2 Geology and Tectonic Development of the Czech Republic

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Abstract

Even if the Czech Republic occupies a small area in Central Europe, it is unique by the very interesting and varied geological and tectonic development that is recorded in the structure of the present-day Earth's crust, especially in the case of the Bohemian Massif. The Bohemian Massif can be interpreted as a heterogeneous unit composed of four separate regional domains. Each of them is defined especially by a specific stratigraphic content, tectomagmatic development and tectonic limitation in relation to its surroundings. The history of its development involves a long time period from the Paleoproterozoic to the recent period, i.e. about 2.1×10^9 years. Basic features of the Earth's crust structure, reflecting in geological maps, were however impressed on the area of the country only by relatively younger phases of Variscan orogeny and, to a lesser extent, Alpine orogeny that affected the eastern part of the country—the Western Carpathians. At the beginning of the Westphalian, the Bohemian Massif became part of the stabilised Variscan crust of the West European Platform, which in consequence meant that it began to act as a single unit, in which any mutual lateral displacement of units, metamorphosis and associated ductile deformation took place no longer. The Western Carpathians are one of partial branches of the vast orogenic belt of the Alpides created from the former Tethys Ocean. The development of the Western Carpathians already begins shortly after terminating the Variscan orogeny. At present, the Carpathians are divided from south to north into the Inner, Central and Outer Western Carpathians. The Central as well as the Inner Carpathians do not occur in the territory of the Czech Republic. The younger accretionary complex in the area of Moravia and Silesia is composed of the Pouzdřany, Ždánice, Subsilesian, Silesian and Fore-Magura Units.

Keywords

Bohemian Massif • Variscan orogeny • Epi-Variscan Platform • Alpine orogeny • Western Carpathians • Tectonic development

2.1 Introduction

The Czech Republic occupies a comparatively small area in Central Europe. In addition to other particularities, it is unique by the very interesting and varied geological development that is recorded in the structure of the present-day Earth's crust, especially in the central and western part of the territory—the Bohemian Massif. According to current knowledge, the history of its development involves a long time period from the Paleoproterozoic to the recent period, i.e. about 2.1×10^9 years. Basic features of the Earth's crust structure, shown on geological maps (Fig. 2.1), were however impressed on the area only by

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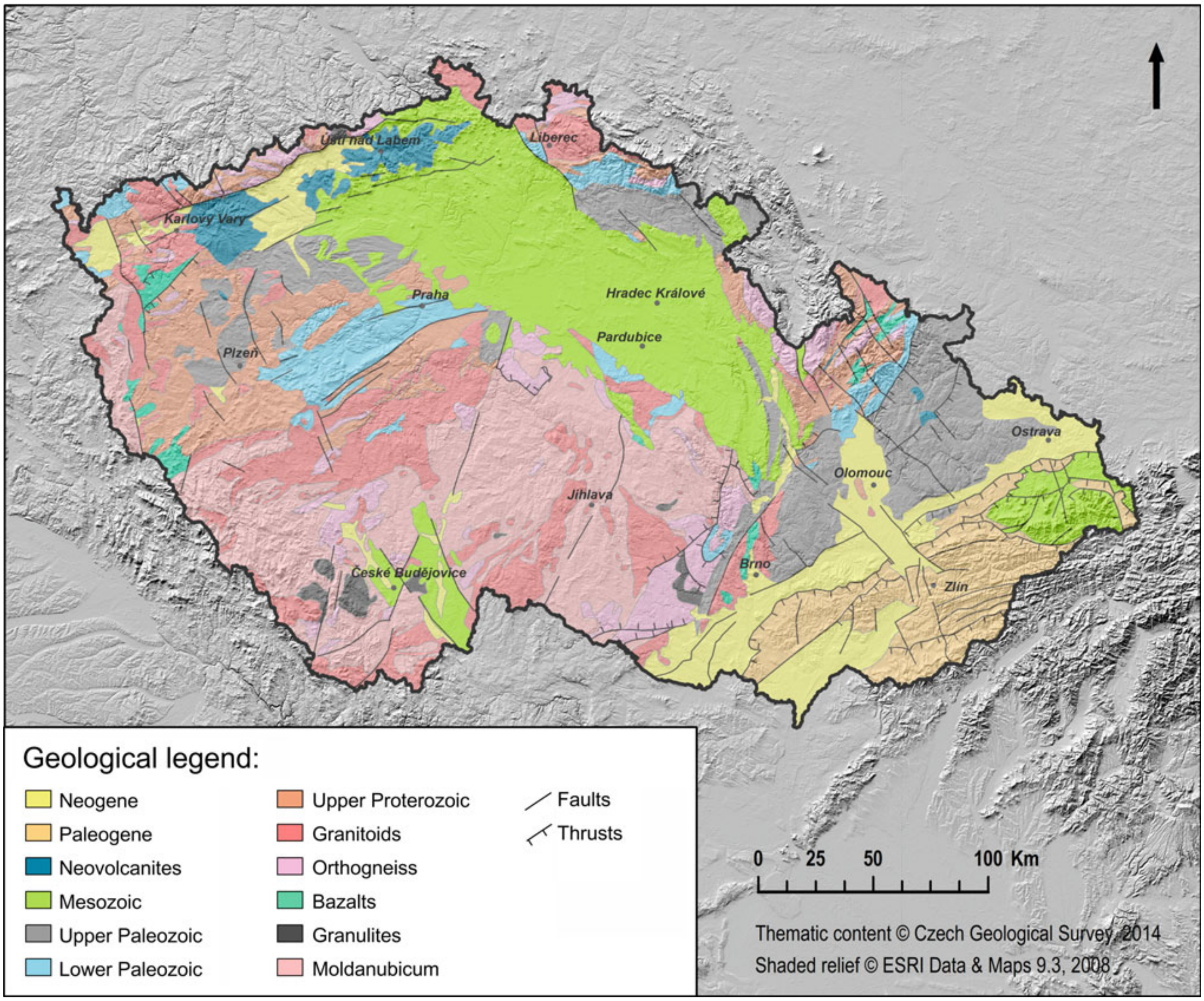

Fig. 2.1 Simplified geological map of Czech Republic draped over digital elevation model (Original made by Czech Geological Survey, courtesy of Lucie Kondrová)

relatively younger phases of geological development—Variscan orogeny and, to a lesser extent, Alpine orogeny that affected primarily the eastern part of the country—the Western Carpathians.

The territory of the Czech Republic is, besides its geographical and geopolitical position, a significant area in the geological pattern of Europe. In Moravia, two parts of Europe vastly different in age, geological development and geophysical parameters of the Earth's crust, meet. Bohemia and part of western Moravia and Silesia are a portion of the Bohemian Massif, one of the most significant and extensive fragments of the Variscan orogen formed during the Devonian and the Carboniferous (over the interval c. 380–320 Ma) by collision of the peri-Gondwana microcontinents (i.e. microcontinents situated in the early Paleozoic originally along the northern edge of the Gondwana continent) with Avalonia and Baltica (East European Platform).

The eastern part of Moravia and Silesia belong to the Western Carpathian orogen, which is one of sub-parts of the Alpine orogen—a vast mountain system of southern Europe. It was formed by collisions of continental fragments situated between the northern edge of Africa and the so-called Epi-Variscan Platform of Western Europe during the Mesozoic and the Tertiary.

The aim of the following chapter is thus to characterise the specific features of development and detailed division of both the above-mentioned different geological units constituting the territory of the Czech Republic.

2.2 The Bohemian Massif

The Bohemian Massif is one of the largest continuously outcropping fragments of the originally vast Variscan orogen that crops out from the basement of younger Epi-Variscan Platform sediments. The comparatively extensive Variscan orogen was formed gradually in the course of joining the peri-Gondwana fragments to (see Franke 1989; Franke et al. 2000; Matte et al. Laurussia1986, 1990, 1991; Winchester 2002; Ziegler 1982, 1984), i.e. to the more northerly situated continent created as the result of Caledonian convergence between Laurentia and Baltica.

Based on the current concepts of development of continents (Condie 1989), which start from the application of principles of plate tectonics, the Bohemian Massif can be interpreted as a heterogeneous unit composed of four separate regional domains. Each of them is defined especially by a specific stratigraphic content, tectomagmatic development and tectonic boundaries in relation to its surroundings.

According to the binding regional geological division of the Bohemian Massif (Commission 1994), the Bohemian Massif can be divided, based on the differences in structure and geological development, into four autonomous regions: Moldanubian Unit, Teplá-Barrandian Unit, Saxo-Thuringian Unit (subdivided by the younger Elbe Fault Zone into the Krušné hory Mountains Zone and the Lugicum = West Sudetic Zone) and Moravo–Silesian Unit (Fig. 2.2). This basic division reflects the existence of four independent

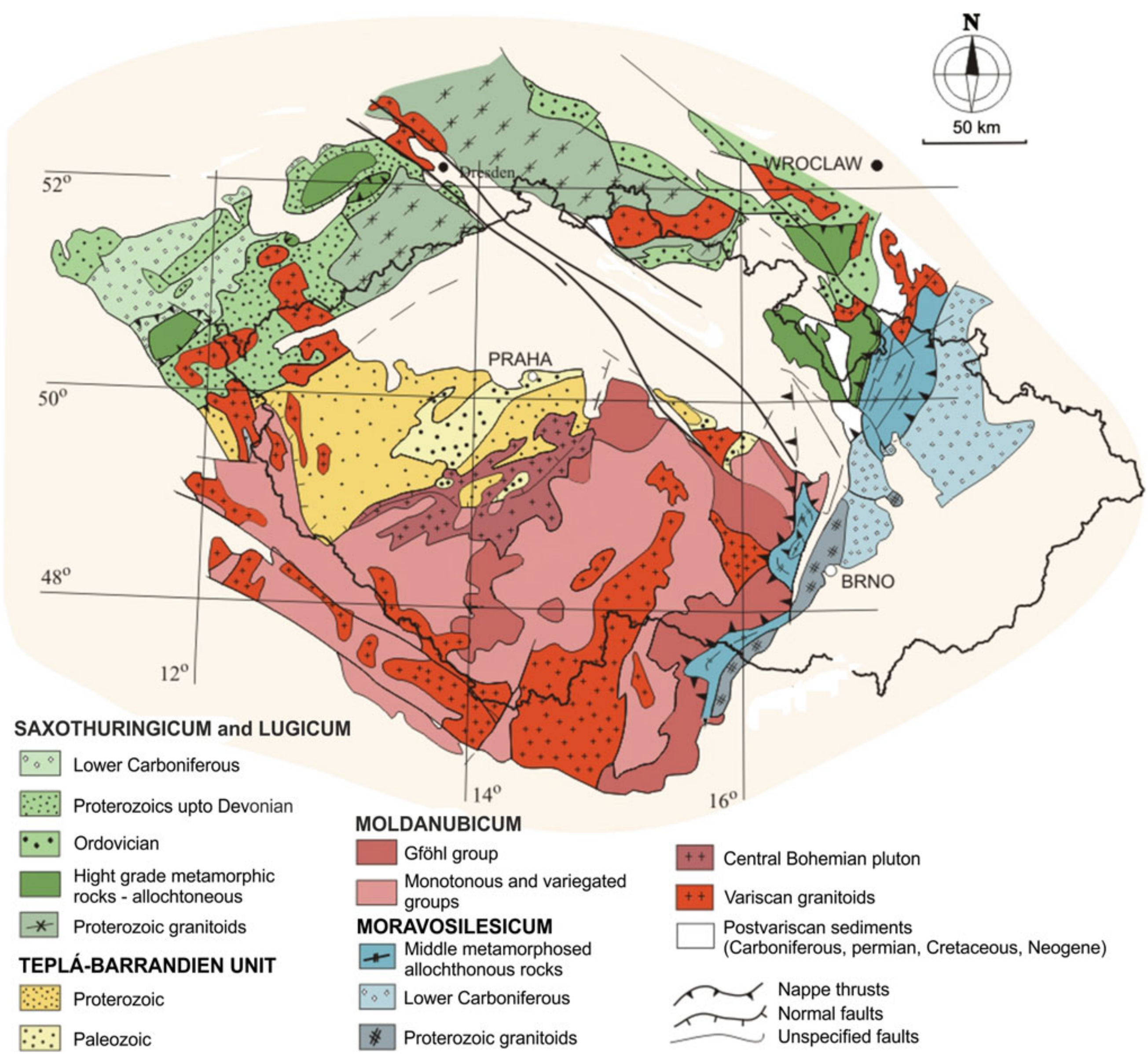

Fig. 2.2 Main Variscan regional units of the Bohemian Massif (Simplified according to Schulmann et al. 2005)

crustal fragments separated originally by oceanic domains, the traces of which are indicated today by the occurrences of ophiolite complexes and/or belts with high-pressure and mantle rocks (Mariánské Lázně complex, Letovice ophiolite complex, blueschists of Železný Brod crystalline complex and Rýchory ridge, high-temperature and high-pressure rocks of the Gföhl Unit). Paleomagnetic data (Krs et al. 2001; Tait et al. 2000), a number of common features in the development of the Cadomian basement, the presence of Cadomian calc–alkaline granitoids, formed by melting rocks above a subduction zone and flysch sequences deformed during the Cadomian orogeny, document that these units were part of a belt of island arcs and perhaps accretionary complexes on the northern edge of Gondwana. In the boundary period between the Proterozoic and the Paleozoic, this belt was situated in the area of low southern latitudes (Fig. 2.3).

It is the independence of the Moldanubian Unit that remains problematic. In comparison with the other units, the Moldanubian Unit has a different lithology, geophysical characteristics of the crust and the subcontinental mantle (Beránek and Dudek 1981; Beránek and Zátopek 1981; Babuška and Plomerová 2001), tectonic boundaries (with the Moravo–Silesian Unit and the Teplá-Barrandian Unit are quite evident) and above all different metamorphic development, given by the substantially deeper present-day denudation level.

In spite of the fact that the above-mentioned units are separated by significant sutures and tectonic zones, they have a number of common features related to the Neoproterozoic and, in part of them, also in the Cambro–Ordovician development; on the contrary, they differ markedly as far as the early stage of Paleozoic development during the Variscan orogeny is concerned.

After the end of the Variscan orogeny, the Bohemian Massif was gradually transformed into a platform unit. Paleomagnetic data for the Early Permian document that all western, central and northern Europe behaved as a single unit designated the North European Platform. It also included the Bohemian Massif. During the Carboniferous, it gradually became dry land. In the most of the area, with the exception of intramontane depressions, deep erosion of the Variscan basement took place. Erosion and continental sedimentation were interrupted only for a short time by a marine transgression over part of the area in the Jurassic, Cretaceous and Neogene Periods. In addition to the

Fig. 2.3 Proterozoic biotitic gneiss of Gföhl group of Moldanubicum. Locality Náměšť nad Oslavou (*Photo* R. Grygar)

deposition of sediments in the depressions, various types of volcanic bodies of Cretaceous to Quaternary age provided the finishing touches to the surface of the platform cover of the Bohemian Massif.

The basis of regional division of the Bohemian Massif is natural geological boundaries represented by significant sutures, and also other types of tectonic boundaries separating microcontinents (also smaller units, so-called terranes) with different paleogeographical provenances, lithologies and tectonometamorphic effects, ages of rock complexes, and maybe with different characters of magmatic manifestations.

The pre-Variscan geodynamic development of the units can be divided into two phases: Neoproterozoic and Paleoproterozoic. The Neoproterozoic development is evidenced best in the Teplá-Barrandian Unit (Fig. 2.4) and in the Saxo-Thuringian Unit reworked slightly by the Variscan orogeny. In a lithological record, a transition to the regime of active subduction in the upper part of the Neoproterozoic (Kralupy-Zbraslav Group), which was accompanied by the formation of island arcs and subsequently of an accretionary wedge of flysch sediments above the subducting oceanic lithosphere, is evident. During the Cambrian, the subduction

Fig. 2.4 Outcrops of Proterozoic silicites from Teplá-Barrandien region. Lokality Hudlice (*Photo* R. Grygar)

died away and the active margin was transformed to a passive margin. Parts consolidated by the pan-African orogeny began separating from the mother continent, Gondwana, in the Cambrian. A system of rifts was formed; along them, the comparatively continuous Avalonian-Cadomian belt of microcontinents was broken up.

The paleomagnetic, paleobiogeographical data and analysis of clastic micas and zircons show that East Avalonia and fragments outcropping on the eastern periphery of the Bohemian Massif separated first and at the fastest rate (Bruno-Vistulicum, Malopolska Massif and also Lysa Gora Unit of Holy Cross Mountains (Góry Swietokrzyskie)—e.g. Belka et al. 2002). The Malopolska Massif and the Bruno-Vistulicum came to direct contact already during the Cambrian.

Later, at the Cambrian–Ordovician boundary, the remaining Armorican microcontinents began separating as well. The separation of these microcontinents is also indicated, in addition to the paleomagnetic records, by extensive bimodal rift volcanism and magmatic activity, the beginning of which falls within the period from 520 to 480 Ma (i.e. Cambrian–Ordovician boundary). This magmatism is observable above all along the rims of gradually separating blocks in the whole area of the Armorican group of continents. Changes in tectonic regime at the Cambrian–Ordovician boundary caused that the Cambrian sedimentation cycle, connected partially with the Cadomian development, was sharply separated from the Ordovician–Devonian cycle in the Teplá-Barrandian Unit so as in the Saxo-Thuringian Unit. An acceleration of the expansion of the originally continental rifts then gradually led to the formation of the Rheic Ocean and, on the contrary, to the closure of the Tornquist Ocean.

From the paleomagnetic data and paleoclimatic indicators (Krs et al. 2001) it is obvious that, e.g. the Teplá-Barrandian Unit moved gradually from lower southern latitudes (about 40° South Latitude in the Ordovician, 20° South Latitude in the Silurian) to the northern hemisphere. In the Devonian, it was located in the tropical equatorial region; during the Early Devonian, it crossed the equator. The extensional regime in these continental fragments continued till the Early Devonian, when the tectonic regime began to change, with the onset of the Variscan orogeny, into compressional one. For this reason, the early Paleozoic sequences that deposited along the passive margins of these fragments in the majority of the units are largely continuous.

The Variscan orogeny was a result of collisions of the Armorican microcontinents and their final amalgamation to Avalonia and Bruno-Vistulicum. In the Bohemian Massif, it is a case of the collisions between the Teplá-Barrandian plate and the Moldanubicum and Saxo-Thuringicum, followed with the final amalgamation of the above-mentioned units to the Variscan foreland formed in N and NW by the block of

East Avalonia consolidated by the Caledonian orogeny and in NE by the Bruno-Vistulicum. Differences in the Variscan development of the four basic units of the Bohemian Massif are given by their different positions in the Armorican group of microcontinents, which entered to the processes of Variscan collisions at considerable intervals. The geometry of subduction zones determined, to a certain extent, even later processes of continental collisions, especially the vergence of overthrusting movements on the boundaries of colliding fragments. Sutures that controlled the processes of Variscan orogeny were as follows: Gföhl suture and its equivalents in the French Massif Central (south Brittany) and the Iberian Peninsula (Galician), Teplá suture (suture between the Teplá-Barrandian Unit and the Saxo-Thuringicum) and Rheic and Rheno-Hercynian sutures, between Avalonia and the northern margin of the Saxo-Thuringicum. First the Gföhl suture between the Moldanubian microblock and the Teplá-Barrandian microblock was closed (based on an analogy with the French Massif Central, this happened probably in the period from the Silurian till the Early Devonian). From the suture, metamorphic complexes mostly of Precambrian to Early Paleozoic age were thrust out towards the south and in the case of the Bohemian Massif towards the south-east. The thickened Moldanubian crust was strongly heated, which led to the origin of extensive granitoid bodies in the Early Carboniferous. A rapid exhumation of the thickened orogenic root caused its deep erosion up to the level of the middle crust. In consequence, less metamorphosed and unmetamorphosed supracrustal units are missing in the Moldanubicum.

The Teplá suture, forming the present-day geological boundary between the Teplá-Barrandian microblock and the Saxo-Thuringicum, was also closed in the Devonian; an obduction of high-pressure rocks took place at the end of the Middle Devonian (c. 380–370 Ma). Rocks from rather deep parts of the Saxo-Thuringian Ocean and both continental margins were thrust out towards NW over the Saxo-Thuringian autochthon. The outermost sutures of the Variscides are the Rheic and Rheno-Hercynian sutures. The older Rheic suture, which was closed already during the Devonian, is indicated by calc-alkaline volcanism and high-pressure low-temperature (HP–LT) metamorphism in the area of so-called Northern Phyllite Zone on the boundary of the Saxo-Thuringicum and the Rheno-Hercynicum. The equivalent of the Rheno-Hercynian suture in the Bohemian Massif is probably complexes on the boundary of the Bruno-Vistulicum and the Lugodanubicum, of which the Devonian–Carboniferous, mostly flysch complexes were thrust out towards E over the Bruno-Vistulian foreland.

The gradual migration of tectonic deformation in time and space from south to north together with different geometries of the main zones of shortening created the characteristic fan-like zonal structure of the Variscan orogen as defined already in classic papers (Suess 1926; Kossmat 1927; Stille 1951). Based on the age of protoliths of rocks of the basement and the Variscan mantle, main tectonic deformation phases, intensity of metamorphism, pre- and post-Variscan magmatic manifestations, the following zones can be defined from south to north: Moldanubian Zone, Saxo-Thuringian Unit, Rheno-Hercynian Zone and Subvariscan Foredeep; they can be observed in all the European Variscides (Cháb et al. 2010).

The Moldanubian Zone is characterised by an inverted internal metamorphic structure, high intensity of metamorphism, presence of HP–HT rocks (Fig. 2.3), which differ from similar rocks in other zones by higher temperatures and pressures of equilibration of high-pressure parageneses. The Teplá-Barrandian Unit, which represents together with the Armorican Massif the best preserved relic of the Cadomian crust, covered partly with discordantly laid unmetamorphosed Early Paleozoic sequences, was earlier regarded either as part of the Moldanubian Region (Kossmat 1927; Franke 1989), or as part of the Saxo-Thuringian Unit (Ellenberger and Tamain 1980; Mísař et al. 1983). It follows from the paleomagnetic data and well-documented suture lines, which delimit it, that these units have, in the framework of the orogen, independent positions. The termination of sedimentation in the Devonian and the main phase of deformation between the Givetian and the Fammenian make it different from the surrounding units, likewise the presence of the fundamental complex slightly reworked by the Variscan orogeny. The metamorphic development, in contrast with the Saxo-Thuringian Unit and the Moldanubian Region, is caused by Early Carboniferous subsidence along the extensive West Bohemian and Central Bohemian shear zones (Zulauf 1994).

The Saxo-Thuringian Unit is characterised, in comparison with the Teplá-Barrandinian Unit, by higher intensity of Variscan reworking of the Cadomian basement, by largely continuous unmetamorphosed to weakly metamorphosed sequences of the Paleozoic in the period from the Cambrian to the Lower Carboniferous (Fig. 2.5) and by Devonian to Carboniferous extension accompanied by intraplate volcanism. A characteristic feature is the presence of allochthonous relics that were thrust out from the Teplá suture and occupy the highest structural position, and the presence of granulite complexes underlying the Lower Carboniferous flysch units.

The Rheno-Hercynian Zone represents a predominantly Devonian–Carboniferous accretionary complex thrust out from the Rheno-Hercynian suture between Avalonia and the Saxo-Thuringicum. Older rock complexes crop out at the surface only rarely. The Zone is characterised by weak metamorphism and fold–thrust structure.

The Variscan Foredeep (Subvariscicum) represents a classical foreland basin formed by lithospheric flexure before the fronts of nappes of the Rheno-Hercynicum

Fig. 2.5 Outcrop of Ordovician quartzite belongs to allochtonian sequences of Krkonoše–Jizera units in the Lugicum region. Locality under the Ještěd Mt. (*Photo* R. Grygar)

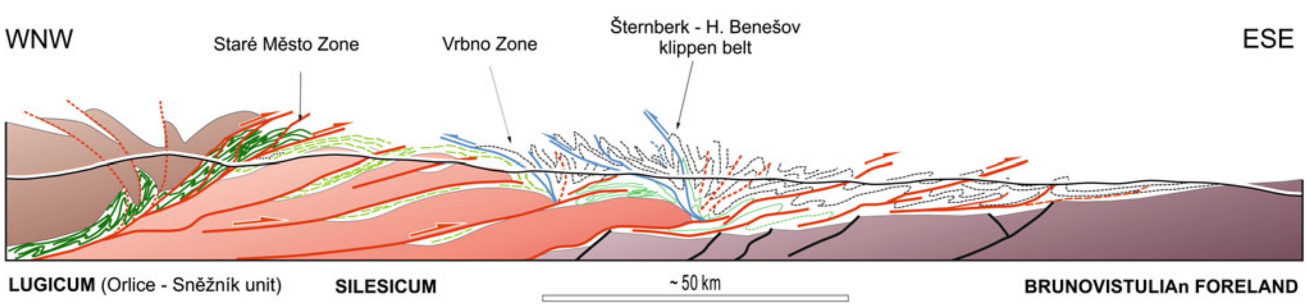

Fig. 2.6 Schematic structural cross section of the Variscan accretion wedge of the Moravo-Silesian unit. According to Grygar and Vavro 1995

finishing their thrust over the Avalon-Bruno-Vistulicum foreland (Figs. 2.6 and 2.7). The stratigraphic range of a molasse, first marine and later continental, is from the Namurian to the Westphalian. Variscan folds disappeared in the course of its filling. The character of fauna and flora shows that at that time oceanic barriers no longer existed in Europe and that newly created Variscan Europe formed one unit with the Gondwana.

2.3 *The Post-Orogenic—Platform Development of the Bohemian Massif*

Basic features of the structure of basement of the Bohemian Massif were formed during the Variscan orogeny. At the beginning of the Westphalian, the Bohemian Massif became part of the stabilized Variscan crust of the West European

Fig. 2.7 Fold and thrust structures of the Variscan flysh foredeep with eastward vergency. Locality Stará Ves near Bílovec (*Photo* R. Grygar)

Platform, which in consequence meant that it began to act as a single unit, in which any mutual lateral displacement of units, metamorphosis and associated ductile deformation no longer were taking place. The majority of later deformations are brittle, when vertical (largely in the order of several hundred metres to several kilometres) and/or lateral movements (in the order of kilometres to several tens of kilometres as a maximum) occured. Mostly it is the case of faults and tectonic zones, created by the Variscan orogeny and later reactivated, which reacted to changes in the stress regime in the lithosphere during the Mesozoic and the Tertiary in the course of so-called Saxonian tectonics due to deformations in the foreland of the Alpine orogen. The most significant lines are NW–SE faults (Sudetic direction), parallel to the Tornquist line, NE–SW faults (Krušné hory Mts. direction) and NNE–SSW faults (originated at the end of the Variscan phase as so-called furrows—Boskovice, Blansko, Jihlava). The Bohemian Massif is segmented by these faults into a series of blocks that show different characters of dominant movements in different phases. Platform sediments are only exceptionally affected by large-wavelength flat-lying folds, such as folds in the Cretaceous in the surroundings of the Orlice Basin, Hořice Ridge, etc.

A transition from the orogenic phase to the post-orogenic phase took place during the Westphalian (Late Carboniferous), in the course of which ductile deformations in the area of Variscan foreland basins terminated. After thickening the Variscan crust in the compressional phases of the Variscan orogeny, a gravitational collapse of the orogen happened. It was accompanied by the formation of asymmetrically bounded inner continental molasse basins (Fig. 2.8). The basins are often created by crustal subsidence along the originally compressional structures (Mattern 2001).

The Variscan molasse basins can be divided into two groups: the older group of intramontane basins of Namurian–Westphalian age is largely parallel to the major zones of the Variscan orogen. After a change in tectonic regime, when especially horizontal movements along the fault systems of Sudetic and NNE-SSW direction began to play their role, the other (i.e. younger) group of Stephanian–Permian basins, having often the character of narrow and deep asymmetric tectonic trenches, was formed. Already in the Early Permian (Saxonian) we can observe that subsidence slowed down and the area of the basins gradually decreased. In the Lugicum area, sedimentation of the Variscan molasse was terminated as late as in the Triassic.

The synconvergent granitoid magmatism, the culmination of which was recorded in the internal zones of the Variscides in the period from the Late Viséan to the Namurian (345–325 Ma), continued by intrusions of post-tectonic, mostly geochemically strongly differentiated granitoids till the Early Permian. As well, manifestations of the volcanic activity passed without interruption from the orogenic period to the post-orogenic molasse stage. In the Westphalian to the Lower Stephanian, explosive acid magmatism extended especially in the area of Central Bohemian and Western Bohemian basins. The final phase of subsequent intraplate magmatism falls to the period from the Stephanian to the Autunian. During this phase, in addition to the acidic members, alkaline members were also formed.

The termination of Triassic sedimentation can be regarded as the beginning of platform development of the Bohemian Massif. Almost for the whole remaining period of the Triassic and the Jurassic, it was exposed to extensive erosion and peneplanisation. In the Late Jurassic, only a narrow strip of the Massif along the Elbe Fault Zone was

Fig. 2.8 Tectonic contact in the zone of the Hronov–Poříčí thrust fault of Upper Cretaceous marine sediments (*left side*) with Permian continental red coloured sandstones (*right side*). Locality Malé Svatoňovice in the SW limb of the Lower Silesian basin (*Photo* R. Grygar)

flooded by the sea to form a channel connecting the North German Basin with the Tethyan area. After a short period, the sea again retreated from this area. The cover, which is more significant from the point of view of thickness, occurs in the south-east slopes of the Bohemian Massif, periodically reached by transgressions from the area of the western Tethys.

The long period of prevailing denudation of the Bohemian Massif was replaced, on a larger scale, by sedimentation only during the eustatic rise in the level of world's oceans in the Late Cretaceous, when part of the Bohemian Massif subsided along the faults of the Elbe Fault Zone and became a site of at first continental and later marine sedimentation in the Bohemian Cretaceous Basin. At the end of the Cretaceous and in the Paleogene, inversion of the Bohemian Cretaceous Basin occurred as a result of folding in the Alpine area. Some NW–SE faults that acted as normal faults or strike-slip faults in the course of deposition of Cretaceous sediments were used for shortening the basin in this stage. The best-known example of an inverted fault is the Lusatian Fault (reverse fault) (Adamovič and Coubal 1999).

In the Tertiary, continental basins of rather small extent were formed in the area of the Ohře/Eger Rift and in southern Bohemia. In the pre-rift stage, older depressions in relief were filled; the rift stage is connected with an increased rate of subsidence of the basin bottom and with sedimentation of several hundred metres of Miocene sediments (Fig. 2.9). In the course of sedimentation, extensive volcanic activity took place along the faults, especially those limiting the south-eastern margin of the rift (Doupov Mountains, Central Bohemian Uplands).

The Quaternary is a period when the Bohemian Massif was, after the regression of the sea of the Carpathian Foredeep in the Tertiary, solely dry land. It is a very short period in comparison with the duration of the other geological units (c. 1.6–1.8 Ma). In the Quaternary, the character of geological, especially exogenous processes was affected by the existence of vast ice sheets that covered considerable part of northern Europe.

Fig. 2.9 Open pit mine Družba in the Neogene Sokolov basin located in the Ohře/Eger graben. Coal seam outcropping along boundary normal falt. In the footwall (*right side*) weathered metamorphic rock of the Saxo-Thuringian zone of the Krušné Hory Mountains cropping out (*Photo* R. Grygar)

2.4 The Western Carpathians

The Western Carpathians are one of partial branches of the vast orogenic belt of the Alpides created from the former Tethys Ocean that extends from Spain to south-eastern Asia. In the territory of the Czech Republic, they occur merely in the easternmost areas of Moravia and Silesia. The development of the Western Carpathians already begins shortly after terminating the Variscan orogeny that gave rise to a huge supercontinent called Pangaea.

The beginnings of the origin of narrow rift basins, meaning the beginning of disintegration of Pangaea, are evident as early as in the Triassic. During the Jurassic and the Cretaceous, the broadening and differentiation of the basins occurred between Africa and Europe. However, at the end of the Jurassic, some of them began to close again, which led later even to continental collisions of partial microblocks that took place in the European area in three waves in the course of the Jurassic to the Early Cretaceous (c. 160–120 Ma), Late Cretaceous (110–80 Ma) and Paleogene to Neogene (45–12 Ma). The basement of the Mesozoic and Tertiary units, later folded during the Alpine cycle, with the exception of oceanic domains, is formed, both in the Alps and in the Carpathians, mostly by various parts of the crust formed by the Variscan orogeny.

In the Western Carpathians, migration of orogenic processes towards the north manifested itself in characteristic orogenic zonation that became the base for the inner zonation of the orogen. At present, the Carpathians are divided from south to north into the Inner, Central and Outer Western Carpathians. The Central as well as the Inner Carpathians do not occur in the territory of the Czech Republic.

In the area of eastern Moravia and Silesia, the Outer Carpathians are represented by two accretionary flysch complexes and the Carpathian Foredeep. The older accretionary complex is composed of Cretaceous but largely Paleogene siliciclastic complexes of the Magura Group of nappes immediately adjacent to the klippen zone interpreted earlier as part of the Outer Carpathians; at present, especially its inner parts are interpreted as part of the Late Cretaceous–Early Tertiary accretionary complex that occurs in the place of an assumed suture after the oceanic domain, the so-called Vahicum.

In the Magura Group of nappes in rhythmically bedded units, which are characteristic of flysch basins, sandy members predominate over claystones, siltstones and coarser-grained clastics. The total thickness of the sediments is several kilometres. The frontal parts of the nappes of this group reached comparatively far, as far as the Moravo–Silesian boundary, approximately the Hodonín–Valašské Meziříčí–Třinec line. They are partly overlain by sediments of the Vienna Basin and Late Miocene and Pliocene sediments of the filling of the Hornomoravský úval basin. This complex was shortened already during the Paleogene, but the thrust over the external group of nappes took place during the Miocene at the end of closure of flysch basins (42–23 Ma). The amplitude of overthrust is estimated at several tens of kilometres.

The younger accretionary complex in the area of Moravia and Silesia is composed of the Pouzdřany, Ždánice, Subsilesian, Silesian and Fore-Magura Units. In the Polish and the Slovakia area, the Skole and Dukla Units belong to this group of nappes as well. In contrast to the above-mentioned Magura Group, they contain sediments of a broader stratigraphic range, from the Jurassic to the Middle Miocene. In addition to the flysch siliciclastic sequences of Jurassic to Early Miocene age (alternation of sandstone, claystones, conglomerates), carbonates of Jurassic and Cretaceous age are present, mainly in the Silesian Unit. The carbonates outcrop as olistoliths and tectonic shreds—klippen in the vicinity of overthrust lines of sub-nappe units. During the Miocene, the units of this younger accretionary complex were thrust over the Carpathian Foredeep, formed by a deflection of the foreland composed of the Cadomian basement of the Bruno-Vistulicum and its Paleozoic and Mesozoic cover.

The Foredeep began to be created already during the Oligocene/Miocene transition, whilst sedimentation continued to the Badenian. Marine sedimentation predominated. The Foredeep was formed by a series of sub-basins created simultaneously with the overthrust of flysch nappes. That is why the sediments of the Foredeep occur in the foreland of the nappes, on them and also far under their fronts. As a result of changes in tectonic regime, rapid changes in the extent of the basin, stratigraphic hiatuses and erosion of older sediments developed unevenly along the longitudinal axis of the basin occurred. Thicknesses of largely clayey and sandy sediments can be even more than 2 km.

In the Carpathian, the Vienna Basin with a very complicated history of tectonic development began to be formed in the depressions of flysch nappes in the area between Vienna and Uherské Hradiště. It belongs to a group of basins of the pull-apart type that, in the Western Carpathians, opened as a result of transtension caused by rotation of the Carpathians in relation to the northern European foreland. During the Late Miocene, marine sandy and clayey sediments passed gradually to brackish and later lacustrine and river sediments of up to Pliocene age. Marine Miocene sediments contain rather limited deposits of hydrocarbons; in continental sediments lignite seams were formed. The total thickness of the sediments is up to 5 km.

A still younger basin of this type is the Hornomoravský úval Basin; it was created by the rejuvenation of movements along the faults of the Elbe Fault Zone. It originated at the end of the Miocene and sedimentation of continental sediments several hundred metres in thickness continued till the Pliocene.

The extension of the crust of the Central and Southern Carpathians in the area above the oceanic lithosphere subducting to the south enabled the ascent of andesitic and basaltic magmas. Volcanic activity culminated in the Middle Miocene, but it continued, in a limited degree, to the Pliocene. To this epoch, minor occurrences of trachyandesite and trachybasalt veins in the surroundings of Uherský Brod belong, whose age of 16 Ma determined by the K–Ar method corresponds to the Late Badenian, (Přichystal et al. 1988).

2.5 Conclusion

The Bohemian Massif is one of the largest continuously outcropping fragments of the originally vast Variscan orogen that crops out from the basement of younger Epi-Variscan Platform sediments. The comparatively extensive Variscan orogen was formed gradually in the course of joining the peri-Gondwana fragments to Laurussia, i.e. to the more northerly situated continent created as the result of Caledonian convergence between Laurentia and Baltica.

Based on the current concepts of development of continents, which start from the application of principles of plate tectonics, the Bohemian Massif can be interpreted as a heterogeneous unit composed of separate regional domains. Each of them is defined especially by a specific stratigraphic content, tectomagmatic development and tectonic limitation in relation to its surroundings. In spite of the fact that the above-mentioned units are separated by significant sutures and tectonic zones, they have a number of common features especially regarding the Neoproterozoic and, in part of them, also the Cambro–Ordovician development; on the contrary, they differ markedly in terms of the early stage of Paleozoic development during the Variscan orogeny.

After the end of the Variscan orogeny, the Bohemian Massif was gradually transformed into a platform unit. During the Carboniferous, it gradually became dry land. In the most of the area, with the exception of intramontane depressions, deep erosion of the Variscan basement took place. Erosion and continental sedimentation were interrupted only for a short time by a marine transgression over part of the area in the Jurassic, Cretaceous and Neogene Periods. In addition to the deposition of sediments in the depressions, various types of volcanic bodies of Cretaceous to Quaternary age provided the finishing touches to the surface of the platform cover of the Bohemian Massif.

The Western Carpathians are one of partial branches of the vast orogenic belt of the Alpides created from the former Tethys Ocean that extends from the area of Spain to south-eastern Asia. In the territory of the Czech Republic, they occur merely in the easternmost areas of Moravia and Silesia. The development of the Western Carpathians already began shortly after termination of the Variscan orogeny. At present, the Carpathians are divided from south to north into the Inner, Central and Outer Western Carpathians. Only Outer Western Carpathians occur in the territory of the Czech Republic.

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