Morphogenic Setting and Diversity of Processes and Landforms: The Geomorphological Regions of Belgium

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Abstract

Following a few words about the historical context of geomorphological research in Belgium and Luxembourg, the main geomorphic regions of the two countries are presented. The dominant controls exerted on morphogenic processes by lithology and elevation (i.e., tectonic background) lead to distinguish northern Belgium, corresponding to the low-elevation Cenozoic Belgian basin where sedimentation generally prevails over erosion, and the Ardennian Paleozoic massif of southern Belgium and northern Luxembourg, uplifted and strongly incised and eroded in the Plio-Quaternary. In between are the transitional plateaus of Middle Belgium. South of the Ardenne, Belgian Lorraine and Luxembourgian Gutland pertain to the homoclinal landscapes of the Paris basin. Finally, a brief overview is presented of the processes and landforms treated in the successive chapters.

Keywords

Geomorphological regions of Belgium and Luxembourg • Morphogenic processes • Geomorphology in Belgium

1.1 Introduction

At the moment of writing an introduction for this book about landscapes and landforms of Belgium and Luxembourg, I gathered ideas that I attempted to formulate as originally as possible, in order to attractively introduce the two countries. However, as I was hesitating about the best way to begin with my subject, I decided to have first a look at introductory texts in the already published books of the series. This led me to discover that, beyond large countries richly provided with magnificent landscapes, most of the smaller territories systematically claimed the same wide diversity of landscapes that I had imagined to make a hallmark of Belgium and Luxembourg's geomorphology. And it is true indeed that, whatever their size, countries more anonymous geomorphologically also contain a variety of landscapes and landforms inherited from the equitably distributed fourth dimension, namely time, which allowed contrasted climatic contexts and tectonic events to succeed each other and leave specific imprints along their long geomorphic history. Perhaps is the value of these landscapes not linked to their grandeur but other qualities such as rarity or excellent preservation of landforms, representativeness of important, though not spectacular, processes, or a very well-documented context of evolution may make them equally or even more interesting. The latter fact, i.e., a wealth of data of all kinds (geomorphology, geology, climate, vegetation, human interference) and extended studies, characterizes particularly Belgium where first valuable geological observations were made by naturalists as early as the second half of the eighteenth century (de Limbourg 1770, 1774) and first synthetic views on the physical geography of the country were published by Houzeau already in 1854.

Besides unveiling the most scenic landscapes of Belgium and Luxembourg, the main aim of the community of Belgian geomorphologists, grouped into the Belgian Association of Geomorphologists (BAG) and seconded by many colleague geologists, in writing this volume has been to produce a

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reference book about geomorphic processes and the resulting landscapes and landforms in the two countries. Indeed, beyond texts that were devoted, mainly or partly, to physical geography, with geomorphological analysis limited at best to a few considerations about fluvial processes (Omalius d'Halloy 1828; Houzeau 1854; Fourmarier 1934), the single existing book dealing explicitly with the geomorphology of Belgium (Pissart 1976) is long outdated, this all the more as the last four decades saw the numbers of geomorphic studies, data sets, new results and ideas increase exponentially and cover all facets of the geomorphological research. This book has been built thus as the most exhaustive possible work presenting the latest geomorphological understanding of the countries' landscapes, not only to help all geoscientists and interested people travelling in Belgium and Luxembourg apprehend the visited landscapes but also to become a benchmark that hopefully will long be used in future research.

1.2 Geomorphic Regions in Belgium and Luxembourg

With respective areas of 30 528 and 2586 km^2, Belgium and Luxembourg together represent a tiny region, i.e., ~0.02% of the earth's land surface or ~0.3% of the surface of Europe. They encompass an accordingly limited range of elevations, from 0 m asl along the Belgian part of the southern North Sea's coastline to 694 m at Botrange and 693 m at Weisser Stein, the two highest summits of NE Ardenne, in eastern Belgium (Fig. 1.1). Beyond the small Ijzer catchment of western Belgium and coastal lowlands drained by artificial ditches directly into the North Sea, most of the country is distributed more or less equally between the Scheldt catchment in the north and the Meuse catchment in the south. The only exception is the Sauer catchment which, as a sub-tributary of the Rhine, covers the SE-sloping margin of SE Ardenne and most of the territory of Luxembourg.

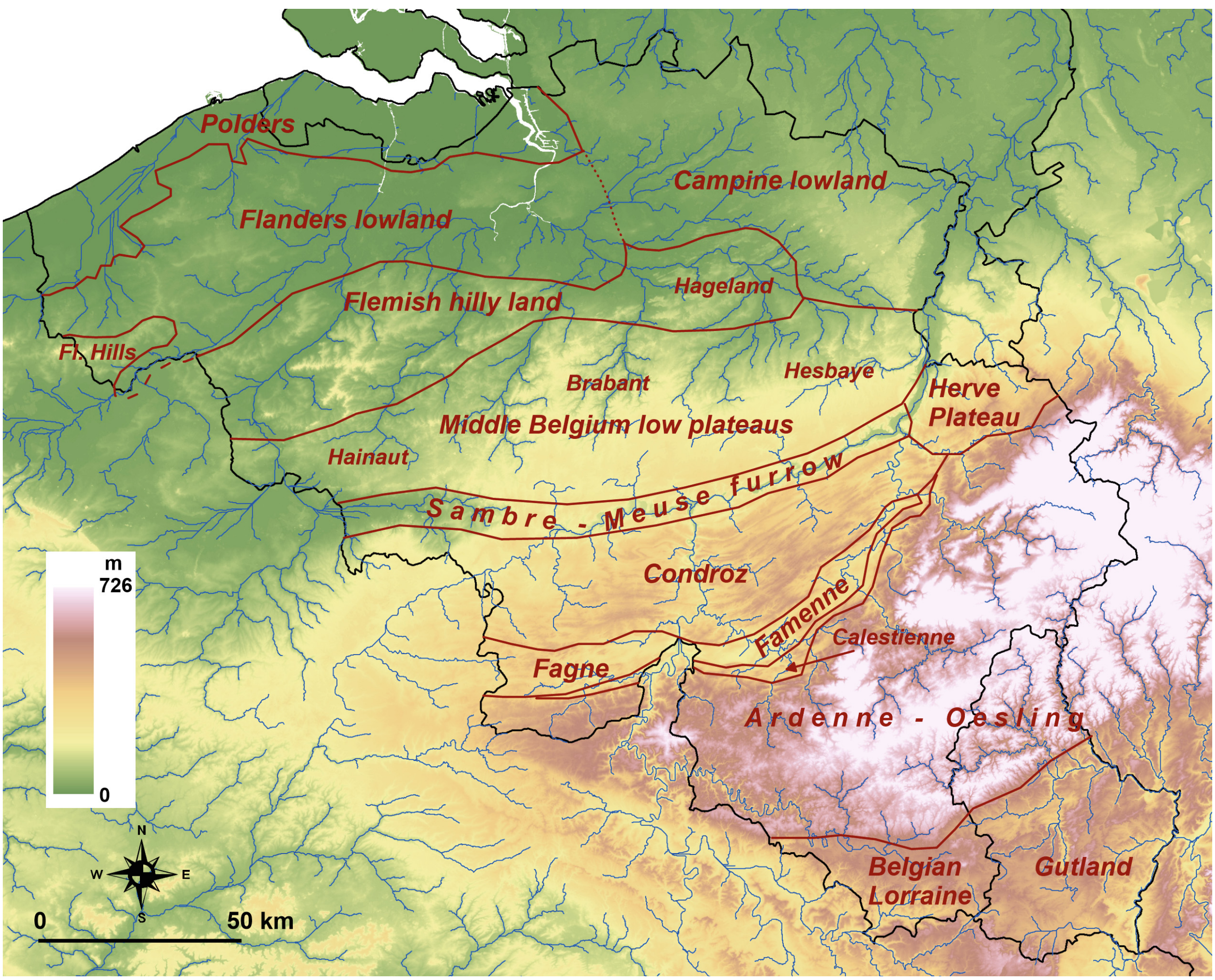

Fig. 1.1 The main geomorphic regions of Belgium and Luxembourg, delineated over the background SRTM 1″ DEM

Although some morphological maps of Belgium distinguished up to 73 geomorphic units (De Moor and Pissart 1992), a reasonable first-order division into ten main regions or so, whose differences in landscape are determined chiefly by elevation and geological constraints, provides a more meaningful basis for highlighting the contrasted geomorphic settings that compose the Belgian and Luxembourgian territories. A succession of essentially E-W trending regions may be followed roughly from NNW to SSE (Fig. 1.1). Starting from the shoreline in the NW, the first region (Polders) corresponds to the flat tract of reclaimed coastal plain and Scheldt tidal flats lying mostly below 7 m asl (or TAW, for Tweede Algemene Waterpassing, i.e., second general levelling). It goes south- and eastward into the lowlands of Low Belgium, whose elevation mostly remains between 10 and 50 m asl. The geology of these lowlands is mainly Cenozoic clays and sands buried under extended coversands of Late Pleistocene age. One distinguishes the lowlands of Flanders in the west, corresponding to the area of the Flemish valley, Middle to Late Pleistocene equivalent of the present middle and lower Scheldt basin, and the Campine (or Kempen in Dutch) in the east, an area rising slightly eastward to an up to ~85-m-high tilted low plateau underlain by Middle Pleistocene Meuse gravels. Between these proper lowlands and the low plateaus of Middle Belgium is a transition zone with elevations between 50 and 100 m asl. Beyond local names, this transitional area is best described as the Flemish hilly land, where, from the eponymous Flemish hills in the west to the Hageland in the east, the landscape is characterized by generally elongate, ferricrete-capped hills dominating by a few tens of metres a network of wide valley floors. Moreover, this is the zone where the coversands of the north progressively give way to finer aeolian deposits heralding the typical loess of Middle Belgium.

The next geomorphic unit corresponds to the low plateaus of Middle Belgium (Fig. 1.1). Coincident with the up to 25-m-thick loess belt that crosses Belgium from west to east, straddling also the major water divide between the Scheldt and Meuse basins, these plateaus display a gently undulating, weakly incised topography rising progressively from ~100 m asl in the north to 220 m asl in the south. Laterally, the western Hainaut plateau hardly exceeds 100 m in elevation, lying thus significantly lower than the central Brabant and eastern Hesbaye (Haspengouw in Dutch) plateaus. The varying deposits of the Meso-Cenozoic Belgian basin directly underlying the loess cover determine to some extent the character of each plateau landscape. In the east for example, while the Tertiary sands and clays that extend beneath the loess cover of northern Hesbaye allowed many broad valleys to develop within a generally humid landscape of rich pastures and orchards, the Cretaceous chalks on which the loess rests in the southern part of the plateau imposed a distinct stamp of dryness to a monotonous landscape whose uniformity is barely interrupted by a network of dry valleys largely concealed by thick loess. In the south, the low plateaus of Middle Belgium are abruptly interrupted by the Sambre-Meuse axis, a ~130-km-long, 80- to 150-m-deep, ENE-trending straight furrow carved by the Meuse and Sambre rivers along a shear zone probably active during the Miocene (Demoulin 1993). Along most of its length, this axis follows the Upper Carboniferous Namur syncline, extending parallel to the Variscan front and continued westward by the Haine basin toward Denain, in France. Intense mining in the coal basins of the Namur syncline during the nineteenth and twentieth centuries contributed anthropogenic landforms such as huge slag heaps to the Sambre-Meuse axis landscape. Based on geomorphic considerations, Colbeaux et al. (1977) defined the North-Artois shear zone extending from Liège to the Dover Strait and corresponding also more or less to the Variscan front line. The present low-level activity of this zone seems supported by instrumental seismicity data (e.g., Camelbeeck et al. 2007).

The Sambre-Meuse axis represents a major discontinuity in the geomorphology of Belgium, separating the fairly uniform topography of Low and Middle Belgium in the north from the deeply incised higher landscapes of High Belgium in the south. The bulk of High Belgium corresponds to the folded Paleozoic Ardenne massif, i.e., the western continuation of the Rhenish shield (see Chap. 2). Its subdivision in geomorphic regions is mainly a product of the long-term geomorphological evolution of the massif, which created distinct erosional levels (see Chap. 5), and the varying lithology of the basement. Climbing the southern hillslopes of the Meuse and Sambre valleys, one reaches the first massive ridge of the Condroz. The Condroz region extends as an erosional landscape whose envelope surface rises from ~240 m asl close to the Sambre-Meuse axis to ~350 m in its southern part. Following the ENE-trending Variscan grain, its structurally controlled topography displays alternating ridges cut in sandstones that outcrop along anticline axes and wide valleys carved in limestones of the intervening synclines, forming a typical Appalachian-type landscape with levelled ridge tops attesting an ancient, now incised erosion surface. As all geomorphic regions of High Belgium, the general elevation of the Condroz progressively decreases westward, where it mostly stays below 300 m asl west of the Upper Meuse valley (Fig. 1.1). East of Liège, the Herve Plateau, or *Pays de Herve*, is a hybrid area juxtaposing characteristics of the Hesbaye and the Condroz. Indeed, a frame made of the same Condrusian ridge-and-valley topography cut in the Paleozoic basement supports there a broad arcuate backbone ridge composed of extended remnants of the Cretaceous cover that also underlies southern Hesbaye, west of Liège.

South of the Condroz, a narrow, up to 10 km-wide tract of lower lying land has been carved as periglacial pediments in Upper Frasnian and Lower Famennian shales highly prone to frost-shattering (Fig. 1.1). At 200–220 m elevation, this E-W depression, called Famenne or Fagne east and west of the Meuse, respectively, lies 100–150 m below the Condrusian topography. Fairly uniform in the east, its surface is more irregular west of the Meuse, where Frasnian bioherms form scattered hills. To the south, the Fagne-Famenne rapidly gives way to a 200- to 300-m-high slope leading to the high Ardenne. However, this slope is interrupted by a narrow bench cut into Middle Devonian limestones at 260–300 m asl, the Calestienne, which hosts many caves developed through the action of acidic waters coming down from the Ardenne (see Chap. 8). South of the Calestienne, the main part of the slope, locally reaching ~200 m in height but rapidly diminishing west of the Meuse, corresponds to an erosional scarp between stepped Paleogene erosion surfaces.

In the heart of High Belgium but also in northern Luxembourg where it bears the name of Oesling, the higher topography of the Ardenne *s.s.*, corresponding to the Lower Devonian core of the massif and its Cambrian inliers, may again be approximated as an erosional plateau landscape, this time at elevations that decrease from 600 to 700 m asl in the east to 450–500 m in the south and 350–400 m west of the Meuse (Fig. 1.1). This plateau physiognomy inherited from etchplanation processes that continued the Mesozoic levelling of the massif in Paleogene times has been partly obliterated, mainly along the massif's margins, by the recent downcutting of deep valleys in response to regional Plio-Quaternary uplift. The geomorphic region of the Ardenne thus consists of central plateau landscapes moderately incised and covered by meagre pastures, and steeper marginal areas interrupted by deep valleys of every size and mainly supporting forests. Finally, south of the Ardenne-Oesling, Belgian Lorraine and Luxembourgian Gutland together make a last homogeneous geomorphic region sharply contrasting with it. Belonging to the Paris basin and its NE extension into the Luxembourg syncline, this region is separated from Ardenne-Oesling by another marked erosional scarp and displays a classical cuesta landscape cut into alternating harder and weaker rocks of the Lower and Middle Mesozoic cover outcropping in this part of the basin.

1.3 Geomorphological Themes

This book attempts at providing the most exhaustive possible overview of the geomorphology of Belgium and Luxembourg. As there is no particular logic between the various geomorphic settings presented in the chapters, we conceived it as a tour of the two countries, starting in Luxembourg, then travelling northward and anticlockwise across Belgium before closing the circle and ending our geomorphological journey in southern Belgium and Luxembourg. However, neither all geomorphic regions nor all geomorphic-specific contexts and mechanisms could be treated. For instance, we judged that, though very typical, the Appalachian topography of the Condroz did neither possess the originality nor offer the recent findings required to make a valuable contribution to the book. Likewise, we gave up the idea of describing geomorphic processes of more local meaning, such as the periglacial carving of the Famenne depression, or dealing with phenomena already tackled in several other chapters, like the development of Neogene cryptokarsts. We briefly review hereafter the regions, landforms, and topics dealt with in the book (Fig. 1.2).

Highlighting the contrast between the Paleozoic paleogeographies and tectonic history of the Ardenne basement in the south and the mostly depositional Meso-Cenozoic evolution of the Belgian part of the Anglo-Belgian basin in the north, Chap. 2 sets the scene and provides the geological background necessary for a sound understanding of the geomorphic processes and evolutionary models presented in the next chapters. By contrast, Chap. 3, devoted to the climate of Belgium and Luxembourg, discusses only the range of observed temperatures and precipitations in the frame of the present atmospheric circulation over Belgium and Luxembourg as a snapshot example of their spatial gradients across the study area. While it helps to appreciate the climatic context of modern geomorphic processes in the two countries, it does not deal with the evolution of past regional climates, which will be evoked when required in the course of specific studies.

Starting our tour in Luxembourg, Chap. 4 presents and discusses the very specific landscapes produced by the Plio-Quaternary geomorphic evolution affecting the thick Lower Liassic sandstones outcropping in Gutland (Fig. 1.2). This topic has awakened sufficient geomorphological interest worldwide to persuade authors to dedicate books and journal's special issues to it (e.g., Young et al. 2009; Migon and Viles 2015) and the Luxemburgian case is a very representative example of sandstone landscapes and landforms in the mid-latitudes. Travelling north to the Ardenne-Oesling and its stepped erosion surfaces, the next chapter (Chap. 5) refers to a key area in the history of long-term geomorphology and erosion cycles, Davis (1899) having already commented on this area at the end of the nineteenth century. However, recent advances in dating of the saprolites associated with old surfaces have brought strong support to the updated understanding of the latter's preserved remnants, whereas the accumulated geomorphic and weathering data

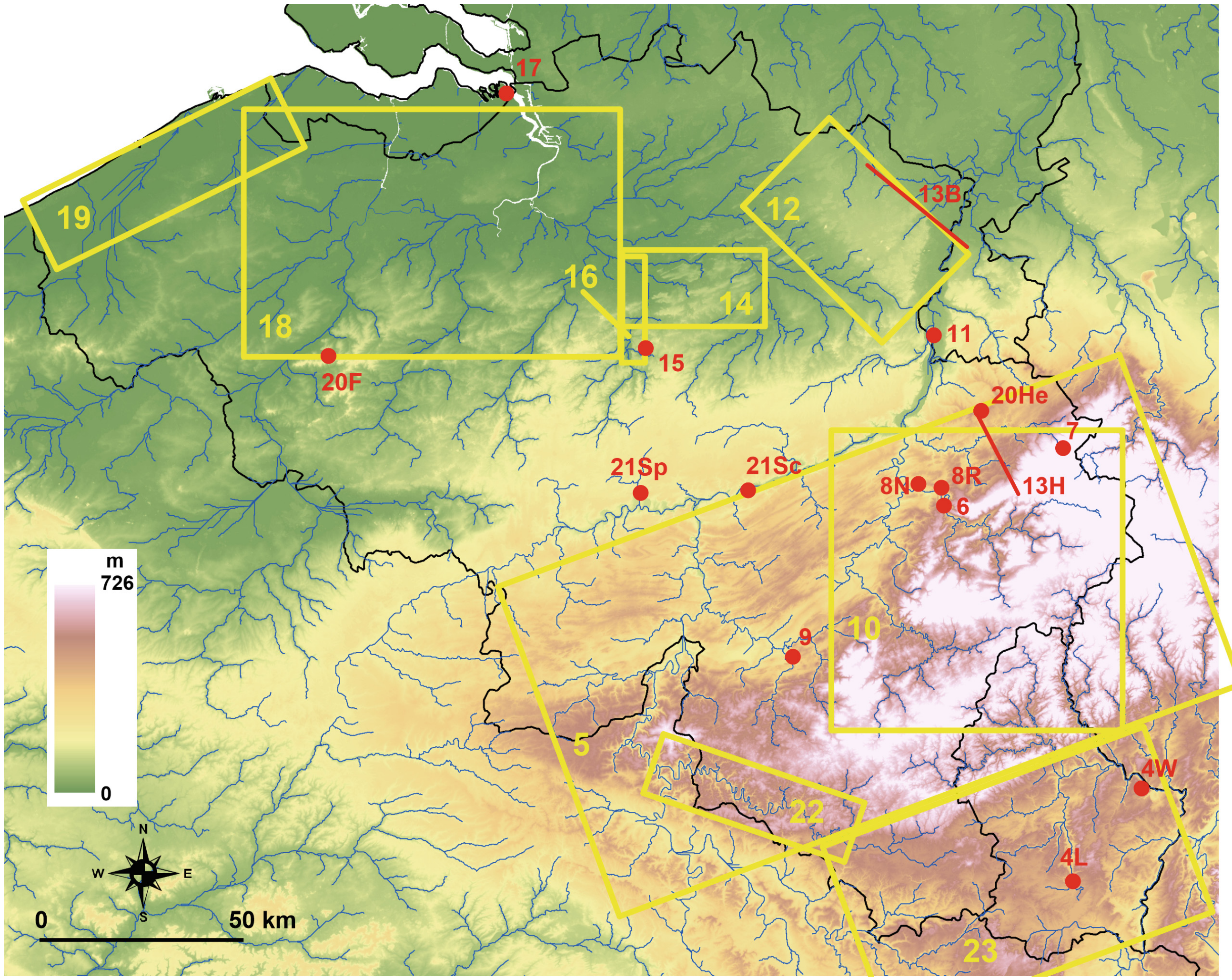

Fig. 1.2 Location of the regions (*yellow rectangles*) and sites (*red dots or lines*) described in this book. *Numbers* refer to the book chapters. *B* Bree scarp. *F* Flemish Ardennes. *H* Hockai fault zone. *He* Herve Plateau. *L* Luxembourg. *N* Noû Bleû. *R* Remouchamps. *Sc* Scladina Cave. *Sp* Spy Cave. *W* Wolfschlucht

sets make the Ardenne-Oesling a good example where the geomorphic evidence clearly contradicts the common interpretation of recently acquired fission track and cosmogenic radionuclide denudation data.

Chapters 6 and 7 consider more local but highly meaningful phenomena attesting the conditions of the Quaternary geomorphic evolution of NE Ardenne. A remarkable scenic section of the Amblève incised valley is presented first, focused on the analysis of a boulder-bed reach with blocks up to several m^3 in volume descended from the local hillslopes. An intriguing, and still not definitively solved, issue is raised of the processes by which many such big boulders were transported over 90 km before being included in terrace deposits of the Lower Meuse. The second of these two chapters describes world-famous features among a diversity of periglacial landforms and deposits inherited from the cold conditions of the Late Quaternary in the Ardenne, namely ramparted depressions attesting the development of lithalsas in NE Ardenne during the Younger Dryas. Dense fields of such periglacial ramparted depressions are especially well preserved in the Hautes Fagnes plateau (Fig. 1.2), which is known as the nicest and best documented place in the world to study relict lithalsas.

The twin Chaps. 8 and 9 deal with karstic phenomena developed in a narrow zone of Middle Devonian limestone, which borders to the north the Lower Devonian Ardenne. There, acidic waters flowing down from the siliceous Ardennian basement have given rise to the development of several extended, and touristically renowned, cave systems. Chapter 8, which presents the famous Remouchamps cave and the newly discovered nearby Noû Bleû karstic system, emphasizes mainly the relationships between the surface and underground evolution of karstic areas and describes many superb speleothem types found in pristine state in the Noû Bleû cave, inaccessible to the public. Chapter 9 is devoted to the karstic system of Han-sur-Lesse, located more to the west (Fig. 1.2). It stresses hydrogeological aspects of the karstic evolution that led to the subterranean cutting off of a meander of the surface Lesse River, and also takes the opportunity of field evidence in the Han cave to expose the concept of two-stage karstification through ghost-rock weathering of limestone massifs. To finish with the geomorphology of the Ardenne region, Chap. 10 brings together recently published new data about, and interpretations of, the Quaternary incision of the Ardennian drainage network in response to combined climatic and tectonic signals. Cosmogenic radionuclide dating of a Middle Pleistocene terrace level revealed its diachronic character, confirmed by the analysis of a set of tectonic knickpoints whose upstream migration is still going on in the Ardennian basin of the Meuse. These observations have led on to a reinterpretation of the classical scheme of climatically triggered Quaternary terrace staircases in the valleys of many European rivers, taking better account of the specific response of drainage systems to tectonic perturbations. In passing, the origin of the course of the Meuse is also briefly reconsidered.

Looking at geomorphic phenomena north of the Ardenne, Chap. 11 comes back to karstic landscapes, but in the particular context of Cretaceous chalk massifs. The described example is a mixture of interacting surface and underground karstic forms well exposed by a dense network of underground quarries within the Montagne Saint-Pierre, a well-known chalk massif along the Belgian-Dutch border where the first *Mosasaurus* fossils were uncovered in the nineteenth century (Van Marum 1790) (Fig. 1.2). Moving further north, Chap. 12 is devoted to the Campine plateau of NE Belgium and proposes a synthetic overview of various geomorphic problems related to the evolution of this area. Beyond offering interesting perspectives on the implications of differential vertical motion between the Roer Valley Graben and its Campine shoulder, the Meuse Quaternary evolution, and landforms related to the accumulation and reworking of Weichselian aeolian sands, this chapter introduces the issue of landscape and landform preservation and valorization in densely populated areas. The next chapter (Chap. 13) is also partly devoted to the Campine area and, more widely, to the morpho- and seismotectonics of assumed and confirmed active seismogenic faults in eastern Belgium. Tectonic landforms and seismic hazard in eastern Belgium are essentially related to the activity of the major Feldbiss fault system bounding to the south the actively subsiding Roer Valley Graben, part of the Lower Rhine segment of the Cenozoic European Rift System, but also to related faults such as the Hockai fault zone of NE Ardenne, whose rupture in 1692 caused one of the most violent historical earthquakes in Europe north of the Alps. The paleoseismological results obtained along the Feldbiss fault during the 1990s and the 2000s were pioneering in evidencing the potential hazard of strong earthquakes in assumed stable intraplate areas (e.g., Camelbeeck and Meghraoui 1996).

Moving west, Chap. 14 proposes a brand new hypothesis about the origin of the elongate hills characterizing the Hageland landscape, in central Middle Belgium (Fig. 1.2). Doing so, it highlights how geology and long-term geomorphology are intricately related and how careful joint geological and geomorphological investigations can shed convincing new light on old problems. A few kilometres south of the Hageland, Chap. 15 comes back to more recent geomorphic processes having induced barely known landforms in the heavily anthropogenically reworked landscapes of the loess belt of Middle Belgium. Mapping and analysing currently largely inactive gullies in the Meerdaal Forest, south of Leuven, and closed depressions under forest and in open cropland, the authors demonstrate how gullies that developed in a phase of land clearing and agricultural activities during the Roman period or earlier were only preserved, as a rather unique occurrence, in areas that remained continuously forested during the last 2 ky. They also point to the human origin of closed depressions as ancient quarries, stressing the human–environment interactions in the (pre)historical landscape evolution of Middle Belgium. Chapter 16 deals with another aspect of the same area, namely the complex evolution of floodplains in the Late Glacial and Holocene as exemplified by the Dijle catchment. It underlines how climatically triggered natural processes and later interference of human action successively caused the incision of large meanders into Weichselian braided river deposits, the cut-off and abandonment of these meanders, peat accumulation, deforestation-induced renewed floodplain sedimentation, and the development of a smaller-amplitude meander belt, often artificially cut-off in the last centuries.

With Chap. 17, we move to western Belgium and, first, the Scheldt estuary (Fig. 1.2). With a full salinity gradient along a length of $\sim$160 km, this typical lowland river estuary is one of the best preserved among those debouching in the North Sea. This study discusses the present intertidal areas morphodynamics along the single-channel Belgian part of the estuary, focusing on the extended Saeftinghe brackish marsh ($\sim$30 km^2). After a review of the functions of intertidal areas and the processes that shape them, it describes how recreation of tidal flats by the Flemish Sigmaplan is used, notably as flood control areas, to remedy the changes in estuary dynamics caused by previous human works. Chapter 18 also deals with the Scheldt basin, the Quaternary, and especially Late Pleistocene evolution of which it reconstructs. Called the Flemish Valley, the Late Pleistocene drainage system of the Middle and Lower Scheldt encompasses a large part of Low Belgium where detailed investigations of complex time-varying sedimentation patterns allowed for reconstructing the history of a remarkable set of nested terraces, likely initiated by a catastrophic dam breaching in the southern North Sea and paced by glacio-eustatic variations. As for Chap. 19, it presents an overview of the Holocene evolution of the coastal plain of Belgium, with detailed histories of two protected areas, namely De Moeren at the western end of the plain and the Zwin region at the other end.

Chapter 20 focuses on particular geomorphic processes and landforms, namely those related to landsliding, rather than to a specific region of Belgium or Luxembourg. Indeed, though still almost unknown in Belgium 20 years ago, ancient landslide scars have been mapped, and present landsliding activity noticed, in many regions of Middle Belgium since then. Two case studies are presented, one from the Flemish Ardennes, a hilly area of the Middle Scheldt basin in western Belgium, and the other one from the Herve Plateau in eastern Belgium. Despite different geological settings, both areas show similar lithological frames, with alternating subhorizontal sands (liquefiable in the Herve Plateau) and weak clays. They also show the same contrast between large deep-seated ancient (Holocene) landslides and small present-day reactivation of these existing landslides. While the present reactivation episodes are climatically triggered, the ancient landslides might be of seismic origin in the two regions. Chapter 21 is no more linked to a particular geomorphic region as it deals with all paleontological and archaeological remains attesting the presence and activities of Neandertals in Belgium. While the Spy and Scladina caves are described as emblematic examples of caves where Neandertal fossils have been found in Wallonia (Fig. 1.2), open-air sites are shown to be also highly instructive with respect to the understanding of territorial exploitation by Neandertals. While all cave sites are by necessity located in Wallonia, a small fraction of the open-air findings have been reported from Flanders.

Chapters 22 and 23 end our tour of Belgium by exploring two last geomorphic landscapes in SE Belgium and southern Luxembourg. Chapter 22 describes the remarkable elongate incised meanders of the Semois valley in southern Ardenne, several of which have been classified as exceptional geoheritage of Wallonia, and discusses their genetic link with the relative orientation between meander loops and the regional slaty cleavage. Chapter 23 presents the cuesta landscape of the NE rim of the Paris basin in Belgian Lorraine and Luxembourgian Gutland, not only providing a careful description of the morphology of the successive cuestas but also paying attention to weathering and duricrusting phenomena and briefly stressing remaining issues about the early evolution of the drainage network.

Finally, it seemed meaningful to dedicate a specific chapter to the geomorphosite concept, showing how it fundamentally intermingles with the notions of geosite and geodiversity and is also to some extent related to those of bio- and cultural diversity. This chapter (Chap. 24) proposes a brief review of Belgian sites classified as exceptional and displaying a specific geomorphic component. It highlights the different approaches by the public and the authorities of landscape and landform conservation in Wallonia (southern Belgium), where really scenic and fairly well-preserved landscapes occur in sparsely populated rural and forested areas, and in Flanders (northern Belgium), whose monotonous natural landscapes are strongly obliterated by a very dense land occupation and exploitation by man, and thus are a priori much less appealing.

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