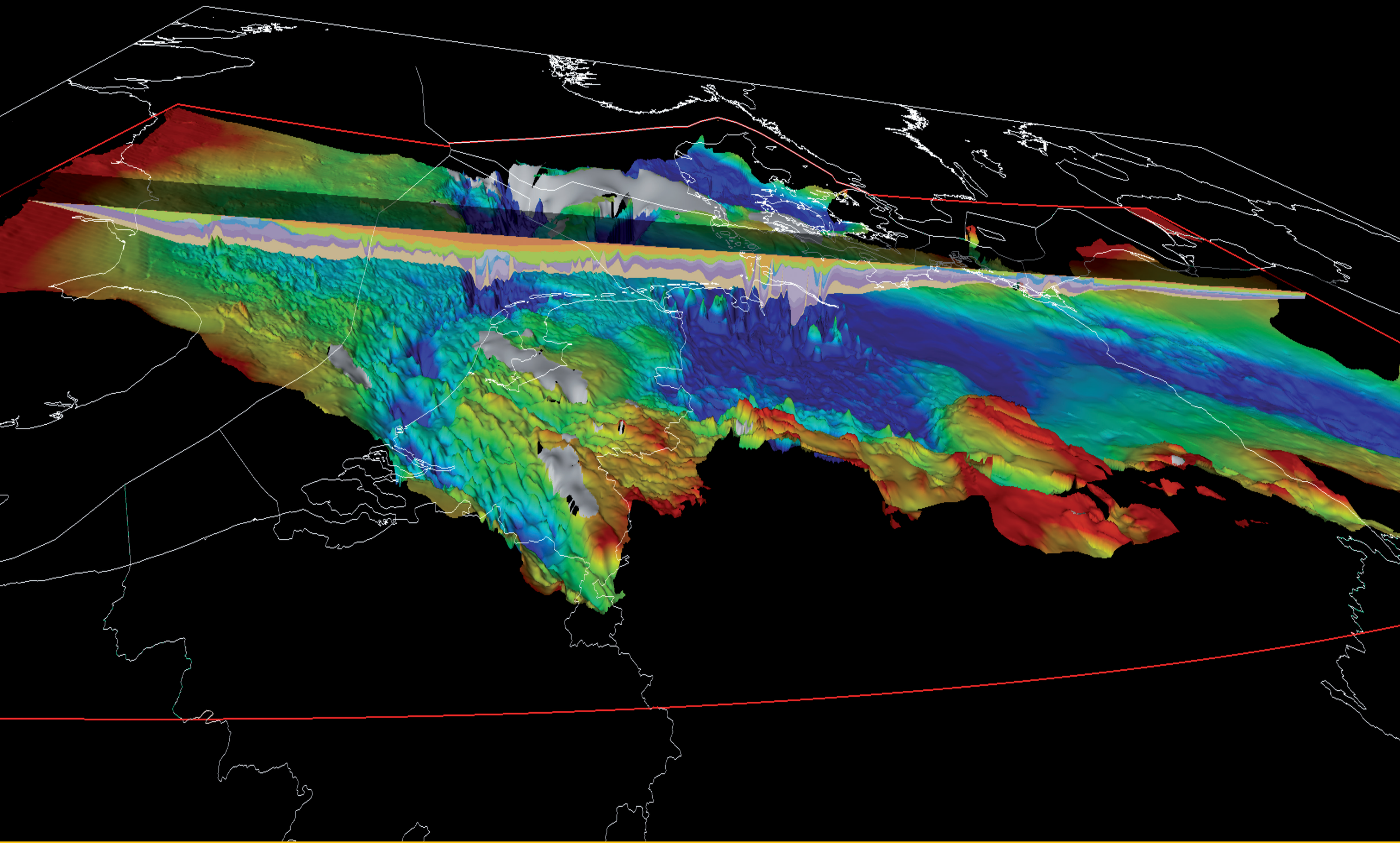

3D view of the base of the Zechstein in the SPBA area, (viewed from the south; red colours are shallow and blue indicates the greatest depths). The section crosses the entire area, a distance of 1525 km. The vertical scale is 1 : 300 000.

Chapter 1 Introduction, stratigraphic framework and mapping

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Bibliographic reference
Doornenbal, J.C., Abbink, O.A., Duin, E.J.T., Dusar, M., Hoth, P., Jasionowski, M., Lott, G.K., Mathiesen, A., Papiernik, B., Peryt, T.M., Veldkamp, J.G. & Wirth, H., 2010. Introduction, stratigraphic framework and mapping. *In:* Doornenbal, J.C. and Stevenson, A.G. (editors): Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications b.v. (Houten): 1-9.

1 Introduction

The Petroleum Geological Atlas of the Southern Permian Basin (SPB) area is a comprehensive overview based on more than 150 years of petroleum exploration and research in the SPB area. The Atlas also aims to stimulate the hydrocarbon exploration and production (E&P) industry to continue their activities in this mature basin. A better understanding of the geology of the deep subsurface of the SPB will also be of great value to governments, researchers and other interested individuals.

The Atlas was planned to mark the 50th anniversary of a milestone in the history of hydrocarbon exploration: the discovery in 1959 of the Groningen gasfield, one of the largest in Europe, which provided a significant boost to the exploration for oil and gas in the SPB area. As the oil and gas province continues to mature, and with field sizes inevitably decreasing, enhanced data integration and geoscientific effort will be required to discover new reserves and to augment recovery from proven hydrocarbon accumulations. The large volume of data that has been made publicly available has allowed the production of this authoritative compilation to support the E&P industry in their efforts to fully develop the basin. The Atlas also provides easier access to the knowledge accumulated by the industry, geological surveys and academic bodies, leading to a better understanding of the geology of the SPB area. Documentation of this knowledge will help to train the next generation of petroleum geologists.

This Atlas follows the success of the 'Millennium Atlas: petroleum geology of the central and northern North Sea' published in 2003 (Evans et al., 2003). The idea for the 'Southern Permian Basin Atlas' (SPBA) was proposed by Kenneth Glennie, who was also one of the principal contributors to the Millennium Atlas. The two atlases have a slightly different emphasis in that, from the outset, the SPBA was principally designed to be a GIS-based product, whereas the GIS for the Millennium Atlas was produced at the conclusion of the project.

A large number of international experts in National Geological Surveys, academic institutions and petroleum exploration companies have contributed to the production of the SPBA. The Atlas reviews the entire SPB area, including the United Kingdom (UK), Belgium, the Netherlands, Denmark, Germany and Poland between latitudes 50°30'N and 56°N and longitudes 1°45'W and 22°E (**Figure 1.1**). To provide a link with the Millennium Atlas, the entire Danish territory is included in the stratigraphic depth and thickness maps. These maps exclude the north of France, southern Sweden and the northern Czech Republic as they lie outside the SPB and have no oil or gasfields; however, Lithuania is included because it does have oil and gasfields and data were readily available from the Lithuanian Geological Survey. Kaliningrad also has oil and gasfields; however, no data were available for the depth and thickness maps.

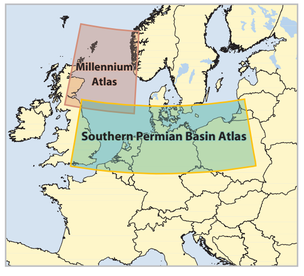

Figure 1.1 Areas described in the Southern Permian Basin Atlas and the Millennium Atlas.

The SPBA presents a review of the geological evolution and hydrocarbon potential of each stratigraphic interval in the basin. The palaeogeographic and tectonic evolution of the principal stratigraphic intervals from the Precambrian basement to the Holocene are also described. The various structural and stratigraphic settings and developments are illustrated by a series of overview maps, diagrams and field examples. The SPBA also includes chapters describing petroleum generation, migration, trapping and production, as well as the history of licensing and exploration in the basin, together with resource assessments. Other potential uses of the subsurface geology are described, such as gas storage and geothermal energy aspects.

1.1 Topography and bathymetry

The present-day topography and bathymetry of the SPBA area is largely shaped by the pattern of uplift and subsidence established during the Cenozoic (**Figure 1.2**). Subsidence was greatest in the North Sea area, whereas uplift was greatest in the Alpine and Carpathian forelands and in the western UK and southern Sweden. Whereas this tectonic setting has persisted throughout the Cenozoic, the present-day distribution of land and sea is mainly the result of the major landscape remodelling that took place during the Late Quaternary. These Quaternary events established the north-west European drainage system seen today, and formed the substantial delta system that influenced the coastline of the Netherlands and north-west Germany. Northward and westward extension of this delta system during the mid-Quaternary is responsible for the relatively shallow water depths of the southern North Sea. The sharp increase in water depth to the north-west marks the northern limit of the Quaternary delta system, whereas the notable overdeepening in the Norwegian and Baltic seas was caused by glacial scouring.

1.2 Surface geology

The surface geology of the SPB area is well-illustrated by the pre-Quaternary subcrop map (**Figure 1.3**). The map is a slightly revised part of the 1 : 5 Million International Geological Map of Europe and Adjacent Areas – IGME 5000 (Asch, 2005). The pre-Quaternary subcrop is principally Mesozoic and Cenozoic rocks, which are broadly conformable over much of the area. The Mesozoic strata overlie a variety of older rocks, ranging from the Lower Paleozoic of England, Belgium and parts of the Baltic region, to crystalline basement in the Scottish and Scandinavian Caledonides, Bohemian Massif, East European Craton and parts of the Rhenish Massif.

Tertiary subcrops reflect the development of two main depocentres during Neogene times, the North Sea Basin and the East German-Polish Basin. The Neogene subcrop is more limited than that of the Paleogene, primarily due to Quaternary erosion near the basin margins. However, the absence of Neogene sediments in southern and eastern England and northern France is also the result of Early Neogene uplift of the western basin margin. Similarly, Quaternary erosion of Neogene sediments to the south of Sweden was enhanced by Late Neogene uplift in that area. Neogene sediments are also absent over salt structures in northern Germany and western Poland.

The subcrop of Mesozoic strata is mostly restricted to a relatively narrow zone fringing the pre-Mesozoic highs, except where Mesozoic rocks have been uplifted due to Mid-Cenozoic inversion, as in the Weald, Cleveland-Sole Pit and German inversion zones. In the east of the region, a combination of Early Paleogene inversion and Late Neogene uplift has exposed Mesozoic rocks along the Sorgenfrei-Tornquist Zone and at the north-western and south-eastern limits of the Mid-Polish Anticlinorium.

1.3 Distribution of hydrocarbons

About 1240 oil and gasfields have been discovered within the SPBA area. The distribution of the fields (Figure 1.4) shows that most are concentrated along a relatively narrow east–west corridor in the southern SPB. Field outlines have been provided by the relevant national Licensing Authorities, National Geological Surveys and/or oil companies; IHS Energy has provided the field outlines for Lithuania and Russia (Kaliningrad). These hydrocarbon fields are listed in **Appendix 3**.

1.4 Geological publications

In some countries, there is a national website to assist in finding references to relevant petroleum geological publications. In the UK, publications of the Geological Society of London's Lyell Collection can be found at www.geolsoc.org.uk/gsl/info. A significant amount of hydrocarbon-related geological information is published on the website of the UK Government's Department of Energy and Climate Change (www.decc.gov.uk).

In Belgium, geological publications can be found on the GNOSIS website (Generalized Natural Online Sciences Spatial Information System of the federal scientific institutes in Belgium; www.gnosis.be/gnosis/index.jsp). The national website for the Netherlands is the NL Oil and Gas Portal, which is managed by TNO – Geological Survey of the Netherlands (www.nlog.nl). There are no standard national websites for Denmark, Germany, and Poland although important German publications can be found on the websites www.dgmk.de, www.bgr.bund.de and www.gfz-potsdam.de.

The following publications describe the general geology, stratigraphy, petroleum geology and/or applied geology of the SPBA area and have been an important source of information during production of the SPBA and in particular for the depth maps: UK (Cameron et al., 1992; Trewin, 2003; Brenchley & Rawson, 2006); the Netherlands (Rondeel et al., 1996; Wong et al., 2007a); Denmark (Michelsen, 1978; Damtoft et al., 1992; Vejbæk et al., 1994; Michelsen et al., 2003; Vejbæk & Andersen, 2003; Hemmet, 2005); Germany (Reinhardt, 1977; Boigk, 1981; Schwab, 1985; Franke, 1990; Reinhardt, 1991; Hoth et al., 1993a; Kockel et al., 1994; Kockel, 1995, 1996; Bandlowa, 1998; Gerling et al., 1999a; Baldschuhn et al., 2001; Littke et al., 2005) and Poland (Dadlez, 1997a; Karnkowski, 1999; Świdrowska et al., 2008).

2 Structure and conventions used in the SPBA

2.1 Structure of the SPBA

The Atlas has sixteen chapters, and is primarily aimed at the non-specialist professional, although a glossary of terms is included to help explain the geology of the SPB to non-specialist readers (**Appendix 1**). Each chapter describes the regional geology, but also includes details from selected areas to help illustrate specific aspects of the geology. It is important to note that it is not the intention to present a unified view of the SPB area, for in such a geologically complex area it would be impossible to find a consensus. Where there is a range of views on a particular subject, the principal arguments are given and appropriate references quoted, although the authors may provide their preferred interpretation.

The Atlas has been written by authors from National Geological Surveys in collaboration with geoscientists from oil companies, research institutes, universities, Licensing Authorities and several independent experts; all chapters have a Principal Author who co-ordinated the production of the chapter. Each chapter was reviewed by two or more external referees, most of whom work in the oil industry. The manuscripts were then assessed by the Chief Editor who, along with the Project Cartographer, was responsible for text and diagram standardisation, consistency of chapter format and the final layout. The Atlas was printed and bound by EAGE.

The chapters of the Atlas can be subdivided into four broad sections:

2.1.1 Chapters 2 and 3

Chapters 2 and 3 provide an overview of the deep-crustal structure, the structural elements of the SPB and sub-basins, their general evolution, and their present-day structural framework.

- Chapter 2, Crustal structure and structural framework, describes the deep-crustal structure of the SPBA area as interpreted from gravity, magnetic and deep-seismic reflection data. It also briefly considers the main hypotheses for basin development.
- Chapter 3, Tectonic evolution, gives an overview of the evolution of the SPBA area from Proterozoic times to the present. This overview is based on a series of palaeogeographic maps for selected geological time intervals and on tectonic element maps that show the main episodes of basin development. The maps are accompanied by regional seismic sections. The influence of tectonic events on hydrocarbon-trapping mechanisms is also considered.

2.1.2 Chapters 4 to 12

Chapters 4 to 12 describe the stratigraphy of the pre-Devonian to Cenozoic geology (**Figure 1.5**). The chapter divisions are not necessarily coincident with geological system boundaries, but may represent

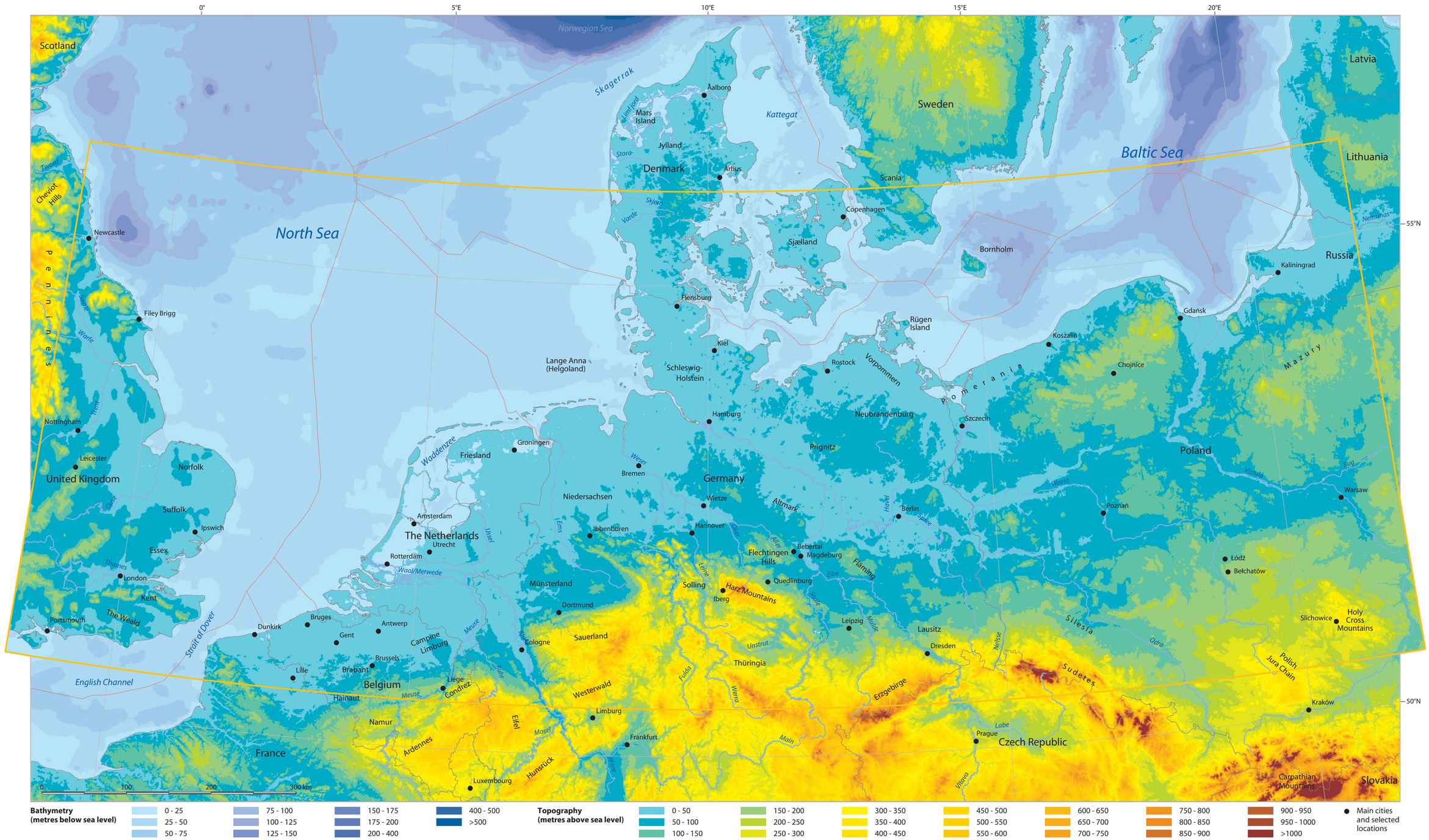

Figure 1.2 Topography and bathymetry. Based on data from the National Geophysical Data Centre (www.ngdc.noaa.gov/mgg/topo/globeget.html). The locations include the places where the photographs at the start of each chapter were taken.

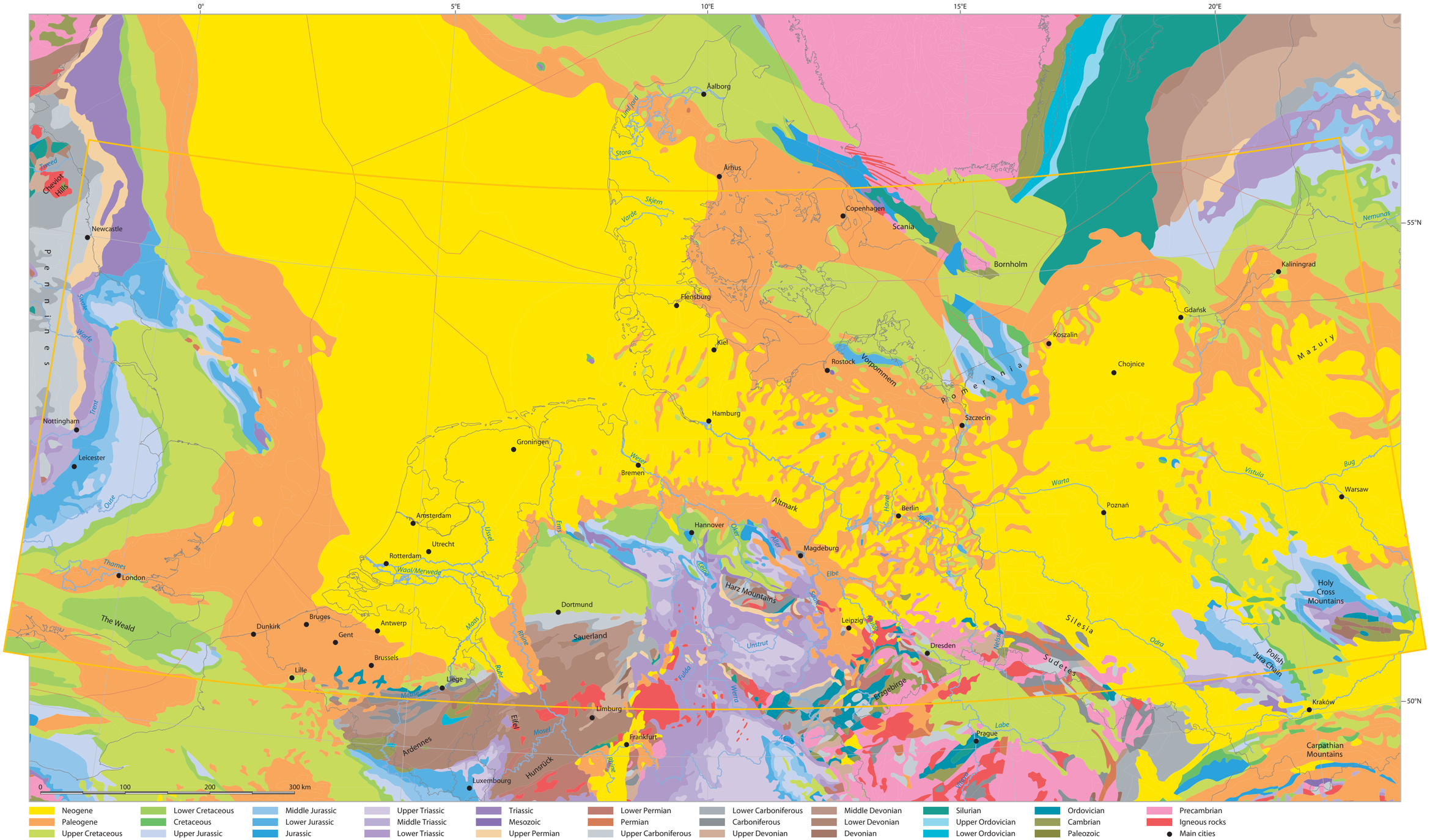

Figure 1.3 Pre-Quaternary subcrop. Based on the 1:5 Million International Geological Map of Europe and Adjacent Areas – IGME 5000. (Asch, 2005).

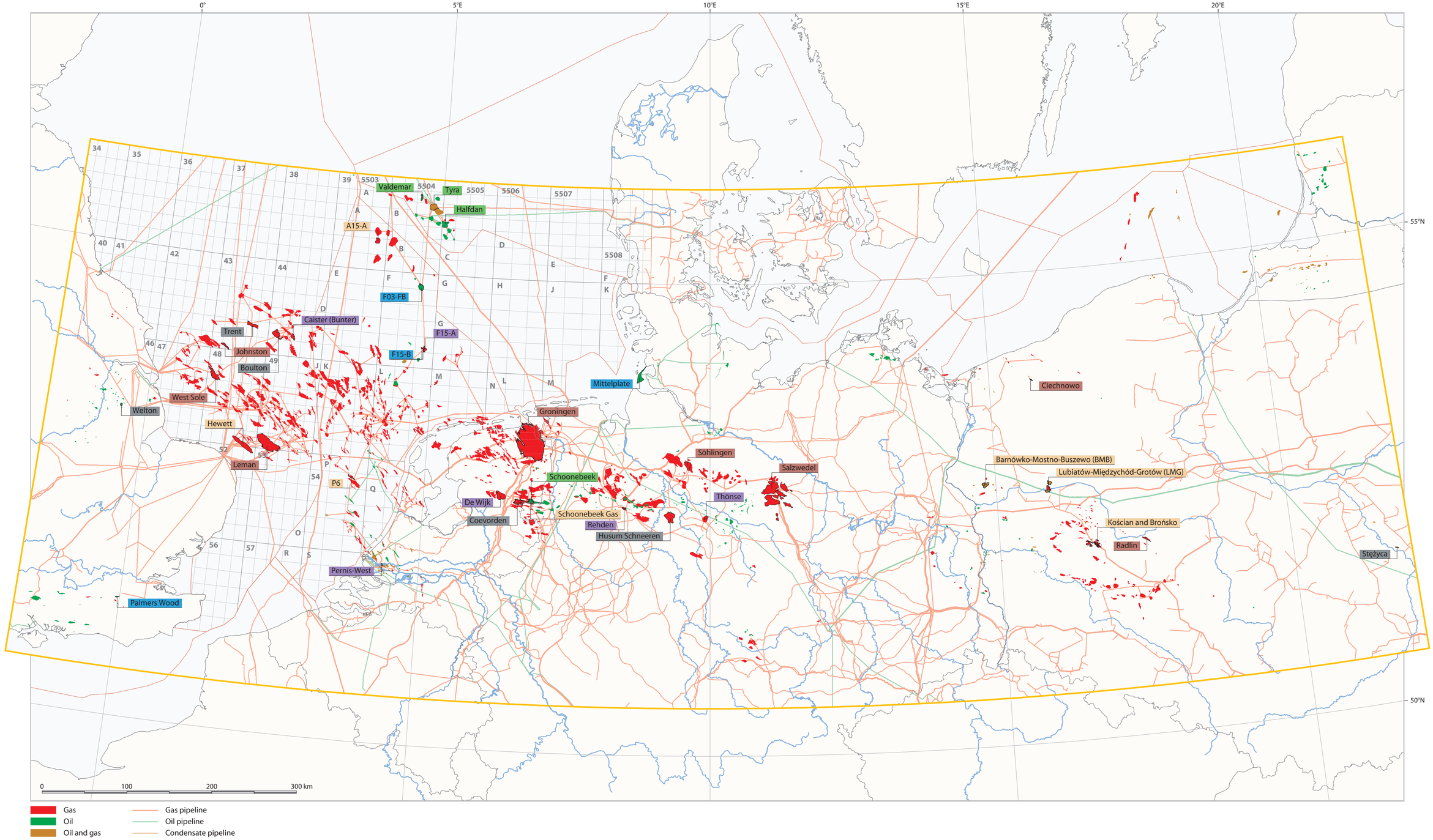

Figure 1.4 The distribution of about 1240 oil and gasfields in the SPBA area. The 35 hydrocarbon fields described in Chapters 6 to 12 are shown , colour-coded according to the stratigraphic chapter in which they are found. The pipeline infrastructure information was provided by IHS Energy. Quadrant blocks and their numbering system is shown for the offshore sectors of the UK, Netherlands, Germany and Denmark.

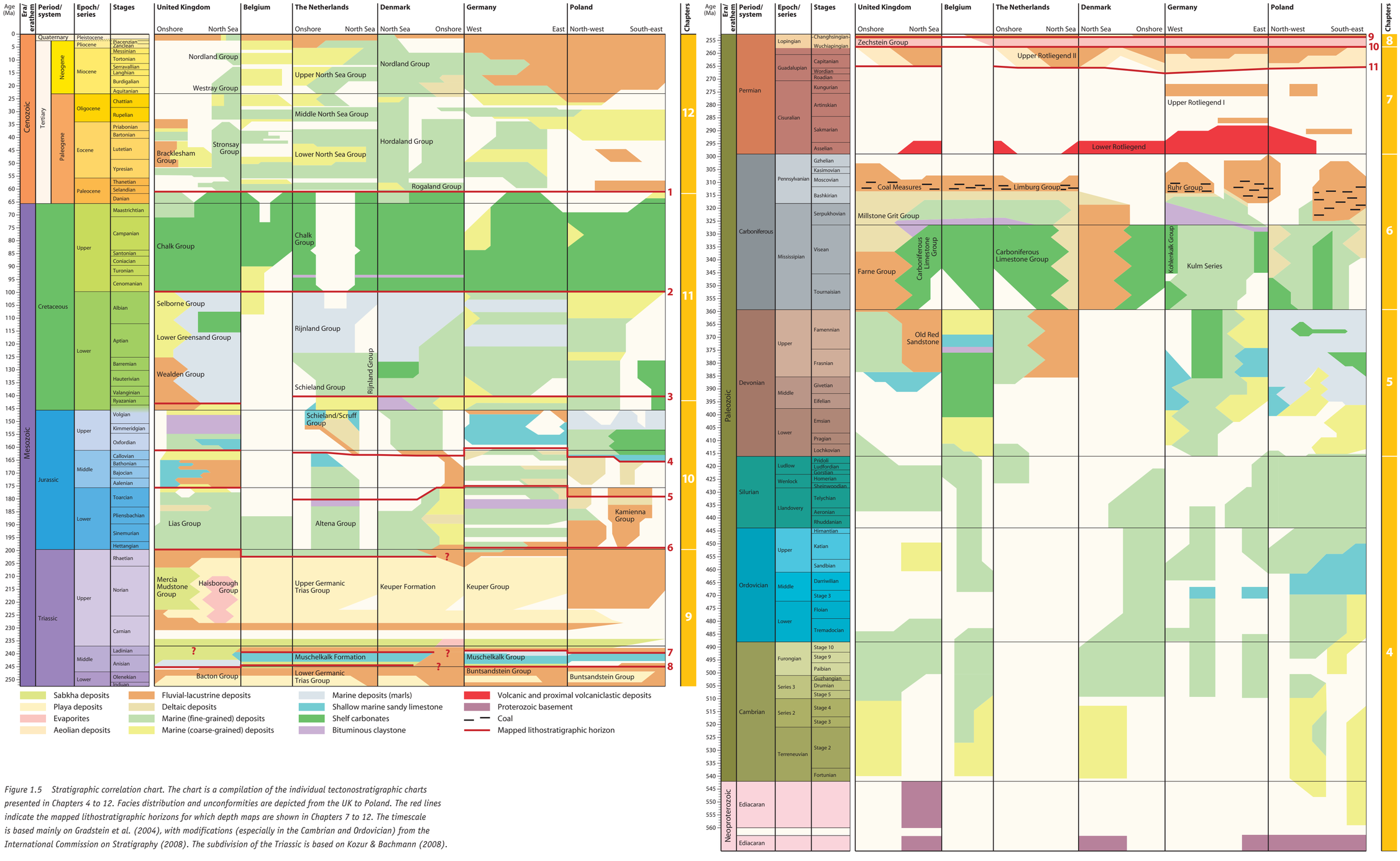

Figure 1.5 Stratigraphic correlation chart. The chart is a compilation of the individual tectonostratigraphic charts presented in Chapters 4 to 12. Facies distribution and unconformities are depicted from the UK to Poland. The red lines indicate the mapped lithostratigraphic horizons for which depth maps are shown in Chapters 7 to 12. The timescale is based mainly on Gradstein et al. (2004), with modifications (especially in the Cambrian and Ordovician) from the International Commission on Stratigraphy (2008). The subdivision of the Triassic is based on Kozur & Bachmann (2008).

major unconformities or easily recognisable and commonly used markers defined from seismic or well-log data (**Figure 1.6**). Each chapter is broadly standardised with similar types of illustrations including tectonostratigraphic charts, depth and thickness maps and, in most cases, well-correlation panels and seismic profiles. Although some chapters have additional information, they generally follow a standard layout:

- **Introduction**. Describes the stratigraphic subdivisions and outlines the structural, stratigraphic and palaeogeographic evolution of the SPBA area during the relevant geological time interval. Aspects of previous research are also introduced.
- **Stratigraphy**. Introduces stratigraphic schemes and describes the main stratigraphic units and their depositional environments. Authors have been given the freedom to choose the stratigraphic scheme that they consider to be the most suitable to describe the geology of their chapter. Lithostratigraphic descriptions take into account the current nomenclatures of the different countries (see section 3) as well as any local variations between sub-basins. In general, the stratigraphy is described from the UK in the west to Poland in the east.
- **Petroleum geology**. This section describes typical hydrocarbon occurrences, their play types, source rocks, migration systems, representative trap styles and reservoir characteristics. Most chapters include descriptions of selected hydrocarbon fields with diagrams to illustrate their geological setting. A total of 35 hydrocarbon fields have been selected for detailed description (**Figure 1.4** and **Table 1.1**).
- **Diagrams**. In addition to the various types of standardised maps (see Section 5 and **Appendix 2**), a number of standardised diagrams have been included to provide continuity between the stratigraphic chapters. These include:
  - A tectonostratigraphic correlation chart illustrating relationships between stratigraphic nomenclatures commonly in current use or those that have been historically significant;
  - Well-correlation panels showing the relationships between the principal units across each of the chosen stratigraphic intervals;
  - Seismic-line and geological profiles illustrating stratigraphic successions, structures and other relevant features.

Table 1.1 Hydrocarbon fields described in the Atlas.

Hydrocarbon field	Chapter	Section	Appendix	Country	Operator	Result
Boulton	6	6.3.1	3.2	UK	ConocoPhillips	Gas
Trent	6	6.3.2	3.2	UK	Perenco	Gas
Welton	6	6.3.3	3.3	UK	Star Energy	Oil
Coevorden	6	6.3.4	3.2	NL	NAM	Gas
Husum Schneeren	6	6.3.5	3.2	GE	EMPG (+GDF SUEZ)	Gas
Stężyca	6	6.3.6	3.7	PL	POGC	Oil and gas
Leman	7	6.1.1	3.2	UK	Shell/Perenco	Gas
Johnston	7	6.1.2	3.2	UK	E.ON Ruhrgas	Gas
West Sole	7	6.1.3	3.2	UK	BP	Gas
Groningen	7	6.2.1	3.2	NL	NAM	Gas
Söhlingen	7	6.3.1	3.2	GE	EMPG	Gas
Salzwedel	7	6.3.2	3.2	GE	GDF SUEZ	Gas
Ciechnowo	7	6.4.1	3.5a	PL	POGC	Gas
Radlin	7	6.4.2	3.6a	PL	POGC	Gas
Hewett	8	3.1	3.2	UK	ENI	Gas
P6	8	3.2	3.2	NL	Wintershall	Gas
Schoonebeek Gas	8	3.3	3.2	NL	NAM	Gas
Barnówko-Mostno-Buszewo	8	3.4	3.6b	PL	POGC	Oil and gas
Kościan and Brońsko	8	3.5	3.6a	PL	POGC	Gas
Lubiatów-Międzychód-Grotów	8	3.6	3.6b	PL	POGC	Oil and gas
Caister (Bunter)	9	4.1.1	3.2	UK	ConocoPhillips	Gas
De Wijk	9	4.1.2	3.2	NL	NAM	Gas
F15-A	9	4.1.3	3.2	NL	Total	Gas
Pernis-West	9	4.1.4	3.2 and 3.11	NL	NAM	Oil and gas
Rehden	9	4.1.5	3.2	GE	Wintershall	Gas
Thönse	9	4.1.6	3.12	GE	EMPG	Gas
Palmers Wood	10	3.6.1	3.8	UK	Star Energy	Oil
F03-FB	10	3.6.2	3.10	NL	NAM	Gas
F15-B	10	3.6.3	3.2	NL	Total	Gas
Mittelplate	10	3.6.4	3.12	GE	RWE Dea	Oil
Schoonebeek	11	4.1	3.12	NL	NAM	Oil
Halfdan	11	4.2	3.9	DK	Maersk	Oil
Tyra	11	4.3	3.9	DK	Maersk	Gas
Valdemar	11	4.4	3.9	DK	Maersk	Oil
A15-A	12	9.2.1	3.13	NL	Centrica Energy	Gas

2.1.3 Chapters 13, 14 and 15

Chapter 13, Petroleum generation and migration, provides an overview by focusing on the various source rocks in the SPBA area.

Chapters 14 and 15 have been produced mainly by representatives from Licensing Authorities of the six participating countries or a delegated person from their National Geological Survey or oil company: Department of Energy and Climate Change (DECC; UK), Administration for Natural Resources and Energy (ANRE; Belgium), Ministry of Economic Affairs (The Netherlands), Danish Energy Agency (DEA; Denmark), State Authority for Mining, Energy and Geology (LBEG; Germany) and Polish Oil and Gas Company (POGC; Poland).

- Chapter 14, Licensing and exploration history, reviews the history for each country and includes charts with historical overviews of drilling and seismic data acquisition. The chapter also examines the success rates for discovering hydrocarbons in the SPBA area and sets out each country's regulatory and fiscal framework.
- Chapter 15, Reserves and production history, aims to provide insights into the history of E&P in the SPBA area by dealing with two key questions: 1) why are the hydrocarbon fields located where they are? and 2) how has the discovery of these fields, and the associated hydrocarbon volumes, evolved over time?

2.1.4 Chapter 16

The final chapter addresses other potential options for the use of the subsurface successions, such as gas and CO_2 storage, geothermal energy recovery and solid-fuel minerals (coal, lignite). Other options for the use of the subsurface, such as salt, ore and mineral mining, are not addressed as they do not have a direct relation to petroleum geology.

2.1.5 Appendices

A glossary has been included to explain selected terms that may not be familiar to the non-specialist reader (**Appendix 1**). A list of maps that are available in GIS format is given in **Appendix 2** including a reference to the figure number in the Atlas. A full listing of hydrocarbon fields presented in the SPBA is given in **Appendix 3** according to the petroleum provinces described in chapters 13 and 15.

A number of conventions and standardised formats are used in the Atlas. The metric system is used for all measurements unless stated otherwise. Depths are given in metres (or kilometres) below sea level in cross-sections and depth maps (**Appendix 4**). Where there are alternative names for the same geological structure, the nomenclature on the tectonic element maps presented in Chapter 3 is used. The references cited in each chapter are given in **Appendix 5**.

3 Stratigraphic framework

Each of the participating geological surveys has published a lithostratigraphic nomenclature for their country: UK (Cameron et al., 1993; Johnson et al., 1994; Lott & Knox, 1994; Waters et al., 2007), Belgium (Bultynck & Dejonghe, 2002), the Netherlands (Van Adrichem Boogaert & Kouwe, 1993), Denmark (Michelson et al., 2003; Schiøler et al., 2005), Germany (STD 2002; Menning & Hendrich, 2005), and Poland (Wagner, 2008).

Lithostratigraphic correlation between each country has been one of the most challenging aspects of the Atlas. The results of these correlations are shown in the tectonostratigraphic charts presented in Chapters 4 to 12. A general overview of the stratigraphy of the SPBA area has been compiled from these individual charts (**Figure 1.5**). The compiled chart depicts the major lithologies and unconformities within the area and illustrates the stratigraphic relationships between the six participating countries.

A number of conventions have been used to harmonise the tectonostratigraphic correlations, the main issue being the use of numerical ages. In principle, the geochronology of Gradstein et al. (2004) is followed although there are a few exceptions, which are explained in the relevant chapter. The main deviation from their geochronology is in the Triassic chapter, where the Permian-Triassic boundary is placed at 252.5 Ma, whereas Gradstein et al. (2004) give an age of 251 Ma. The geochronology of the Triassic stages also differs from the generally accepted standard geochronology (see Chapter 9 for further discussion).

The figures and maps showing, for example, thickness, facies and resources in Chapters 4 (Pre-Devonian) to 12 (Cenozoic) are based on the stratigraphic units in each area. Most are lithostratigraphic mapping units; their boundaries are therefore not isochronous and represent slightly variable time spans. These well-established units provide the most practicable approach to mapping geological units across the entire SPB area. The unit boundaries generally follow the major chronostratigraphic boundaries, with a few notable exceptions; i.e. the base of the Zechstein (Chapter 8) falls within the Upper Permian; the base of the Triassic (Chapter 9) is placed just below the chronostratigraphic Permian-Triassic boundary; the base of the Cretaceous (Chapter 11) coincides with the Boreal Jurassic-Cretaceous boundary (i.e. base Ryazanian), although the base of the Cretaceous is formally placed at the base of the Berriasian Stage, which correlates to the base of the upper Volgian (Hoedemaeker & Herngreen, 2003); the base of the Cenozoic (Chapter 12) is placed at the top of the Chalk Group, which approximates to the top of the Danian in much of the area.

It is clear that the mapped lithostratigraphic horizons (**Table 1.2**) do not always coincide with the interpreted horizons on seismic data. In general, these discrepancies have been corrected by adding a residual map, derived from the mismatch with well depths, to the grid of the interpreted seismic horizon to produce a well-corrected surface of the mapped horizon. As the boundaries of most units are not isochronous, particularly on a regional scale, their absolute ages may vary. The ages given in **Table 1.2** are therefore only approximate.

Table 1.2 Overview of the lithostratigraphic horizons mapped in the SPBA area (see the corresponding depth maps in Chapters 7 to 12). These horizons have been numbered from 1 to 11 and are indicated on Figure 1.5 and also on the individual tectonostratigraphic charts in Chapters 7 to 12.

No.	Name of mapped lithostratigraphic horizon	Description	Approximate age (Ma)
1	Near base Tertiary	Top Danian or top of the Chalk Group	61
2	Base Upper Cretaceous	Base of the Chalk Group (base Cenomanian)	100
3	Near base Lower Cretaceous	Approximately near base Ryazanian; may correspond to an unconformity	140
4	Near base Upper Jurassic	This horizon corresponds to a level varying from the Callovian to the base of the Oxfordian.	162
5	Near base Middle Jurassic	This level corresponds to the top of the Lias Group (base West Sole Group and equivalents in the UK; top of the Posidonia Shale Formation in the Netherlands) and is a marked unconformity over much of the area	176
6	Near base Lower Jurassic	Base of the Lias Group. This level corresponds to the mudstone/sandstone boundary in the upper part of the Rhaetian, which is often an unconformity	201
7	Near base Upper Triassic	This level corresponds to a change from clastic-dominated to limestone-dominated sediments. It is not mapped in the UK and Denmark	237
8	Near base Middle Triassic	Base of the Röt evaporites	245
9	Near base Lower Triassic	Base of the Buntsandstein	253
10	Base Zechstein	The base-Kupferschiefer reflector is mostly indistinct or not present because of low impedance contrast. In general, the seismic reflector that has been used is a younger horizon: top basal anhydrite (Stassfurt series). An agreed thickness has been added to this marker to create the base-Zechstein map	258
11	Base upper Rotliegend	This level corresponds with the base of the upper Rotliegend clastics. In general, the horizon was created by combining the upper Rotliegend thickness map, based on well data, and the depth of the base-Zechstein horizon	265

4 Data confidentiality and the SPBA Project Database

4.1 Data confidentiality

The confidentiality of data is determined by legislation in each country (see Chapter 14).

In the UK, the relevant confidentiality periods are:

- For data acquired under offshore licences awarded up to and including the 19th round (2001), confidentiality is maintained for 4 years, and for those awarded in the 20th and subsequent rounds for 3 years. For spec-seismic data acquired under offshore exploration licences, current guidelines (subject to annual review) require a 10-year confidentiality period.

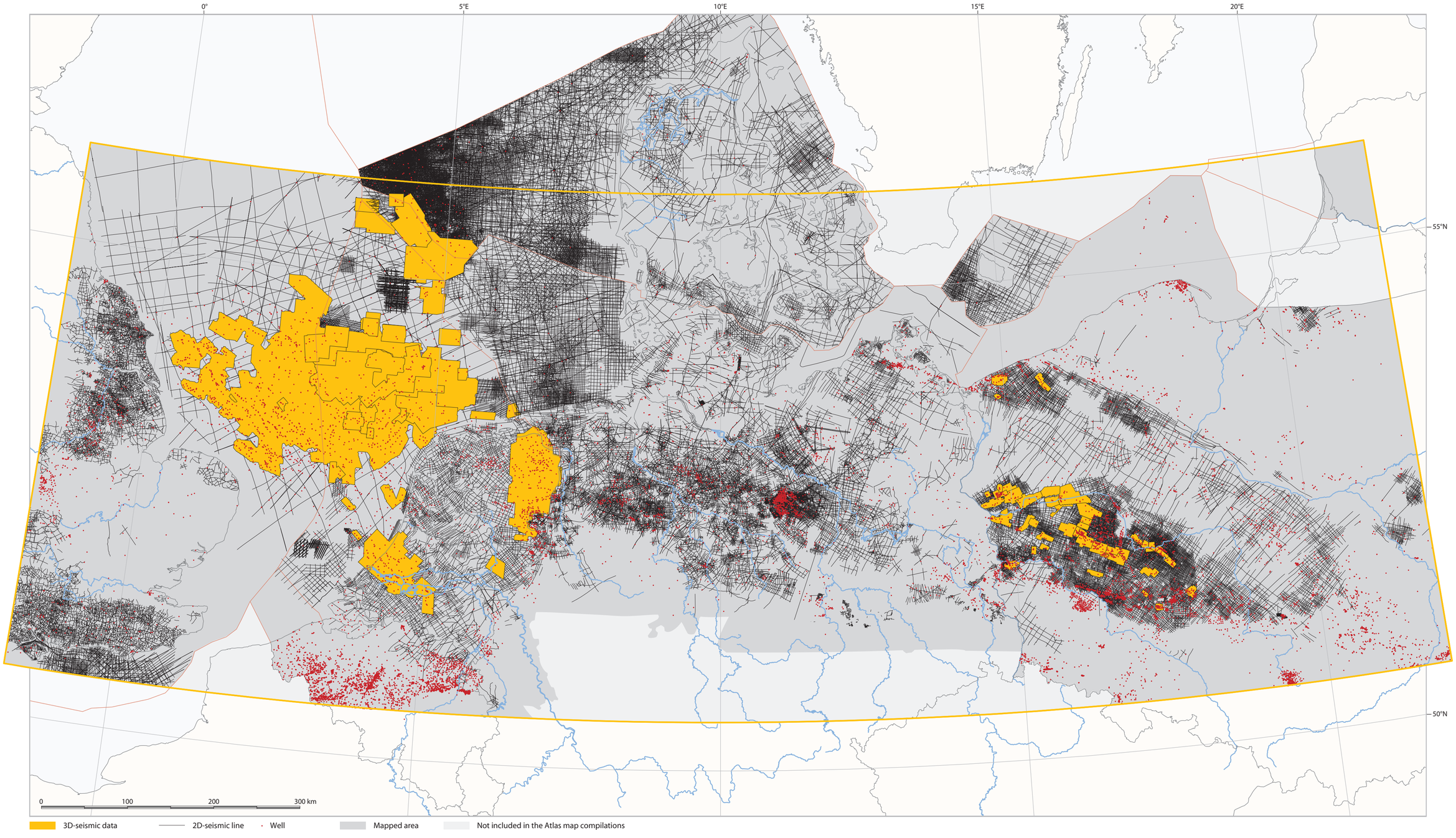

Figure 1.6 Locations of well and seismic data used to produce the 1 : 3 million scale lithostratigraphic depth maps.

- For data acquired under onshore licences awarded up to and including the 11th round (1989), confidentiality is maintained for 5½ years, and for those awarded in the 12th and subsequent rounds for 4 years.

In Belgium, most exploration data can be used publicly. In the Netherlands, a new Mining Law came into force on 1st January 2003. Before this date, there was no legal regulation for the release of onshore well and seismic data, whereas offshore data remained confidential for 10 years. Since the new Mining Law was established, all geological data becomes publicly available after 5 years.

In Denmark, all relevant data used for regional mapping have been released. All geological data from Germany are confidential and the initial owner must give approval for subsequent access. Although there are differences between Federal States, German regulations for exploration and production of mineral resources and hydrocarbons still stipulate that data are owned by the companies that carried out the exploration and production. Under these rules, a certain amount of data has to be delivered to the Geological Surveys and Mining Authorities of the Federal States, who can use the data only for their internal work. For detailed data that are published, permission must be requested from all relevant oil and gas companies. A special agreement for data use within the SPBA project was therefore established between 'Wirtschaftsverband Erdöl-Erdgas' (www.erdoel-erdgas.de), the Geological Surveys of the Federal States and the Federal Institute for Geosciences and Natural Resources (BGR). In Poland, the Geological and Mining Law (of 4th February 1994) states that ownership of data collected during geological activities between 1st January 1989 and 31st December 2001 is retained by the funding organisation, and that the data gained from (and prior to) 1945 to 31st December 1988 and after 1st January 2002 belong to the State. The organisation financing the geological activity has the right to use the data free of charge for a period of 5 years. The Polish Geological Institute (PGI) also has the right to use and publish the data. The Polish Oil and Gas Company (POGC) owns 99% of the deeper subsurface data.

4.2 Geological data repositories

United Kingdom
The Department of Energy and Climate Change (DECC) is responsible for licensing exploration and regulating development of the UK's oil and gas resources. DECC aims to make as much of this information and data publicly available as early as possible; the database of formation tops from UK released wells is available on their website: www.decc.gov.uk. DEAL is a web-based service that provides free index information about UK offshore oil and gas and has catalogues of data available from release agents, spec-survey companies and operators: www.ukdeal.co.uk.

Belgium
Most exploration data are available from the Geological Survey of Belgium (GSB) and all geological publications and maps can be ordered via www.naturalsciences.be/geology/products. The only exceptions are some data from gas-storage projects. Due to changes in the Belgian Government structure, there is no longer a unique repository for geological data, and recent exploration data are no longer available from the GSB. Geological data from northern Belgium (Flanders) can be obtained from the 'Databank Ondergrond Vlaanderen' (dov.vlaanderen.be) or from gisvlaanderen.be. Other unpublished documents (logs, well-reports, cores, seismic sections) must be examined at the office, although the GNOSIS internet portal (see above) does provide internet access to metadata. Geological data and maps from the Walloon region can be accessed at environnement.wallonie.be/cartosig.

The Netherlands
Non-confidential well and seismic data, licences and some publications can be ordered or downloaded via the following links: www.nlog.nl and www.dinoloket.nl.

Denmark
All data and well information are available on the Geological Survey of Denmark and Greenland (GEUS) website (www.geus.dk) and information concerning regulations and licensing on the website of the Danish Energy Authority (ENS): www.ens.dk.

Germany
Exploration data are stored at the Geological Surveys or the Mining Authorities of the Federal States (within the SPBA area these are Niedersachsen, Nordrhein-Westfalen, Schleswig-Holstein, Sachsen-Anhalt, Brandenburg and Mecklenburg-Vorpommern). Geological publications and maps can be ordered from those institutions or from the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

Poland
Permission has to be obtained from the owner for the use of geological information on condition of payment for commercial purposes. If the owner of the geological information is the Ministry of Treasury then permission is granted by the Director of the Polish Geological Institute (authorised by the Minister of the Environment). The right to use the geological information is granted for a limited time period. Detailed information about regulations, available geological documentation and available well data can be obtained from the PGI website at www.pgi.gov.pl

4.3 SPBA Project Database

The SPBA Project Database contains various types of spatial data: well, seismic, oil and gasfields, geochemical and gas composition. Each type is described in the following section and their attributes are presented in **Tables 1.3** to **1.8**.

4.3.1 Well and seismic data

Databases of exploration wells, 2D-seismic lines and 3D-seismic surveys were compiled from input provided by the participating countries. They are provided as an ArcGIS Geodatabase. **Tables 1.3**, **1.4** and **1.5** list the attributes of these data.

Table 1.3 Metadata for exploration wells.

Name	Description
ID	Unique number for each entry
Country	Name of the country where the well is situated
Well/location name	Name of the well or well location (geographic)
Well short name	Short name, number or code of the well
Co-ordinates (x, y)	Co-ordinates of the well surface location
Spud date	Start date (drilling of the well)
Completion date	End date (drilling of the well)
Owner/operator	Name or ID of the owner or operator of the well
End depth (MD, TVD)	End depth of the well (measured depth, total vertical depth)
End stratigraphy (general, details)	Stratigraphic level at the end depth of the well (general period, formation or group)
Target stratigraphy (general, details)	Target stratigraphic level (general period, formation or group)
Result	Result with respect to hydrocarbon exploration (e.g. gas, oil, dry hole)

Table 1.4 Metadata for 2D-seismic lines.

Name	Description
ID	Unique number for each entry
Country	Name of the country supplying the data / where the 2D seismic line was recorded
Survey	Name of the 2D-seismic survey
Line	Name of the 2D-seismic line
Additional information	Optional additional information on the survey or survey operator
Completion date	Year (or a more specific date) when the seismic line was recorded

Table 1.5 Metadata for 3D-seismic surveys.

Name	Description
ID	Unique number for each entry
Country	Name of the country supplying the data / where the 3D-seismic survey was recorded
Survey	Name of the 3D-seismic survey
Additional information	Optional information about the survey or survey operator
Completion date	Year (or a more specific date) when the seismic survey was recorded

4.3.2 Oil and gasfields

A dataset of oil and gasfields in the SPBA area has been compiled with input mainly from the participating organisations (**Table 1.6**). In some cases, regulatory or commercial confidentiality, or lack of data, did not allow the datasets to be completed. Where possible, the data gaps were filled by data provided by IHS Energy (see **Appendix 3**).

Table 1.6 Oil and gasfield attribute data in the SPBA Project Database.

Name	Description
ID	Unique number for each entry
Country	Name of the country where the field is located
Field name	Name of the field
Discovery year	Year in which the discovery well was drilled
Discovery well	Well that discovered the field
Reservoir age	Age of the reservoir rock
Reservoir lithology	Lithology of the reservoir
Fluid type	Gas, oil or oil and gas
Source rock	Name of the rock that sourced the reservoir
Depth	Approximate depth of the top of the structure
Initial pressure	Initial pressure of the reservoir
Temperature	Temperature of the reservoir
Field size	Gas or stock tank oil initially in place (STOIIP)
Recoverable volume	The quantity of oil or gas to be recovered
Cumulative production	Amount of gas/oil produced until present
Development status	Status of the development
Year start of production	Year of production start
Year end of production	Year of production end
Petroleum province number	Number of petroleum province used in Appendix 3 and Chapter 15

4.3.3 Source-rock geochemistry

The geochemical properties of the source rocks in the SPBA area are described in Chapter 13. The diagrams and graphs in the chapter are based on the data held in the SPBA Project Database (**Table 1.7**). This database was compiled from contributions by the participating countries with additional information from published sources. The geochemical data show the source-rock organic-matter quality and quantity, as well as its maturity. Rock-Eval pyrolysis and vitrinite reflectance (VR) data make up most of the geochemical data in the SPBA Project Database, although it also holds molecular and isotope data. All data are categorised by area (basin) and unit (stratigraphy).

Table 1.7 Approximate numbers of datasets in the SPBA Project Database – source-rock geochemistry.

Country	OM quantity (TOC)	OM quality (S_2, HI)	Maturity	Other (%Ro, T_{max})	Main data suppliers
Entire database	9750	9950	13 450	720	All participating countries
United Kingdom	900	850	900	180	TNO, CCGS, IGI Ltd.
Belgium	200	200	250	0	GSB, TNO
The Netherlands	4500	4500	8650	200	TNO
Denmark	1200	1200	1350	40	GEUS
Germany	1100	1100	750	250	BGR
Poland	1600	1550	1250	30	POGC, PGI
Lithuania/Russia	250	550	300	20	IGI Ltd.

4.3.4 Gas composition

In addition to source-rock data, the SPBA Project Database includes a gas database and selected molecular data on oils. The gas database consists of gas composition and isotope data from more than a thousand locations (**Table 1.8**). The database contains contributions from the participating countries combined with data from the Northwest European Gas Atlas Project (Lokhorst et al., 1998).

Table 1.8 Number of datasets in the SPBA Project Database – gas composition.

Country	Gas composition	Gas isotopes	Main data suppliers
Entire database	2309	130	All participating countries
United Kingdom	26	0	NW European Gas Atlas Project
The Netherlands	1416	130	TNO
Denmark	14	0	NW European Gas Atlas Project
Germany	258	0	NW European Gas Atlas Project
Poland	595	0	POGC, PGI

5 SPBA mapping activities

One of the main goals of the project was to create a comprehensive set of digital maps for the entire SPBA area. The maps show the location, depth, vertical thickness, subcrop, tectonic element, source rock, reservoir (facies) distribution and paleogeography of oil and gasfields throughout the SPBA area (**Appendix 2**).

The following geological papers and atlases dealing with the regional geology and mapping of the participating countries have been published: UK (Cameron et al., 1992); the Netherlands (TNO-NITG, 2004; Duin et al., 2006); Denmark (Britze et al., 1995; Japsen, 1998; Japsen, 1999; Vejbæk et al., 2003); Germany (Reinhardt, 1991; Kockel, 1995; Kockel, 1996; Bandlowa, 1998; Baldschuhn et al., 2001) and Poland (Dadlez et al., 1998; Górecki, 2006a, 2006b; Świdrowska et al., 2008). Other publications that describe the geology of the SPBA area and its margins include: Ziegler (1990a), Lokhorst et al. (1998), Geluk (2005) and McCann et al. (2008c).

5.1 Map projection and scale

Maps of the entire SPBA area are presented at 1 : 3 million and 1 : 6 million scales. The map projection is Lambert Conformal Conic, which is well suited for displaying extended east-west areas in mid-latitude regions. The map projection parameters are listed in **Table 1.9**.

Table 1.9 Map projection parameters used in the SPBA.

Standard Parallels	52.67°N and 54.33°N
Central Meridian	10°E
Latitude of origin's projection	48°N
False Easting	815000
False Northing	0
Datum	European Datum 1950 (ED50)
Spheroid	International 1924

5.2 Depth maps

The depth maps were created by the National Geological Surveys and compiled by TNO. The 3D-seismic survey area, the total length of interpreted 2D-seismic lines and the total number of wells used in the compilations are given in **Table 1.10**. The wells and seismic surveys used to compile the lithostratigraphic depth maps are shown in **Figure 1.6**.

United Kingdom
The maps produced for the UK offshore area are based on data generously supplied by Petroleum Geo-services (PGS) from their 2D North Sea Digital Atlas and the PGS Southern North Sea 3D MegaSurvey Projects. The data were derived by merging oil company (released) and contractor non-exclusive 2D- and 3D-seismic data (PGS and others). The isochron maps were converted from time to depth by the British Geological Survey (BGS) using the seismic velocity model of Van Dalfsen et al. (2006), which was extended from the Netherlands into the UK offshore area. Released well data for the UK part of the SPBA area were also made available by the DECC.

The substantial dataset used to construct the maps for the UK onshore area were derived from exploration (hydrocarbon, coal and water) and production companies and are held in the BGS archives. Stratigraphic information from boreholes and mine shafts have been used when necessary to interpret the seismic data. The seismic data were converted from time to depth using models based on calibrated velocity logs from the boreholes.

There is a much greater density of seismic data available offshore than onshore in the UK. However, the much higher concentration of borehole and outcrop data available onshore has enabled maps to be compiled with a high degree of confidence.

Belgium
Maps are based on publicly available data, mainly from geo-energy prospects other than hydrocarbon exploration. Deep geological reconnaissance boreholes and geophysical surveys from the Campine Basin have also been used.

The Netherlands
Data used to compile the maps were acquired during the many oil exploration and production activities carried out since the beginning of the 20th century. Only publicly released seismic and borehole data have been used. Stratigraphic information from the boreholes has been used in the interpretation of the seismic data. The interpreted seismic data were converted from time to depth using mainly depth-dependent velocity functions (Van Dalfsen et al., 2006).

The maps of the onshore area are derived from a regional mapping project (TNO-NITG, 2004), whereas maps of the offshore area are based on all available interpretations of 2D- and 3D-seismic surveys (Duin et al., 2006).

Denmark
The comprehensive database used to compile the maps includes high-resolution and conventional 2D- and 3D-seismic data as well as published maps (e.g. Britze et al., 1995). More than 180 released deep wells and numerous onshore water wells have provided controls on the mapping results. Stratigraphic information from these wells has been used in the interpretation of the seismic data.

Depth conversion was undertaken using depth-dependent velocity functions including a gradient of velocity increasing with depth (e.g. Japsen, 1998, 1999). The surface velocity variation is typically mapped on the basis of well data and may reflect lateral facies changes, burial anomalies or excess fluid pressures. For example, the Cenozoic velocity model consists of a single layer for onshore Denmark and two layers for the offshore area. The division between the two layers is taken at the 'near top Middle Miocene marker', which approximates to the top of the overpressured section. The parameters for these layers were taken from Britze et al. (1995) and Japsen (1999) based on a large well database from the entire North Sea, which is generally applicable to most of the surrounding area.

Germany
The comprehensive database used to construct the maps includes data from published sources and the Geological Surveys and Mining Authorities of the Federal States (mainly Niedersachsen, Schleswig-Holstein, Nordrhein-Westfalen, Sachsen-Anhalt, Mecklenburg-Vorpommern and Brandenburg), oil and gas companies, and BGR in Hannover and Berlin.

Data consist of conventional 2D-seismic data, a limited number of 3D-seismic surveys (provided by RWE DEA and Wintershall for the north-western German offshore area) and published maps. Two major well databases have been used: the oil and gas exploration database from the State Authority for Mining, Energy and Geology and the BGR well database. These well databases contain metadata and stratigraphic and lithological data for all major wells drilled for exploration and production of hydrocarbons, salt, ores, coal and other natural resources, and also include wells drilled to help map the deeper subsurface.

Two major compilations were used as the basis for mapping in north-west Germany, the 'Tectonic Atlas of North-West Germany' (Kockel, 1996) and the 'Geotektonischer Atlas von Nordwestdeutschland und dem deutschen Nordsee-Sektor' (Baldschuhn et al., 2001). BGR mapping was carried out during these projects between the mid-1970s and 1998. More than 1300 boreholes have been analysed to establish regional velocity models, taking into account different starting velocities and different velocity gradients for ten generalised stratigraphic layers (Jaritz et al., 1991). Maps were compiled at 1 : 100 000 scale for fourteen stratigraphic horizons (from base Middle Miocene to base Zechstein) and were published at 1 : 300 000 scale (Baldschuhn et al., 2001).

The compilation for eastern Germany is the 'Geophysical Atlas of Northeast Germany' (Reinhardt, 1991), which was put together between 1960 and 1991 by Geophysik Leipzig, the company solely responsible for geophysical exploration during German Democratic Republic (GDR) times. This atlas was updated using all 2D-seismic results until 1989. More than 1000 boreholes were analysed between 1960 and 1989 to establish regional velocity models, taking into account different starting velocities and velocity gradients for seven generalised stratigraphic layers and eight different regions of the GDR. Corresponding maps (velocity and depth) at various scales (1 : 100 000 to 1 : 500 000) have not been published, but are available from the BGR in Berlin and the Geological Surveys of the Federal States.

Map compilation for the German area of the SPBA was based on:
- Digitisation of geophysical maps of eastern Germany and recalibration of the maps by adjusting depth maps with well data from the area and the results of the interpretation of 2D-seismic surveys made after 1989.
- Incorporation of data from Petrobaltic (a former company owned by Russia, Poland, and partly by the GDR) for the German sector of the Baltic Sea.
- Adjustment of the depth maps of the 'Geotektonischer Atlas von Nordwestdeutschland und dem deutschen Nordsee-Sektor' with depth information from wells and some new 2D-seismic data.
- Incorporation of seismic data from Wintershall and RWE DEA for the north-western German offshore and depth maps from the Geological Survey of Nordrhein-Westfalen.
- Matching of mapping results between the western and eastern German parts of the SPBA by detailed well analyses and 2D-seismic interpretations of selected profiles.
- Determination of a residual map representing the mismatch between the depth in the wells and the depth of the seismic reflector. The residual map is added to the grid of the seismic reflector to obtain a well-corrected surface of true vertical depth.

Major re-interpretation of seismic information used in the 'Tectonic Atlas of North-west Germany' and the 'Geophysical Atlas of Northeast Germany' was not possible because of limited staff resources. Work for the SPBA therefore focussed on areas where well and seismic results highlighted areas where there were problems matching the north-west and north-east German compilations and on areas with no previous interpretations.

As there are data gaps within Germany, especially in the Mecklenburger Bucht area and elsewhere in the Baltic Sea, note that the maps in these regions are mainly the result of interpolation from the surrounding areas.

Poland
Maps are based on data from published maps and atlases (Depowski, 1978; Dadlez, 1980a, 1998c; Pożaryski & Dembowski, 1983; Żelichowski, 1983; Dadlez et al., 1998; Górecki, 2006a, 2006b;) and archived data from digital and analogue maps, diagrams and geological cross-sections derived from geological reports from both research (regional geology) and exploration and production (hydrocarbons and thermal waters) programmes. Seismic data were used to elaborate the many analogue maps.

Table 1.10 The total number of wells, the entire 3D-seismic survey area and the total length of interpreted 2D-seismic lines used during mapping in each of the participating countries.

	UK[1]	BE	NL	DK[2]	GE[3]	PL[4]
Number of wells	Onshore >10 000 Offshore 3311	4017	1686	188	In general >10 000 2450	5083
3D seismic (km²)	20 473	0	37 200	0	3186	6659
2D seismic (km)	65 547	1282	51 000	177 200	136 717	97 785

1 From the 3311 offshore wells there are 1085 exploration, 527 appraisal and 1699 development wells.
2 Totals after 1st January 1960.
3 The total number of boreholes that have been considered in previous work from Germany is more than 10 000; however, only 2450 boreholes were analysed in detail during production of the SPBA.
4 Seismic data figures are based on information up to 2005.

6 Digital products

All grid and vector data presented in the SPBA are also available digitally on a DVD. The DVD includes all GIS maps shown in the Atlas (see Appendix 2) as ESRI Arc Map Document (MXD) and Adobe Portable Document Format (PDF). Attribute data of the SPBA Project Database are available in tabular format (see Section 4.3).

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