



Geoheritage in the Minett UNESCO Biosphere (Southern Luxembourg): Inventory, Evaluation, and Conservation Aspects of Representative Geosites

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Abstract

The southwestern part of Luxembourg, known as Minett in the local language use, exposes an exceptionally high diversity of marine near-shore sediment rocks from the Early to Middle Jurassic, owing to its proximal position at the north-eastern margins of the Paris Basin. The iconic Minette ironstone formation is known as the worldwide largest oolitic ironstone deposit from the last 500 my and the abandoned open cast mines are nowadays protected sites with a high biodiversity, intrinsically linked to geodiversity. The schistes bitumineux unit, a lateral equivalent of the well-known Posidonienschiefer of the Holzmaden region (South Germany), is frequently studied for its exceptionally preserved fossils of marine vertebrates, cephalopods, and insect remains, deserving its status as a Fossil-Lagerstätte of international relevance. Of regional importance are the Rumelange limestones, with coral patch-reef paleo-environments. The geomorphological main feature of the region is the Cuesta of the Middle Jurassic ('Dogger-Schichtstufe'), with several outliers ('Zeugenberge') that represent widely visible landmarks in the landscape. In this paper, 16 geosites, representative of the geological, palaeontological, geomorphological, and hydrogeological heritage in the Minett UNESCO biosphere, are presented and evaluated according to scientific, educational, and geotouristic criteria.

Keywords Southern Luxembourg · Minette · Geoheritage · Geomorphology · UNESCO Man and the Biosphere programme

Introduction

In the Grand Duchy of Luxembourg, the concept of geoheritage and its conservation has not been in the focus of national nature conservation agencies until recently (Weis and Di Cencio 2018; Weis 2020). Inventories of geosites and evaluation of geoheritage are currently in an embryonic stage and first results were included in unpublished reports only. Two regions stand up to advocate for their geological heritage: the rural region of the Nature and Geoparc Mëllerdall in the east, where the unique landscape of the Luxembourg Sandstone attracts tourists since the late

nineteenth century ('Luxembourg's Little Switzerland'), and the Minett UNESCO Biosphere region in the south, where the mining of local iron ore between ca. 1850 and 1981 was at the base of the success of the steel industry in Luxembourg, leaving behind an impressive industrial heritage (Goedert 2020; Kohl 2020). In both areas, the cultural and natural heritage is intrinsically linked with the area's geodiversity. The rocks influence the close relationship between topography, groundwater, building stones, settlement activities, land use, and the highly diversified flora and fauna, often with an outstanding value for biodiversity and natural heritage conservation (Herr & Colling 2020). In the following, we identify 16 geosites in the Minett UNESCO biosphere region, which are considered representative but not exhaustive, for the region's geodiversity. The geosites are evaluated and classified following scientific, educational, and geotouristic criteria.

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Geological Background

The area of the Minett UNESCO Biosphere (MUB) is entirely located in the morphostructural unit of the Luxembourgish ‘Guttländ’, at the north-eastern margin of the Paris Basin (N.B.: ‘Minett’, in Luxembourgish language stands here for the geographic area of south-eastern Luxembourg; in contrast, ‘Minette’, in French, stands for the Minette iron ore rocks). The Palaeozoic basement (Devonian) that crops out in the northern part of the Grand Duchy, in the region of the Luxembourgish Ardennes named also ‘Eislek’, is covered here by at least 700 m of Mesozoic sediments. In the south of Luxembourg, in the Minett region, rocks of early and middle Jurassic age (190–168 my) crop out. The main geological units are as follows:

- **Grès Médioliasique** (acronym on geological maps: lm3); this unit represents a peculiar facies inserted in the middle Liassic marlstones, chiefly represented in the municipality of Bascharage (Waterlot et al. 1973). It is composed by calcareous sandstone, partially ferruginous, with a thickness of 35–52 m. The age of the unit is late Pliensbachian (ca. 185 my), and it locally contains numerous invertebrate fossils, including ammonites and echinoderms (Fig. 1).
- **Schistes Bitumineux** (acronym on geological maps: lo1-2); the unit is composed by marlstones and black shales with a considerably high content in organic matter (under the form of kerogen) that were locally studied for their energetic properties during the nineteenth century (Maquil 2010). The unit is dated to the early Toarcian (ca. 182 my) and encompasses a maximum thickness of 60 m. The sediments contain geochemical signatures witnessing major environmental changes in the epicontinental seas of the Tethys Ocean (e.g. the Toarcian Oceanic Anoxic Event) (Hermoso et al. 2014; Song et al. 2014). Numerous well-preserved fossils are present in the marls and the occasionally occurring carbonate nodules. The nodules in particular contain a diversified vertebrate fauna such as marine reptiles (Godefroit 1994; Vincent et al. 2019; Johnson et al. 2019) and bony fish (Delsate 1997a, 1999a,b,c; Taverne & Steurbaut 2017), but also numerous invertebrates, namely cephalopods and terrestrial insects (Henrotay et al. 1997; Nel et al. 2004; Nel & Weis 2017; Bechly 2018), which are particularly well preserved and qualify the deposit as a Konservat-Lagerstätte. There are no permanent outcrops of the Schistes bitumineux, but they are observable during frequent construction works in and around the municipalities of Bascharage, Sanem, Esch-sur-Alzette, Mondernange, Bettembourg, and Dudelange.

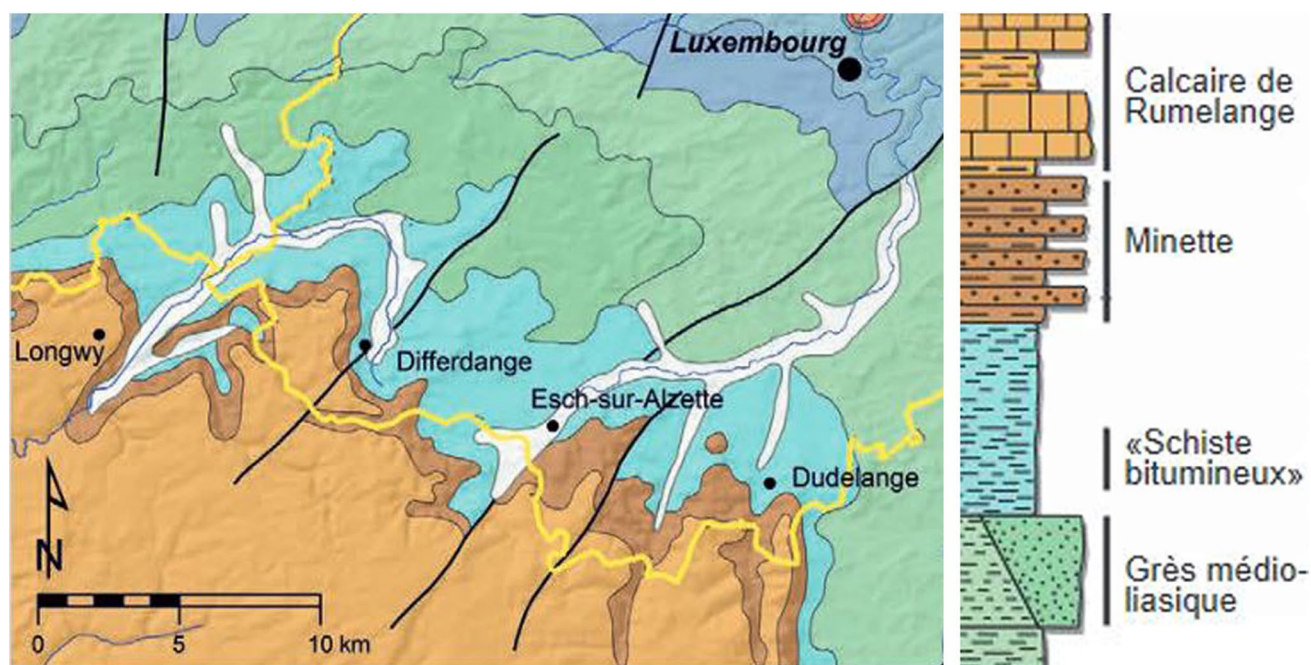


Fig. 1 Simplified geological map of south-western Luxembourg (country border marked with a yellow line). Copyright: Service géologique du Luxembourg, Administration des pont-et-chaussées (www.geologie.lu)

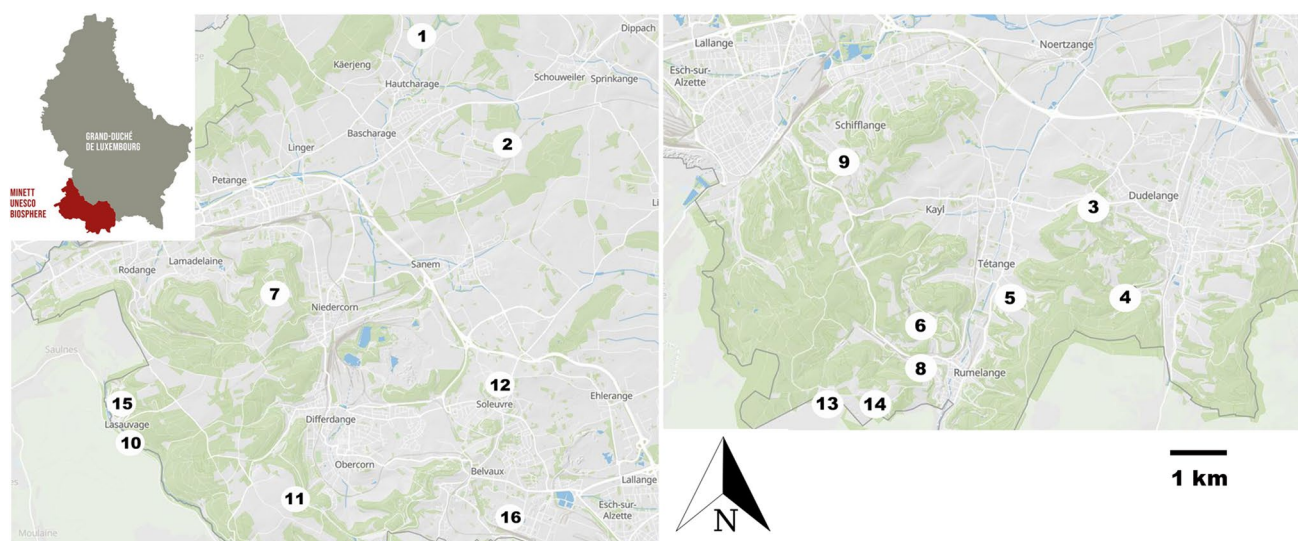


Fig. 2 (a) Position of the Minette UNESCO Biosphere (red colour) in the southern Luxembourg former mining basin; (b) detail of the Differdange-Esch sub-basin, with positions of the geosites as described

in the text; (c) detail of the Esch-Dudelange sub-basin, with positions of the geosites as described in the text. Map from Geoportail.lu, Administration du cadastre et de la topographie, Luxembourg

- **Minette** ironstone (acronym on geological maps: lo6, lo7, dou) (Fig. 2); this unit is dated to the Early to Middle Jurassic boundary (ca. 175–170 my) and shows a thickness between 35 and 68 m. It crops out in southern Luxembourg, but extends below the surface into the French Lorraine region and is one of the largest iron ore deposits worldwide. From a geochemical point of view, the rocks are characterised by iron and similar metals as V, Ni, Co, Mn, and P. The high phosphorus content is the reason why the iron ore was not exploited on a large scale until the end of the nineteenth century. The unit shows important lateral facies' variations, especially between the sub-basins of Differdange and Esch-sur-Alzette which are separated by two north-east to south-west striking faults. The Minette iron ore is concentrated as ferruginous oolites: the iron-rich layers are separated by sterile intermediate layers ('Buch' in the local miner's terminology) and coquina beds ('Bengelëck'). The sequence of intermediate layers, iron ore, and coquina beds follows a sedimentary cycle that represents an evolution from a low-energy towards a high-energy depositional environment. A total number of up to 12 of these cycles can be recognised in the Esch-sur-Alzette sub-basin, against 8 in the Differdange sub-basin (Teyssen 1984; Siehl & Thein 1989). At the top of the unit, several conglomerates occur, e.g. the so-called Conglomérat à Sonninia, a Konzentrat-Lagerstätte of early Bajocian age containing rich gastropod and ammonite faunas (Sadki et al. 2015; Gatto et al. 2015; Monari & Gatto 2013a, b; Monari et al. 2018).

The extraction of the Minette ore has been documented since the Gallo-Roman time period and played a major economic role since the middle of the nineteenth century until 1981, when the last mine was closed down on Luxembourgish territory. Large historical fossil collections are detained by the National Museum of Natural History, in Luxembourg (Weis 2020; Di Cencio & Weis 2020). Former open cast mining sites allow studying the Minette rocks in the municipalities of Pétange, Differdange, Sanem, Esch-sur-Alzette, Schiffflange, Rumelange, Kayl, and Dudelange.

- **Calcaires de Rumelange**; this unit (acronym on geological maps: dom) is widespread in the municipalities of Differdange and Rumelange. With an early Bajocian age (ca. 169 my) and an approximate thickness of 60–70 m, the unit is composed by alternating marlstone and limestone containing coral patch reefs (Hary 1970). These rocks are the youngest sedimentary deposits in the Grand Duchy. The limestone has been used since the Gallo-Roman period as construction stone, and the marls and reef limestone are nowadays still used in the production. Noteworthy, palaeontological features are the diversity of fossils from the reef environments (Fayard et al. 2005) and the first dinosaur remains from southern Luxembourg (Delsate et al. 2018). The limestone quarries offer a high educational potential, introducing students to fossils and various Jurassic marine palaeoenvironments.

Methods

In this study, only the non-moveable Geoheritage has been taken into account (geosites, geological or geomorphological sites; Crofts et al. 2020). The selection of the 16 geosites has been done according to the following criteria, through a combination of both literature review and collaborations with different actors working on the field, namely private collectors and volunteer collaborators of the Natural History Museum Luxembourg:

- Sites mentioned in an unpublished report on geosites in the Grand-duchy of Luxembourg. This concerns three sites in southern Luxembourg that are considered herein: the Hutbierg-Leffrâchen site, the Waisskaul site, and the Griechten site.
- Sites mentioned in regional geological guide and excursion books (Waterlot et al. 1973; Berners et al. 1984). This concerns 3–4 sites.
- Sites that were prospected and/or excavated by members and volunteers of the National Museum of Natural History Luxembourg, between 1984 and 2019. This concerns 4–5 sites.
- Sites that are classified as national monument (2 sites: Pierre de Cron, Zolverknapp) or that are part of a Museum site (Mine Walert).

The selected geosites have been chosen according to their representativeness. The list should therefore be considered as preliminary, and as a first step to a more complete inventory of geosites in southern Luxembourg and the Grand Duchy as a whole. The evaluation of the geosites following scientific, educational, and geotouristic

criteria was conducted using the standards established by Brilha (2016).

Inventory of Geoheritage Sites in the MUB region

The following 16 sites have been identified and assessed. The sites are listed hereafter according to their geological age. Four geological formations are concerned, of Early to Middle Jurassic age (Pliensbachian to Bajocian stages).

Grès médioliasique Unit (Pliensbachian)

Geosite 1: ‘Griechten’ River Section (Hautcharage).

The local denomination ‘Griechten’ designates a series of micro-canyons cut in the ‘Grès-médioliasique’ member, northwards the locality of Hautcharage (Fig. 3a). These are among the rare and most representative outcrops in the middle Lias of the area the siltstones yield frequent invertebrate fossils; a remarkable palaeontological feature is the findings of connected brittle stars, particularly rare in Luxembourg, and currently under description as a new taxon (Thuy, in progress). The ‘Griechten’ are protected as national nature reserve since 2017 and access is strictly limited.

Schistes bitumineux Unit (Lower Toarcian)

Geosite 2: ‘ZAE Edward Steichen ‘ Fossil Site (Bascharage).

The Bascharage area is widely known as a Konservat-Lagerstätte for its well-preserved fossil faunas from the lower Toarcian (Godefroit 1994; Henrotay et al. 1998; Delsate & Maubeuge 2000). The industrial activity

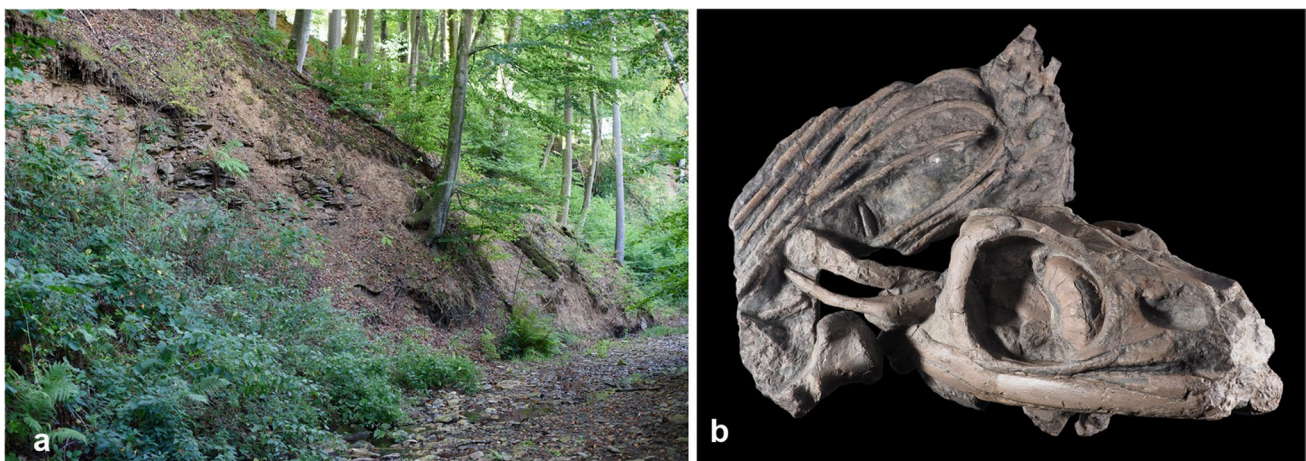


Fig. 3 Minett UNESCO Biosphere geosites, part 1: (a) geosite 1, ‘Griechten’ river section with outcropping ‘Grès médioliasique’ nearby Hautcharage; photo R. Weis in March 2020; (b) geosite 2, fos-

sil skull and thorax of a marine reptile (Ichthyosaur), *Stenopterygius* sp., ZAE Edward Steichen, Bascharage.; coll. Luxembourg Museum of Natural History n° TV603, photo Denis Hillebrandt/MNHNL

zone Edward Steichen (formerly Z. I. Bommelscheier and Z. I. Op Zaemer) yielded several temporarily accessible excavation sites especially during the early '90 of the last century. Joint venture excavations between the Luxembourg National Museum of Natural History and the 'Institut Royal des Sciences de Belgique' (Bruxelles) resulted in many fossils (Fig. 3b) that are now preserved in Brussels (vertebrates mainly) and Luxembourg (311 specimens in the collections of the Luxembourg National Museum of Natural History). Private collectors also gathered important fossil collections that nowadays are partially in public repositories, such as an important insect collection (former coll. M. Henrotay), preserved now at the Muséum d'histoire naturelle in Paris. The site is type locality of several insect species (Nel et al. 2004; Szwedo 2011; Bechly 2018). Currently (2020), outcrops are not accessible, though new construction works are planned until 2030.

Minette Ironstone Unit and Conglomérat à Sonninia Bed (Upper Toarcian to Lowermost Bajocian)

Geosite 3: 'Galgebierg-Scherr' Site (Dudelange).

The site presents a natural ravine (Fig. 4a) exposing the Grès à Dumortieria (Lucius 1945), a local marly-sandy facies of the Minette formation that is devoid of iron ooids (Waterlot et al. 1973). The site has yielded also ammonites and belemnites of upper Toarcian age, and is currently still accessible.

Geosite 4: 'Quartier italien' Fossil Site (Dudelange).

A former open cast mining site nearby the neighbourhood is called 'Italie' in the city of Dudelange (Fig. 4b). Here, the Minette iron ore, and specifically the top of the 'Couche grise' cycle, has yielded numerous ammonites of the genus *Pleydellia*, described as new species by Maubeuge (1947, 1950) and re-described by Di Cencio and Weis (2020). The site is for instance the type locality of *Pleydellia buckmani* Maubeuge, 1947, an index ammonite for the Buckmani horizon, Pseudolotharingicum Subzone, Aalenis Zone, in the uppermost Toarcian (Di Cencio & Weis 2020). Currently, the site is overgrown and fenced, as it is part of a former industrial site.

Geosite 5: 'Hesselsbiérg' Former Open Cast Iron Mine (Tétange).

The Hesselsbiérg former open cast mining site exposes an impressive cliff showing the particularly well-developed Couche jaune cycle of the Minette formation (Fig. 4c). It is part of a larger system of open cast pits that extended from Kayl in the north to Rumelange in the south, and nowadays part of the nature protection area 'Haard-Hesselsbiérg-Staebierg'.

Geosite 6: 'Hutbiérg' Former Open Cast Iron Mine (Rumelange).

The former Hutbiérg iron mine, on the slopes of the Holleschbiérg hill nearby Rumelange and now part of the nature reserve 'Leffrâchen', is an internationally known palaeontological and geomorphological site (Fig. 4d), exposing also very well the sedimentary sequence from the Minette Formation (uppermost Toarcian) towards the Bajocian marls and limestones (Achilles & Schulz 1980; Järling 1992; Guérin-Franiatte & Weis 2010). The collections of the Luxembourg National Museum of Natural History preserve circa 560 specimens from the Hutbiérg site, comprising the holotypes of a new belemnite species (Weis & Mariotti 2008) and a new brittlestar (Numberger-Thuy & Thuy 2015). Most fossils are stratigraphically important ammonites from the Aalenian Murchisonae and Concavum zones (Guérin-Franiatte & Weis 2010; Sadki et al. 2020).

Geosite 7: 'Giele Botter' Former Open Cast Iron Mine (Differdange).

The former open cast mines in the Giele Botter-Prénzebiérg area, are nowadays a protected nature reserve. The area is accessible for visitors, which can follow a 3-km long geological trail (Circuit géologique Giele Botter). The outcrop of the Toarcian-Aalenian Minette formation (Thein 1975) and the overlying rocks from the Marnes micacées and Couches à Sonninia members (Bajocian: Köwius 1977; Sadki et al. 2015) are still well exposed and can easily be studied in situ (Berners et al. 1984). The Couches à Sonninia also contain a conglomeratic bed (Fig. 4e), the 'Conglomérat à Sonninia' (Lucius 1945; Sadki et al. 2015), and a Konservat-Lagerstätte that yielded exceptionally well-preserved marine invertebrate fossils, namely gastropods (Gatto et al. 2015; Monari & Gatto 2013a, b; Monari et al. 2018), echinids (Thuy 2010a), ammonites, and belemnites (Maubeuge 1994b; Sadki et al. 2015).

Geosite 8: Underground Iron Mine Walert (Rumelange).

This underground iron mine is well preserved and can be visited as a part of the National Mining Museum (Musée national des mines de fer de Rumelange; Fig. 4f). The different iron ore cycles that were exploited here until 1964 can be studied in situ.

Geosite 9: 'Lalléngierbiérg' former Open Cast Mine (Esch-sur-Alzette).

The Lalléngierbiérg open cast mining area is protected nowadays as a national nature reserve. The sedimentological sequence of the Minette ironstones is still well visible nowadays (Fig. 4g) (Waterlot et al. 1973; Achilles & Schulz 1980), and it is a reference outcrop for the Minette sequence in the Esch-sur-Alzette sub-basin (Berners et al. 1984).

Geosite 10: Vallée de la Crosnière Old Quarry Site (Lasauvage).

A small open cast mine cut onto the wooded slopes eastwards of the former miner's village of Lasauvage is part of

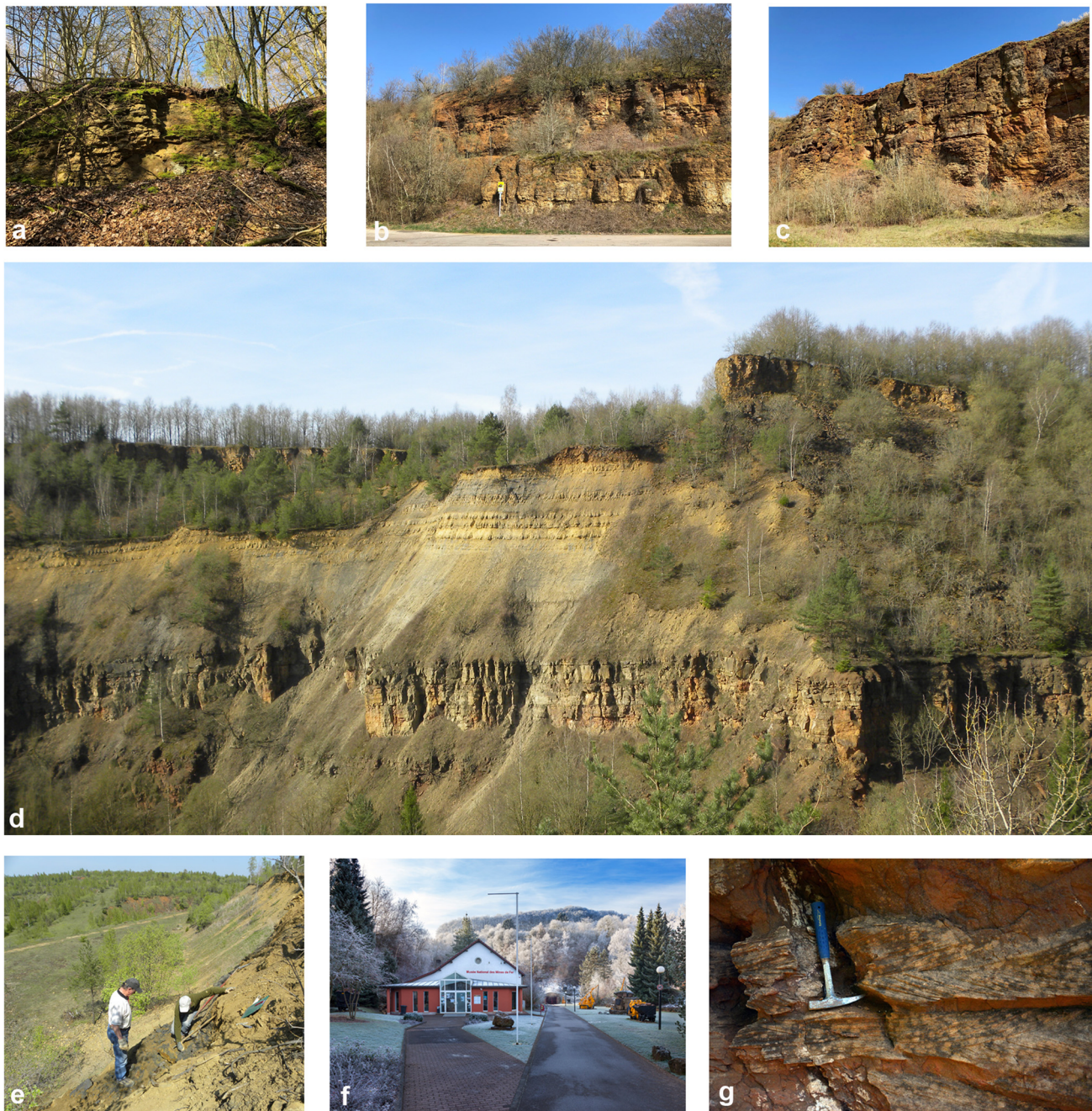


Fig. 4 Minett UNESCO Biosphere geosites, part 2: **(a)** geosite 3, ravine Galgenberg-Scheer nearby Dudelange, exposing the ‘Grès à Dumortieria’; photo by R. Weis/MNHNL, March 2020; **(b)** geosite 4, Couche grise and Couche jaune cycles of the Minette ironstone formation at locality ‘Italie’ nearby Dudelange; photo by R. Weis/MNHNL, March 2020; **(c)** geosite 5, ironstone cliff at the Hesselsbiert hilltop, nearby Tétange; photo by R. Weis/MNHNL, March 2020; **(d)** geosite 6, overview of a rock sequence comprising the upper part of the Minette formation and the overlying marls and limestones of the Bajocian, former open cast mine Hutbiert nearby

Rumelange; photo by R. Weis/MNHNL, April 2017; **(e)** geosite 7, palaeontological excavation in the ‘Conglomérat à Sonnina’ Konzentrat-Lagerstätte (early Bajocian) at Giele Botter, nearby Differdange in 2013; photo by R. Weis/MNHNL; **(f)** geosite 8, entrance of the National Mining Museum and the underground mine ‘Walert’, in Rumelange; photo by Musée national des Mines de fer Rumelange; **(g)**, Geosite 9, Cross-stratifications in situ, a detail of the sandwave complex building up the Minette sedimentological cycles at former open cast mine ‘Lalléngerbiert’ nearby Esch-sur-Alzette; photo by R. Weis/MNHNL, 2017



Fig. 5 Minett UNESCO Biosphere geosites, part 3: (a) geosite 10, explanatory panel about local geology at the nature trail in the ‘Crosnières’ valley nearby Lasauvage; photo by R. Weis/MNHNL, March 2020; (b) geosite 11, excavations by collaborators of the Luxembourg National Museum of Natural History at the ‘Rollesbierg-Kiemerchen’ fossil site, nearby Differdange, in 1984; photo by A. Faber/MNHNL; (c) geosite 12, the Zolverknapp, Loetschet, Pakebiert and Galgebierg hilltops seen from Obercorn; photo by K. Totaro, February 2021; (d) geosite 13, view of the active quarry ‘op der hënneschter

Heed’ nearby Rumelange, showing the ‘Calcaire de Rumelange’ unit; photo by R. Felten/MNHNL; (e) geosite 14, view of the abandoned and partially overgrown quarry site ‘Waisskaul’ nearby Rumelange, showing the Bajocian coral reef facies; photo by R. Weis/MNHNL, March 2020; (f) geosite 15, travertine rock ‘Pierre de Cron’, nowadays a place of whorship; photo by R. Weis/MNHNL, March 2020; (g) geosite 16, former site of the Bel-Val well near the locality of Belvaux, currently an abandoned industrial wasteland; photo by R. Weis/MNHNL, March 2020

the pedagogical nature trail through the valley of the Crosnière creek (Fig. 5a). The outcrop shows the upper part of the Minette formation and the passage towards the overlying Bajocian marls and limestones in the Differdange basin; unfortunately, it is nowadays partially overgrown by vegetation and geological observations are difficult under the given circumstances.

Geosite 11: ‘Rollesbiere-Kiemerchen’ Fossil Site (Obercorn).

This site, now overgrown by vegetation, is situated in the nature reserve Kiemerchen, at the slope of the Rollesbiere hill. In the 1980, it yielded a well-preserved invertebrate fossil fauna from the ‘Conglomérat à Sonninia’ (Fig. 5b) (Lucius 1945; Sadki et al. 2015), a Konzentrat-Lagerstätte of early Bajocian age, that crops also out in the neighbouring ‘Giele Botter’ geosite. Fossils include remarkably diverse gastropods (Gatto et al. 2015; Monari & Gatto 2013a, b; Monari et al. 2018), echinids (Thuy 2010a), ammonites, and belemnites (Maubeuge 1994b; Sadki et al. 2015). The collections of the Luxembourg National Museum of Natural History preserve a total number of 421 specimens from the Rollesbiere site, giving a rather complete overview about the early Bajocian marine palaeofauna.

Geosite 12: ‘Zolverknapp-Loetschet-Pakebiere’ Geomorphological Site (Sanem).

The mounds (French: ‘Butte témoin’) of Zolverknapp, Loetschet, and Pakebiere, nearby the locality of Soleuvre, form a widely visible landmark (Storoni 2010). The hill tops, culminating at 422, 396, and 380 m, respectively, are composed of erosion-resistant rocks of the lower part of the Minette formation (Fig. 5c). The Zolverknapp hill, classified and protected as a national monument, features several viewpoints, which allow outlooks towards the plain of the middle Liassic. This triple mound range also forms the watershed between the Meuse river system westwards and the Rhine river system eastwards (Storoni 2010).

Calcaire de Rumelange Unit (Lower Bajocian)

Geosite 13: ‘Op der hënneschter Heed’, Active Limestone Quarry (Rumelange-Ottange).

This impressive cross-border quarry site (Fayard et al. 2005; Weis 2006), active since the ’70 of the last century, is included herein although the major part is situated on French territory. It represents a major geological site in the whole NE Paris Basin, attracting geologist and fossil hunters alike from all over Europe (Fayard et al. 2005). Four lithostratigraphic members are outcropping at the different levels of the quarry (Fig. 5d), notably the ‘Calcaire d’Audun-le-Tiche’ with coral patch reefs (Lucius 1945; Hary 1970; Geister 1984, 1986; Lathuilière 2000a,b) and the ‘Marnes sableuses d’Audun-le-Tiche’

with namely large cephalopods (Weis 2006), fish teeth (Delsate & Felten 2015; Popov et al. 2019), echinids (Thuy 2003, 2010b), and marine reptile remains (Fischer et al. 2021), as well as a single dinosaur osteoderm (Delsate et al. 2018). The site has high educational potential and access is possible to professionals, under certain conditions and with a special permit.

Geosite 14: ‘Waisskaul’, Abandoned Limestone Quarry (Rumelange).

This abandoned quarry site shows the impressive coral reef facies (Fig. 5e) of the Calcaire de Rumelange (Lucius 1945; Hary 1970; Waterlot et al. 1973; Berners et al. 1984). The quarry is situated in a Natura2000 protected zone, and has recently been cleaned from vegetation (2013); geological observations are currently possible, although access is subject to a special permit. The numerous fossils from the Waisskaul have been occasionally described (corals and ammonites: Hary 1970; echinids: Thuy 2003).

Post-Mesozoic Sites

Geosite 15: ‘Pierre de Cron’, Travertine Rock (Lasauvage).

The travertine rock mass, called ‘Pierre de Cron’ (FR) or ‘Dauschsteen’ (L), is a well-known feature in the former miner’s village of Lasauvage, and part of local folkloristic tales (Fig. 5f). It is protected by law as a national monument since 2015. It is the only travertine rock of these dimensions in the south of Luxembourg.

Geosite 16: ‘Source Bel-Val’, Artesian Well (Belvaux).

In the area of the village of Belvaux, the Schistes Bitumineux unit is cut by a minor fault line (Maquil 2010); along this fault-line, an artesian well has been discovered in the late nineteenth century (d’Huart 1892). The mineral water of the well was extracted commercially and shipped worldwide until 1935 (Gengler 1980). Later, the site of the well was covered by industrial installations (Belval steel works), and currently, it is hidden under industrial wasteland (Fig. 5g). More recently, a project has been presented by the local municipality with the aim of making the site of the ‘Source Bel-Val’ accessible again as a recreational area in 2022 (Coubray 2020).

Evaluation of the Studied Geosites: Results

The 16 reported geosites have been analysed according to scientific, educational, and touristic criteria, following the methodology developed by Brilha (2016): the results are exposed in Tab. 1. Considering the average values, most remarkable geosites include the Giele Botter site (geosite 12), the quarry ‘op der hënneschter Heed’ (geosite 18), and the Hutbiere site (geosite 11). These three sites are also the ones featuring the highest scientific value.

Table 1 Assessment of geosites in the Minett UNESCO Biosphere, after Brilha (2016)

Geosite	Scientific V	Educational V	Touristic V	Average V
Giele Botter (7)	320	220	250	263
Heed quarry (13)	350	230	185	255
Hutbiert (6)	330	220	205	252
Hesselsbiert (5)	170	255	250	225
Mine Walert (8)	115	255	285	218
Waisskaul (14)	245	195	205	215
Crosnière (10)	95	255	275	208
Petite Italie (4)	190	215	215	207
Source Belval (16)	215	200	185	200
Lalléngerbierg (9)	150	215	210	192
Gaalgebierg (3)	95	220	240	185
Zolverknapp (12)	90	225	215	177
Pierre de Cron (15)	205	150	155	170
Kiernerchen (11)	120	190	195	168
Griechten (1)	190	150	155	165
Edward Steichen (2)	145	135	125	135

Meanwhile, the sites with most educational potential are the Walert Mine (geosite 13), which is already part of a Museum site, and thus easily accessible to the public, and the Hesselsbiert (geosite 10), one of the most impressive red-coloured cliffs in the whole area. The sites with the highest touristic potential are, once again, the Walert mine museum site (geosite 13), and the Crosnières site nearby Lasauvage (geosite 15), which is part of a nature trail in an area with high touristic potential, a potential that will be further developed in the coming years. The lowest values for educational and touristic values are attributed to those sites which are currently inaccessible, either for current

lack of outcrop (geosite 2) or for strict nature preservation policies (geosite 1).

Discussion

The present study is intended as a first step towards an inventory and assessment of geosites in southern Luxembourg's Minett UNESCO Biosphere region. As a further step after site inventory and selection, propose two stages: (1) the analysis of conservation needs and (2) conservation planning and delivery. Applied to Luxembourg, this would

Table 2 Protection status and degradation risk (based on Brilha 2016) of geosites in the Minett UNESCO Biosphere

Geosite	Protection status	Degradation risk
Giele Botter (7)	Nature Reserve 'Prénzebiert' (since 1991)	Low
Heed quarry (13)	Active quarry	High
Hutbiert (6)	Nature Reserve 'Léiffrächen' (since 2019)	Low
Hesselsbiert (5)	Nature Reserve 'Haard-Hesselsbiert-Staebiert' (since 1994)	Low
Mine Walert (8)	Museum site	Low
Waisskaul (14)	Natura2000 zone	Moderate
Crosnière (10)	Natura2000 zone	Moderate
Petite Italie (4)	Nature Reserve 'Haard-Hesselsbiert-Staebiert' (since 1994)	High
Source Belval (16)	n/a	High
Lalléngerbierg (9)	Nature Reserve 'Brucherbiert-Lalléngerbierg' (since 2016)	Low
Gaalgebierg (3)	Nature Reserve 'Haard-Hesselsbiert-Staebiert' (since 1994)	Low
Zolverknapp (12)	Classified as National Monument	Low
Pierre de Cron (15)	Classified as National Monument	Moderate
Kiernerchen (11)	Nature Reserve 'Kiernerchen/Scheiergronn/Groussebës' (since 2020)	Low
Griechten (1)	Nature Reserve 'Griechten' (since 2017)	Low
Edward Steichen (2)	n/a	High

imply the establishment of site documentation reports for example in the framework of a hypothetical national Geoheritage inventory. Currently, no geoconservation management measures are applied in the Minett UNESCO Biosphere. However, a legal protection of geological sites is in several cases implicitly provided as they often coincide with biodiversity hotspots (national nature reserves or European Natura2000 network) (Tab. 2). In rare cases, geological sites were classified as a national monument. However, explicit recognition of the geological heritage of these sites is not yet given. Reinforcing the work capacity of nature conservation agencies and inclusion of geoconservation strategies in the management of the areas greatly contribute to valorize geoheritage as the ‘natural link’ between natural and cultural heritage.

Conclusion

The geoheritage in the Minett UNESCO Biosphere is intrinsically linked to former mining activities: it comprises geosites and geomorphosites as well as geological collections of international significance. Recognition of the importance of geoheritage and its potential for scientific, educational activities, and the development of ‘slow tourism’ seems especially rewarding in case of the former mining sites, nowadays classified as national nature reserves. An inventory of geosites, with a focus on sites representative of the area’s geodiversity, is a first step, attempted in this publication. On a long-term perspective, reinforcing the work capacity of nature conservation agencies and inclusion of geoconservation strategies in the management of protected areas would greatly contribute to valorise the role of geoheritage as the ‘natural link’ between natural heritage and cultural/industrial heritage; geoheritage appears therefore as a suitable field of research to fulfil the scientific goals and missions of the UNESCO Man and the Biosphere programme.

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Declarations

Conflict of Interest The author declares no competing interests.

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