lamens 1986, Lamens, Geukens & Viaene 1985).

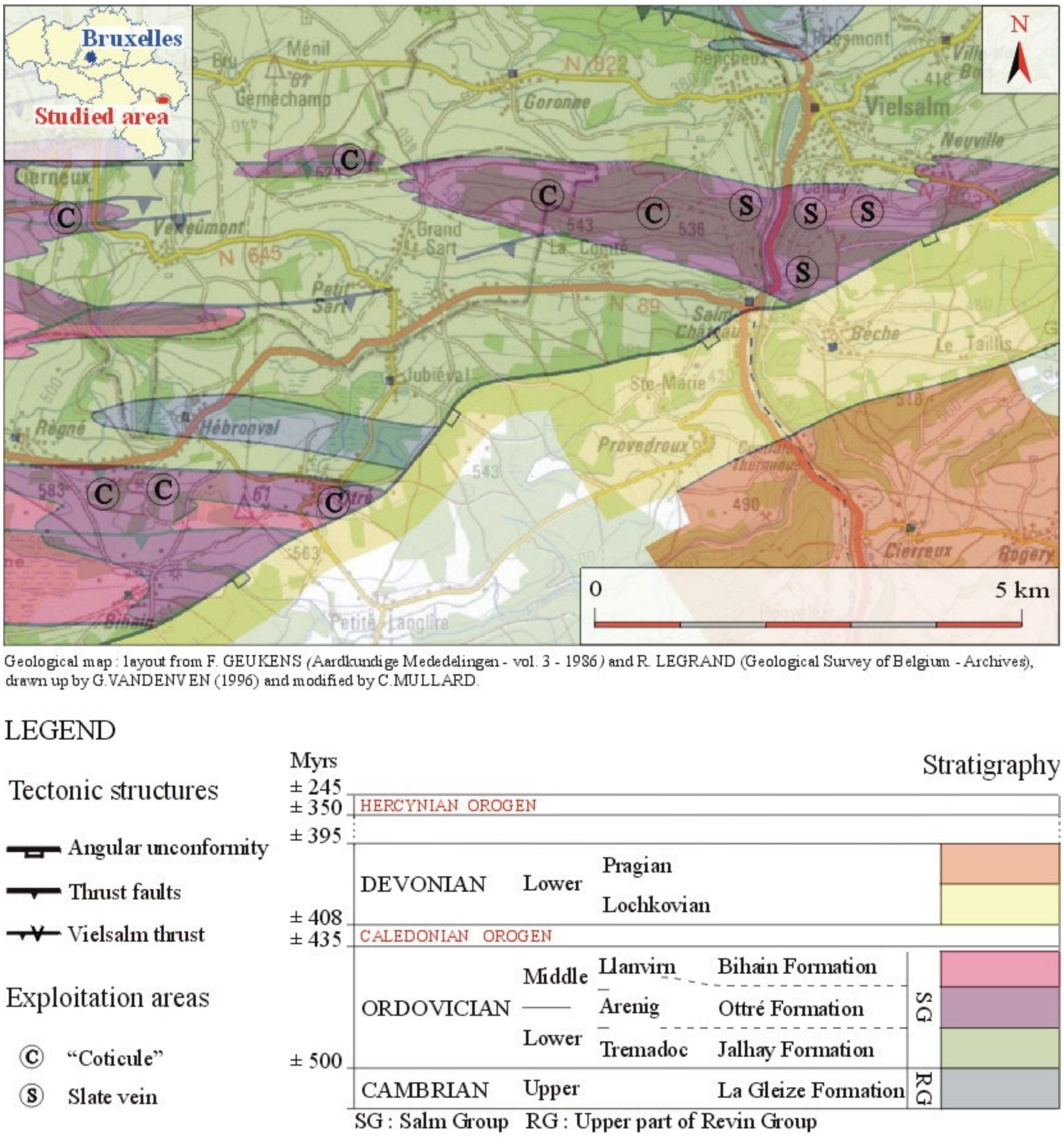

Figure 1. Simplified geological map superimposed on the Belgian topographic map (1:100 000 scale-map) of the area between Lierneux and Vielsalm.

GIS APPLICATION

The global architecture of the GSB’s GIS application is illustrated on Figure 2. Technically, two different modules have been created in parallel to treat the spatial data that are related to geographically localized entities corresponding to raster and vector. Raster- held data includes “mining” documents, geological maps, orthophotoplans, georeferenced scans of the Vielsalm land register, topographic 1/10.000 and 1/100.000 scale-maps and the topographic maps of Ferraris realized between 1770 and 1778 and vector- based data includes vectorized geological maps, cartographic database, communal, provincial and regional vectorized supports, vectorized Natura 2000 zones, cadastral parcels, buildings. Semantic data, including a chronological account of exploitations, socio-economic data, geological publications, biological data, describe these entities.

The GIS tool's architecture

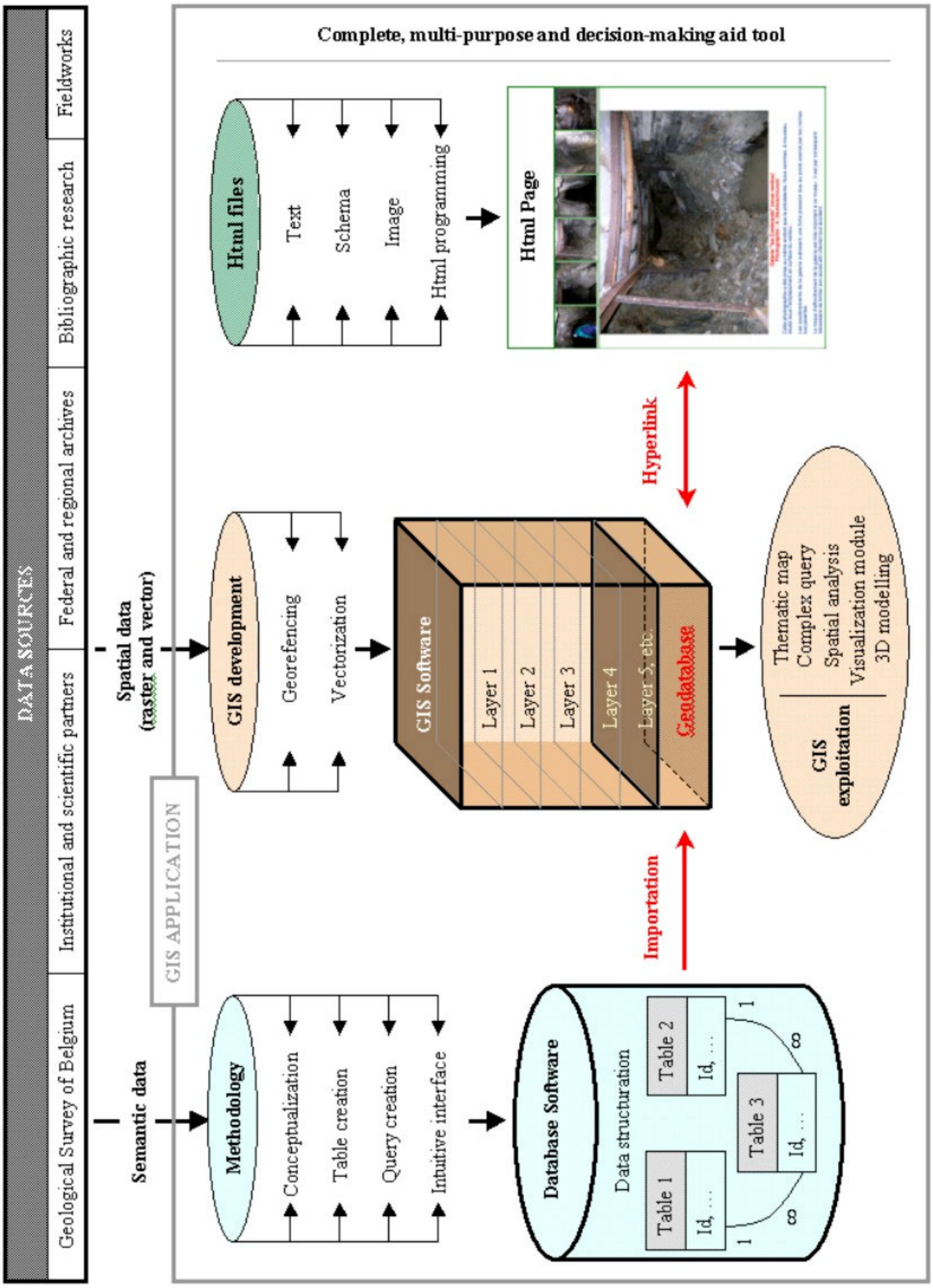

Figure 2. Functional diagram showing the architecture of the GSB's GIS application.

The semantic data are organized and structured by means of a relational database management system under the Microsoft Access 2000 software (Copyright © 1991-2002 Microsoft Corporation). Initially, a reflection phase based on the Merise method allowed building a Conceptual Data Model (CMD) and allowed the relations between each entity to be defined. The Merise method, elaborated in 1978-1979, aims to separate data and data processing, strengthening the longevity of the system. In contrast to data processing, the structuring of the data doesn't require frequent alterations. The CMD initiates the technical phase of table, query, acquisition and consultation data interface creation inside the database software. The database dedicated to our institutional partner, the General Direction of Natural Resources and Environment (DGRNE) of the Walloon Region, is exhaustive. The CMD links all the "mining", geological, biological, geographical, historic and administrative information linked to the old exploitations. The database is intuitive, due to easy-use interfaces, allowing for better data acquisition, exploitation and visualisation, and is dynamic with the development of numerous navigation buttons.

The spatial data are integrated within a cartographic management system, the ESRI® ArcView 8.X (Copyright © 1999-2002 ESRI Inc.), in the form of information layers. The image layers (or raster) are georeferenced to the Belgian coordinate system using the Belgian Lambert 72 projection. The georeferencing procedure of the "mining" plans corresponds to a crucial stage of the DB-ARCO programme. These documents constitute an essential element of this programme. The data is, however, relatively poor compared to modern records, and the scarcity and the poor precision of the mining plans, the lack of geographical reference marks and the small number of usable historical documents is partly explained by the historic nature of the data and the limited area of the exploited slate vein deposits.

The georeferencing step is difficult and requires the acquisition of new data sources (including federal and regional archives and the research of scientific publications) as well as GPS measures of the surface elements (open pits, gallery entrances, shafts, old buildings) represented in the "mining" plans during fieldwork. The georeferencing technique is presented and detailed in Devleeschouwer, Mullard & Goemaere (2005). Each entity shown on a "mining" plan is vectorized and constitutes a new information layer. This step is developed in the following section.

Semantic and spatial data are imported and stored in a geographical database (geodatabase). The geodatabase is a system integrated into the ESRI® ArcView 8.X GIS software, where all functionalities of traditional databases are available (queries, interfaces development). This system avoids double data acquisition and facilitates the management of new information. Its main interest resides in data exploitation. Under the GIS software, the end-user can carry out cross-checking of semantic and geographical data issuing from the geodatabase and build value-added documents as thematic maps, complex queries, raster or vector spatial analysis, and 3D modelling. Many scripts have been developed including, for example, an Access consultation form that is based on many queries and imported in the geodatabase where it is displayed for each vectorized object selected.

Finally, Html (and Javascript) pages composed of field photographs, schemas and texts, illustrating each vectorized object, are available through a hyperlink. These pages show fieldwork examples and may help the user to better understand the data held within the GIS.

VIELSALM AND BERTRIX: A COMPARISON OF THE SLATE VEIN EXPLOITATIONS

The program launched in 2004 on the Vielsalm area has been followed by a study carried out during summer 2005 on the Bertrix area (southern part of Belgium), where slate veins have been also exploited for many centuries. A comparison of these exploitations based on the geological setting, the methodology through the "mining" plans and the risk associated to these underground workings will be assessed in the following chapters.

Geological setting comparison

The Bertrix slate veins have a younger geological age (Pragian, Lower Devonian) compared to those of Vielsalm (Lower to Middle Ordovician). They have been exploited since the second half of the 17th century. Around eleven exploitations are distributed along the "Slate veins road" (known in French as "Route des Ardoisières") in the Aise Valley near Bertrix. Two slate vein layers are recognized in the area (Asselberghs 1924), each of them is around 25 m thick.

In the Bertrix area, the main Lower Devonian series comprises, from base to top, the Mirwart, Villé and La Roche formations (Figure 3). These formations are classified according to the new geological maps of the Walloon Region (1/25.000 scale-map), which covers the Bertrix area. The Mirwart Formation is composed of argillaceous sandstone and quartzite ranging in thickness between tens of centimetres to a few metres, interbedded with green-grey or black slate and siltstone. Siltites, grey laminated slates and exploited slate veins are present mainly in the south of the Aise Valley. These exploitations are not discussed here. The Villé Formation corresponds to dark blue slate with intercalations of red-brown sandy laminated layers, blue sandstone, often with red-brown pellicular weathering, and subordinate white sandstone and quartzite and blue fossiliferous carbonate sandstone. These rocks contain crinoids, corals and brachiopods sometimes found in layers a few tens of centimetres thick. The La Roche Formation is described by Asselberghs (1924) as dark blue slate with rare fossils and pyrite. Slate veins have been recognized in this formation and correspond to the main underground workings of the Aise Valley. Rare fossils (corals, orthocones, molluscs, trilobites and few star-fishes) and numerous pyrite crystals characterize these slate veins. All the slate veins exploitations are opened in the La Roche Formation, which is elongated along an east-west axis. The Linglé, la Fortelle and Wilbauroche sites represent the westward limit of the formation, where the westernmost slate veins exploitations are observed.

The exploitation methodology revealed by the "mining" plans

The slate vein extraction differs from that of coticule. Initially, the quarrymen dug in open pits, but later they crosscut galleries 150 to 450 m long on the hillside until they reached the slate vein layer. The slate vein deposit was exploited in rooms (following the method of room and pillar) of a maximum height of 30 m. In Vielsalm, the maximum depth of the underground workings could reach 60 to 70 m due to several superimposed exploited levels and limited by the water table level. The lower levels, generally flooded, as well as the dewatered galleries and their exits are not well known and probably sealed. Shafts are used as emergency exits and for the ventilation of the galleries.

The "mining" plans of the underground workings of Vielsalm form the baseline data to the project; these were georeferenced using geographical reference frameworks. Difficulties arise at this stage due to differences between the current field situation and that represented on the "mining" plans, which generally predate the closure of the underground workings. A two-step procedure to accommodate this situation is described by Devleeschouwer, Mullard & Goemaere (2005). Firstly, similar anchor points are found on the limits of the cadastral parcels on both the "mining" plans and on the digital vectorized georeferenced land register of the Vielsalm commune. Secondly, GPS measurements taken during fieldwork identify the surface elements represented on the "mining" plans, such as shaft and gallery entrances and the buildings related to exploitation at the surface.

Coordinate points allow the shafts or gallery entrances present on the "mining" plans to be used as new anchor points to increase the accuracy of the georeferencing procedure. The last step consists in vectorizing the "mining plan" inside the GIS. The original "mining" plan (Figure 4), with the underground workings (rooms and galleries) and the associate profiles, show that rooms have been exploited at different levels down to 60-70 m below the surface. The main problem encountered during the vectorization step of these underground workings corresponds to the superposition of the whole exploited levels (blue, green and yellow surfaces). Where it has not been possible to decipher the original plan, a solution has been adopted where the areas of all exploited levels are amalgamated, as indicated by the brown coloured surface on the Figure 4. Several vectorized layers are thus created in the GIS; they correspond to the underground chambers, the main galleries and the junction galleries that link two underground exploitation areas at the same level, the shafts, and the gallery entrances.

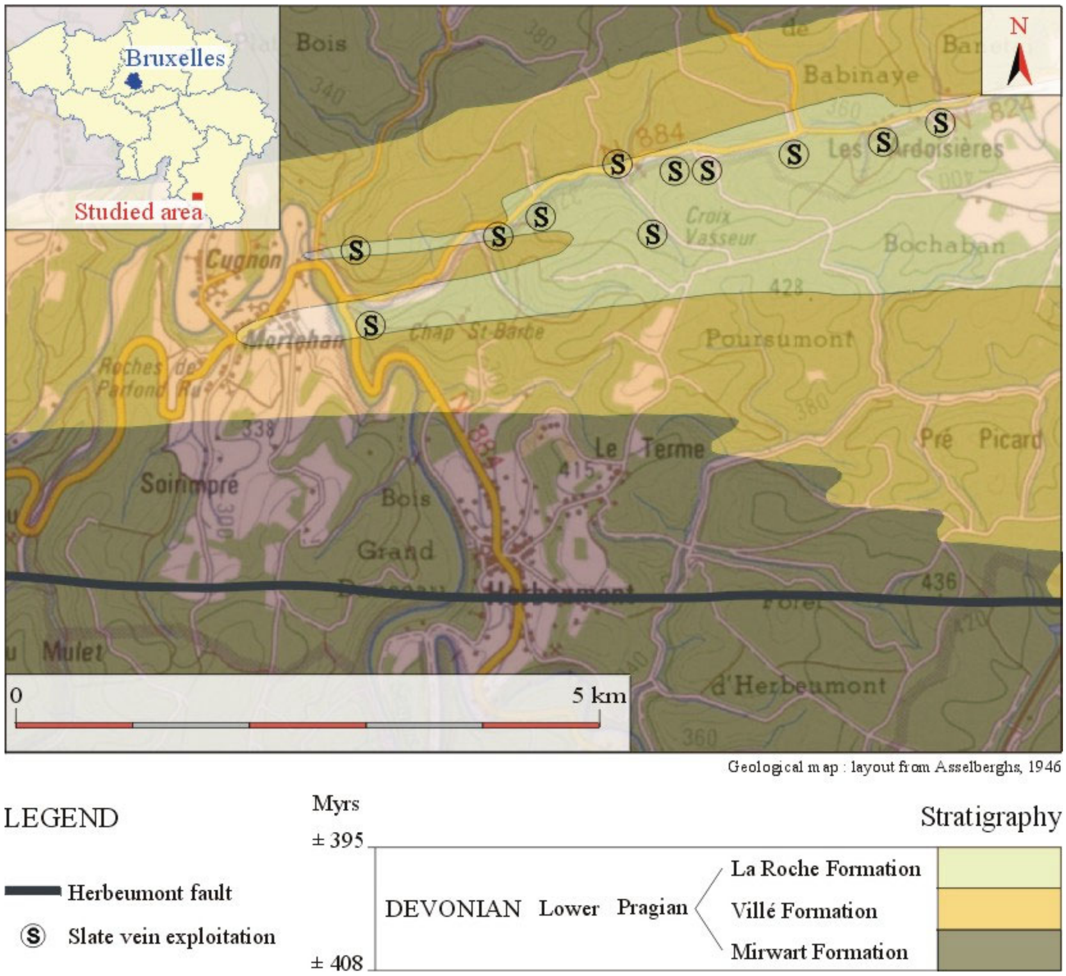

Figure 3. Simplified geological map superimposed on the Belgian topographic map (1/100.000 scale-map) of the Aise Valley area.

In the Bertrix area, the underground workings have been exploited using inclines or galleries. The inclines are excavated following the inclination of the slate vein layer, which is generally around 40-45° towards the south. The galleries are opened at the base of the slate vein layer and follow the direction of this layer. The exploitation starts by excavating inclined rooms within the slate vein layer. Each room is separated from the next one by a pillar that is a few metres thick, called a " pilier longrain"; these are perpendicular to the direction of the slate vein layer. The rooms excavated at different exploitation floors are superimposed one on the other according to the inclination of the slate vein layer. Each exploitation floor is separated from the preceding or the following one by a pillar ("pilier éponte"). These pillars are abandoned in the rooms and have a general thickness of 5 m. The rooms have dimensions of 15-20 m in height and 25-30 m in length. In the Bertrix area, the rooms are excavated progressively from the base to the roof of the slate vein layer. The room is backfilled as the slate is extracted. The backfill, up to 4 m high, is used as a ledge from which the excavation of the roof of the gallery could proceed. In contrast to this approach, in the Vielsalm area, the slate vein is excavated from the top to the base and the pillars are absent.

The background documents from the Bertrix area correspond to the "mining" plans, as is the case in the Vielsalm area. On these plans, the limits of the cadastral parcels are not indicated. The geo-referencing procedure uses the topographic information drawn on the plans such as the buildings related to the exploitation (such as workshops), the roads and road intersections, and watercourses. The second step is similar to that used in the Vielsalm area: GPS measurements are taken during fieldwork of the gallery, inclines and shaft entrances. Distances between fixed points (for example, from the end of a gallery to an inclined ramp) measured in the field compared with the "mining" plans.

The vectorization step is simpler then the approach in the Vielsalm area, as all the important objects (gallery entrances, shafts, inclines, rooms) are clearly identified on the plans. Due to the inclination of the slate vein layer, the rooms at the lower levels are not beneath those at higher levels on the horizontal projection plan of the underground workings (Figure 5).

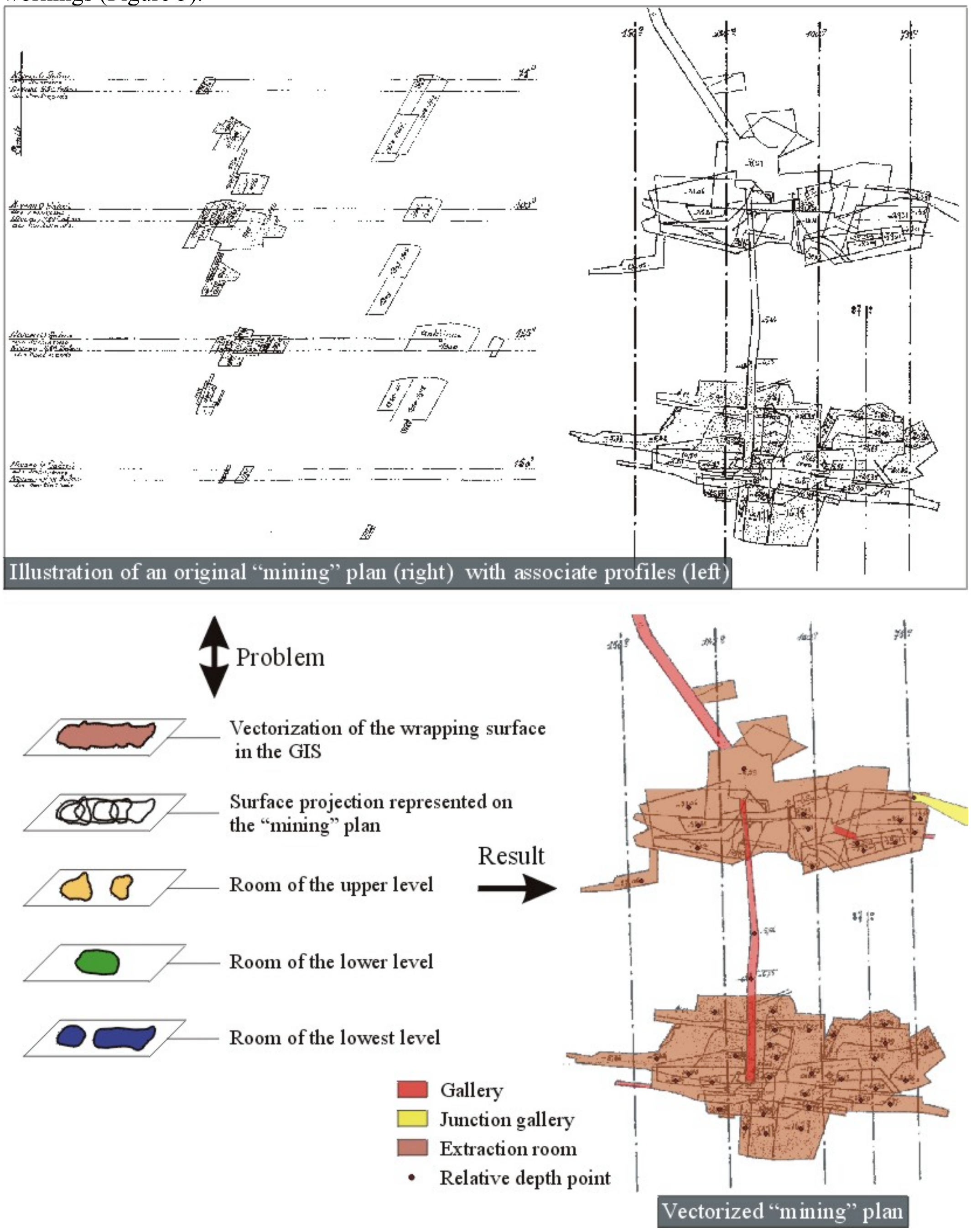

Figure 4. Illustration shows an original "mining" plan in the Vielsalm area with underground workings (chambers, galleries) above right and the associate profiles above left. The main problem during the vectorization step corresponds to the superposition of several exploited chambers at different levels (blue, green and yellow surfaces, lower left diagram) but drawn one in another. The solution adopted is to vectorize the limits of all workings, as viewed in plan view as indicated by the brown coloured surface as illustrated by the lower right diagram.

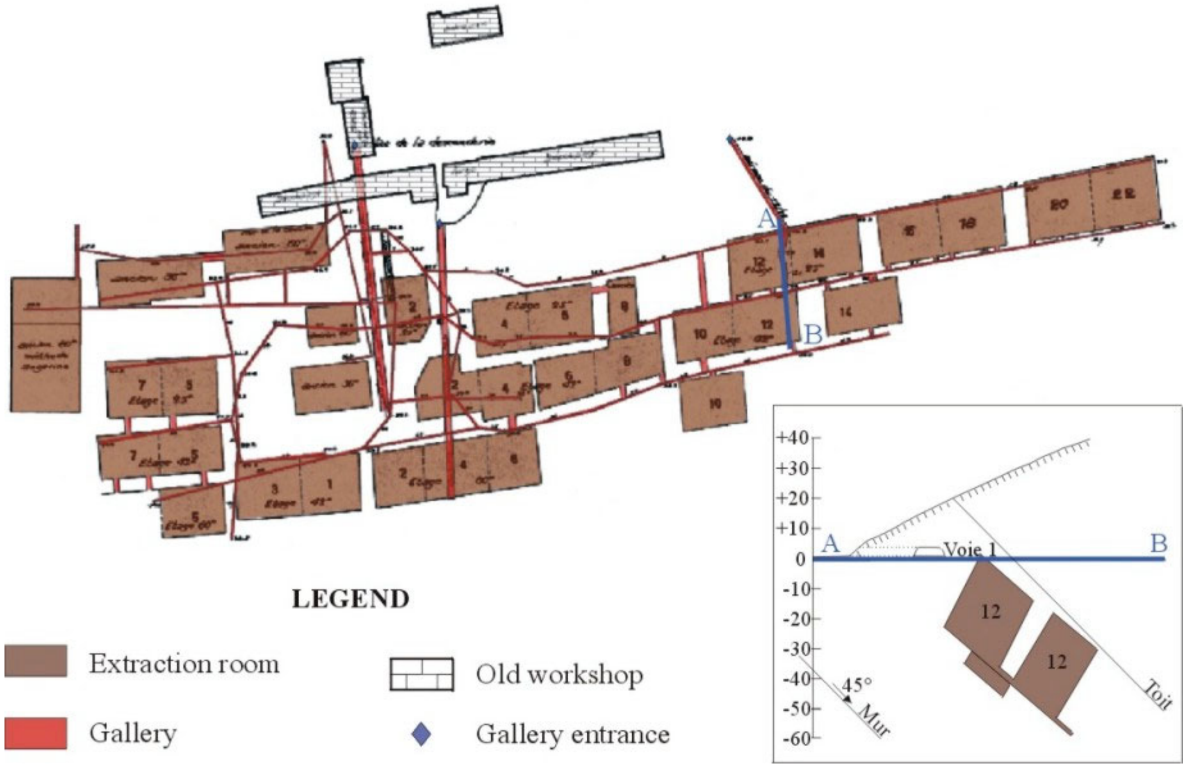

Figure 5. Vectorization of different aerial (workshops and gallery entrances) and underground (galleries and extraction rooms) elements from the "La Morepire" mining plan (horizontal projection and vertical profile).

The geological risk related to these abandoned underground workings

Five criteria (the state of the shafts and the gallery entrances, and their protections; the state of the galleries and rooms; the damage to the buildings present at ground level) were used to estimate the risk represented by these abandoned underground workings in the Vielsalm and Bertrix areas. This simple evaluation approach is based on the stability of the underground workings and their potential impact at ground level. The people accessing to these zones in underground as well as on the surface must be taken into account to estimate the risk level.

In the Vielsalm area, the slate vein exploitations are mainly observed in the northern and southern parts "Thier des Carrières" hill. Locally, residential houses are partly built above some galleries. The GIS tool has allowed the identification of the possible presence of a gallery underneath nine houses. Some traces of the walls of the old workshops are still visible around some of the shafts and galleries. Possible damage at the surface is relatively low to locally high, as in the Cahay quarter where the stability of some galleries could have an impact at ground level. Almost all the slate vein underground workings in the Bertrix area are located in forested or Natura 2000 zones; these areas typically have no buildings on the surface. Two exceptions must be taken into account on the "La Morepire" and "Grand Babinay" sites where, respectively, a mining museum and entertainment infrastructure, and an active quarry using the backfilling products of the old exploitation are currently under development. Possible damage resulting from the disused slate workings in the Bertrix area is therefore relatively low.

The gallery entrances of these old and abandoned underground exploitations in Vielsalm as well as in Bertrix are mostly open and easily accessible to the public. In the last few years, the Walloon authorities have closed some of these entrances essentially to protect this heritage but also to preserve the biodiversity of the resident populations of bats. It is planned that other gallery entrances will be closed with metallic doors. Many of these entrances are included in "Natura 2000" zones, which correspond to protected areas currently surveyed by the agents of the Nature and Forest Division of the Walloon Authorities. Many walkers and mineral collectors visit these areas and, typically, they do not eek permission to enter the underground cavities. There is a 'moderate' estimated risk level for these two areas.

The shafts in both areas are opened and easily accessible and metallic grids protect only a few of them. Some shafts are now hidden under waste heaps. The ventilation and extraction shafts are located close to footpaths, and in wooded zones these can constitute a danger for the public. The shafts can become overgrown with vegetation, representing an obvious hazard. Shafts associated with some galleries in the Vielsalm area have been completely filled by waste materials. Observations of filled shafts indicate that that the fill rests on (now decayed) wooden beams, which prevents it from collapsing into the galleries. The fieldwork reveals that only one or two shafts have been excavated during the slate vein exploitation period. The estimated risk is high and a systematic closing and protection of the shafts in the coming years is needed to prevent accidents.

Figure 6. These pictures have been taken during fieldwork. Images n°3, 5 and 6 from the Vielsalm area illustrate an open gallery entrance, a shaft in a forest area and a gallery with the presence of a filled shaft (on the roof, upper left corner) underlined by some decayed wooden beams. Images n°1, 2 and 4 from the Aise Valley illustrate respectively a closed gallery entrance, an open gallery entrance (red arrow) and a gallery with metallic beam supporting the backfilling of an adjacent room located on the right side of the picture. Backfilling slate wall delimits the room.

The state of the underground workings is analyzed in terms of the stability of the galleries and rooms. In the Vielsalm exploitations, several galleries are partly collapsed and/or located under large waste heaps. Some gallery entrances are no longer visible in the field. The rooms of the lower level are completely flooded, which has prevented the acquisition of further information about the state and the stability of this part of the underground workings. The rooms at the first level of the underground exploitation are relatively empty and bigger in size than those of Bertrix. The roof of these rooms corresponds to the floor of the open quarries present on the surface that are delimitated on their southern face by a natural cliff. If a rockslide happens on the surface then the roof of the gallery could collapse- this happened during the exploitation time. In the Bertrix area, the rooms are mostly filled with the back fillings of the exploitation and are mostly located in the hillside. The rooms are superimposed on different floors (eight for the Linglé exploitation) but a pillar of 5 m thick separates two levels. A 1-2 m thick pillar separates two adjacent rooms. Due to this, the rooms and galleries in Bertrix appear to be better stabilized than those of Vielsalm.

The following table indicates the evaluated risk both in Vielsalm and Bertrix through the five criteria set out in the preceding paragraphs. It appears that the underground workings of Vielsalm should be surveyed and all the gallery and shaft entrances should be protected New fieldwork could be useful to characterize and gather other information to answer the next few questions:Are there other cavities (rooms or galleries) outside the underground workings described on the “mining plans”? Is it possible to find surface evidence of all the shafts? Are there any radon gas emissions? What is the quality of the groundwater?

Table 1. Evaluation grid of the risk represented by the old underground workings in the Vielsalm and Bertrix areas.

	Shafts	**Gallery entrances**	**State of the galleries**	**State of the rooms**	**Damages to the buildings**
Vielsalm	High	Middle	Middle	Middle	Low to locally high
Bertrix	High	Middle	Low to Middle	Low	Low

CONCLUSIONS

The purpose of the DB-ARCO program in the areas where there are abandoned and potentially unknown slate veins and coticule workings is to:

- gather all available ‘mining’ data (mining plans, mining profiles)
- compile an inventory the abandoned mined sites
- map out, using GIS methods, the underground workings of the slate vein and coticule deposits
- confirm and validate the data with fieldwork (GPS measurements of gallery entrances, shafts, surface infrastructure)
- determine medium- and long-term behavior of cavities
- assess the effect on the surface (if any) of cavities
- compile, if possible, risk-reduction procedures
- to suggest methods for monitoring high-risk areas

In order to introduce the multiple data sources in the computerized management of the old slate vein and coticule exploitations, a complete multi-purpose, decision-making aid tool has been developed using GIS.

This application is the result of detailed bibliographic research and consultation of numerous data sources to understand the problematic nature of these underground workings and to acquire as much high quality data as necessary. The database structure was established to be as exhaustive as possible and will allow future developments that may be needed as new data is acquired. The tool contains three complementary modules that store, upgrade, and organize, exploit and valorise the gathered data.

The GIS tool allows the precise location of old underground workings, and enables the identification of potential geological risk zones, and the determination of the location of the zones with a geological, biological or cultural interest.

The GIS tool could help to manage country planning by taking into account the geological risk in suburban areas and improving the protection and valorisation of this remarkable heritage, which includes bats and industrial vestiges in addition to minerals. This GIS tool could be used to collate new subsurface data captured during fieldwork, such as the location of mineral veins, internal shafts related to the lower levels and the presence of roof cracks.

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