
World Geomorphological Landscapes

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Editors

Landscapes and Landforms of France

 Springer

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Series Editor Preface

Landforms and landscapes vary enormously across the Earth, from high mountains to endless plains. At a smaller scale, nature often surprises us, creating shapes which look improbable. Many physical landscapes are so immensely beautiful that they received the highest possible recognition – they hold the status of World Heritage properties. Apart from often being immensely scenic, landscapes tell stories which not uncommonly can be traced back in time for tens of million years and include unique events. In addition, many landscapes owe their appearance and harmony not solely to the natural forces. Since centuries, or even millennia, they have been shaped by humans who modified hillslopes, river courses, and coastlines, and erected structures which often blend with the natural landforms to form inseparable entities.

These landscapes are studied by geomorphology – ‘the science of scenery’ – a part of Earth sciences that focuses on landforms, their assemblages, and surface and subsurface processes that moulded them in the past and that change them today. Shapes of landforms and regularities of their spatial distribution, their origin, evolution, and ages are the subject of research. Geomorphology is also a science of considerable practical importance since many geomorphic processes occur so suddenly and unexpectedly, and with such a force, that they pose significant hazards to human populations and not uncommonly result in considerable damage or even casualties.

With this book focused on France, we launch a new book series *World Geomorphological Landscapes*. It aims to be a scientific library of monographs that present and explain physical landscapes across the globe, focusing on both representative and uniquely spectacular examples. Each book will contain details on geomorphology of a particular country or a geographically coherent region. The core of each book is a succinct presentation of key geomorphological localities (landscapes), representative for the geomorphic diversity of each country. Written in easy-to-read language, the landform evolution stories presented in each volume give together an overview of what each particular country has to offer. But they can also serve as a guidance for holidaymaking geoscientists as to where to go to enjoy the best of geomorphology.

The series is thus a unique reference source not only for geomorphologists, but all Earth scientists, geographers, and conservationists. It complements the existing reference books in geomorphology which focus on specific themes rather than regions or localities and fills a growing gap between poorly accessible regional studies, often in national languages, and papers in international journals which put major emphasis on understanding processes rather than particular landscapes.

The World Geomorphological Landscapes series is produced under the scientific patronage of the International Association of Geomorphologists – a society that brings together geomorphologists from all around the world. The IAG was established in 1989 and is an independent scientific association affiliated at the International Geographical Union and the International Union of Geological Sciences. Among its main aims are to promote geomorphology and to foster dissemination of geomorphological knowledge. I believe that this lavishly illustrated series, which however sticks to the scientific rigour, is a most appropriate means to fulfil these aims and to serve the geoscientific community.

Series Editor

Piotr Migoń

Foreword

France presents a wide variety of landscapes, both natural and cultural, making this country the most visited in the world (Chap. 1). If we consider physical aspects of the landscape, this variety can be explained by a series of factors: (1) the topographical contrasts, from the highest summit of Europe down to the ocean; (2) a comprehensive collection of rock types (Fig. 1) and their related morphostructural units (sedimentary basins, basement uplands, active orogens, faulted systems with volcanism, coastal plains, deltas and marshes); (3) the long geological history and the succession of bioclimatic environments from tropical to glacial and periglacial environments, which left their imprint in the landscape; and (4) the large present-day bioclimatic diversity, at the junction of the Atlantic, Continental, and Mediterranean influences, which gives the geomorphological landscapes different atmospheres and lights (e.g. Brittany compared with French Riviera).

Prehistoric and historical (including Roman) legacies are also an integral part of French landscapes and landforms, often requiring a geoarcheological approach to better appreciate the role of early cultural groups in modelling their environment, exploiting their resources, and understanding the advantages of specific sites beyond their potential constraints or hazards. In that respect, two major characteristics should be highlighted. First, the abundance of limestone plateaus in the south of France explains both the number of beautifully ornamented caves and the wall paintings left by prehistoric humans as they sought sheltered sites during the last glaciation. Second, the combination of suitable soils and well-exposed slopes made France the country of viticultural ‘terroirs’, often developed on south- or southeast-facing scarps ensuring a good drainage and a sunny atmosphere whatever their structural origin: fault steps of Alsace, Burgundy, or Rhone Valley, cuesta of Champagne or thrust front of the western Jura.

This book is intended to provide the reader with an overview of French landscapes and landforms, reflecting as far as possible their diversity. To date, France is a country endowed with 34 sites inscribed as cultural heritage sites on the UNESCO World Heritage list, often backed by exceptional natural sites (e.g. Mont St-Michel (Chap. 5) or Paris and the banks of the Seine River (Chap. 2)). On the other hand, only three sites have been inscribed as natural heritage sites, including Corsican granitic landscapes (Chap. 23) and La Reunion volcanic landforms (Chap. 25), whereas the mixed ‘Cultural and Natural Heritage’ label is recognised in one site only (Gavarnie in the Pyrenees (Chap. 12)). Many chapters of this book deal with World Heritage Sites (WHS), either already listed by UNESCO or currently under consideration for UNESCO label recognition (e.g. Mont Blanc Massif, Chaîne des Puys volcanoes, Chauvet Cave – Pont d’Arc, and Camargue). Others have already received the label of ‘Grands Sites de France’: this is the case of Aven d’Orgnac (Chap. 19), Massif du Canigou (Chap. 13), and Cirque de Navacelles (Chap. 11). These UNESCO WHS and ‘Grands Sites de France’ are shown in Fig. 2.

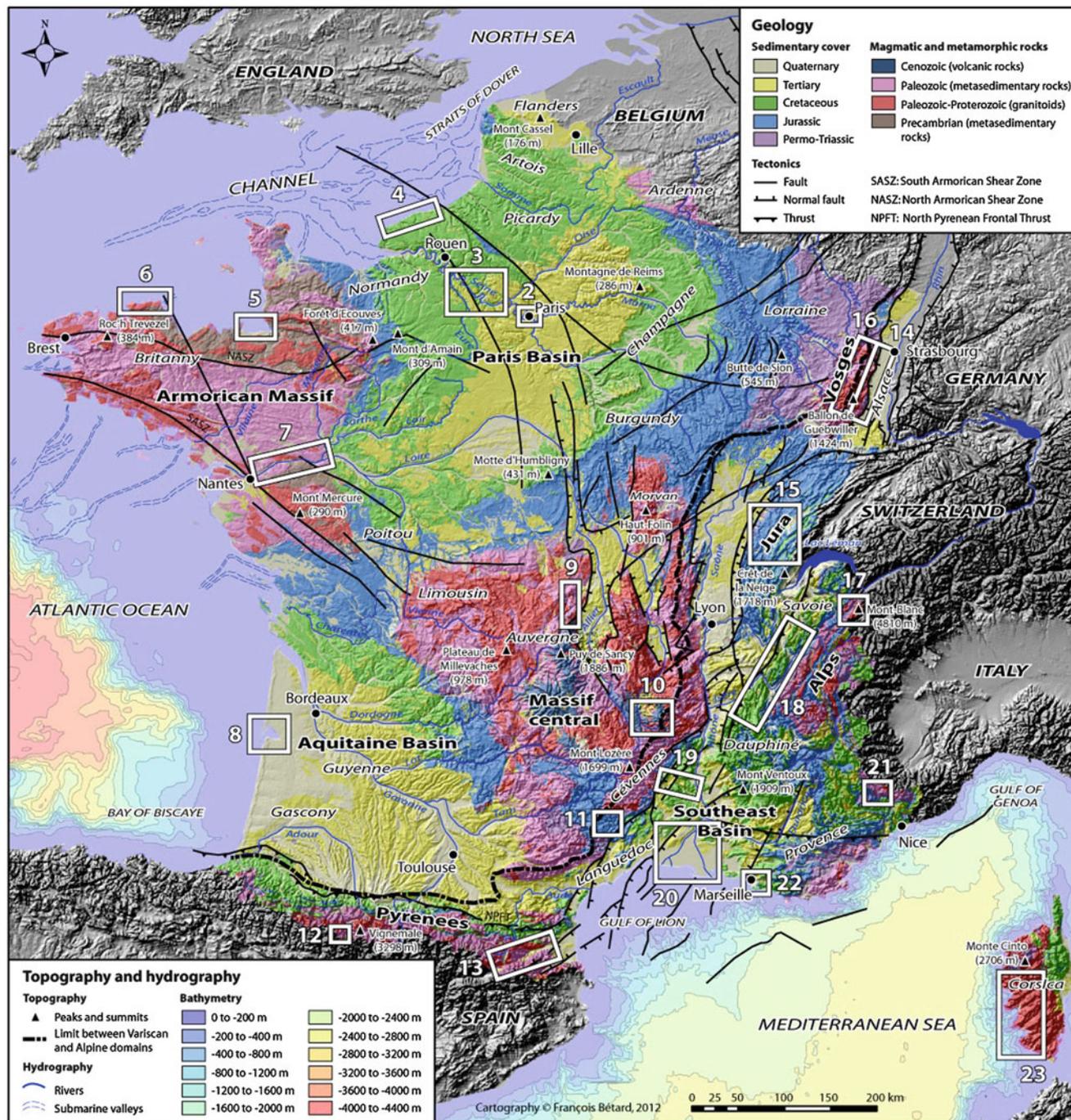


Fig. 1 Main geological frame of the different areas described in this book, with numbers referring to chapters (Drawing F. Bétard)

The book is organised in a sequence of chapters according to the following itinerary. Starting from Paris (Chap. 2), founded by the Romans, it is shown how in its early development the capital city benefited from links along the Seine River that favoured fluvial trade and from its substrate that offers abundant resource for building stones. Chapter 3 describes the famous entrenched meanders of the Seine River Valley downstream of Paris, developed under

the alternation of glacial/interglacial periods: rich in mediaeval castles built on the chalk cliffs, the valley later attracted many Impressionist painters (Fig. 2).

The high Normandy coast and cliffs (Chap. 4), with their imposing verticality, their whiteness varying in tone with the ever-changing light and tide, and their ghostly shapes, also exerted a powerful attraction to painters and novelists. The instability of the cliffs has become a real concern for policymakers. Quite different is the Mont Saint-Michel bay (Chap. 5), characterised by its exceptional tidal range and the immensity of its tidal flat, overlooked by the Abbey perched on an island of which integrity is endangered by the progress of sedimentation. In contrast, the celebrated Pink Granite coast of northern Brittany (Chap. 6) illustrates both the influence of selective weathering under terrestrial conditions and the stripping of the saprolite by marine processes.

The Loire River Valley (Chap. 7), famous for its vineyards and royal châteaux, is much wider than the Seine Valley, and in its lower part it consists of a patchwork of geomorphic compartments (islands, separated by multiple branches of the river) that are remodelled under the influence of floods originating from the Massif Central highlands. Arcachon Bay (Chap. 8) is already part of southern France: bordered by the largest coastal dune belt in Europe, it is a typical semi-sheltered lagoon located on the Atlantic coast of France, facing the wave-dominated coast of the Bay of Biscay. It has become a famous oyster cultivation area and hosts various recreational activities (sport-fishing, sailing, and ecotourism) all year around.

The volcanic *Chaîne des Puys* range (Chap. 9) displays a wide spectrum of potentially active volcano types, very attractive for scientists, students, and visitors. Used for grazing as far back as the Neolithic period, and more intensively since the Roman Empire, volcanic slopes have been heavily deforested and eroded. With its status of French Regional Nature Park acquired in 1977, the *Chaîne des Puys* has been protected ever since. To the south, the Velay and its Vivarais rim (Chap. 10) combine many historical aspects of the Massif Central, from its Hercynian basement to the Tertiary tectonic and volcanic reactivations following the Pyrenean and Alpine orogenies, and from the Mesozoic and Tertiary planations to the Plio-Quaternary excavation of valleys. With the Cirque de Navacelles (Chap. 11), we have a perfect example of a meander incised by the Vis River in its gorge across the Causse du Larzac (limestone plateau), downstream from the metamorphic and granitic Cévennes Mountains. Yet it is much more complex than a simple bend in a watercourse, as karstic influence contributed to its evolution. Overlooked by panoramic viewpoints, it is listed on the 'Grand sites de France'.

The Cirque de Gavarnie (Chap. 12), a 1,500-m-high limestone theatre, is an exceptional landscape recognised in 1997 as a UNESCO World Heritage site for both its natural and cultural values. It results from a long evolution, including the formation of the Pyrenean range, the combination of both karstic and glacial influences, and a long history of human occupation and exchanges across the French-Spanish border. In the Eastern Pyrenees (Chap. 13), where the Mediterranean and Atlantic biomes meet, the Têt river catchment displays a spectacular suite of tectonic, glacial, periglacial, fluvial, and hillslope forms. Famous for its prominent fragments of smooth, pre-Quaternary Paleic relief remnants where glacial erosion has not serrated the interfluves, this Mediterranean part of the Pyrenees also preserves good records of post-orogenic landscape evolution and base-level changes since the early Neogene.

The Vosgian-Alsatian side of the Rhine Graben (Chap. 14) developed in response to Alpine orogeny: it is a unique, tectonically controlled landscape, famous for its vineyards and its traditional well-preserved architecture and culture. Nearby, the Jura Massif (Chap. 15) displays in its external part an original fold-and-thrust belt overriding the Bresse graben and bearing famous vineyards, in addition to scenic blind valleys, exurgence springs and glacially formed lakes with Neolithic pile-dwelling settlements. The Vosges Mountains (Chap. 16) formed in uplifted Hercynian basement, affected by Quaternary glaciation. Upon its bald, rounded summit ridges, heathland and meadows with specific vegetal communities result from deforestation

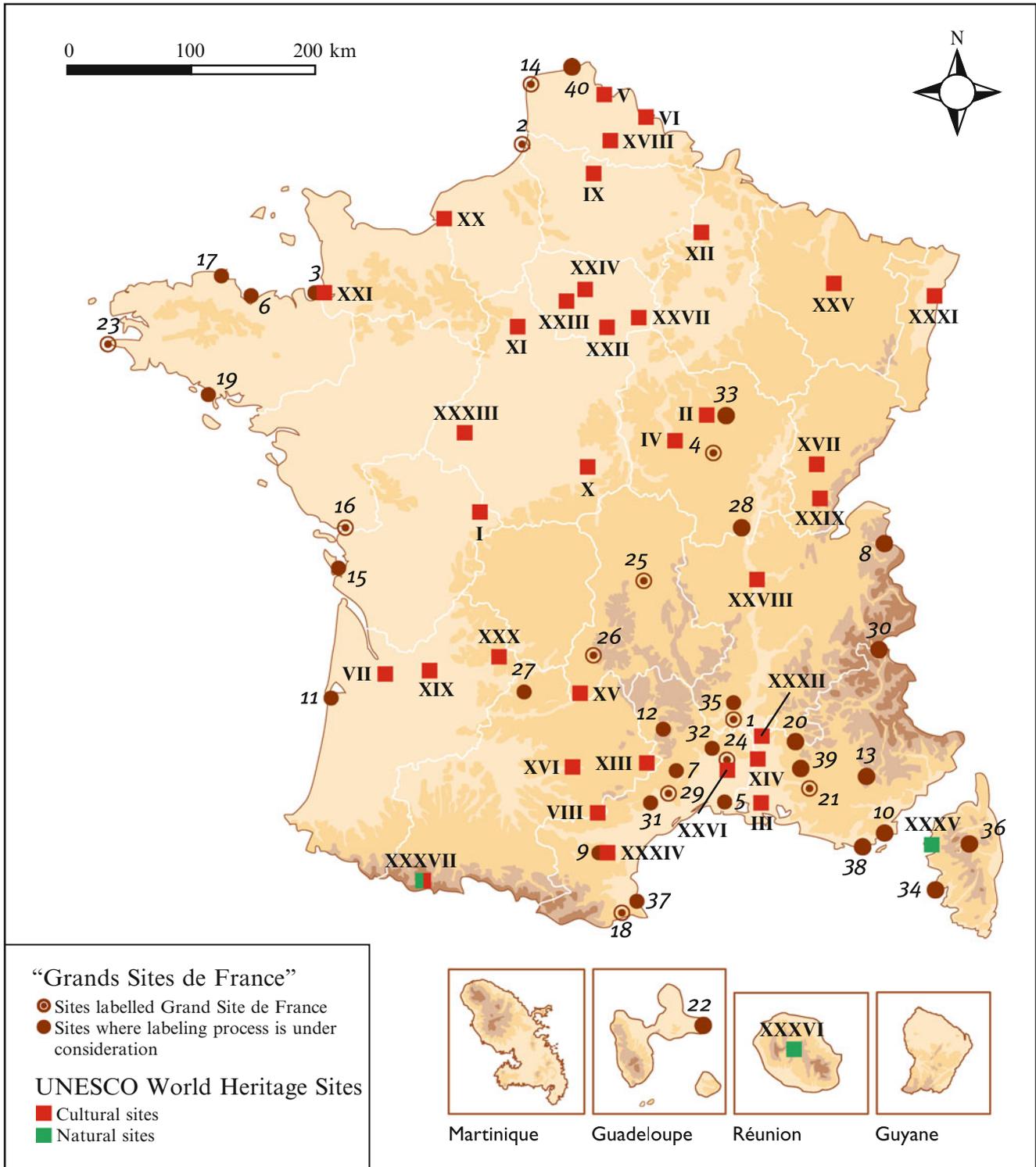


Fig. 2 Sites with Grands Sites de France Label (in arabic numbers). 1: Aven d’Orgnac; 2: Baie de Somme; 3: Baie du Mont-Saint-Michel *; 4: Bibracte-Mont Beuvray; 5: Camargue gardoise; 6: Caps d’Erquy-Fréhel; 7: Cirque de Navacelles ***; 8: Cirque de Sixt Fer à Cheval; 9: Cité de Carcassonne *; 10: Domaine du Rayol, Le Jardin des Méditerranées; 11: Dune du Pilat; 12: Gorges du Tarn et de la Jonte ***; 13: Gorges du Verdon; 14: Les Deux Caps Blanc-Nez, Gris-Nez; 15: Marais et Place Forte de Brouage; 16: Marais Poitevin; 17: Abbaye de Beauport; 18: Massif du Canigó; 19: Massif dunaire de Gávres-Quiberon; 20: Mont Ventoux; 21: Sainte-Victoire; 22: Pointe des Châteaux; 23: Pointe du Raz en Cap Sizun;

since the Bronze Age period. The protection and management of this natural heritage is ensured by a Nature Park and four Nature Reserves.

The Mont Blanc Massif (Chap. 17), the highest of the external crystalline massifs of the Western Alps, deserves a special place. Renowned for its extensive glacier cover, steep granite rockwalls and vertiginous peaks, the massif has attracted both tourists and scientists over several centuries. Accelerating glacier retreat and permafrost degradation both represent major threat to this emblematic landscape. Nearby, the French Prealpine geomorphological landscapes (Chap. 18) are excellent examples of sedimentary folded relief, and they host the four French members of the European and Global Geoparks Network including the Bauges Regional Nature Park, famous for its perched synclines and karstified relief. Great limestone cliffs overlying marly bedrock favour dramatic collapses like that of Mont Granier in 1248 AD.

Continuing southwards, Mediterranean influences become predominant. In the Lower Ardèche region (Chap. 19), the Messinian Salinity Crisis was the primary cause of the incision of the Ardèche Canyon and of the reorganisation of the Rhône River catchment. The end of this crisis contributed to the development of a specific karst system, including the Orgnac aven and the Chauvet cave, famous for its outstanding prehistoric wall paintings (the oldest in the world to date). The Lower Rhône River valley and its Delta (Chap. 20) have been a major axis of communication linking the Mediterranean to northern Europe since antiquity. Numerous archaeological excavations demonstrate human-environment interactions, emphasising the strong constraint of fluvial-deltaic environments, and how human societies, since the Greeks and the Romans, found some solutions to mitigate the fluvial risk. The landforms are now subject to different changes related to human activities, and the protection of the natural component has become a real challenge. The region of Mount Bego (Chap. 21) in the Southern French Alps, is an interesting place to observe scenic inherited landforms as well as cultural remains left by the ancient societies who lived there. The glacial imprint is widespread, and

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Fig. 2 (continued) 24: Pont du Gard *; 25: Puy de Dôme; 26: Puy Mary – Volcan du Cantal; 27: Rocamadour **; 28: Roches de Solutré-Pouilly-Vergisson; 29: Saint-Guilhem le Désert et Gorges de l’Hérault **; 30: Vallée de la Clarée et Vallée Étroite; 31: Vallée du Salagou; 32: Gorges du Gardon; 33: Alésia; 34: Iles Sanguinaires – Pointe de la Parata; 35: Gorges de l’Ardèche; 36: Vallée de la Restonica; 37: Anse de Paulilles; 38: Presqu’île de Giens, Salins d’Hyères; 39: Massif des Ogres; 40: Dunes de Flandre. * *World Heritage UNESCO site*; ** *World Heritage UNESCO site on grounds of Saint-Jacques de Compostelle trails*; *** *World Heritage UNESCO site on grounds of Causses and Cévennes, Cultural Landscape of Mediterranean agropastoralism*. Note that this label ‘Grand Site de France’ is decerned by the French State to the Grand Site Manager for a period of 6 years. This label acknowledges the manager’s action agrees well with sustainable development principles.

French World Heritage Sites (in Roman numbers). *I*: Abbey Church of Saint-Savin-sur-Gartempe; *II*: Cistercian Abbey of Fontenay; *III*: Arles, Roman and Romanesque Monuments; *IV*: Vézelay, Church and Hill; *V*: Belfries of Belgium and France; *VI*: Nord-Pas de Calais Mining Basin; *VII*: Bordeaux, Port of the Moon; *VIII*: Canal du Midi; *IX*: Amiens Cathedral; *X*: Bourges Cathedral; *XI*: Chartres Cathedral; *XII*: Cathedral of Notre-Dame, Abbey of Saint-Remi, & Palace of Tau, Reims; *XIII*: The Causses and Cévennes; *XIV*: Historical center of Avignon: Papal Palace & Avignon Bridge; *XV*: Routes of Santiago de Compostela in France; *XVI*: Episcopal City of Albi; *XVII*: Royal Saltworks of Arc-et-Senans; *XVIII*: Fortifications of Vauban; *XIX*: Jurisdiction of Saint-Émilien; *XX*: Le Havre, the City rebuilt by Auguste Perret; *XXI*: Mont Saint-Michel and its Bay; *XXII*: Palace and Park of Fontainebleau; *XXIII*: Palace and Park of Versailles; *XXIV*: Paris, Banks of the Seine; *XXV*: Place Stanislas, Place de la Carrière, and Place d’Alliance in Nancy; *XXVI*: Pont du Gard, Roman Aqueduct; *XXVII*: Provins, Town of Medieval Fairs; *XXVIII*: Historic Old Town center of Lyon; *XXIX*: Prehistoric pile dwellings around the Alps; *XXX*: Prehistoric Sites and Decorated Caves of the Vézère Valley; *XXXI*: Strasbourg – Grande Île; *XXXII*: Roman Theatre and its Surroundings and the “Triumphal Arch” of Orange; *XXXIII*: The Loire Valley between Sully-sur-Loire and Chalonnes-sur-Loire; *XXXIV*: Cité de Carcassonne – historic Fortified City of Carcassonne; *XXXV*: Gulf of Porto: Calanche of Piana, Gulf of Girolata, Scandola Reserve, Corsica; *XXXVI*: The Pitons, Cirques and Remparts of La Réunion; *XXXVII*: Pyrénées: Gavarnie-Mont Perdu (Drawing F. Bétard)

the first human traces date back to the Neolithic, three millennia before Protohistoric societies left the outstanding petroglyphs of the so-called Vallée des Merveilles (Valley of Wonders). The Cosquer cave (Chap. 22) with its famous prehistoric paintings is located along a karstic coast submerged after the Last Glacial Maximum. Both lithology and tectonics explain the coexistence in the same area of terrestrial and submerged karst features that developed since the Neogene period.

The book concludes with three chapters about islands. First Corsica (Chap. 23) is like a granitic mountain in the sea, offering a large set of mesoscale forms and rock slopes carved by differential surface weathering, with contrasting landforms between the upper areas that were glaciated and the coastal landforms influenced by the sea. At local scales granite slabs and castellated tors, and at microscales, gnammas, and tafoni, are emblematic landforms that attracted early societies. The coral reefs and lagoons of French Polynesia islands (Chap. 24) illustrate well the pioneering theory of Darwin, revised by plate tectonics. These islands also offer an interesting example of combined volcanic geomorphology and karst development on an uplifted coral reef, affected both by high-energy events, and the generation of microforms by reef bioerosion. Finally, La Réunion (Chap. 25) is a volcanic island dating back at least 3 million years. It is celebrated as a Natural UNESCO Heritage site, thanks to its dormant volcano Piton des Neiges and its very active Piton de la Fournaise. Outstanding landforms include the steep *Remparts*, deep gorges, and waterfalls that favoured the development of endemic species that are now protected.

This book could not have been completed without the help and assistance of various individuals. We would like first to warmly thank Piotr Migoń, the director of the Landscapes and Landforms Book series, who encouraged us to prepare this book in coordination with the Paris 8th International Conference of Geomorphology. Working with Elodie Tronche (Springer) was also a pleasure and we are most grateful to her for her involvement in the making of the book. Warm thanks also go to our French colleagues who agreed to prepare their contributions in a limited time period despite their many other commitments, and to additional partners who helped with the illustration, either by adapting existing figures or by kindly giving their permission for reproduction. Last, special thanks are due to Ian Evans, from Durham University, who greatly helped us in the final stage of English editing, and to François Bétard who provided the final general maps attached to this foreword and to Chap. 1. To all, we express our sincere gratitude.

Monique Fort
Marie-Françoise André

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Jacques Collina-Girard is Professor in Aix-Marseille University. As a geologist and prehistorian, he is mainly interested in continental shelves, sea level rise and prehistoric archaeology. As a diver, he participated in Cosquer Cave Study in Marseilles and in geomorphological observations conducted, using scuba diving, in west Mediterranean Sea. He is the author of three books and 76 scientific papers.

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Stéphane Jaillet is a Research Engineer at CNRS. Geomorphologist, speleologist and cartographer, he specializes in the study of karst and underground networks speleogenesis. At EDYTEM laboratory (University of Savoie), he develops the platform CTI3D (Cartography, Topography, Imaging and 3D). He is a member of the scientific team of the Chauvet cave, a scientific diving leader and also a member of the Ultima Patagonia expeditions.

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Charles Le Coeur is Professor of Physical Geography at the University of Paris 1-Sorbonne and the former Director of the Laboratory of Physical Geography (CNRS-Meudon). He has studied long term and Quaternary geomorphology in intrusive ring complexes in Northern Ireland and Western Scotland. He has carried varied research on geomorphological responses to environmental change on Alpine slopes and rockglaciers, on Mediterranean rivers and coasts, and on numerous river restoration schemes.

Jerome Magail is an Anthropologist and an Administrator at the Museum of Prehistoric Anthropology of Monaco. In 2001 he submitted his thesis on the Bronze Age petroglyphs of Mont Bego situated in the south of France. Since 2006 he is the co-director of the Monaco-Mongolian joint archaeological expedition. He works in the center of Mongolia on an archaeological site of the Bronze Age. He is Associate Researcher in Traces Laboratory (UMR 5608) of the French National Center for Scientific Research.

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Ludovic Mocochain is a Geoscientist working at the Paris 6 University. Besides karstology, he studies the impacts of huge geological catastrophic events like the Messinian Salinity Crisis in the Mediterranean Sea.

Jean-Pierre Peulvast is Emeritus Professor of Geomorphology at the University of Paris-Sorbonne. He also teaches in the Master degree and Doctorate program at the Federal University of Ceará (UFC), Fortaleza, Brazil. His principal field of interest is structural geomorphology, but he is also involved in programs of geoarcheology (Egypt) and in studies on natural hazards and risks (Northeast Brazil). He mainly works on passive margins around the Atlantic ocean (Scandinavia, Canada, Brazil, Argentina), but also on various regions of France, Mediterranean Europe and Central Asia.

Alexandre Poiraud is a Geomorphologist, member of the Laboratory of Physical and Environmental Geography GEOLAB (CNRS-Blaise Pascal University). His main research

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Mireille Provansal is Emeritus Professor of Physical Geography in Aix-Marseille University, France, and is a member of CEREGE (CNRS UMR 7330). Her recent research topics are fluvial geomorphology and sedimentology of large rivers and deltas, impacts of engineering works on fluvial functioning and fluvial risks since 150 years, and palaeoenvironments in fluvial archaeological sites. Her countries of expertise are south France, Romania and Vietnam.

Ludovic Ravanel is researcher in geomorphology working at the EDYTEM Laboratory (UMR 5204 Université de Savoie – CNRS, Le Bourget-du-Lac, France) on rockfalls, warming permafrost, paraglacial dynamics, and risks in high mountain areas. His main study area is the Mont Blanc region in the western Alps. He participated in various European projects including the recent PermaNET program (alpine-wide and long-term permafrost monitoring network). He is currently heavily involved in risk management in Chamonix.

Patrick Simon is Director of the Museum of prehistoric Anthropology of Monaco (Principality of Monaco). Being a geologist, his principal field of interest is Quaternary Geology and more particularly the relations between prehistoric lithic industry and raw materials (flint, quartzite, radiolarite, etc.). He is also editor of the Bulletin of Museum of Prehistoric Anthropology of Monaco.

Gilles Thomas is an underground historian and writer. He co-edited the work *Atlas du Paris souterrain* (Parigramme 2001) and is the author of *The Catacombs of Paris* (Parigramme 2011) and *Inscriptions des Catacombes de Paris* (Cherche-midi 2012). He produces an average of ten papers each year and also provides at the same time technical advices for journalistic, literary and academic projects, documentaries (BBC, Discovery Channel, National Geographic, etc.), and his name appears in film credits, including Pixar's *Ratatouille*.

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