improved version
Figures 2, 6 and 9 are changed due to printing errors (Fig. 2) as well as because of new data for Leukersdorf Fm. (Fig. 9) and for Hornburg Fm. (Fig. 6; Gebhardt & Lützner in press 2011).

The Late Variscan Molasses (Late Carboniferous to Late Permian) of the Saxo-Thuringian Zone

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The syn- to post-orogenic evolution of Variscan Central Europe was dominated by the formation of a variety of basins (Figs. 1 and 2), into which the erosional debris of the orogen, the so called molasses, was deposited. The sedimentary and volcanic fill of these basins records apart from the erosion of the Variscan orogen the tectonic and magmatic activity associated with the post-Variscan reorganization of the stress field that led to Permian rifting also the Carboniferous and Permian climatic development with wet and dry phases that are superimposed on the general aridisation during this time. The character of the basins of the Saxo-Thuringian Zone and bordering areas (Fig. 1) changes systematically from north to the south. Located to the north of the orogenic deformation front, the Variscan ***foredeep basin*** was mainly filled by submarine turbidite sequences and only during its final stage by paralic to increasingly continental clastic sediments (e.g., in the Ruhr, Emsland, and North-Mecklenburg-Rügen areas of Germany). ***Peri-montane basins*** (e.g., Hainichen, Saale, and Saar basins) are located at the transition from the foredeep basin to the mountain slopes in the south. These basins may have had the character of wide depressions opening into the foreland, where sediments transported by rivers formed alluvial plain and delta complexes in the area of the increasingly filled foredeep. Large valley-like basins between the mountain chains of the orogen are called ***intermontane basins*** (e.g., the Bohemian basins). Additionally, there are smaller basins within the mountains ranges, the ***intramontane basins*** (e.g., Zwickau Basin). The latter two basin types belong to the Variscan internides. In contrast to the foredeep and the perimontane basins, the early history of these basins is not well known. They were uplifted and largely eroded together with the orogen. Only after the last phase of strong uplift during the Namurian, the geological record for the development of these basins became more complete.

Repeated tectonic activity led to relief rejuvenations, basin reorganisation, and formation of new basins, as well as reorganisation of the drainage systems with erosional hiatuses in the Variscan internides (e.g., Saar-Nahe Basin) and the formation of new basins (e.g., Saale Basin) at the Westphalian/Stephanian transition. The Franconian volacanotectonic activity at the Stephanian/Rotliegend (Autunian) transition are characterised by increased magmatic activity, which produced huge volcanic complexes, as for instance the Gehren Subgroup with close to 1,000 m of volcanic rocks in the Thuringian Forest Basin, the first stage of the Halle Volcanic

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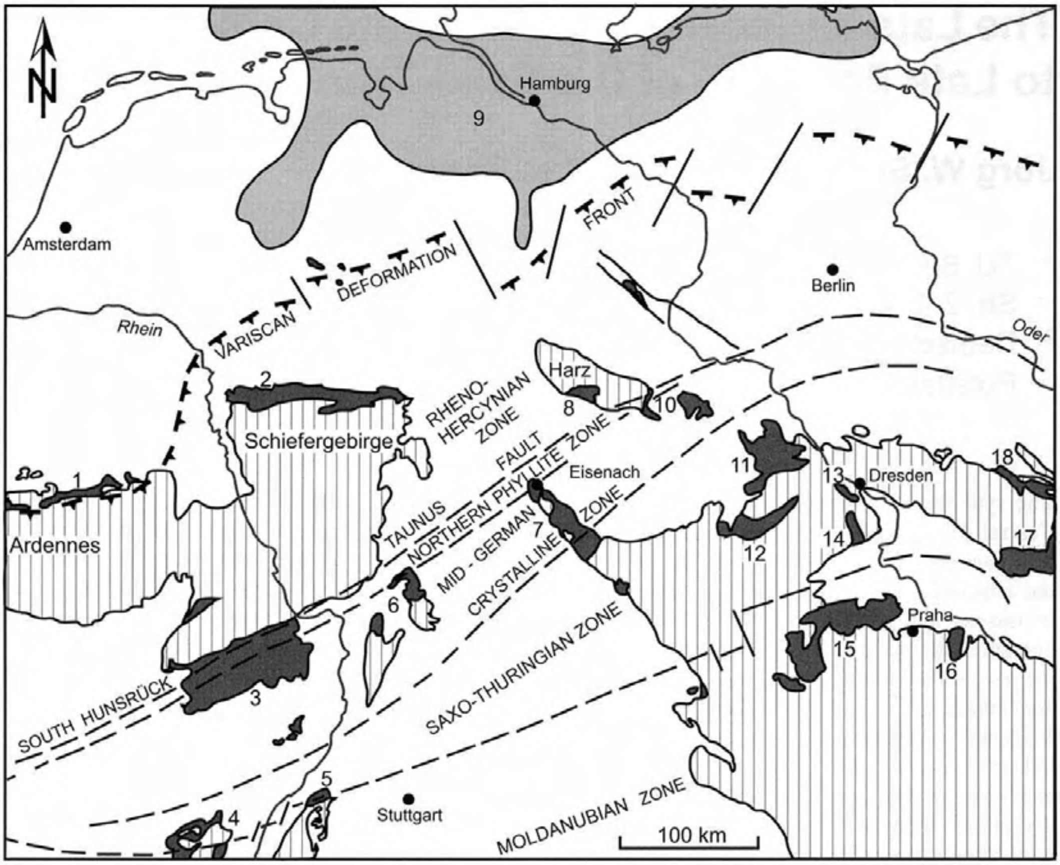


Fig. 1. Outcrop areas of Carboniferous an Permian continental basins in Central Europe. ***1*** paralic Namurian to Westphalian Aachen and Campine basins of the Variscan foredeep. **2** paralic Namurian to Westphalian Ruhr basin of the Variscan foredeep. **3** Westphalian to Permian Saar-Nahe Basin. ***4*** Stephanian-Permian Saint-Dié and Villé basins of the Vosges area. ***5*** Stephanian-Permian Baden-Baden Basin. ***6*** Permian Wetterau Basin. ***7*** Stephanian-Permian Thuringian Forest Basin. ***8*** Permian Ilfeld Basin. ***9*** subsurface Stephanian relict basin of the Variscan foredeep in the area of the later Southern Permian Basin. ***10*** Stephanian-Permian Saale Basin. ***11*** Permian NW Saxon Basin and Volcanite Complex. ***12*** Westphalian to Permian Erzgebirge Basin. ***13*** Stephanian-Permian Döhlen Basin. ***14*** Westphalian Schönfeld-Altenberg Basin. ***15*** Westphalian Central and West Bohemian basins. ***16*** Ceský Brod area of the Stephanian to Permian Blanice graben. ***17*** Westphalian to Permian Krkonoše Basin. ***18*** North Sudetic Basin (map based on Schäfer, 2005).

Complex in the Saale Basin, and the lower part of the North German Volcanic Complex in the North German-Polish Basin (Southern Permian Basin). Associated tectonic activity resulted in relief rejuvenations and progradation of conglomerate fans. New Rotliegend basins, the ***extramontane basins***, formed to the north of the Variscan orogen in the area of the later North German-Polish Basin (Gaitzsch, 1995a, 1995b). At the Lower/Upper Rotliegend transition, the Saalian tectonic activities were linked to increased volcanism. The Oberhof Volcanic Complex of the Thuringian Forest Basin, the Donnersberg volcanites of the Saar-Nahe Basin, the Planitz volcanites of the Erzgebirge Basin, and the upper part of the North German Volcanic Complex all formed at this time (Schneider *et al.*, 1995; Roscher & Schneider, 2005). Mostly strong erosional hiatuses occur around the Lower/Upper

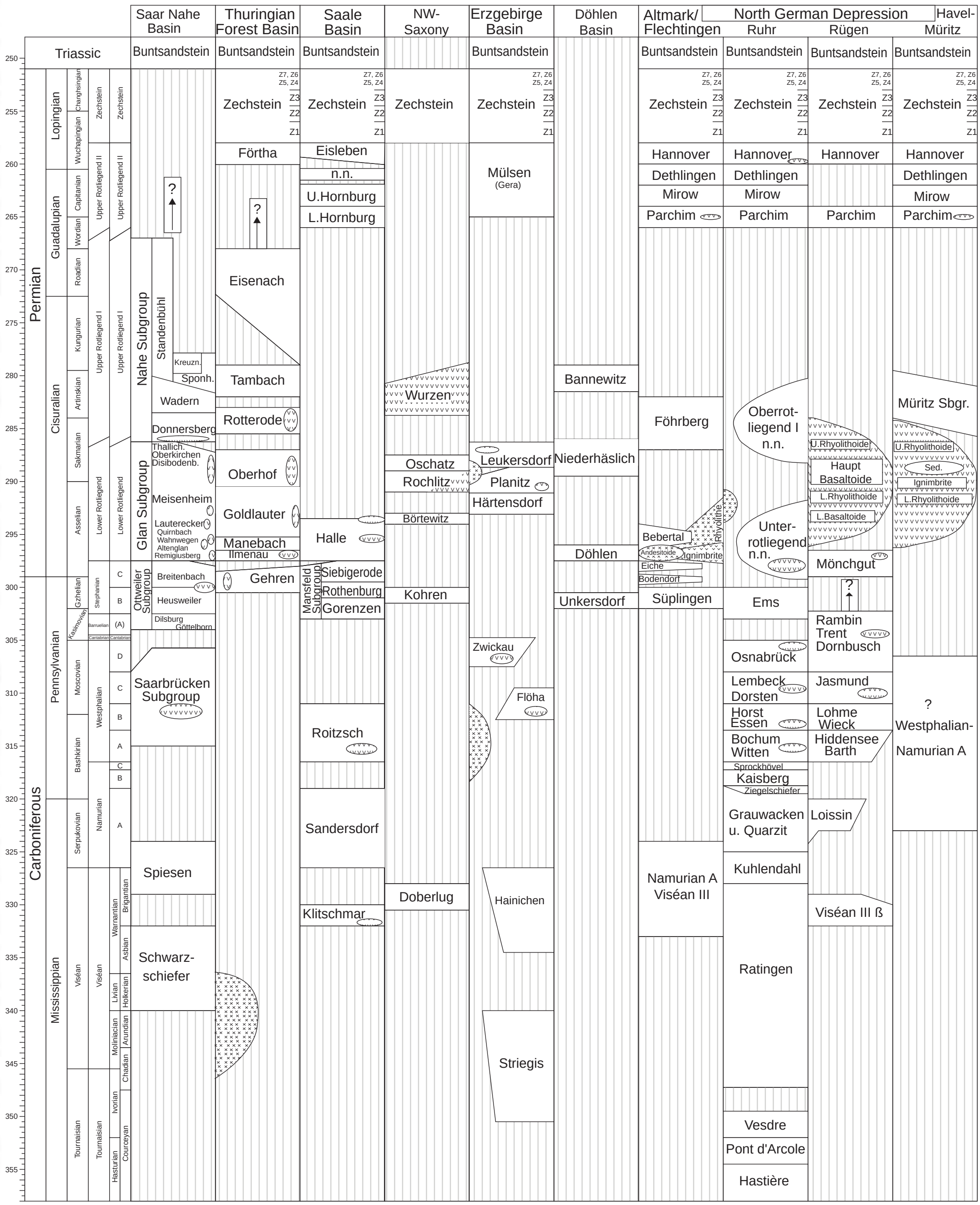


Fig. 2. Correlation chart of the Saxothuringian basins described in the text; added for comparison are the profiles of the Mississippian to Pennsylvanian Variscan foredeep in North Germany as well as of the North German Volcanite Complex and the Southern Permian Basin. Granites are marked with **+**, levels of intense volcanism with **v**. For data sources see description of individual basins as well as Schneider (2001), Menning & German Stratigraphic Comission (2002), and Roscher & Schneider (2005).

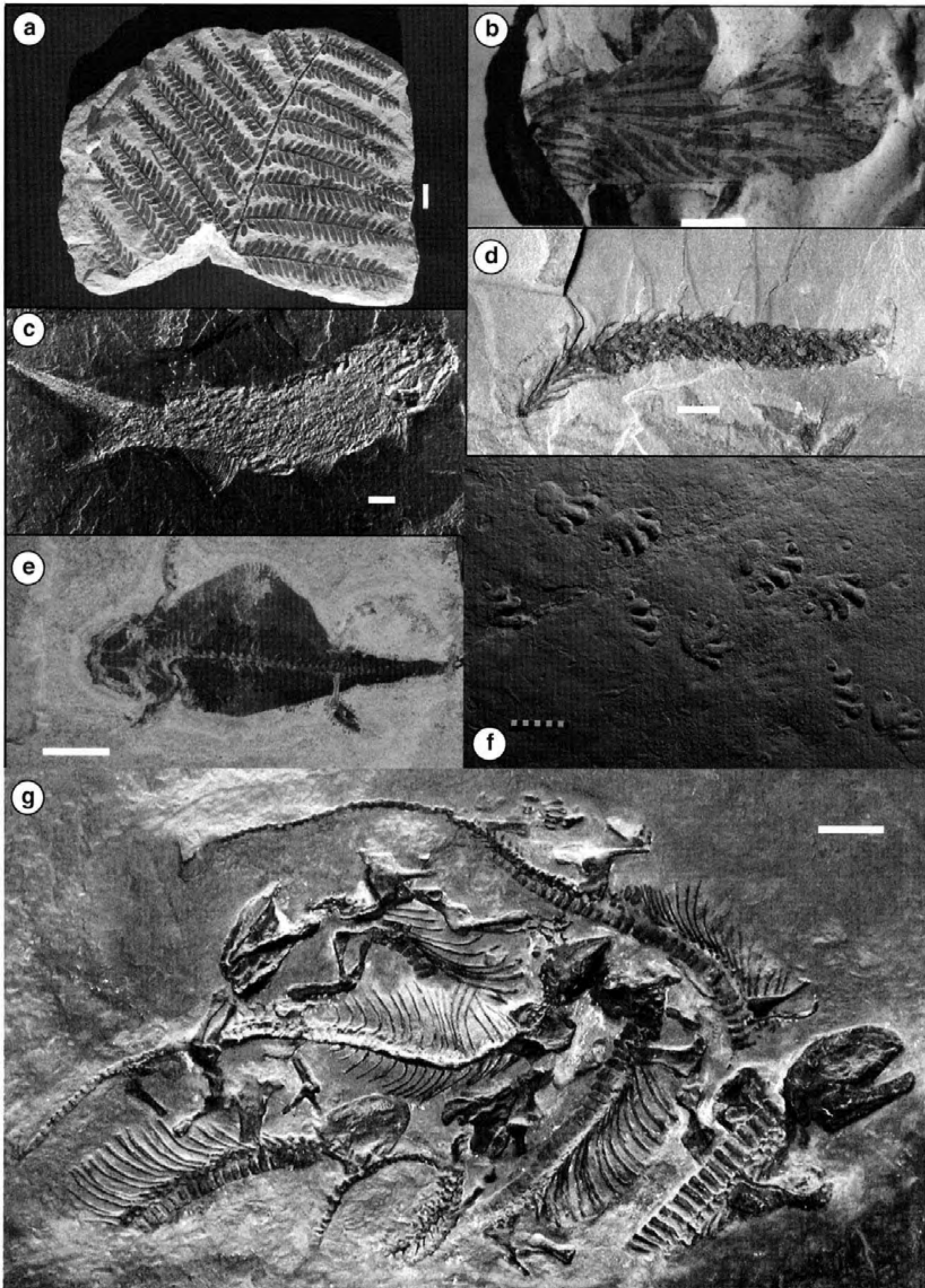
Rotliegend transition, when the sediment character changed from interbedded grey and red sediments to purely red beds. At the onset of the Upper Rotliegend II, thermal subsidence accompanied by extrusions of rift-related basalts led to the formation of the North German-Polish Basin, heralding the embryonic stage of the Mesozoic/Cenozoic Central European Basin (Gebhardt *et al.*, 1991; Schneider & Gebhardt, 1993). This basin and the peneplained areas to its south, i.e., the Rheno-Hercynian Zone, the Mid-German Crystalline Zone, and the northern part of the Saxo-Thuringian Zone, were flooded by the Zechstein Sea. Reef sediments and sabkha deposits of the first Zechstein cycle were deposited in places directly on Variscan metamorphic and magmatic rocks and on Rotliegend volcanic rocks, which earlier had represented erosional areas to the Rotliegend basins, indicate that the Variscan morphogene was nearly levelled during late Upper Rotliegend.

Biostratigraphic age control on the basin evolution

The fast economic expansion during the 18th and 19th centuries in Central Europe was based on the rapidly increasing exploitation of ore and coal deposits, which in turn led to ambitious mapping programs of the territories (geologische Landesaufnahme) at the scale 1: 25,000. The first detailed lithostratigraphical subdivisions date back to this time. Interestingly, the definition of the terminus ***Formation*** given by von Cotta (1856, 1878) is nearly identical with the actual use. Many of the formation names given by Weiss (1889) for the Saar-Nahe Basin and by Beyschlag (1895) for the Thuringian Forest Basin, are still in use. Very early, plant fossils have been used for the characterization and correlation of coal bearing sequences, as shown by the voluminous and richly illustrated descriptions of floras of the Carboniferous "Steinkohlengebirge" and the Permian "Rothliegend" by von Schlotheim (1804), Sternberg (1820), Göppert (1836), Geinitz (1856, 1858), Weiss (1876), and Potonié (1893). Geinitz (1856), based on his six "vegetation belts", made the first attempts for interregional biostratigraphic correlation. Modern revisions, especially of Rotliegend floras, published by Barthel (1976, 2003) and Kerp (e.g., Kerp & Fichter, 1985; Kerp & Haubold, 1988), focused, however, increasingly on palaeo-ecological aspects (Kerp, 2000). Macrofloras and palynomorphs are still in use for non-marine Carboniferous biostratigraphy (e.g., Clayton *et al.*, 1977; Cleal & Thomas, 1996), but are increasingly considered to be problematic in the Permian biostratigraphy (e.g., Broutin *et al.*, 1990; DiMichele *et al.*, 1996, 2001; Kerp, 1996).

Following the early compilations on Rotliegend animal fossils (e.g., Geinitz, 1861), Weiss (1864) attempted for the first time to use fossil animals to correlate Rotliegend sediments biostratigraphically. Initiated by demands of natural gas exploration in Pennsylvanian and Permian deposits of Europe in the 20th century, different biostratigraphic tools were developed for diverse environments and different litho- and biofacies pattern (for details see Schneider, 2001; Roscher & Schneider, 2005). They include in particular the conchostracan (Spinicaudata) zonation (e.g., Martens, 1983, 1984; Schneider *et al.,* 2005a, 2005b) and the higher resolving insect zonation for the Middle

Fig. 3. Typical Carboniferous and Permian fossils of the Saxo-Thuringian basins. ***a*** Seed fern *Alethopteris subdavreuxi*, Westphalian D, Oberhohndorf, Zwickau Basin, scale bar 2 cm (collection TU Bergakademie Freiberg). ***b*** Cockroach zone species *Sysciophlebia ilfeldensis*, Lower Rotliegend Netzkater Formation, Ilfeld Basin, scale bar 0.5 cm (collection F. Trostheide). ***c*** Palaeoniscid fish *Elonichthys*, Lower Rotliegend Goldlauter Formation, Gottlob quarry, Thuringian Forest Basin, scale bar 1 cm (collection TU Bergakademie Freiberg). ***d*** Male cone of the conifer *Walchia piniformis*, Lower Rotliegend Goldlauter Formation, Cabarz quarry, Thuringian Forest Basin, scale bar 1 cm (collection TU Bergakademie Freiberg). ***e*** Branchiosaur zone species amphibian *Melanerpeton tenerum*, Lower Rotliegend Börtewitz lake horizon, Oschatz Formation, NW Saxony Basin, scale bar 1 cm (collection Geological Survey of Saxony). ***f*** *Ichniotherium sphaerodactylum*, the track of a diadectid reptile, Upper Rotliegend Tambach Formation, Bromacker quarry, Thuringian Forest Basin, scale bar 10 cm (Holotype, collection Natural Museum Gotha). ***g*** Group of the synapsid reptile *Pantelosaurus saxonicus*, Lower Rotliegend Niederhäslich Formation, Döhlen Basin, former Königin Carola coal mine, scale bar 20 cm (collection Geological Survey of Saxony). A color version of this figure is shown on page 485.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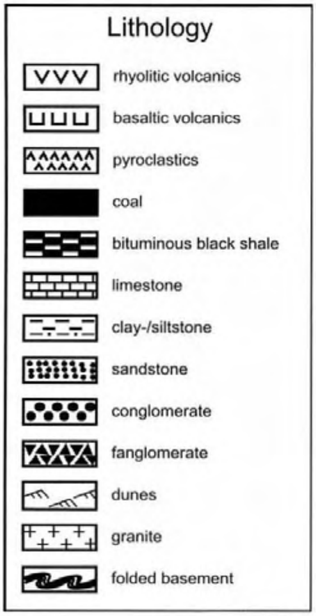

Fig. 4. Explanation to figures 5 to 7 and 9 to 11.

Bashkirian (Westphalian A, Early Pennsylvanian) to the Artinskian (lower Upper Rotliegend, Late Cisuralian; Schneider *et al.*, 2005a, 2005b; Schneider & Werneburg, 2006). From the Late Moscovian (Westphalian D) to the Artinskian (lower Upper Rotliegend, Late Cisuralian), the amphibian zonation of Werneburg (1989a, 1989b, 1996a, 1996b) is successfully applied (Werneburg & Schneider, 2006). Additionally, freshwater shark teeth (Schneider & Zajic, 1994; Schneider *et al.,* 2000), and tetrapod tracks could be used (e.g., Haubold, 1970; Voigt, 2005). Comparable faunal and biostratigraphic investigations were made in the Saar-Nahe Basin (e.g., Boy & Fichter, 1982; Boy, 1987; Hampe, 1989). Detailed palaeobotanical correlations between the basins were problematic as recurring humid phases during the Permian were superposed on a general trend to increasingly more arid climate (for a review see Schneider *et al.,* 2006; Roscher & Schneider, 2006). The recurrent humid phases made that Carboniferous hygro- and hydrophile floras locally persisted far into the Rotliegend (e.g., Kerp & Fichter, 1985; Broutin *et al.,* 1990; DiMichele *et al.,* 1996), whereas the more arid conditions made that in other basins floras with a mesophytic character already occurred in the Permian (e.g., Kerp, 1996; Kerp *et al.,* 2006b). In recent years, palaeomagnetic studies (e.g., Menning *et al.,* 1988, 2006) and isotopic dating (starting with Lippolt & Hess, 1983) have been increasingly combined with biostratigraphic data for regional and interregional correlation and the correlation of continental profiles with the marine global standard scale (e.g., Lützner *et al.,* 2007; Roscher & Schneider, 2005).

Thuringian Forest Basin

The Thuringian Forest Basin (formerly SW-Saale Basin), an approximately 40 to 60 km wide SW-NE orientated depression, is to large parts exposed in the horst structure of the Thuringian Forest (Fig. 1). It belongs to the classical Rotliegend areas in Europe because of the mining – since the 12th century – of Permian Zechstein Kupferschiefer deposits along the borders of this horst, sulfide ores in Rotliegend lacustrine black shales, Stephanian and Rotliegend coals, and Mesozoic vein deposits. In 1775, one of the worldwide oldest coloured geological maps, which included parts of the Thuringian Forest, was published F.G. Gläser. First geological descriptions and mapping activities date back to Voigt (1789) – a pupil of Abraham Gottlob Werner –, Freiesleben (1807), and von Hoff & Jacobs (1807), who had developed here, before Lyell, ideas about the "principle of actualism". The first description of Rotliegend plants where given by the coal mine owner Heyn in 1695, and the first Rotliegend plant was pictured by Mylius (a lawyer of Leipzig) in 1709. The richly illustrated publication of von Schlotheim (1804) on floras of the "Rothliegend" and the "Steinkohlen-Formation" of the Thuringian Forest mark the start of scientific palaeobotany (cf. Barthel & Rößler, 1995; Barthel, 1994, 2003). Nowadays, this Rotliegend basin is one of the biostratigraphically best investigated and correlated basins in the Variscan area (Schneider 1996, 2001; Lützner, *et al.*, 2007; Andreas *et al.*, 2005; Schneider & Werneburg, 2006; Werneburg & Schneider, 2006).

Basin development and basin fill (Figs. 4 and 5): The basin is situated on deeply eroded and peneplained Variscan basement of the Saxo-Thuringian Zone in the southeast, Visean granites in the center, and the inverted Mid-German Crystalline Zone (MGCZ) in the northwest (Fig. 1). Basin development, sedimentation and volcanism were controlled by NE-SW, NW-SE, N-S, and E-W striking fault systems that define a pattern of variably subsiding and uplifting blocks during sedimentation. In consequence, small sub-basins with partially strong relief gradients were created (see Andreas, 1988; Lützner, 1988; Lützner *et al.*, 2007).

Sedimentation began on deeply weathered granites with red (basin margin) and grey (basin center) conglomerates and coarse arkosic sandstones that are overlain by fluvial to lacustrine and palustrine fine-clastic deposits with fossiliferous lake horizons and thin coal seams with hygrophilous to hydrophilous floras of the ***Gehren Subgroup*** (Möhrenbach and Georgenthal formations). Typical lake sediments are black shales and thin, partially onkolithic limestones. Xenacanthid freshwater sharks and branchiosaurid amphibians of the Ilmtal-lake horizon close to the base of the Gehren Subgroup give a Stephanian C age (Werneburg & Schneider, 2006), which is confirmed by the isotopic age of about 295 ± 3 Ma (Lützner *et al.*, 2007). The freshwater sharks of this lake horizon indicate the connection to a Central Europe-wide drainage system (Schneider & Zajic, 1994; Schneider *et al.*, 2000). The sedimentary sequence is overlain by up to 1,000 m of intermediate to acidic pyroclastics and lavas, in places subintrusive, with intercalated fluvial to lacustrine red and grey sediments and thin lacustrine limestones. Sparse floral remains belong to meso- to xerophilous plants.

After the development of a basin-wide erosional disconformity, the maximally 450 m thick ***Ilmenau Formation***, which is characterized by bimodal volcanism (rhyolites and basalts), was deposited. The base of this formation marks the base of the Rotliegend. The formation contains several sedimentary members, mainly grey facies, which are dominated by local volcaniclastic components. The Sembachtal-lake horizon close to the top of the Ilmenau Formation consists of

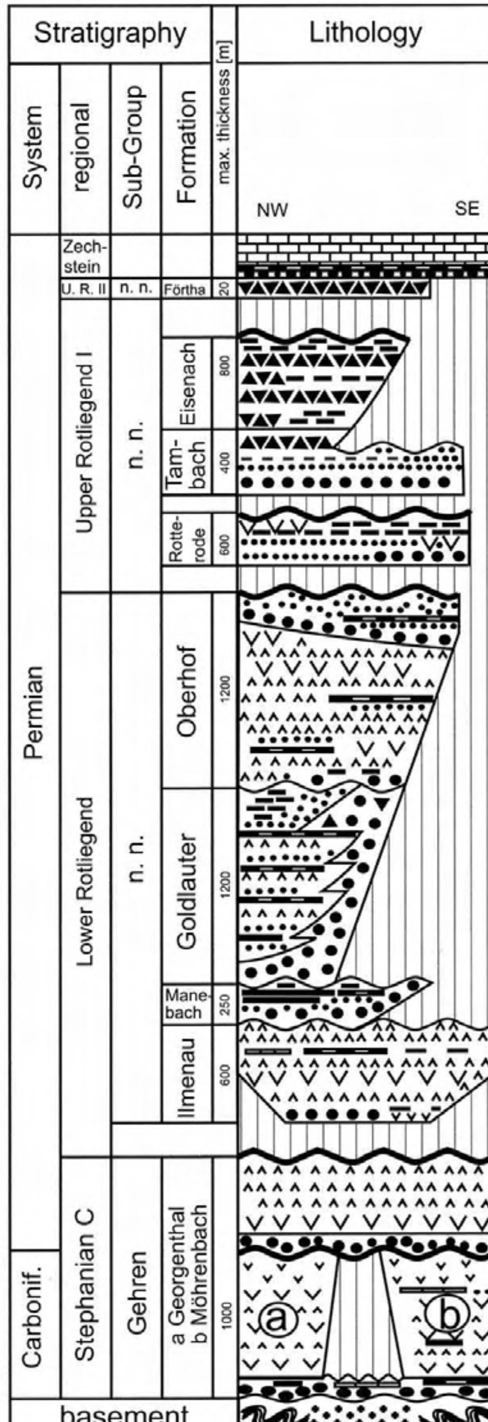

Fig. 5. Thuringian Forest Basin; based on Schneider (1996), Andreas *et al.* (2005), and Lützner *et al.* (2007). Symbols as in Fig. 4.

fluvial grey sediments and lacustrine laminated black shales with stromatolithic layers. Based on amphibians, this horizon belongs together with the following Manebach Formation to the *Apateon dracyiensis - Melanerpeton sembachense* Zone, which is of early Asselian age (Werneburg & Schneider, 2006).

The overlying coal-bearing, maximally 250 m thick, completely grey ***Manebach Formation*** was deposited in a low-relief landscape with forest swamps, local lakes, and fluvial slurry deposits rich in organic matter (Lützner, 2001). Volcanic rocks in the Manebach Formation are restricted to millimeter to centimeter thick ash layers within the lacustrine black shales. This formation is famous for its characteristic and well-investigated Euramerian Stephanian/Lower Rotliegend flora (e.g., Barthel, 2001, 2003).

During the deposition of the up to 1,200 m thick ***Goldlauter Formation***, a marked palaeorelief developed, which is reflected in red-brown coarse-clastic alluvial fan deposits along the margins of the basin. The fans interfinger distally with red, alluvial plain sandstones and siltstones, fluvio-lacustrine brownish to grey sandstones, and lacustrine laminated to varved black shales in the center of the basin. Some of the lake horizons could be traced at the scale of the entire basin by pyroclastic marker beds (Andreas & Haubold, 1975). These mostly black shales were deposited in interchanging acanthodian/xenacanthid and palaeoniscid/amphibian dominated lakes. Very common blattid insects and branchiosaurid amphibians allowed for detailed correlations within the entire Euramerian palaeotropical belt (Schneider & Werneburg, 2006; Werneburg & Schneider, 2006).

At the base of the ***Oberhof Formation***, the widespread 5 to 50 m thick Dörmbach pyroclastic horizon initiates the second major phase of volcanism, which led to up to 1,200 m rhyolitic lavas, in places subintrusive, and pyroclastic rocks, with minor intercalations of epiclastic sediments, that form the Oberhof Volcanic Complex (Lützner *et al.*, 2007). Laterally, this complex goes over into alluvial und lacustrine sediments with minor intercalations of lavas and pyroclastic rocks. Epiclastic sediments amount to only 10% of the formation. Red facies is more widespread than in the preceding Goldlauter Formation. In the upper Oberhof Formation, the last perennial lake horizon of the Thuringian Basin is very widespread and grades laterally from calcareous, bituminous, varved black shales into red, varved, carbonate-clay laminites (Schneider & Gebhardt, 1993). These sediments are covered by alluvial plain and playa-like deposits at the top of the Oberhof Formation.

The fauna of the Oberhof lake horizons is dominated by amphibians. Fishes are rare and of low diversity. Based on the amphibians, this formation is very well correlatable with the latest Lower Rotliegend (Sakmarian) of most basins in Europe (Werneburg & Schneider, 2006).

After an erosional event, which cut down as far as into the Lower Oberhof Formation, the deposition of the ***Rotterode Formation*** started with entirely red clastics. This sequence of sandstones with intercalated channel and sheet flood conglomerates as well as siltstones was deposited in an alluvial fan to alluvial plain environment. The appearance of granite pebbles and arkoses of granite detritus indicate the first uplift of the Ruhla Crystalline Complex at the western border of the basin. Rhyolitic lavas and pyroclastics occur locally. The emplacement of the S-N directed, up to 250 m wide Höhenberg dolerite was a major event dated at 280 ± 2 Ma (Artinskian, see Lützner *et al.*, 2007). *Scoyenia* burrows and plant roots in sandy alluvial plain siltstones are typical of the "wet red bed facies". Siltstones and claystones of temporary pools and small playa-like ponds contain the freshwater jellyfish *Medusina limnica* as well as common arthropod and tetrapod tracks (Walter, 1983). Biostratigraphically, the Rotterode Formation belongs to the *Moravamylacris kokulovae* insect zone, which indicates an Upper Rotliegend I (Sakmarian/Artinskian) age (Schneider & Werneburg, 2006).

With the shift of the depocentres to the north, again after a hiatus, the up to 250 m thick ***Tambach Formation*** was deposited on a volcanic relief dissected in part by canyons (Lützner & Mädler, 1994; Lützner *et al.*, 2007). Facies patterns range from very coarse, matrix supported wadi-fill conglomerates to proximal and distal debris-flow dominated alluvial fan clastics as well as floodplain sandstones and floodbasin siltstones.

The sandstones are interpreted as fluvial reworked aeolian sandstones, primarily accumulated in the hinterland (Schneider & Gebhardt, 1993). *Scoyenia*-facies, indicative for wet red beds, is typical of these alluvial plain deposits (Martens *et al.*, 1981). The flora consists of xerophilous walchians and cones of the drought-adapted *Calamites gigas*. Tambach is famous for complete, articulated vertebrate skeletons, preserved in mud flows (Martens, 1988; Berman & Martens, 1993; Eberth *et al.*, 2000). The fauna includes reptiles and terrestrially adapted amphibians, which at the genus level are close to North American Early Permian tetrapod faunas (Berman *et al.*, 2001). Based on tetrapods and insects (*Moravamylacris kukalovae*), the Tambach Formation is correlated with the North American late Wolfcampian/early Leonardian, i.e., the Sakmarian/earliest Kungurian (Schneider & Werneburg, 2006; Lucas, 2006).

The 400 m to 600 m thick completely red ***Eisenach Formation*** occurs only at the western flank of the Ruhla Crystalline Complex and the adjacent Werra Basin (Lützner, 1981, 1994). The marginal facies is represented by the interfingering of monotonous fanglomeratic alluvial fan deposits and red silty to sandy mudstones. They were deposited on an apron of alluvial fans with predominantly sheet-flood deposits that interfinger towards the basin center with fine clastics of playa mudflats. Evaporitic conditions are indicated by common haloturbation and mm-sized gypsum crystal casts in playa siltstones. Well-rounded, coarse sand grains (2-3 mm) in the alluvial fan fine-clastics are indicative for reworked aeolian deposits. The fossil content consists of the playa-jellyfish *Medusina limnica*; ephemeral pond deposits contain conchostracans and leaves of *Taeniopteris* sp. (Voigt & Rößler, 2004). In places arthropod and tetrapod tracks are not rare (Walter *et al.*, 1983).

The ***Förtha*** (Schneider, 1996) or ***Neuenhof Formation*** (Lützner *et al.*, 2007) comprises the youngest Rotliegend sediments below the marine Zechstein. The up to 20 m thick sandy and conglomeratic sediments are partly fluvial deposits; poorly sorted, indistinctly horizontally stratified, matrix-supported fanglomerates are interpreted as debris flows. Their primary red colour changed to grey some meters below the marine Zechstein conglomerate, even granite pebbles are completely leached to pale grey. Horizontal nodule layers are regarded as groundwater calcretes. These calcretes and the leaching are interpreted as effects of the marine pre-Zechstein-ingressions into the Southern Permian Basin and the Zechstein-transgression, which caused a maritime influence on the arid continental climate (Schneider, 1996, 2001). Above this formation, marine reworked coarse clastics and the Kupferschiefer form the base of the Zechstein. The Kupferschiefer is dated by the conodont *Mesogondolella britannica* as Wuchiapingian (Legler *et al.*, 2005), which fits well with the ^{187}Re-^{187}Os isochron age of 257.3 ± 1.6 Ma (Brauns *et al.*, 2003).

Saale Basin

The Saale Basin to the SE of the Harz Mountains (Fig. 1) is the type area for the old miner terms "Rotliegend" (the "rote todte Liegende" = the red dead (barren) rocks below the copper shale) and "Zechstein" (hard limestone in the hanging of the copper shale), as well as the Saalian phase (Stille, 1920). As a lithostratigraphic term, ***Rotliegend*** has been defined by von Veltheim (1821-1826) and Laspeyres (1875). Referring to this region, de Lapparent (1893) defined the "Saxonian" and Renevier (1874) the "Thuringian". These terms are still in use as regional "stages" in some parts of western and eastern Europe, but because of poor definition not in Germany. Coal prospection during the 19th and 20th century and uranium prospection in the second half of the 20th century form the base of the present knowledge of this region. After nearly 600 years of hard coal mining in the region of Halle, the last mine closed in 1967. A geotechnical and scientific highlight was the 1748 m deep, in large parts cored coal-exploration well Schladebach near Leipzig, described in detail by Beyschlag & von Fritsch (1899). Drilled from 1880 to 1886, it was for a long time the deepest drill hole.

Only Lower Rotliegend volcanites and Upper Rotliegend sediments are partially well exposed in surface outcrops. Late Carboniferous outcrops are restricted to the Kyffhäuser Mountains and the deep incised valley of the Saale river to the north of Halle. Therefore, most knowledge is based on drilling cores (e.g., Gaitzsch *et al.*, 1998; Schneider *et al.*, 2005a, 2005b).

Basin development and basin fill (Figs. 4 and 6): The Late Carboniferous Stephanian (Kasimovian) to Middle Permian Upper Rotliegend I (Kungurian) Saale Basin is a continental basin of 150 km length and 90 km width (Schneider *et al.*, 2005b). It is situated above the inverted SW-NE striking MGCZ at the outer border of the Variscian fold belt (Fig. 1). Therefore, it represents a "perimontane" rather than an "intramontane" basin. The underlying Visean grey sediments of the up 1,400 m thick continental ***Klitschmar Formation*** and the more than 400 m thick Namurian paralic ***Sandersdorf Formation*** are only known from drillings in an area to the north of Leipzig (Gaitzsch *et al.,* this volume). Above an angular unconformity, this formation is overlain by grey sediments of the Westphalian ***Roitzsch Formation***, which is only known from a few wells in the area between Leipzig and Wittenberg. The coal-bearing, mainly coarse-clastic rocks of this formation were deposited in a drainage system reaching from the NE border of the Central Bohemian Basin (Gaitzsch *et al.,* 1998, Opluštil & Pešek, 1998; Pešek, 2004) to the Variscan fore deep. The development of the Saale Basin started with the Stephanian deposits of the Mansfeld subgroup that rests disconformably on the Viséan to Westphalian sediments and Variscian metamorphic rocks and granites. The basin is contoured by SW-NE striking border faults and is internally structured by NW-SE striking faults (e.g., Finne-Gera-Jachymov fault, Halle fault, Elbe Zone). This fault pattern controls syn-sedimentary block subsidence and corresponding changes in thicknesses and facies architectures. During the early Lower Rotliegend, this tectonism in conjunction with the formation of the Halle Volcanic Complex reduced the size of the sedimentary basin after the deposition of the Mansfeld Subgroup.

The up to 1,000 m thick Stephanian (Gzhelian/Asselian) wet red beds of the ***Mansfeld Subgroup*** are subdivided in three fining-up megacycles, which correspond to formations. Near the top of each megacycle occur commonly spatially restricted lacustrine and palustrine grey sediments, which are classified as subformations.

The 60 m to 200 m thick ***Gorenzen Formation*** starts with grey-violet to red conglomerates that grade into grey and red colored sandstones. Grey sediments with carbonaceous sandstones and thin impure coal seams of the ***Grillenberg Subformation*** occur in distal fan deposits and in local depocentres. The overlying c. 400 m thick megacycle of the ***Rothenburg Formation*** includes dominantly wet red beds of the *Scoyenia* facies that rest expansively and partially erosive with basal coarse conglomerates on the Gorenzen Formation, the Westphalian Roitzsch Formation, and the Variscan basement. The basal coarse clastics grade vertically into about 30 m thick mesocycles of fluvial and sheet flood conglomerates, alluvial plain sandstones, and siltstones. Calcisoils of different maturity are common. Towards the top of the formation, such soils, horizons with calcareous rhizoconcretions, and meter-thick calcretes are increasingly abundant. Near the top appear decimeter thick lacustrine micritic limestones precipitated in ephemeral shallow lakes and ponds with characean algae, gastropods, and aistopod amphibian bones as well as rare palaeoniscid and xenacanthid fish teeth (Gebhardt & Schneider, 1985; Gebhardt, 1988). The fluvial, lacustrine, and palustrine grey sediments of the ***Querfurt Subformation*** are restricted to the depocentres.

The base of the 500 m to 800 m thick wet red beds of the ***Siebigerode Formation*** is marked by to the NE forestepping deposition of coarse pebbly quartz sandstones, rich in kaolinized feldspar, that originates from the metamorphosed granites of the MGCZ at the SW border of the basin. Facies architecture comprises alluvial fan to alluvial plain and flood plain/flood basin associations consisting of stacked minor cycles of about 15 m thickness. Stacked coarse fluvial channel and fluvial bar conglomerates as well as sheet flood fanglomerates characterize medial to distal fan environments. The alluvial plain is dominated by trough cross bedded sandstones with intercalated conglomerate channels. Silicified tree logs are found from the western border of the basin (Kyffhäuser Mountains) to the basin center near Halle. Alluvial plain and floodplain siltstones are developed in *Scoyenia* facies and characterized by immature vertisols and calcisols. Changes in the sediment color from violet and greyish-green to grey mark the transition to the coal-bearing grey facies of the up to 300 m thick ***Wettin Subformation*** in the depocenters of the upper Siebigerode Formation. Distinctive marker horizons close to the base of the Wettin Subformation are the "Liegender Kalkstein", a bioclastic bivalve shell bearing oncoidal limestone, as well as the "Unterer Muschelschiefer", a bivalve-rich claystone that could be traced laterally from the grey into the red facies. These lacustrine deposits are followed by grey fluvial sandstones and siltstones of a floodplain/floodbasin facies with back swamps. Coal seams cover only restricted areas of 2 km by 8 km. Lacustrine bioclastic limestones with fish-remains and bivalve-rich claystones of the "Hangender Kalkstein" and the "Hangender Muschelschiefer" form the top of the Wettin Subformation.

Based on macroflora and microflora, the Grillenberg Subformation is dated as Stephanian A and the Wettin Subformation as Stephanian C (Schneider *et al.*, 2005a). The Wettin Subformation belongs to the *Apateon intermedius - Branchierpeton saalensis*-zone (Werneburg & Schneider, 2006) and the *Sysciophlebia euglyptica - Syscioblatta dohrni*-assemblage zone (Schneider & Werneburg, 2006), i.e., the Gzhelian/Asselian transition. The lake deposits of the Wettin Subformation bear a diverse fish fauna with fresh water sharks, which are widespread and typical for the Stephanian of all larger European basins (Schneider *et al.*, 2000).

The base of the Rotliegend ***Halle Formation*** is defined by the "Kieselschiefer-Quarzit-Konglomerat" (Chert-Quartzite Conglomerate), which interfinger locally with lacustrine black shales of the "Hangender Muschelschiefer". The about 600 m thick formation constitutes of grey and red sandstones to claystones with intercalated horizons of conglomerate and pyroclastic rocks. The formation is dominated by acidic volcanic rocks of the Halle Volcanic Complex with laccoliths (> 1,000 m thickness), lava domes, and rare lava flows (Breitkreuz & Kennedy, 1999; Romer *et al.*, 2001).

The following completely red ***Hornburg Formation*** includes two fining up megacycles, each 200 m thick (Falk *et al.*, 1979). The first

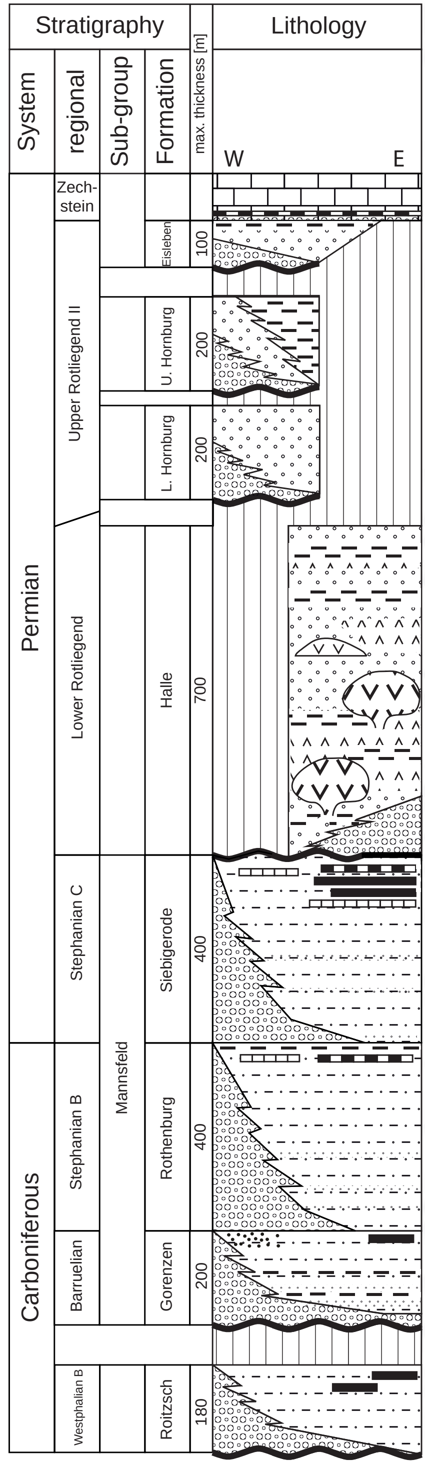

Fig. 6. Saale basin; based on Lützner (1988), Gaitzsch *et al.* (1998), and Schneider *et al.* (2005a, 2005b). Symbols as in Fig. 4.

megacycle starts with a 30 m thick quartzite dominated conglomerate followed by 30 m red silty sandstones with rare thin intercalations of supposedly pyroclastics. The second megacycle starts with quartzite-dominated conglomerates that are overlain by bimodal sandstones of fine sand and well rounded coarse sand ("Rundkörniger Sandstein"). These exceptionally well-rounded and sorted grains are unquestionably the result of aeolian saltation transport. Vertically, these sandstones grade into playa siltstones and claystones with locally up to two meter deep desiccation cracks. The playa deposits are characterised by the freshwater jellyfish *Medusina limnica* and diverse arthropod and rare tetrapod tracks (Walter, 1982; Schneider & Gebhardt, 1993). Commonly, an Upper Rotliegend I age is assumed, although facies pattern and tetrapod tracks possibly indicate a lower Upper Rotliegend II age.

After a long hiatus follows the up to 100 m thick Upper Rotliegend II ***Eisleben Formation***, which is regarded as equivalent to the Hannover Formation of the Southern Permian Basin (cf. Legler, 2005). The braided river, sheet flood, and wet to dry sand flat deposits belong to one of the large N-S striking extended wadi systems that delivered the material for the up to 2,400 m thick fill of the Southern Permian Basin. In this regard, the sediments of the Eisleben Formation belong to border facies of the Southern Permian Basin rather than to the Saale Basin.

The marine ***Zechstein*** deposits seal the continental facies of the Rotliegend. During the transgression, reworked Rotliegend sediments form the first marine deposits below the metalliferous black pelites of the Kupferschiefer (copper shale). The Zechstein conglomerate consist predominantly of reworked coarser Rotliegend clastics, whereas the "Weißliegend" – pale grey to whitish sandstones of locally changing thickness from 0.5 m to 15 m – represent predominantly reworked Rotliegend alluvial and aeolian deposits.

Saar-Nahe Basin

With an extension of 300 km by 100 km, the Saar-Nahe Basin is the largest Permocarboniferous basin in Europe. It is largely covered by Mesozoic sediments and exposed only along the southern border of the Hunsrück Mountains (Fig. 1). Mining activity on Carboniferous and Permian coals started latest in the Middle Age. The Carboniferous fill of this basin includes 140 named coal seams that are mainly concentrated in the Westphalian; 120 of them are workable (Schäfer, 2005). Carboniferous plants from this basin have been included in the pioneering palaeobotanical works of von Schlotheim (1804) and Brongniart (1828–38). Up into the 20th century, lacustrine Rotliegend limestones and fluvial and aeolian sandstones have been quarried for dimension stones. Clay and siltstones were exploited up to recent times for brick production. Due to local iron production based on sideritic concretions in Rotliegend lacustrine shales, the Saar-Nahe Basin became in the 19th century world-famous for the exceptionally well-preserved animal fossils inside the "Lebacher Eier (eggs)". In this early period, a variety of Rotliegend arthropods, amphibians, and fishes have been described by Jordan (1847, 1849a, 1849b, 1870). The "Leitfische des Rothliegenden in den Lebacher … Schichten" (guide fishes of the Rotliegend in the Lebach beds) of Weiss (1864) was the first attempt to use Permian fishes for non-marine biostratigraphy. Detailed palecological studies were carried out by Boy (1998) and Boy & Schindler (2000). The fossil content of this basin is described in detail by Schindler & Heidtke (2007). The actual lithostratigraphy of the basin is based mainly on Falke (1974), Boy & Fichter (1982, 1988), Boy *et al.* (1990), Stapf (1990), Stollhofen & Stanistreet (1994), Königer *et al.* (2002), and Schäfer (2001, 2005).

Basin development and basin fill (Figs. 4 and 7): The basin is situated above the inverted MGCZ and extends only to the SE onto the Saxo-Thuringian Zone (Schäfer, 2005). During its entire history, the basin was a halfgraben structure bordered by the NE-SW striking Hunsrück fault. NW-SE striking fault systems segment the basin in a number of sub-basins with differing facies and thickness pattern. The early history of the basin started possibly with conglomerates of the Namurian ***Spiesen Formation***, which rests on marine Early Carboniferous sediments. The Westphalian to mid-Permian sediments (stacked thickness of about 8,000 m) of this basin are subdivided into four subgroups that reflect the temporal changes of the geotectonic setting of the basin (Fig. 7; cf. Stollhofen, 1991). These are, from the oldest to the youngest, the Westphalian Saarbrücken Subgroup, which is regarded as the transgressive proto-rift phase, the Stephanian Ottweiler Subgroup and the Lower Rotliegend Glan Subgroup, which are regarded as the pre-volcanic syn-rift phase, the basal Upper Rotliegend I volcanites of the Donnersberg Formation (lower Nahe Subgroup) form the volcanic syn-rift phase and the remaining formations of the upper Nahe Subgroup represent the post-rift phase of thermal subsidence.

The fluvio-lacustrine Westphalian A to D ***Saarbrücken Subgroup*** of about 2,400 to 3,000 m thickness is subdivided in seven formations. They were mainly deposited in an alluvial plain–flood plain–delta plain environment by anastomosing rivers. During the Westphalian, the drainage system was N-S directed, in the Stephanian SW to NE. Larger lakes are lacking. Abrupt facies changes between grey clay-, silt- and sandstones with intercalated conglomerates and coal seams are typical. The highest abundance of coal seams occurs in the late Westphalian B Rothell and the early Westphalian C Sulzbach formations. Additional workable seams occur in the early Westphalian D Heiligenwald Formation. There is a large hiatus from the late Westphalian D to the earliest Stephanian A in the Saar part of the basin (Hartkopf-Fröder, 2005), whereas in the Lorain part of the basin, the 1,500 m thick Westphalian D sediments of the Falkenberg Formation were deposited. There occur widespread fine air-fall ash horizons (kaolin coal tonsteins), that permit for regional to interregional correlations. The biostratigraphy of the Westphalian is mainly based on sporomorphs (Hartkopf-Fröder, 2005).

The deposition of the maximal 710 m thick Stephanian ***Ottweiler Subgroup*** starts at an angular discordance with the basal 50 m thick Holz conglomerate. It belong to the 450 m thick ***Göttelborn Formation*** with basal reddish to grey-green sandy to silty sediments that are overlain by grey fine clastics, containing widespread coal seams and lake deposits (*Leaia*-horizons). The lower part

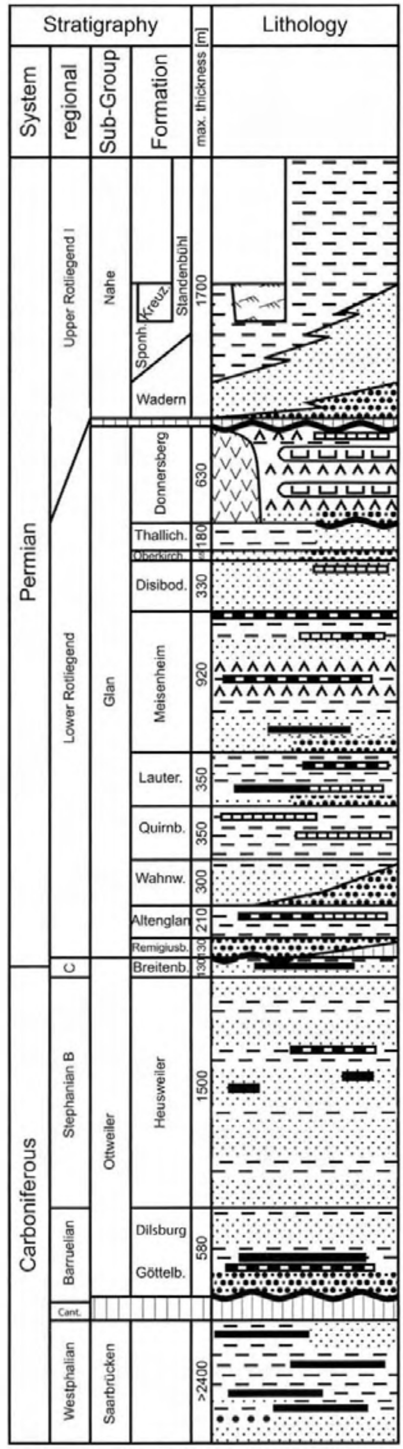

Fig. 7. Saar-Nahe Basin; based on Boy *et al.* (1990), Stapf (1990), Schäfer (2005), and Schindler & Heidtke (2007). Symbols as in Fig. 4.

of the overlaying 130 m thick ***Dilsburg Formation*** display similar grey facies pattern, which change in the upper half to reddish sediments. Wet red beds with calcisols dominate in the up to 1,500 m thick ***Heusweiler Formation***. Rare coal seams and lake horizons are restricted to the middle part of the formation. Coal seams, one of them nearly basin-wide, and lake horizons are common in the 130 m thick grey ***Breitenbach Formation***.

The Stephanian is biostratigraphically dated by the *Sysciophlebia* n. sp. A - *Syscioblatta intermedia*-assemblage zone (Kasimovian) in the Göttelborn Formation, the *Syscioblatta variegata - Spiloblattina pygmaea*-zone (Kasimovian) in the basal Heusweiler Formation and the *Sysciophlebia euglyptica - Syscioblatta dohrni*-assemblage zone (Gzhelian/Asselian transition) in the Breitenbach Formation (Schneider & Werneburg, 2006). The diverse Stephanian freshwater shark fauna of the Saar-Nahe Basin compares well to contemporaneous shark faunas in the whole Variscan area, indicating interconnected drainage systems of the basins (Schneider & Zajic, 1994; Schneider *et al.*, 2000).

The Rotliegend is subdivided in the Lower Rotliegend ***Glan Subgroup*** of 2,400 m thickness and the Upper Rotliegend 1,800 m thick red beds of the ***Nahe Subgroup*** (Stapf, 1990; Boy *et al.*, 1990). Rotliegend sedimentation starts with the 130 m thick ***Remigiusberg Formation***, which is characterised by alluvial red beds, fan conglomerates (especially in the basal part) and fluvial to fluviolacustrine red clastics; grey sediments dominate in the northeastern part of the basin. Vertically, this formation grades into lacustrine grey to grey-green fine sediments with several intercalated lacustrine bituminous limestones to black shales of the 210 m thick ***Altenglan Formation***. The next cycle, the maximaly 230 m thick ***Wahnwegen Formation***, started with prograding fan and fluvial deposits of red coarse sandstones and conglomerates. Grey alluvial plain sediments with local lakes and swamps are rare. The 350 m thick ***Quirnbach Formation*** is dominated by grey fine clastics, laminated lacustrine limestones and claystones are common.

Up to 20 m thick red basal conglomerates form the base of the fluviolacustrine 350 m thick ***Lauterecken Formation***. In the lower part of the formation, the up to 15 cm thick, Odenbach-carbonate-coal seam spans an area of about 3300 km^2. Additional meter-thick lake horizons consist of limestone/black shale interbeddings. The overlying 340 m to 920 m thick ***Meisenheim Formation*** contains abundant lake horizons and approximately 40 tuff horizons. The base of the formation is marked by an up to 70 m thick partly conglomeratic, red sandstone. The fluviolacustrine middle part, with lacustrine black shales and fluvial red sandstones grade upward into lacustrine grey-brown to grey fine sandstones and pelites with subordinate red clastics. The top of the formation is formed by the bituminous paper shales of the Humberg lake horizon, the most widespread lake of the Saar-Nahe Basin. This horizon contains the world-famous Lebach-limonite-siderite concretions with three-dimensionally preserved fishes and amphibians. The top of the Meisenheim Formation belongs to the *Melanerpeton pusillum - M. gracile*-zone (Werneburg & Schneider, 2006) and in the *Spiloblattina odernheimensis*-zone respectively (Schneider & Werneburg, 2006). The Pappelberg tuff of this formation is dated to 297 ± 3.2 Ma (Königer, 2000). The predominantly grey 330 m thick ***Disibodenberg Formation*** consists of monotonous deltaic sand- and siltstones, prograding into the former Humberg lake environment. The top of the Glan Subgroup is formed by the about 180 m thick ***Thallichtenberg Formation*** that is built up by grey-olive to red-grey siltstones and sandstones.

The Upper Rotliegend ***Nahe Subgroup*** starts with the 400 m to 900 m thick volcano-sedimentary ***Donnersberg Formation*** (Stollhofen *et al.*, 1999). This formation consists of red-grey conglomerates, arkoses, and red to grey-green pelites with intercalated basaltic lava flows and common rhyolitic tuff horizons (Stollhofen, 1994a, 1994b). Locally, there occur lacustrine limestones and thin coaly horizons. Huge, up to 1,000 m high rhyolite-domes, e.g., the Donnersberg and Nohfelden massifs, form the source areas for rhyolite fanglomerates and conglomerates. The deposition of the up to 100 m thick quarzite conglomerate at the base of the ***Wadern Formation*** mark a distinct change in the basin development (Stollhofen & Stanistreet, 1994) – the beginning of the post-rift phase, governed by thermal subsidence. In the lower part

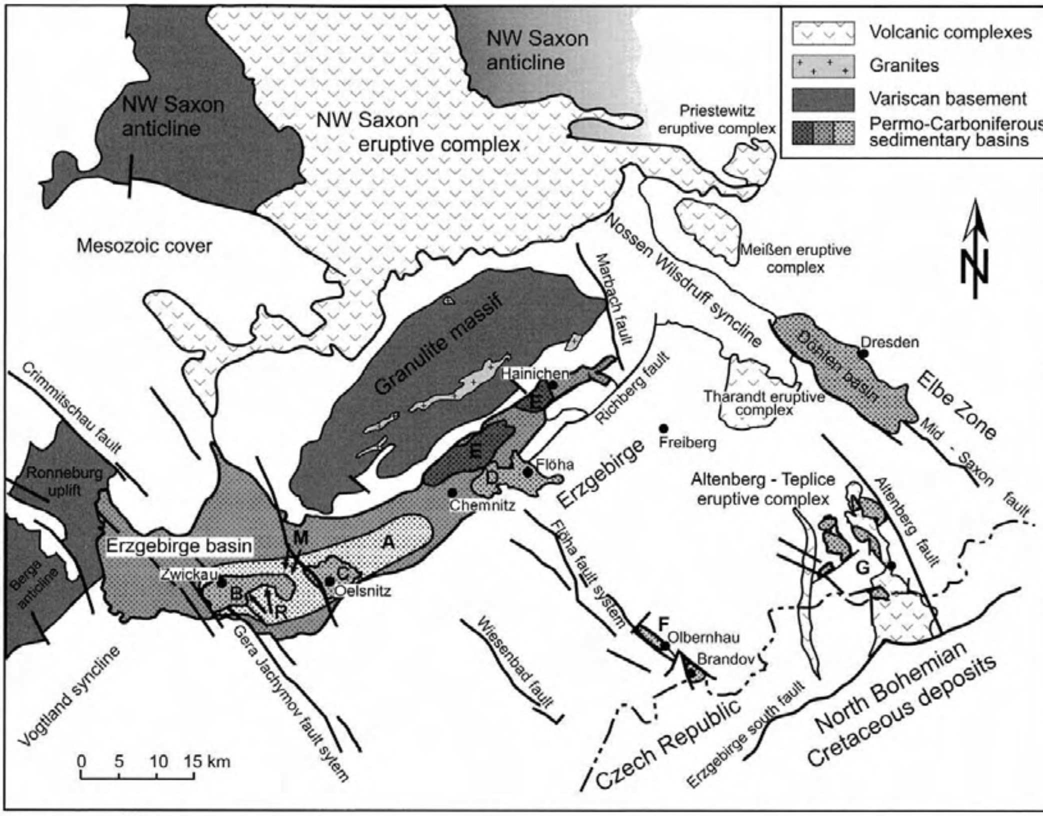

Fig. 8. Map of the Saxon basins. ***A*** primary extend of the Westphalian D to ?Cantabrian Zwickau-Oelsnitz basin. ***B*** erosional remnant of the Zwickau Subbasin. ***C*** remnant of the Oelsnitz Subbasin. ***D*** Westphalian B/C Flöha Basin. ***E*** remnants of the Visean Hainichen Basin. ***F*** remnants of the Westphalian B/C and Permian Olbernhau-Brandov Basin. ***G*** remnants of the Westphalian B-D Schönfeld-Altenberg Basin. ***R*** Reinsdorf fan of the Zwickau Subbasin. ***M*** Mülsen fan of the Zwickau Subbasin. The thick line around the Erzgebirge Basin marks the actual extend of the Rotliegend Chemnitz Basin (modified from Schneider *et al.*, 2005a).

of the Wadern Formation, one of the last fish and amphibian containing lake horizons of the Central European Rotliegend – the very local Sobernheim horizon (*Moravamylacris kukalovae*-insect zone; Schneider & Werneburg, 2006) – is intercalated with stromatolites and plant-rich beds. The debris fans of the Wadern Formation interfinger with the exclusively red beds of an alluvial plain to playa environment of the 220 m thick ***Sponheim*** and the up to 1,700 m thick ***Standenbühl*** formations. Intercalated in the upper Wadern and Sponheim formations and partially superimposed on the Standenbühl Formation are the up to 230 m thick aeolian sandstones of the ***Kreuznach Formation***.

Erzgebirge Basin

The present-day 70 km by 30 km large and NE-SW striking Erzgebirge Basin in south Saxony (Fig. 8 was discontinuously filled with the molasses of the Variscan orogen (Figs. 4 and 9). Sedimentation was interrupted by long periods of non-sedimentation and erosion of older basin fill. Subsequent basins were controlled by different geodynamic regimes and, therefore, had a development independent of their precursors. The term Erzgebirge Basin includes the entity of these subsequent basins as it describes the present-day distribution of Late Palaeozoic deposits at the northern flank of the Erzgebirge, rather than a specific basin in geotectonic terms.

The Late Visean is represented by relics of the ***Hainichen Basin*** (see Gaitzsch *et al.*, this volume). At intersections of deep faults, local basins developed, such as the postorogenic basins of ***Flöha*** (Westphalian B/C; Duckmantian/Bolsovian) and the ***Oelsnitz*** and ***Zwickau*** basins (Westphalian D - ?Cantabrian). Erosional relicts of additional Westphalian basins exist in the Eastern Erzgebirge, e.g., the Westphalian B/C ***Olbernhau-Brandov*** and Westphalian B-D ***Schönfeld-Altenberg*** basins (Fig. 8). The Rotliegend ***Chemnitz Basin*** developed after the Franconian volcano-tectonic activity and basin re-organization. It is superimposed on the deep-reaching detachment between the Erzgebirge and the Saxon Granulite Massif (Fischer, 1991; Kroner, 1995). In the western part of the basin, the oldest Lower Rotliegend sediments (Härtensdorf Formation) rest with an angular unconformity on the deeply eroded upper late Westphalian to ?Cantabrian Zwickau Formation. This unconformity and erosional gap could be related to the Franconian movements at the Stephanian/ Rotliegend transition, but also to the preceding Asturian movements during or after the Cantabrian. Basin development and configuration during the Lower Rotliegend and Upper Rotliegend I was mainly controlled by volcano-tectonic processes. Abundant ash falls originated from volcanic activity mostly outside the basin, possibly from the NW-Saxon Volcanic Complex that flanked the basin to the north (Fig. 8). Starting with the Upper Rotliegend II, facies patterns follows increasingly NW-SE directions. The Middle to Late Permian red beds of the Mülsen Formation possibly form the transition to the Late Permian Zechstein and Mesozoic platform development (Fig. 2). In the northwestern part of the Chemnitz Basin, these Upper Rotliegend coarse clastic sediments are transgressively covered by marine Zechstein deposits and their terrestrial equivalents.

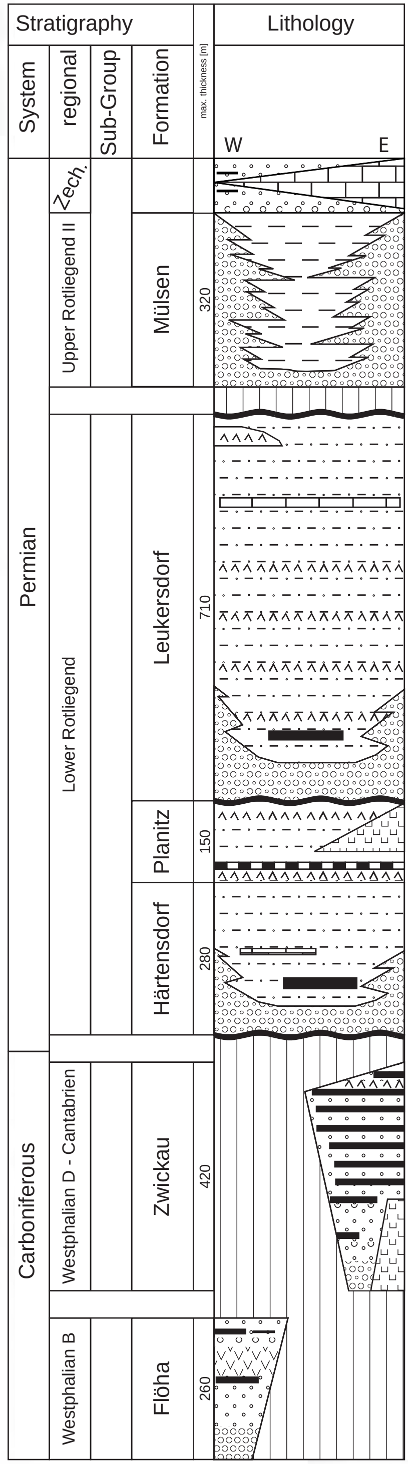

Fig. 9. Erzgebirge Basin; based on Fischer (1991) and Schneider *et al.* (2005a). Symbols as in Fig. 4.

Late Carboniferous Zwickau-Oelsnitz Basin

The long history of exploration and exploitation of hard coal in Saxony has its first written record in 1348 by the prohibition for blacksmiths to use hard coal within the city walls of the town of Zwickau because of "poisonous smoke". Later G. Agricola (1556) and B. von Cotta (1856) wrote about the coal mining in Zwickau. The palaeobotanical research on the Carboniferous in Saxony started here with the descriptions of the Zwickau coal floras by A. von Gutbier (1834, 1835) and H.B. Geinitz (1854a, 1854b, 1855). Up to 1978, when the last mine was closed, 210 million tons of hard coal had been exploited in the Zwickau coal district.

Basin development and basin fill (Figs. 4 and 10): A synsedimentary active swell and the Mülsen fan segment the basin into the sub-basins of Zwickau and Oelsnitz. The postorogenic Zwickau sub-basin (Fig. 8) is controlled by the intersection between regional deep faults: the NW-SE Gera-Jáchymov-zone, the SW-NE detachment between the Erzgebirge and the Saxon Granulite Massif, and the N-S zone of Plauen-Dessau-Leipzig as well as subordinate E-W-oriented faults. During the Duckmantian, Bolsovian, and Westphalian D, a drainage system linked to this fault pattern drained the central and western Bohemian basins. It interconnected the eastern part of the Kladno-Rakovnik Basin (Gaitzsch *et al.*, 1998; Opluštil & Pešek, 1998) with the basins of Olbernhau-Brandov, Altenberg-Schönfeld, Zwickau-Oelsnitz, and Flöha (Fig. 6). Lower Rotliegend red beds unconformably cover the Westphalian deposits that have been deeply eroded, particularly to the north and west. Therefore, neither the original thickness nor the extent of the basin is known. Only the NW-dipping south-eastern flank of the Zwickau sub-basin is preserved as erosional remnant. This basin remnant covers an area of about 12 km by 7 km.

Early stages of basin development followed NNW-SSE to N-S directions, later stages follow NE directions. The origin of the basin and the change of basin axis and depocenters are related to increased tectonic activity during the Westphalian D. Early in the basin development, the Reinsdorf and the Mülsen fans grew from the south-east and the north, respectively, into the basin (Fig. 8). Coal forming swamps were located in front and especially along the flanks of these fans.

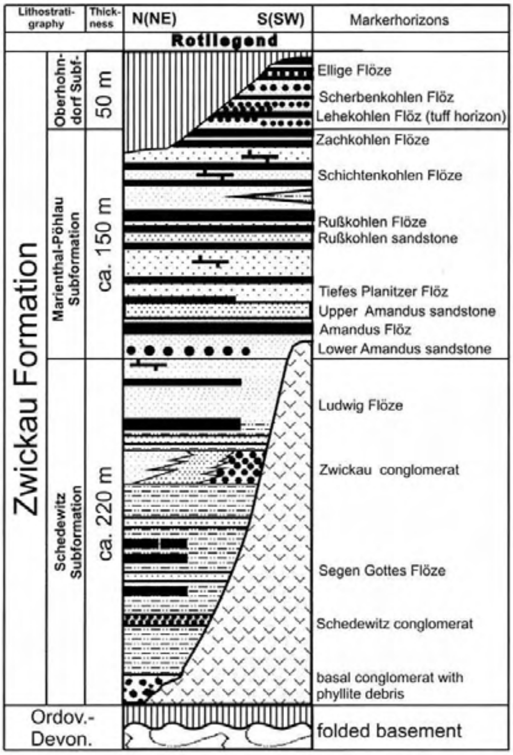

Fig. 10. Zwickau Basin; based on Schneider *et al.* (2005a, 2005b). Symbols as in Fig. 4.

Traditionally, the Carboniferous deposits of the Zwickau Basin have been subdivided lithostratigraphically by means of coal seams. The present lithostratigraphy (cf. Fig. 10) is based on lithofacies and sedimentary cycles (Hoth, 1984; Schneider *et al.*, 2005a, 2005b). The only formation of this basin, the ***Zwickau Formation*** with a remaining stacked thickness of maximally 420 m, is covered at an erosional unconformity (Stephanian to Rotliegend erosion) by the Lower Rotliegend Härtensdorf Formation. The Zwickau formation is subdivided from bottom to the top in three sub-formations: ***Schedewitz Subformation*** (thickness 220 m), ***Marienthal-Pöhlau Subformation*** (thickness 150 m), and ***Oberhohndorf Subformation*** (remaining thickness up to 50 m).

The early topography of the basin was influenced by local Late Carboniferous (?Westphalian) basalt flows that form synsedimentary swells with up-stepping sedimentation on the flanks. Sedimentation of the ***Schedewitz Subformation*** starts with local breccias on deeply weathered, partially kaolinised basalts and Variscian folded early Palaeozoic rocks. This subformation is dominated by alluvial to flood plain deposits of alternating sandstones and siltstones with intercalated pebbly sandstone and conglomerate channels. The first workable coals (more than 40 cm thickness) appear in the western part of the basin, which had subsided more. The following Segen-Gottes-Flöze complex includes three groups of 1 m to 2 m thick seams. Later coal seams are thicker (e.g., up to 3 m for the Ludwig-Flöz) and have reached farther to the north-east.

The ***Marienthal-Pöhlau Subformation*** is dominated by sandstones and siltstones of alluvial to flood plain facies with swamps. Fine to coarse and pebbly sandstones, locally with conglomerates at the base of the subformation, mark the progradation of the fans. A change in basin configuration (from NNW-SSE to SW-NE directions) is reflected in the distribution and thickness of coal seams. The Amandus-Flöz seam has a maximum coal thickness of up to 7 m in the south and the Tiefe Planitzer-Flöze seams reach a thickness of 3.5 m. The Rußkohlen-Flöze horizon, which is traceable across the entire Zwickau sub-basin, consists of up to three seams that could amalgamate to a single seam of maximum thickness of 10 m. Due to erosion in the Stephanian and Lower Rotliegend, the ***Oberhohndorf Subformation*** is only locally preserved in the western part of the basin. Sedimentation of this subformation starts with deposition of relatively coarse clastics that reflect tectonic rejuvenation of the relief. There are five cycles of progradation of conglomerates and sandstones of alluvial fan to alluvial plain facies that are separated by coal seam horizons with a maximum thickness for individual seams of 3.0 m. The Lehekohlen-Flöz seam is particular as it contains a 1-3 cm thick pyroclastics layer ("Kaolin Graupen Tonstein").

The fossil content of the Zwickau formation is characterized by hydro- to hygrophilous macrofloras (Daber, 1957; Rößler & Buschmann, 1994) and hygrophilous to mesophilous microfloras (Döring *et al.*, 1988). Faunal remains are comparatively rare. Reported are some arachnids (Rößler & Dunlop, 1997) and arthropods (ostracods, conchostracans, *Arthropleura*, eurypterids, insects), as well as pelecypods and tetrapod tracks (for details see Schneider *et al.*, 2005a, 2005b). Macrofloras, microfloras, insects, and conchostracans give a Westphalian D to lower Cantabrian age (Döring *et al.*, 1988; Rößler & Dunlop, 1997; Schneider *et al.*, 2005a, 2005b).

Rotliegend Chemnitz Basin

The Rotliegend of the Chemnitz Basin is world-famous for its Permian petrified forest. The often colorfully silicified tree trunks have attracted the Saxon electors for their splendid collections of jewellery and gem stones. Special officials, the gem stone inspectors, searched the country for such "noble stones". One of them was David Frenzel from Chemnitz. From 1740 onward he discovered several large petrified trunks in Chemnitz-Hilbersdorf, which he transported to the Saxon capital of Dresden, where they were processed into beautiful works of art, exposed in the "Grünes Gewölbe" in Dresden (Rößler, 2001). In the early years of the scientific palaeobotany in the first half of the 19[th] century, the descriptions of this silicified wood have stimulated the study of three-dimensionally preserved plant fossils in general. Geinitz´s (1858) publication on plant guide-fossils of the Permian of Saxony is one of the first attempts in plant-biostratigraphy and was directly linked to the demands of the geological mapping of Saxony.

Basin development and basin fill (Figs. 4 and 9): The Rotliegend Chemnitz Basin covered an area of about 70 km by 30 km (Fig. 1). Rotliegend sedimentation started after a long lasting hiatus on the Variscian basement and – with an angular unconformity – on the Visean Hainichen subgroup and the Westphalian of the Zwickau-Oelsnitz Basin. The up to 1830 m thick basin fill consist mainly of alluvial red beds and volcanites and is subdivided in four formations (Fischer, 1991).

The oldest one, the 180 m (maximally 280 m) thick ***Härtensdorf Formation***, deposited in a

WSW-ENE to SW-NE orientated basin, shows basal matrix-supported fan conglomerates. These coarse clastic deposits are dominated by debris flows that interfinger towards the basin centre with fine-clastic alluvial and flood plain sediments, mainly siltstones with intercalated channel conglomerates of braided river systems. The often greenish to light grey leached fills of those channels point on palaeo-groundwater flow. Flood plain deposits contain sporadically centimeter to decimeter thick coal seams of local swamps. Very typical for the flood plain siltstones and silty sandstones are invertebrate burrows (0.5 mm diameter) of *Scoyenia*-type. Common are calcareous rhizoconcretions in the neighborhood of the channels and calcisols of different maturity. Decimeter thick micritic limestones with mm-sized gastropods and minute isolated skeletal remains of snake-like aistopod amphibians indicate the existence of temporary pools and lakes (Schneider & Rößler, 1996). The age of the Härtensdorf Formation is determined by the macroflora (*Alethopteris schneideri*, *Callipteridium gigas*; Barthel, 1976) as Lower Rotliegend and by sporomorphs as late Asselian based on the dominance of *Vittatina* spp. (Döring *et al.*, 1999). Volcanism starts in the upper Härtensdorf Formation with pyroclastic horizons due to plinianian eruptions and continues into the Planitz Formation where volcanic deposits dominate.

The base of the up to 170 m thick ***Planitz Formation*** is marked by the 5 to 25 m thick Grüna tuff. This formation consists mainly of volcanic ashes, ignimbrites, and lava flows as well as their reworked products. Depending on the position to the eruption areas inside and outside the basin, there are regional changes in thickness and facies pattern although some tuff horizons form nearly basin wide marker horizons. Intercalations of conglomerates, sandstones, and siltstones are subordinate. The Grüna pyroclastic rocks are directly overlain by the distinctive Niederplanitz lake horizon, which represents a vertical and lateral sequence of centimeter to decimeter thick lacustrine black, greenish-grey to red claystones and siltstones with intercalated air fall and reworked pyroclastics. These deposits formed during a wet climatic phase in an extended lake landscape. The low-diversity vertebrate fauna consist only of palaeoniscid fishes and xenacanthid fresh water sharks that indicate the linkage of this basin to a larger, interregional drainage system, enabling the immigration of fish. Flows of trachybasaltic and shoshonitic lavas of up to 70 m thickness originate from different fault controlled eruption centers in the south-western part of the basin. The upper part of the Planitz Formation contains widespread ignimbrites, locally deposited as vitrophyres (pitchstone). The age of the Planitz Formation is determined as late Lower Rotliegend (late Asselian/early Sakmarian) by xenacanthid shark teeth (Schneider, 1988); sporomorphs indicate a late Autunian age, comparable to the late Asselian of the Donetsk Basin (Döring *et al.*, 1999).

The up to 700 m thick ***Leukersdorf Formation*** rests erosive on the Planitz Formation. Decameter thick basal conglomerates contain the debris of the eroded Planitz volcanites. Generally, the formation consists of red fan and predominating alluvial to flood plain deposits in three fining up cycles. Alluvial and flood plain deposits are characterised by the *Scoyenia* facies of wet red beds as well as calcisols of changing maturity. The top of the first cycle is formed by the maximally 25 m thick fluvial-palustrine Rottluff Horizon, consisting of grey clastics with plant remains and thin coaly layers. The top of the second cycle is marked by several thin limestone beds of the Reinsdorf Lake Horizon. This grey micritic limestone contains gastropods, ostracods, and sparse disarticulated tetrapod remains. Rarely, laminites delivered poorly preserved branchiosaurid amphibian skeletons. The third cycle is marked by the eruption of the up to 90 m thick Zeisigwald tuff in the area of Chemnitz in the eastern part of the basin. The base surge sequence of the Zeisigwald caldera eruption is responsible for the formation of the "Petrified forest of Chemnitz" (e.g., Fischer, 1991; Rößler, 1995). Up to 30 m high trees were laid down in east-west direction by the initial blast of a phreatomagmatic eruption.

Based on remains of the amphibian *Onchiodon* sp. the Leukersdorf Formation could be of transitional Lower/Upper Rotliegend (Sakmarian) age (Werneburg & Schneider, 2006). Sporomorphs correspond to the late Asselian of the Donetsk Basin (Döring *et al.*, 1999).

The following ***Mülsen Formation***, separated from the Oberrotliegend Leukersdorf Formation by a long lasting hiatus, may reach up to 400 m thickness. This formation consists completely of red fanglomeratic conglomerates, sandstones, and siltstones deposited in a debris flow/sheet flood dominated fan and alluvial plain environment. Nodular dolocretes are common. Well-rounded coarse sand grains, in places concentrated in the matrix of the fanglomerates, and strips of well-sorted fine to medium sand indicate reworked aeolian deposits. The fossil content is restricted to rare invertebrate burrows and very sparse root structures. Based on facies pattern, palaeoclimatic considerations, and the relationship to the overlying continental equivalents of near shore marine Zechstein deposits, an Upper Rotliegend II (late Guadalupian to earliest Lopingian) age is estimated. Most possibly, the Mülsen Formation forms the transition between the post-orogenic Variscan molasses and the platform sedimentation of the Zechstein.

NW Saxon Basin

The Rotliegend NW Saxon Basin with the NW Saxon Volcanic Complex covers an area of about 2,000 square kilometres to the north of the Saxon Granulite Massiv (Fig. 8). Because of the thick cover by Cenozoic sediments, information on the facies pattern and lithostratigraphy of the Rotliegend deposits is mainly based on exploration drillings for water, kaoline, and uranium. Kaolinite as an important raw material for the world-famous Saxon porcelain was first discovered in 1883 and has been exploited for ceramics since then up to recent times. The most fossiliferous Early Permian lake horizon of Saxony has recently been discovered and excavated in this area (description in preparation). The geological research history, starting in the first half of the 19th century, and the actual state of knowledge for this area have been summarized by Walter (2006).

Basin development and basin fill: The basin extends about 60 km in N-S and 50 km in E-W direction. It is bordered to the SE by the Saxon Granulite Massif, to the NE by the Meissen Massif, and to the east and west by Variscan lowgrade metamorphic rocks. The SW part the basin was connected with the Erzgebirge Basin during the Rotliegend. Furthermore, some of the pyroclastic marker horizons in the Erzgebirge (Chemnitz) Basin have been forned by eruptions in the NW Saxon Volcanic Complex. The lithostratigraphic relationship between these two basins, however, is poorly known.

Deposition starts with the up to 200 m thick ***Kohren Formation*** on the Variscan metamorphic basement. The lower part of the formation consist mainly of red fanglomerates, sandstones, and siltstones, the higher part shows increasingly more important intercalations of acidic to basic pyroclastics and lava flows. Silicified tree trunks occur in the entire section and characteristic Lower Rotliegend plants occur very locally in grey beds (Barthel, 1976).

The overlying ***Rochlitz Formation*** with up to 400 m thick stacked ignimbrites marks the first maximum of volcanism in this area. Equivalents of the four eruption units form very distinctive marker horizons in the Erzgebirge Basin.

Clastic deposits as fanglomerates, sandstones, and siltstones, which interfinger with acidic pyroclastics, ignimbrites, and thick rhyolitic lava flows, form the up to 250 m thick ***Oschatz Formation***. Black carbonaceous shale of the Saalhausen beds and the Börtewitz lake horizon contain a predominantly mesophilous flora as well as xenacanthid freshwater sharks, *Acanthodes*, and aquatic and terrestrial arthropods. In places, branchiosaurs are very common. They provide the only exact biostratigraphic datum in the entire basin (Werneburg & Schneider, 2006).

Lava flows, ignimbrites, intrusive bodies of andesitic volcanites are typical for the more than 600 m thick ***Wurzen Formation***. After a long lasting erosional hiatus, the Lower Rotliegend sequence is covered by continental to nearshore clastic equivalents of the marine Zechstein deposits.

Döhlen Basin

The Döhlen Basin, which is situated in the Elbe Zone, is famous for the in situ preservation of earliest Permian plant communities by volcanic ash falls (Rößler & Barthel, 1998). The fossilized plants that preserved many anatomic details were discovered during coal mining, which lasted several hundred years. The oldest document about coal mining is the permission granted to a company in 1542 by duke Moritz of Saxony. In the same year the "Oberbergamt", the main mining administration of Saxony, was founded in the old mining town of Freiberg. Several technical innovations were first introduced in coal mines of the Döhlen Basin, such as, e.g. flotation of hard coal (1810), the first cross cutter (channelling machine; by the German aviation pioneers, the Lilienthal brothers, 1877), and the first electric mine locomotive (1882). After the Second World War, the German/Soviet SDAG Wismut started in 1947 with the extraction of uranium from coal (Reichel & Schauer, 2007). Up to 1989, when the last mine was closed, 3,670 tons of uranium had been produced.

Basin development and basin fill (Figs. 4 and 11): The basin forms a small half graben of 22 km by 6 km primary extension in the Elbe zone, which is part of the NW-SE striking Elbe lineament (Reichel, 1970; Schneider, 1994). It is bordered by the Meißen Intrusive Complex, the Nossen-Wilsdruff and Elbe Slate Complex, and the Erzgebirge gneisses (Fig. 8). Basin topology and the high number of clastic dikes (formed by earthquakes) indicate that basin development and tectonic activity along the Elbe zone were coeval. Preserved basin fill amounts to about 800 m thickness and is subdivided into four fining up megacycles or formations, respectively. In contrast to other Permocarboniferous basins, pyroclastic rocks form up to 50 % of the deposits of this basin (Schneider & Hoffmann, 2001). Generally, sedimentation and facies pattern are governed by higher subsidence along the main fault at the southwestern graben border as well as strong volcano-tectonic activity including strong seismicity.

The oldest deposits, the Late Carboniferous (Stephanian, Gzhelian), maximally 160 m thick ***Unkersdorf Formation***, start with autochthonous weathering debris on folded and metamorphosed sediments as well as plutonic rocks of the Variscan

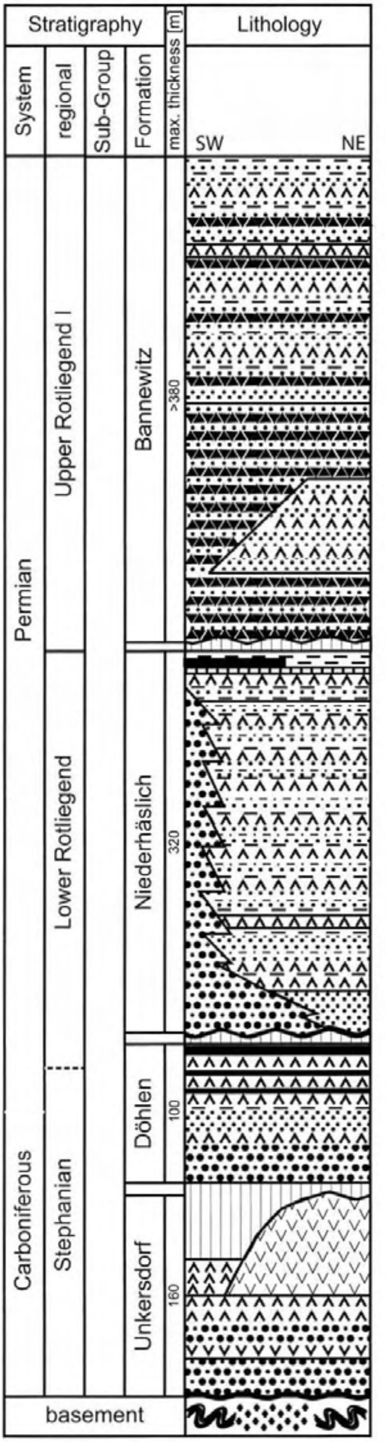

Fig. 11. Döhlen Basin; based on Reichel (1970), Schneider (1994), and Schneider & Hoffmann (2001). Symbols as in Fig. 4.

basement, followed by up to 45 m of polymictic conglomerates and up to 40 m of pyroclastic rocks. Locally, they are covered by up to 80 m of subaerial rhyodacite to trachyandesite that forms lava flows and domes.

The up to 100 m thick ***Döhlen Formation*** comprise two about 50 m thick fining-up mesocycles. Decameters of basal conglomerate indicate strong tectonic activity, possibly resulting in local erosion of Unkersdorf deposits. In the Briesnitz sub-basin at the northeastern border of the main basin, these basal conglomerates reach a thickness of 600 m and include blocks with up to 2 m diameter (Schauer *et al.,* 2005). There may have been a longer hiatus between the Unkersdorf and Döhlen formations. The mainly red basal conglomerates are overlain by grey sandstones, siltstones, and locally with seams of carbonaceous shale. The second mesocycle consist of fluvial pebbly arkoses, pyroclastic rocks, and five seams of carbonaceous shale and coal with up to 6 m, locally 12 m thickness. The presence of subaerial to subaquatic and fluvially reworked pyroclastic rocks between the coal seams indicate that more or less continuous peat formation occasionally was interrupted by strong ash falls. Upright-standing, up to 3 m tall calamite trunks at the top of seams indicate that ash-falls buried them catastrophically. Extraordinarily abundant clastic dikes have been found during coal mining. The dikes range from a few centimetres to 15 m thickness and vary in length from a few meters to up to 800 m. Abundant dikes are also known from the Unkersdorf and the Niederhäslich formations. They are likely to have formed by earthquakes linked to the intense volcanism prevailing during the deposition of these formations. The well-investigated macroflora of the Döhlen Formation is typical for the lowermost Rotliegend association of lower Asselian age (Barthel, 1976; Schneider & Barthel, 1997).

The up to 320 m thick ***Niederhäslich Formation*** starts with up to 35 m of conglomerates and sandstones that grade toward the basin center into coarse sandstones and siltstones and are overlain by c. 50 m of green-grey fluvial to shallow lacustrine siltstones with rare conglomeratic channels. Thin layers of ash and crystal tuffs are common. The top of this sequence is defined by a distinct marker horizon, the 6 m thick phreatomagmatic Zauckerode Tuff. The overlaying c. 170 m of grey-green siltstones with common intercalations of conglomerate and sandstone channels, sandstone, and pyroclastic horizons, are topped by 40 m of carbonaceous shales, coaly siltstones, lacustrine carbonates deposited in local depressions and sub-basins (Gebhardt & Schneider, 1993). Subsurface mining of this limestone in the 19th century revealed one of the most diverse tetrapod faunas, dominated by various amphibians and reptiles (e.g., Werneburg, 1991). Based on the *Melanerpeton pusillum - Melanerpeton gracile* amphibian zone (Werneburg & Schneider, 2006), the formation is correlated with the upper Lower Rotliegend (Sakmarian).

After an erosional hiatus, which is related with distinctive tectonic relief activation, coarse clastic rocks of the ***Bannewitz Formation*** (up to 380 m preserved thickness) were deposited on the Niederhäslich Formation. Conspicuous "Rhyolite Fanglomerates", including poorly sorted, partially matrix-supported coarse volcaniclastic sediments with clasts of flow-foliated rhyolite may be derived from the Meißen Volcanic Complex to the NW. The "Rhyolite Fanglomerates" were deposited from debris flows and hyperconcentrated flows. They are interlayered with primary pyroclastic horizons. The upper part of this formation, consisting of predominately volcaniclastic rocks deposited in an alluvial braid plain environment, include the 12 m thick Wachtelberg ignimbrite. Red silicites in different levels of the formation contain three-dimensionally preserved plant and arthropod remains. Based on facies pattern, tectonostratigraphical, and climatic indications, an Upper Rotliegend I age is assumed.

Synthesis

The Late Carboniferous and the Permian are characterized on the global scale by a degree of "continentality" that is only known for the last 5 million years of Earth's history. This character is the result of the assemblage of Pangea. The former Rheic Ocean between the huge landmasses Gondwana and Laurussia closed successively from east to west (Roscher & Schneider, 2006). The westward progression of the continental collision caused a more or less continuous formation and erosional destruction of huge mountain ranges along the palaeo-equator. The oldest orogen to the east, the European Variscides, was already eroded to low mountains by the end of the Carboniferous, when the youngest alpino-type orogen to the west, the Middle Permian Appalachian-Ouachita belt, was just about to form. Collision and orogeny produced foreland, intermontane, and intramontane basins, at times associated with regionally volumetrically important volcanism. These processes were accompanied by Carboniferous-Permian glaciations of southernmost Gondwana. The storage of water in the south polar icecap and in mountain glaciers resulted in a very low sea level. The interplay of the formation of Pangea – with the build-up and erosion of huge mountain chains –, glaciations and deglaciations, and atmospheric changes caused by temporally intense volcanism resulted in the complete disappearance of the equatorial wet tropical belt, which is unique for the Phanerozoic, and its substitution by semi-deserts and deserts. As shown by Roscher & Schneider (2006), the transition from the late Early Carboniferous (Mississippian) to Middle Permian (Guadalupian) cold-house into the Late Permian-Mesozoic warm-house Earth by increasing aridisation was a process of interchanging wet and dry periods, of about 7 to 9 Ma duration each. This cyclically increasing aridisation has directly influenced the litho- and biofacial pattern of the Late Carboniferous to Permian basins in Europe. The above discussed Saxo-Thuringian basins are typical Variscan basins because of their identical geotectonically and climatically controlled sedimentary infill and their large scale record of the evolution of biofacies pattern during the Carboniferous and Permian of Euramerica. They are individual because of their specific position in the Variscan belt, which controls basin formation and size, as well as changes in subsidence pattern and facies architectures during basin development. Furthermore, the onset of sedimentation within a given basin, the temporal distribution of sedimentation hiatuses, and the preservation of the basin fill strongly depended on the setting of each basin.

Because of the evolution of the orogen and the migration of its front, basins of different geotectonic setting in relation to orogenic and post-orogenic processes could occur in the vertical stratigraphic sequence of one and the same area, as for instance the Erzgebirge Basin (Figs. 8 and 9). There, marine turbiditic flysch deposits are followed by sediments of Culm facies (Gaitzsch *et al.,* this volume) in a foredeep setting. They are overlain by transitional (?)marine to continental early molasses of the Hainichen Basin, deposited during the collapse of the orogen in a perimontane basin, transitional to the foredeep. After a hiatus follow post-orogenic pure continental Late Carboniferous deposits of the Westphalian Flöha and Zwickau-Oelsnitz basins in an intramontane basin setting. They are overlain, again after a long lasting hiatus, by the Permian Rotliegend deposits of the Chemnitz Basin, transgressively overlain by marine to transitional marine-continental deposits of the Zechstein basin in a platform setting.

The Saale and the Saar-Nahe basins are large basins characterised by subsidence linked to the inversion of the MGCZ. Both basins are bound to the NW by a fault in the Northern Phylite Zone that gives them a half-graben structure (Stollhofen, 2000; Schäfer, 2005; Gaitzsch *et al.,* 2008). Nearly uninterrupted subsidence in the Saar-Nahe Basin starts as early as late Namurian times (Schäfer, 2005) and continues into the Upper Rotliegend I. In the Saale Basin sedimentation starts eventually in the Visean to Westphalian, but the basin outline becomes firstly discernible with Stephanian deposits. The Thuringian Forest Basin originates in a pattern of fault blocks. The Lower Rotliegend basin fits into a transtensional dextral pull-apart structure that is integrated in the Thuringian-Franconian shear zone along the SW border of the Bohemian Massif. Sedimentation in the Thuringian Forest Basin differs from all other basins by recurrent very strong intrabasinal volcanism, producing hundreds of meters thick piles of lava flows, in the Stephanian C to the end of Lower Rotliegend. In contrast to all of these Variscan SW-NE striking basins, the small graben of the Döhlen Basin cross cuts the Variscan structure plan, confined to the NW-SE striking Elbe lineament. This basin is singular among the European Permian basins because of his unusual high content of pyroclastics and its abundant earthquake-generated clastic dikes.

During the Upper Rotliegend I (Middle Cisuralian to Middle Guadalupian) all Saxo-Thuringian basins are characterised by vanishing volcanism and the predominance of discontinuously deposited exclusively red beds (Fig. 2). The general peneplanation of the Variscan morphogene and the complete filling up of the Variscan basins during this time is interrupted only shortly by local to regional relief rejuvenations. The Upper Rotliegend II (Middle Cisuralian to Early Lopingian) marks the start of a new geotectonical stage in Europe: the transition from the Variscan orogenic era to the post-Variscan platform development, influenced by tectonics and volcanism related to the earliest Pangea break-up and leading to the formation of the Southern Permian Basin. This 1,700 km long and 600 km wide intracontinental basin is the embryonic stage of the Mesozoic/Cenozoic Central European Basin. In the time before the Southern Permian Basin developed, sediment transport was directed concentrically into the local Variscan basins. With the formation of the Southern Permian Basin, the erosional debris was transported to the north via huge wadi-systems (Hessen depression, Eisleben-Bebertal wadi) into this exceptional large intracontinental Middle to Late Permian mega-playa and sabkha system, which was filled by about 2,500 m of siliciclastic rocks and evaporites in the Upper Rotliegend II and 2,000 m of siliciclastic rocks, carbonates, and evaporites in the Zechstein (Ziegler, 1990; Plein, 1995). The Upper Rotliegend II basin-fill is dominated by desert sediments affected by an arid to semiarid climate. Alluvial fans and dunes occur, especially at the southern basin margin, whereas saline lake deposits dominate in the center. The sedimentation was tectonically and climatically controlled. Tectonically driven large-scale cycles are interpreted as formations, whereas the members are climatically governed cycles on a smaller scale (Gast, 1995; Gaupp *et al.*, 2000; Legler, 2006).

The basin-wide, over hundreds of kilometers correlatable cyclicity of the Southern Permian Basin heralds the transition into the post-Variscan platform sedimentation, which start with the flooding of this basin and large parts of the former hinterland by the Late Permian Zechstein Sea.

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