Carbonate platform slope succession in the Upper Devonian at Slichowice, Holy Cross Mountains, central Poland.
1.1 Date sources and literature review

Devonian rocks within the basement of the SPB are found primarily along the basin margins and adjacent regions (Figure 5.1). They may also occur in the onshore part of the basin, but are too deep to have been reached by brecciation. The hydrocarbon potential of the Devonian deposits within the SPB area remains limited even though Devonian reservoirs are locally very thin and include organic-rich sediments as well as carbonate and clastic rocks of good reservoir quality. This is partly because of the high thermal maturation level acquired by Devonian rocks during the Variscan Orogeny in most areas, on account potential reservoirs are exposed on the surface elsewhere. Although oil seepages can therefore be seen locally in some outcrops, for example in the Holy Cross Mountains, no hydrocarbons are currently produced from the Devonian.

This chapter is a compilation of the Devonian geology of the SPB area based on local and regional studies published mainly during the last decade. Additional information from boreholes that reached Devonian rocks has been provided by the on-going Geological Survey and, to a lesser extent, the oil industry and are included in the geological descriptions and the maps presented in Figures 5.1.5 and 5.2. A recent publication by Bełka & Narkiewicz (2008) provides an overview of the Devonian geology in central Europe, including the entire SPB area. The UK offshore stratigraphic succession was described by Gatliff et al. (1986), and there have been no published reports on the onshore Devonian strata of the UK since the work of Burton (1981). The Devonian stratigraphy of Belgium is described in overviews by Vliek et al. (2003) and Vlietinck & Dejonghe (2001). The Devonian geology of the Netherlands was described by Gatliff et al. (1997a). Summaries of Devonian depositional and palaeogeographical evolution of the Rheno-Hercynian Shell in Germany (Rheno-Massif, Harz Mountains) have been published by Meischner (1996), Meischner (1998) and Steins & Schäfer (2002), and the geotectonic evolution has been treated comprehensively by Frank (2000) and Grobe et al. (2000). The Devonian geology of the Bogen area (Germany), Pomerania (Poland) and the Baltic region was recently reviewed by Martyn, H. (2008); this compilation includes information from earlier papers by Vladek et al. (1977), Duda & Martyn (1987), Martyn (1999), Kozarska (1995), Kozarska et al. (1995), Kozarska & Tumans (2000) and Narkiewicz (2002). Information on Devonian rocks in various hexagonal stratigraphic units of the Saxo-Thuringian Zone was published by Franke & Zelazowski (2000).

1.2 Tectonic evolution

In terms of palaeogeography and geotectonic evolution, almost the entire SPB area was located on the passive continental margin of the Euramerica Palaeocontinent. A fragment of this palaeocontinent was separated from the margin of the East European Platform during post-Variscan erosion. Devonian strata are also exposed along the Saxo-Thuringian Zone, which can be traced within the Boulonnais (Wallace, 1968; Brice, 1988) where the succession is very similar to the Devonian of western Europe. Devonian rocks are also exposed along the Saxo-Thuringian Zone, which can be traced within the Boulonnais (Wallace, 1968; Brice, 1988), where the succession is very similar to the Devonian of western Europe. Devonian outcrops are found mainly along the southern margin of the SPB (Figure 5.2). Magnetic rocks in the Saxo-Thuringian Zone provide evidence for closure of the Rheno-Bezoarian-Liassic basin (P. Humpage, 1998), but no evidence of deformation or metamorphism related to this convergence episode has been observed within the Saxo-Thuringian continental margin. One scenario that has been put forward is that the opening of a narrow Rheno-Hercynian Ocean may have started before the Rheno-Bezoarian-Liassic basin closed (Frank, 2000). A strong pulse of extension had already started during Early Devonian times and led to the formation of a rift basin on the Rheno-Bezoarian Shelf filled with a considerable thickness (up to 14 km) of marine Lower Devonian sediments (Trägårdh et al., 2000). The extensional regime continued during Mid- and Late Devonian times and caused rapid subsidence of the shelf and the local occurrence of basaltic intrusions (Tarczewski et al., 2003) and the final collision took place during the Carboniferous.

Devonian strata throughout the SPB area have been consequently folded and locally metamorphosed within the Saxo-Thuringian Zone. The Devonian rocks are therefore deformed in the basement of the SPB, but there are no major unconformities within the Devonian succession. The only exceptions occur in eastern England and beyond the SPB area in Wales and northern England, where Lower Devonian strata are slightly deformed and unconformably overlain by rocks that are mainly of very Late Devonian (Famennian) age. This regionally important unconformity is related to the Aalandian Phase, the final Caledonian deformation episode that took place at the Upretian Ocean closed (McKerrow, 1998) during the Late Emilian and Mid-Dervanian interval (Ferrers et al., 2002).

Stratigraphic gaps associated with extensional phenomena are quite common in the Devonian succession of the SPB area. One such gap is a global discontinuity and occurs at the top of the Devonian sequence, usually encompassing the equivalent Famennian and lower Carboniferous strata. In the past, this discontinuity was related to the Brotian Phase of the Devonian Orogeny in Belgium (130 Ma) concept of tectonic deformation. However, recent studies have shown that the (gaps) were due to glacially induced eustatic sea-level changes (e.g. Stroob et al., 2000; Sandberg et al., 2002).

1.3 Distribution of Devonian rocks

Devonian strata are found mainly along the southern margins of the SPB area (Figure 5.1). In the UK part of the SPB area, there is only one outcrop at Meare, Worlewick, where Upper Devonian strata are unconformably overlying Cambrian and Triassic rocks and unconformably overlying marine strata (Taylor & Rust, 1971). In northern France, Devonian rocks are exposed in small outcrops near Fouesnant in the Boulonnais (Wallace, 1989; Brice, 1988) where the succession is very similar to the Devonian of England south of the Variscan front. Eastwards, Devonian rocks crop out extensively within the Rheno-Hercynian Zone in the Ardennes and the Rhenish Massif. During Devonian times, these areas were situated on the passive continental margin of the Euramerica Palaeocontinent. A fragment of this palaeocontinent was separated from the margin of the East European Platform during post-Variscan erosion. Devonian rocks are also exposed along the Saxo-Thuringian Zone, which can be traced within the British and Dutch sectors of the southern North Sea. Further east, only major deep boreholes have drilled Devonian rocks north of the Rheno-Massif of Germany and the northern flank of the Rhenish Mountains. Devonian rocks of the Rheno-Hercynian and Saxo-Thuringian Zones have been encountered only in a few boreholes north of the Sudetes in south-western Poland (Figure 5.2). The most detailed information on the Devonian subsurface geology is from the eastern part of the SPB area. In north-eastern Poland, more than 150 boreholes have penetrated Devonian rocks; mostly during exploration for mineral deposits or hydrocarbons. To the north of the Holy Cross Mountains, the Devonian probably extends northwards beneath the Polish Trough towards Pomerania and further to the Baltic area of north-east Germany; more than 50 deep boreholes have encountered Devonian rocks in these areas (Figure 5.1). North of this zone, from eastern Poland to Sweden, the Devonian succession was removed from the margin of the East European Platform during post-Venianian erosion. Devonian strata are also absent from Denmark and the Danish and northern German sectors of the North Sea (Figure 5.1). The extent of Devonian rocks in the Baltic area has been proved by several deep boreholes in Poland, Lithuani...
2 Stratiﬁcation and lithology

2.1 Eastern England and offshore

Lower Devonian

Six boreholes have reached Lower Devonian strata in England, all of them onshore. Lower Devonian rocks lie conformably on Silurian strata, but are usually unconformable with the overlying Upper Devonian.

The Lower Devonian succession can generally be subdivided into two complexes. The lower complex developed as thick siliciclastic units during the Late Emsian and early part of the Late Emsian. The upper complex is mostly late Emsian limestone-rich facies. Lower Devonian rocks are missing in the area of the Braemar Massif due to the prevailing erosional regime.

The main palaeogeographical feature in this region was the elevated Braemar Massif area, which was characterised by a continental or continental regressive area to the south of the massif where they are represented by a major overthrust (Midi Overthrust) and its eastern continuation, the Aachen Overthrust (Figure 5.5). This west-north-west-trending structure has displayed Carboniferous and underlying rocks up to about 10 km towards the south. However, it does not obscure the general palaeogeography of the Devonian, which has been deduced from the reactivated strata in the south (Ardennes and Beaufort nappes) and architectural succession towards the north (Rocky Synformal along the southern flank of the Braemar Massif). The basement of the Devonian succession is part of the Ambitious Terrain (Feustal et al., 2002).

The main palaeogeographical feature in this region was the elevated Braemar Massif area, which was characterised by an erosional or continental regime. The area to the south of the massif was gradually subsiding to give progressively greater sediment thicknesses and more marine influence in the coeval depositional units. Second-order structures that developed mainly during Early Devonian and Eifelian times partly controlled the sedimentation patterns. These structures include the elevated areas formed by Lower Palaeozoic rocks (essentially the Braemar, Gonneville and Stavelot massifs; Figure 5.4). Synsedimentary block-tectonics are also thought to have aﬀected deposition, particularly during the Early and Late Devonian.

Lower Devonian

The Lower Devonian succession is characterised by sediment of mixed continental to shallow-marine facies (Figure 5.5). The facies range from shallower marine to carbonates interspersed with carbonates (Bultynck et al., 2000). The upper carbonate complex has been documented only in the region of the Lower Devonian succession is part of the Avalonian Terrane (Verniers et al., 2002).

The Lower Devonian succession can generally be subdivided into two complexes. The lower complex developed as thick siliciclastic units during the Late Emsian and early part of the Late Emsian. The upper complex is mostly late Emsian limestone-rich facies. Lower Devonian rocks are missing in the area of the Braemar Massif.
sandstone of the Lennze Formation, which are up to 110 m thick and were deposited during a regressive phase that predated late Eifelian times (Figure 5.6).

The Lennze Formation is overlain by shales and marly nodular limestones (Hasselt Formation) with abundant brachiopods and rugose corals, and biostromal intercalations in the upper part. This unit corresponds to a transgressive regime during Eifelian to Givetian times. The Eikelaar-Givetian strata boundary is in the lower part of the Hasselt Formation (10-70 m thick) and passes laterally into the continental and evaporitic limestones (technically Ekkens Formation) of the Lower Eifelian (i.e., the Solheim Formation). The lowermost part of the Eifelian succession is represented by two marly cycles consisting of greenish shales with subordinate siliciclastic intervals.

Towards the south in the Namur Synclinorium, only a single cycle of nodular limestone is recorded (e.g., the Beaufort Formation). The Eifelian-Givetian succession is thereby characterized by a transgressive-regressive cycle (e.g., Lecompte, 1970; Tsien, 1979; Sandberg et al., 1992). The buildups are surrounded by shaly and marly sediments yielding mostly small pelagic fauna. This formation is 50 m thick in the south, but it thins progressively towards the north (e.g., the Philippineville area). It is composed of two units: the first unit consists of coarse-grained siliciclastics, commonly arkosic sandstones, with subordinate conglomerates that pass upwards into medium-grained sandstones and siltstones. The second unit is composed of medium-grained sandstones and siltstones, yielding mostly small pelagic fauna. This formation is about 100 m thick in the southern Dinant Synclinorium (Figure 5.7).

Each of the two succeeding formations (Minori Limestone and Grande Breau) marks a separate transgressive-regressive cycle (e.g., Goyens & Boulvain, 2000). They correspond to a basal marly carbonate ramp with local development of large-scale evaporitic limestones and evaporitic deposits. The buildups, referred to as the Arche and Lion members (Figure 5.7), have thicknesses of up to 150 m in the south, but they thin progressively towards the north. These buildups are characterized by biostromes and brachiopod coquinas (Lambert Synclinorium). Da Silva & Boulvain (2002) suggested that the southern limit of these facies was controlled by pre-existing karst structures.

A transgressive event at the beginning of the late Frasnian led to the development of a third biohermal stage, represented by numerous red stromatoporoid mounds (Petit-Mont Member). These mounds are found within nodular marls (Nesville Formation) and are usually 50 to 80 m high; at places (e.g., the Philippineville area), they protrude into the overlying shales (La Valouse Formation). According to Sandberg et al. (1992), the development of the stromatoporoid mounds was preceded by a regression that led to karstification of the surrounding sediments. The uppermost Frasnian sediments are black shales (Matagne Formation) with thin limestone intercalations yielding mainly small pelagic fauna. This formation is 50 m thick in the south, but it thins progressively towards the north, particularly in the Philippineville area, where the thickness is only about 10 m. The equivalent of the Matagne Formation is 50 to 100 m thick in the southern Dinant Synclinorium, where it overlies the overlying shales and limestone intercalations including a biostrome and brachiopod coquina (Lambert Synclinorium). In the south, the Matagne Formation is about 100 m thick and consists of coarse-grained siliciclastics, commonly arkosic sandstones, with subordinate conglomerates that pass upwards into medium-grained sandstones and siltstones. The second unit is composed of medium-grained sandstones and siltstones, yielding mostly small pelagic fauna. This formation is about 100 m thick in the southern Dinant Synclinorium (Figure 5.7).
sandstones and siltstones (Ciney Formation). The overlying sediments are mostly sandstones (Montfort to 150 m-thick Baelen Member). In more proximal locations, the nodular limestones intercalate with deposits are shaly (Aye Formation), passing northwards into more proximal sandy-silty facies (Esneux Formation).

Late Famennian time was characterised by a transgressive regime that led to the deposition of marine, dark-coloured shaly mudstone (Figure 5.3). The overlying Famennian Bollen Claystone (in Kastanjelaan-2), and the Famennian Breviere Formation (in 305-1 and 302-1) comprise claystones and siltstones with sandstone and shale-water limestone intercalations. The group reaches thicknesses of 300 to 700 m in the southern Netherlands, but is thinner in the eastern Netherlands where it is up to 500 m thick (NITL, 1999).

Figure 5.6    Middle Devonian Lithostratigraphy in the southern part of the Dinant Synclinorium. See Figure 5.4 for locations.

Figure 5.7 Stratigraphy of the Frasnian succession in the Dinant Synclinorium (from Bulbyck & Depuydt, 2003). See Figure 5.4 for locations.

Bajomian Group sediments where they developed in a focus with abundant carbonate streaks. The successions of Kastanjelaan-2 have been dated using microfossils (Wiss et al., 1981). The informal Bajomian Group consists of the late Frasnian to early Famennian Bollen Claystone (in Kastanjelaan-2), and the Famennian Bonchveeld Formation (in 305-1 and 302-1) comprising claystones and siltstones with sandstone and shale-water limestone intercalations. The group reaches thicknesses of 100 to 700 m in the southern Netherlands, but is thinner in the eastern Netherlands where it is up to 500 m thick (NITL, 1999).

Late Famennian time was characterized by a transgressive regime that led to the deposition of marine shales with siltstones in the lower part, common sandy interbeds in the middle part, and crinoidal limestones in the upper part of the succession. Three lithostratigraphic zones (Breviere Formation) are 120 to 200 m thick and pass laterally into 30 to 60 m thick crinoidal-bedded horizons of the Doleux Formation. The buildups are mostly known from the Yeux Nappe area (Figure 5.5). Devonian sedimentation ended with significant regressions during late Famennian times, which was responsible for the deposition of extremely shallow-water carbonates and/or stratigraphic gaps in the Devonian-Carboniferous transition.

The Devonian rocks of the Braunsand (France) crop out in the Palaeozoic mantle of Perigueux (Figure 5.3). The succession starts with clastic lithologies of the Calvados Formation (lower Givetian) and limestones with nodule sands in the Blanmont Formation (middle to upper Givetian). The Frasnian formations (Beaulieu, Perigueux and Hydropenne) have alternating clays and siltstones and carbonates lithologies with a total thickness of 100 m. The overlying Sainte-Germaine Formation (lower Famennian) comprises 50-m-thick fine-grained sandstones.

2.3 The Netherlands

Devonian rocks in the Netherlands have been encountered in a few deep wells, most of them offshore. The Lower Devonian is absent. In the western part of the Dutch offshore sector on the flanks of the Braakman Mound, wells S02-2, S05-1 and O18-1 have penetrated the marine, dark-coloured shaly mudstone and intercalated white to greenish-grey, fine-grained sandstones of the Banjaard Group (Figure 5.11). Directly east of the Braakman Mound, well Kastanjelaan-2 in Limburg has also penetrated some 120 m of...
In the northern Dutch offshore sector, three wells (A17-1, E06-1 and E02-1) (Figure 5.10) encountered a 600 m-thick succession of fluvial sandstones, conglomerates, claystones and siltstones. Acid volcanics of the Buchan and Tayport formations (Van Adrichem Boogaert et al., 1993). A Givetian to Famennian age is recognised as far as the Münsterland-01 well and with increasing thickness and possible basinal trend to the east (Richards et al., 1998; Ahrendt et al., 2001). The predicted ‘Krefeld High’ (Bless et al., 1976) could therefore be proved (see Figure 5.12 in Chapter 5). The development of the carbonate platform in the early Emsian followed a period of Early Devonian siliciclastic shelf sedimentation. In the Elian area, the succession is mainly Lower Devonian marginal-marine to shallow-marine clastics and Lower Devonian carbonate (Figure 5.14).

### 2.4 Rhenish Massif and Harz Mountains

The Rhenish Massif has the most complete palaeogeographic record of the Rheno-Hercynian Zone. Traditionally, it has been subdivided into a western part, including the Eifel and Rhenish Mountains, and an eastern area that includes the Bergisches Land, Sauerland-Sieg Marsh and Taunus; the boundary corresponds broadly to the Rhine River (Figure 5.12). Moreover, this subdivision reflects a major difference in terms of the general development of Devonian sedimentation. The boundary may have been controlled by a deep-crustal discontinuity (cf. Engi, 1983); for example, the faults bordering the elongated structural feature termed the Zeddel-Triefel High (Bens et al., 1970) or a transform fault named the Lower Rhine Lineament by Franke (1995a). The latter reaches as far as the North Sea and possibly continues in the Lahn-Dill according to Bethell (1960), although Marshall et al. (1996) did not see evidence for continued in the east.

The Devonian rocks of the Rhenish Massif and Harz Mountains can be subdivided into several north-west–north-east-trending structural sedimentary belts that developed from the sedimentary prism of a passive continental margin of Euramerica. Early Devonian rifting led to the formation of an intracratonic rift (the Rheno-Trough) and a marginal plate at the transition to the ocean to the south (Stroeven et al., 2000). According to the palaeogeographic reconstruction by Franke (2000) (see also Franke (1995a) for a review, and Jansen et al. (2001) for alternative views), the allochthonous units recognised in the south-east Rhenish and Harz Mountains constitute fragments of the two north-easternmost belts of the Rheno-Hercynian Zone (Figures 5.12 and 5.13). The belts are:

1. Dated continental margins/lips with rifted basement comprised of a Silurian / Early Devonian magnetic arc and adjoining Archaean crust. The Devonian deposits, mostly assigned to the so-called Hercynian Complex, are Eifelian to Upper Devonian condensed pelagic limestones, Saxonian quartz arenites intercalated with pelagic shales and radiolites, Middle to Upper Devonian intramontane turbidites and shales overlying by hypersaline, and Lower Devonian sandstones topped by Middle to Upper Devonian hemipelagic shales and limestones.

2. The oceanic Rheno-Hercynian crust overlies by Eifelian to Upper Devonian condensed shales and radiolites, succeeded by Frasnian hypersaline with metamorphic material derived from the Mid-German Crystalline High. The latter deposits record the first stages of compressional deformation related to the development of the active south-east margin of the Rheno-Hercynian Basin.

Devonian rocks have also been encountered in several research boreholes (up to 5766 m deep) beneath the Lower Devonian sandstones topped by Middle to Upper Devonian intramontane turbidites and shales overlain by hypersaline, and Lower Devonian sandstones topped by Middle to Upper Devonian hemipelagic shales and limestones. In the north, these sediments represent a terrestrial environment dominated by large deltas and fluvial clastics (Middle Devonian). In the south, the sediments were deposited in a fluvial setting (Lower Devonian).
Middle and Upper Devonian

In the Eifel Mountains, the type area for the Eifelian Stage, the base of the stage is established in the upper part of an umbreto-argillaceous succession (Bänderschiefere). Lower Devonian shales were deposited in the formerly elevated areas, whereas the Bänderschiefere continued to be deposited in the deeper basins. The lithostratigraphic zonation was largely controlled by marine reef complexes and by volcanic-red bed deposits in the Late-Dinantian stage. The lithostratigraphic zonation was largely controlled by marine reef complexes and by volcanic-red bed deposits in the Late-Dinantian stage.

2.4.2 Eastern Rhenish Massif

Lesser Devonian

In the Rhenish Trough, it is generally assumed that the clastic deposition that developed and reached its maximum during Early Devonian times was sourced from the Givetian basin exposure to the north-west. The southern part of the Rhenish Trough (Bergisches Land) is a continuation of the Paris Basin, and the southern margin of the Rhenish Trough (Bergisches Land) is a continuation of the Paris Basin.

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deposited during the latest Emsian (Küllke, 1997). The area was subsequently influenced by the development of shallow-marine volcanic terranes that continued into the early Givetian. It is derived from the platform of Lower Devonian rocks and is overlain conformably by Lower Carboniferous or unconformably by Upper Carboniferous rocks. In each case, there is a significant stratigraphic gap between the Devonian and Carboniferous successions. The base of the Devonian is marked by transgressive, fine-grained shelf sandstones with up to 10 m thick red mudstones, with claystones and siltstones. The middle Devonian is characterized by graywacke-type successions (greywacke turbidites and shales) that started to accumulate during the early Frasnian and continued into Early Carboniferous time.

2.5 North-east Germany (Rügen area)

The Devonian succession in north-east Germany is up to 300 m thick and was deposited in a local north-west-trending fault-bound basin (Rügen Depression) subregional between the Ahden and Stralsund cliffs (Figures 5.16 & 5.17). It is unconformably overlain by Lower Devonian rocks and is overlain conformably or unconformably by Upper Carboniferous rocks. In each case, there is a significant stratigraphic break between the Devonian and Carboniferous successions. The base of the Devonian is marked by transgressive, fine-grained shelf sandstones with up to 10 m thick red mudstones, with claystones and siltstones. The middle Devonian is characterized by graywacke-type successions (greywacke turbidites and shales) that started to accumulate during the early Frasnian and continued into Early Carboniferous time.

2.6 Pomerania

The Devonian rocks of Pomerania form a north-west-trending wedge-shaped subcrop area along the Świętojański-Toruń-Zebrzydowice Zone (Figures 5.15 & 5.16). Unconformably prolonged from a marine platform of the Polish-Central European domain, the Pomeranian Devonian rocks are overlain by Lower Devonian rocks and are overlain conformably or unconformably by Upper Carboniferous rocks. In each case, there is a significant stratigraphic break between the Devonian and Carboniferous successions. The base of the Devonian is marked by transgressive, fine-grained shelf sandstones with up to 10 m thick red mudstones, with claystones and siltstones. The middle Devonian is characterized by graywacke-type successions (greywacke turbidites and shales) that started to accumulate during the early Frasnian and continued into Early Carboniferous time.

2.7 Central Baltic area

The Devonian rocks of the eastern Baltic area are part of the main Devonian field, the largest continuous area of Devonian shallow synclines and subsidence in Europe. The field extends from northern Lithuania to Latvia, southern Estonia and the adjacent Baltic Sea in the west, to Russia in the east (Figures 5.4). Structurally, the area is part of the Baltic Basin with an axis defined by trends north-eastwards from Gdańsk Bay. The syncline is situated between the elevated areas of the East European Platform, the Masurian-Baltic High in the south, and the Baltic High in the north-west.

The Devonian succession is part of the flat-lying Palaeozoic cover of the East European Craton. In the central part of the syncline, there was continuous deposition from the Ukrainian to Devonian within a sequence of shallow-marine sediments. The Devonian rocks are up to 1000 m thick, with a range of 840 m in western Latvia. Towards the basin margins, the succession becomes thinner, and the碳酸岩 facies is overlain unconformably on different Lower Paleozoic units and locally on the crystalline Precambrian basement. Away from the basin axis, the upper part of the Devonian succession is progressively truncated by erosion.

The Lower Devonian rocks are a regionally disconformable unit of mostly fine-grained clastic sediments, which are overlain disconformably by an erosional surface, which is overlain by the Middle Devonian succession. The Middle Devonian succession is marked by a sequence of shallow-marine clastics and carbonate deposits. The Carboniferous succession is of shelf carbonate, which is overlain by a carbonate platform of the Coal Measures age.

2.8 South-eastern Poland

The Devonian rocks of southeastern Poland are part of the Tsingpo-Tonghai-Zone (Figures 5.15 & 5.16). Unconformably prolonged from a marine platform of the Polish-Central European domain, the Pomeranian Devonian rocks are overlain by Lower Devonian rocks and are overlain conformably or unconformably by Upper Carboniferous rocks. In each case, there is a significant stratigraphic break between the Devonian and Carboniferous successions. The base of the Devonian is marked by transgressive, fine-grained shelf sandstones with up to 10 m thick red mudstones, with claystones and siltstones. The middle Devonian is characterized by graywacke-type successions (greywacke turbidites and shales) that started to accumulate during the early Frasnian and continued into Early Carboniferous time.

2.9 Upper Devonian

The Upper Devonian succession is mainly marine carbonate and with coarse-grained sandstones and mudstones with an erosional surface, which is overlain by the Upper Carboniferous succession. The Upper Devonian succession is overlain by a carbonate platform of the Coal Measures age.
exposed in the Holy Cross Mountains on the Syzęcza-Badom and Małopolska blocks (Figures 5.2 & 5.20). Elsewhere, Devonian rocks have been encountered in numerous deep wells.

Lower Devonian

Continental deposition across the Silurian-Devonian boundary is observed only in the Syzęcza-Badom Block and even a small part of the Lubelsko-Lesie area. In the former area, the Lochkovian deposits are mainly fine-grained marine clastics with thicknesses between 170 and 700 m (Miłaczewski, 1981). In Syzęcza, the lower Lochkovian deposits are sandstone (Sępniowicki Beds) with interbedded marls (Figure 5.19) (Barcza & Tarnawski, 2000). These sediments grade both upwards and laterally into alluvial and marginal-marine clastics (Elkowicki Beds) of variable thickness (up to 200 m) (Świderski, 1995; Konieczniak et al., 1998). This latter unit is also found in the Małopolska Block where it includes fine- to coarse-grained clastic sediments, mainly greywackes and limestones, which were deposited in alluvial fan, braided stream and braided delta settings.

Pragian and Emsian rocks are found across most of the Holy Cross Mountains area (Kowalczewski et al., 1998). The succession, which is usually several hundred metres thick, is mainly sandy deposits of alluvial and marginal-marine facies (Barcza Beds) overlain by sandstones with clastic-opal intercalations (Zagórze Pragian Formation) that were deposited in a shallow-marine, nearshore, storm-dominated setting and marginal-marine facies (Barcza Beds) overlain by sandstones with clayey-silty intercalations (Zagórze Pragian and Emsian rocks are found across most of the Holy Cross Mountains area (Kowalczewski et al., 1998). These sediments are mostly quartz sandstones and siltstones predominantly shaly and carbonate (ages, are interpreted as having been derived from northerly sources dominated by upper Silurian reefal carbonate platform dominated by corallalitomorphous faunas (Kowalczewski Formation) developed across the entire Holy Cross Mountains area at the time of the Ediacaran-Givetian transition (Kowalczewski et al., 1998; Barcza, 1995). The platform’s internal architecture and stratigraphy remain unknown in many places due to extensive secondary dolomitization (Narwików, 1991). The Givetian section of the carbonate-platform system is at least 500 m thick. Its basal part is formed by peloidal, with oolitic-collapse breccias marking primary epignastic sanguineous levels. These are overlain by sediments of more open-marine facies (Figure 5.22) comprising rhythmically-bedded corallalitomorphous bioturbated and various peloidal limestones. The late-Givetian transgression led to the development of marly and dolomitic limestone (Janośa Member) with a rich in the southern Holy Cross Mountains, which forms the northern margin of the Małopolska Block, the basin Middle Devonian succession is considered to be latest Emsian to early Eifelian in age. The deposits are open-marine fusulindalitomorphous and black shales (Zbożyński Shale), which are up to several tens of metres thick. These sediments are succeeded by peritidal-lagoonal, usually laminated, dolomicrites. Despite the absence of fauniston stratigraphy evidence, it is generally assumed that a shallow-marine carbonate platform dominated by corallalitomorphous facies (Kowalczewski Formation) developed across the entire Holy Cross Mountains area at the time of the Ediacaran-Givetian transition (Narwików et al., 1998; Barcza, 1995). The platform’s internal architecture and stratigraphy remain unknown in many places due to extensive secondary dolomitization (Narwików, 1991). The Givetian section of the carbonate-platform system is at least 500 m thick. Its basal part is formed by peloidal, with oolitic-collapse breccias marking primary epignastic sanguineous levels. These are overlain by sediments of more open-marine facies (Figure 5.22) comprising rhythmically-bedded corallalitomorphous bioturbated and various peloidal limestones. The late-Givetian transgression led to the development of marly and dolomitic limestone (Janośa Member) with a rich
In the Lublin region, the lower Frasnian succession (~100 m thick) is a carbonate-platform system overlain by condensed pelagic sediments, took place on only a small fragment of the former carbonate platform, but the Frasnian–Famennian transition. These reflect episodes of erosion and re-sedimentation related to a crinoids fauna. On the flanks of the buildups, or in proximal basinal settings where the sedimentary cephalopod wackestones with abundant nektonic (cephalopods, conodonts) and/or benthic (brachiopods, ostracods, graptolites) faunas were preserved. These rocks have never been exposed to temperatures higher than ~100°C (Dopieralska et al., 2006). The latter is a coral-stromatoporoid facies of a shallow-water carbonate platform (Lower Sitkówka Beds), which was covered by thick coral-stromatoporoids (Sitkówka Beds) that continued into the Frasnian (Dopieralska et al., 2006). The Devonian succession of the northern part of the Holy Cross Mountains even as early as the early Frasnian.

Upper Devonian

Upper Devonian rocks are rather poorly documented in the northern part of the Holy Cross Mountains even though they reach thicknesses of several hundred metres. The basal Frasnian sediments are a monotonous marly sequence (Nieczulice Formation) deposited in a deep-water basinal environment, which also accumulated on the sea floor to form submarine highs. Coarse-grained greywackes were deposited around the highs. During the late Frasnian and Famennian, each accumulated on the highs while mainly shallow sediments were deposited in the deep waters between. In the upper Famennian, there are several clastic interbeds representing turbidites derived from the active margins of the Bohemian Terrane (equivalent to the Tjalar-Barnaian Terrane).

Münnich, W. von, and Frankenberg, K. maps

The tectonic blocks of Münnich, Wildenlohe, and Frankenberg represent the allithithic structural level of the Saar-Thüringian Zone (Figure 5.23). They have lithologies that derived from the northern continental slope of the Saxo-Thüringian Zone (Franke, 2000) and are usually termed the ‘Bavarian facies’. The Palaeozoic volcanic and fissurosite sediments are of very low metamorphic grade and are mainly found in the basal parts of the nappes. Devonian rocks are intraglacial Holocene volcanics associated with polies and sandstones (Rith, 1976), but the most typical are radiolarian cherts, which were deposited in the deep parts of the depositional lobes before the Baltic Carolina Compensation Depression. Metamorphic carbonate wackestones and mudstones are the subordinate lithologies in the Münnich Block; however, carbonates are predominant in the Devonian successions of the Wildenlohe and Frankenberg units.

Elbe Valley

The rocks exposed in the Elbe Valley are mudstones, which are usually rich in tinctorial matter in the Lower and Middle Devonian succession. During early Frasnian times, there was a phase of volcanic activity that subsequently controlled facies distributions in the area. The volcanic complex consists of basaltic pillow lava covered by tuffs. Local uplifted ultramafic material to deeper parts of the area. The Devonian succession includes basaltic silica cherts with chert.

Sudetic Ophiolite

The Sudetic Ophiolite, a tectonometamorphic unit bordering the Silesian Granite in the West Sudetes, is a unique part of the Variscan belt where Devonian sediments deposited directly into the crust are preserved. These rocks have never been exposed to temperatures higher than ~100°C (Dopieralska et al., 2006). The succession consists of about 60 m of Palaeozoic ophiolites underling upper Silurian Lower Frasnian gabbros (Franke & Zalewski, 2000). The sequence is accessible in the abandoned quarry at Dzikowiec. The base is a breccia of gabbro-clastics overlain by calcareous algae, overlain by ~0–5 mm thick fine-grained basaltic wackestones to packstones (Main Limestone) typical of shallow-water deposition (Budkowski, 2002). At the top, there is a small graptolite stratigraphic gap separating the Main Limestone from the overlying Wolfcampia limestone (Dopieralska et al., 2006). The latter is a condensed (~0.5–1.5 m) sequence of evolved, reworked wackestones and mudstones with a typical nodular appearance that was deposited during a period of pelagic, deep-water deposition.

Skoleodolje Depression

The Skoleodolje Depression is a small synorogenic basin that developed adjacent to the Silesia–Góry Blidzkie Block (Figure 5.23) during the Late Devonian and underwent major subsidence at that time. It contains:

2.9 Sauvage-Thüringian Zone

In the Sauvage-Thüringian Zone of the British Province, Devonian rocks are isolated in small areas within the Saxo-Thüringian tectonometamorphic suites (Figure 5.22). They are separated by several metamorphic belts, and all are situated south of the SPM margin. The Devonian rocks in the Thuringia and Vogtland are considered autochthonous. However, Devonian strata occur in different allochthonous units in which the palaeotectonically reconstructed palaeogeographical arrangement is not well understood.

East Thuringia and Vogtland

The largest outcrop of Devonian rocks within the Sauvage-Thüringian Zone is found in the East Thuringia-Vogtland area, where the complete Devonian succession is part of the anticlinorium structural level of the Selk. The succession consists of pelagic sediments up to 400 m thick and volcanic deposits in a deep-water, distal inner shelf setting within the Sauvage-Thüringian Zone (Franke, 2000). The oldest part of the succession is Luxembourgian graptolitic cherts. The Pragian to Givetian intervals include pelagic carbonates (wackestones) and cherts, both with a very rich invertebrate fauna. During the Eifelian, the foraminiferous shales passed upward into a nummulitid-bank cherty succession. Pelagic sedimentation was dominated by mud volcanism and was interrupted in the early Frasnian by intense marine volcanism related to a pulse of crustal rifting (Franke, 1983). The volcanism gave rise to 150–200 m thick andalusitseis and tuffs that accumulated on the sea floor to form submarine highs. Course-grained geyersites were deposited around the highs. During the late Frasnian and Famennian, each accumulated on the highs while mainly shallow sediments were deposited in the deep waters between. In the upper Famennian, there are several clastic interbeds representing turbidites derived from the active margins of the Bohemian Terrane (equivalent to the Tjalar-Barnaian Terrane).