The specific geology of the Famenne – Ardenne Geopark

Karst systems in an Appalachian-style relief

A Geopark is characterised by geological phenomena and objects distinguishing it from other Geoparks and other regions of interest, and this is clearly the case of our Geopark. But what exactly do geological objects and phenomena consist of? Since geology is a science of landforms, let us look at the field. As you will see, dear reader, the science of the earth is not all that complicated.

The first thing needed is a map of the location of the Geopark. In figure 1, it emerges as an area of transition between the Ardenne to the south and the Condroz to the north. It includes the south of the Famenne, a great shale depression, and a strip of calcareous rocks running from west to east named “Calestienne”.

Figure 1. Natural zones in Belgium. The confines of the Geopark are indicated by the red line.

For a better understanding of the characteristics of this region, let us examine a photograph taken from the top of Boine hill, under which lie the Caves of Han-sur-Lesse, looking south towards the village of Belvaux (figure 2). What do we see? In the foreground, the Lesse intersects a depression, in the middle of which stands the village. In the near distance, the relief rises into a hill through which the Lesse flows in a narrow incised valley. Finally, in the far distance, can be seen the heights of the Ardenne plateau.

Figure 2. Panoramic view of the village of Belvaux, seen from Boine hill.

Looking at another photograph (figure 3), this time taken looking north from the heights above the village of Sohier, the view reveals a shale depression, to the north of which rise hills of calcareous rock, beyond which lies a new and even bigger depression, partially hidden: the Famenne. On the far horizon rise the heights of the Condroz.

Let us summarise the structure of the landscape, since it holds the secret to the Famenne – Ardenne Geopark. We have a series of depressions from which emerge limestone hills. These depressions are aligned along a general east-west axis. To the south, the region is confined by the high Ardenne plateau, down from which the Geopark's main rivers flow: the Ourthe to the east, the Lomme and the Lesse in the center, the Ry d'Ave and the Wimbe to the west. Note that all these rivers flow from south to north, except for the bends to the west made by the Lomme at Jemelle and the Lesse at Eprave. To the north, the area is bounded by the heights of the Condroz. **This is described as an Appalachian-style relief**. This name finds its origin in the Appalachian Mountains in USA. This Mountain range is the extension to the West of the Variscan Mountain in Europe before the genesis of Atlantic Ocean; our Ardenne region constitutes the North part of this mountain. Both region have evolved in the same way and Appalachian Mountain is became the region type.

The rivers running north to south cut perpendicularly across the limestone hills: this means they must cross these hills in segments of incised valleys. They do not, therefore, follow the large depressions, which do not channel the rivers in an east to west direction. There are **epigenetic rivers**. Instead, the rivers continue their course to cross the Condroz before flowing into the Meuse River. We will see and understand how this geomorphological disposition (the relief) arises from the region's geological evolution.

Figure 3. Panoramic view from the village of Sohier. In the foreground, the gentle slopes run down to a first depression. This is separated by hills from a second depression visible in the middle distance, which is in turn overlooked on the north by the heights of the Condroz.

How geology provides an understanding of the landscape

Now let us examine the more detailed map of the Geopark (figure 4). The first point to note is that its outer limits are purely administrative. So what can we learn from this apparently complicated figure? A geological map is a representation of the outcrops of different rock formations. Each colour therefore corresponds to a particular type of rock formed over a clearly defined period of time. Overall, there are three strips of colour: mauve in the south, blue in the middle and yellow in the north. These are the three geological domains of importance to our Geopark. To the south, sandstones and shales form the high-altitude Ardenne bedrock. In the center, the limestones feature in relief between the last of the Ardenne shales (the Belvaux depression shown in figure 2) and the first of the Famenne shales (the second depression outside Sohier in figure 3). The map shows very clearly how the main rivers, highlighted by their alluvial plains, cut through the terrain. It is clear to see how the reliefs and depressions are thus linked to the nature of the underlying rock.

Any aerial view of the region is filtered by vegetation. Recent technology has, however, provided us with the means to examine the surface of the "bare" earth: remote sensing by side-scanning light detection and ranging (LiDAR). The image this technique provides is astonishing, because it shows us a "desert" landscape, stripped of its vegetation (figure 5). The reliefs running from west to east are clearly visible, corresponding to the limestone hills through which the rivers cut perpendicularly.

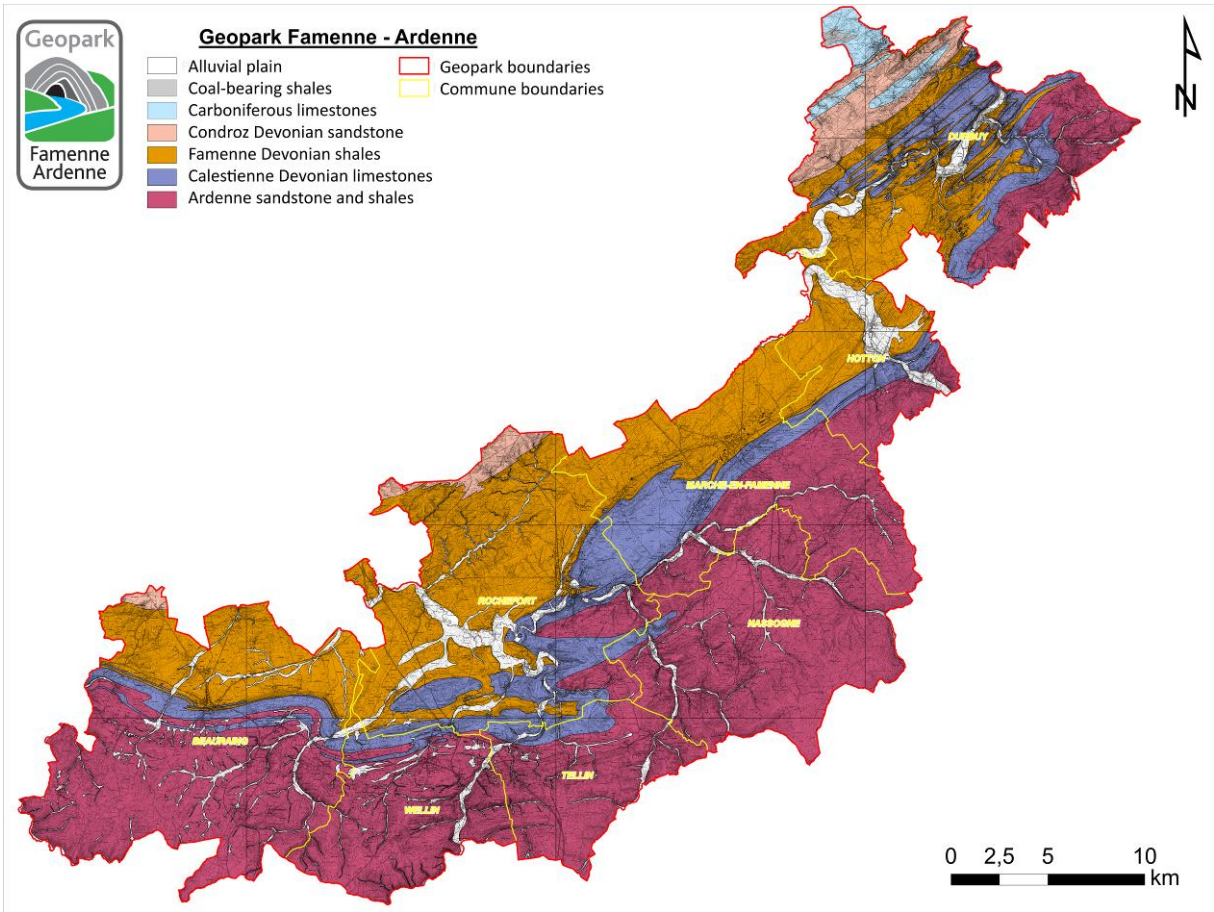

Figure 4. Simplified geological map of the Geopark. The geological domains are defined in the key. This map offers an interesting comparison with figure 5, the LiDAR image that eliminates vegetation.

The first line to emerge on this figure is the alignment of the valleys, deeply incised into the bedrock. Reference point (1) marks the massif in which the Caves of Han are located. At reference point (2), the shale depressions separate the limestone ridges standing out in relief (3). Point (4) is the limestone relief that is home to the Lomme and Wamme subterranean river systems, of which the Cave of Lorette forms part.

From what lengthy and complex evolution did this landscape and this geological structure emerge (figure 6)? The answer lies far back in time, when what is now our Geopark was a tropical ocean. Some 390 million years ago, coral reefs were being formed in this tropical sea, in what is now the Rochefort region. These reefs, broken down by the waves and mixed with carbonate muds, were slowly transformed into calcareous rock. On either side of these limestone deposits, clays and sands were gradually transformed into shale and sandstone. Around 320 million years ago, at the end of the Primary period, two tectonic plates collided and this collision gave birth to a massive mountain chain, the Variscan chain, which stretched from what is now eastern America to the middle of Europe: the Atlantic Ocean had not yet been formed. The Ardenne makes up the northern part of this chain.

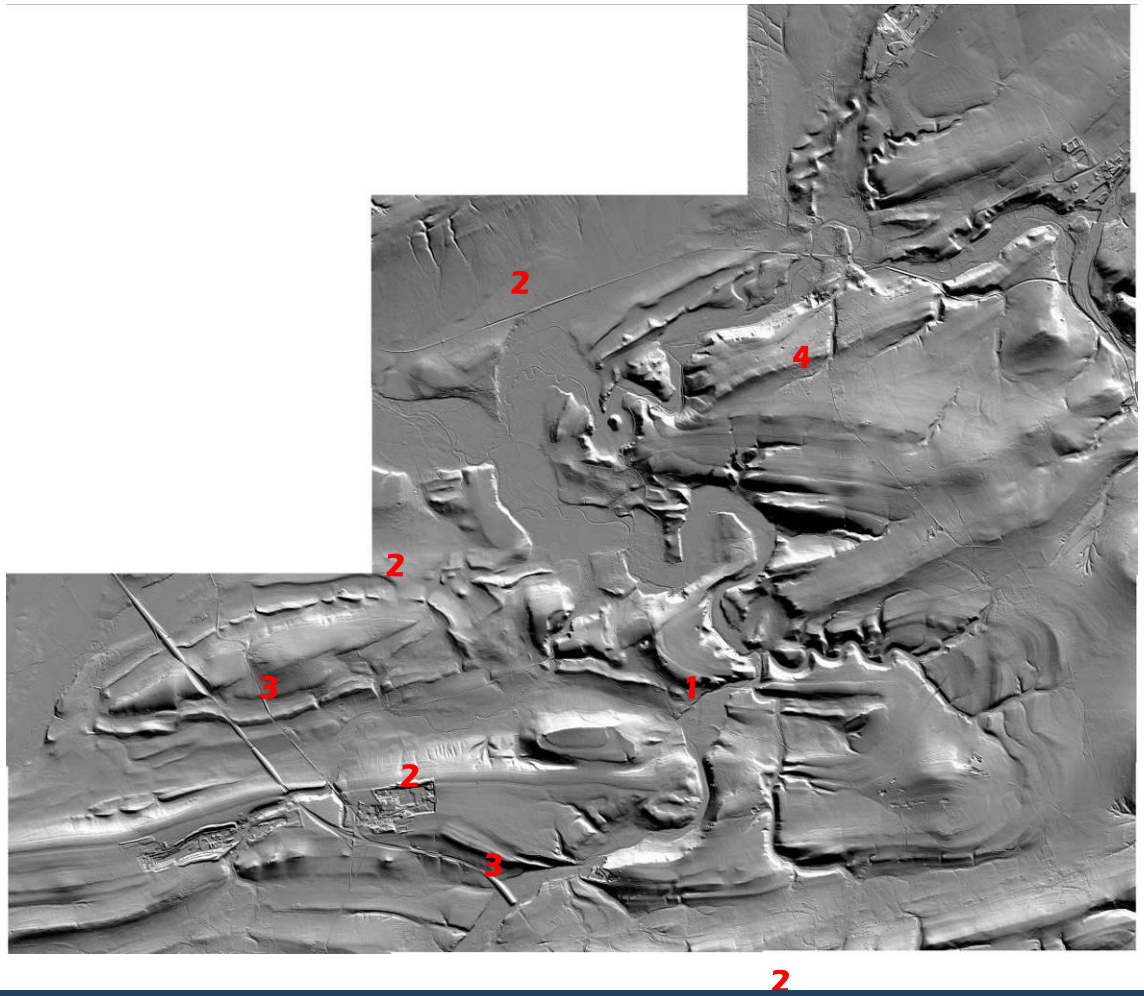

Figure 5. LiDAR map of the central region of the Geopark. 1. Boine massif beneath which lie the Caves of Han. 2. Shale depressions. 3. Limestone ridges. 4. Limestone ridge housing the karst system of the subterranean Lomme and Wamme rivers.

Later, during the Secondary period, this chain was eroded away to become a flat continental landmass. This rather monotonous evolution continued throughout the Tertiary period. The sea repeatedly flooded this new, flattened continent, depositing sand and clay. A hydrographic network became established on this surface, flowing north-north-west, perpendicular to the shoreline of the North Sea. As they carved out their beds, these rivers encountered the primary bedrock and established their course across it, taking little account of the resistance of the different types of rock: these are the **epigenetic rivers**. Multiple episodes followed before the current hydrographic network of Upper Belgium was formed, in particular the uplift of the entire Ardenne, a process that began in the Tertiary period, at the same time as that of the Alps; this uplift further accentuated the incision of the valleys.

Finally, the cold periods of the Quaternary left their imprint on the landscape. The Calestienne developed through the formation of limestone hills separated by shale depressions. Shale rocks, because of their fragile layered nature, are easily eroded by frost action, known as frost wedging. They are then transformed into clayey mud that runs downslope in the form of mudflows, a process known as solifluction. This explains how the great depressions are oriented east to west, depending on the shale outcrops, but generally transversally to the overall direction of the valleys.

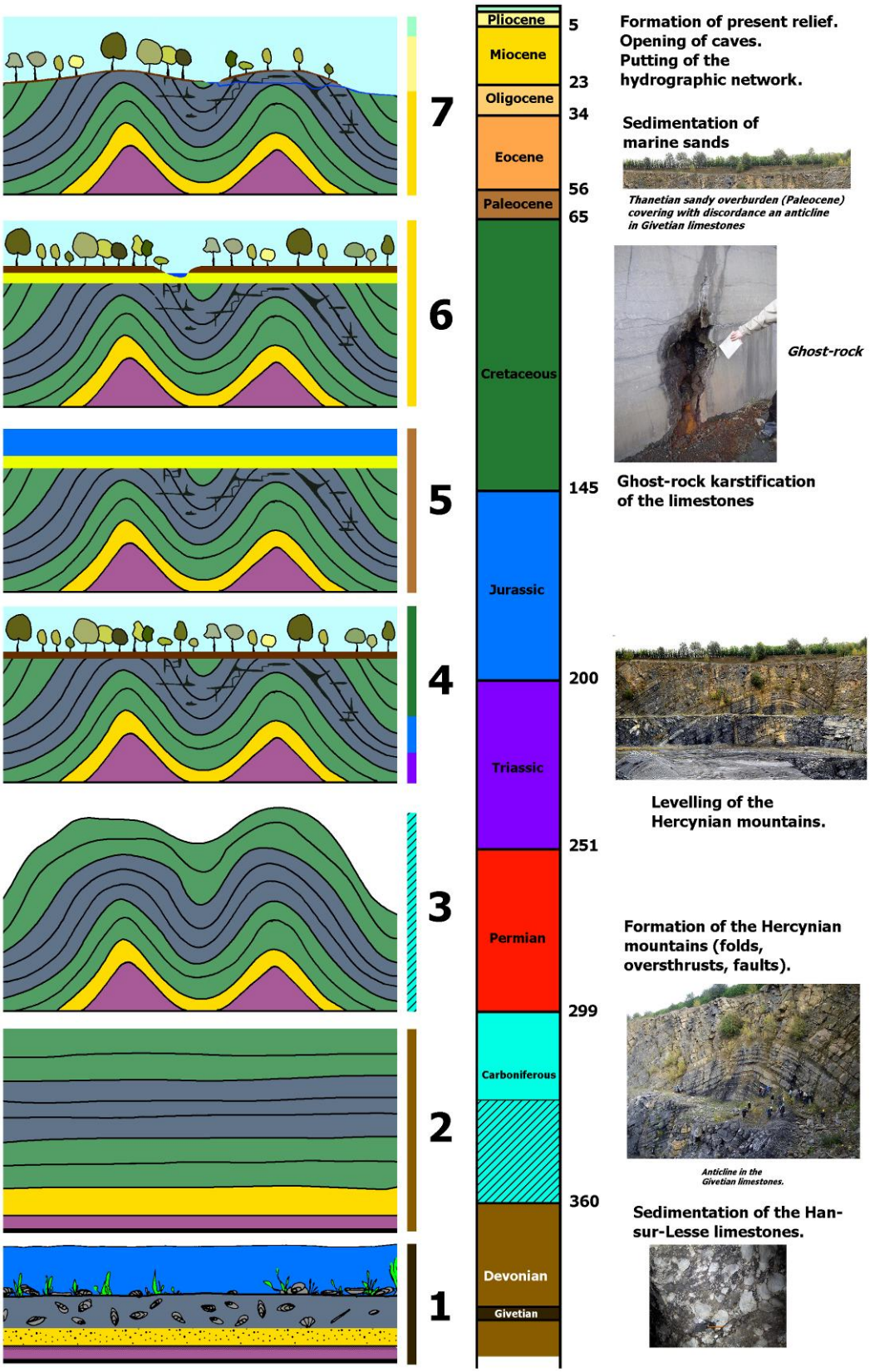

Figure 6. Theoretical geological cross-sections illustrating the evolution of the Ardenne. On the right, a representation of the geological epochs from the oldest at the bottom to the more recent at the top.

Regional geological evolution: the specific aspects of the Geopark

Figure 6 summarises the geological history of the region that has given rise to the specific features of the Geopark. The key episode is stage 4: erosion of the folded mountain chain exposes the various alternating rock formations. This explains the succession of shale and limestone across the Geopark, and the Ardenne massif to the south with its more resistant rocks. Over this vast, flattened territory, the hot, humid climates of the Secondary period encouraged the growth of tropical forest cover. This caused major weathering to the bedrock: chemical attack by waters rich in carbon dioxide led to the formation of a deep soil, for example, and the formation of weathered zones at depth, following the various fissures in the bedrock generated by tectonic stresses (definition given elsewhere): these are known as ghost-rocks. The remains of the weathered rocks are known as residual alterite, a looser, more fragile type of material that forms ghost-rocks (definition given elsewhere). At the beginning of the Tertiary, the sea flooded part of the Geopark, depositing sands (stage 5 of figure 6). It was through this soft covering that the first rivers established their course, flowing NNW. At the start of the second half of the Tertiary, the bedrock of Southern Belgium rose and the rivers cut deeper into the surface layers of sand or deep soil. As their course was thus fixed, they then went on to incise their way into the harder rocks of the bedrock, taking advantage of phantomised zones (definition given elsewhere).

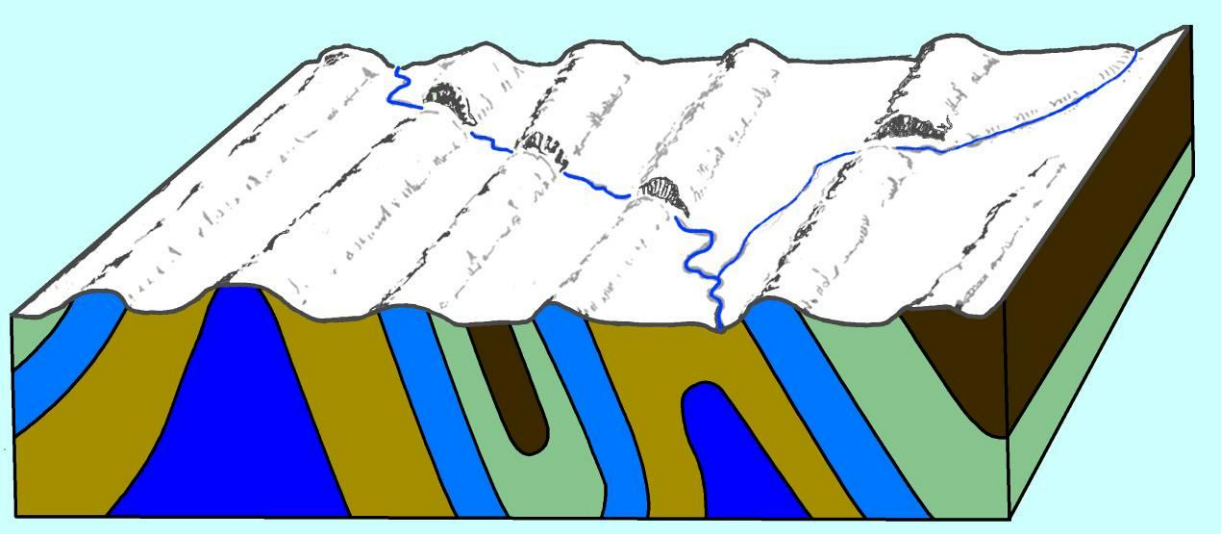

Figure 7. Appalachian-style relief. Here we see the rivers generating little canyons (incised valleys linking two depressions) in the limestone ridges shown in blue, rising above the shale formations (brown and green).

This marked a turning point in the process of evolution that would determine the relief we see today. The climate began to turn colder: frost action broke down the rocks, especially the more fissile such as shales, during the ice ages. The Scandinavian Ice Sheet did not reach quite this far but the landscape at this time was that of a tundra during the coldest phases. Over 10 times in just over a million years, glacial periods alternated with warming periods (interglacial period) ruled supreme. The shale formations, running largely east to west, evolved into depressions. The clay masses formed as a result of frost action flowed slowly towards the great rivers that ran, as we have noted, perpendicular to the depressions. Thus there emerged a landscape made up of limestone hills separated by shale depressions,

carved out by the major epigenetic rivers (definition given elsewhere) (figure 7).

The karst phenomena of the Geopark are the outcome of this configuration. As a result of the relief created by the uplift of the Ardenne massif and the incision of its rivers, the subterranean waters acquired the energy that would, at least partially, sweep away the ghost-rocks to create caves open to exploration by humankind, with their accompanying subterranean rivers (definition given elsewhere).

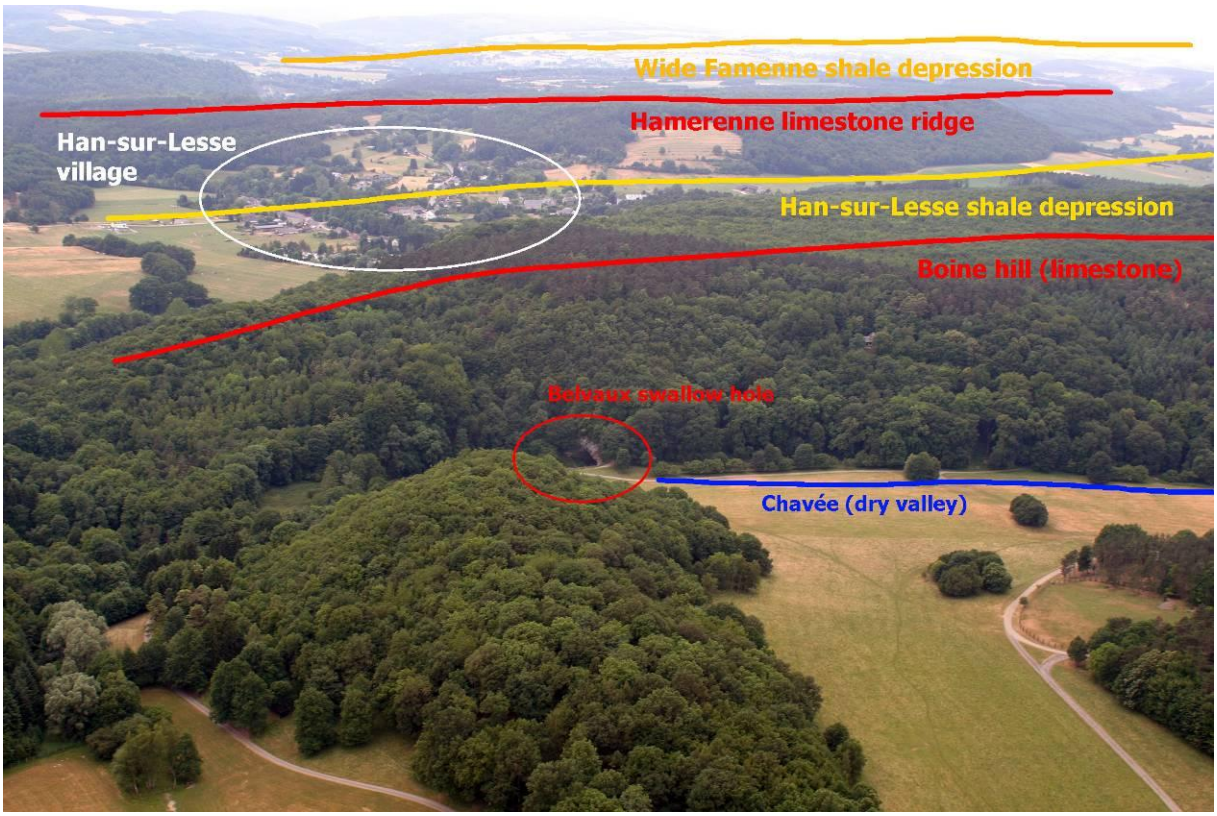

Figure 8. Illustration of the Appalachian-style relief. The photograph is taken from the south looking north, and takes in Boine hill (limestone), which houses the Han-sur-Lesse karst system. It also shows the Gouffre de Belvaux, the permanent swallow-hole of the river Lesse where it enters the karst system. In the middle ground can be seen first the Han-sur-Lesse shale depression, followed by the Hamerenne limestone ridge, under which lies the karst system of the subterranean Lomme and Wamme rivers running beneath the village of Rochefort. Further in the distance lies the wide Famenne shale depression and, on the horizon, the limestone and sandstone heights of the Condroz.

Figure 9. Illustration of the freezing action. The limestone cut by the way trench are progressively destroyed by the freezing. We obtain a blocks slope at the feet of the outcrop. This deposit is the witness of the freezing action speed.