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Tectono-Sedimentary Evolution of Western Carpathian Tertiary Basins

J. Janočko & M. Elečko (Eds.)



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COVER: Typical sediments of the Outher Western Carpathian Basins (sediments from localities Dubinné – the figure on the left side, and from Drienica – the figure on the right side). The figures in the middle show typical Neogene sediments (locality Lada, eastern Slovakia). Photo and graphics: J. Janočko

OBÁLKA: Sedimentárne súslednosti ukazujúce príklad sedimentárnej výplne paleogénnych bazénov Slovenska. Foto a grafika: J. Janočko

Preface

Since 1998 the Geological Survey of Slovak Republic solved and coordinated research works concerning the project No. 0801840303/130 "Tectogenesis of Western Carpathians Sedimentary Basins". The project, financed by Ministry of Environment of Slovak Republic, was aimed at geological research of Tertiary, Mesozoic and Paleozoic basins of the Western Carpathians.

The monograph represents the results obtained by the research of Tertiary basins of the Western Carpathians. The research was based on wide cooperation between experts from Geological Survey, Faculty of Natural Sciences of Comenius University, Geophysical and Geological Institutes of Slovak Academy of Sciences and Technical University in Zvolen and Košice. The resulting study contains comprehensive information on tectono-sedimentary evolution and structure of the main Tertiary basins in the Western Carpathians, and presents results of six particular thematic projects:

Tectonic and paleogeographic analysis of original sedimentary areas of Flysch Belt

Tectonic and paleogeographic analysis of Paleogene and Late Cretaceous sedimentary areas of Inner Western Carpathians

Tectogenesis of the Vienna Basin

Tectogenesis of the Danube Basin and Western Carpathians intramountain depressions

Tectogenesis of South Slovakian Basin

Tectogenesis of East Slovakian Basin

The results, widened by further specific information gained during the research, will be also edited in monograph in Slovak language. The monograph will be edited by the Dionýz Štúr Publishing House in 2004.

Acknowledgement

We express our sincere thanks to the Section of Geology and Natural Sources of the Ministry of Environment of Slovak Republic for the guarantee of the project. Thanks are extended to the management of the Geological Survey of Slovak Republic for supporting of the project and permission to publish its results.

Juraj Janočko and Michal Elečko
Editors

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Tectono-sedimentary evolution of Western Carpathian Tertiary basins

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I. TECTONO-SEDIMENTARY EVOLUTION OF WESTERN CARPATHIAN TERTIARY BASINS: AN OVERVIEW

JURAJ JANOČKO[1], DIONÝZ VASS[2], MICHAL KOVÁČ[3], VLASTIMIL KONEČNÝ[4] and JAROSLAV LEXA[4]

The Western Carpathians are a part of the extensive Alpine–Carpathian mountain range consisting of the Western and Eastern Alps, Carpathians and Dinarides (Fig. I.1). In the area of Hundsheim hills the Carpathians border with the Eastern Alps. Their eastern boundary is conventionally placed to the Uh river valley in Eastern Slovakia, from where the Eastern Carpathian segment continues eastward. The arc of Carpathians and Dinarides encloses the Pannonian area – the Vienna, Danube and Transcarpathian basins that are an organic part of the geological unit of Western Carpathians.

The area of Western Carpathians represents the northernmost part of the orogene of European Alpides adjacent to the North-European Platform at its foreland. The North European Platform includes a Paleozoic basement, an epi-Variscan platform cover of the Bohemian Massif and the Polish Platform. In the northeast it neighbours the Russian Platform from which it is separated by Teisseyr-Tornquist line (Plašienka et al., 1997).

The present structure of Western Carpathians, that resulted from complex Mesozoic–Tertiary orogenic processes, is traditionally divided into three belts: the Outer Western Carpathians – separated by the Klippen Belt from the Central and Inner Western Carpathians. The boundary between the Central and Inner Carpathians is represented by a so called Meliata–Hallstatt suture (Plašienka et al., 1997). Some authors (e. g. Biely, 1989; Biely et al., 1996) divide Western Carpathians into Outer and Inner ones with the Klippen Belt as their common boundary.

An important constituent of the Western Carpathian structure are the Tertiary sedimentary and volcanic complexes. The volcanics are related to the tectogenesis of Tertiary basins, the initial stages of which may already be discerned in the Mesozoic. The opening and further evolution of Tertiary sedimentary areas in the Western Carpathians were decisively affected by the convergence and collision of the orogene with the platform units in the north. Associated with this process there were riftogenesis, extension of the thrusted nappes area and tectonic drifting of microcontinents away from the Eastern Alps area (e. g. Csontos et al., 1992, 1995; Kováč, 2000).

Among the Tertiary basins of Western Carpathians there are included the sedimentary areas in the realms of the Outer Western Carpathians (Outer Flysch Zone sensu Vass et al., 1988), the Central Carpathian Paleogene Basin, the area of the Hungarian Paleogene Basin ("Buda Paleogene") and a system of Neogene basins of the Western Carpathians such as the Vienna Basin, Danube Basin, the area of the South Slovakian Depressions and the East Slovakian Basin (Fig. I.1). Tertiary sediments further occur in local depocentres represented mainly by the intramountain depressions of Western Carpathians that include the Trenčín, Ilava and Bánovce depressions (a genetic part of the Danube Basin), as well as the Hornonitrianska kotlina, Žiar, Zvolen-Slatina, Turiec and Orava depressions as well as Upper Hron valley.

The largest accumulation of Tertiary deposits in the area of Outer Western Carpathians is present north of the Klippen Belt in the eastern, middle and western sectors of Slovakia, continuing further northward in Poland. The thickness of sedimentary sequences in this area exceeds 8 km.

The area of the Central Carpathian Paleogene Basin borders in the northeast, north and southwest with the Klippen Belt. Adjacent in the west and south there are the pre-Tertiary geological units and to the southeast and east it neighbours the East Slovakian Neogene Basin (Fig. I.1). This elongated basin is some 280 km long and 50 km wide. Erosional remnants of the sediments filling of the basin are found south of its present margin in the area of Slovenský raj Mts., Spišsko-gemerské rudohorie Mts. (Mello et al., 2000), Hornonitrianska kotlina Depression and in the vicinity of Banská Štiavnica (Marschalko, 1968; Gross, 1978). Further, they include the continuation of Paleogene deposits beneath the Neogene fill of the

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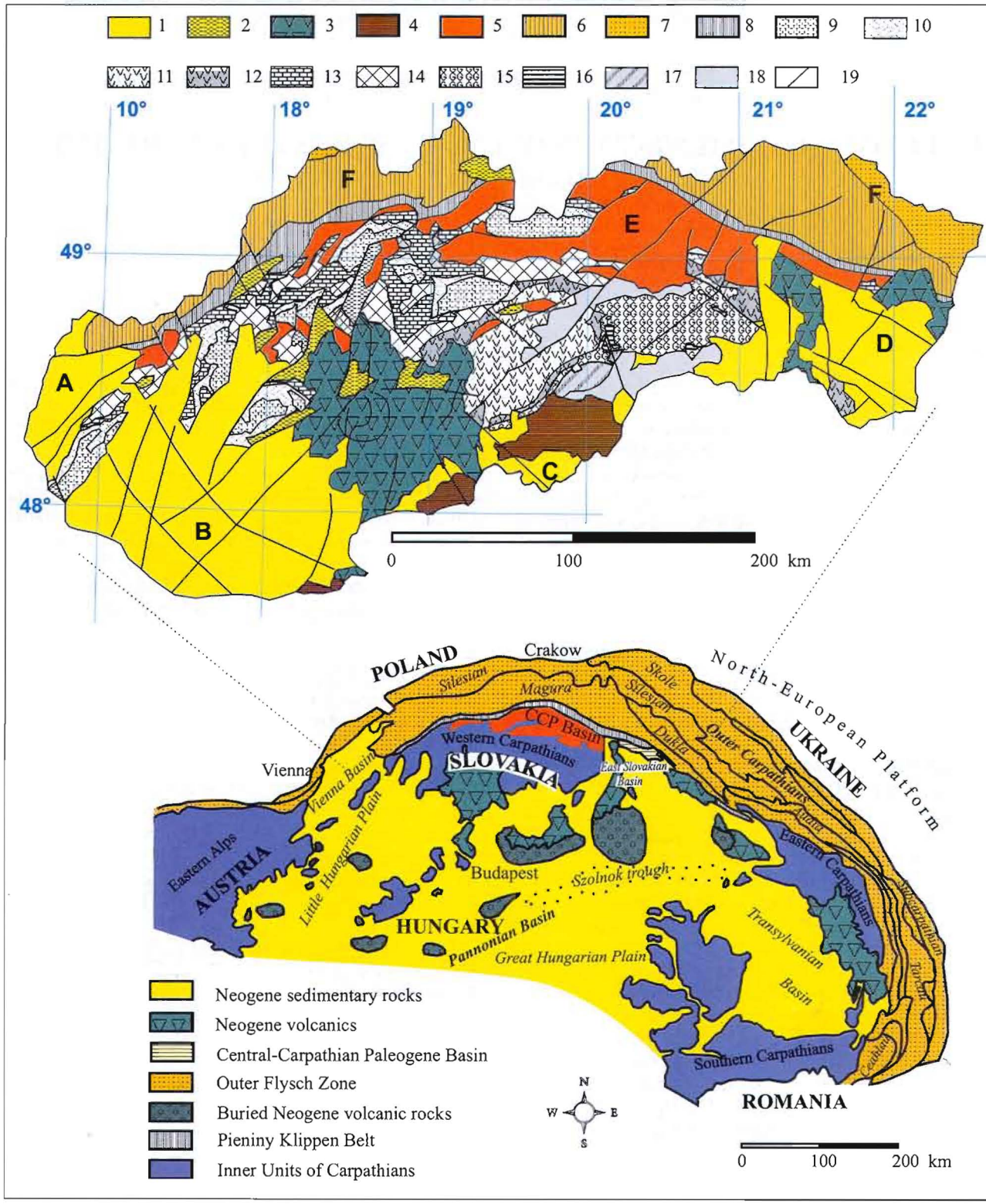


Fig. I.1. Sketch of Carpathian mountain system and geological map of Western Carpathians. Tertiary basins of the Western Carpathians are coloured. Tectonic sketch of the Western Carpathians after Biely et al., 1996, modified. 1 – Neogene basins, 2 – Neogene intramountaine depressions, 3 – Neogene volcanic rocks. 4 – Paleogene Hungarian (Buda) Basin, 5 – Central-Carpathian Paleogene Basin, 6 – Outer Flysch Belt, Magura Unit, 7 – Outer Flysch Belt, Dukla Unit, 8 – Pieniny Klippen Belt, 9 – crystalline rocks of Tatricum, 10 – sedimentary cover of Tatricum, 11 – crystalline rocks of Veporicum, 12 – sedimentary cover of Veporicum, 13 – Fatricum, 14 – Hronicum, 15 – Gemericum, 16 – Meliaticum, 17 – Turnaicum, 18 – Silicicum, 19 – main faults; A – Vienna Basin, B – Danube Basin, C – South Slovakian Basins, D – East Slovakian Basin, E – Central-Carpathian Paleogene Basin, F – Basins of the Outer Flysch Belt of the Western Carpathians.

East Slovakian Neogene basin found in several boreholes (e. g. Trhovište-26; Rudinec, 1978). The distribution of these deposits suggests that the original size of the basin was larger than its present area. Additional reduction of the basin extent can be seen at the contact with the Klippen Belt effectively cutting off its northernmost part. The maximum thickness of sediments in the basin is estimated approximately to 3.5 km (Janočko, 2002).

The Vienna Basin (Fig. I.1) occurs at the boundary of the Eastern Alps and Western Carpathians. Its western margin comprises units of folded Eastern Alps mollase and Krosno – menilite thrust units of the Outer Western Carpathians. At the northern margin of the basin the units of the Outer Carpathians – Magura Flysch Belt thrusts crop out from beneath the Neogene sediments while at the northeastern margin these overlie the Klippen Belt. The eastern boundary is represented by Litava Mts. and Malé Karpaty Mts. The units of Northern Calcareous Alps as well as the Central Eastern Alps form the southern margin of the basin. The Slovak sector of the Vienna Basin is called Záhorská nížina Lowland and the Czech part the Dolnomoravský úval Furrow. The name of the Austrian sector of the basin is identical with the geological designation – the Vienna Basin.

The Danube Basin is a part of the Pannonian back-arc system basin consisting of partial basins having different evolution during the Neogene. They differ with the thickness of the Miocene and Pliocene sedimentary fill. The Slovak sector of the Danube Basin is limited in the west by Malé Karpaty Mts., while in the north it protrudes in shape of small fingerlike promotories – bays among core mountains of Malé Karpaty, Považský Inovec and Tribeč Mts. The northeastern boundary is made up of the complexes of the Middle-Slovakian Neovolcanics while in the east it is limited by the neovolcanic rocks of the Burda Mts. The southern boundary of the Slovak sector of the basin represents the Danube river. The present shape of the basin resulted from a complex evolution in time and space. This is reflected by several depocentres on our territory with maximum subsidence activity occurring in different time periods. In the north these depressions located among the core mountains, going from west to east, are as follows: the Blatné, Rišňovce and Komjatice depressions. Between the Levice Horst and Zadunajské stredohorie Mts. the Želiezovce Depression is located. The deepest, central part of the basin is formed by Gabčíkovo Depression with sediment thickness exceeding 8.5 km (Kilényi and Šefara, 1989; Hrušecký et al., 1996).

South-Slovakian Depressions comprise sediments of three basins (Fig. I.1) that started deposition in Paleogene. They are the Buda, Fiľakovo–Pétervására and Novohrad basins. In the Lučenec and Rimava depressions the Tertiary sequences are capped by sediments of the Poltár partial depression. Besides these sediments the South-Slovakian Tertiary units comprise acid Lower Miocene volcanics, Middle Miocene intermediate volcanics and Pliocene to Quaternary basic volcanics.

The East Slovakian Neogene Basin (Fig. I.1) is a part of the Transcarpathian Depression to which also belong the Mukatchevo and Solotvina basins already on the Ukrainian territory. The East Slovakian Neogene Basin is some 60 km wide and 90 km long. It can be subdivided into Čelovce, Prešov, Moldava and Trebišov depressions and a smaller Roňava Bay (Vass et al., 1988). The volcanic rocks of the Slanské vrchy and Vihorlat Mts. are a prominent element of this basin. Adjacent in the west there are the Central Carpathian Paleogene Basin and pre-Tertiary units of Čierna Hora and Spišsko-gemerské rudohorie Mts. The Moldava Depression in the western part of the basin also neighbours the carbonate rocks of the Slovak Karst. In the north the basin neighbours Central Carpathian Paleogene units and locally also the Klippen Belt. In the south and east it continually merges into the Neogene sediments of the Mukatchevo part of the basin and the Pannonian Basin. The centres of deposition migrated in the NW to SE direction with maximum thickness of the basin fill exceeding 8 km.

Tectogenetic evolution of the Western Carpathian Tertiary basins began already in the Mesozoic. This is evident mainly in basins with Paleogene sedimentary fill – basins of the Outer Western Carpathians, Central Carpathian Paleogene Basin and the Hungarian (Buda) Paleogene Basin.

The area of Outer Western Carpathians displays a typical folded thrusted structure of an accretionary wedge from south to north consisting of the following geological units: the Magura, Dukla – Foremagura, Silesian, Subsilesian and Skole units (e. g. Ksiazkiewicz, 1962; Birkenmajer, 1977; Poprawa et al., 2002). Originally, these units represented sedimentary areas of the northern Tethys, isolated in certain evolutionary stages by elevation structures (Golonka and Ślaczka, 2000). In the north these units pass into relatively weekly deformed Miocene sediments of the Carpathian Foredeep. In the East Slovakian sector only Magura and Dukla units are found (Fig. I.1).

The accretionary wedge is mainly composed of siliciclastic, deep-marine sediments. Their stratigraphic range is Late Jurassic to Early Miocene (Poprawa et al., 2002; Oszczypko, 1999; Oszczypko-Clowes, 1999). The tectonosedimentary analysis and modelling of subsidence history suggest the primary opening of the Outer Western Carpathian basins by Middle to Late Jurassic rifting (Pescatore and Ślaczka, 1984; Poprawa and Malata, 2000; Poprawa et al., 2002). Sediment relics from that time suggest strongly dissected basins typical for rift environments – alternation of deep-water and shallow-water sediments that may be explained by the synrift deposition control (Nowak, 1973; Sikora, 1976). A post-rift stage of thermal basin disintegrations commenced during the Early Cretaceous resulting in calm, pelagic sedimentation (Cieszkowski et al., 1985). In Baremian and Albian, as well as in Cenomanian, the entire realm of the Outer Western Carpathians was unified bringing similar facial development to the entire region (development of variegated marls and radiolaria sediments; Koszarski, 1985). Events in the Late Jurassic and the subsequent thermal basin disintegrations that resulted in the oceanization of

the crust or development of transitional crustal types, are genetically related to the beginning of the Pieniny ocean subduction extending south of the described area (Birkenmajer, 1986; Golonka et al., 2000).

During the Middle and Late Cretaceous the Outer Carpathian basins and their source areas were tectonically uplifted (Slomka, 1995; Strzebonski, 2001; Nemčok et al., 2001). This development phase may be well correlated with compressional and transpressional phases of the Late Cretaceous evolution in the Alpine foreland (e. g. Ziegler et al., 1995; Wagreich, 1995).

The Late Cretaceous and Early Paleocene represent the time of important geotectonic processes in the Alpine–Carpathian realm. At that time the Pieniny ocean was closing and the Carpathian Orogene collided with the Czorsztyn Ridge (Birkenmajer, 1986; Winkler and Ślaczka, 1992; Golonka et al., 2000). At the same time the final thrusting of the Western Carpathian superficial nappes took place as well as the commencement of subduction of the oceanic bottom and/or of the transitional crust of the Magura basin followed in the area of the Outer Western Carpathians by typical deep-water sedimentation with predominating gravity flows.

Another feature of that period is the opening of sedimentary areas at the front of a mobile block of the Carpathian superficial nappes characterized by sudden and very intensive subsidence with the deposition of shallow-water sediments (e. g. Salaj, 1995) as well as deep-water, gravity flow sediments (Marschalko, 1985; Marschalko and Samuel, 1993). In Slovakia the sedimentation in these areas, often marked as deposition of the Gossau Cretaceous, could reflect opening of basins in transpressional or transtensional regime (Janočko, 2002) or tectonic erosion during subduction (e. g. Wagreich, 1995).

At the end of the Late Cretaceous and at the beginning of the Paleocene the basins of the Outer Carpathians became foreland basins. The main mechanism triggering the basin subsidence was the crust flexure due to subduction processes and related formation of the accretionary wedge loading the crust. Basin depocentres migrated, depending on the subduction development, northward of the subduction boundary (Birkenmajer and Oszczypko, 1989; Oszczypko, 1992; Pícha and Stráník, 1999) and determined diachronous beginning of synorogenic deposition in the Magura, Dukla, Silesian and Skole basins (Poprawa et al., 2002). The compression assigned to the Early Eocene (Tokarski et al., 1991) resulted in initial differentiation of the Magura basin and its subdivision into four tectonostratigraphic units: Krynica, Bystrica, Rača and in Poland the subdivided Siary Unit. Included further, in the western part of the Slovakian Outer Western Carpathians, is the Biele Karpaty Unit (e. g. Potfaj in Biely et al., 1996). It appears that compressions during the Eocene and Oligocene (Decker et al., 1999, interpreted the compression phase already in the Paleocene) with prevailing N–S and NW–SE maxima, probably often followed the weakness zones represented by extensional faults inherited from older, rift and postrift phases of the basin evolution (Enfield, personal commun.).

The roll-back effect in the Middle Eocene caused a retreat of the subduction boundary (Royden, 1993b; Bielik et al., 1995) when the total speed of the leading plate of the Carpathian block was smaller than the speed of the lower plate retreat. Under this conditions, an extensional regime was established in the tail of the subduction boundary with subsequent opening of the Central Carpathian Paleogene Basin. Thus in the eastern part of the basin the NE–SW extension prevailed while in the western part the extension was oriented in the NNW–SSE direction (Janočko, 2002; Jacko and Janočko, 2002) causing the widening of the basin southward.

At the beginning of the Luthetian the Buda (Hungarian) Basin opened along the NE faults on the Slovak territory extending to the vicinity of Štúrovo town and its northeastern margin extended as far as Drienovec in Eastern Slovakia. During the Kiscellian the Buda Basin progressed including the area of South Slovakian Depressions. According to Vass (1995) the opening of the basin (due to dextral strike-slip along the Balaton and Middle Hungarian lineaments) was conditioned by the tectonic drift of Western Carpathian–Northern Pannonian terranes away from the Alpine–Dinaride area.

During the Late Eocene the northern part of the Outer Carpathians was a single sedimentary area. At that time the hemipelagic and pelagic deep-water deposition prevailed and was represented mainly by green claystones merging into Globigerina Marls. It would appear that at that time the spaces accupied by the Dukla, Silesia and Subsilesia units communicated together. The evidence of this may be found in the similarity of Menilite Member and the Mszanki Sandstone with the deposits along the southern margin of the Silesia Unit and the northern margin of the unit of Dukla (Ślaczka, 1971). At the same time we observe the differentiation of the Magura Basin bottom being reflected in polyfacial development of the sediments. A pronounce shallowing of the basins occurred at the boundary between the Eocene and Oligocene resulting in their isolation. This caused the stagnation of water circulation and formation of menilite sediments under reduction conditions. Subsequently, during Late Eocene and Lower Miocene, the nappes of Outer Carpathians were subject to further thrusting while piggy-back basins were developing in the ensuing depressions. The Magura Basin, at the time of Malcov Formation deposition, may be included here.

The Central Carpathian Paleogene Basin reached its maximum extension during the Oligocene with a consequent NE–SW extension in the eastern part of the basin with increasing N–S compression.

After the Late Oligocene phase of thrusting, the Magura Unit was thrusted northward over the remnants of the Silesian Ridge. In the more external zones (Silesian, Subsilesian and Skole units) the deep-water, mostly turbidite deposition continued. In the northern part of Outer Western Carpathians the formation of Outer Carpathians zone was completed in the Middle Miocene (Early Sarmatian). Thereafter the geological evolution of the area continued only in the Carpathian Foredeep.

While the Neogene evolution of Western Carpathian basins continued under control of subduction between the Carpathian Orogene and North-European Platform, other geotectonic processes were also very important. Among the most prominent processes belong the tectonic drift of litospheric fragments from the Eastern Alps realm as well as uplift of the Pannonian asthenolith with subsequent collaps of the Pannonian lithosphere. The Neogene basins of the Western Carpathians, evolving in these conditions, may be subdivided into five categories (see also Vass, 1998):

- foredeep basins originating by the flexure of North-European Platform triggered by load of accretionary prism of the Outer Carpathians and deep subsurface load of submerging plate
- piggy-back basins
- wrench-fault furrow basins originating at the transforming boundaries between the Tertiary accretionary prism and the consolidated paleo-Alpine part of the orogene at its active margin
- transtensional pull-apart basins originating at the transforming boundaries of individual segments of the mountain range in conditions of oblique convergence between the Carpathian Orogene and the North-European Platform
- back-arc basins originating in conditions of back-arc extension as a result of Pannonian asthenolith uplift. Included in this group there are also the basins formed by final thermal subsidence

Foredeep basins are not found on the Slovakian territory and, therefore, shall not be discussed here.

Piggy-back basins originated on the thrusted nappes of flysch accretionary prism. On the Slovakian territory the relics of Lužice Formation deposited in the area of the present Vienna Basin and the Laborec Member near Humenné are included in this group. Wrench-fault furrow basins, which formed as a result of oblique convergence between the ALCAPA (Alpine-Carpathian Orogene) and North-European Platform, developed along the inner margin of the Klippen Belt. We include here Senica and Koválov depressions (Marko and Kováč, 1995). These depressions were opened in transpressional conditions along dextral strike-slips of ENE direction at the beginning of the Eggenburgian. They had short existence and at the end of the Ottnangian they were closed by NW–SE back-thrusts (Marko et al., 1990, 1991; Marko and Kováč, 1995). The smaller Beckov, Trenčín and Ilava depressions are included in this group.

Wrench faults also affected the Eggenburgian sedimentation in the northern part of the East Slovakian Basin. The formation of the basin at the end of the Eggenburgian was mainly controlled by dextral NW strike-slips (Kováč et al., 1994; Kováč et al., 1995). The direction of compression changed in the Ottnangian to NNW–SSE causing a depositional hiatus in the basin (Kováč et al., 1994; Jacko in Janočko et al., this volume).

The Karpatian and Early Badenian periods mark the beginning of the Carpathian–Pannonian volcanic activity. Volcanic products may be subdivided into western, older segment with areal indistributed volcanism and eastern, younger segment, parallel with the subduction zone of Eastern Carpathians. The western segment consists of magma generated by subduction of lithospheric basement of the Outer Western Carpathians followed by the Pannonian lithosphere during the uplift of the Pannonian asthenolith (Lexa and Konečný, 1974, 1979; Lexa et al., 1993).

Formation of the eastern segment was controlled by the subduction of the Outer Carpathian basement indicated by spatial distribution of volcanism (Vass et al., 1988; Poka, 1988; Lexa et al., 1993; Lexa and Konečný, 1998).

Areally distributed acid volcanism in the area of the Pannonian Basin and its northern margins is associated with the processes of back-arc extension and diapiric uplift of the asthenospheric mantle, which was metasomatically enriched by the processes of previous subduction. The surface volcanism is typical by high explosivity with eruptions of large volume of pyroclastic material subsequently deposited in sedimentary basins in marine and subaerial conditions. After initial paroxysmatic eruptions during the Eggenburgian and Ottnangian ("Lower Rhyolite Tuff") the explosive volcanism attains further maximum at the boundary between Karpatian and Early Badenian ("Middle Rhyolite Tuff") and during Early Sarmatian ("Upper Rhyolite Tuff") when it is accompanied by extrusive and effusive activities.

Areally distributed andesite volcanism in the area of Central Slovakia and Northern Hungary represents the continuation of processes of diapiric uplift of enriched asthenospheric mantle with the further evolution of primary basalt magmas located at the base of partially weakened crust. At this depth (ca. 30 km) the magmas underwent a high pressure fractionation with assimilation of crustal material and transformation of magmas into andesitic composition. During the ascent to the surface and emplacement in subsurface reservoirs the magmas underwent processes of fractional crystallization and mixing which resulted in a wide spectrum of differentiated rocks ranging from acid andesites, dacites and rhyodacites to rhyolites (Lexa and Konečný, 1998).

The result of this surface volcanic activity during the Badenian, Sarmatian and Early Pannonian (16–9 Ma) is the formation of medium to large andesite stratovolcanoes with differentiated volcanic products, development of calderas, volcanotectonic depressions and intrusive complexes. More differentiated andesite, dacite and the rhyolite lavas formed monogenic extrusive forms of domatic type. Characteristic there is a syngenetic development of horst–graben structures filled during their subsidence by volcanic and volcanosedimentary materials.

Basaltic–andesite and andesitic volcanism of volcanic arc type in Eastern Slovakia shows a different features. It is in space and time associated closely with the processes of subduction indicated by the arrangement of volcanoes in belts or chains subparallel to the subduction zone extending from Eastern Slovakia over to Western Ukraine

and Romania. At the surface the volcanic activity is represented by small stratovolcanoes with substantial to predominant occurrence of effusive products as compared to pyroclastics (in contrast to the areal andesite volcanism in Central Slovakia) and with limited development of subvolcanic intrusions and volcanotectonic depressions.

The area of Eastern Slovakia is reached also by the eastern segment of the arching Middle Sarmatian belt of shallow intrusions of garnetiferous andesites (SE Moravia – Pieniny Mts. – Vihorlat Mts.).

Basaltic/andesitic volcanism of the western volcanic arc segment on our territory and territory of the Ukraine (Slanské vrchy Mts. – Vihorlat Mts. – Gutin Mts.) is represented by three subparallel belts: the inner belt (overlying the products of the areal andesite volcanism Tokaj – Zemplín – Berehovo) developed during the Late Badenian and Early Sarmatian (14.5–12 Ma). The second belt with andesite stratovolcanoes of Sarmatian age (13.5–11 Ma), includes the northern part of the Slanské vrchy Mts. as well as the burried volcanoes of the Eastern and Trans-carpathian basin with continuation to Beregovo and Baia Mare areas. The third, outer belt of basaltic/andesitic stratovolcanoes, formed in the Late Sarmatian and Early Pannonian (12–9 Ma) commences with Vihorlat Mts. and continues to the Western Ukraine and to Gutin Mts. in Romania.

The products of basaltic/andesitic volcanism, including products of acid areal volcanism, represent an essential part of the East Slovakian Basin fill. The deposition of volcanic products, particularly their redeposited facies (tuffs and epiclastics) compensated the subsidence of the basin.

Alkali basalt volcanism in the area of Central and Southern Slovakia, represented by alkaline basalts and nefeline basanites, is a product of partial melting of a depleted asthenospheric mantle (with traces of subduction process). During their ascent to the surface the basaltic magmas used rejuvenated, older fault systems originated during the thermal subsidence of previous extensional basins.

An extensive volcanic area formed during the activity of basaltic volcanism (5.4–1.1 Ma) in Southern Slovakia (Lučenec Depression and Cerová vrchovina Mts.) and Northern Hungary in the vicinity of Salgótarján. Representative volcanic forms include maars, phreatopyroclastic cones, scoria cones with associated lava flows. Following erosion exposed the supply systems such as necks and diatremes.

Sporadic scoria cones and lava flows can also be found in the area of the Central Slovakian Volcanic Field. The youngest one is a scoria cone with the lava flow near Nová Baňa (0.23 Ma).

The Karpatian and Early Badenian transtensional pull-apart basins started to develop along the transform boundaries. The Vienna Basin formed between the East Alpine and Western Carpathian segments and East Slovakian Basin opened between the Western and Eastern Carpathian orogene segments.

At the beginning of the Middle Miocene the subduction in the western part of the Western Carpathians was substituted by collisional stage, substantially affecting further development of the Vienna Basin characterized by the transtensional regime of compression changing progressively from N–S to NE–SW direction, with accompanying perpendicular extension (Kováč et al., 1989; Marko et al., 1990, 1991). A dominant role during the opening of sedimentary areas played the NE–SW striking sinistral strike-slip faults, later transformed into normal faults (e. g. Litava faults). In the Late Miocene the fault activity faded out resulting in deceleration of subsidence. The final stage of the basin development is represented by the basin inversion which occurred under conditions of E–W compression in the Late Miocene. In the Pliocene maximum compression changed progressively into N–S to NW–SE direction (Gutdeutch and Aric, 1988; Becker, 1993) triggering new NW–SE faulting.

The development of East Slovakian Basin from the Early Karpatian is characterized by transtensional regime with prevailing NW–SE dextral strike-slips which later became normal faults. In the Late Karpatian the subsidence was mainly controlled by transtension which resulted from the uplift of asthenolith in the back-arc area. The transtensional regime induced the ascent of acid magma of crustal origin (Salters et al., 1988) and subsequent volcanism.

Tectonic activity of the East Slovakian Neogene Basin considerably diminished in Middle Badenian when the subsidence slowed down bringing sedimentation in hypersaline environments. During Late Badenian the stress field returned to NW–SE compression and predominant NE–SW extension. The period between Late Badenian and Middle Sarmatian was again characterized by intensive subsidence. The sinistral strike-slips opened the space for the Klčovo Delta (Jiříček, 1972; Janočko, 1990; Řeřicha, 1992). In Pannonian NW–SE extension prevailed due to the final thermal subsidence of the back-arc basin. During Pontian the basin underwent a compression – a tectonic inversion manifested by significant fading out of subsidence followed by weak thrusting of basin fill (Kováč et al., 1994).

Most of the intramountaine depressions containing Neogene sediments exhibit graben or half-graben character. Typical is the development of marine sediments at the base passing upward into terrestrial facies.

Back-arc Neogene basins are represented by the Fiľakovo –Pétervására Basin replacing the Hungarian Paleogene– Buda Basin which includes only Eggenburgian sediments (Vass, 1995). Short duration of deposition was probably caused by the rise of the Pannonian asthenolith. This also induced rhyolite–rhyodacite volcanism in the Pannonian region (Pántó et al., 1966; Szabó et al., 1992; Lexa et al., 1993). The lithosphere uplift caused by the Pannonian asthenolith may be regarded as active rifting followed by passive rifting. This rifting caused then the opening of the Novohrad/Nógrad Basin (Vass, 1995).

Basins dominantly affected by the final stages of thermal subsidence in the Pannonian back-arc area on the Slovakian territory include the Danube.

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II. GEOTECTONIC BACKGROUND OF ORIGIN OF WESTERN CARPATHIAN SEDIMENTARY BASINS

JURAJ JANOČKO[1] and MICHAL KOVÁČ[2]

II.1 Origin of Paleogene sedimentary basins and structural evolution of Western Carpathian orogene in the Paleogene

JURAJ JANOČKO

The Tertiary tectogenetic evolution represented a new period in the evolution of Western Carpathians. Beginning of this period may already be placed to the Mesozoic what is most apparent in the basins of the Outer Western Carpathians (Fig. II.1). Their sedimentary fill provides a continual record across the Cretaceous–Paleogene boundary. However, the Mesozoic geotectonic processes affected also the opening of the Central Western Carpathian Tertiary basins. The main events controlling initiation of the Tertiary evolution in the Central Carpathian realm were the Middle Jurassic opening of the Magura Basin (e. g. Oszczypko et al., 2003), Late Jurassic rift and Cretaceous post-rift stages of the Western Carpathian basins developing at the margin of European Platform, that converged at the beginning of the Paleocene with the Carpathian–Pannonian block. Another important event related to the rifting in the area of Outer Western Carpathians is represented by a closure of Pieniny ocean at the Central and Outer Carpathian boundary. The incipient Pieniny Klippen Belt, which is presently associated with direction of subduction suture between the North-European Platform and the Carpathian–Pannonian block, represented during the Tertiary evolution a zone of weakness that was a site of complex tectonic processes. One of the last, but not least important geotectonic events was represented by final thrusting of the superficial Central and Inner Carpathian nappes whose isostatic load contributed to the opening of Paleogene basins in the region.

Outer Western Carpathians

The geotectonic and sedimentary conditions during the Late Mesozoic and Tertiary evolution of the Western Carpathian basins caused the largest extent of the oldest Tertiary sediments in the basins belonging to Outer Western Carpathians. After the initial Middle? and Late Jurassic rift stage the Outer Western Carpathian basins considerably widened in Cretaceous. During Late Cretaceous and Early Paleocene the Pieniny ocean was gradually closed (Birkenmajer, 1986; Winkler and Ślaczka, 1992; Golonka et al., 2000). Final thrusting of the Western Carpathian superficial nappes and onset of subduction of the oceanic or transitional crusts of the Magura basin stimulated deep-water deposition with predominating gravity flows.

The maximum size of unified sedimentary area in Outer Carpathians is assumed to be in Hauterivian and Aptian (Golonka et al., 2003). After that time the unified area started to be gradually separated by rising submarine highs and ridges into individual subbasins. The area of the Outer Western Carpathian Zone represented by Dukla, Silesian, Subsilesian and Skole units was during the initial stages of the basins evolution separated from the Magura Basin. The Magura Basin originaly formed NE arm of the Pieniny ocean separated from the Pieniny ocean by the Czorstyn Ridge (Oszczypko et al., 2003) and from the Outer Flysch Zone by the Silesian Ridge (Golonka et al., 2000). The uplift of the ridge is assumed to take place in the Turonian (Golonka et al., l. c.). During Santonian and Paleocene the Silesian and Skole basins were separated by Subsilesian High. Its uplift was according to some authors related to the shortening of the Silesian Basin (e. g. Oszczypko, 1999). During Paleocene and at the beginning of Eocene deposition occured in remnant oceanic basins. The subsidence at the end of the Paleocene affected the most of basins of the Outer Flysch Zone and resulted in their connection with the world ocean in the Eocene and unification of facies of these basins (Oszczypko et al., 2003). Sedimentary load of the accretionary prism of the Klippen Belt and proximal part of the Magura Unit caused flexure of the crust and gradual migration of depocentres. Depending on subduction development the depocentres migrated northward of the subduction boundary (Birken-

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majer and Oszczypko, 1989; Oszczypko, 1992; Pícha and Stráník, 1999) causing diachronic commencement of synorogenic sedimentation in the Magura, Dukla, Silesian and Skole basins (Poprawa et al., 2002). Sedimentary record from that period suggests that the formation of accretionary prism crucially influenced depositional environments formed by deep-water turbidite systems feeded by sediments from the prism. In Early Eocene (at the latest in Middle Eocene) a compression appeared (Tokarski et al., 1991) causing differentiation of the Magura Basin and its subdivision into partial tectonostratigraphic units – Krynica (Kochanovce), Bystrica, Rača and Siary units. At that time deposition of the remnant oceanic basin changed to deposition in peripheral foreland basins (Oszczypko, 1999).

Central and Inner Carpathians

Oblique convergence between the North-European Platform and Carpathian–Pannonian block together with synergic effect of crust flexure caused by isostatic load at the front of superficial nappes of Central Western Carpathians were probably the main geotectonic factors triggering opening of sedimentary basins along the southern margin of the Klippen Belt. In these areas, described by Samuel (1972) as Považie–Hanušovce Belt with various sedimentary developments (Myjava, Domaniže, Hričov–Žilina, Varín, Haligovce and Beňatina developments), and which Andrusov (1965) characterized as Myjava–Hričov–Žilina facies, intensive block movements, took places during the Paleocene and Eocene.

The sediments, often called "Klippen Belt Paleogene", surround the northern margin of Central Western Carpathians. They overlie the Central Carpathian pre-Paleogene units and/or are partly incorporated into the Pieniny Klippen Belt sedimentary units as a result of folding (e. g. Leško, 1960; Leško and Samuel, 1960; Salaj, 1962; Samuel, 1972, 1973). They are typical by lithofacial variability – the facies are laterally and vertically discontinuous. Characteristic there is occurrence of large olistoliths consisting of bioherm limestones (Samuel et al., 1972) and locally enormous accumulation of detritic material derived prevailingly from units of the Central Western Carpathians (Samuel, 1973; Marschalko, 1980; Marschalko

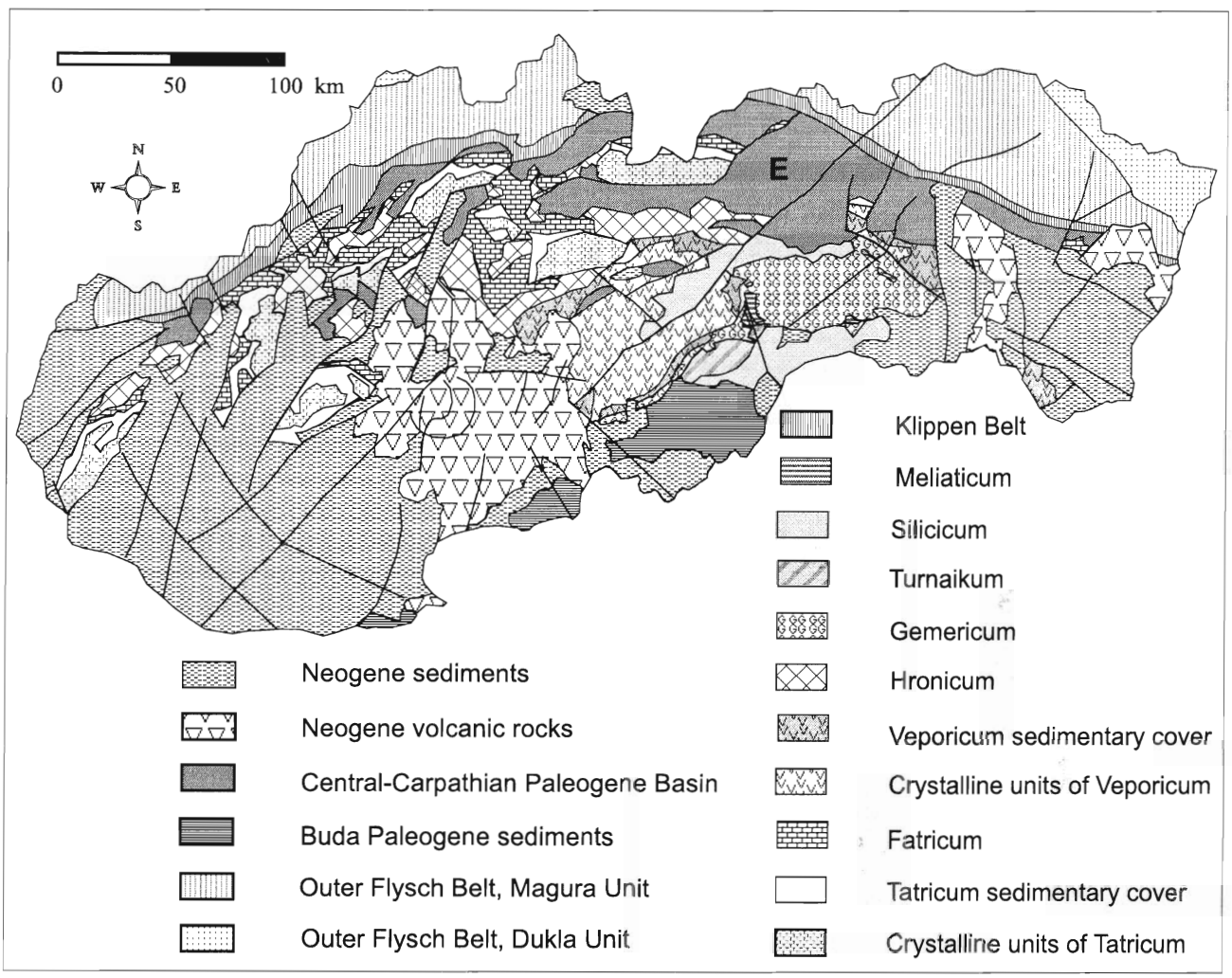


Fig. II.1. Geologic scheme of Slovakian sector of Western Carpathians.

and Samuel, 1993). The blocks of bioherm limestones of the Danian, Montian and Thanetian age (Samuel, 1973) occur in fine-grained mudstones and also in breccias and graded conglomerates. Based on their position it is assumed that they slided down along the submarine slope into deeper parts of the basin (Samuel, 1972; Marschalko, 1980). The absence of reef facies between sediments at the southern – Central Carpathian side of the area, composed of units belonging to the Choč nappe, indicates development of the limestone blocks at the northern margin of the trough adjacent to the Pieniny Klippen Belt. The main supply of sediments to the basin was from the Central Western Carpathians as it is suggested by prevailing occurrence of clasts derived from the Choč and Strážov nappes (Marschalko, 1980). Relatively calm deposition at the margin of the Pieniny Klippen Belt favoured development of carbonate platform or reefs (Marschalko, l. c.).

Besides blocks of bioherm limestones one of the typical features of the area there is also the extensive accumulation of coarse-grained, mostly gravity flow sediments (prevailingly debris flow sediments and sediments of a wide range of turbidity flows). Typical example is the Súľov Conglomerate of the Žilina – Domaniža area, which originated in fastly subsiding, terrestric and subaqueous environments (Marschalko, 1980; Marschalko and Samuel, 1993). The sediments, up to 1200 m thick, are typical for the mobile marginal troughs (Marschalko, l. c.). Similar development have sediments between Chmeľov and Hanušovce in East Slovakia and also in the vicinity of Humenné, Jasenov and Beňatina. In the lower part they contain numerous exotic granites, quartzites and reef limestones of the Montian and Thanetian age. These sediments alternate with hemipelagic mudstones. In the upper part of the sedimentary succession dolomitic conglomerates occur (Marschalko, 1980). The sediments were intensively tectonically deformed and locally incorporated into Klippen Belt.

The mechanism of fast subsidence in the described areas, that according to the thickness and lithofacial development of sediments undoubtedly existed, is not clear until now. Similar development in the area of Gossau basins in the Eastern Alps is explained by mechanism of tectonic erosion (Wagreich, 1995) when the leading plate is eroded by rugged relief of subducting plate. The erosion caused a fast subsidence of the area at the plate boundary and following fast deposition. The oblique subduction caused diachronic subsidence and its migration eastward.

Another model explains fast opening of sedimentary areas and their intensive subsidence in releasing bands along strike-slip faults activated during the oblique subduction (Janočko, 2002). Variable thickness of prevailingly deep-marine sediments, that at some places reach thickness over 1200 m (e. g. the area of Súľov Conglomerates) and at another places they are absent or only preserved in remnants, is typical for some types of strike-slip basins in transtensional and transpressional regime (Nilsen, 1995). Fast subsidence and following emergence of individual blocks also caused a change of source areas, which is in

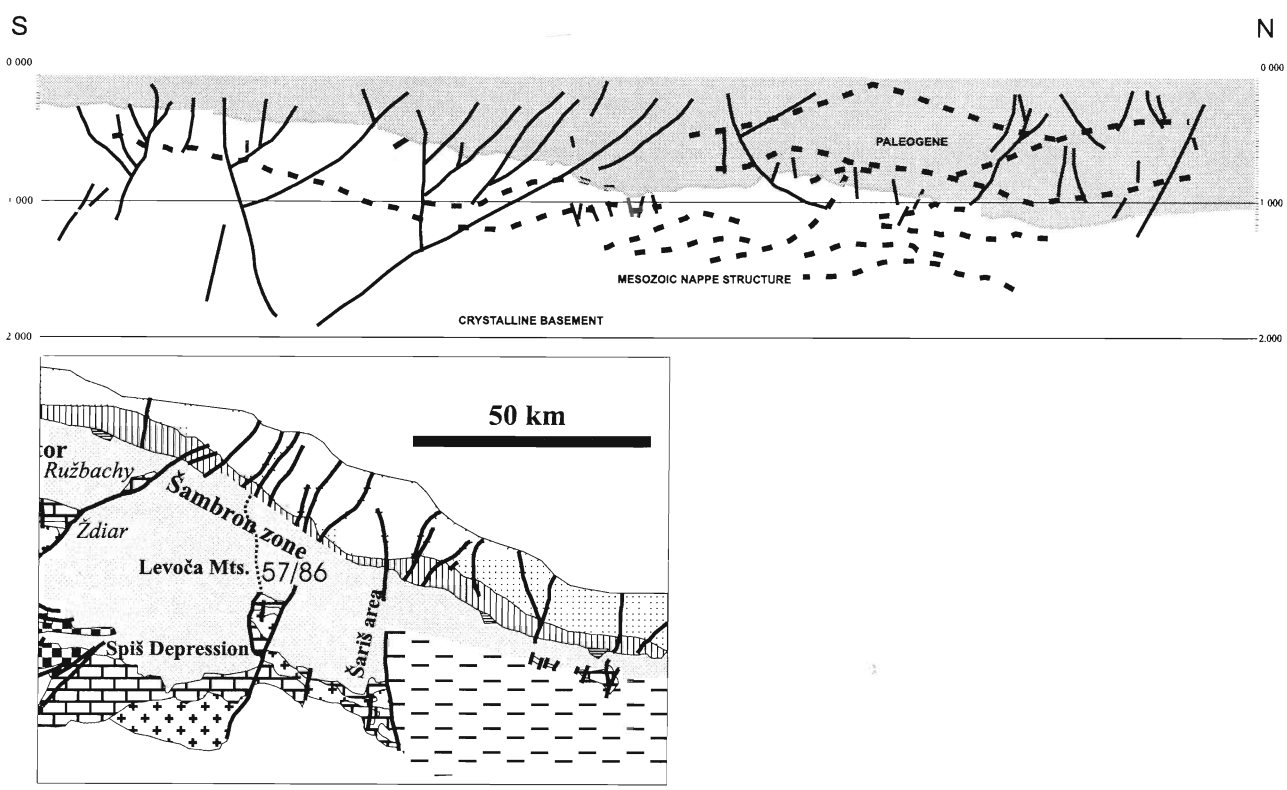


Fig. II.2. Seismic section 57/85 showing CKP Basin (gray colour) asymmetry. The elevation structure in the north lies in the Šambron zone. For location of seismic section see the lower figure.

the "Carpathian" literature explained by emergence of various exotic cordilleras (e. g. Samuel, 1973; Marschalko, 1975, 1978, 1980; Gross and Köhler, 1980; Birkenmajer, 1988). Continuing process of oblique convergence could trigger destruction and "canibalism" of older strike-slip basins at the contact with the Pieniny Klippen Belt. Subsequently, new basins, opened by identical tectonic regime, were formed south of them. We assume that in Paleocene and Eocene the area of future Klippen Belt morphostructure was rimmed from the south by several autonomous strike-slip basins characterized by fast subsidence and uplift. Findings of sandy limestones with sideroliths and orbitoids near Brezovica, containing Senonnian fauna, as well as findings of Danian and Montian sediments west of Žilina (Salaj et al., 1978; Salaj, 1987) suggest existence of initial basin stages already at the end of Cretaceous.

The largest Slovakian Paleogene basin south of the Klippen belt is the Central Carpathian Paleogene Basin. Geophysical models (e. g. Dewey et al., 1989; Royden, 1993; Bielik et al, 1998) and geologic data (e. g. Leško and Samuel, 1968; Marschalko and Samuel, 1993; Salaj, 1995; Janočko, 2002; Jacko and Janočko, 2002) suggest the initial evolutionary stage of the basin in conditions of oblique convergence during the retreat of subduction boundary, when the thrusting velocity of the upper plate was lower than the retreat velocity of the lower plate. The retreating subduction boundary resulted in prevailing compressional regime at its front (the area of Outer Carpathians) and extension in the tail. The extension affected opening of the Central Carpathian Paleogene Basin. Based on large foraminifera analyses (e. g. Köhler, 1998) found in the sedimentary basin fill, the beginning of the extension is assumed in Middle Eocene – Lutetian. Sediment distribution and N–S asymmetry of the basin (clearly indicated by seismic profiles and interpreted from boreholes, Fig. II.2) suggest initial opening of the basin close to the subduction zone indicated today by the Klippen Belt position. The asymmetric extension triggered southward shift of basin depocentres and gradual marine transgression on pre-Tertiary units of Western Carpathians. In Oligocene NE–SW extension continued in the eastern part of the basin, however, it already was complemented by increasing NNW–SSE compressional stress. At the western margin of the basin NW–SE extension prevailed and increasing compressional stress had N–S direction. The compresion resulted in uplift along the NE–SW structures that are morphologically conspicuous along the Subtatric – Ružbachy fault system (Jacko in Jacko and Janočko, 2003).

At the beginning of Lutetian also the Hungarian Paleogene (Buda) Basin developed. The basin extends mainly in the vicinity of Štúrovo in the Slovakian sector, however, its northeastern margin is assumed to be near Drienovec in Eastern Slovakia. During Kiscellian the Buda Basin extended into the area of South Slovakian Depressions (according to Báldi and Báldi-Béké, 1985; Báldi, 1986 and Vass, 1995) the opening of the basin was induced by dextral strike-slip along the Balaton and Middle Hungarian lineament.

II.2 Origin of Neogene sedimentary basins and structural evolution of Western Carpathian orogene in the Neogene

MICHAL KOVÁČ

To understand Neogene geodynamic evolution of the Western Carpathian orogene and origin of Neogene sedimentary basins it is necessary to realize that the orogene is a part of lithospheric fragment – microplate ALCAPA. After tectonic escape from the realm of the Eastern Alps the ALCAPA had a complicated trajectory of movement until it reached today's position defined in addition to distance (about 300 km) also by almost 90° counter clockwise rotation (Márton et al., 1995; Kováč and Márton, 1998; Kováč, 2000).

The next, but not least important fact is represented by processes controlling origin of the Pannonian back-arc area. First, it is pull of subducting slab at the front of the orogen and subsequent stretching of leading edge of the plate and second, is the evolution of basins determined by diapirism of asthenospheric mantle and related deep structural unroofing of basement units.

Evolution of Neogene sedimentary basins during the Eggenburgian and Ottnangian

At the beginning of Early Miocene Western Carpathians formed the eastern margin of the Alpine-Carpathian orogene moving northward as a result of Adriatic plate compression (Fig. II.1). Geodynamic evolution was characterized by compression in subduction zone and subsequent collision of Eastern Alps with the North-European Platform. The loading of foredeep resulted in subsidence and deposition of "Upper marine molasse" in the Alpine foredeep. Deep subcrustal loading of the last connection of submerging plate with the platform defines foredeep depocentrum with maximal thickness of Eggenburgian and Ottnangian sediments exceeding 2000 m at the boundary between the Eastern Alps and Western Carpathians (Meulenkamp et al., 1996).

Collision of the Alpine–Carpathian orogen with the European platform was significantly influenced by paleomorphology of the platform southern slopes, particularly southward extending offshoot of Bohemian Massif. Westward of it northvergent thrusting of the East-Alpine orogene on the foredeep bay continued while eastward the lithospheric fragment of Western Carpathians lag behind. The collisional tectonics mainly generated NW–SE dextral strike-slip faults in order to compensate slow movement of the Western Carpathian orogene (comparing to the Eastern Alps) as a result of collision with promontory of Bohemian Massif. The uplift of Western Carpathians in Ottnangian, recorded by shallowing sediments (Vienna Basin), retreat of marine deposition (South Slovakia) or even erosion (East Slovakian Basin), may be considered as culmination of compressional regime and subsequent extension (Fig. II.3).

In the foreland of the Western Carpathian orogene, extensive sedimentary areas of residual flysch troughs occurred (e. g. Ždánice, Sub-Silesian, Skole, Skiba Units) flanked from the north and northeast by shelf basins of "inner foredeep zone" formed on the margin of the platform (e. g. Stebnik, Borislav – Pokuty, and Sambor Units). The southern margin of residual flysch troughs reached the area of inner flysch belt zones (e. g. Magura, Silesian and Dukla Units).

The Early Miocene sedimentary basins are characterized by their geodynamic position. The most external type of basins are piggy-back basins developed in the area of the Outer Carpathian accretionary prism. We assign here preserved sedimentary relics of Eggenburgian–Ottnangian age in the area of Vienna Basin (Vass, 1998; Kováč, 2000), in the northern part of the Western Carpathian belt (Cieszkowski, 1992) and in the Eastern Slovakia (Maťašovský and Andreyeva-Grigorovich, 2002).

At colliding margin of the Central Western Carpathians wrench-fault furrow basins were generated (Marko et al., 1991) which mostly occur at the contemporary northern margin of the orogene (presently western part of the Western Carpathians). The deposition on the southern margin (eastern part of recent Western Carpathians) represented termination of the Central-Carpathian Paleogene Basin evolution even if it is not possible to exclude similar character of basins like at the northern margin (e. g. Kováč et al., 1994; Janočko, 2002). In the tail of the orogene, in the south Slovakian – north Hungarian area extensional regime started in the Ottnangian (Vass, 1995) resulting in generation of graben-type depocentres.

Development of paleostress field during the Eggenburgian and Ottnangian and its structural record in the Western Carpathians

Compressional regime in the area of Eastern Alps during Eggenburgian and Ottnangian was characterized by stress paleofield with main compressional component in the N–S direction (Peresson and Decker, 1997). Eastward, in the western part of Carpathians, a change of paleostress field direction is documented. The direction of main compressional component is NW–SE and reflects Miocene rotation of the ALCAPA microplate 60–80° counter clockwise (Márton et al., 1995; Márton and Fodor, 1995; Kováč and Túnyi, 1995; Kováč and Márton, 1998). Compressional tectonic regime reactivated ENE–WSW dextral strike-slips and NE–SW backthrusts (Fig. II.3) which controlled generation of wrech-fault furrow basins (sensu Montenat et al., 1987). The basins were filled by marine, littoral and neritic clastic deposits thick up to 500 m (Nemčok et al., 1989; Fodor, 1995; Kováč et al., 1994, 1995, 1997a, b).

In the area of Transdanubian Mts. (Dunajské stredohorie) identical paleostress field with the main NW–SE compressional component was recorded. Also, a similar tectonics with prevailing NE–SW thrusts and ENE–WSW dextral horizontal strike-slips was recorded (Csontos et al., 1991; Fodor et al., 1991, 1992). Similarly in the South Slovakian–North Hungarian Basin, containing 700 m thick Eggenburgian marine sediments (Sztanó, 1994), the Eggerian deposition was controlled by ENE–WSW thrust fault at the northern margin of the basin (Sztanó and Tari, 1993). This suggests identical paleostress field like in the above mentioned areas.

In the eastern part of the Western Carpathian orogene similar paleostress field with NE–SW extension lasted as long as Eggenburgian (Kováč. et al., 1994; Janočko, 2002; Jacko and Janočko, in press).

Reorientation of the paleostress field is recorded in both East Slovakian Basin and South Slovakian–North Hungarian Basin during Eggenburgian. In both cases the documented field had maximum NNE–SSW compressional component. In the South Slovakian–North Hungarian Basin it triggered reactivation of ENE–WSW sinistral strike-slip fault at its northern margin resulting in gradual degradation of the basin (Vass et al., 1993). Similar compression is also recorded in the area flanking the Klippen Belt in the East Slovakia, which resulted in sediment folding and shortage of space during that time (Plašienka et al., 1998).

After compressional period in the evolution of the South Slovakian–North Hungarian Basin at the end of Eggenburgian the paleostress field changed to NE–SW extension (Fig. II.3). Deposition in the Ottnangian basin was controlled by NW–SE normal faults since that time (Vass et al., 1993). Sedimentary environment was subaerial – lacustrine with occasional marine ingressions from southwest (Vass et al., 1987; Šutovská, 1993) as suggested by denudation relics of the Ottnangian marine deposits in the area of Transdanubian Mts. (Kókay, 1973).

Similar extension like in the South Slovakian–North Hungarian Basin (Vass et al., 1993) was also recorded in the central part of Western Carpathians where NW–SE normal faults and N–S sinistral strike-slips controlled evolution of basins in the area of Bánovce, Horná Nitra and Turiec Depressions (Kováč and Hók, 1993; Hók et al., 1995). The basins were flooded by sea in Eggenburgian. The thickness of preserved deposits is not more than 200 m (Kováč et al., 1993a, c).

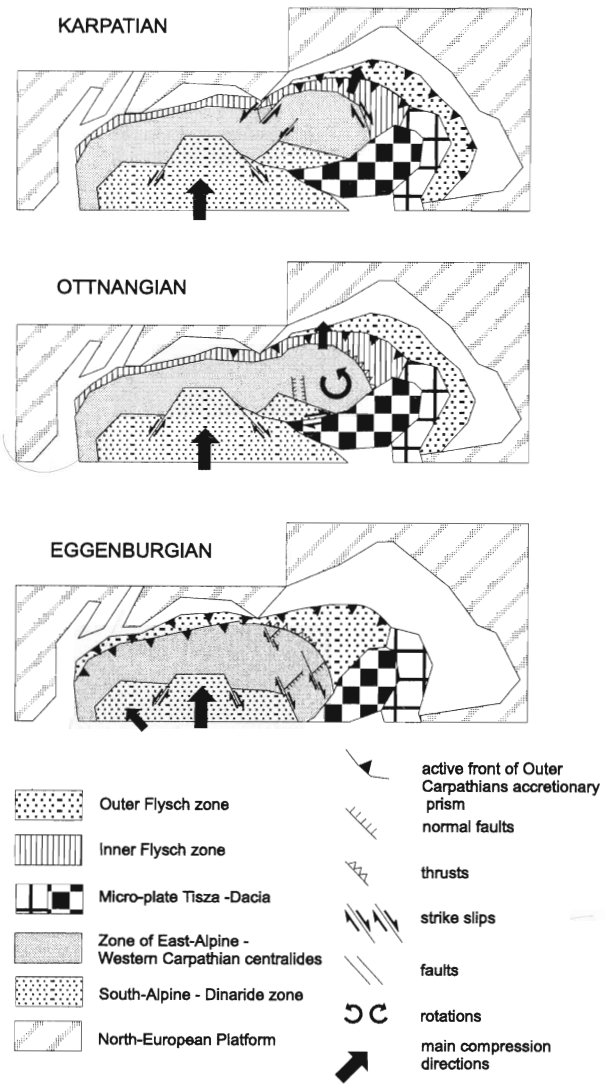


Fig. II.3. Palinspastic scheme of structural evolution of Western Carpathian Neogene basins (Eggenburgian, Ottnangian and Karpatian) in dependence on orogene evolution, complemented by structural record in recent position.

In contrast to the central part, the evolution in the eastern part of the orogene was still characterized by compressional tectonic regime with main compressional component in NNE–SSW and N–S directions (Ratschbacher et al., 1993; Kováč et al., 1995; Jacko and Janočko, 2003). The paleostress field, associated with fold deformations and overthrusts, induced gradual disintegration of the Central-Carpathian Paleogene Basin at the frontal part of the leading plate. Divergent regime in dextral transpressional zone of the Klippen Belt caused opening of the Čelovce Depression (Jacko and Janočko, 2003) in the Eggenburgian. To the end of Ottnangian we assume reactivation of dextral shears along the boundary of Pieniny Klippen Belt and Central Western Carpathians which enabled counter clockwise rotation of the microplate (Fig. II.3) and coevally opening Karpatian sedimentary area of the East Slovakian Basin (Kováč et al., 1995; Kováč and Márton, 1998; Jacko and Janočko, 2003).

Evolution of Neogene sedimentary basins during the Karpatian and Early Badenian

Collisional tectonics of escaping Western Carpathian orogene generated in the western part of the Western Carpathians sinistral NE–SW horizontal strike-slips at the end of Early and beginning of Middle Miocene. The strike-slips compensated halt of the Eastern Alps movement. In the eastern part of the Carpathian orogene dextral NW–SE strike-

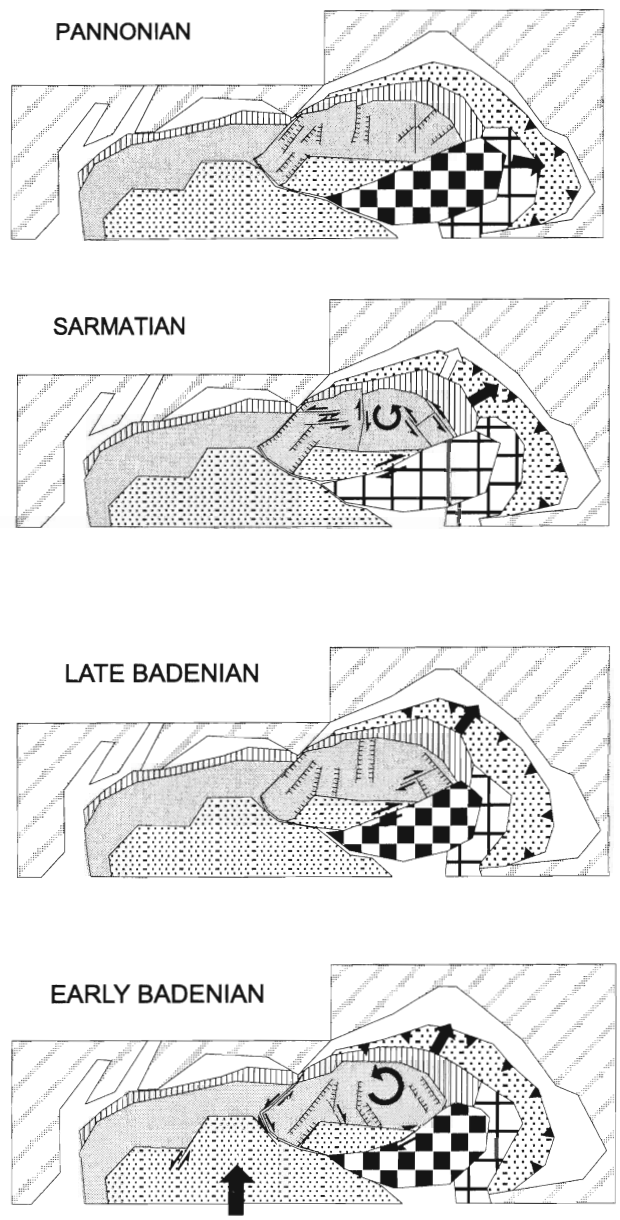


Fig. II.4. Palinspastic scheme of structural evolution of Western Carpathian Neogene basins (Lower and Upper Badenian, Sarmatian and Pannonian) in dependence on orogene evolution, complemented by structural record in recent position. Explanations as in Fig. II.2.

-slips were activated (Fig. II.3). The uplift of Western Carpathians at the end of Karpatian and at the beginning of Early Badenian, that is recorded in the most Western Carpathian basins by extensive erosion and conspicuous angular unconformity, may be considered as a demonstration of culminating compressional regime at that time.

Sedimentary basins at the boundary between Early and Middle Miocene originated in transtensional regime along transform boundaries and in extensional regime of initial back-arc rift stage. The most important are pull-apart basins formed in the area of Vienna Basin at the west and in the area of the East Slovakian Basin at the east. The ascent of asthenospheric mantle was accompanied by graben formations mainly in the South Slovakian–North Hungarian realm.

Evolution of paleostress field during the Karpatian and Early Badenian and its structural record in Western Carpathians

Collision of the Alps with the North European Platform activated ENE–WSW and NE–SW sinistral strike-slips in the area of Eastern Alps. The strike-slips followed tectonic lines Salzachtal – Ennstal and Mur – Murz – Leitha. At the boundary of the Alps and Carpathians the pull-apart Vienna Basin opened in this sinistral shear zone (Royden, 1985, 1988; Fodor, 1995; Kováč et al., 1997a, b).

Similar transtensional regime caused opening of the central part of Danube Basin located east of Vienna Basin. From this area 300–500 m thick subaerial deposits of the Karpatian and Early Badenian age are described (Kováč et al., 1997a; Hrušecký et al., 1998). Marine transgression reached central part of the present Danube Basin as soon as Middle Badenian.

In the area of Transdanubian Mts. the older Karpatian ductile deformations is manifested by normal NW–SE faults generated in paleostress field with NE–SW extension. The extensional amplitude of Danube Basin in similar direction is assumed to be some 80 km (Tari and Horváth, 1995). Since Early Badenian the basin subsidence was influenced by N–S and NNE–SSW normal and listric faults. The stretching induced structural uproofing of the lowermost elements of the East-Alpine fundament at its western margin (Tari et al., 1992; Horváth, 1993).

In the western part of Western Carpathians older extensional phase with predominant NE–SW extension has been recorded. The extension controlled evolution of Bánovce and Hornonitrianska kotlina Depressions (Kováč et al., 1993b; Hók et al., 1995). The Karpatian deposits are up to 500 m thick and they represent a remnant of extensive marine sedimentary area extending from the present Vienna Basin as far as present Novohrad–Nógrad Basin. The termination of marine sedimentation in the Early Badenian was controlled by compressional regime related to the counter clockwise rotation of ALCAPA microplate (Kováč and Márton, 1998). The NW–SE dextral shears opened at the same time sedimentary area of Želiezovce Depression at recent eastern margin of the Danube Basin (Fig. II.4).

In the South Slovakian–North Hungarian Basin the Karpatian subsidence was controlled by NW–SE normal faults (Vass et al., 1993). Maximum thickness of the Karpatian deposits attains 600–700 m.

Similar extension has been also documented from the East Slovakian Basin where NNE–SSW compression at the beginning of Karpatian was changed by NE–SW oriented extension at the end of Karpatian and in Early Badenian (Kováč et al., 1994; Kováč et al., 1995). Extensional regime induced structural unroofing of units belonging to deep basement of present basin and exhumation of Iňačevo–Kritchevo Unit (Soták et al., 1993, 1994). At the beginning of Karpatian NW–SE dextral strike-slips were activated (compensating counter clockwise rotation of ALCAPA microplate) which in Karpatian and Early Badenian changed mainly to listric faults (Fig. II.4). During the tectonically controlled subsidence of the East Slovakian basin more than 2000 m of shallow-water sediments were deposited (Vass and Čverčko, 1985).

Development of Neogene sedimentary basins during Badenian and Sarmatian

The Middle Miocene development of the Western Carpathian orogene and adjacent northern part of the Pannonian back-arc basin were significantly influenced by two most important geodynamic factors. In the western part of orogene the decay of collision resulted in termination of formation of the western (Moravian) segment of Carpathian accretionary prism. Breakaway of submerging plate resulted in uplift and termination of sedimentation in the Western Carpathian foredeep. In the back-arc basin the extension above the ascending asthenospheric mantle was strikingly expressed (Konečný et al., 2002).

The Badenian and Sarmatian time was also characteristic by evolution of intensive acid and calc-alkaline volcanism. While in the western and central part it had mixed character suggesting origin from asthenospheric mantle affected by previous subduction, in the eastern part it unambiguously points to affinity to subduction process – it was the arc-type volcanism (Lexa et al., 1993; Konečný et al., 2002.)

During Middle Miocene the important paleogeographic changes occurred. The uplift of the northern part of orogene is well recorded by directional change of marine transgression which started to advance from south northward in contrast to Early Miocene when transgression advanced mainly from north southward. Another important paleogeographic phenomenon was the development of deltaic systems in the Vienna, Danube and East Slovakian Basins directed toward the back-arc area.

Sedimentary basins during Middle Miocene originated in the extensional regime along normal faults that partly were of the strike-slip type. In the western part NE–SW faults dominated. In the central part of the region N–S faults occurred while in the eastern part NW–SE faults predominated (Fig. II.4). Active elongation of the orogene at the end of Badenian and Sarmatian (Fig. II.4) was in

the western and northern part of the orogene manifested by activation of sinistral NNE–SSW strike-slip faults (Kováč, 2000). In the eastern part of the orogene it resulted in conjugated system of NE–SW dextral and NW–SE sinistral shears and E–W and ENE–WSW normal faults (Vass et al., 2000; Jacko, 2002). The synrift stage of basins evolution is characterized by graben- and half-graben-type depocentres and rarely by pull-apart-type depocentres.

The uplift of Western Carpathians at the end of Sarmatian, which is recorded by erosion in sedimentary successions and also by unconformity of the overlying Pannonian deposits, may be considered as evidence of the last phase of compressional regime at the front of orogene.

Paleostress field evolution in the Badenian and Sarmatian and its structural record in the Western Carpathians

Subsidence of depocentres of the Pannonian back-arc basins related to synrift stage continued in the Vienna and Danube Basins in the western part of Western Carpathians and in the East Slovakian Basin in their eastern part. The basin evolution was controlled by extensional tectonic regime (Kováč et al., 1995, 1997b).

Formation of the Vienna and Danube Basins was accompanied by striking change of tectonic style and structural characteristic of faults (Fig. II.3). Besides normal faults (Vienna Basin), also NNE–SSW and NE–SW listric faults frequently with character of sinistral oblique strike-slips (Danube Basin) began to predominate. The ENE–WSW faults at the northern margin of the basins show distinctive characteristic of sinistral strike-slips (e. g. Farský or Senica fault systems, Dobrá Voda or Ripňany fault belt etc.). Their activation in the Sarmatian is related to the elongation of the Western Carpathian region under the influence of subduction at the front of the Eastern Carpathians (Csontos and Horváth, 1995).

The back-arc extension above the ascending asthenospheric mantle caused in its marginal parts the structural unroofing of core complexes. This process is documented in the west by uplift and erosion of the Penninicum Units in Rechnitz window (which already started in the Early Miocene; Dunkl, 1992; Dunkl and Demény, 1997) and in Považský Inovec Mts. (Plašienka, 1995).

The Vienna and Danube Basins were formed in the paleostress field with NW–SE extensional component (Fodor, 1995; Tari and Horváth, 1995). The thickness of the Badenian and Sarmatian synrift fill varies from 1000 to 3000 m in both basins (Horváth, 1995; Kováč et al., 1997b). The NW–SE extension of depocentres in the Danube Basin is estimated to some 40 km (Tari and Horváth, 1995).

Intramountain basins of Central Western Carpathians, filled by 500–1000 m thick volcanosedimentary complexes, show subsidence in rotating paleostress field from NE–SW direction of extensional component in Early Badenian into NE–SW direction during the Sarmatian (Hók et al., 1995). The NW–SE extension is also documented from uplifted southern slopes of Central Western Carpathians in Novograd area (Vass et al., 1993). This is consistent with similar paleostress direction in the Bükk Mts. where orientation of the main compressional component is NE–SW (Csontos et al., 1991).

Evolution of the paleostress direction in the East Slovakian Basin was dependent on development of both the back-arc area and the Carpathian accretionary wedge. The Late Badenian NE–SW extension changed during the Early Sarmatian. The structural development of the basin since the Middle Sarmatian was characterized by paleostress field with the main E–W compression (Kováč et al., 1994, 1995) suggesting N–S extension which rotated during Late Sarmatian into NW–SE direction at the Sarmatian–Pannonian boundary (Jacko, 2002).

During Late Badenian and Sarmatian more than 4000 m shallow-marine and deltaic sediments were deposited in the East Slovakian Basin (Vass and Čverčko, 1985). At that time mainly normal NW–SE faults were activated which created new sedimentary space in the Late Badenian and Early Sarmatian basin. The dextral NE–SW and NNE–SSW strike-slips controlled evolution of its depocentres (Fig. II.4). After onset of the main E–W compression (extension N–S) the conjugated shear faults were activated. The dextral NE–SW and sinistral NW–SE strike-slips clearly compensated decelerated motion of the Western Carpathian orogene at the terminal subduction stage at the front of Western Carpathians (break-up of the submerging plate at the boundary of Western and Eastern Carpathians). The NE–SW normal faults and N–S dextral strike-slips active as long as Pannonian are related to the counterclockwise rotation of the area at that time (Fig. II.4).

Evolution of the Neogene sedimentary basins during the Late Miocene and Pliocene

One of the main geodynamic factors influencing the development of the Carpathian–Pannonian region during Late Miocene was the retreat of subduction into southeastern part of the foreland of the Carpathian belt connected with the split of the northern part of the submerging plate (Wortel and Spakmann, 1992; Tomek and Hall, 1993). This tectonic event also evidently initiated "new rifting phase" in the intra-Pannonian area in Early Pannonian (Lankreijer, 1998; Kováč, 2000). This phase was followed by thermal subsidence of the postrift evolutionary stage of the Pannonian back-arc basin (Fig. II.4).

The Late Miocene compressional and thrust tectonics is only known from the accretionary prism of the Eastern and Southern Carpathians. On the flexure of the platform occurring at the front of the Eastern Carpathian thrust front 1000–2000 m thick Pannonian and Pontian molasse sediments were deposited (Dicea, 1996).

Onset of thermal subsidence accompanied by extension above the ascending asthenospheric mantle at the beginnig of the Pannonian was related to the renewal of tectonic activity in the back-arc basin (so called wide rifting) at that time.

The Late Miocene sedimentary basins originated in extensional regime along normal faults. These faults only seldom had a character of oblique strike-slips. The post-rift stage of the basins evolution is characterized by restricted fault activity except basins margins. In the western part of the Western Carpathians NE–SW and N–S faults dominated. In the central part of the region N–S and in the eastern part NE–SW and N–S faults predominated (Fig. II.4). Sedimentary successions are conformable and only smaller depocentres show features of grabens and halfgrabens (e. g. Turiec Depression). The uplift of the Western Carpathian area in Pliocene is recorded in the sediments by erosion and angular unconformity in relation to the youngest deposits.

In Pliocene the central part of the orogene is uplifted, which is accompanied by the tectonic inversion of the northern margin of the largest Neogene basins of the Western Carpathians. The youngest stress field, resembling the recent one (Kováč et al., 2002), is essentially characterized by direction of the main compression perpendicular to the Outer Western Carpathian arc (NW–SE and N–S). While in the areas of Outer Carpathians and Klippen Belt the prevailing tectonic regime is transtensional, in the area of Central Western Carpathians the youngest NE–SW and E–W extension was documented by surface structural measurements (Vojtko et al., 2001; Jacko, 2002).

Evolution of paleostress field during the Late Miocene and Pliocene and its structural record in the Western Carpathians

The Late Miocene evolution of the Pannonian back-arc basin commenced by partial tectonic inversion of relief resulting in shallowing and uplift of its central part at the Sarmatian–Pannonian boundary. The Early Pannonian rifting enabled transgression of brackish waters into most of the Western Carpathian basins and was later replaced by thermal subsidence of postrift evolutionary stage (Horváth, 1993; Csontos and Horváth, 1995; Meulenkamp et al., 1996; Lankreijer, 1998).

The subsidence of the back-arc basin depocentres was controlled by sinistral transtensional zones and main listric decoulements which reached as deep as fundament. At the most of the area paleostress field with NW–SE extension predominated (Csontos et al., 1991; Csontos and Horváth, 1995).

The deposition in the western part of the Inner Carpathian region, in the Vienna and Danube Basins, was still controlled by paleostress field with NW–SE extension which mainly activated NE–SW and NNE–SSW normal faults at the basin margins (Fodor et al., 1995; Fodor, 1995; Hrušecký et al., 1996; Kováč et al., 1997b). Maximum subsidence is known from the Gabčíkovo and Komjatice Depressions of the Danube Basin where thickness of the lacustrine and deltaic sediments of the Pannonan brackish lake attains about 2000 m in the central part (Tanacs and Radich, 1991; Mattic et al., 1996; Kováč et al., 1997a, b).

In the eastern part of the Inner Carpathian region the compression, which caused deformation of the Pannonian sediments in the East Slovakian Basin, is characterized by NE–SW paleostress field (Kováč et al., 1995). The subsidence was controlled by NW–SE extension (Jacko, 2002).

The reactivation of horizontal strike-slips, compensating extension of the Pannonian back-arc area, is reflected by one of the most important zones with ENE–WSW sinistral strike-slips at that time – the Middle Hungarian lineament along which several Pannonian depocentres were opened between Kiskun Basin in the west and Derecke Basin in the east. The extension in the central part of this zone resulted in subsidence of depocentres of the Zagyva, Jászág and Hernád Basins restricted by N–S faults. In the Jászág basin, for example, the thickness of deltaic sediments is about 2000 m (Juhász, 1991).

Based on current data, above all from the Hungarian territory, the Late Miocene extension of the back-arc basin was punctuated by local (regional?) compressional events (Horváth and Cloething, 1996; Kováč, 2000) which may be assumed as onset of tectonic inversion of the Pannonian back-arc basin (Fig. II.4).

Tectonic inversion of the western part oif the Pannonian bac,-arc basin is documented by compressional events occurring since Late Miocene with maximum expression in Pliocene. During Pannonian and Pontian NW–SE and N–S compression was recorded (Csontos, 1995). The compression resulted in the thrusts and large-scale folds in the NE–SW and E–W direction in the area of Sava folds south of the Mecsek Mts., at the southern margin of the Transdanubian Mts. and in the area of the Hungarian lineament (Csontos et al., 1991; Csontos and Horváth, 1995). Similar phenomenon is also known from the middle part of the Western Carpathians where recorded paleostress field rotation indicates rotation of the main compressional component from NE–SW direction into N–S and NW–SE direction between Upper Pannonian and Pontian (Hók et al., 1995). The mentioned orientations of the youngest, Late Miocene–Pliocene compression in the Carpathian–Pannonian area strongly resemble the recent – Quaternary paleostress field of the Inner Carpathian and Pannonian regions, which is in the stage of tectonic inversion (Horváth and Cloething, 1996; Kováč et al., 2002).

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III. SEDIMENTARY EVOLUTION OF WESTERN CARPATHIAN TERTIARY BASINS

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III.1 Evolution of sedimentary areas of the eastern part of Outer Western Carpathians

Tectono-sedimentary evolution of basins, which comprise deposits forming the accretionary prism of the Outer Western Carpathians, reflects complicated tectonic processes in the Carpathians and at the southern margin of the North European Platform. These processes included the initial rift stages developing further into the postrift stage, convergence and subsequent collision of the Carpathian orogene with the North-European Platform. The complex tectonic evolution is partly preserved in sedimentary record of individual tectonostratigraphic units of the Outer Western Carpathians.

The area of the Flysch Belt of the Outer Western Carpathians in Eastern Slovakia, the main objective of our study, consists of Magura and Dukla geological units (Fig. III.1). The Dukla Unit as an individual structural

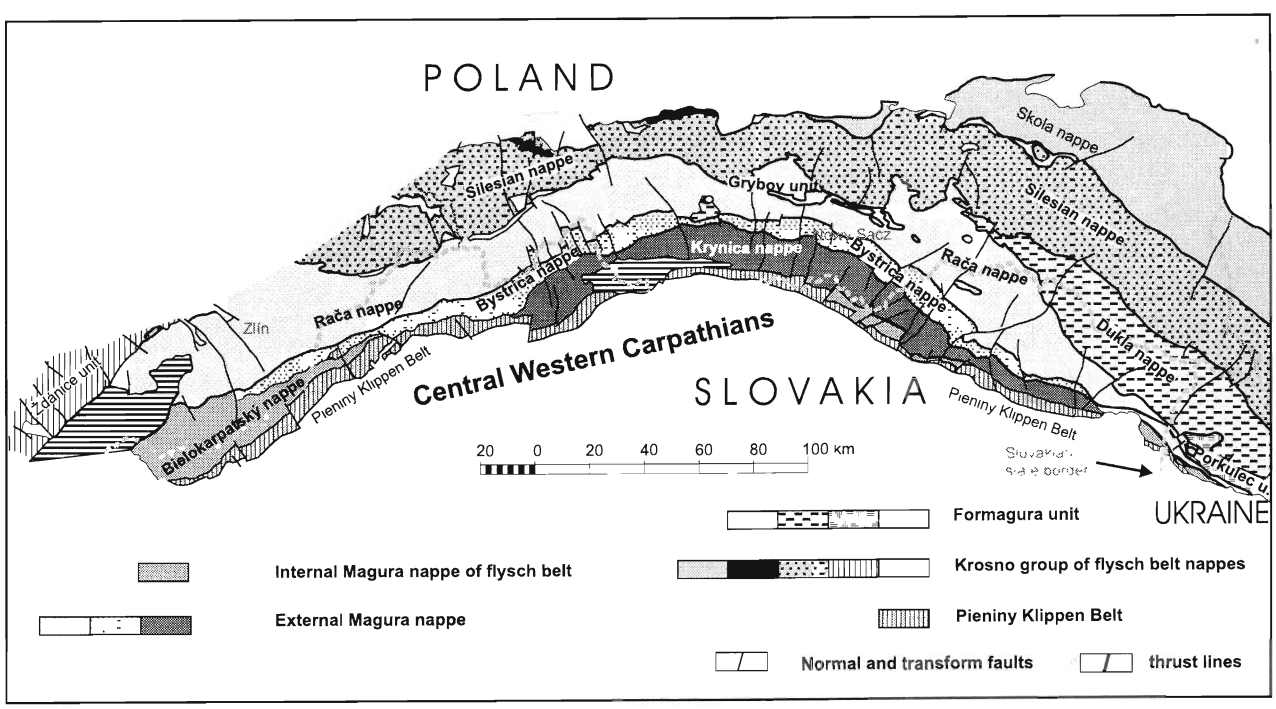


Fig. III.1. Structural scheme of Outer Western Carpathians and Pieniny Klippen Belt (after Lexa et al., 2000, modified).

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zone of the Outer Western Carpathians emerges south of Zmigrod in Poland and continues southeastward across Slovakian and Polish territories as far as Ukraine Carpathians (Koráb and Ďurkovič, 1978). The Dukla Unit occupies the northeastern part of Eastern Slovakia. To the north and east it crosses over to Poland and Ukraine. In the south it is limited by the thrust plane of the Magura nappe trending from the NW margin of Miková across Sukov, Zbudská Belá, Kalná Ráztoka, Ubľa and Slovak-Ukraine border.

Magura Unit lies south of the Dukla Unit and is the most extensive Outer Western Carpathian unit in Eastern Slovakia. The sediments of the Dukla Unit are older, containing the Lupkov Formation with sedimentation beginning in Cenomanian. The unit is divided into Lupkov, Cisna, Submenilite, Menilite and Cergow Formations.

The sediments of the Magura Unit, which comprise Krynica (Čerchov, Udava, Kochanovská), Bystrica and Rača tectono-stratigraphic units, were deposited in the period of Late Cretaceous to Oligocene. The lithological composition in partial Magura units is slightly different as a result of lateral changes, however, the general features of sediments are often similar. In the Eastern Slovakia the Krynica Unit consists of Beloveža and Strihovce Formations, Globigerina Marls and Malcov Formation with Menilite Member. The Bystrica Unit consists of Inoceramus Formation (Potfaj and Nemčok in Biely et al., 1996), Beloveža and Bystrica Formations, Lackov and Globigerina Marls. The whole succession is capped by Malcov Formation. The Rača Unit is composed of Inoceramus Formation overlain by Beloveža Formation, which passes into Zlín Formation with Makovice Sandstone, Globigerina Marls and Malcov Formation.

Beloveža Formation

The formation was originally defined by C. Paul in 1869 as formation consisting of bluish-green and red shales and hieroglyphs sandstones with prints of unknown origin. Matějka and Zelenka (1932) redefined the formation as a complex of variegated (red and green) shales with sandstone layers developed beneath the Zlín Formation. Stratigraphic range of the formation, yielded by foraminifers, is the Late Paleocene to the Middle Eocene with maximum deposition in Early Eocene.

The Beloveža Formation, typical by alternation of thin beds of sandstones and mudstones and variegated shales, occurs in the entire area of the Carpathian arc in the Magura tectono-stratigraphic unit. In the Eastern Slovakia it is developed in the Rača, Bystrica and Krynica units. In the Bystrica Unit the formation is subdivided by some authors (e. g. Stráník, 1967) into lower part, characteristic by variegated claystones, and upper part with prevailing alternation of thin beds of sandstones and mudstones. Nemčok (Nemčok, 1980; Nemčok et al., 1990) described beneath the formation so-called Tvarožec Sandstone, however, our research showed that this sandstone is a part of stratigraphically higher unit marked as Makovice Sandstone. The sandstones, thick up to 1000 m, are massive and are arranged in thick, often amalgamated beds. Thick beds of these sandstones occur in the surroundings of Dubinné village. The deposits in the quarry near Dubinné consist of alternating sandstones and mudstones. The beds thickness varies from several centimetres up to 1 m. The sandstones are fine- and medium grained, massive and sharply- and scour-based. The flute casts show paleoflow direction from south to north.

Strihovce Formation

The Strihovce Formation is characterized by prevailingly coarse-grained deposits predominantly consisting of sandstone and microconglomerate beds thick up to 6 m (Photo 1). Pelites have only minor occurrence and usually form thin, discontinuous layers separating sandstone beds. The mostly yellowish sand is often friable and contains large spheric calcareous concretions. The formation is typical by submarine slump bodies consisting of gray and grayish-green claystones, grayish-green and red marlstones belonging to Klippen Belt and massive crinoid limestones.

The lithofacial analysis suggest deposition of the formation during the fall of relative sea level on submarine slope. Typical outcrops of the deposits are located east of Humenné. The exposed deposits are represented by poorly-sorted, coarse-grained sandstones with scattered pebbles and by conglomerates. The sandstone and conglomerate beds are occasionally separated by thin, laterally discontinuous mudstone layers. The base of sandstone and conglomerate beds is sharp and erosive. The friable, often synsedimentary deformed sandstones contain large blocks of carbonates and to a lesser amount the crystalline rocks.

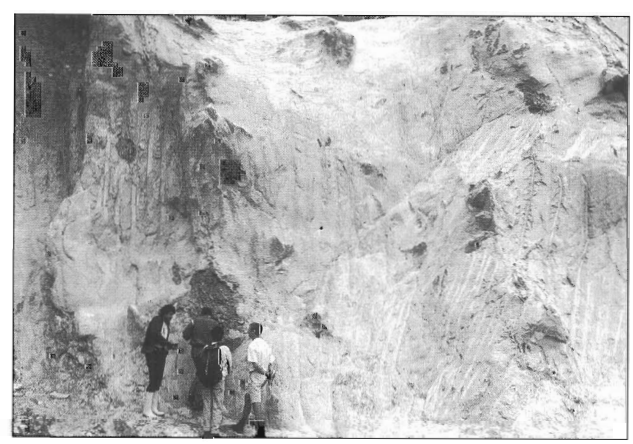


Photo 1. Strihov Sandstone near Modrá nad Cirochou village. Typical there are the friable sandstone and large intraclasts.

Makovice Sandstone

The Makovice Sandstone, defined by Nemčok (1961), is mainly extended in the northwestern part of the Ondavská vrchovina Upland. Stráník (1967) describes the unit



Photo 2. Thick bedded Makovice sandstone near Drienica village

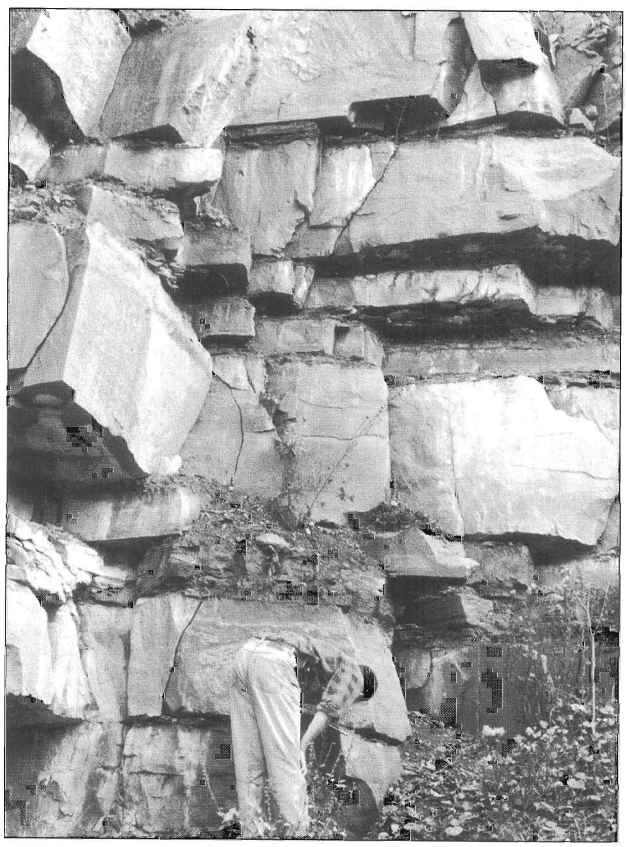


Photo 3. Thick bedded Makovice (Zborov) sandstone near Zborov village

as Zborov Member or Lower Zlín Formation. According to this author (Pesl, 1968; Stráník, 1965) the formation is one of the main diagnostic features for restriction of the inner part of the partial Rača tectono-stratigraphic unit.

The Makovice Sandstone represents alternating thick and medium-thick bedded sandstones and mudstones with striking predominance of sandstones. It gradually evolves from the Beloveža Formation and eastward and southeastward passes laterally into lower part of the Zlín Formation (e. g. Leško and Samuel, 1968).

The sediments of Makovice Formation are well exposed south of Svidník (Photos 2 and 3). The prevailing lithofacies is represented by massive, medium-grained, sharply- and scour-based sandstones. The beds, which are often amalgamated, are thick from several centimetres to 1.5 m. Occasionally, the sandstones are normally-graded and ripple-cross laminated. Rare are Bouma's $T_{a.b.c}$ intervals. The flute casts at the base of sandstone beds indicate paleotransport from south toward north. The overall bed thickness trend in the studied 40 m high exposure is thickening-upward.

The described sediments are interpreted as channel-lobe transition deposits. The upward thickening trend of sandstone beds suggests the increasing supply of sediments into the system as a result of relative sea level fall.

The Makovice Formation is almost bare of fauna. For this reason the position of the formation is only defined at the base of overlying the Zlín Formation and underlying the Beloveža Formation. The Makovice Sandstone partially interfingers with these formations. Based on this we assume prevailing the Middle Eocene age and partially also the Late Eocene age of the Makovice Sandstone.

Zlín Formation

The formation was defined by Zapletal (1937) as shales and fine-grained sandstones in the Magura Unit of Western Carpathians and redefined by Matějka and Roth in 1949. Pesl (1968) subdivided several lithostratigraphic units in the formation occurring in the western part of the Magura Unit. In the Eastern Slovakia the lower Zlín Formation (Matějka and Stráník, 1961; Matějka, 1964) or Zlín Sandy Member (Matějka et al., 1964) are analogous to Makovice (Zborov) Sandstone.

Stratigraphic range of the Zlín Formation is from the upper part of the Middle Eocene up to the Late Eocene.

Globigerina Marls

The horizon of the Globigerina Marls represents an important correlation horizon occurring in the entire Outer Western Carpathian zone. The sediments are mostly represented by red marls underlying Malcov Formation in Magura Unit or, in the zone of Klippen Belt Paleogene formations, by green, grayish-green marls underlying menilite-type shales.

Malcov Formation

Malcov Formation is developed in the Magura Unit of the Eastern Slovakia. Similar formation was described in the Central Carpathian Paleogene Basin as Šariš Member (Leško, 1960).

In the lower part of the formation intercalations of menilite shales and conglomerates were observed. In the middle part volcanic tuffs and sediments resembling Tylawa Limestones occur.

Well-exposed sediments of the Malcov Formation south of Okrúhle village (Photo 4) show black-gray and black,

massive and occasionally parallelly laminated shales alternating with thin beds of massive, parallelly and ripple-cross laminated fine-grained sandstones. Rarely medium- and coarse-grained sandstones with erosive base appear. The thickness of these sandstones is up to 3 m.

The Malcov Formation represents the youngest complex in the succession of the Magura Unit. The foraminifera analyses yielded Late Priabonian–Early Oligocene age. However, the recent research also suggests the Late Oligocene age.

Dukla Unit

Dukla Unit, as the individual structural unit, is extended in the northeastern part of the Eastern Slovakian Outer Western Carpathians (Fig. III.1).

The oldest sediments of the Dukla Unit on the Slovakian territory are assigned to the Lupkov Formation (Leško, 1960). They are characterized by occurrence of hard claystones and fine-grained sandstones of Cenomanian and Early Paleocene age. The formation gradually passes into the Cisna Formation being typical by thicker sandstone beds. The Cisna Formation consists of alternating mudstone beds with thick sandstone beds. The age of the formation is Santonian – Early Eocene. In the upper part of the formation thin-bedded sandstones alternating with thicker beds of mudstones appear.

The Cisna Formation is overlain by Submenilite Formation comprising thick flysch complex in the Dukla Unit. The complex is composed of variegated red claystones with sporadic admixture of quartzose sandstones. In the upper part of sedimentary succession the Papín Member, composed of calcareous, micaceous, parallelly and convolutely laminated fine-grained sandstones and siltstones, occurs. In the upper part of Papín Member the black claystones occur indicating transition to Menilite Formation. The age of the Submenilite Formation is Middle Eocene.

Menilite Formation consists of calcareous claystone with sporadic intercalations of sandstone and pelocarbonate lenses. The middle part of the formation is characterized by quarzose rocks. The uppermost complex of the formation is composed of dark calcareous claystones with minor occurrence of cherts. In the upper part of this interval also the calcareous claystones and sandstones occur. The age of the Menilite Formation is Late Eocene – Early Oligocene.

The uppermost formation of the Dukla Unit on the Slovakian territory is Cergov Formation. The age of this formation is Early Oligocene.

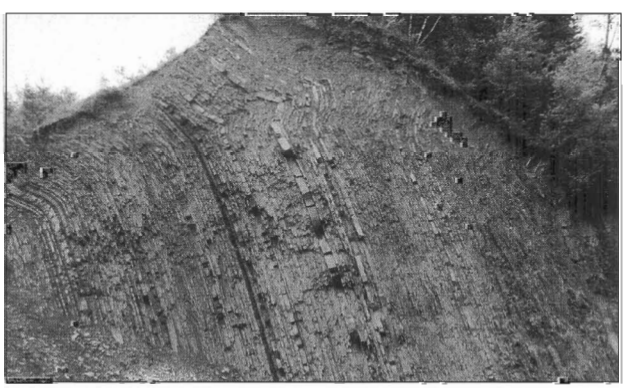


Photo 4. Alternation of thin-bedded sandstone and mudstone of Beloveža Fm. near village Dubinné.

III.2 Evolution of the Central Carpathian Paleogene Basin

Complicated tectonic evolution of the Central Carpathian Paleogene Basin (CCP Basin, Fig. III.2), eustatic fluctuation of sea level, climate changes and sediment input caused the facies complexity of basin sedimentary fill. After first basic studies concerning lithology and tectonics of the basinal sediments at the end of nineteenth and first half of twenties (e. g. Štúr, 1860; Uhlig, 1903) a systematic research, related to mapping, stratigraphy and sedimentology was launched in the second half of the last century (e. g. Andrusov, 1950; Leško, 1958; Chmelík, 1959; Pícha, 1964; Marschalko, 1965, 1970, 1980). The knowledge of the geology and tectonics of basin fill was markedly improved after drilling of deep boreholes aimed at hydrocarbon prospection and related realization of seismic investigations (e. g. Rudinec, 1981, 1984, 1989; Rudinec and Řeřicha, 1985; Kullmanová and Rudinec, 1988; Koráb, 1986; Nemčok et al., 1977; Leško et al., 1982). These works showed thick accumulation of the basin fill locally reaching more than 3 km (borehole Lipany 4).

The first comprehensive mapping of the sediments in the Central Carpathian Paleogene Basin (Chmelík, 1957, 1958, 1959, 1963) showed occurrence of four basic formations deposited from the Middle Eocene to Oligocene. The formations consist of basal, prevailingly coarse-grained deposits, clayey formation with predominating claystones and minor sandstones, sandstone–claystone formation and sandstone formation with layers of conglomerates. The subdivision of the CCP Basin fill was modified by Marschalko (e. g. Marschalko, 1962, 1965, 1966). Based on benthos foraminifers, he assigned the basin fill to the Late Eocene and Oligocene (Marschalko and Samuel, 1960). According to lithology, he subdivided the fill into basal transgressive lithofacies, clayey lithofacies and subflysch, transitional flysch, conglomerate and microconglomerate flysch, typical and atypical wild flysch.

The basal transgressive lithofacies represents according to this author one cycle unconformably overlying crystalline and Mesozoic basements. It consists of two main lithological types: basal conglomerates and breccias in the lower part and sandstones and siltstones with occasional slumps containing macrofauna of different composition when comparing with the basal parts.

The clayey lithofacies and subflysch developed gradually from the upper part of the transgressive lithofacies. It is composed of calcareous, light-blue, faintly laminated claystones (Marschalko, 1965).

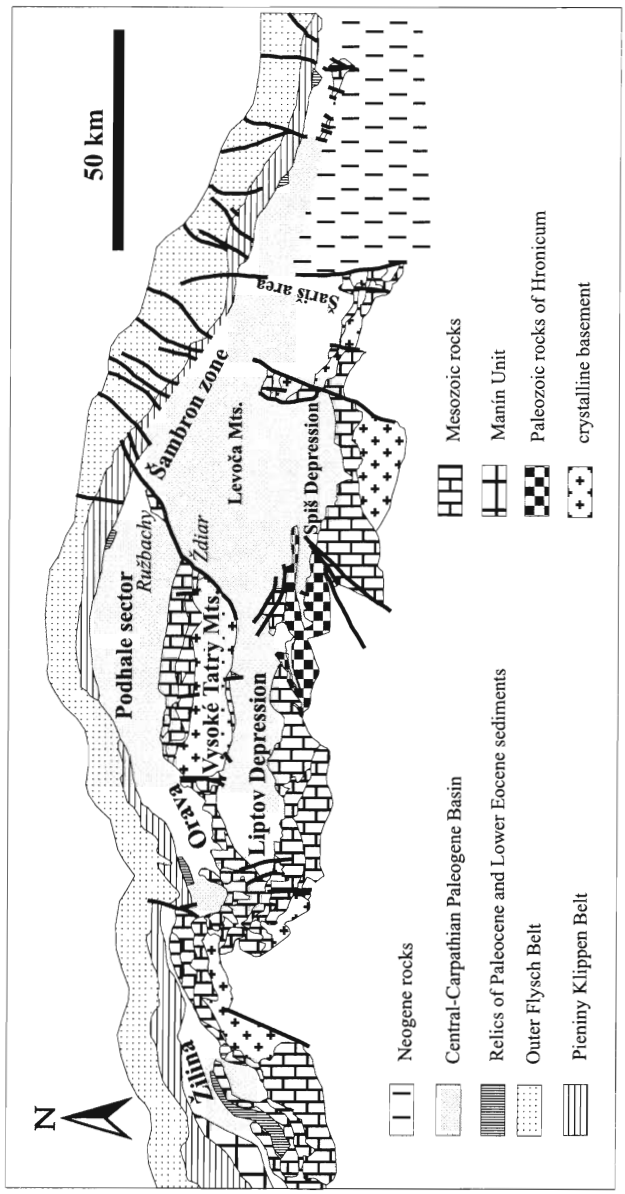


Fig. III.2. Localization of the Central-Carpathian Paleogene Basin including its individual parts.

Conglomerate and microconglomerate flysch comprises three thicker packages forming atypical wild flysch. Typical wild flysch consists of homogenous middle-grained sandstones and coarse-grained siltstones with claystone chips. It often contains gigantic slump bodies. Atypical wild flysch has less slump bodies, however, it is typical by the occurrence of numerous angular claystone clasts. The transitional flysch represents distal equivalent of wild and conglomerate flysch in the basin. It contains 75–90 % of graded sandstones (Marschalko, 1975).

The subdivision of the CCP Basin fill for mapping purposes was introduced by Gross et al. (1984). They subdivided the sedimentary fill into four formations – Borové, Huty, Zuberec and Biely Potok Formations which comprise a higher lithostratigraphic unit – Subtatric Group.

Stratigraphically, the lowermost formation of the Subtatric Group is represented by Borové Formation which contains shallow-water transgressive sediments of Middle and Late Eocene age (Gross et al., 1984). Lithologically it represents classical transgressive succession with prevailing coarse-grained sediments particularly in the lower part of the succession. The most frequent rock types are breccias, conglomerates, sandstones, sandy limestones, organodetritic and organogenic limestones which vertically and laterally alternate. The breccias and conglomerates are mostly composed of rocks from immediately underlying basement. The crystalline rocks from more distant sources have a minor occurrence. A part of Borové Formation consists of organodetritic, nummulitic limestones. However, in the eastern part of the CCP Basin the occurrence of these limestones *in situ* is rare and the limestones mostly form clasts in breccias and conglomerates. Maximum thickness of Borové Formation is about 150 m (Gross et al., 1984; Janočko et al., 2000).

The Borové Formation passes upward into the Huty Formation, consisting mainly of mudstones. The boundary between the formations is both sharp and transitional. The transitional boundary consists of either gradual fining-upward of sediments or alternation of coarser and finer sediments with gradual disappearance of coarser deposits (e. g. Olszewska and Wieczorek, 1998; Janočko, 2002).

The Huty Formation, which age was defined by Gross et al. (1984) as Late Eocene, consists of thick mudstones with thin layers of fine-grained conglomerates, sandstones or siltstones. The Huty Formation vertically passes into the Zuberec Formation of Late Eocene and Early Oligocene age. The formation is, according to the mentioned authors (Gross et al., 1984), composed of regular alternation of sandstone and mudstone beds with ratio 1:1, 1:2 and 2:1. Maximum thickness of the formation is assumed to be 1200 m. The uppermost formation of the Subtatric Group is the Biely Potok Formation mostly consisting of sandstones. The formation also contains minor mudstones and conglomerates. The thickness of the formation is recently assumed to be 700 m (Gross et al., 1996).

The above mentioned authors (Gross et al., 1984) also defined the Pucov Member. The polymict conglomerates, also containing Paleogene intraclasts, were defined as canyon-fill deposits belonging to submarine fans. The age of the Pucov Member was defined as Middle Eocene – Oligocene.

More detailed research of the CCP Basin required subdivision of further lower lithostratigraphic units. In 1996 the Tomášovce Member was defined in the eastern part of the basin (Filo and Siráňová, 1996). It is represented by up to 150 m thick complex of fine-grained sandstones and siltstones with pyrite concretions, molluscs, plant remnants and frequent coatings of Fe and Mn oxides. The Tomášovce Member represents shallow-marine sediments probably of Late Priabonian age.

The Hornád and Chrast' Members were defined by Filo and Siráňová in 1998. The Hornád Member consists of alternating pebble, cobble and bouldery conglomerates, coarse- and medium-grained sandstones with layers of breccias

and carbonate conglomerates, fine-grained sandstones, siltstones and sandy claystones. According to Filo and Siráňová (1998) the ?Paleocene–Late Eocene member represents pre-transgressive, mainly fluvial sediments thick up to 200 m.

The Chrasť Member (Filo and Siráňová, 1998) consists of a complex of coarse-, medium- and fine-grained sandstones with scattered clasts and cross-lamination. The sandstones contain lenses of conglomerates. They also contain a horizon of bouldery carbonate breccias (Vítkovce Breccias). They represent sediments of alluvial fan and deltas (with prevailing fluvial activity?). Maximum thickness of these Upper Eocene sediments is about 100 m (Filo and Siráňová, 1998).

The Kežmarok Member, defined by Gross (1998), represents up to 130 m thick sedimentary succession which caps the Zuberec Formation. The member is represented by alternation of thick sandstone beds and claystones. According to the author it represents transitional beds between the Zuberec and Biely Potok Formations. Stratigraphically, it is assigned to the Oligocene.

Often discussed bed succession, which is a part of the CCP Basin fill, is represented by Šambron Member. The member occurs in so called "Hromoš–Šambron Ridge" (e. g. Chmelík, 1958; Buday et al., 1967; Marschalko, 1975; Nemčok et al., 1990). Ďurkovič (Ďurkovič et al., 1995, in Gross et al., 1996) defines the Šambron Member as Early Oligocene coarse-clastic proximal facies developed within the Huty Formation. According to this definition a characteristic feature of the Šambron Member is the occurrence of several decimetres to maximum ten metres thick layers of polymict conglomerates with characteristic intraclasts. These layers alternate with claystones or "flysch" deposits suggesting their intraformational character (Ďurkovič in Gross et al., 1996).

A comprehensive characteristic of the CCP Basin fill was provided by studies aimed at basin fill genesis, sedimentological, tectonic and sequence-stratigraphic characteristics. The first modern sedimentological studies from the eastern part of the CCP Basin were published by Marschalko (e. g. Marschalko, 1961, 1962, 1965, 1966, 1975, 1978). He suggests existence of longitudinal, deep-water turbidite system in the basin with some laterally entering systems. He also analyzed marginal deposits of the basin and explained genesis of these deposits.

Depositional systems of the basin

In the CCP Basin fill we can recognize several depositional systems, which are tied to particular position in the basin and time period of its evolution. In the eastern part of the basin we can recognize subaerial depositional systems and deltaic systems representing transition between mainland and sea, as well as marine depositional systems developed on shelf, submarine slope and in deep-water areas. Development of these systems depended on several factors among which the most important are tectonics including convergence between the North-European Platform and Carpathian-Pannonian block, eustatic fluctuation of sea level and climatic conditions.

Tectonic activity induced formation of individual depocentres – subbasins, their migration in time and space, water circulation and development of intra and extrabasinal sources. The synsedimentary tectonics significantly participated in spatial distribution of sediments and their thickness. It controlled size of source areas and depending amount of sediments supplied to the basin.

Eustatic sea level fluctuation conspicuously influenced the size of accommodation space what affected depositional environment, thickness of sedimentary accumulations and erosion intensity.

Climatic conditions controlled intensity of weathering processes and subsequent amount for sediments delivered into basin as well as conditions of fauna and flora development in the basin, which in some stages represented an important part of geologic evolution.

Subaerial and shallow-marine depositional systems of the Central Carpathian Paleogene Basin

Gradual migration of basin depocentres southward of the Pieniny Klippen Belt caused diachronous evolution of basal formation. Based on the age of large foraminifers, the oldest sediments of the Borové Formation were stratigraphically assigned to Middle and Late Eocene (Gross et al., 1980, 1993; Filo in Mello et al., 2000; Janočko et al., 2000; Buček, 2001; Olszewska and Wieczorek, 1998). However, in the Slovakian eastern part of the basin, the Middle Eocene foraminifers were only found in the clasts or in redeposited position suggesting that the oldest sediments of the basin fill today are of Late Eocene age. *Nummulites perforatus perforatus* (Montfort), *N.* ex gr. *perforatus* (Montfort), *N. striatus* minor D'Archich et Haime, *Operculina* sp. and *Discocyclina* sp. indicating Middle Eocene–Bartonian age were found in the basal Borové Formation in the borehole Lipany-1 (Leško et al., 1982) and they were also described from the basal formation occurring near Jasenovo nearby Humenné (Buček, 2001) and from the borehole PU-1 (Váňová in Nemčok et al., 1977). Similar assemblages of large foraminifers were found at several localities in the area of the Šambron zone or at localities adjacent to this zone: Jakubovany, Šarišské Dravce (Váňová and Nemčok, 1977 fide Buček, 2001), Kamenica and boreholes Lipany-6 (Buček, 2001) and Šariš-1 (Koráb, 1986). This data strongly suggests the Middle- and Late Eocene transgression in the vicinity of the Pieniny Klippen Belt in the entire eastern part of the CCP Basin. In the area north or northeastward of the Subtatric-Ružbachy fault the redeposited Middle Eocene and Late Eocene nummulites occur even several tens of kilometres south of the Pieniny Klippen Belt: in the area of Ružbachy Mesozoic (elevation point Kýčera, Nemčok and Váňová, 1977), and at northern slopes of the Tatry Mts. (Bieda, 1959, 1960, 1963; Kulka, 1984, 1985; Bartholdy et al., 1999; Köhler in Janočko et al., 2000). Southeast of the Subtatric-Ružbachy fault system in the basal formation south of the Šambron–Kamenica

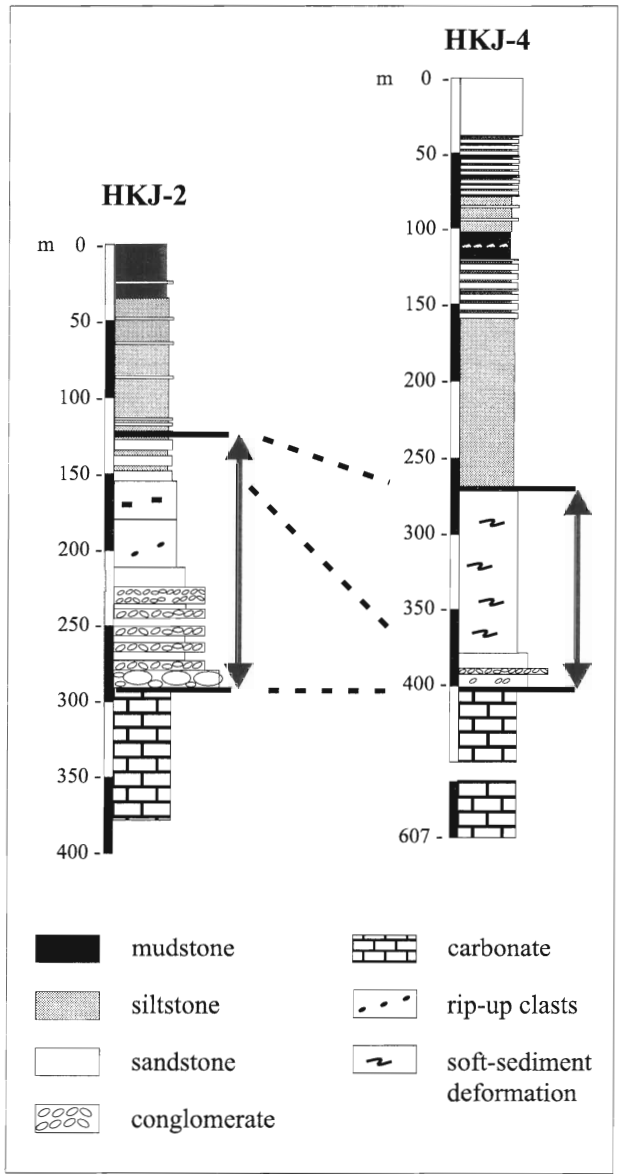


Fig. III.3. Transition between the basal sediments of Borové Formation and overlying sediments of Huty Formation of the Subtatric Group (Central-Carpathian Paleogene Basin fill) in HKJ boreholes drilled in the Hornád Depression. Note the different transition zones between the two formations.

zone (i. e. several kilometres south of the Pieniny Klippen Belt) the large foraminifers disappear. The reason may be Oligocene age of marine transgression above the boundary of large foraminifers occurrence in the Western Carpathians which is assumed to be at the Eocene–Oligocene boundary (Köhler, 1998). The Late Eocene–Early Oligocene age of the basal formation in this part of the basin is defined only indirectly by the Oligocene age of overlying deep--water sediments.

Studies of basal Borové Formation deposits from numerous boreholes and outcrops at margins of the CCP Basin showed several transition types of the sediments passing into overlying sedimentary successions. In some areas the basal, mainly coarse-clastic deposits pass into overlying sediments by gradual decrease of grain size from conglomerates and sandstones into siltstones and claystones. The uppermost parts of the basal formation have increased number of mudstone layers typical for overlying Huty Formation. This sedimentary succession is for example well-developed in the borehole HKJ-4 in the Hornád valley (Fig. III.3). The transitional part of the Borové Formation, consisting of conglomerates, sandstones and siltstones is well exposed near Štrba. The occurrence of Bryozoa in these sediments suggests about 150 m depth during deposition.

The best example of the margin evolution of the CCP Basin may be observed along the southern margin of the basin between Hrabušice and Margecany (Fig. III.4), where subaerial depositional systems developed during Eocene and Oligocene. The sediments were after transgression covered by shallow-marine and later also by deep-marine sediments.

The subaerial depositional system consists of fluvial, alluvial fan and also fan deltaic subsystems. Rivers delivered into the basin sediments from distant sources. At the foothill of cliff and mountain slope deposits (colluvium) and alluvial fans were formed. If the alluvial fans were close to the shore line, they entered the sea resulting in fan delta formation. When sediments reached the sea, they were reworked by longshore currents and waves and redistributed on inner- and outer shelf. Relatively fast lateral transition of shallow-marine sediments into deep--marine sediments suggests occurrence of a narrow shelf passing into the submarine slope or steeply inclined ramp as suggested by Wieczorek (1989).

The best example of the fluvial system occurs in the area of Markušovce, south of Spišská Nová Ves. At this locality it is possible to identify a southwest–northeast trending paleovalley (Baráth and Kováč, 1995; Janočko and Soták, 2001; Janočko, 2002). The valley had most probably polyphase evolution and reflected variable tectonic activity and climatic conditions affecting depositional processes. The valley fill consists of coarse-grained sediments with variable thickness depending on relief of pre-Tertiary basement. Numerous boreholes related to kaolinite prospection (Rényi et al., 1987) show that the thickness of valley fill increases southeastward from 20–30 m to 120 m near Markušovce. Lateral correlation of individual beds clearly indicates that the change of the valley fill thickness reflects original morphology of the valley and is not a result of postsedimentary differentiated erosion.

The valley fill sediments consist of polymict conglomerates composed of phyllites, metarhyolites, metatuffs, metasandstones, quartz and minor carbonates. However, some layers in the fill are exclusively composed of carbonate conglomerates. The size of clasts varies from pebble to boulder size. In conglomerates the intercalations of sandstones and siltstones occasionally occur. Interesting are layers of ochreous-brown kaolinic rocks comprising beds thick up to 50 cm. X-ray analysis of these sediments suggested their origin by weathering of crystalline

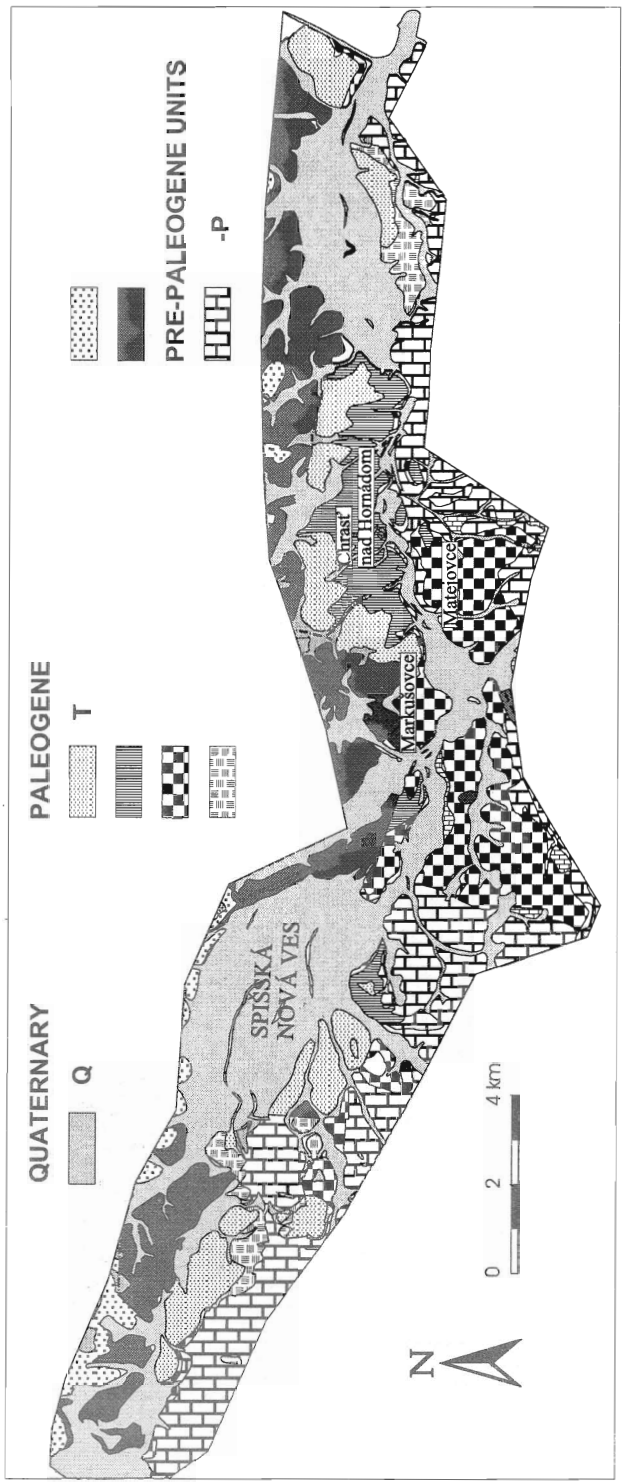


Fig. III.4. Geologic map of the SE area of the CCP Basin. After Mello et al., 2000, modified. Note the SW–NE oriented distribution of sediments comprising Hornád Mb. suggesting orientation of paleoriver valley

schists, most probably in the Spišsko-gemerské rudohorie Mts.

The facies and facies associations of the sediments exposed along the Hornád river valley east of Markušovce also suggest their fluvial and alluvial fan origin. The valley fill structure points to polycyclic evolution with alternating erosional and depositional phases. The sediment characteristics suggests that main factors determining the type of deposition were both climate and tectonics. Massive conglomerates cropping out at the base of the profile in Markušovce (Photo 5) were deposited by catastrophic debris flows which used the paleorelief of the valley. These sediments pass upward into normally graded and cross-bedded conglomerates, sandstones and siltstones deposited in fluvial channels and overbank position. The overbank deposits are represented by massive and parallelly-laminated siltstones which locally have ochreous colour. They were redeposited from source areas during catastrophic floods. The sediments recovered by boreholes as well as some sediments in outcrops show interfingering of fluvial polymict conglomerates with layers of oligomict carbonate conglomerates. The carbonate conglomerates represent lateral input of sediments belonging to the alluvial fan systems into the axial valley.

Alluvial fan deposits are also well exposed at the southern margin of the CCP Basin between Markušovce and Margecany. Lithofacies of alluvial fan sediments in the area and their spatial distribution strongly suggest that tectonics was the main triggering factor for their development. The analysis of alluvial fan depositional systems in the studied area showed existence of two different types of these systems.

The first system of alluvial fans is represented by sediments cropping out between Spišská Nová Ves and Chrast nad Hornádom (Photo 6) where they were described by Filo (in Mello et al., 2000). The sediments consist of carbonate conglomerates with clasts up to 50 cm and occasionally even 3 meters in diameter (Filo in Mello et al., 2000). Occasionally quartz and crystalline schist clasts occur. The conglomerates, thick up to 70 m, are clast-supported and prevailingly massive, only sporadically normal grading may be observed. The sharply and to a lesser amount erosively based beds are thick up to several metres. Occasionally thin layers of sandstones or layers of fine-grained conglomerates occur. The sandstones are rarely cross-laminated (Filo in Mello et al., 2000). In some outcrops layers composed of ochreous siltstone were described.

The coarse conglomerates with sharp and erosive bases are interpreted as cohesion debris flows deposited in proximal parts of alluvial fans (Nemec and Steel, 1984). Occasional cross-bedded sandstones suggest deposition by traction currents, however, their role in the system was only inferior. They could be also formed after debris flow freezing when its upper part was transformed into traction current.

The ochreous layers of siltstones resemble similar rocks in the river paleovalley near Markušovce. The large areal extent of these sediments shows phases of tectonic quiescence in the source area during which intensive weathering in warm and humid conditions occurred. We assume that these beds were deposited coevally with similar beds



Photo 5. Massive, thick-bedded cobble conglomerate near village Markušovce.

in the river valley near Markušovce. The distribution of these sediments also suggests that during time of their deposition (Late Eocene – Oligocene) the differentiated block movements of pre-Tertiary units existed along the southern margin of the CCP Basin triggering alluvial fan deposition. Alluvial fans probably hugged foothill of mountains along the paleoriver valley sides.

Dissected relief of the described area existing before the marine transgression is also suggested by alluvial fan sediments recovered by borehole RHV-22 south of Matejovce (Fig. III.5). The borehole recovered 158 m thick coarse-grained Paleogene sediments prevailingly composed of carbonate clasts. The sediments consist of several facies. The most frequent facies is represented by normally graded conglomerates occasionally capped by cross-bedded fine--grained conglomerates. Other facies are represented by massive, matrix- and clast-supported conglomerates, massive sandstones occasionally grading into mudstones, parallelly laminated and ripple cross-laminated mudstones and coal layers. The described facies are typical for braided rivers developed in the area of alluvial fans. The development of such system in vicinity of the Markušovce paleoriver valley and in vicinity of alluvial fans consisting of chaotic sediments described above, suggest dissected relief determining development of individual depocentres with individual depositional systems.

Important links between the subaerial and marine sediments are represented by depositional systems of fan deltas (e. g. Holmes, 1965; Nemec, 1988). Fan deltas, originating by submergence of alluvial fans into bodies of standing waters, record sedimentary processes occurring in subaerial and subaqueous conditions as well as in the transitional area between them. A typical depositional

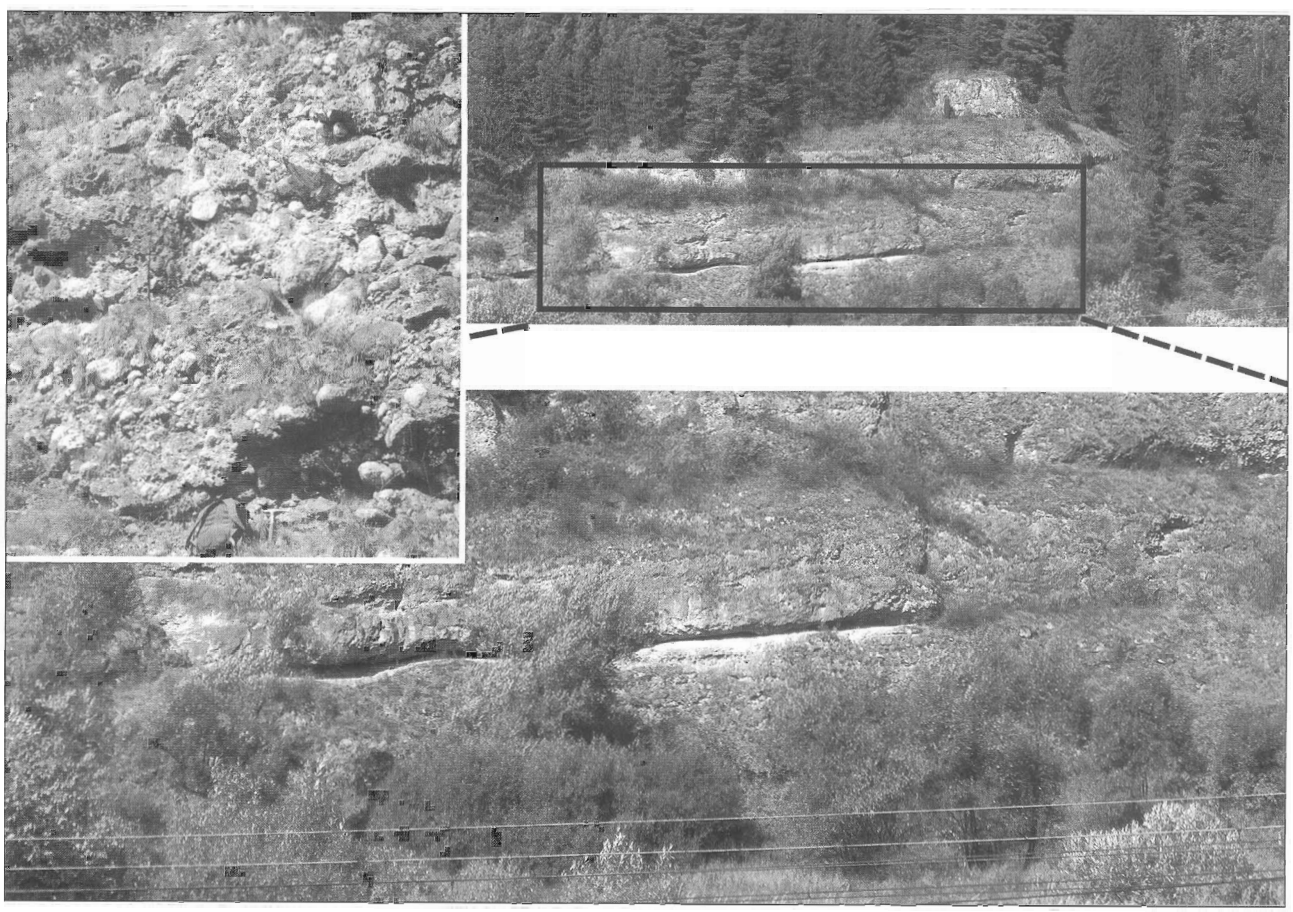


Photo 6. Alluvial fan deposits near Matejovce village showing pronounced cyclic structure.

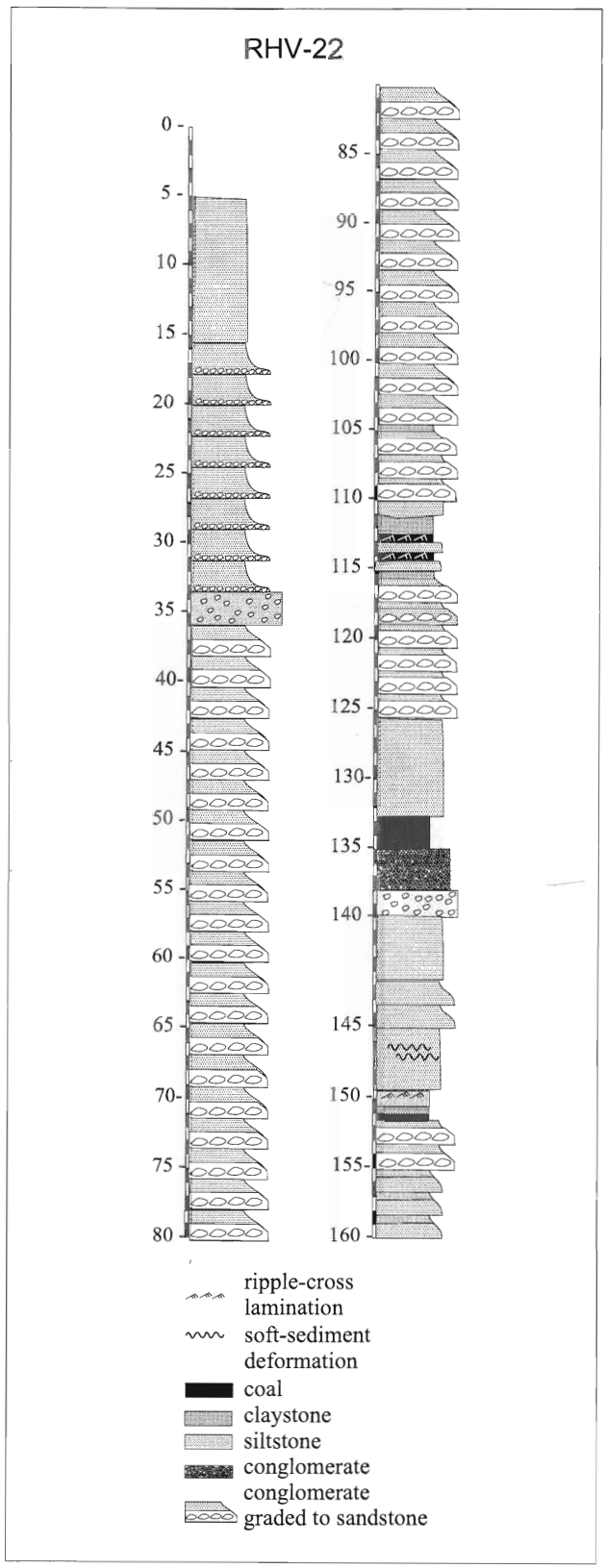


Fig. III.5. Alluvial fan deposits recovered by the borehole RHV-22 near Matejovce, east of Spišská Nová Ves. The sediments are arranged into normally-graded cycles which occasionally contain thin coal layers.

system of a fan delta, developed during the Late Eocene – ?Early Oligocene marine transgression between Spišská Nová Ves and Margecany, is preserved in the area of Štefanská Huta (Fig. III.6). Normally graded conglomerates and sandstones, occasionally comprising wide channels, record deposition by traction currents. Bimodal, matrix-supported conglomerates suggest deposition by debris flows in subaqueous environment. Normally graded and parallelly-laminated, medium-grained sandstones indicate deposition by high-density turbidity flows (e. g. Mutti, 1992). The layer consisting of angular clasts composed of strongly weathered crystalline schists, occurring in sedimentary succession, may be analogue of ochreous deposits in the Markušovce paleoriver valley.

Typical feature of fan deltas is reworking of sediments supplied into marine environment by basinal processes. In the studied sediments this is recorded by ripple-cross laminated and trough-cross laminated sandstones.

Shallow-water depositional systems comprise an important part of the CCP Basin fill. Individual parts of these systems crop out along the entire southern margin of the eastern part of the CCP Basin and they are also described from the foothill of the Tatry Mts. and Ružbachy Mesozoic Island (Janočko et al., 2000). The best examples of these sediments are exposed between Hrabušice and Margecany (Fig. III.4). These sediments are assigned to the Tomášovce and Chrasť Members defined by Filo and Siráňová (1996, resp. 1998). The facies associations suggest deposition in environments of inner and outer shelf. Their development is complicated by lateral interference with deltaic sediments. Such succession of shoreface sediments overlying deltaic (fan deltaic) sediments occur near village Vítaz–Dolina (Marschalko, 1961, 1962, 1965, 1970; Janočko, 2002; Fig. III.7). The lower part of sedimentary succession is prevailingly composed of deltaic conglomerates passing into medium- and coarse-grained, cross- and trough-laminated sandstones of shoreface.

Similar sediments have also been described from Chrasť nad Hornádom (Filo and Siráňová, 1998). The sediments consist of coarse- to medium-grained sandstones with scattered pebbles. The sandstones are mainly trough cross-laminated and contain lenses of pebbly conglomerate. Filo and Siráňová (1998) interpreted these sediments as deltaic sediments. Marschalko (1970) described them as fluvial sediments originated on slopes of alluvial fans at larger distance from mountains. The development of trough- and ripple cross-laminated sandstones, parallelly-laminated sandstones, hummocky cross-bedded sandstones and well-sorted conglomerates and sandstones strongly suggest environment of inner and even of outer shelf.

The described sediments contain layers of carbonate breccias and conglomerates. They are laterally inconsistent and have variable thickness. The layers of cobble and blocky breccias representing sediments of gravity flows are typically developed at their stratotype site near village Vítkovce (Filo and Siráňová, 1998). Similar deposits occur along the southern margin of the eastern part of the CCP Basin between Chrasť nad Hornádom and Margecany.

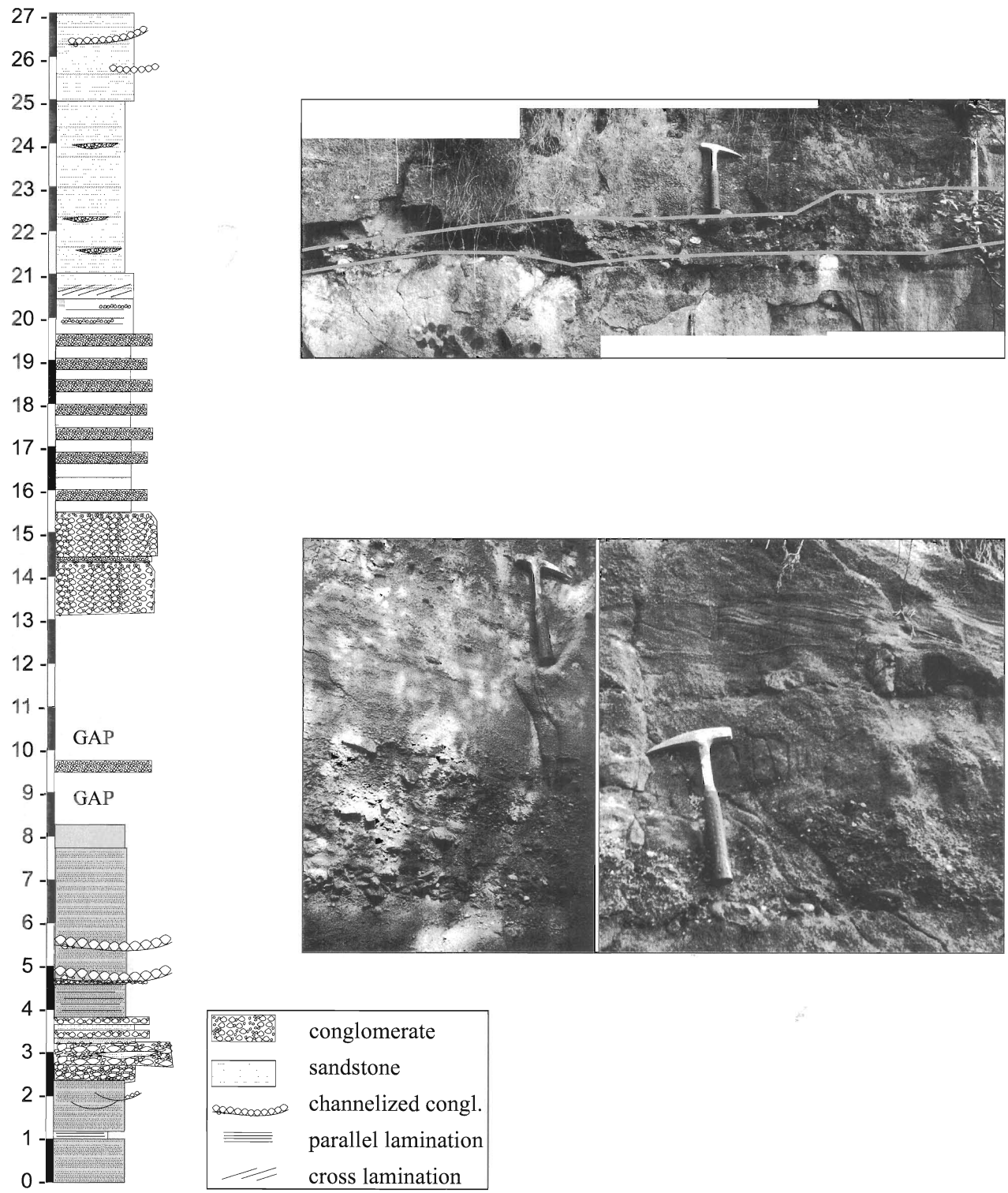


Fig. III.6. Sedimentary log showing deposits of fan delta deposits near Štefanská Huta village. The upper photo shows pinching out of a gravelly lobe. The lower photo shows parallelly laminated, coarse-grained sandstone deposited by high-density turbidity current (right) and ripple-cross laminated sandstone recording ripple migration.

These layers represent sediments of fan deltas submerging into sea in landscape with dissected shore line. The Vítkovce Breccias, sandwiched by well-sorted shoreface sandstones of Chrasť Member, indicate seismic activity along the basin margins already suggested by structure of alluvial fans.

The deposits of outer shoreface are described by Filo and Siráňová (1996) from the vicinity of Tomášovce village

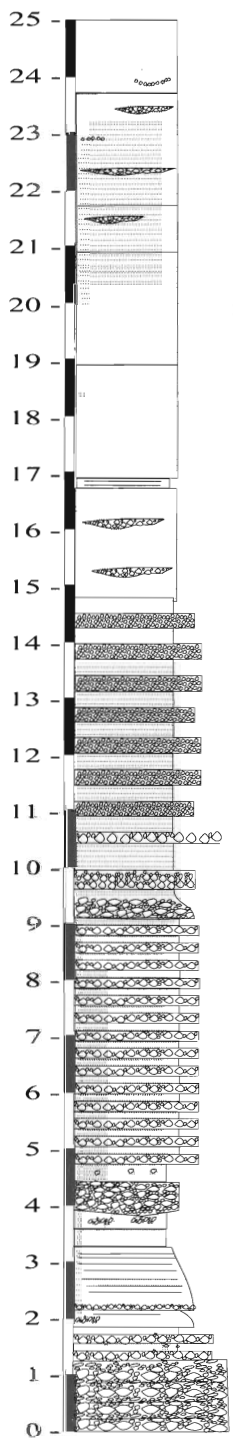






Fig. 10.7. Sedimentary log of fan-deltaic and shoreface deposits at the locality Vítaz–Dolina. Note the upward-fining grain-size trend of the sedimentary succession. The lower part of the succession is represented by fan-delta deposits (the lower photo) while the upper part shows mostly shoreface deposits (the upper photo).

as Tomášovce Member (see above). Similar sediments have also been described from Radačov surroundings (Haszlinszki, 1852 fide Filo and Siráňová, 1996). The sediments are typical by plant reprints and macrofauna. The analyses of gymnospermous and angiospermous plants suggest tropic humid climate of Eocene overlapping to Oligocene (Haszlinszki, 1852 fide Filo and Siráňová, 1996; Volfová, 1961, 1962, 1963a, b, 1964; Gross et al., 1973).

The sediments consist of prevailingly massive, fine- and medium-grained sandstones with occasionally scattered pebbles. The massive sandstones fill wide scours and

small shallow channels. The beds are amalgamated. The scours and channels point to erosive currents on shelf. Similar sediments often occur in distal parts of deltaic fronts with periodic input of sediments from mainland.

In spite of the fact that the age of described sediments deposited in individual subaerial and shallow-marine environments is not firmly documented, stratigraphy and spatial distribution of individual facies suggest their coeval deposition in deltaic front environment.

Deep-water depositional systems

Sediments of deep-water depositional systems comprise the largest volume of the sedimentary basin fill of the CCP Basin. These sediments were during the individual stages of the basin evolution deposited in various tectono--sedimentary conditions. Analyses of sediment architecture, paleoflow directions and stratigraphy suggest several depositional systems, which developed at different time and different depocentres of the basin. After initial transgression and deepening of the basin the prevailing type of deposition was by gravity, mainly turbidity flows. In the eastern part of the CCP Basin several turbidite depositional systems were formed. The systems differ by bathymetry, geologic-geomorphological characteristics of the source area and shelf width which comprised transitional zone between the source area and deep-water environment. In the eastern part of the CCP Basin it is possible to assume deposition in laterally restricted basins which passes into deposition of an open system. This type of deposition continued until the Early Miocene as evidenced by channel-lobe transition sediments described from the Levoča Mts. (Janočko et al., 1998). The terminal stages of deposition probably again occurred in laterally restricted depocentres developed in the northern part of the CCP Basin.

The age of deep-marine depositional systems was proved in the time interval Late Eocene – Early Miocene (e. g. Soták et al., 1996; Janočko et al., 1998; Janočko et al., 2000; Soták et al., 2001).

Depositional systems of laterally restricted basin

Evolution of the CCP Basin was mainly dependent on the interplay of tectonics, eustatic sea level fluctuation and sediment input. The interplay of these factors resulted in opening of basin depocentres, their shift, geometry, type of sedimentary processes, amount of sediment delivered into the depocentrum and resulting thickness of sediments. Time slices analysis of basin fill sediments shows that these attributes essentially changed during the basin evolution. At the beginning of the basin evolution deposition in several abruptly subsiding depocentres – subbasins occurred. Subsequently an elongated basin originated resembling foreland basins with predominating axial flow. At the margins of these elongated basins the sediments of fan aprons, entering basin laterally, were deposited. Extensive area of the basin at the end of Oligocene and beginnig of Miocene is recorded by the deposition in channel-lobe transitional environment, which does not show features of lateral restriction. However, the changes of paleoflow directions in the uppermost part of the sedimentary succession in the channel-lobe sedimentary succession again suggest uplift of some source areas and commencement of basin restriction which represented terminal phases in basin evolution.

Existence of laterally confined subbasin during the evolution of the CCP Basin is recorded by sediments in the Šambron–Kamenica zone occurring in the eastern part of the basin south of Pieniny Klippen Belt (Fig. III.8). The thickness of sediments, which are deformed in the vicinity of the Pieniny Klippen Belt, is about 3 km (borehole Lipany-4). The sediment architecture is well documented by several boreholes performed for hydrocarbon prospection (the boreholes in the surroundings of Lipany, Šariš-1, Šambron-1, Plavnica-1, 2) and by several shallower boreholes drilled for hydrogeologic and engineering purposes. In addition, several seismic sections were shot in the area which considerably improved our knowledge on the geologic structure.

Structurally the Šambron–Kamenica zone is an anticline with oldest (Upper Eocene) sediments in the core and younger (Oligocene) sediments on wings. The sediments are characteristic by their facial, structural and textural variability and polymodal paleoflow direction in the basin. Chmelík (1957), who defined these sediments as Šambron Member, subdivided the lower part into the greenish-gray, calcareous sandstones and bluish-green sandy limestones with clayey intercalations and frequent layers of fine-grained conglomerates with nummulites as well as thick layers of conglomerates. The upper part is prevailingly composed of "flysch" like sediments capped by mostly claystones.

Rudinec (1989) assumes superimposed, double-etage structure in the area of Šambron–Kamenica zone. At the base of the Paleogene succession he described dark claystones with intercalations and layers of sandstones. The sandstones, which are laterally inconsistent, have local thickness up to 100 m (borehole Lipany-2). The upper part is represented by typical "flysch" like deposits with fold-slice structure. This part, composed of gray and dark gray claystones, siltstones and sandstones, is according to the author (Rudinec, 1989) overthrusted over the lower part.

Marschalko (1975) performed sedimentological analysis at several localities of the Šambron–Kamenica zone. He recognized three megarhythms in the coarse-grained conglomerates near Kamenica which he interpreted as sediments deposited at the foot of submarine slope. According to the author these sediments resemble sediments of submarine canyons. "Classical flysch", into which the conglomerates pass laterally, probably represents more distal analogue of conglomerates deposited by turbidite flows (Marschalko, 1975).

Šambron Member is often correlated with the Upper Eocene sediments of Szaflary Member defined in Polish Podhale part of the CCP Basin (Golab, 1952; Watycha, 1974; Olszewska and Wieczorek, 1998). The sediments,

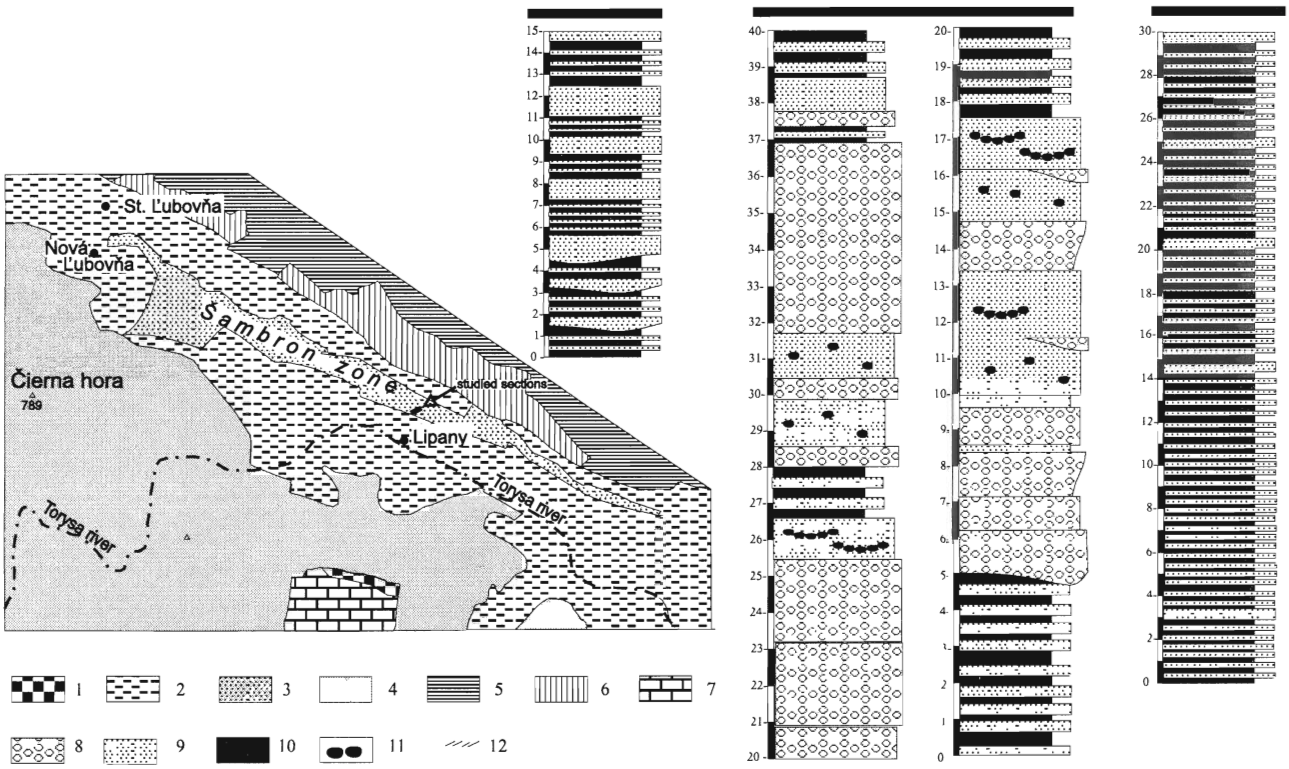


Fig. III.8. Localization of Šambron zone and sedimentary logs of coarse-grained deposits logged in the zone. 1 – basal sediments of Subtatric Group (Borové Formation), 2 – Huty Formation, mainly mudstones, 3 – sediments of Šambron zone, 4 – Biely Potok Formation, mainly sandstones, 5 – Outer Flysch Belt sediments, 6 – Pieniny Klippen Belt, 7 – Mesozoic sediments, 8 – conglomerates, 9 – sandstones, 10 – mudstones, 11 – intraclasts, 12 – cross bedding.

characterized by thick sandstone beds, mudstones and claystones of menilite type as well as occurrence of submarine slumps, also occur in similar geological position like the Šambron Member. They extend along the southern rim of the Pieniny Klippen Belt and comprise approximately 13 km wide belt (Watycha, 1974; Kępinska, 1998). The oldest part of these sediments was recovered by boreholes Banska IG-1, Bialy Dunajec PAN-1, Poronin PAN-1, Furmanova PIG-1, Chocholów PIG-1 a Bukowina Tatrzanska PIG-1 (Kępinska, 1998). Sediment thickness of Szaflary Member in the boreholes varies from 176 m in the Poronin PIG-1 borehole to 1500 m in the Banska IG-1 borehole. According to Kępinska (1978) in the recovered sediment it is possible to recognize transitional part between basal sediments (in Polish terminology "Nummulite Eocene") and overlying typical deep-marine sediments. The transitional part is best described from the borehole Bialy Dunajec PAN-1 where it was recovered above the basal conglomerates at depth 2040–2113 m. It consists of mudstones with sandstone layers and occasional thin layers of limestones and conglomerates with calcareous matrix. This is overlain by slump sediments. The described sediments pass upward into typical Szaflary Member consisting of mudstones, thick sandstone and conglomerate intervals and frequent sediments of submarine slumps. Planctonic foraminifers *Globigerina officinalis Subbotina*, g. ex. gr. *praebulloides Blow, tenuitella liverovskae* (Bykova) yielded Late Eocene and Early Oligocene age (Olszewska and Wieczorek, 1998). The Late Eocene age is also indicated by large foraminifers *Nummulites perforatus* (Montfort), *Nummulites fabianii* Prever, *Grzybowskia multifida* Bieda, *Orbitoclypeus nummuliticus* (Gumber). The sediments are typical by abrupt change of bed thickness, thick beds without internal organization, frequent synsedimentary deformations and deposits of submarine slumps. Based on these characteristics Krysiak (1976) suggested their origin in proximal parts of submarine fans in the area of submarine slope. Wieczorek (1989) prefers a model of tectonically controlled submarine ramp as depositional environment of described sediments. Investigation of these sediments south of Czorsztyn enabled their subdivision into lower interval with thick sandstones, middle interval with mudstones and spherodolomites and the upper interval with sandstones and submarine slumps (Mastella et al., 1977). Similar subdivision is also observable in the mentioned boreholes.

Paleocurrent measurements in the Szaflary Member show prevailing south- and southward directions (Krysiak, 1976). Several Polish authors assume that the main source area of the sediments is the exotic Andrusov Ridge and the area of Pieniny Klippen Belt (e. g. Kępinska, 1998).

Numerous boreholes and seismic sections performed in relation to hydrocarbon prospection in the Šambron–Kamenica zone (the boreholes from series Lipany, Plav-

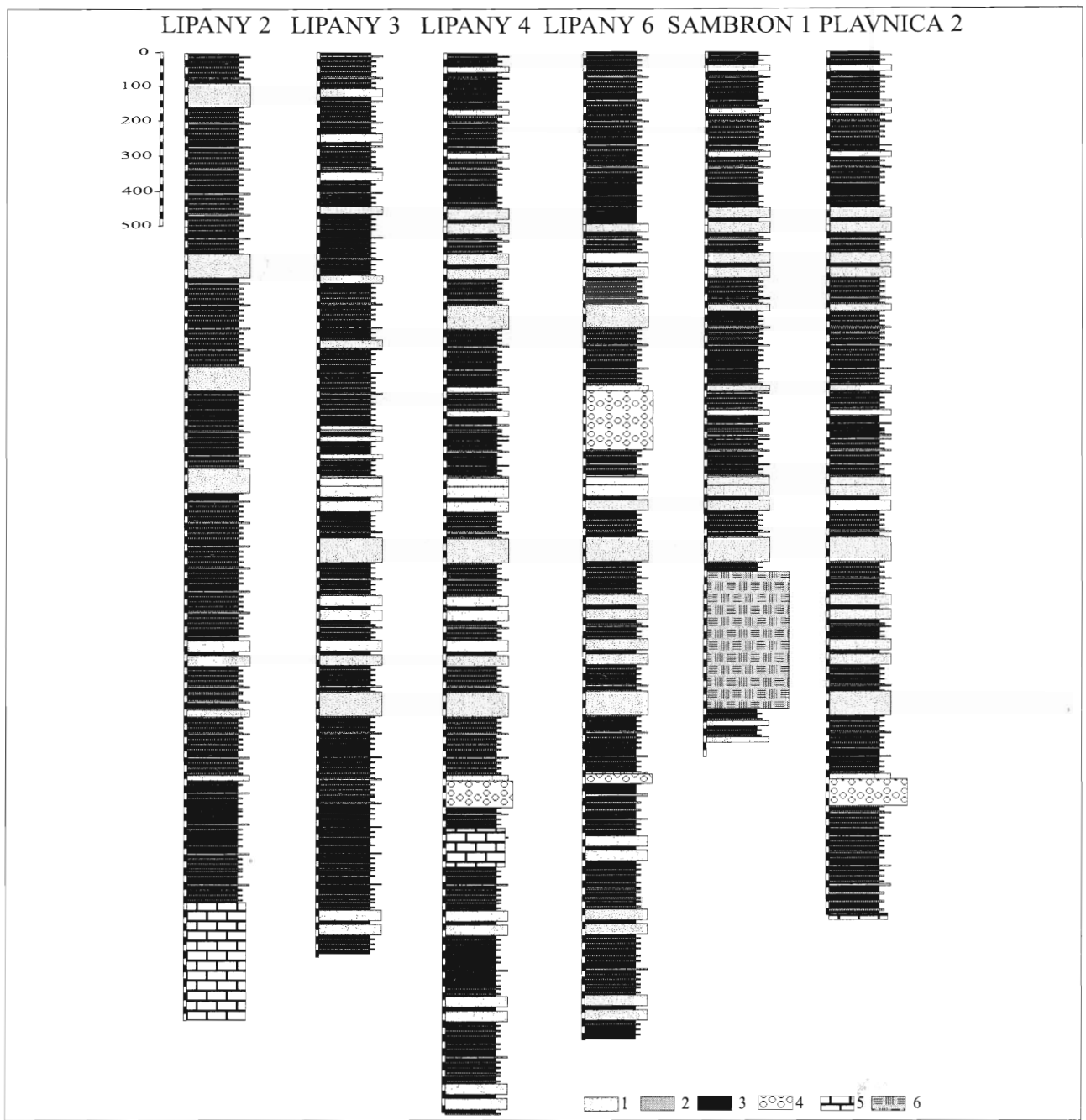


Fig. III.9. Sedimentary succession of deep boreholes from Šambron zone (for localization see Fig. III.8). The sediments are interpreted as the fill of confined basin. 1 – sandstones. 2 – siltstones, 3 – claystones, 4 – conglomerates, 5 – carbonates, 6 – slump.

nica, Šambron PU-1 and Šariš-1; Leško et al., 1982; Rudinec, 1981, 1984; Rudinec and Řeřicha, 1985; Rudinec et al., 1988) proved over 3 km thick Paleogene basin fill in the Šambron–Kamenica zone (the borehole L-4 did not encountered the base of Paleogene at depth 3000 m; Fig. 9). Together with seismic sections and hydrogeologic and engineering geologic boreholes they provided worthy information on the geologic structure of this area. Especially worthy were hydrogeologic boreholes drilled in the surroundings of Nová Ľubovňa (Bajo, 2000). They confirmed abrupt lateral and vertical changes of facies. The 50 m deep borehole SMH-6 (Fig. III.10) recovered medium-grained sandstones and conglomerates and only minor of siltstones. The sandstones are massive and normally graded with typical sharp base of beds. The sandstones occasionally contain intraclasts located in the upper part of beds. The sandstones rarely pass into parallelly laminated mudstone with high organic content. The conglomerates, which are also very common, are normally graded and pass upward into coarse- and medium-grained

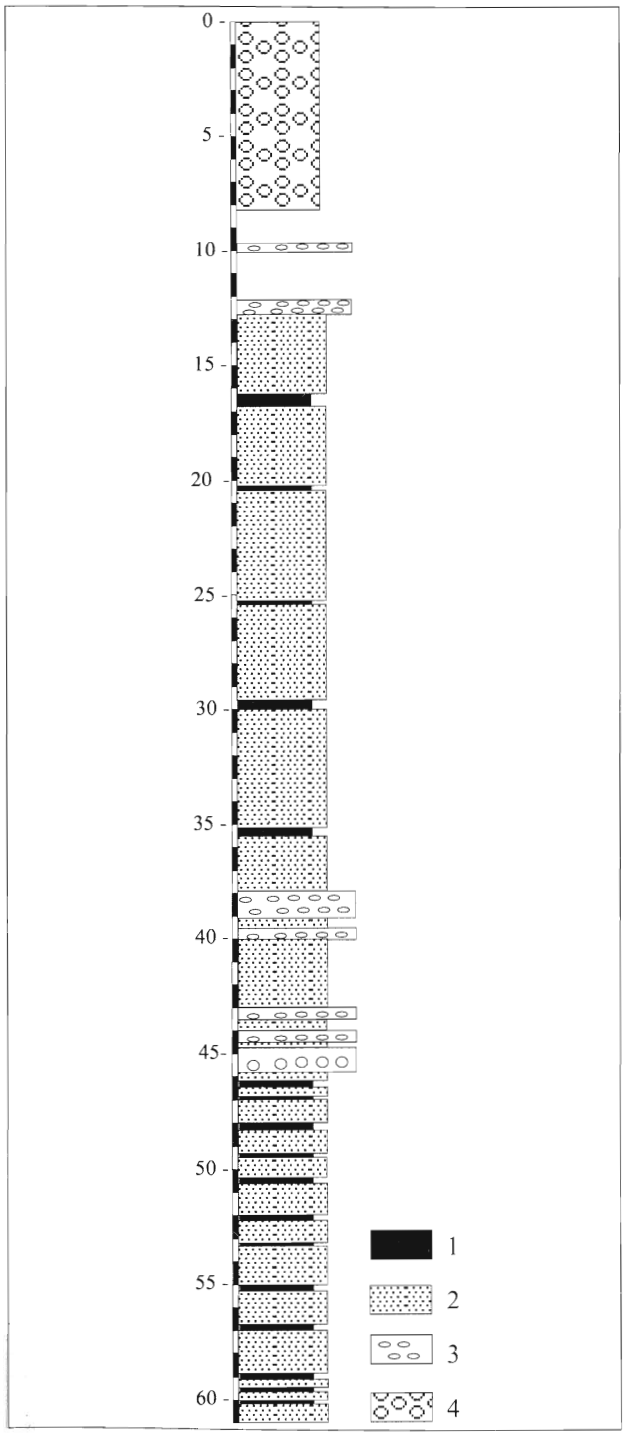


Fig. III.10. Typical deposits of the Šambron Zone recovered by hydrogeologic borehole near village Vislanka. 1 - mudstone, 2 - sandstone, 3 - conglomerate, 4 - Quaternary sediments.

sandstones. Usually the conglomerate beds are sharply based. The conglomerates, mostly composed of quartz and occasional carbonate and crystalline schist clasts, are normally graded and have matrix-supported structure.

Predominancy of sandstones and conglomerates, which are massive, normally graded, with sharp and occasionally erosive bases suggest deposition by high-density turbidite flows. Occasional occurrence of claystone chips points to erosion ability of turbidite flow in more proximal part of the depositional system, probably in the zone of hydraulic jump where abrupt dilution of the flow occurs. This triggers increased turbulency of the flow and, at the same time, decreasing competency resulting in relatively fast deposition of the coarsest clasts contained in the flow. Position of the intraclasts in the upper part of sandstone beds suggests that the zone of hydraulic jump was close (Mutti and Normark, 1987). Shortage of pelites in the sediment caused fast deposition (low-efficiency turbidite flow of Mutti, 1980) and we believe, that these sandy deposits comprised lateral aprons along the base of slope. The described characteristics suggest a short extent of the aprons basinward.

Similar sediments were recovered by next hydrogeologic borehole near Vislanka, some 10 km south of the SMH-6. It shows 60 m thick succession of prevailing sandstones and minor conglomerates. The sandstones are medium- and coarse-grained, massive and parallelly laminated. They comprise sharply based, up to 40 cm thick, often amalgamated beds. The conglomerates, which are frequently normally graded, are composed of quartz and crystalline schists. Similarly to the sediments recovered by the borehole SMH-6, the described sediments also represent deposition by high-density turbidity flows in apron environments.

The borehole SMH-7, which penetrated 95 m of Paleogene deposits, was drilled closely to the described SMH-6. In the borehole profile the succession of alternating mudstones and sandstones prevails. The sandstone beds are sharply based and 2–10 cm thick. The sandstone is fine- and medium-grained, massive and ripple cross-laminated. The mudstones are dark, massive and parallelly laminated. In the whole profile only a few thicker (20–30 cm) sandstone beds were described.

Alternation of mudstones and sandstones, parallel lamination of mudstones and ripple-cross-lamination of sandstones suggest deposition by turbidity flows. According to geologic position, the deposition occurred on the



Photo 7. Thick-bedded conglomerate beds separated by thin beds of mudstone and sandstone, Šambron zone. Outcrop near Lipany town.

submarine slope where a bypass of sediments prevailed and only occasionally sandstones and mudstones were deposited.

The sediments of Šambron Member may be also studied from well-exposed outcrops in the area close to Lipany and Kamenica (Fig. III.8, Photos 7 and 8). It is possible to observe strong tectonic deformation of sediments, which comprise high-angle dipping beds and folds of various types (Plašienka et al., 1998; Jacko, 2000). The folds are dominated by angular, less frequently sinusoidal, upright, symmetric or only slightly asymmetric cylindrical fold types. Folds are open to close in competent layers and tight in incompetent shales squeezed into the fold cores (Plašienka et al., 1998). Measured and constructed fold axes are subhorizontal and strike W–E and WNW–ESE. Axial planes are subvertical or steeply north-dipping. Axial plane cleavage is rare and restricted to fold hinges. Dipping to the north 60–80 degrees, it documents the southern vergency of rounded folds more clearly than the fold asymmetry. The shortening of the 50 % is assumed on the basis of tectonic study (Plašienka et al., 1998).

Tectonic deformation is also obvious from the sediment lithology – the mudstones are often slaty suggesting their alteration in higher pressure and thermal conditions. The tectonic deformation and convergence is also suggested by spatial distribution of individual facies and facial associations.

Based on facies associations, the sediments exposed in the defile located along the railway between Lipany and Kamenica consist of three main units:

The sharply based unit 1 overlies alternating thin shales and sandstones. It is 40 m thick (Fig. III.8). The sediments of the unit consist of thick beds of conglomerates, minor sandstones and alternating sandstone and shale beds. The general trend of the unit 1 is fining- and thinning-upward. The conglomerates are clast-supported, minor matrix-supported conglomerates occur too. They are massive and inversely graded, normal grading occurs scarcely. The size of angular, subangular and suboval clasts strongly varies from bed to bed, the maximum clast size observed is about 120 cm. The clasts are composed of carbonates (99 %), quartzite and crystalline rocks (1 %). The matrix of conglomerates consists of coarse sand and clasts of pebble size. Flute casts and skip marks showing paleoflow direction from E, SE to W, NW (mean 300 degrees) occur occasionally if the conglomerate bed overlies sandstone or shale beds. Sometimes matrix-supported conglomerates form fill of small and shallow (up to 2 m wide and 30 cm high) diffuse channels or scours in sandstones.

The sandstones and pebbly sandstones have only minor occurrence in unit 1. They are medium- and coarse-grained and mostly show massive structure. They comprise sharply based beds thick up to 1.7 m. Sometimes small diffuse channels filled by conglomerates occur in the sandstones.

The sharp base, floating larger clasts in matrix, the tendency of larger clasts to concentrate toward the top of the bed strongly suggest deposition by cohesive debris flows (e. g. Mutti, 1992). This is also supported by poor clast roundness due to flow strength. The massive structure of some conglomerates and occasional normally graded conglomerates suggest progressive dillution of debris flow by ambient water and transition into hyperconcentrated flows (e. g. Nemec and Steel, 1984). The massive, sharply based sandstones were probably deposited after transformation of hyperconcentrated flows into high-density turbidity flows (e. g. facies F5 of Mutti, 1992) and basically represents the waning stage of the flow. The fluctuation of the flow strength is recorded by conglomerate fill of small diffuse channels formed in sandstones.

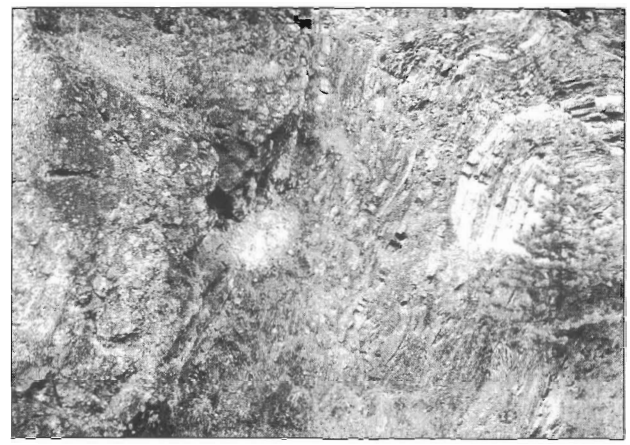


Photo 8. Base of thick-bedded conglomerates shown in Photo 7 is formed by alternating and strongly deformed, thin-bedded mudstones and sandstones.

Unit 2 consists of thick sandstone beds alternating with thin sandstone and shale beds (Fig. III.8). The thickness of the unit is about 15 m in the measured section. The thick sandstone beds consist of fine- to coarse-grained massive, parallel and rarely ripple cross-laminated sublithic sandstones. The sandstones are occasionally normally graded. They often contain rip-up clasts of sandstone and mudstone in the lower part of the bed. Sometimes shallow, laterally restricted diffuse channels filled by pebbly sandstones are developed in sandstone beds. If the sandstones are parallelly laminated, the laminae are 1–2 mm thick. The base of the beds is sharp and/or loaded. Very scarce flute marks suggest paleoflow direction from the east toward west (mean 250 degrees). The beds are sometimes amalgamated forming bed sets thick up to 70 cm.

The thick sandstone beds are interbedded by the alternating thin beds of sandstone and shale. The fine and medium-grained sandstone is prevailingly massive and parallel laminated with superimposed ripple cross-lamination. The beds are sharply based, laterally they sometimes pinch out. The thickness of the beds is around 20–25 cm. The dark shales are macroscopically massive, in the thin section they reveal parallel lamination. They comprise beds 20–25 cm thick with sharp bases. The bed sets of alternating sandstones and shales are usually around 1 m thick.

The thick sandstone beds alternating with thin sandstone and shale beds are thought to be channel and levee deposits. The massive and normally graded sandstones containing rip-up clasts are interpreted as channel deposits. Also in the scale of the section the base of the beds seems to be sharp, the rip-up clasts suggest erosional ability of the turbidity flow. The alternating beds of fine- and medium--grained sandstone and shale are interpreted as levee deposits. This is supported by the finer sandstones comparing to the thick beds, presence of parallel and ripple-cross laminations suggesting the upper, lower-density part of the turbidity current overflowing the topographically higher levee and by the lateral pinch out of the beds. The architecture of these deposits is similar to architecture of channel and levee deposits described elsewhere (e. g. Mutti and Ricchi Lucchi, 1972; Janočko et al., 1997).

The deposits of unit 3 consist of alternation of laterally persistent thin beds of sandstone and shales (Fig. III.8). The sharply-based beds are 10–15 cm thick. The sandstone is fine-grained, massive, parallel laminated and occasionally ripple cross-laminated. The shales are dark, massive and parallel laminated.

The thin, laterally persistent alternating beds of fine sandstone and shale are usually interpreted as outer fan deposits. The massive and parallel-laminated fine-grained sandstone coupled with shale are thought to be deposited by low-density unchannelized turbidity flow.

The location of the three described units (Fig. III.8) suggests enormous shortening during the postdepositional tectonic phases occurring during the uplift of the Pieniny Klippen Belt. The sediments of unit 1 are thought to develop on the slope or base of slope. The sediments of unit 2 and 3 probably developed more basinward and represent distal analogues of unit 1 sediments.

The analyses of paleocurrents from the investigated area show variable directions. Together with interpretation of depositional environments of described sediments and analysis of their spatial distribution we suggest, that the prevailing depositional environments were linear sourced aprons located at base of slopes. Such systems are typical for smaller, fault-bordered, confined basins (e. g. Stow, 1985).

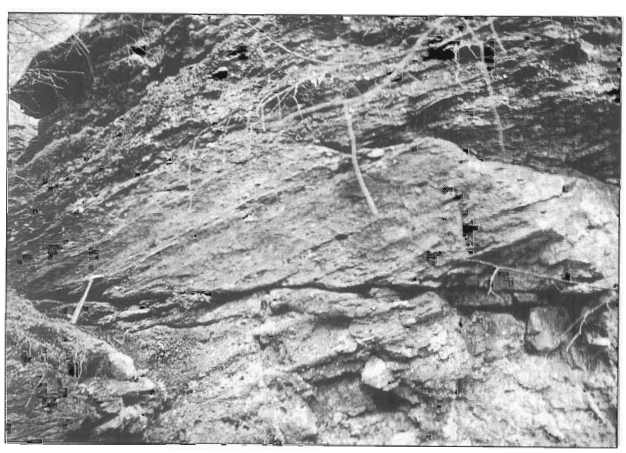
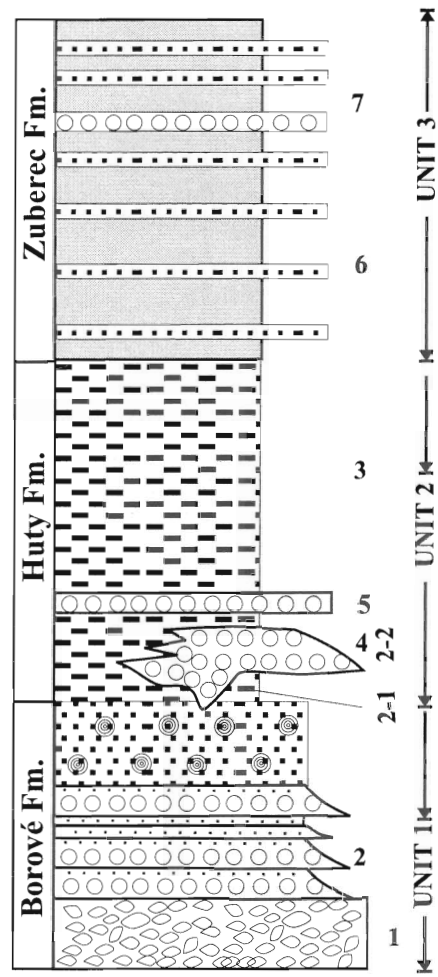


Photo 9. Cross bedded conglomerates of basal Borove Formation.



1 breccias and conglomerate
2 nummulite sandstone and limestone
3 mudstone
4 canyon fill, mostly conglomerate
5 conglomerate
6 alternating sandstone and mudstone
7 thick beds of sandstone alternating with mudstone

Fig. III.11. Sedimentary succession in the Spišská Magura region near village Ždiar. The succession consists of Borové, Huty and Zuberec Formations and is subdivided into 3 units (see text for more detail explanation).

Basin slope environments – example from Spišská Magura region

The thick sedimentary succession in the northern, Spišská Magura part of the CCP Basin, records deposition from initial transgression to deep marine sedimentation. It resembles successions known from the entire northern and eastern part of the basin (Podhale, Spiš, Levoča and Šariš regions, Fig. III.2), however, some sedimentary

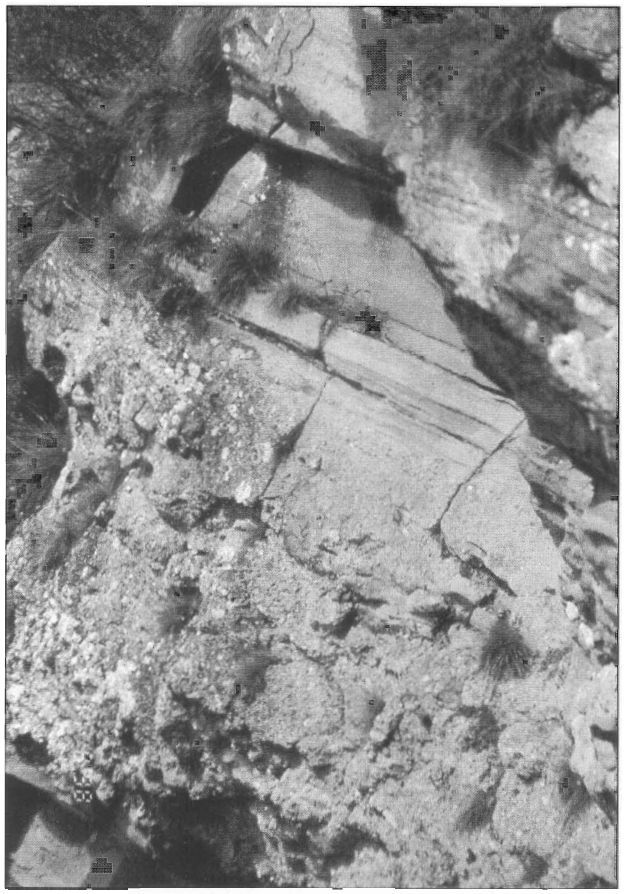


Photo 10. Parallelly-laminated coarse-grained sandstones overlying conglomerates represent a part of submarine canyon fill near Ždiar village.

features show deposition in unique subenvironments within the basin which makes it important for understanding basin sedimentary history.

The Paleogene deposits consist of basal Borové Formation (Photo 9) overlain by dark shales with minor sandstone and conglomerate beds (Huty Fm. of Gross et al., 1984) and occasional of thick, laterally restricted gravity flow deposits (Pucov Mb. of Gross et al., 1984; Marschalko and Radomski, 1970; Tokáreň Fan of Westwalewicz-Mogilska, 1986). The whole Paleogene succession is capped by shales alternating with variable thick sandstones of Zuberec Formation.

The post-Paleogene uplift of the Mesozoic and Paleozoic rocks of the Vysoké Tatry Mts. (ca. 15 Ma ago; Kráľ, 1977, Fig. III.2) also elevated the oldest, buried Paleogene deposits, which now flank the slopes of the mountains. The profile from the mountains toward the deeper parts of the basin provides a complete section through the Paleogene sedimentary succession in the region. The sections obtained from outcrops were compared with archive boreholes penetrating the Paleogene succession. The thickness of the deposits in the studied area is about 1600 m and it probably represents only the lower, preserved part of the basin fill. Based on clay mineral analysis and vitrinite reflectance data the uplift of at least 2 km is assumed in the area close to the Pieniny Klippen Belt in the northern part of the studied area (Milička, 1998). This is supported by data from the Levoča Mts. located to the south of the studied area where a similar amplitude of the uplift is suggested (Kotulová, Biroň et al., 1998).

The sedimentary succession was divided into three units based on lithology (Fig. III.11). Prevailingly breccias, conglomerates and sandstones comprise the base of succession (unit 1). The age of the unit, determined by analysis of nummulites fauna, is the Late Eocene (Janočko et al., 1998).

The overlying deposits of unit 2 consist of two subunits. The subunit 2–1 is composed of dark, massive and faintly parallelly laminated shales with variable amount of prevailingly thin sandstones showing Bouma's divisions T_{bcd} and T_{cd} and conglomerates.

The subunit 2–2 is composed of coarse-grained conglomerate and sandstone deposits, reaching thickness of about 200 m. They are cut into the underlying shales of the subunit 2–1, basal deposits of the unit 1 and even into the Mesozoic basement. The conglomerates are arranged into thick, sharply based beds which are often amalgamated. Flute casts developed at the base of some beds show paleoflow direction toward west. The conglomerates are prevailingly normally graded, inverse grading and massive structure are also locally developed (Photo 10).

The conglomerate beds are separated by pebbly sandstones and medium- to coarse-grained sandstones. The sandstones are horizontally and ripple cross-laminated, some beds are normally graded (facies F4, 5 and F6 of Mutti, 1992). Water escape structures are common (Photo 11). Pebbly sandstones either float in sandy matrix or they form small diffuse channels in sandstones. The sharply-based beds are thick from a few centimeters to 80 centimeters. The overall trend of sandstone occurrence is increasing upward – in the lower part of the profile conglomerates prevail, in the uppermost part conglomerates only form thin beds in sandstones (Fig. III.12). The age of unit 2 is Late Eocene – Early Oligocene.

Unit 3 consists of alternating sandstone and shale beds and occasional thin conglomerate beds. The transition



Photo 11. Water-escape structures in coarse-grained sandstone are common in the sedimentary succession forming submarine canyon fill.

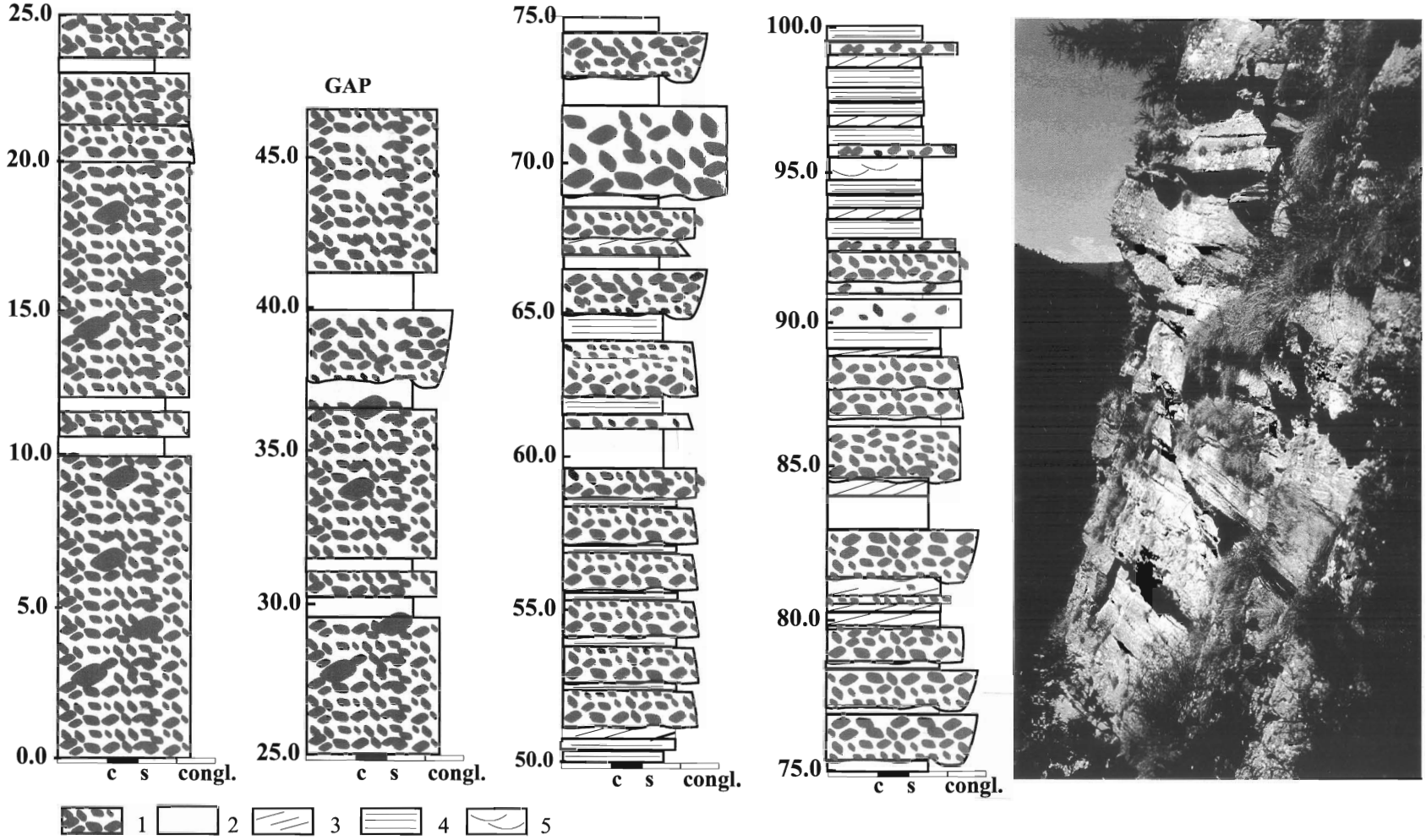


Fig. III.12. Sedimentary profile and photo of submarine canyon fill sediments in the vicinity of the village Ždiar Note fininng-upward and thickening-upward trend of the doposits 1 - conglomerate, 2 – sandstone, 3 – cross bedding, 4 – parallel bedding, 5 – trough cross bedding.

from unit 2 is gradual and is marked by increasing frequency and thickness of sandstone beds within the shale of unit 2.

The breccias of unit 1, showing sharp-edged clasts of cobble to boulder size, poor sorting, weak internal organization as well as composition of clasts derived from the directly underlying Mesozoic basement, suggest extremely short transport during deposition. The deposits probably represent gravitational deposits at the foot of coastal cliffs abraded by transgressing sea. A better sorting and internal organization of the overlying conglomerates of this same unit 1 suggest reworking of breccias by basinal processes. Based on the clast-size of reworked coarse-grained deposits we assume high-energy, shallow-marine environment. The well-rounded quartz clasts, comprising admixture of the conglomerates, suggest redeposition of at least 2nd cycle. It is not known the occurrence of possible quartz source area in the vicinity of the studied region and we suppose that the clasts were delivered by fluvial and deltaic system to the basin and subsequently redeposited by basinal processes.

The massive shales of subunit 2–1 were deposited from suspension clouds in a quiet, low-energy environment of the outer shelf and submarine slope or steeply inclined ramp. We assume that the deposition of the shale belonging to the lowermost part of the unit 2 occurred on the basin slope (or lower part of ramp) contemporarily with the deposition of the unit 1 deposits during the rise and high stand of sea level. The sharp boundary between the underlying unit 1 and shales suggest steep ramp gradient, where transitional offshore-transition facies could not be developed. Such facies may be observed nearby Štrba in Liptov Depression (Gross et al., 1980) or they were described from numerous boreholes in the Hornád Depression (e. g. Jetel and Vranovská, 1997).

The thin, massive, horizontally and ripple cross-laminated sandstone beds (Bouma's divisions T_{bcd} and T_{cd}) are interpreted as low-density turbidity flows. We assume their generation by failures on submarine slope.

The massive structure of seldom conglomerates of subunit 2–1, their poor sorting, weak internal organization and sharp base of beds are indicative for deposition by gravity flows, mostly slumps and debris flows. Rare normally graded beds suggest dilution of the upper part of debris flows and generation of hyperconcentrated flows (e. g. Lowe, 1975; Nemec and Steel, 1984; Mutti, 1992). The upward decreasing frequency of bed occurrences points to gradually higher stability of slope. This is consistent with the interpretation of sea level rise during deposition when gradually higher amount of sediment was trapped in nearshore environment and outer shelf and basin slope became sediment starved.

Conglomerate and sandstone deposits of subunit 2–2 are interpreted as fill of a submarine canyon evolved during the sea level lowstand. The massive, sharp-based conglomerates are interpreted as the cohesive debris flow deposits (e. g. Nelson and Nilsen, 1997).

The sandstone beds alternating with shales are interpreted as distal and proximal overbank deposits of a submarine fan.

Channel – lobe transitional area, Levočské vrchy Mts.

The Levočské vrchy Mts. are located in the middle part of the eastern section of the CCP Basin (Fig. III.13). The clay analysis and vitrinite reflectance data suggest that the postdepositional uplift of the area (and consequently erosional truncation) was not so intensive as in the Spišská Magura region and the Šambron zone (Kotulová et al., 1998; Milička, 1998). It is reflected by younger, prevailingly Upper Oligocene and Lower Miocene deposits (mostly NP 24, 25 – NN 1/2 zones) comprising the geological structure of the area.

Extensive hydrogeological drilling in the last years and good outcrops in the surroundings of Tichý Potok village located in the Levočské vrchy Mts. (Fig. III.13) provided data for sedimentological evaluation. The drillings and seismic profiles indicate the thickness of the CCP Basin fill ranging from 700 m to 3500 m in the area of Levoča Mts. (Polák et al., 1992; Gíret, 1991; Neupauer, 1990; Gross et al., 1996). The lithology of the fill is identified only tentatively. The transgressive deposits are assumed

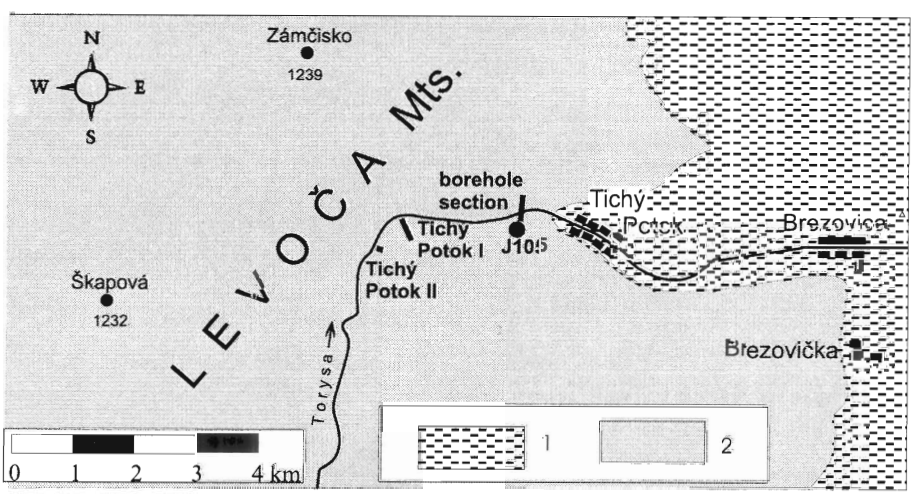


Fig. III.13. Localization of Levočské vrchy Mts. and sections described in the text. 1 - Huty Formation, 2 - Biely potok Formation

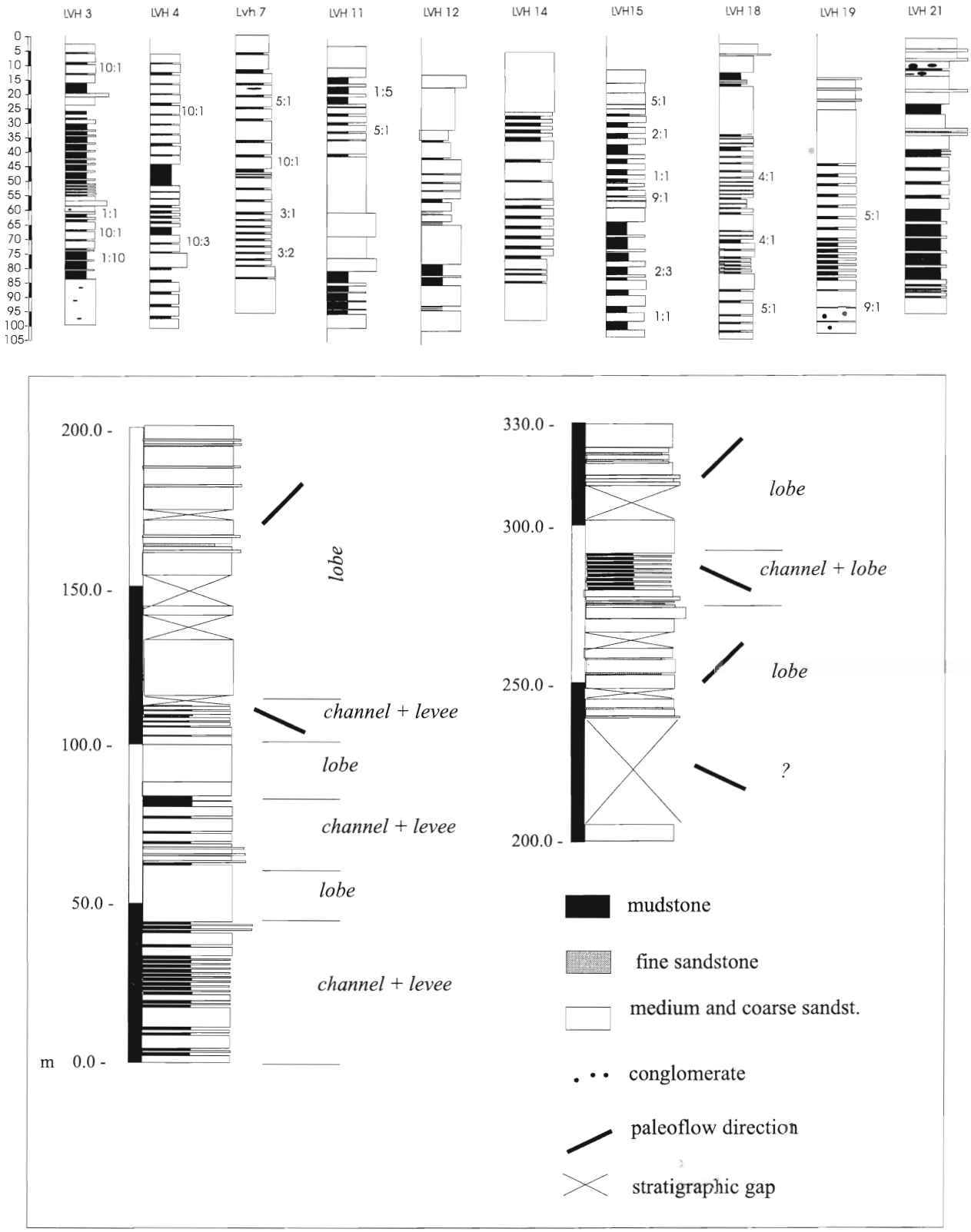


Fig. III.14. Sedimentary logs from several boreholes and outcrops showing vertical succession of sediments and sandstone: mudstone ratio in the Levoča sector of the CCP Basin. Note the change of sediment paleoflow suggesting longitudinal and lateral input of sediments. The sediments are interpreted as channel and lobe transition deposits.

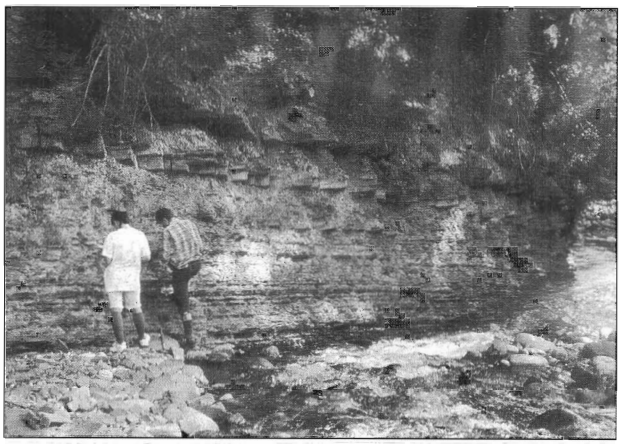


Photo 12. Alternating thin beds of sandstone and mudstone interpreted as overbank deposits in a turbidite system.

at the base of the sedimentary succession (Borové Fm.). They are overlain by thick (up to 1000 m) shales of Huty Fm. which, in turn, are overlain by rhythmical flysch of Zuberec Fm. which is around 1600 m thick. The deposits of Zuberec Fm. are locally missing and the whole succession is capped by sandstones of Biely Potok Fm. The thickness of the Biely Potok Fm. deposits, estimated on the basis of boreholes and outcrops, is around 700 m. At studied sections in surroundings of Tichý Potok village a thickness of more than 500 m of prevailingly coarse-grained deposits (mostly sandstones, minor pebbly sandstone and conglomerates) has been confirmed.

Well-exposed sediments in the area of Levočské vrchy Mts. enabled a detail sedimentological analysis. We were able to recognize several facies and facies associations suggesting origin of the sediments in the channel – lobe transitional area.

One of the most frequently occurring facies association consists of thick sandstone beds alternating with thin sandstone and shale beds (zebra facies, Fig. III.14, Photo 12). The thickness of thick sandstone beds varies from 20 cm to 1 m. The beds are often amalgamated, erosively and sharply based. Flute and tool marks are very common at their bases suggesting paleocurrent direction toward northwest. The sandstones are medium- and coarse-grained, massive or normally graded. Usually they represent Bouma's T_a division, only scarcerly T_{ab} divisions occur. They are classified as medium-grained, sublithic arenites sensu Pettijohn et al. (1972). Conglomerates or pebbly sandstones occur scarcerly on the base of the beds. The thickness of this thick sandstone bed complex is from 50 to 200 cm.



Photo 13. Lateral tapering of thin sandstone bed typical for levee environment.

The thick sandstone beds alternate with thin sandstone and shale beds often marked as zebra facies (Nelson and Nilsen, 1997). The sandstones comprising thin beds are fine- to medium-grained and show Bouma's T_{ae}, T_{be} and T_{bce} divisions. Starving ripples are common. Sharply based sand beds are 2 cm to 20 cm thick. Their geometry is very irregular, they often pinch out laterally (Photo 13). Soft-sediment deformation is very common. The shales comprise sharply-based beds of the same thickness like sandstone beds. Shales are massive, occasionally the ripple cross-lamination occur. The thickness of these thin sandstone-shale complexes varies from 20 to 50 cm.

The described facies association suggests deposition of the sediments in a submarine fan channel and levee subenvironment. The channel-fill deposits are composed of thick sandstone beds. The alternating thin sandstone and shale beds comprising zebra facies are interpreted as levee deposits. They were deposited on flanks of channels by spilling over the turbidity currents from the conduits. This interpretation is strengthened by the occurrence of starving ripples, indicating a shortage of sand in suspension typical for overbank facies, the irregular extent of beds pinching out laterally and soft-sediment deformations often occurring on levee slopes.

Another frequent facies association in the investigated sedimentary succession of the Levočské vrchy Mts. consists of thick to very thick-bedded, medium-grained to granule-sized sandstones and pebble sandstones separated by discontinuous fine-grained sandstone partings. The sandstone beds are often amalgamated. Individual sandstone intervals are 10–15 m thick. The internal structure of these intervals consists of 20–70 cm thick amalgamated sandstone beds. The sandstones and pebbly sandstones are mostly normally graded and massive. Many beds, which macroscopically show massive structure, were found to be normally graded in the oriented thin sections. The most common are R_2, S_1, S_2 and S_3 divisions sensu Lowe (1982), occasionally fine-grained horizontal laminated (Bouma's T_d division) sandstone partings occur. In pebbly sandstone the pebbles are either organized into layers or irregularly distributed. The sole marks are rare, all indicating paleocurrent direction toward southwest. Water-escape structures and soft-sediment deformation are common. The sandstone beds rest with either flat sharp contact on each other or they form scours.

The sediment succession, its vertical and lateral development, the character of beds and the lack of channelization suggest deposition in the suprafan lobe subenvironment. Prevailing conglomerates, pebbly conglomerates and massive sandstone, representing S_1, S_2, S_3 and R_2 divisions sensu Lowe (1982), suggest deposition by

high-density turbidity currents (Lowe, 1982; Walker, 1978). Most of these deposits probably originated from traction and traction-carpet stage as showed by Lowe (1982). The occurrence of T_d Bouma's division suggests deposition from suspension in diluted turbidite flow, probably of a subsequent sedimentation stage.

The boreholes drilled in the described area revealed: 1) up to 25 m thick sandstone, pebbly sandstone and conglomerate complexes; 2) up to 5 m thick sandstone, pebbly sandstone and conglomerate complexes consisting of thick beds; 3) complexes composed of alternation of thin bedded sandstones and shales (Gíret, 1991; Fig. III.15). Athough we could not observe sediment samples from the boreholes, the described deposits imply an origin in the suprafan subenvironment (up to 25 m thick sandstone complexes), and an origin in a channel-and--levee subenvironment (up to 5 m thick sandstone complexes and complexes consisting of alternating thin beds of sandstones and shales).

Implication for basin history

The sedimentary succession at studied sections and boreholes consists of channel-and-levee deposits and suprafan deposits. The channel-and-levee facies association suggests an existence of depositional/erosional (sensu Normark, 1970) or aggradational (sensu Clark and Pickering, 1996) channels. This kind of channels is associated with large terrestrial drainage basin areas (Kenyon, 1992), high channel sinuosity, lower slopes and finer-grained sediment that aids suspension in turbidity currents (Clark and Pickering, 1996). The correlation of borehole cores shows increasing interconnectivity of sandstone bodies toward the top of the profile. This may be a result of multilateral channel amalgamation determining connection of individual channel-fill elements or, more likely, it reflects alternation of channel--and-levee and suprafan deposits (see below). The width of the channels in the lower part of the section is estimated to vary from 200 m to 2 km. Depth of the channels is from 20 to 40 m. The thickness of levee complexes is variable. The borehole profiles suggest a thickness up to 40 m.

The suprafan deposits indicate a change of depositional style connected with the high-density unchannelized gravity (mostly turbidity) flows. This kind of deposition is typical for areas with intensive uplift of basin margins (source areas) and narrow shelf. It is often described from tectonically-controlled basins where abrupt uplift/subsidence events result in formation of turbiditic aprons (Chan and Dott, 1983; Reading and Richards, 1985; Stow, 1985). The formation of such aprons originated by flows entering the basin perpendicularly would be consistent with the paleoflow indications found in the channel-and-levee deposits and in the suprafan deposits. The change of the paleoflow direction from the SE–NW in the channel-and-levee deposits to the NE–SW in the suprafan deposits suggests a paleoflow pattern perpendicular to the basin axis in some phases of the basin development.

The correlation of deposits between two basic studied sections and boreholes shows an alternation of channel--and-fill deposits and suprafan deposits (Fig. III.14). The alternation may have been caused by more factors e. g. basinward or lateral shift of a suprafan, change of the sediment input or tectonics. The presence of channel-and--fill and suprafan deposits alternation may have implication for the interpretation of basin stratigraphy. The deposits resembling channel-and-fill deposits from studied sections were described as Kežmarok Member which forms the uppermost part of the Zuberec Formation (Gross, 1998). However, at the studied localities these deposits are overlain by 160 m thick deposits typical for Biely Potok Formation, which are, in turn, again overlain by

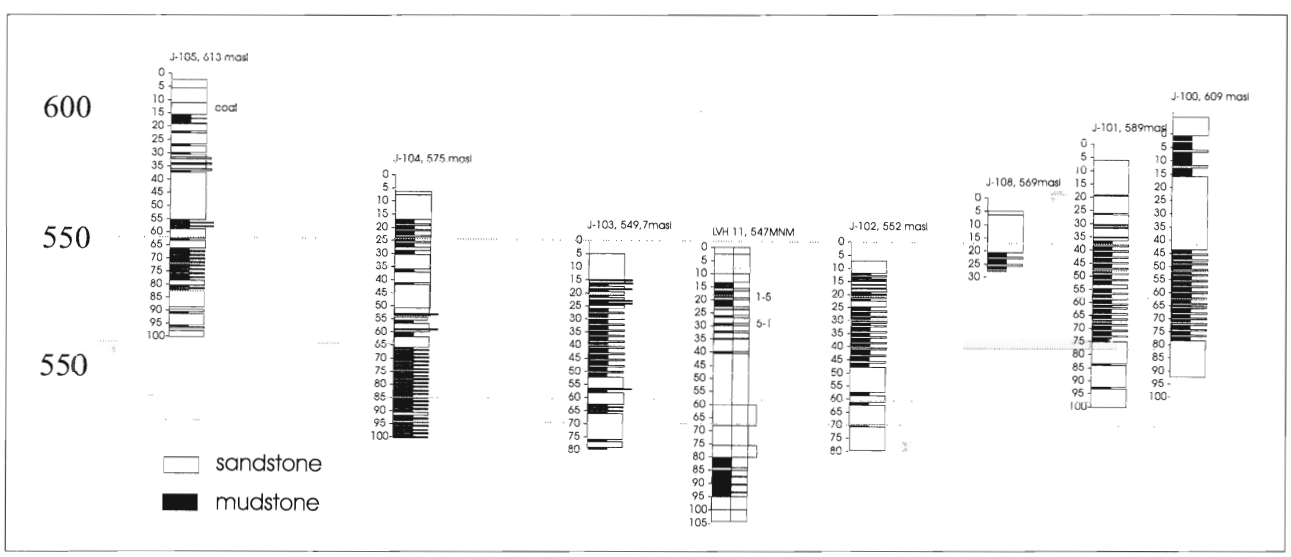


Fig. III.15. Profile of boreholes showing lateral and vertical distribution of sandstones and mudstones forming channel and levee deposits of the turbidite system in the Levoča Mts.

the channel-and-levee deposits (Kežmarok Member?). According to this finding the Kežmarok Member (channel-and--levee deposits) could be a part of Biely Potok Formation. The correlation of these deposits also suggests the Late Oligocene–Early Miocene age (NP 24, 25/NN 1/2) for all investigated deposits.

Axial deep-water depositional system of the CCP Basin

Morphology of basin belongs to important factors controlling evolution of deep-water sedimentary system. Because of various obstacles, elevations and depressions turbidity and contour flows are reflected and deflected resulting in variable spatial distribution and lithology of sediments. Tectonics, which triggered opening of the CCP Basin, had also critical influence on its morphology.

tions superimposed on each other or partly also assing into each other laterally (Fig. III.16). The scheme may be well applied for geological mapping, however, from the sequence stratigraphy point of view the general cake layer stratigraphy may be questioned. The scheme is recently explained by some authors as the phase of starving basin when basin is only supplied by fine-grained sediments (deposition of Huty Formation) or by terminal stage of the basin fill (deposition of Biely Potok Formation; e. g. Soták et al., 2001).

A detail analysis of sedimentary basin fill shows variable development of sediments along the basin axis. The change of thickness and morphology of sandstone bodies and nett to gross ratio suggest variation of erosive ability of turbidite flows from place to place. This contrasts with philosophy of gradually decreasing velocity

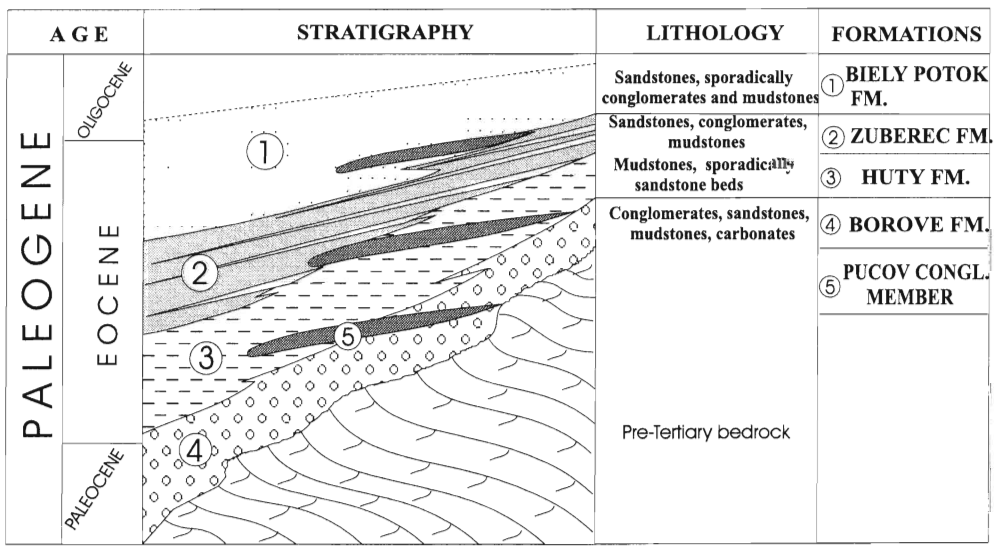


Fig. III.16. Lithostratigraphic column of the Subtatric Group forming basin fill of the CCP Basin (after Gross et al., 1984).

During the first stages we assume opening of small, laterally restricted basins with depositional processes described at the example from the Šambron–Kamenica zone (see above). The phase of extensional opening of the basin resulted in gradual subsidence of the area south of the Pieniny Klippen Belt. The extension documented from a wide area of the CCP Basin caused unification of the individual depocentres and formation of an elongated shape of the basin. This shape affected evolution of axial deep-water depositional system, which some authors defined as longitudinal turbidite system of the basin (e. g. Marschalko, 1965, 1966; Baráth et al., 1997; Gross et al., 1996; Soták et al., 2001). The authors assume sustainable turbidite flows entering basin from up till now non-identified source area located southeast of the present basin and continuation of these flows along the basin longitudinal axis as far as Spišská Magura region. General lithostratigraphic scheme of the basin fill presented by Gross et al. (1984) shows four basic forma-

of turbidity flow resulting in Mutti and Ricchi Lucchi's "classical scheme" of inner, middle and outer fan (Mutti and Ricchi Lucchi, 1972). In the region of the Spišská Magura, where we should expect according to this idea the fine-grained deposits of diluted turbidite flows we record coarse-grained bodies sandwiched by mudstones, thick beds of sandstones and synsedimentary folds indicating positive relief. Sedimentological analysis of thick-bedded sandstones in the Levočské vrchy Mts. showed their development in the channel – lobe transition thus in the deepest part of the turbidite system, which contrasts with the idea of its belonging to the terminal stage of the basin fill.

The architecture of the basin fill strongly suggests decisive role of tectonics for the development of depositional systems in the CCP Basin. During the extensional stage of the basin evolution, the eastern part of the elongated basin had general dip toward west and northwest. The natural dip of the basin affected prevailing circulation of

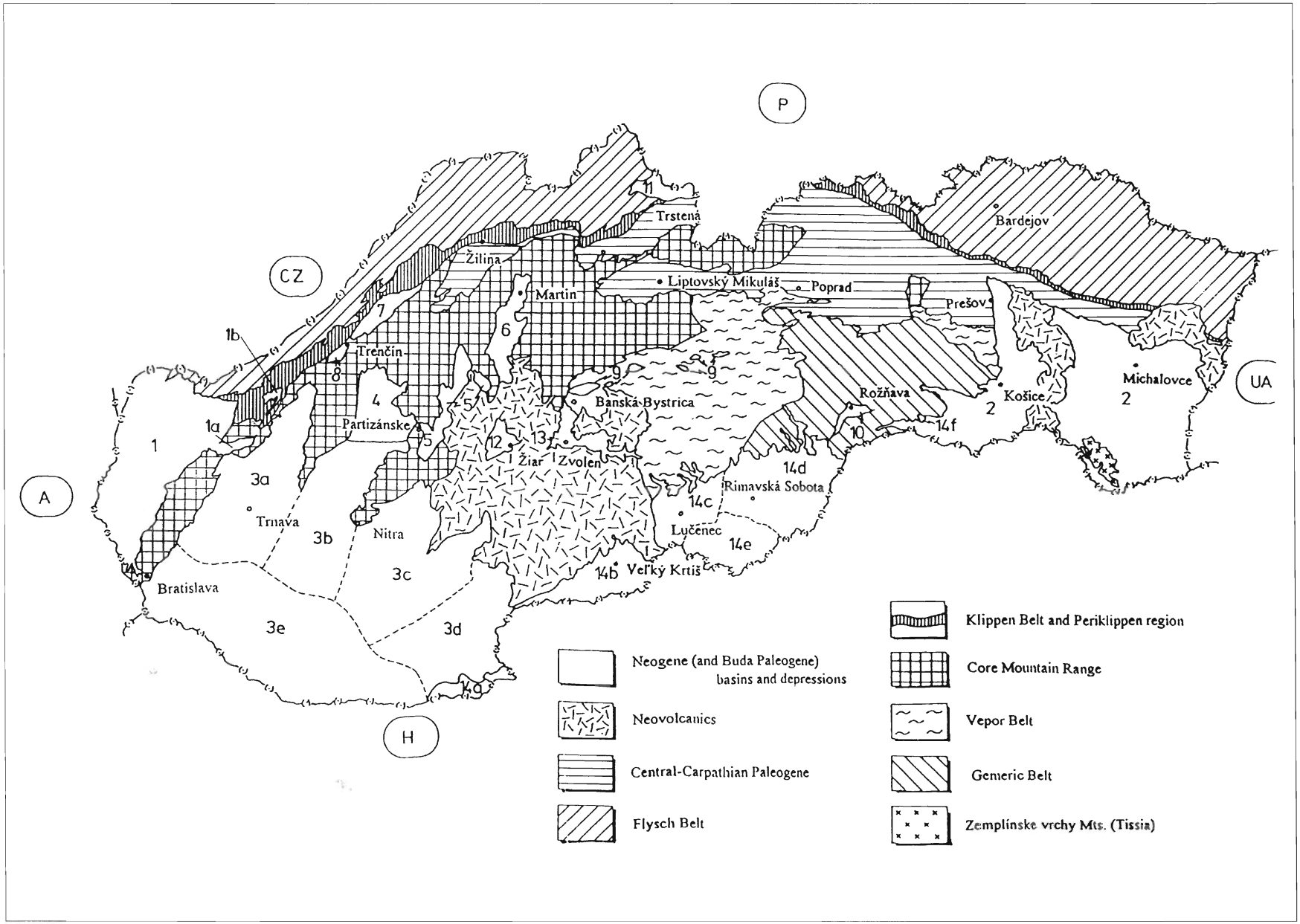


Fig. III.17. Localization of Neogene depressions in the Slovak part of Western Carpathians. The largest basins are represented by Vienna, Danube, South Slovakian and East Slovakian basins.

water masses from southeast toward northwest. Sediment supply was not constant and mainly depended on the tectonic uplift of individual blocks adjacent to the basin. The sediments entering the basin laterally were gradually turn into the axial SE–NW direction (see also Marschalko, 1965). Because at different places different amount of sediments entered into the basin, the sedimentary fill is variable and differs from place to place. The fine-grained, pelitic deposition occurred during the entire evolution of the basin, however, it only comprised the background sedimentation and the dominant role played the lateral input of sediments.

The basal, shallow-marine deposits of Borové Formation are commonly overlain by mudstones of Huty Formation. However, the deposition of both basal formation and overlying mudstones was partly contemporaneous – during the deposition of basal formation at the southern margin of the basin mudstones were deposited further northward. Similarly, when mudstones were deposited on the basal formation at the southern margin of the basin, alternating sandstones and mudstones were deposited in the north. This questions the idea of starving basin applied for the entire area of the CCP Basin.

It seems, that during transgression triggered by widened subsidence of the basin, mobilization of sediments, which were in the subsequent phase supplied into the basin, required certain time. During this time the deposition had really fine-grained characteristics. However, only particular part of the basin was undersaturated by sediments while in the other parts of the basin there could be other type of sedimentation in progress.

III.3 Evolution of the Buda (Hungarian) Paleogene Basin

The Buda Paleogene on the territory of Slovakia extends in the depressions of Southern Slovakia (Ipeľská, Lučenská, Rimavská kotlina depressions) as well as it builds up the slopes of the Cerová vrchovina Upland. Beside it the Buda Paleogene occurs at the town of Štúrovo (Štúrovo Paleogene) in the area geographically belonging to the Danube Basin. Eastward it outcrops in the Turnianska kotlina Depression being the westernmost partial depression of the East Slovakian Basin at Drienovec village.

The basin of the Buda Paleogene originated mostly on the lithospheric fragments escaping from the Central Alps and North–Western Dinarides. In respect to the contemporaneous subduction of the Outer Carpathians the Buda Paleogene Basin is in back-arc position.

The most complete Buda Paleogene sequence is preserved in the area of Štúrovo (Fig. III.18). The age of the Štúrovo Paleogene is Lutetian – Egerian. The Paleogene of Drienovec is approximately of the same age: from the Eocene to Egerian. The Buda Paleogene covering the largest area being distributed in South Slovakian Depressions is Kiscellian to Egerian in age.

Eocene

Štúrovo Paleogene

Lutetian and even younger Paleogene deposits at Štúrovo town were encountered by boreholes. The oldest are detritic basal deposits with limestone layers passing upwards into claystone. Those deposits originated in fluvial and lacustrine environment (Seneš, 1960, 1962) and may be correlated with the Darvastö Formation in the Transdanubian Mts. (Vass, 2002). Detrital basal deposits are covered by the Obid Member – the coal-bearing deposits of swamps being a member or equivalent of the whole Dorog Formation in Transdanubian Mts. Following marine transgression covered the non-marine deposits by the Turritella Marlstone and Coral Member (Seneš, l. c.) – deposits originated on marine shelf. They are correlated with the Szöc Formation of Transdanubian Mts. (Vass, 2002), its age is Lutetian – Bartonian.

The Štúrovo Paleogene marine sedimentation continued during the Bartonian. The motley deposits with thin coal seams and sandstone (Striatus Member) rich in Nummulites (N. striatus) originated in shallow waters conditions (Seneš, l. c.). Those deposits are correlated with the Tokod Formation of Transdanubian Mts. (Vass, 2002). Following organodetritic deposits: Nummulites – Orthofragmina Member and biotite tuffaceous sandstone indicating distal volcanism (Seneš, l. c.) are correlated with the upper part of Padrag Formation (Bartonian – Priabonian) in the Transdanubian Mts. (Vass, 2002).

The Priabonian is represented by the Nummulites Member consisting mainly of Nummulites limestone passing into calcareous sandstone (Seneš, l. c.). Both limestone and sandstone originated in shallow marine (shelf) environment and are considered as equivalent of the Szépvölgy Limestone in the Transdanubian Mts. (Vass, 2002).

The above described limestone and sandstone are overlain by the calcareous claystone and marlstone of the Bryozoa Member of Seneš (l. c.), indicating deeper marine environment. The member is correlated with the Buda Marls and/or Piszke Marls of the Transdanubian Mts. (Vass, 2002) According to Báldi (1986) the fauna of the Buda Marls indicates the shallow bathyal environment. Its age is Priabonian – Early Kiscellian.

Eocene – Oligocene

Turňa Depression (Drienovec)

In the Turňa Partial Depression at the village Drienovec there is preserved an erosional remnant of the lithologically extremely diversified Somodi (Somody) Formation (Vass et al., 1994). The formation originated at the NE margin of the Buda Paleogene Basin and is mostly non-marine. The lower portion of the formation is unknown. The oldest rocks of the formation were found by the boreholes and are represented by laminated algal limestone originated in a near shore lagoon of the carbonate shelf.

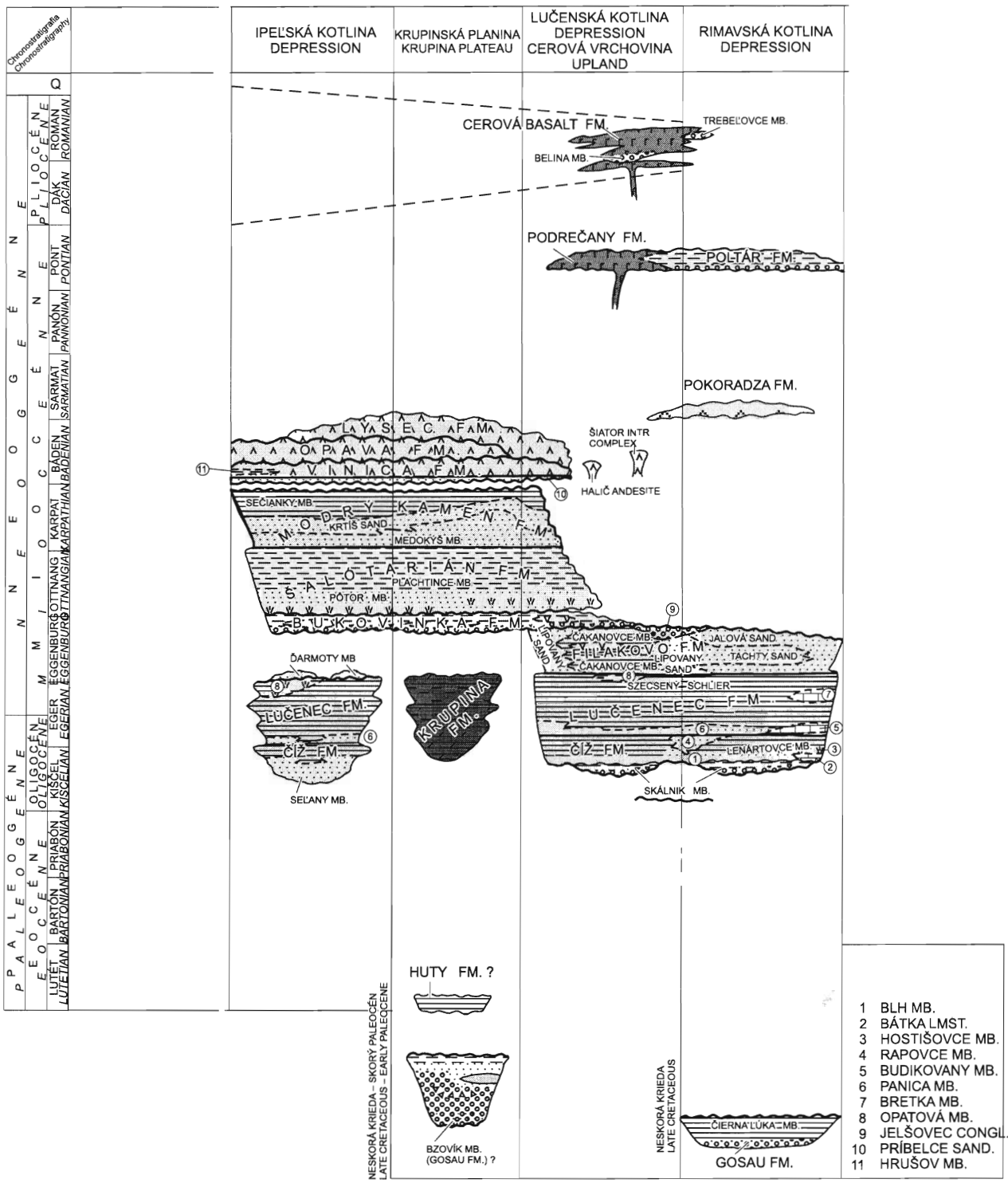


Fig. III.18. Lithostratigraphy of Southern Slovakia Neogene – Paleogene. 1 – Blh Mb., 2 – Bátka Limestone, 3 – Hostišovce Mb., 4 – Rapovce Mb., 5 – Budikovany Mb., 6 – Panica Mb., 7 – Bretka Mb., 8 – Opatová Mb., 9 – Jelšovec Conglomerate, 10 – Príbelce Sandstone, 11 – Hrušov Mb.

The algal limestone laterally passes into the dark-gray massive limestone with glance coal seams and coal laminae. Those rocks originated in a lagoon where sometimes a paludal environment occurred. Deposits of the lagoon are covered by upward graded coarse conglomerate with freshwater limestone layers. The conglomerate is a river channel lag deposit and limestone indicate temporal lacustrine environment. Coarse clastics are overlain by

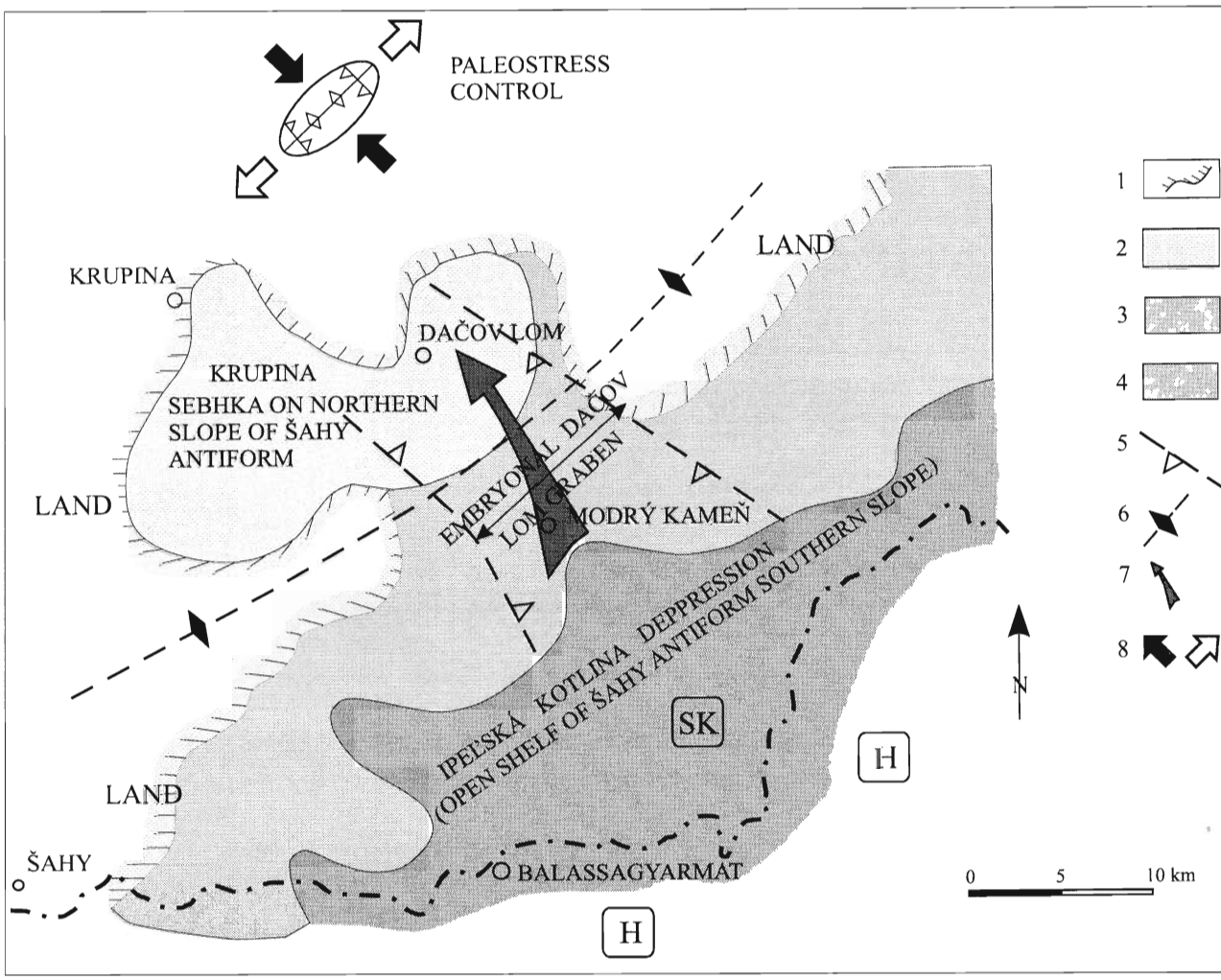


Fig. III.19. Barrier effect of the Šahy Antiform as a decisive factor for the Krupina Sebhka origin on the northern slope of the Šahy Antiform, middle of the Kiscellian. The penetration of marine water through the Šahy Antiform into the Sebhka occurred by way of the faults of the embryonic Dačov Graben. 1 – shoreline, 2 – clastic littoral deposits (shallow water), 3 – pelitic deposits of the neritic zone (deep shelf), 2, 3 – Číž Formation, 4 – Krupina Formation: Sebhka evaporites, 5 – normal fault, 6 – antiform axis, 7 – direction of marine incursions into the Sebhka.

motley sandy deposits with glance coal intercalations and/or seams. They originated on the river banks and alluvial plain with swamp and bog. Within those deposits the pebbly sandstone occurs representing the mudflow slumps. The formation is overlain by dark-gray organoclastic limestone with laminae of glance coal deposited in a lake. The thickness of the whole formation is about 500 m. The age is Eocene – Oligocene proved by freshwater mollusc fauna (Bůžek et al., 1987, 1989; fide Vass et al., 1994).

Kiscellian

Both areas of Eocene sedimentation at Štúrovo and in the Turňa Depression were uplifted and eroded after the Eocene. In the Middle Kiscellian a new marine transgression reached the South Slovakia of present day. The sea flooded also the South Slovakian Depressions. All Kiscellian sediments are ranged into the Číž Formation consisting of 7 members including two pre-transgressive ones. The pre-transgressive, mostly fluvial deposits are gathered into the Skálnik and Seľany members. They consist of motley kaolinitic clay/claystone, silt/siltstone, conglomerate and/or breccia with detritus of immediate basement and thin layers of coal.

The lowermost marine sediments of the Číž Formation are grouped into the Blh and Hostišovce members as well as in the Bátka Limestone (Fig. III.18). They represent the transgressive depositional sequence. The Blh Member (Vass and Elečko, 1982) consists of coarse clastics: breccia, conglomerate and coarse sandstone. They originated in littoral marine environment and are considered to be Kiscellian on the basis of stratigraphic superposition.

The Hostišovce Member (Vass and Elečko, 1982) consists of gray, greenish clay/claystone and silt/siltstone sometimes calcareous, friable sandstone and fine-grained conglomerate. The typical feature of the member is the presence of laminae and thin coal seams. At Bátka village clastic deposits are replaced by laminated micritic lime-

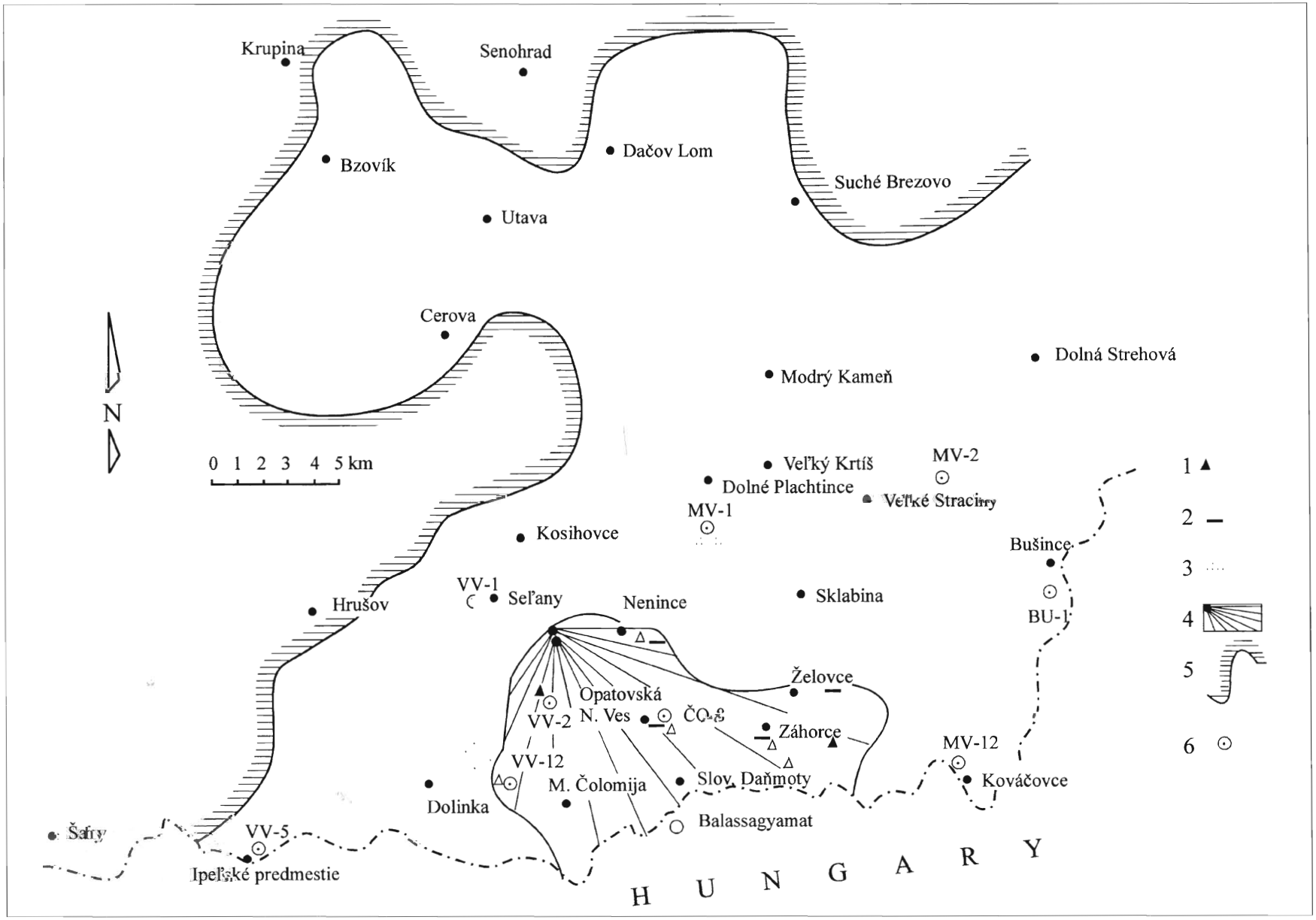


Fig. III.20. Extension of the Opatovce Member in the Ipeľská kotlina Depression. 1 – brackish macrofauna, 2 – coal seams, 3 – gravel and friable conglomerates, 4 – Opatovce delta (Opatovce Member), 5 – extension of the Egerian (Lučenec Formation) in the Ipeľská kotlina Depression, 6 – boreholes.

stone. The member originated in a lagoon or in a marsh on the sea beach. The age is proved by marine foraminifers as well as by sporomorphs.

The Bátka Limestone (Jurkovičová et al., 1990) is formed by the sponge biodetrital limestone and intraclast limestone originated on the offshore as well as on the onshore slope of barrier islands.

The Lenártovce Member (Vass and Elečko, eds., 1992) is built up by gray, calcareous friable claystone and siltstone in the lower part with sandy lamination or lenticular bedding. The member contains marine foraminifers mollusc sand nannoplankton and represents the open shelf and basinal (shallow bathyal) facies.

In the Buda Paleogene Basin northern margin a delta prograded. The deposits of delta, the Rapovce Member (Vass and Elečko, eds., 1992), consist of sand and/or sandstone with coalified plants and glance coal fragments. The Kiscellian age is proved by poor foraminifer assemblage.

Egerian

The Egerian in Southern Slovakia is represented by the Lučenec Formation (Vass and Elečko, 1982; Fig. III.18). In deep basinal areas the transition from the Číž Formation to Lučenec Formation is gradual. At the basin margin the Lučenec Formation transgressively overpasses even the littoral deposits of the Číž Formation. The basal part of formation is represented by Panica Member built up by friable sandstone with conglomerate intercalation or the pebbles dispersed in sandy matrix which signalize a transgression in littoral environment. Another littoral facies are organodetrital limestone and fine-grained conglomerate passing into calcareous sandstone with Lithothamnium and large foraminifers including Miogypsina septentrionalis and Lepidocyclina morgani – the Budikovany Member, Early Egerian in age (Seneš in Steininger et al., 1975). Lithologically very similar is the Bretka Member consisting of detrital limestone and breccia and marine molluscs fauna. The member originated in littoral or cliff zone. It is considered to be the marginal facies of Buda Paleogene Basin. The presence of Miogypsina gunteri and M. tani indicates the Late Egerian age (Seneš in Báldi and Seneš, 1975; Báldi, 1986).

The basinal deposits of the Lučenec Formation are represented by the Széczeny Schlier (Báldi, 1971; Hámor, 1985). It is a dominant member of the formation consisting of the gray calcareous siltstone rich in marine molluscs, foraminifers and nannoplankton. According to mollusc assemblage, the Schlier originated in the marine open shelf (Báldi, 1986), according to foraminifer assemblage the Széczeny Schlier originated in shallow bathyal environment (Kantorová, 1981–1985; fide Vass and Elečko, eds., Šutovská, 1990).

To the end of the Egerian in the Buda Paleogene Basin the deltas prograded signalizing the basin termination. The Opatová Member consists of delta sediments prograding into the Ipeľská kotlina Depression (Holcová-Šutovská et al., 1993; Fig. III.20). Another delta prograded in the area of Štúrovo and is represented by the Kováčov Sand (Hoffman, 1872; Seneš, 1958). The predominant sand passes upward into calcareous clay.

During the Late Kiscellian and Egerian on the NW margin of the Buda Paleogene Basin behind and on-shore of the Šahy Antiform a sebkha persisted (Fig. III.19). There were claystone, calcareous claystone and dolostone deposited. The evaporitic sedimentation signalizes the presence of anhydrite, celestine and chemogenic calcite. There are the acid glassy tuff intercalations (Planderová and Marková, 1972). The sebkha deposits were designated as the Krupina Formation (Vass, 1989, 1995).

III.4 Evolution of Neogene basins in the Western Carpathians

Evolution of the Western Carpathians basins during Neogene was still controlled by the character of subduction between the Carpathian Orogene and the North-European Platform. However, other geotectonic events contributed decisively to this evolution. It was, in particular, the tectonic escape of lithosphere fragments from the area of Eastern Alps as well as the uplift of the Pannonian asthenolith with the subsequent collapse of the Pannonian lithosphere.

In the area of Outer Flysch Carpathians, on the Slovak territory, the sedimentation continued only in isolated piggy-back basins situated on the Magura thrust unit (Poprawa et al., 2001). Sedimentation along the inner side of the Carpathian arc continued in some areas of the Central Carpathian Paleogene basin and in the area of the Hungarian Paleogene Basin (Buda Paleogene). At the end of Egerian the Buda Paleogene Basin disintegrated and was substituted by Fiľakovo–Pétervására Basin.

At the beginning of the Neogene under conditions of oblique stress, which resulted from oblique convergence between the Alpine-Carpathian Orogene and North-European Platform, the first nuclei of extensive Neogene basins – the Vienna and East Slovakian basins started to form. At the same time the Danube Basin and several intramountain depressions started to open, too (Fig. III.17). These basins and depressions became the main areas of sedimentation during the Neogene.

Eggenburgian

Vienna Basin

Erosional remnants of Eggenburgian sedimentary area of Vienna Basin (Fig. III.21a) appear in several partial depressions and elevations, which controlled the thickness and facies of the sediments. Among the depression structures from west to east there belongs the W–E elongated Lužice Depression, which passes into the narrow NW–SE Kopčany Depression. This, in turn, continues to SW–NE extended Štefanov Depression situated in the area of the Klippen Belt which separates it from Senica Depression of similar direction (Jiříček, 1988). Following erosional

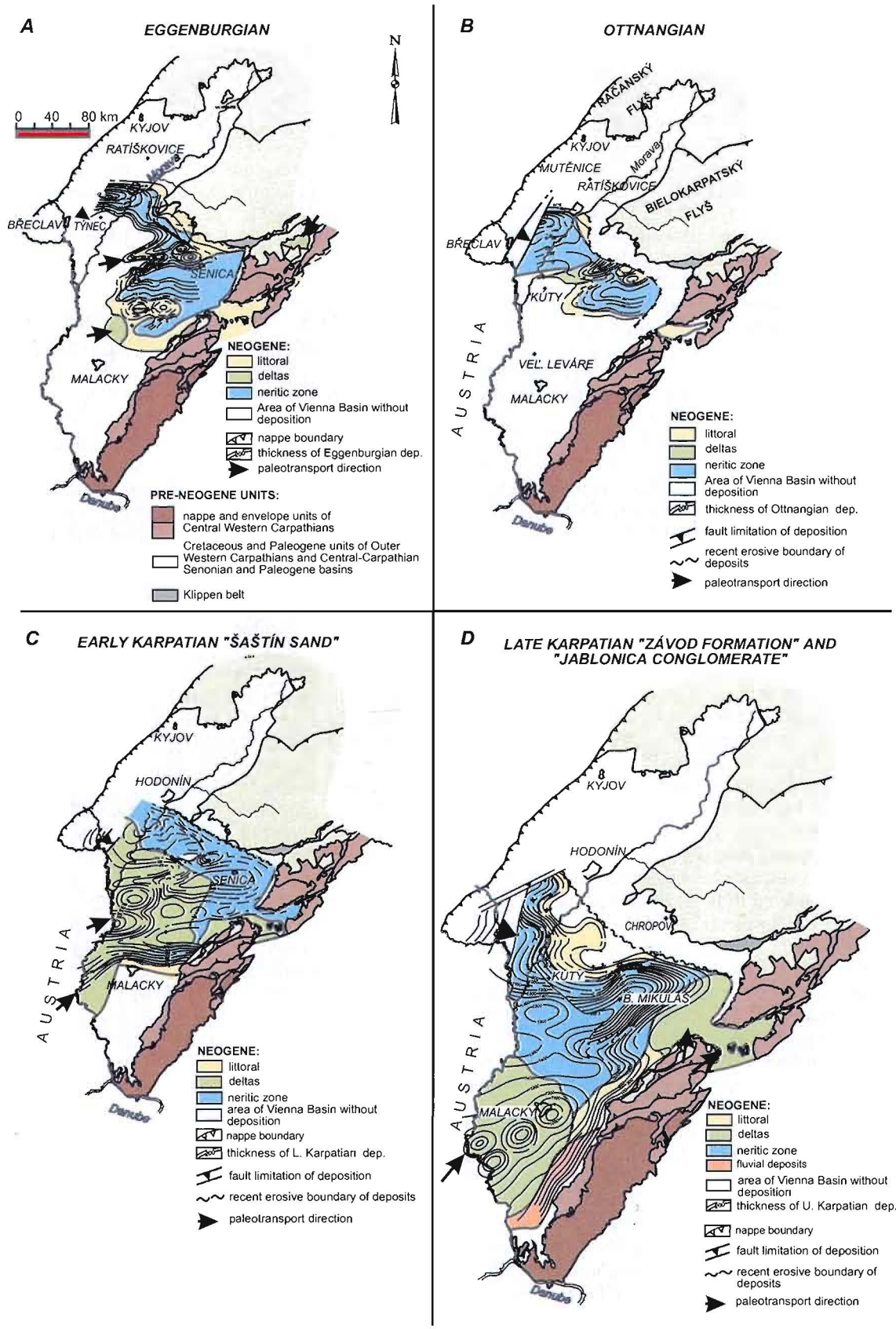


Fig. III.21. Eggenburgian, Ottnangian, Lower and Upper Karpatian depositional systems in the Vienna Basin.

interruption this depression continues NE in Vadovo Depression. Along the NW margin of the Malé Karpaty Mts. there appears a weakly pronounced Plavec Depression passing eastnorth-eastward into the Dobrá Voda Depression (Baráth and Kováč, 1989). Among the most prominent elevations in the area belong those of the Klippen Belt, then Brezová and Čachtice elevations as well as the Lakšáre Elevation. The southern limit of Eggenburgian sediments follows the line of localities of Týnec, Kopčany, Gbely, Štefanov, Borský Jur, Závod and Rohožník. The Eggenburgian sediments continue eastward into the Dobrá Voda and Blatná depressions of the Danube Basin. The southern boundary of these sediments may be considered to be the original paleogeographic shoreline (Jiříček, 1988). The northern, erosional limit is observable at the line between Podbranč, Chropov and Skalica.

The extent of the Eggenburgian sediments in the Vienna Basin indicates in part the original paleogeography of the area controlled by Savian orogenic movements which resulted in an archipelago sea with dissected shoreline and clastic sedimentation (Baráth and Kováč, 1989). Depositional systems of Eggenburgian sediments in the Vienna Basin show distinctively transgressive character.

The early stages of subsidence in depressions are recorded in the deposition of variegated alluvial clay and sand of Strážov Formation (Jiříček and Seifert, 1990), while gravitational talus along the foothill of mountains deposited. During the transgression of Eggenburgian sea the lowest depressions were flooded first in which alluvial deposits were reworked by waves into basal clastics. Along the sea margin we can find mostly transgressive depositional systems of sandy shelf bars. At the NE margin of the Vienna Basin and in the surroundings of Šaštín upward deepening depositional systems of rocky cliffs, shoreline front and shelf evolved.

In the area of Chropov the basal part of the depositional system consists of coarse-grained Chropov Conglomerate with blocks up to 2 m in diameter. Littoral depositional environment is documented by occurrence of molluscs (Čtyroký, 1961) and abundant traces of boring organisms on the surface of pebbles (Baráth and Kováč, 1988). The grain size of conglomerates diminishes upward and locally they alternate with sandstones. Genetic analysis of pebbles suggests deposition in a shallow littoral environment in shoreline bars (Ambrož, 1980). The pebbles of the Chropov Conglomerate originated exclusively from the Magura Unit of the Outer Western Carpathians. Deepening of the sedimentary area and change of the source area is indicated by the composition of the overlying Winterberg Conglomerate which are interpreted as a product of submarine slumps. Slumping from margins into the deeper parts of the basin is also indicated by occurrence of clay chips and armoured clasts (Ambrož, 1980).

In the segment between Podbranč and Myjava there is evidence of direct transgression of the Eggenburgian sea over the Klippen Belt. The basal part of the depositional system near Podbranč is represented by bouldery Podbranč (Brezovo) Conglomerate (Kodym and Matějka, 1923), which grade upward into fine-grained conglomerates and sandstones. In the Myjava surroundings the structural features of Brezovo Conglomerate indicate that they formed in a transgressive depositional system of shoreface bars where deposition was affected by E–W flow along the shoreline and at the same time by waves from the south. The littoral conditions are also documented by abundant boring organisms (Baráth and Kováč, 1988). In the area of Hradište pod Vrátnou the pebbles of Podbranč Conglomerate are almost exclusively composed of Upper Triassic Hauptdolomite of underlying Jablonica Unit. The conglomerates were deposited in dissected rocky shoreline with high dynamics as suggested by blocks up to 5 m in diameter. The boulders like those of the underlying rocks, also show traces of boring marine organisms. The grain size diminishes upward and there is an increase of sandy beds.

The SE part of Štefanov Depression and the NE part of Vadovce Depression included sea bays with bay-type deltas which in the depositional system passed upward into estuary deposits. In Vadovce Depression the weak coal seams appear in sediments of the delta plain. Semi-brackish character is also shown by Eggenburgian deposits in the surroundings of Studienka and Lakšárska Nová Ves (Jiříček, 1983), suggesting the location of bay delta in the area of Závod.

The sandstones of the shoreline front with littoral fauna in the area of Podbranč, Dobrá Voda and Vadovce depressions retrogradationally interfinger with shelf "schlier" sediments. The neritic schlier facies of Eggenburgian Lužice Formation (Buday and Cicha, 1956; Vass, 2002), gradually extended from depocentres of the Vienna Basin toward its margins. Terrigenous, mainly clayey sediments, from considerably peneplained sources located in the south, are found in the southern parts of the basin (Jiříček, 1988).

The Eggenburgian sediments, known from boreholes, represent the entire range of marine depositional environments. Coarse-grained clastic sediments in the southern part of the basin in the area of Lakšárska Nová Ves, Studienka and Šaštín are of brackish and shallow-water origin. The conglomerates alternate with pelitic beds.

Shallow-marine sublittoral development in the area of the basin with flysch basement continues as far as Hodonín, Lužice and Mikulčice being represented by marginal depositional systems such as Chropovce and Winterberg conglomerates with rich mollusc fauna. Further southward and eastward the sediments merge laterally with marine basin development typified by gray calcareous clays with thin beds of micaceous sand ("schlier" in Austrian literature). The basin development gradually extends over sublittoral sediments due to the transgression progressing toward the marginal areas.

Danube Basin and intramountain depression

Marine transgression during the Eggenburgian advanced from the Alpine foredeep eastward across the flysch accretionary prism of the present northern part of the Vienna Basin. The sea gradually incursed further northeastward as

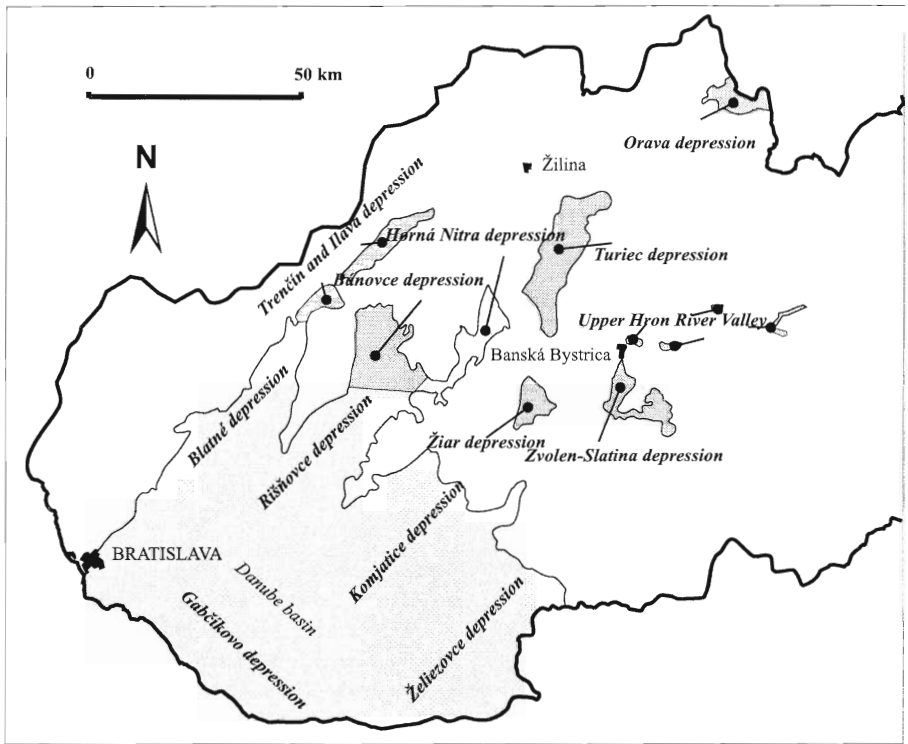


Fig. III.22. Localization of the Danube Basin and intramountain depressions described in the text.

far as the area of Blatné Depression of the Danube Basin, Bánovce and Horná Nitra depressions. These sedimentary areas, where the basement of Eggenburgian, Ottnangian and Karpatian sediments consists of Central Carpathian Paleogene units, represent wrench-fault furrow basins.

The oldest Neogene sediments of Eggenburgian age (Figs. 22 and 23) are known from northern margins of the Danube Basin – Trenčín, Ilava, Bánovce, Horná Nitra and Turiec depressions. The Eggenburgian marine sedimentary area at the northern margin of the Central Western Carpathians was paleogeographically connected with the sedimentary area in the northern part of the Vienna Basin.

In the Blatné Depression the basinal development, represented by Čausa Formation (Gašparik in Steininger et al., 1985), is characterized by gray calcareous clay, sandy claystone and siltstone with thin beds of rhyodacite tuff. The sediments are thick up to 450 m.

The marginal and/or basal facies are represented by conglomerates and sandstones of Kľačno Conglomerate defined by Gašparik in Steininger et al. (1985). Their thickness ranges from a few metres up to 90 m.

In Bánovce Depression the base of the Eggenburgian is represented by Kľačno Conglomerate consisting of conglomerates and sandstones with thin beds of pelitic rocks. They unconformably overlie the considerably dissected basement composed of Mesozoic and Paleogene rocks (Brestenská, 1983). The conglomerate clasts are exclusively composed of Mesozoic carbonate rocks (limestones and dolomites), with minor occurrences of quartz. Kľačno Conglomerate originated in talus at the margins of rocky marine shoreline. It is possible to observe cross-bedding in these sediments due to wave action. The increase of sediment thickness basinward is the result of considerably steep paleoslope of the shore (Baráth and Kováč, 1989).

The basinal facies is represented by sediments of Čausa Formation. They consist of gray, dark-gray and yellow-gray calcareous siltstones and claystones with sandy admixture. In these sediments there were found layers of rhyodacite and rhyolite tuffs (Krystek, 1963). Pelitic sediments of Čausa Formation contain rich and diversified assemblages of foraminifers typical for neritic and upper bathyal environments (Lehotayová, 1982, 1984; Kováč et al., 1999; Fordinál et al., 2001). At the end of Eggenburgian the environment became shallower with decreased salinity.

In Ilava Depression at the base of Eggenburgian sediments there occur the sequences of light-green, brown-spotted and locally pinky sandy clays and fine- to medium-grained sandstones without autochthonous fauna. They were probably deposited in shallow, fresh-water lake (Gabčo et al., 1963; Gabčo in Began et al., 1963). They are an equivalent of Veľká Čausa Member from Horná Nitra Depression (Elečko and Vass in Šimon et al., 1997). These sediments are overlain by gray and dark gray calcareous clays found in the borehole PB-1 (Gabčo et al., 1963) which were probably deposited in brackish lagoons at the front of the advancing transgression.

Marine sediments are represented by marginal coarse-clastic Kľačno Conglomerate. In the NE margin of Ilava Depression they are composed of sandstone and conglomerate intercalations. Genetic analysis of pebbles indicates sedimentation of coarse clastics by surges from inner

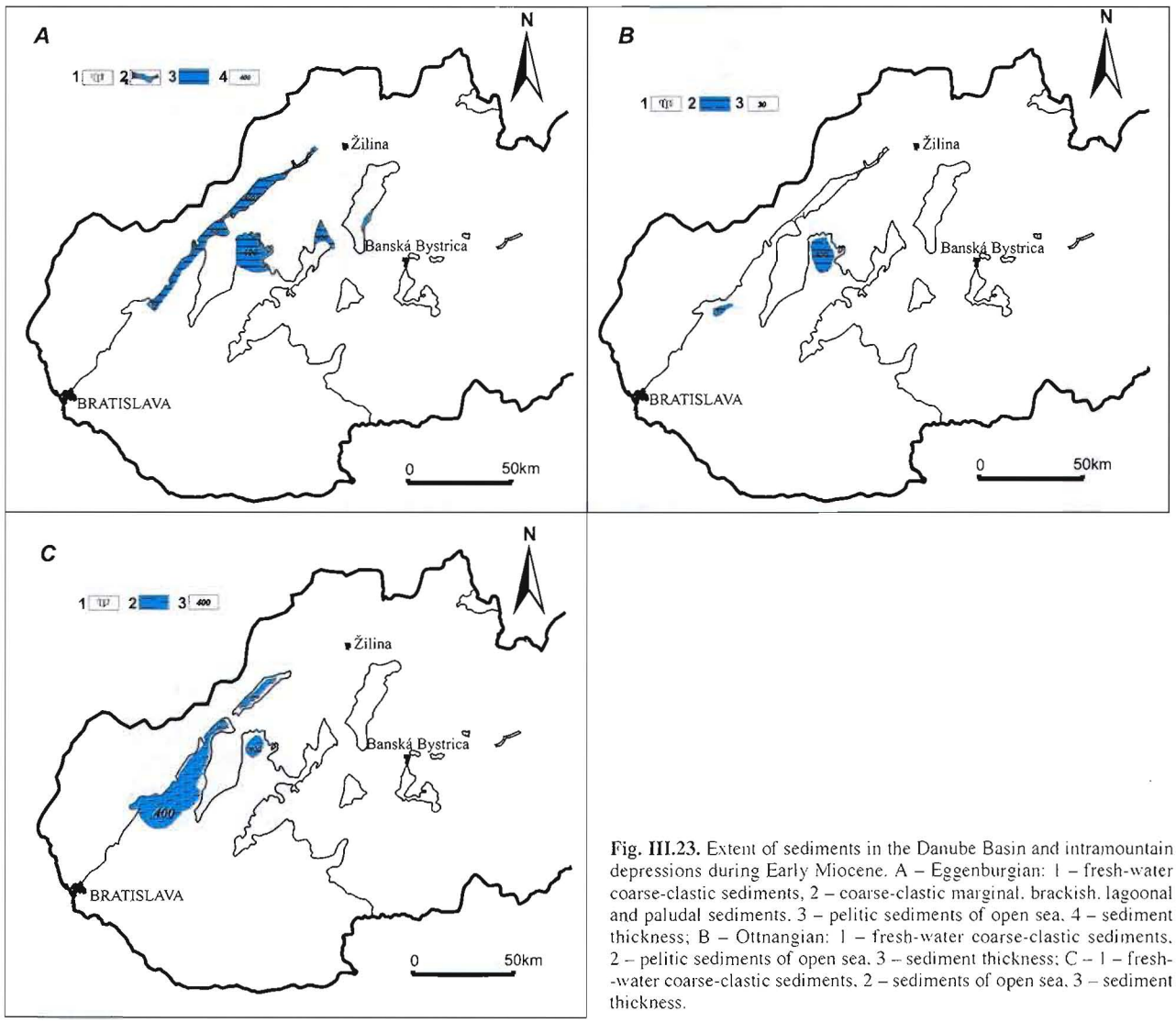


Fig. III.23. Extent of sediments in the Danube Basin and intramountain depressions during Early Miocene. A – Eggenburgian: 1 – fresh-water coarse-clastic sediments, 2 – coarse-clastic marginal, brackish, lagoonal and paludal sediments, 3 – pelitic sediments of open sea, 4 – sediment thickness; B – Ottnangian: 1 – fresh-water coarse-clastic sediments, 2 – pelitic sediments of open sea, 3 – sediment thickness; C – 1 – fresh-water coarse-clastic sediments, 2 – sediments of open sea, 3 – sediment thickness.

shelf to the deeper part of littoral area or they may represent gravel cones and lenses in sandy, littoral sediments (Baráth and Kováč, 1989). Such origins are further suggested by chaotic arrangements and absence of molluscs in sediments.

Pelitic sediments of Čausa Formation are represented by grayish-blue, dark gray and brownish-yellow calcareous clays and claystones. They were deposited in sublittoral and deep neritic zones as confirmed by the molluscs fauna.

Also in Trenčín Depression the marginal coarse clastic sediments are represented by Kľačno Conglomerate. They contain pebbles of limestones, dolomites, calcareous sandstones, radiolarites, cherts and vein quartz. The conglomerates are believed to be gravel cones and lenses in a sandy littoral zone (Baráth and Kováč, 1989).

The basin-type development comprises pelitic sediments of Čausa Formation containing rich assemblages of foraminifera suggesting slightly dropped salinity of the environment (Čechovič, 1959a).

The Prievidza Member, described from Horná Nitra Depression (Elečko, Vass and Šoltésová in Elečko and Vass et al., 1998) also belongs to the members of Čausa Formation. Typical sediments are composed of gray, pelitic-sandy beds with rhytmically alternating thin layers of friable sandstone (5–15 cm) with thicker layers of schistose claystone (50–100 cm). The sediments are considered as distal turbidites or prodeltaic deposits. They originated in a reduction environment which communicated with the open sea. The thickness of sediments is some 450 m.

The Veľká Čausa Member (Elečko and Vass in Šimon et al., 1997) consists of light to greenish-gray clays containing small polymict gravels. It represents pre-transgressional, fluvial sediments overlain by deposits of a transgressing sea (Čechovič, 1959). The bed thickness varies from several metres to several tens of metres. The age of sediments has not been yet proved. However, based on the age of overlying strata containing Eggenburgian fauna, they may be considered as Eggenburgian.

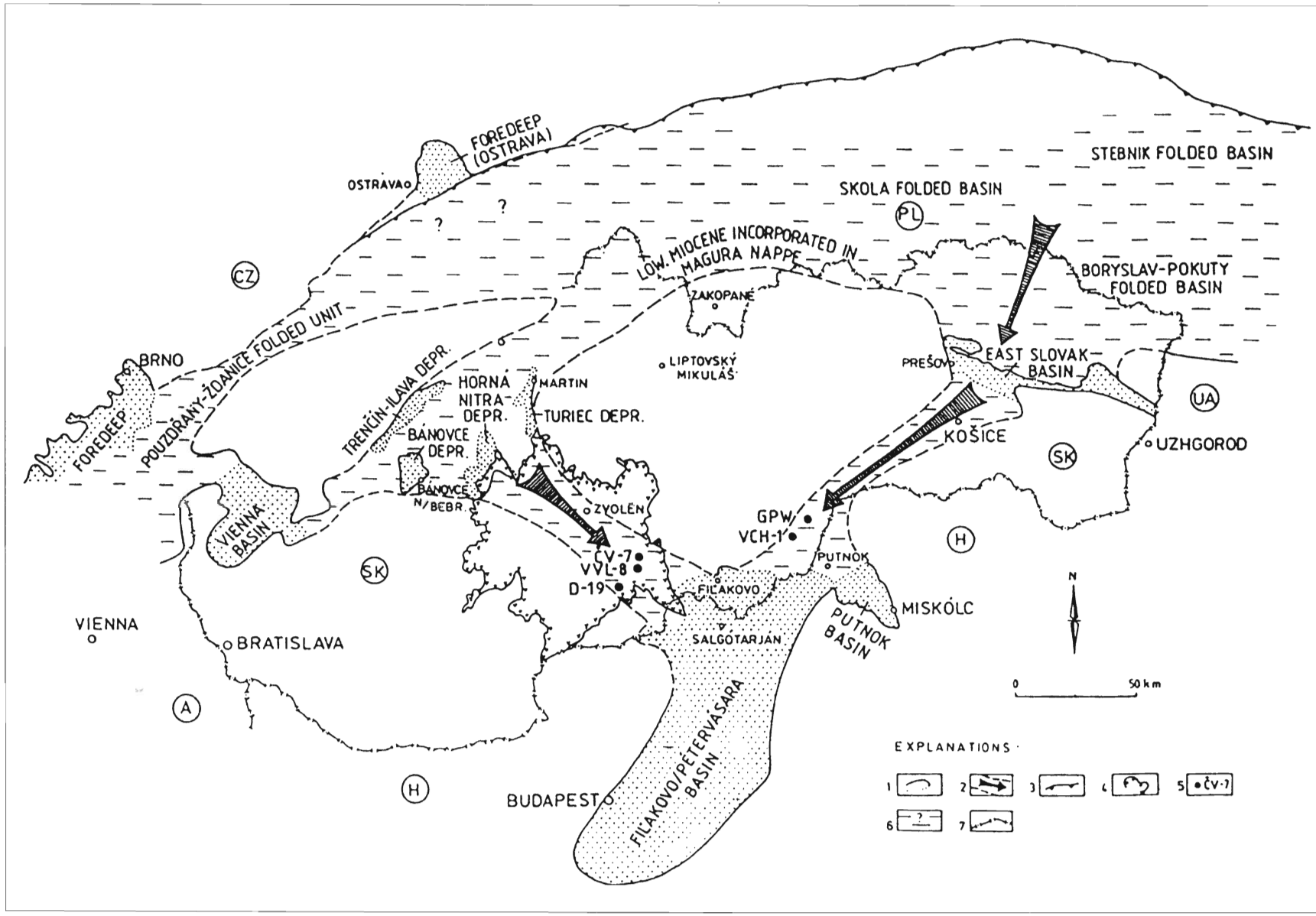


Fig. III.24. Eggenburgian sea-ways in the Western Carpathians. 1 – recent distribution in the area of Eggenburgian sediments (sediments incorporated into nappe units are not shown), 2 – assumed connection of the Eggenburgian sea, 3 – recent front of Outer Flysch Carpathians, 4 – Central-Slovakian neovolcanics, 5 – boreholes which recovered Eggenburgian sediments, 6 – assumed sea areas, 7 – state border

Conglomerates and breccias with red matrix, designated as Vajskova Conglomerate, found in the Horehronská kotlina Depression, are believed to have originated in subaerial conditions (Biely and Samuel, 1982). The conglomerate occurring in beds 10–100 cm thick, may alternate with sandstones and minor pelite layers. The pebbles and clasts are poorly sorted, subrounded to angular (0.5–30 cm in diameter). In their petrographic composition the Triassic carbonates prevail with minor occurrence of Permian andesites, melaphyres or basalts and Permian or Lower Triassic conglomerates. They originated in depressions filled by debris flows and attain thicknesses more than 250 m.

In the Turiec Depression the coarse clastics, composed of sand/sandstone and sandy limestone, were deposited. They belong to the basal part of the formation with basin-type sediments already eroded. These clastic sediments, some 200–400 thick, are included in the Rakša Formation (Gašparik in Gašparik et al., 1995).

The area of South Slovakian Depressions

In Southern Slovakia during the Eggenburgian a transgressive Fiľakovo Formation (Vass and Elečko, 1982) was deposited in a nearshore, shallow-marine environment. Equivalent marine sediments in other south Slovakian depressions are not known, however, Drienovec Conglomerate in the Turňa Depression may be considered as their coeval fluvial equivalent. Today the Turňa Depression is geographically separated from the South Slovakian Depressions being a part of the Moldava Depression. During the Eggenburgian, however, marine environment was replaced by subaerial sedimentation resulting in the deposition of the Bukovinka Formation.

The Fiľakovo Formation in the Southern Slovakia, together with Pétervására Formation in the Northern Hungary, represent nearshore sediments of an epicontinental sea of Fiľakovo–Pétervására Basin shaped in form of a bay (North Hungarian Bay of Sztanó, 1994). In the Southern Slovakia the Fiľakovo Formation occurs in the Cerová vrchovina Upland and in the western part of the Lučenec Depression. From there the formation extends into Dačov Lom Depression beneath the volcanic rocks of the Krupiná Plateau. Originally, the formation also extended in the Ipeľ Depression as indicated by its erosional remnants (Ďarmoty Member, Vass in Vass et al., 1983).

The thickness of Fiľakovo Formation in the area of Cerová vrchovina Upland increases from north to south where it attains max. 500 m. The thickness also increases toward Dačov Lom Depression from east to west assuming in the central part more than 200 m.

The shallowest marine environment in the Fiľakovo Formation is represented by the Jalová Member. The sediments of this member include sand dune facies indicating tidal environment (Vass and Elečko, 1982).

In a deeper shelf environment of a marine bay the Tachty Sandstone was formed (Vass and Elečko, 1982). The occurrence of marine fossils is extremly rare. Other typical feature includes syngenetically cemented bed of sandstones. Tachty Sandstone is considered as a transgressive lithofacies. This lithofacies, which formed during a new transgression, displays the largest extension of all lithofacial types of the Fiľakovo Formation in the Cerová vrchovina Upland (Vass and Elečko in Vass and Elečko, eds., 1992).

The Lipovany Sandstone and Čakanovce Member originated in an open shelf environment. The Lipovany Sandstone is an equivalent of Budafók Sandstone in Northern Hungary. They are relatively finer-grained in comparison with the Jalová Sandstone and Tachty Sandstone. The sediments display often cross-bedding and contain abundant marine fauna. Based on sedimentary structures and fossil biotopes it is possible to assume that Lipovany Sandstone originated in a shallow shelf zone in an dynamic environment controlled by tide and occasional storms.

Closes resemblance to the Lipovany Sandstone appears to have the Ďarmoty Member considered as erosional relict of the Fiľakovo Formation and preserved in the Ipeľ Depression. It locally contains the abundance of fauna and lumachella associations even if at the stratotype locality near Slovenské Ďarmoty the macrofauna was not found. The depositional environment of the Ďarmoty Member was similar to that of Lipovany sandstone.

The Čakanovce Member is represented by relatively deepest marine sediments of the Fiľakovo Formation. The pre-dominance of siltstones suggests their deep-water origin and a more distal location during the deposition in comparison to the Lipovany Sandstone. As further evidence may be considered the absence of current structures in the sediment.

The mutual relationship between the Lipovany Sandstone and Čakanovce Member – interfingering each other – may be seen as evidence of marine transgression with occasional deepening of the water.

The Pétervására Sandstone and Fiľakovo Formation were both deposited in large marine bay (the North Hungarian Bay), located at that time in the Carpathian Foredeep, which communicated with an open sea via the East Slovakian basin. The bay was closed at its southern side. This conclusion is supported by the distribution of Pétervására Sandstone facies arranged in zones along the implied SE and SW or E and W margins of the North Hungarian Bay. This distribution shows the facies, typical for shallower environment near the shore, and facies typical for deep-water environment in the centre of the implied bay (Sztanó, 1994). Recently found Eggenburgian marine sediments in the NE part of the Rimava Depression near Gemerská Panica, and paleogeography of distribution of Fiľakovo Formation in Rimava Depression (Halásová et al., 1996) suggest the possibility of a connection between the North Hungarian Bay and the East Slovakian Basin. This communication happened across relatively recently emerged Slovak Karst and Spišsko-gemerské rudohorie Mts. (alternatively may be also across the Moldava Depression even if marine Eggenburgian deposits have not been found there).

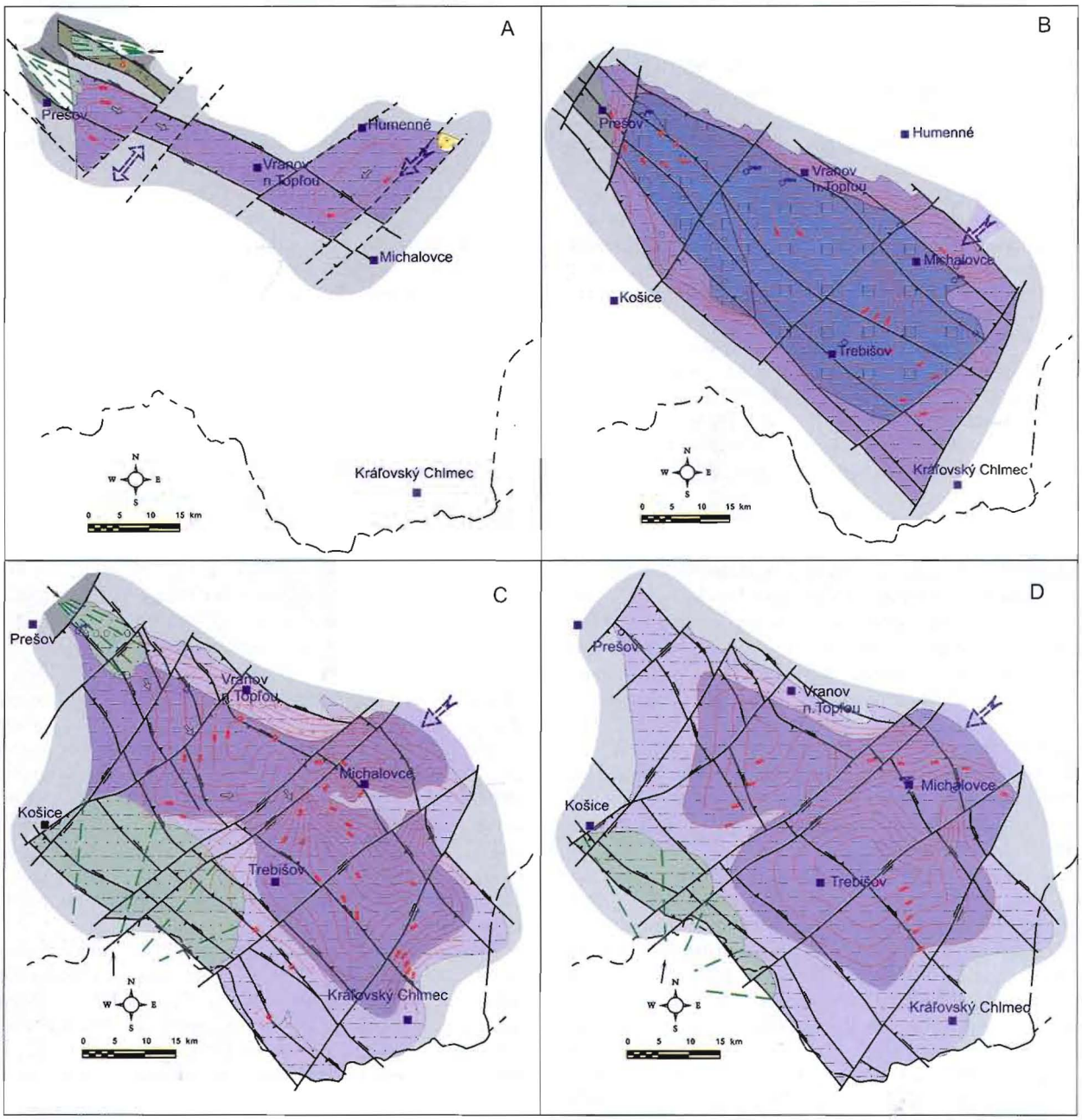


Fig. III.25. Paleogeography of East-Slovakian Neogene Basin during. A – Eggenburgian, B – Karpatian, C – Early Badenian. D – Middle Badenian. For legend see Fig. 2. After Vass et al., 2000, modified.

A further connection of the North Hungarian Bay with Eggenburgian sedimentary areas of the Horná Nitra Depression, Bánovce Depression and along Middle Váh in Slovakia cannot be excluded as well (Fig. III.24). Such a possibility is suggested by findings of marine Eggenburgian sediments in the Dačov Lom Depression in boreholes located near Horné Struháre, Červeňany and Veľký Lom. Epiphytic and cibicidoides foraminifers in these sediments have large forms and a facial affinity to the Eggenburgian assemblages from the Middle Váh area or from the Horná Nitra Depression. This suggests a possibility of a marine corridor leading across the present area of the Central Slovakian Neovolcanics connecting Alpine-Carpathian Foredeep, the Vienna Basin, Middle Váh area, Bánovce and Horná Nitra depressions with the North Hungarian marine bay (Halásová et al., 1996).

Deltaic environment in the Fiľakovo Formation is represented by the Jelšovec Conglomerate (Vass and Elečko in Vass and Elečko, eds., 1992) with prevailing lithotype

being unlithified conglomerates with sand and unlithified layers of sandstone. The sediments are cyclically arranged with erosive, sharp and uneven boundaries between the individual cycles.

The Drienovec Conglomerate (Matějka, 1958; Vass et al., 1994) was formed in a fluvial environment. It represents the northeastern erosive relic of deposits at the margin of Fiľakovo-Pétervására marine bay. The conglomerates form an alluvial fan of a stream or system of streams entering the depression at the southern foothills of Mesozoic rocks of the Slovak Karst. It is a subaerial accumulation of coarse clastics of local provenance (Vass et al., 1994).

Volcanism with distant centres was active during the deposition of Fiľakovo Formation. The volcanic material, transported via air, was deposited in marine nearshore environment and included the acid tuffs and tuffites which form layers in Lipovany Sandstone and in Čakanovce Member. In northern Hungary in Pétervására and Istenmezej the thick layers of bentonites occur which probably could be lateral equivalents of tuffs and tuffites in the Lipovany Sandstones.

It is assumed that the volcanic centres were the common sources of tuffs in the Fiľakovo Formation, bentonite tuffs of Pétervására and Istenmezej as well as tuffs found at the southern periphery of Bükk Mts. The same sources are assumed for Szomolya and Czerépváralja north of Sála (Márton and Pécskay, 1998) which, according to radiometric analysis, are of the same age as the Fiľakovo Formation.

After the deposition of Fiľakovo Formation the sea retreated from the area of South Slovakian Depressions as well as from the entire Pannonian region. The reason for this was the uplift caused by the activation of asthenosphere as a reaction to the tectonic drift of crustal fragments from the Alps and Dinarides into the area of Carpathians and the Pannonian Basin (Vass, 1995). Under these conditions the Bukovinka Formation was deposited consisting of fluvial and lacustrine deposits (Vass in Vass et al., 1983). The fluvial facies appear as erosion relics on the ridges of Cerová vrchovina Mts., in the western sector of the Lučenec Depression and in the Ipeľ Depression. They are further known beneath the younger Neogene sediments and volcanics of the Krupina Plateau and as a part of the Dačov Lom Depression fill (Vass et al., 1979). The thickness of the Bukovinka Formation ranges from several tens up to 200 metres.

The main lithotype of flood plain lakes in the Bukovinka Formation are variegated clays, sometimes locally predominant, for example south of Lipovany village.

The products of syngenetic volcanism include subaerial and water laid tuffs. Pumice tuffs thick from several tens of centimetres up to 17 metres are frequent. Rhyodacite ignimbrites were found in the surroundings of Dunivá hora hill west of Stará Bašta village leading to the assumption that one of the volcanic centres was located here. It appears to sit on the intersection of NW trending (Fiľakovo) and another NE trending (unnamed) fault. Strong explosive activity of rhyodacite volcanism with centres on the Hungarian territory is evidenced by the wide extension of tuffs and tuffites practically in the entire area of the Bukovinka Formation occurrence. Explosive volcanic material was transported via air and locally was redeposited in fluvial and lacustrine environments.

East Slovakian Basin

Eggenburgian sediments stretch in a narrow belt along the northern margin of the basin continuing uninterrupted into the Ukraine sector of the Transcarpathian Basin (Burkalovo Formation; Vialov in Muratov and Neveskaja, 1986; Rudinec, 1989). The Eggenburgian sediments consist of Prešov and Čelovce Formations.

The Čelovce Formation (Leško, 1957) is limited to a narrow and elongated (WNW–ESE) structure of pull-apart type extending from Terňa as far as Podhrabina, the evolution of which is related to the dextral transpression in a zone the attached to the Klippen Belt (Fig. III.25).

The maximum thickness of the formation is documented by Čelovce-1 borehole which penetrated 415 m of sediments before encountering Eocene deposits (Slávik et al., 1960). The prevailingly pelitic sediments are marine, however, the uppermost part of the sedimentary succession suggests a brackish environment with the deposition of coarse clastics and coal seams as well as rhyolite volcanics. The coarse-grained sediments are well exposed in the sandpit of Lada.

Čelovce Formation is a stratigraphic equivalent to the higher part of the Prešov Formation (Vass and Čverčko, 1985) and both may in fact be of the same age (Karoli in Kaličiak et al., 1991).

Prešov Formation (Prešov facies, Buday in Matějka et al., 1964) is developed along the southern margin of a narrow, Paleogene horst structure known as Kapušany Horst. It unconformably overlies Paleogene and pre-Tertiary basement. It crops out only in the surroundings of Prešov. The Prešov Formation continues as far as Ukraine part of the Transcarpathian Depression, while its easternmost extension in Eastern Slovakia was documented from the surroundings of Vranov. The maximum thickness of the formation found in the borehole Prešov-1 is 1000 m. The coarse- and medium-grained conglomerates grading into siltstones and alternating with clays are the characteristic feature of the formation. Occurrence of fine-grained sandstones in the sedimentary succession is common. Tuffs and tuffites occur like in the Čelovce Formation. The tuffs are often seladonized and bentonitized. The volcanic elements probably reflect Lower Miocene explosive acid volcanism with the centre north of Prešov (Kaličiak et al., 1991). Compared to Čelovce Formation glauconitic sandstones at the base are absent.

The sediments were apparently deposited in a shallow-marine environment with occasional inflow of coarse-grained material from mainland. The thickness of the formation and an assumed postsedimentary erosion indicate a continuous and pronounced basin subsidence.

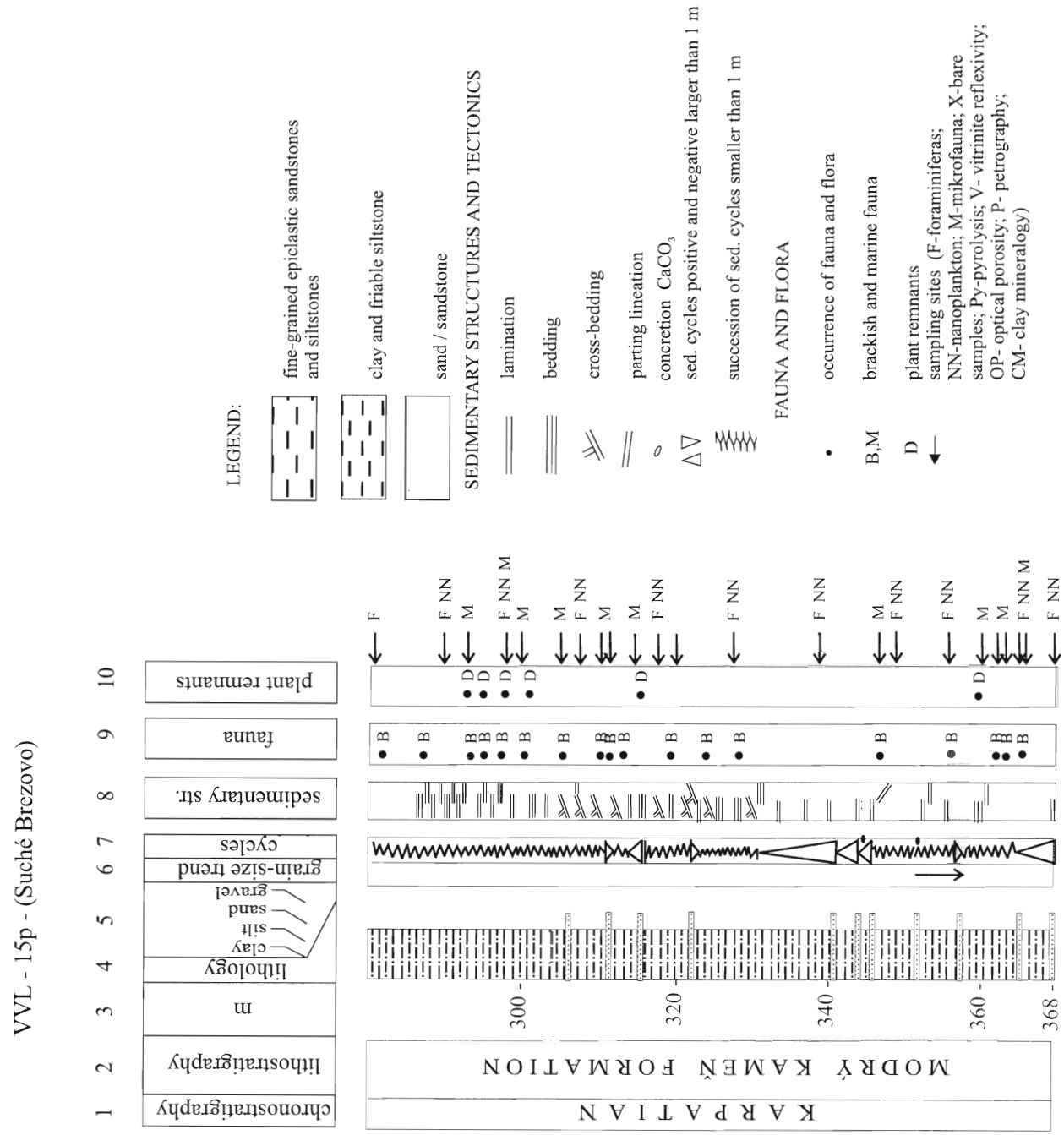


Fig. III.26. Modrý kameň Formation recovered by borehole VVL-15p at Suché Brezovo village, Krupinská planina Plateau.

Ottnangian

Vienna Basin

Erosional relics of Ottnangian in the Vienna Basin have an extension similar to Eggenburgian (Fig. III.21). In the western sector of the basin the Ottnangian transgression extended some 10 km southward as far as Brodské village. However, the steep slopes of the Klippen Belt were covered only by few tens of metres of sediments (Jiříček, 1988). The uplift of the Lakšáre Elevation at the inner margin of the Klippen Belt limited the spreading of the sediments to the line Borský Jur – Jablonica while the northern boundary of the Ottnangian sediments is strongly modified by erosion due to the Upper Ottnangian uplift. Erosively separated relics of the Ottnangian deposits also occur in Dobrá Voda Depression representing a connection into the Blatné Depression of the Danube Basin.

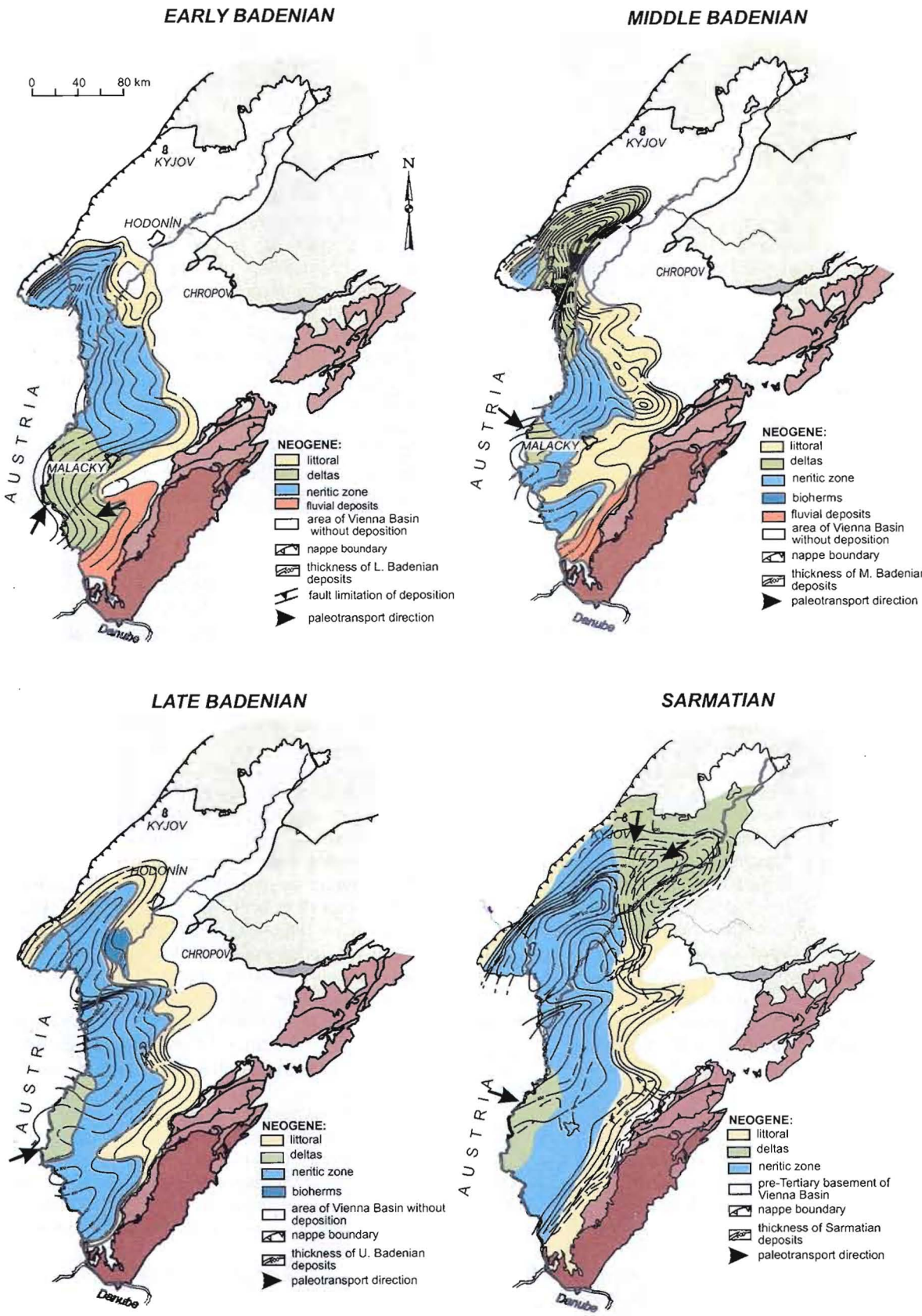


Fig. III.27. Early, Middle and Late Badenian and Sarmatian depositional systems in the Vienna Basin.

The Lužice Depression widened during the Ottnangian and in its eastern part the depocentrum slightly turned south-eastward. Compared to the Eggenburgian the Kopčany channel also widened and in the southeast it opened into intensively subsiding Štefanov Depression of SW–NE direction. The Senica Depression was relatively shallow and its northeastern part underwent erosion at the end of Ottnangian.

Ottnangian sediments in the Dobrá Voda Depression may be also characterized as a transgressive depositional system of barrier, lagoon and estuary type affected by inflow of clastic material from the bay delta. The sediments suggest weak aeration and anoxic regime near the bottom. The described sediments of Planinka Formation (Kováč et al., 1992) in the uppermost part of the Ottnangian show upward coarsening trend suggesting the onset of the next regression. The beginning of the Ottnangian is indicated by a regional deposition of sands at the base of both margins and the centre of the basin. In the area of Lužice Depression Ottnangian is represented by Hodonín Sand thick up to 40 m. In the Štefanov Depression the temporary regression at the Eggenburgian and Ottnangian boundary is marked by formation of a 150 m thick deltaic body of Štefanov Sand. The slopes of Týnec–Cunín Elevation were transgressively covered by Upper Ottnangian sands directly over the flysch basement. The sands contain abundant fauna of foraminifers showing typical deep-water assemblages mostly of species tolerating the lowering of oxygene content near the bottom of the basin.

The Late Ottnangian is represented by prevailingly pelitic sedimentation of "schlier". In the central Lužice area sediments include neritic pelites with *Spiroplectamina*, *Uvigerina* and *Lenticulina* fossils.

Depleted "fish schlier" occurs in the zone attached to the Klippen Belt in the area of Šaštín and Štefanov. In the marginal sectors of the Gbely Plateau and Smolinské, terminal deposits of Ottnangian with characteristic fauna of *Silicoplacentina* overlie transgressively the pre-Neogene basement.

The end of Ottnangian in the southern part of the Vienna Basin is marked by deposition of clastic fluvial sediments as well as sands of prograding mouth bars. These sediments are correlated with the Bockfliess Formation in the Austrian sector of the basin and are known to appear also in the transgressive lower part of the Karpatian.

Danube Basin

Similarly to the Eggenburgian, also in the Ottnangian (Fig. III.22) the sedimentation at the northern margin of the present Danube Basin is characterized by common evolution of marine depositional environment with depocentres in the area of the present Vienna Basin and Bánovce Depression (Kováč et al., 1993).

The Ottnangian deposits are only preserved in the Blatné and Bánovce depressions. They were intersected by deep boreholes indicating flysch-like marine basin sediments affected by turbidity currents. These sediments comprise the Bánovce Formation (Vass, 1989 and Vass in Keith et al., 1989, 1994) and consist of alternating gray calcareous claystones, siltstones, sandstones and conglomerates at the base. Both sandstone quantity and bed thickness increase upward.

Area of South Slovakian Depressions

During Ottnangian in the South Slovakian Depressions and in the Cerová vrchovina Upland the sedimentation was continental as recorded in the Šalgótarján Formation (Noszky, 1930; Seneš in Papp and Rögl, 1973). The sediments overlie unconformly the Bukovinka Formation. The existence of a non-depositionary hiatus is assumed between both formations resulting in highly variable thickness of Bukovinka Formation strata even over short distances. Proximity of the sea during the deposition is indicated by marine ingressions into fluvial-swamp and lacustrine environments.

The maximum thickness of 250 m of the Šalgótarján Formation was described from the Dačov Lom Depression while in the Cerová vrchovina Upland the thickness of formation reaches only some 50 m and the formation in this region appears only as erosional remnants limited to the lower section of the formation. The lower part of the formation is represented by Pôtor Member (Vass in Vass et al., 1983). It is built up by the sand with 1 to 3 coal seams up to 5 m thick originated in fluvial and swamp environments.

Such environments were later replaced by lacustrine one built up by monotonous, gray and grayish-blue siltstones with layers of very fine-grained sands – Plachtince Member (Vass in Vass et al., 1983). The sediments are either massive or faintly laminated with occasional wavy lamination (alternation of clay and silt laminae). Locally the pelites are replaced by sands resembling those of the Pôtor Member.

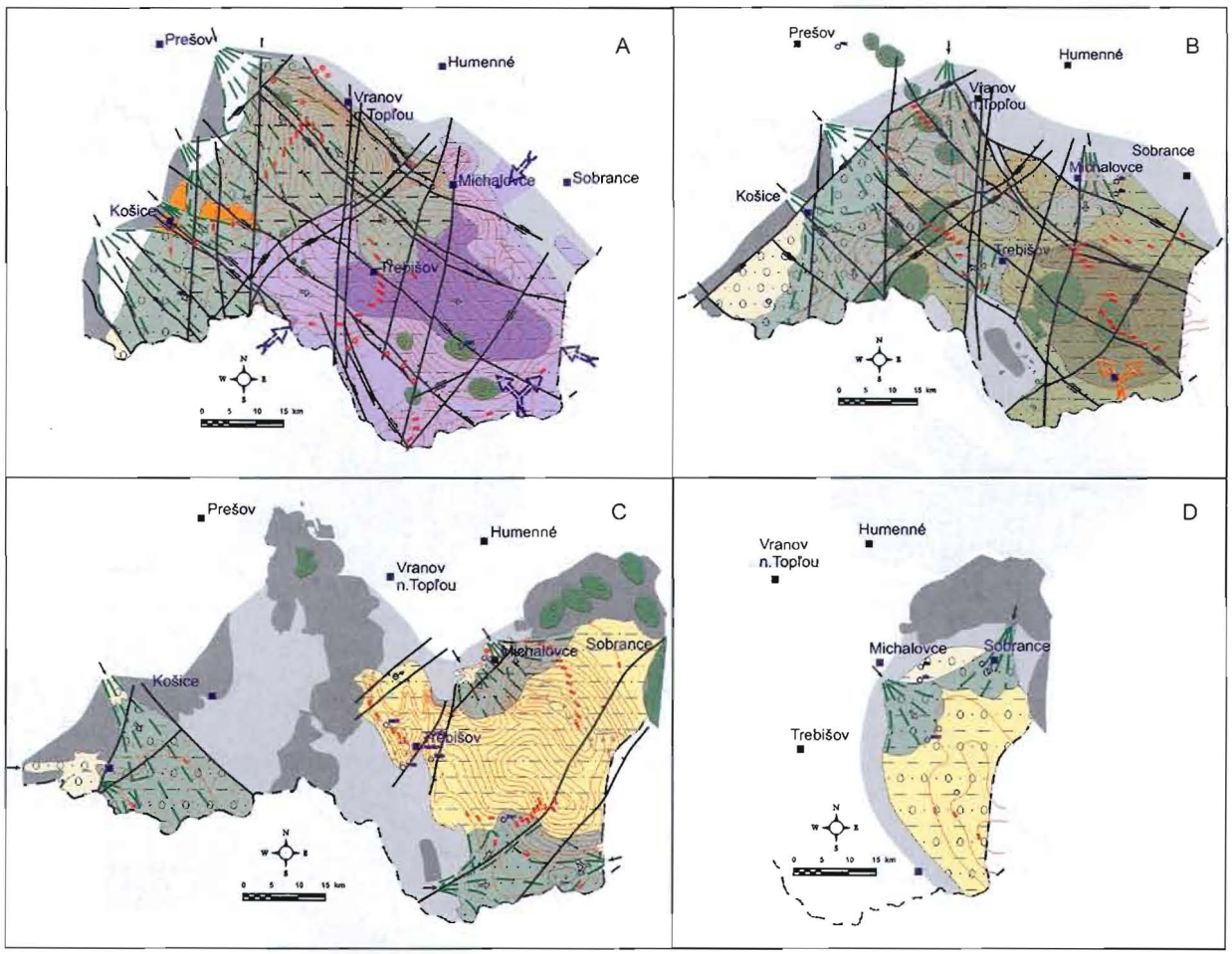
This lacustrine environment was relatively deep (absence of flow structures or wave structures). Marine water, intruding for a short period the lake, brought foraminifera and calcareous nanoflora. The foraminifera assemblages found in the upper section of Plachtince Member would indicate a well-aerated environment deeper than 100 m (Škvarka et al., 1989; Šutovská, 1990).

Siliciclastic material was entering the depositional area of Šalgótarján Formation from the north and/or northeast mostly from the eroded Vepor belt of the Western Carpathians.

The synsedimentary volcanic activity during this period brought into the Šalgótarján Formation tuff and tuffite and volcanic minerals. Conspicuous clasts of volcanogenic biotite were found in Plachtince Member of the Ipeľ Depression (Vass et al., 1979). Most of the volcanic material was transported via air from a distant volcanic centre.

East Slovakian Basin

An unambiguous paleontological evidence confirming the occurrence of Ottnangian in the basin has not been



Areas of erosion and denudation

- Flat relief
- Sharp relief

Areas of sedimentation

Continental

- Alluvial
- Lacustrine
- Swamp

Brackish

- Lagoon
- Delta
- Nearshore (Onshore)
- Offshore

Marine

- Inner shelf
- Outer shelf

Hypersaline

- b) Hypersaline sandwiched by marine

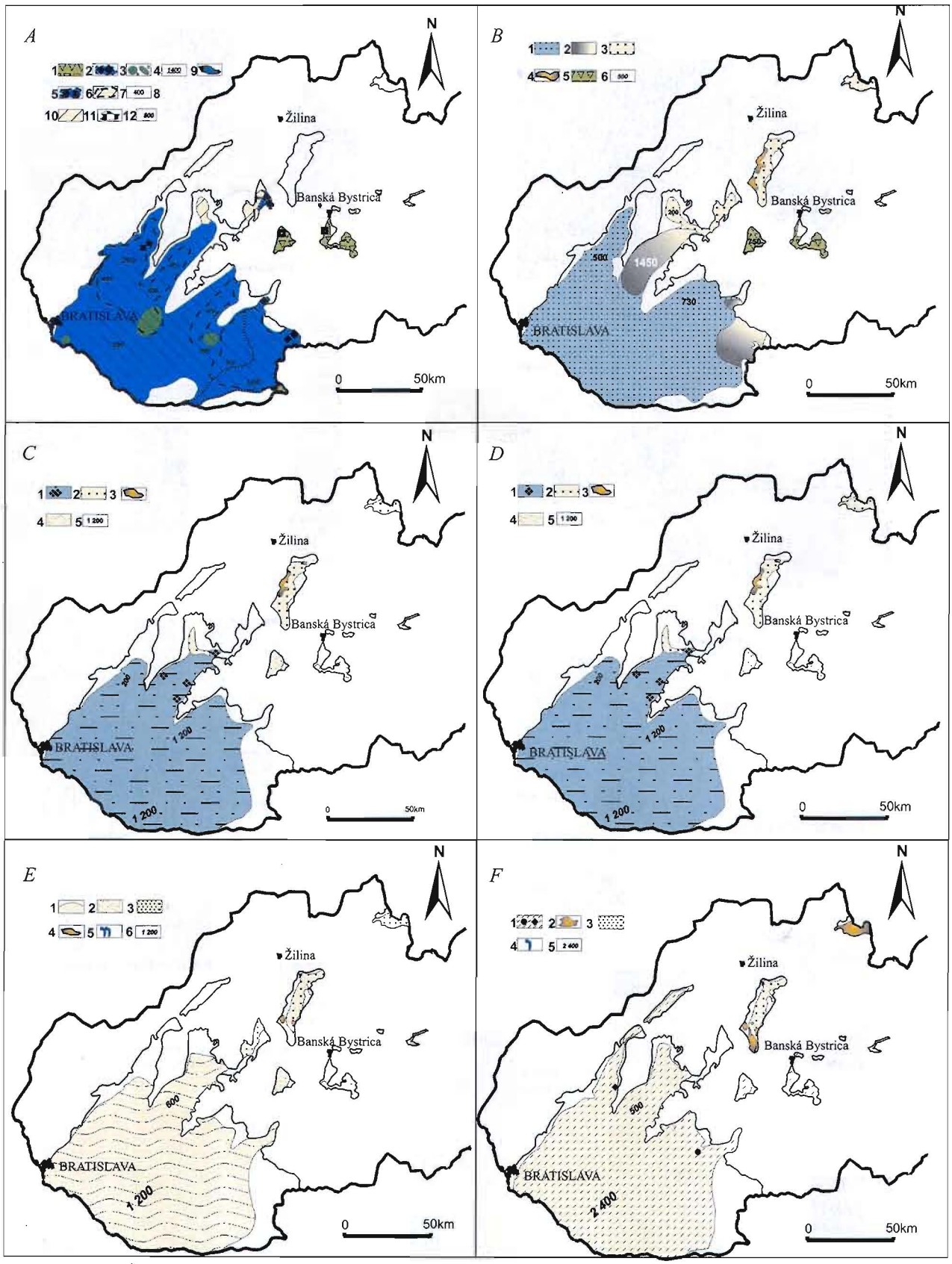
Volcanics

- b) Andesite, b) Volcanoclastics
- b) Rhyolite, Rhyodacite, b) Volcanoclastics
- b) Stratovolcano, b) Volcanic extrusion

Other symbols

- Synsedimentary fault active during presented time period
- Other significant fault
- Strike slip
- Recent thickness isoline
- Presumable direction of sediment input
- Presumable direction of sediment transport
- Sea way and/or direction of sea transgression (direction is not object of rotation !)
- Inlet and direction of hyposaline sea transgression (direction is not object of rotation !)
- Delta contour
- Important borehole

Fig. III.28. Paleogeography of East Slovakian Neogene Basin during. A – Late Badenian. B – Early Sarmatian. C – Late Sarmatian. D – Pliocene.


A
B
C
D
E
F
N
Žilina
Banská Bystrica
BRATISLAVA
0
50km
500
1450
730
1 200
2 400

yet provided. Therefore, it is assumed that a stratigraphic hiatus and uplift dominated the area at that time.

Karpatian

Vienna Basin

Compared to the Ottnangian, the surface extent of Lower Karpatian sediments is considerably different (Fig. III.21). On one hand it is a result of subsidence of the Vienna Basin facilitating the fast accumulation of coarse marine and deltaic sediments over an relativelly large area while on the other hand it was strongly affected by the rise of sea level during this time (Špička, 1969; Kováč et al., 1989; Lankreijer et al., 1995).

The old Lužice Depression and Gbely–Steinberg uplifted plateau exchanged their roles – the former was partially uplifted while the later became submerged. The old Štefanov Depression north of the Klippen Belt extended in the east–west direction as far as Brodské village and in the south the Senica and Leváre depressions were separated by the Závod–Lakšáre Elevation. On the southern slopes of Leváre Depression are presented the sediments of the Early Karpatian sea (Jiříček, 1988). The north and northeast boundaries of Karpatian marine sediments along the line Holíč, Podbranč, Jablonica and Dobrá Voda are obviously erosive as suggested by the absence of marginal facies. Paleogeographically emerged elevation structure north of Štefanov is bordered by littoral sandy facies. Marine Karpatian sediments build Lakšáre Formation (Špička and Zapletalová, 1964).

In the western part of the Štefanov Depression at the base of the Karpatian sediments occurs thick Týnec Sand believed to be a deltaic front from which were reaching sandy gravitational flows even neritic areas. In the southern part of the basin deltaic sediments of Bockfliess Member extended into the area of Gajary. The northern margins of Malé Karpaty Mts. were flanked by deltaic sand and gravel of the upper part of Planinka Formation. The basin facies are characterized by pelitic (schlier) development of Lakšáre Formation.

In the western part of the Vienna Basin the Early Karpatian depositional systems (Fig. III.21) have transgressive character reflected in the retreat of Týnec deltaic front, substituted by a depositional system of shelf sand bars and overlain by shelf "schlier" facies of Lakšáre Formation. Transgressive origin of the rear portion of Týnec deltaic body is well apparent in the accumulation of deltaic sands in depression structures (bay type of delta) while the open space appearing on elevations allowed the deposition of alluvial pelitic sediments. On the adjacent Austrian territory of Vienna Basin the vertical transition from lacustrine to brackish sediments may be observed, too.

Accommodation space generated in the southern part of the basin was continuosly filled resulting in a huge complex of deltaic sediments. In the Austrian sector of the basin, in the tail of these sediments the thick accumulations of alluvial–lacustrine sediments were deposited (Sauer et al., 1992). Clastic material of described Bockfliess deltaic complex shows predominance of resistant rock types – quartz and quartzose sandstone suggesting transport from the Central Eastern Alps.

Transgressive character of Lower Karpatian portion of the Planinka Formation in the Dobrá Voda Depression reflects a direct contact of alluvial–deltaic coarse-clastic deposits with the Senonian basement. The pebbles of conglomerates at the base of Karpatian came predominantly from Triassic dolomites and limestones and to a lesser extent from Jurassic radiolarites and Cretaceous Calpionella limestones. Frequently found there are pebbles of Senonian green arcosic sandstones from the immediate basement. The quartzose sandstones, cherts, vein quartz and quartzites which dominate in more distal areas are also abundant. An association of heavy minerals such as garnet, staurolite and chlorite from metamorphic rocks suggests that the clastic material arrived from the south. During the transgression the deltaic complex was gradually replaced by prodeltaic, lagoonal and shelf facies composed of siltstones with layers of sandstones and claystones, reflecting barrier, lagoon and estuary transgressive depositional environment.

At the end of the Early Karpatian (Middle Karpatian) an extensive regression event set on in the south of the Vienna Basin. It resulted in overlying of Bockfliess deltaic–brackish complex by limnic–subaerial Gänserndorf Member passing northward in the Štefanov, Senica and Leváre depressions passed into huge deltaic–brackish cross-bedded Šaštín Sand (Špička and Zapletalová, 1964; Fig. III.21). Between Gbely and Studienka the sands are up to 100–400 m thick (Jiříček and Seifert, 1990). It is a typical regressive depositional system of prograding mouth bars which supplied the sandy deltaic front north of the zone Závod – Lanžhot. In the upper part of Gärn-

Fig. III.29. Extent of sediments in the Danube Basin and intramountain depressions during Late Miocene. A – Badenian: 1 – volcanic and volcanosedimentary rocks of marine environment belonging to intravolcanic depressions, 2–4 – Early Badenian: 2 – marine deposits with coarse clastics at margin, 3–3 – Šurany volcanics, a) burried volcanic centres, b) Burda volcanics, 4 – Lower Badenian sediment thickness, 5–7 – Middle Badenian: 5 – marine sandy-pelitic sediments, 6 – fresh-water fluvial sediments, 7 – thickness of Middle Badenian sediments. Late Badenian: 8 – marine littoral sediments, 9 – marginal coarse-grained deposits, 10 – fresh-water, fluvial and lacustrine sediments, 11 – coal seams, 12 – thickness of Late Badenian sediments. B – Sarmatian: 1 – marine sediments of hyposaline environment on shelf and deltaic plain, 2 – lacustrine and deltaic sediments, 3 – deltaic sediments, 4 – alluvial fan sediments, 5 – volcanic and volcanosedimentary rocks of marine environment of intravolcanic depressions, undivided. C – Pannonian: 1 – brackish deltaic sediments, 2 – lacustrine and deltaic sediments, 3 – alluvial fan sediments, 4 – volcanic and volcanosedimentary rocks of intravolcanic depressions, 5 – sediment thickness. D – Pontian: 1 – continental deltaic and lacustrine sediments, 2 – upper part of the Trubín Fm., 3 – fluvial and lacustrine sediments, 4 – alluvial fan sediments, 5 – fresh-water clastic sediments and limestones, 6 – sediment thickness. E – Pliocene: 1 – fluvial and lacustrine sediments, 2 – lacustrine sediments, 3 – fluvial sediments, 4 – fresh-water clastic sediments and limestones, 5 – sediment thickness.

sendorf Member between the deltaic lobes probably lagoonal depressions were formed, locally having a hypersaline regime (Jiříček and Seifert, 1990).

At the northern margin of the Malé Karpaty Mts. at that time the progradation of Jablonica Conglomerate (and sandstone) of a delta began (Buday, 1955; Kováč, 1986; Mišík, 1986; Kováč et al., 1989). The uplift of Malé Karpaty Mts. and increasing size of catchment area due to regression triggered change in pebble composition of deltaic conglomerates. In contrast to the Planinka Formation conglomerates the Jablonica Conglomerate contains increased number of Jurassic and Cretaceous limestones besides Triassic and Permian clastics as well as Senonnian and Paleogene clastics, granites, acid and basic volcanics coming from southern sources. Marine neritic deposition of Lakšáre Formation Schlier was in that time mainly situated in the Senica Depression.

The lower part of the Lower Karpatian sediments is of a transgressive character. The locally coarse-grained basal sediments pass into fining-upward succession of sands and "schlier" with uvigerinas. The centrum of Lakšáre Formation pelitic deposition shifted southward of the Klippen Belt into the area of Borský Jur, Šaštín and Senica villages.

Also in the southern part of the basin fining-upward trend of the sediments occur in the transgressive part of the Bockfliess Formation. Following conspicuous regression determined progradation of Gänserndorf Member in the southern part of the basin.

In contrast to the Lower Karpatian, the extension of the Upper Karpatian deposits in the northern part of Vienna Basin is characterized by the shift of erosion to the south (Jiříček, 1979). The sediments are restricted by the line Týnec, Gbely, Koválov and Senica (Fig. III.28). The original shoreline is shifted southeastward and contours margins of the Malé Karpaty Mts. For the first time the entire Vienna Basin was covered by sedimentation which already suggested present shape of the basin. While the northern part had marine character, the southern areas were mostly represented by a huge limnic–deltaic formation.

The western margins of the Malé Karpaty Mts. were in the southern part flanked by alluvial clastics passing northward of Kuchyňa village into littoral sandy development. In the northeast in the area of Prievaly, Senica and Dobrá Voda depressions the northvergent Jablonica deltaic complex occurred (Fig. III.21).

Upper Karpatian depositional systems have transgressive-regressive character and the regressive phase stratigraphically extended into the lowermost Badenian.

In the southern part of the basin, which was uncovered until that time, a deltaic–lagoonal system of Aderklaa Formation developed. The formation includes Láb Member (Láb Ostracoda Member; Buday, 1955) represented by variegated, mostly greenish, grayish and dark gray bedded muscovitic aleuropelites with sand beds. The succession is assigned to the transgressive depositional system of barrier, lagoon and estuary type. At the end of Karpatian the regression occurred. The regression is recorded by covering of lagoonal system of Aderklaa Formation by Late Karpatian and Early Badenian fluvial conglomerate and by alluvial–deltaic Malacky Sand with intercalations of variegated clays. The regressive depositional system is characterized as a system of bifurcated mouth bars. In the areas of the basin located more northward prevailingly Schlier of the Závod Formation was deposited at that time (Špička and Zapletalová, 1964). The lower – transgressive part has a neritic character passing upward into more shallow-water environment with salinity fluctuation up to the hypersaline environment recorded by appearence of anhydrite. The hypersaline depositional environment lasted as long as the earliest Badenian and anhydrite-bearing deposits almost bare of foraminifers are assigned to the Kúty Member.

Aleuropelitic facies with sand and anhydrite-bearing beds extends from Lakšárska Nová Ves in the east as far as Lanžhot and Hrušky in the Moravian part of the basin. Typical for the upper part of the Závod Formation are numerous erosive channels. The most conspicuous Čáry Channel well visible in seismic sections (Jiříček, 1988; Jiříček, 1990; Jiříček and Seifert, 1990) trends from the Malé Karpaty Mts. northward between villages of Kuklov and Šaštín.

At northeastern tips of the Malé Karpaty Mts. at that time a new progradation of mouth bars of Jablonica Conglomerate and sandstone become. Similarly to Adreklaa Conglomerate they passed upward to the Lower Badenian (Kováč et al., 1991, 1999).

Regression and tectonic inversion of the relief in the northeastern part of the Vienna Basin above the Karpatian/Badenian boundary triggered an extensive erosion.

Danube Basin

Similarly to the Eggenburgian and Ottnangian, also during the Karpatian (Figs. 22 and 23) the sedimentation at the northern margin of recent Danube Basin is characterized by common sedimentary areas of the basin with depocentres in recent Vienna Basin and Bánovská kotlina Depression (Kováč et al., 1993).

In Blatné, Trenčín and Ilava depressions the marine basinal pelitic deposits occur. They consist of gray calcareous friable claystones and siltstones (Schlier) and/or alternating sandstones and claystones resembling flysch. These sediments are correlated to the Lakšárska Nová Ves Formation described in the Vienna Basin (Špička and Zapletalová, 1964). The up to 400 m thick formation contains also layers of acid tuff and bentonite. In the Bánovce Depression a normal marine deposition was gradually restored during the Karpatian. In the Early Karpatian fine-grained gray sandstones and siltstones and calcareous claystones (flysch-like development) were deposited. The Late Karpatian is characterized by calcareous claystones (Schlier) with tuff intercalations. These sediments are assigned to the Lakšárska Nová Ves Formation (sensu Vass, 2002).

In the lower part of the Karpatian isolation still lasted (sea with low salinity) as the poor fauna suggests. In the

upper part of the Karpatian deepening of the sedimentary environment and connection with the open sea is recorded by rich assemblages of foraminifers.

South Slovakian Depressions

At the beginning of the Karpatian the areas of the Southern Slovakia were again flooded by sea transgressing from south and southwest. The marine transgression determined the origin of Modrý Kameň Formation (Vass in Vass et al., 1983) which gradually developed from underlying Šalgótarján Formation. It is probable that sea flood has not covered the entire Lučenec Depression and has not penetrated into the Rimava Depression. The transgression was particularly related to the Dačov Lom Graben from where it extended further westward to the town of Šahy (Vass et al., 1979) and northward to the area of recent Krupinská vrchovina Plateau.

The lower part of the Modrý Kameň Formation consists of Medokýš Member (Vass in Vass et al., 1983) which originated in hyposaline environment. The member, which is thick some 40 m, is composed of fine-grained sand and silt. Based on the foraminifers content the Medokýš Member originated in shallow-water, lagoonal environment partly separated from the open sea. Hummocky cross-stratification in the sediments, occurring at the Šahy Elevation indicates the environment under influence of storm-waves.

The sediments of hyposaline environment passes upward into littoral sands of a sea with normal salinity: Krtíš Sand (Vass in Vass et al., 1979). The Krtíš Sand, thick some 50 m, is mainly massive and only occasionally cross- and horizontally stratified. The stratification was probably disturbed by bioturbation. The interpretation of sedimentary environment is based on the occasional findings of marine macrofauna and more abundant occurrence of marine foraminifera. The fauna suggests shallow-marine environment (Kučerová in Vass et al., 1985).

The Sečianky Member (Vass and Elečko in Vass and Elečko, eds., 1992), which overlies the Krtíš Sandstone and being built up by schlier facies, originated in deeper environment. Maximum thickness of the Sečianky Member is 317 m.

The Modrý Kameň Formation occurring on the Šahy Elevation and on its northern slope has a particular development. The formation could not be lithologically subdivided into three members and the entire formation lithologically and by fauna content resembles Medokýš Member (Fig. III.26). We assume that during the whole period of Modrý Kameň Formation a lagoon existed here. The similar lagoon existed in the Ipeľská kotlina Depression when the Medokýš Member originated. But the Medokýš Member south of Šahy Elevation comprises only the lower part of the Modrý Kameň Formation.

Volcanic activity during the deposition of Modrý Kameň Formation is evidenced by tuffs and redeposited tuffs described from Sečianky Member in the western part of the Ipeľská kotlina Depression (Vass et al., 1979).

East Slovakian Basin

After the hiatus in Ottnangian in the Early Karpatian a new marine transgression penetrated into the basin (Fig. III.25). The transgression entered Trebišov Depression from northeast, from the area of recent Transcarpathian Ukraine. In the centre of the basin at the base of the formation sandstones occur (boreholes Iňačovce-1 and Rebrin-1). In the Prešov Depression, which was gradually flooded from southeast, the transgression is recorded by coarse-grained sediments. The sediments crop out at the margin of the basin and they were also recovered in several boreholes (e. g. Drienov I–III, Prešov-1, geothermal boreholes HGJ near Ďurkov). The basal coarse-grained sediments are interpreted as fluvial sediments suggesting their origin before the trangression.

The Karpatian in the East Slovakian Basin is subdivided into three formations (from the base to the top): Teriakovce Formation, Soľná Baňa Formation and Kladzany Formation (Vass and Čverčko, 1985).

Teriakovce Formation is an upward-fining flysch-like alternation of siltstone and claystone deposited in conditions of outer shelf suggesting deepening of the basin. The thickness of formation attains 500 m. The connection of the basin with the Carpathian Foredeep e. g. from the northeast is suggested.

Soľná Baňa Formations extends in the surrounding of Prešov where it locally crops out. The deep boreholes indicated the formation also in the basin's central part (the boreholes Trhovište 26, Albinov 7; Rudinec, 1978). The formation, which is characteristic by occurrence of evaporites, especially halite, originated in the conditions of shallow water with relatively low input of river waters. The origin of shallow-marine environment was determined by uplift of Outer Flysch Belt. The flooding of the basin was sporadic and probably depended on tectonic activity and short-time oscillation of sea level. Thickness of the formation, which is extended mainly in the northwestern part of the East Slovakian Basin, does not exceed 300 m.

Kladzany Formation gradually develops from the Soľná Baňa Formation in slowly deepening basin. The deepening of the basin was affected by NW–SE faults. The sedimentary area extends as far as southern margin of the Prešov Depression and further eastward into the Trebišov Depression. Sedimentation at that time represented one of the most conspicuous subsidence phases of the East Slovakian Basin with sediment thickness more than 1300 m. Lithologically the formation consists of alternation of siltstones and claystones with layers of fine-grained sandstones deposited in the area of outer shelf.

Volcanic activity during the Karpatian was represented by acid areal explosive volcanism with crustal origin of magma. The buried products of volcanism occur in the surroundings of Zlatá Baňa (SE of Prešov) where also volcanic centres are assumed (Kaličiak et al., 1991) and they outcrop NE of Prešov (Fintice Tuff – Kuthan, 1948; Vass, 2002).

Badenian

Vienna Basin

During Badenian the extensive paleogeographic changes occurred in the Western Carpathians. In the Vienna Basin they are recorded by inversion of relief and by the change of direction of transgressions. During the Badenian the general direction was from south toward north.

The extension of the Lower Badenian sediments of the Upper Lagenide Zone (Grill, 1941) in the Slovak part of the Vienna Basin (Fig. III.24) is approximately identical with the original curved shore line running from Stupava to Kuchyňa. At this point it forms tectonically predicted penninsula and its continuation is an "island" nearby Láb village. Then, the shore line turn from the western slopes of the Malé Karpaty Mts. northwestward to Lakšárska Nová Ves, Gbely and Holíč villages. In the surroundings of Holíč the Týnec Island was established (Jiříček, 1988). Depocentrum of the basin originated at the sunken block east of the Steinberg Fault in the Austria.

The most striking depression in the Slovak part of the basin is Leváre Depression. Alluvial–deltaic complex of Zohor Conglomerate (equivalent of the Kúty Member) originated at the eastern margin of the Vienna Basin due to uplift of the Malé Karpaty–Litava Horst in transitional zone between the Alps and Carpathians. The clastic material is derived from crystalline and Mesozoic sources located in the southeast (Kováč and Baráth, 1995). The bodies of Suchohrad Sand extend from southwest as far as Gajary and Malacky. This deltaic succession passes upward into littoral sandy-clayey development with marine fauna of the Upper Lagenide Zone, which represents transgressive depositional system of shelf sand bars. Similar depositional systems also flank northern margin of the basin. However, in this part the deltaic regime did not develop and transgressive shelf sand bars are derived by the erosion of Lower Miocene sediments, the Badenian sediments overlie the Lower Miocene sediments with angular disconformity. The littoral sands of shore front are in this area overlain by neritic facies above the flooding surface. The neritic facies consist of calcareous clays of Lanžhot Formation (Špička, 1966), which also fill depocentres of the Vienna Basin.

After inversion of the basin relief, the first transgressive succession is represented by basal clastics – Aderklaa Conglomerate in the western part of the basin and by time-equivalent Zohor Conglomerates at the eastern margin along the Malé Karpaty Mts. Above the pelites of the upper part of the Lower Lagenide Zone occur. The full succession probably exists only in the partial depression of the basin (Gajary Depression, Suchohrad Depression, Leváre Depression). The upper part of the succession is probably eroded under the base of the Upper Lagenide Zone.

The Upper Lagenide Zone is mainly represented by so called Tegl of Lanžhot Formation with basal sands in the marginal parts.

During Middle Badenian the tectonic inversion of the Vienna Basin continued. The tectonic activity resulted in formation of Moravian Central Depression which contains more than 1200 m mainly fresh-water and brackish sediments. The depression is connected with the Gajary Depression over the Austrian territory (Fig. III.29).

The Hodonín–Gbely Horst, situated more eastward, had a character of wide and long peninsula contoured by line Hodonín, Lanžhot, Brodské and Smolinské. The Kúty Depression was separated by Kuklov Ridge from a vague depression in original Lower Miocene Senica Depression. The Rohožník Spit, directed from the Malé Karpaty Mts. southwestward, reached via Malacky and Láb as far as the area of Vysoká village. Along the Malé Karpaty Mts. a depression near village Lozorno deepened (Jiříček, 1988).

Depositional systems of the Middle Badenian in the Vienna Basin are transgressive. In the entire northern part of the basin variegated Žižkov Member (Buday, 1946; Vass, 2002) deposited at the beginning of the Middle Badenian. It consists of greenish-gray, gray and green calcareous, often rusty spotted clays. Sand lenses with cross-stratified sand occasionally occur. The biggest thickness of sediments is assumed in the Moravian Central Depression (more than 1000 m), where it is a part of a huge delta with river input from northeast (Jiříček, 1988).

Another subaquatic deltaic system is composed of huge Matzen Sand (Kreutzer, 1986) near Gajary and Suchohrad. According to Jiříček (1988, 1990) it is not excluded, that in both cases it is the same deltaic system with delta plain developed in the Moravian Central Depression and with subaqeuous part of the delta developed near Gajary. Seifert (in Sauer et al., 1992) interprets Matzen Sand as paleodelta of Danube river.

The sediments of Žižkov Member in the eastern part of the Vienna Basin have fresh-water and brackish lagoonal character and it represents the regressive depositional system of beach plain and shelf. At the base of these sediments littoral sand occurs which probably represents early regressive depositional system of shelfal sand with orientation of dispersal mechanism basinward.

The described extensive lagoon in the northeastern part of the Vienna Basin originated due to isolation resulted from progradation of regressive depositional system of Matzen deltaic sand mouth bars in the southwest and by regressive uncovering of Rohožník Elevation (spit) in the south.

At the southwestern margin of the Malé Karpaty Mts. a thick debris flow accumulations of coarse clastic Devínska Nová Ves Member was deposited at that time (Vass et al., 1988).

In the upper part of Žižkov Formation the sands are developed. They are heterochronous and toward shore line are gradually younger. It is typical transgressive depositional system of shelf sand bars. The sands contain abundant littoral marine fossils and during transgression lithothamnia limestones originated at the transitions to the basinal facies near Láb, Malacky and Lednica (Fig. III.27). This confirms predominancy of transgressive dispersion processes toward shore.

Above the flooding surface of deltaic, lagoonal and later bioherm facies succession of monotonous gray and greenish

gray calcareous clays of neritic Jakubov Formation (Špička, 1966) is developed.

The extension of the Upper Badenian sediments considerably exceeds the margins of the Middle Badenian sediments, even if they generally have more shallow-water character (Fig. III.27). The older sediments were gradually covered during the transgression of Late Badenian sea northeastward and recent margin of the Upper Badenian sediments at the NE and W margin of the basin are close to the original paleogeographic basin margin. The transgression was also controlled by continuing tectonic inversion of the basin during which normal fault systems originated. The faults confine the Hodonín–Gbely and Malé Karpaty–Litava horsts (Jiříček, 1988; Kováč et al., 1997).

The margin of the Upper Badenian sedimentary area in the Viena Basin extends in the south into the Lamač Bay and follows the slopes of the Malé Karpaty Mts. At that time the Sološnica Depression bordering the Lakšár Fault and Senica Depression are very conspicuous. Near Štefanov, the shore line is controlled by the Klippen Belt structure, behind the belt the curved shore line continues to the area of Hodonín.

The marginal part of the basin in the Slovakia is a wide and flat area with exception of described depressions. The flat areas extend between Týnec – Gbely and Štefanov – Borský Mikuláš. Maximum thickness of the Upper Badenian littoral sediments in these areas is of 100 m (Jiříček, 1988).

From lithologic-sedimentologic point of view the basinal sediments mostly consist of marine greenish-gray and dark gray calcareous clays of Studienka Formation (Špička, 1966). In the lowest and also in the upper part of the formation the layers of yellowish sand occur. In the marginals part of the basin in the north and east the littoral sand with gravel and clay intercalations prevail. This succession represents Sandberg Member. Near Devínska Nová Ves, Rohožník, Kúty and Hrušky the lithotamnium limestone of the biostroma and reef type occurs in this member (Buday, 1955; Baráth et al., 1994; Hladilová et al., 1998).

From the first consideration of Buday (1955) it has not been satisfactory solved the position of variegated lagoonal beds overlying marine deposits of the Upper Badenian. They are mostly assigned to the Lower Sarmatian, however, according to several authors a part of these sediments belongs to the Upper Badenian.

Upper Badenian depositional system in the Slovakian part of the Vienna Basin is predominantly of transgressive character. The transgression gradually changes into regression connected with salinity drop at the end of the Late Badenian (variegated lagoonal beds). Transgressive depositional systems of the Upper Badenian in the eastern and northern margins of the Vienna Basin have typical features of shelfal sand bar systems. Transgressive dispersed system is suggested by occurrence of lithothamnium limestone typical for transgressive depositional system tract.

Extension of the variegated beds with lowered salinity of depositional environment at the end of the Badenian probably does not correspond to the transgressive depositional systems of the barrier, lagoon and estuary type. To the contrary, it suggests progradation of shore and deltaic fronts during the deposition of regressive depositional systems of the beach plain and shelf type or flat deltaic mouth bars of Gajary Sand type.

The sediments assigned to the Upper Badenian, as suggested by biostratigraphy (NN6) occur in the entire Studienka Formation. Based on the lithology the base of the Upper Badenian was marked by sands with *Bolivina-Bulimina* fauna overlying the *Spiroplectamina* Zone. However, correlation of well logs and interpretation of seismic profiles questions the reliability of foraminiferal zones for establishing the age boundary.

Clinoform progradational deltaic bodies in the area of Gajary and Suchohrad Depressions as well as their prodeltaic environments in the arc of Leváre, Jakubov, Vysoká and Zohor grabens are assigned to the Upper Badenian.

In the northeastern part of the basin the Upper Badenian is represented by marginal facies with alternation of sand and calcareous clay.

In the northern, marginal part of the basin the Upper Badenian sequence boundary of SB1 type is emphasized by angular unconformity when the Uppermost Badenian sediments cover the Middle and Lower Badenian sediments (the area of Brodské, Kúty and Gbely villages) as well as Karpatian sediments (the area of Cunín, Štefanov and Koválov villages). The sediments are represented by littoral and sublittoral sands with lithothamnium horizon in the area of Týnec – Cunín, Kostice and Kúty villages.

Danube Basin and intramountain depressions

The subsidence during the synrift stage of the Danube Basin evolution commenced in the northeastern part, whereas in the Želiezovce Depression the marine sedimentary and volcanoclastic succession was deposited.

The Želiezovce Depression represents the deepest part of the Lower Badenian basin system. The sedimentary area is characterized as circumlittoral open shelf plain (Seneš and Ondrejičková, 1991).

The crustal extension of the synrift stage was accompanied by volcanic activity in the Danube Basin (Slávik, 1974; Gnojek and Heinz, 1993). The discontinuous belt of calc-alkaline volcanic bodies was described from Steyer Basin along the Raab Lineament and central part of the basin as far as Middle Slovakian Neovolcanics. Geodynamic evolution of the Danube Basin suggests a close relation to the mantle diapirism in back-arc area.

Lower Badenian sediments occur in Želiezovce and Komjatice depressions (Figs. III.22 and III.23) and are represented by Bajtava Formation (Seneš et al., 1971; Vass, 1989 and Vass in Keith et al., 1989). The main volume of sediments is represented by gray calcareous friable siltstone and claystone with slaty splitting. The formation is of marine origin and is about 1100 m thick.

In the NE and E part of the Želiezovce Depression Turovce Member occurs (Vass in Melioris and Vass, 1982). The member is composed of quartzose sand with

occasional clasts of quartz and quartzite, conglomerate and breccia, variegated clay and silt and andesite tuffs. The member probably originated in fluvial and/or deltaic environments (Marková in Vass et al., 1981). They are pre--transgressive sediments of Bajtava Formation. The Turovce Member lies unconformably on pre-Tertiary basement. The thickness of the member is several tens of metres (in the ŠV-8 borehole about 70 m). The member occurs in the Želiezovce Depression (boreholes FGK-1 and K-5), in the Semerovce, Plášťovce and Bátovce partial depressions (Vass et al., 1979; Nagy, 1988).

At the contact with peripheral zone of Štiavnica Stratovolcano the Pláštovce Member originated (Vass, 1971) representing sediments of littoral zone and dense turbidite flows of volcanic rocks descending from the slopes of Štiavnica Stratovolcano (Vass and Krystek, 1975; Vass et al., 1995). The member consists of alternating epiclastic conglomerate, breccia, sandstone, siltstone and occasional lumachella limestone. The thickness of the member is maximum 300 m.

In the Danube Basin (Fig. III.22) buried andesite volcanics occur beneath the Middle Badenian sediments. The volcanics have mostly stratovolcanic structure, i.e. andesite lava flows and andesite volcanoclastics alternate. They occur in the middle and western part of the basin and represent Šurany Volcanics (Vass, 2002). According to boreholes they are 230–890 m thick. The volcanics comprise a part of the Badenian volcanic arc continuing eastward into Buda Mts., Börszöny Mts., Dunazug Mts., Krupinská vrchovina Plateau, Czerhát and Mátra Mts. The arc is similarly as in the Danube Basin again buried in the area of Transtissia.

In the southeastern part of the Danube Basin peripheral zone of the Börszöny Stratovolcano interfingers with the sediments of the Bajtava Formation. The stratovolcano delivered coarse-clastic material of, andesite conglomerate volcanoclastics, epiclastic sandstone, breccia and tuff with intercalations of lumachella limestone and Amfistegina sandstone. These, several 100 m thick rock complex comprises a formation called Burda Volcanics (Vass, 2002). The Lower Badenian age is well defined by interfingering into the Bajtava Formation which biostratigraphic age is defined on the base of marine fauna. The age is also confirmed by mollusca fauna and other marine organism occurring in the volcanoclastic rocks of the formation.

In the Bánovce Depression Lower Miocene sediments were emerged and denudated before the Lower Badenian. The Lower Badenian Svinná Formation, represented by claystone and sandstone with lignite seams, originated in limnic fresh-water conditions with irregular sea ingressions from the Horná Nitra Depression and from the area of recent Central Slovakian Neovolcanics. We assume deposition in semidetached depression with insufficient circulation of water mass and reduction conditions at the bottom as suggested by abundant occurrence of organic matter, pelosiderite, pyrite and occasionally occurring phosphates. During short-time sea ingressions the depression probably became shallow, marginal part of sea as suggested by glauconite occurrence and well-sorted sediments (Gabčo, 1969). The contemporary volcanism is indicated by acid and intermediate rocks and tuff layers in the upper part of the formation.

The Lower Badenian marine deposits in the Horná Nitra Depression (Elečko in Šimon et al., 1997) are represented by Kordíky Formation (Andrusov, 1954; Konečný et al., 1983). The formation consists of gray tuffitic claystone, siltstone, sandstone, redeposited tuff, tuffitic sandstone with coal clays intercalations, coal seams, dark-gray laminated clay and conglomerate and gravel with andesite and non-volcanic clasts (Lexa in Konečný et al., 1983; in Šimon et al., 1997). The formation was deposited in fluvial-limnic and marsh environments with occasional marine incursions. It is mainly extended in the central and eastern part of the Kremnické vrchy Mts. The thickness of the formation is from 200 to 600 m.

In the Horehronské podolie Depression (Depression of Upper Hron valley) the Kordíky Formation occurs at the base of volcanic rocks at the eastern margin of the Kremnické vrchy Mts. It mostly consists of tuffitic siltstone, sandstone and conglomerate with intercalations of gravels composed of nonvolcanic material. Tuffitic pelites with redeposited tuffs and coal clays have minor occurrence (Lexa et al., 1998).

The sediments of the Middle Badenian were deposited in the marine environment with a trend of lowering salinity and depth decrease toward the end of that time.

In the Blatné Depression the sediments of the Middle Badenian are represented by Špačince Formation (Jiříček in Papp et al., 1978; Vass, 1989 and Vass in Keith et al., 1989). The lower and marginal parts of the formation consist of sandstone, conglomerate, occasionally organogenic sandy limestone. The basinal development is represented by gray calcareous clay with slaty splitting, siltstone and claystone. The thickness of the formation is about 2500 m.

The formation is subdivided into basal coarse-detritic part – the Ratkovce Member (Jiříček in Steininger et al., 1985). The member is composed of basal coarse clastics – conglomerates overlain by pelitic sediments with intercalations of acid redeposited tuffs. They are marine sediments of an unspecified origin. The thickness of sediments is some 420 m as indicated by boreholes of oil prospection (Gaža fide Biela, 1978). The age of the member is probably Middle Badenian.

The claystone of the upper part of Špačince Formation passes into sand on the NW margin of the Blatné Depression. The sand is defined by Jiříček (in Papp et al., 1978) as Madunice Sand. According to Cicha (in Mišík et al., 1985), the member is composed of sandy clay and sand alternating and represents deltaic front prograding into Blatné Depression at the end of the Badenian. Maximum thickness of the sand is 400 m (Jiříček, l. c.). The member occurs only in the Blatné Depression.

In the Komjatice and Želiezovce depressions the Middle and Upper Badenian sediments have been gathered into Pozba Formation (Hók et al., 1999). The division was made on the base of occurrence of andesite and acid volca-

noclastics and gradual mutual transition. Thus, the sediments of the Middle Badenian represent the lower part of the Pozba Formation.

In the Bánovce Depression in the upper part of the Lower Badenian and mainly in the Middle Badenian in the fresh-water conditions the sediments of Kamenec Formation gradually evolved from the underlying Svinná Formation. The formation has high lateral variability. The rocks are mostly composed of subrounded and rounded andesite clasts and clasts of non-volcanic rocks. The matrix is sandy, tuffitic-sandy or sandy-clayey.

In the Hornonitrianská kotlina Depression the sediments of the Middle Badenian are represented by Kamenec Formation (or by its lower part). The formation consists of andesite fine- to coarse-grained conglomerate and epiclastic volcanic conglomerate with intercalations of tuffitic siltstone and layers of autochthonous volcanic pyroclastics and tuff. The conglomerate contains non-volcanic pebbles. The formation originated in fluvial environment (Konečný et al., 1983; Šimon et al., 1997). Maximum thickness of the formation is 300 m. The age of the formation is still ambiguous and according Konečný et al. (1983) it may be assigned to the Middle and Upper Badenian (it contains clasts of Lower and Middle Badenian volcanics of the Štiavnica and Kremnica stratovolcanoes).

The sediments of the Upper Badenian are preserved in almost whole Danube Basin. In the Blatné Depression they are represented by Báhoň Formation (Vass, 2002). It is composed of alternating gray calcareous friable siltstone and claystone with subordinate layers of sandstone and sand (Homola, 1951; fide Biela, 1978; Homola in Homola, ed., 1958). At the western margin of the Blatné Depression the upper part of the formation consists of clay, coal clay with coal seams thick up to 0.8–3 m (Vass and Gašparik et al., 1978). The formation was deposited in marine littoral and shelf zone. The coal seams suggest delta plain environment (Vass in Keith et al., 1989, 1994). Maximum thickness of the formation is some 1000 m.

At the western margin of the Blatné Depression the polymict conglomerate with sandstone lenses are preserved (Buday in Buday et al., 1992) representing Doľany Conglomerate (Kováč in Plašienka et al., 1991). The conglomerate thick up to several tens of metres unconformably and transgressively overlies pre-Neogene basement and is capped by pelitic deposits of Báhoň Formation.

In the Komjatice and Želiezovce depressions Pozba Formation extends (Priechodská and Harčár, 1988; Vass, 1989), its upper part is equivalent of Báhoň Formation. From the Báhoň Formation it differs by abundant occurrence of volcanoclastics. At the marginal parts the formation consists of conglomerate, sandstone and tuff. These rocks gradually disappear basinward. The basinal development is represented by gray calcareous friable siltstone and claystone. Closer to the northern basin margin the calcareous, locally sandy claystone and siltstone predominate. On the slopes of Levice Horst, separating Komjatice and Želiezovce depressions, the bioherms of lumachella limestone may be expected according to geophysical investigations (Hrušecký et al., 1996). The formation originated in marine littoral zone and on the shelf. Maximum thickness of the formation is 300 m.

In Bánovce Depression gray epiclastic volcanic sandstones and claystones with intercalations of coal clay deposited during the Late Badenian. They are equivalents of the Handlová Formation deposited in fresh-water swamp environment.

In the Hornonitrianska kotlina Depression sediments of the Upper Badenian are represented by the upper part of above mentioned Kamenec Formation. Typical for the depression are sediments containing coal gradually developed from the Kamenec Formation. These sediments are represented by Handlová Formation (Konečný et al., 1983; Vass, 2002). In the lower part of the formation sandy-clayey and tuffitic sediments occur. They pass upward into brown and black clay and coal clay with coal seams. In tha Handlová area they comprise coal seam 7–9 m thick which is subdivided into partial seams 1–4 m, 2–6 m and 5–7 m thick. Between the seams shaly clay, sandy-clayey redeposited tuff and tuffitic sandstone occur. At the Nováky Coal Deposit one main, 8–10 m, locally up to 25 m thick coal seam occurs with intercalations of pale redeposited tuffs and clay subdividing the seam into two – three beds (Čechovič, 1959; Gašparik, 1959; Brodňan, 1970). The formation originated in the environment of *Taxodiacea* swamp. The thickness of the formation is 5–50 m.

Gray, locally dark-gray monotonous massive clay and calcareous clay with shaly splitting overlying the coal seams belong to the Koš Formation (Konečný et al., 1983). The thickness of the formation is 10–300 m. The Upper Badenian age is suggested by sporomorphs (Planderová in Konečný et al., 1983).

At the base of Koš Formation laminated diatomite and dark bituminous diatomitic clay representing Račí potok Member occur (Šimon and Macinská, 1995). They are locally extended in the western surroundings of Handlová. The only fossils are represented by *Diatomaceae*.

The Koš Formation is overlain by Lehota Formation (Konečný et al., 1983). It consists of gravel, sand, occasionally silt and sandy clay. The gravel is mostly composed of Mesozoic carbonates and minor admixture of andesite pebbles. It is interpreted as fluvial channel fill sediment or sediment of alluvial fans (Čechovič, 1959). Maximum thickness of the formation is 300–350 m. The formation interfingers with the upper part of volcanics of Kľakovská dolina Formation of Early Sarmatian age which indicates its Late Badenian–Early Sarmatian age.

During the Badenian the fill of Žiar and Zvolen–Slatina depressions was composed of volcanic and volcanoclastic rocks derived from volcanic centres of the Vtáčnik Mts., Kremnické vrchy Mts., Poľana, Javorie and Štiavnica stratovolcanoes. In the northern part of Žiar Depression and in the western part of Zvolen–Slatina Depression the volcanic rocks are underlain by sediments of Kordíky Formation described above.

In the area of Horehronské podolie Depression fresh-water sediments of Brezno Formation (Vass, 2002) are

preserved. They consist of fine-grained clayey sands and sandy clays. They contain leaf prints, plant remnants and locally coal lenses thick up to 0.4 m. The formation passes upward into more coarse-grained sands passing into gravels and conglomerates with boulders. The clasts are derived from crystalline rocks and occasionally from Mesozoic limestones. They do not contain andesite clasts (Buday and Seneš in Maheľ et al., 1964). The formation originated in fluvial–lacustrine environments. The upward--coarsening grain-size trend suggests that the succession represents alluvial fan – a simple delta filling of Brezno Depression. The sediments are thick up to several tens of meters. The age is based on the position under volcanics of the Upper Badenian and Sarmatian age. Direct biostratigraphic evidence does not exist.

Central Slovakian Volcanic Field

During the Lower Badenian time the extrusive andesite volcanism of garnet-bearing amphibole-pyroxene and pyroxene–amphibole andesites was activated as a result of extension and block movements related to the formation of horst and graben structures. Eruptive centres of the Vinice Formation (Konečný, 1970, 1977) represented by submarine andesite extrusions were active along NW–SE oriented Šahy-Lysec volcano-tectonic zone, often at crossings with transversally NW–SE oriented faults. Andesite extrusions – submarine domes in the marine environment were subject to extensive brecciation and explosive destruction. Clastic material was accumulated around extrusive domes or was transported farther by lahar and submarine breccia flows. Reworking at shores gave rise to epiclastic volcanic breccias, conglomerates and sandstones (Konečný in Vass et al., 1979).

Submarine extrusive volcanism of the Vinice Formation was a part of a wider volcanic region extending southward into Börszöny Mts. and Visegrad Mts. in the northern Hungary and Burda Mts. in Slovakia.

In the lower portion of the Burda Formation the submarine extrusive domes and related breccias were a source of coarse-grained volcanoclastic material transported by submarine breccia flows and debris flows into their surroundings (Konečný and Lexa, 1994). Epiclastic and pyroclastic facies of volcanoclastic rocks transported from a source in the Börszöny Mts. make up the upper portion of the formation. Reworked epiclastic rocks (sandstones and conglomerates) prevail in the western portion of the formation and in Belianske Kopce hills.

Extrusive andesite volcanism north of the Šahy Elevation took place in the subaerial environment. Extrusive domes of garnet-bearing hyperstene-amphibole andesites were tied to marginal faults of grabens. Extrusive volcanism was a source of a large volume of volcanoclastic material comprising fill of subsiding grabens. Scattered bodies of garnet-bearing andesites and related coarse to blocky breccias crop out SW of Zvolen (Neresnická dolina valley), in the area of Kremnické vrchy Mts., Vtáčnik Mts. and they have been identified by structural boreholes beneath the Štiavnica Stratovolcano. Laccoliths crop out within the Lower Miocene sediments of Southern Slovakia (Karanč – Šiatoroš) and continue into Hungary. Remnants of domes occur also in the area of the Veporicum. Related epiclastic volcanic rocks are known from the area of Hajná Hora (near Čierny Balog village) and at basal levels of the Pokoradz Formation at the northern edge of the Rimava Depression.

After a partial retreat of the Lower Badenian sea from the eastern part of the area the Vinice Formation was partly denudated. During a new transgression of sea eastward the explosive volcanism of the Čelovce Volcano took place in the middle part of the Šahy–Lysec Zone (Konečný, 1970). Necks and dykes of the eruption centrum are located near the village Čelovce. Pyroclastic material laid down by pyroclastic flows and debris flows or lahars was predominantly transported northward into the subsiding Bzovík Depression. Thickness of the Čelovce Formation in the Bzovík Depression attains more than 300 m. The development of volcanic structure resulted in a gradual isolation of the eastern part from the marine environment.

In the western part of the volcanic field an extensive Štiavnica Stratovolcano evolved during the Middle Badenian time (or in the upper part of Lower Badenian). The centrum of the stratovolcano was in the area of Banská Štiavnica – Hodruša. The Štiavnica Stratovolcano was an important source of coarse- and fine-grained volcanoclastic material transported to the SW and W into subsiding depositional centres in the eastern part of the Danube Basin in the area of the Želiezovce and Komjatice depressions (Špačince Formation).

In the NE part of the region a more extensive andesite stratovolcano Javorie evolved during Middle Badenian. Volcanoclastic material was transported mostly southward and deposited in the fluvial and lacustrine environments in the subsiding Strháre–Trenč Depression. At the same time the Vepor Stratovolcano evolved in the western part of the Veporicum. Its centrum was in the surroundings of Tisovec. Volcanoclastic material transported southward and southeastward was deposited at the foothills of the stratovolcano in alluvial fans of the Pokoradz Formation.

The northern part of the region was occupied by the andesite stratovolcano of the Zlatá Studňa Formation. During the Upper Badenian time sea retreated from the southeastern part of the region and depocentres shifted westward to the area of Danube Basin. During a period of inactivity the Štiavnica Stratovolcano underwent intensive denudation reaching the level of shallow intravolcanic intrusions.

During the Late Badenian morphology of andesite stratovolcanoes changed dramatically. In the northern part of the region a huge Kremnica Graben subsided along NNE–SSW faults. The graben continued southward and reached the northern slopes of the Štiavnica Stratovolcano. The subsidence of the graben reaching 1000 m was compensated by accumulations of lava flows and hyaloclastite breccias.

Another graben evolved in the NE part of the region in the central and NE portions of the Javorie Stratovol-

cano. Its subsidence was compensated by effusions of basic andesite lavas representing the Blýskavica Formation (over 300 m). Hyaloclastite brecciation of lava flows in grabens indicated water environment. The graben fill was subsequently penetrated by extrusive domes of pyroxene-amphibole andesites ascending along marginal faults.

In the southern part of the region in the NE part of the Šahy–Lysec volcanotectonic zone during the explosive eruptions a smaller monogenic pyroclastic volcano Lysec was formed. Volcanoclastic material was transported mainly southward into the subsiding syngenetic Strháre–Trenč Depression where it comprised 250–300 m thick fill. The fill consists of epiclastic volcanic sandstones with conglomerate and fine breccia horizons.

At the Štiavnica Stratovolcano the initial subsidence resulted in the formation of a depression in the central part of the stratovolcano. The depression was filled by sands and silts with lignite intercalations representing the Červená studňa Formation. During following explosions and effusions of acid andesite lavas a caldera with diameter 18 x 22 km was formed. The caldera subsidence was compensated by 350–500 m thick accumulation of pyroclastics, lava flows and extrusions. At places where caldera fault was interrupted the volcanoclastic material was transported on slope of the stratovolcano and laid down in paleovalleys with radial orientation.

East Slovakian Basin

In the Badenian the East Slovakian Basin was still connected with open sea across the Carpathian Foredeep. While in the central part of the basin the base of the Badenian consists of volcanoclastics and sandstones, in the Prešov Depression the Badenian sediments are exclusively developed in the pelitic facies. The Lower Badenian deposits are represented by Nižný Hrabovec and Mirkovce Formations. The Nižný Hrabovec Formation is mainly extended in the Trebišov Depression while the Mirkovce Formation, representing Early and Middle Badenian, occurs in the Prešov Depression. The Middle Badenian in central basin part is represented by Vranov Formation and the Badenian sedimentary succession is capped by the Upper Badenian Zbudza, Klčovo and Lastomír Formations.

The Nižný Hrabovec Formation (Vass and Čverčko, 1985) of Lower Badenian, consists of sandstone and claystone and it contains a conspicuous layer of Hrabovec zeolitized tuff at the top of the formation. A typical member of the formation is Hrabovec Tuff (Buday in Matějka, ed., 1964; Vass and Čverčko, 1985) forming several meters to several tens of meters thick light green layers.

The Mirkovce Formation of Lower and Middle Badenian (Karoli and Zlinská, 1988) occurs in the Prešov Depression. It consists of monotonous gray claystone and siltstone originated below the wave base.

The Vranov Formation (Vass and Čverčko, 1985) of the Middle Badenian is characteristic by sandstone and pelitic development. In the western part of the basin, in Prešov Depression, it crops out near Ruská Nová Ves. At this locality sandy facies prevail. Parallel- and cross-stratified sand with occasional conglomerate layers indicates high energy of depositional environment. Such sediments were described from fan delta environments (Nemec and Steel, 1984). In the central part of the basin, in Trebišov Depression, the formation consists mainly of pelites. In this area the thickness of the formation is about 600 m. Facial development of sediments suggests deposition in the outer shelf environment.

Zbudza Formation (Vass and Čverčko, 1985) of Upper Badenian (Túnyi et al., in lit.) represents the second and last salinity crisis in the area of the East Slovakian Basin. Degradation of the basin is indicated by deposition of evaporites. The thickest halite accumulations occur in the surroundins of Zbudza village north of Michalovce. At the base of the formation massive and cross-stratified siltstones and claystones occur suggesting shallow-marine environment. These deposits contain anhydrite nodules and laminae indicating gradual isolation of the basin from the Carpathian Foredeep. The gradual isolation terminates into evaporic, predominantly halite deposition. The Zbudza Formation gradually passes into Upper Badenian Lastomír and Klčovo Formations.

The Lastomír Formation (Vass and Čverčko, 1985), with maximum thickness of 2000 m as indicated by boreholes east of Trebišov, consists of calcareous, gray clay with sandstone and acid tuff intercalations. Beside it the volcanic activity of the Upper Badenian is manifested by Zatín Volcanics (Vass in Baňacký, 1987) composed of alternating pyroxenic andesite lava flows, volcanoclastics and rhyolite. The Lastomír Formation came to origin as prodelta of the Klčov and/or Sečovce deltas.

The Lastomír Formation laterally passes into Klčov Formation represented by deltaic deposits. The largest delta (Klčov delta, Čverčko et al., 1968; Sečovce delta, Jiříček, 1972; Janočko, 1998; Řeřicha, 1992) entered the basin from northwest and reached as far as Trebišov and Michalovce area. In the Prešov Depression at the base of Klčov Formation the Kráľovce rhyolite tuffs (Bagdasarjan et al., 1971) were deposited. The tuff passes upward into clay thick up to several hundreds metres. This, in turn, passes into coarse-grained deposits – both gravel and sand alternating with sand. The coarse-clastic sediments, flanking the western part of the basin, were mostly deposited in the fan deltaic environments (Janočko, 1990). Eastward the sediment is more sandy and represents delta front environment.

During the Late Badenian the basin depositon was accompanied by an important volcanic activity. It started by explosive rhyodacite volcanism resulting in redeposited and pumice rhyodacite tuff underlying andesites of the Kráľovský Chlmec Stratovolcano. It was followed by andesite volcanism, products of which redeposited andesite tuff overlain by the lava flows of pyroxenic andesite. The stratovolcanoes occur in the surroundings of Zatín, Brehov, Sirník and Somotor. Radiometric ages of the Zatín andesite is 15.0 Ma and Brehov andesite 14.6 Ma (Bagdasarjan et al., 1971). The extrusive rhyodacite volcanism is today represented by individual bodies located S and SE of

Trebišov. Rhyodacites (rhyolites) occurring near Zemplín and Hrčeľ villages are associated with silicified and adularized breccia. Their radiometric age is 13.5 and 14.9 Ma (Tsonj and Slávik, 1971). The character of alteration points to submarine volcanism. The redeposited volcanoclastics are a product of explosive–hydrothermal breccia in a submarine environment.

South of Soľ village (NE of Vranov) a horizon of rhyolite tuff occurs which is associated with epiclastic rhyolite sandstone. The radiometric age of the tuff is 14.2 Ma (Repčok in Kaličiak et al., 1991). South of Zamutov village (W of Vranov) an extrusive rhyodacite dome occurs. Its analogue found in the borehole Zam-2 was radiometrically dated to 14.4 Ma (Bagdasarjan et al., 1971).

The evolution of the andesite stratovolcano Ošvárska (W of Vranov) commenced in the Late Badenian. It consists of autochthonous pyroclastics, pyroxenic andesite lava flows and andesite necks. The stratovolcano was also active during the Early Sarmatian.

Sarmatian

Vienna Basin

The Sarmatian deposits are extended in the Vienna Basin much more northward comparing to the Badenian sediments. At localities with the Upper Badenian shoreline the thickness of the Sarmatian deposits is to 200 metres (Jiříček, 1988). This documents transgression of the Sarmatian sediments over the Upper Badenian deposits. The Sarmatian depocentrum with more than 800 m thick sediments occurs in the Moravian Central Depression. The depression is toward east separated by Lanžhot Spit from the Kúty Depression where also 800 m of Sarmatian sediments occur (Jiříček and Seifert, 1990).

The northern continuation of the Moravian Central Depression is the Hradište Depression where Sarmatian sediments directly overlie the flysch basement. To the east the Kopčany Graben is bordered by uplifted Štefanov Block. In the continuation of the depression westward the Gbely Elevation occurs. The Koválov Depression belongs to the conspicuous structures of the basin. It flanks the Klippen Belt in the basement. In the south elevation of Lakšár Fault occurs and northeastward of Studienka Sološnica Depression extends. The Sarmatian deposits also flank slopes of Malé Karpaty Mts. and in the area of Láb – Suchohrad they comprise a flat plateau.

The Sarmatian sediments of the Vienna Basin have fresh-water character at the base and they pass upward into brackish deposits.

From the paleogeographic viewpoint it is important, that after the Upper Badenian widening of the marine and brackish basin northward before the Lower Sarmatian the intensive regression occured resulting in retreat of the brackish sea southward as far as Malacky, Láb and Vysoká villages. The next transgression again incursed as far to the north as Hradište Depression.

In the fresh-water basal part of the Sarmatian sediments of Holíč Formation (Elečko and Vass, 2001) the deposition of alluvial variegated, green, yellowish, bluish-green and gray sandy calcareous clay with local sand and silt lenses (Kopčany Member) prevailed. In transversal Kopčany Depression, the bodies of fluvial Radimov Gravel occur. The gravel is composed of flysch sandstones and shales.

The sediments of Holíč Formation, passing southward into brackish facies, represent prevailingly regressive depositional system of alluvial plain, beach plain and shelf. The sand of the upper part of Holíč Formation, which contains in the southernmost zones of its occurrence the microfauna of *Elphidium reginum* zone, represents initial stage of transgression in depositional system of shelf sand bars.

The sediments of Holíč Formation were during transgression overlain by the Skalica Formation (Elečko and Vass in Baňacký et al., 1996). The formation consists of monotonous greenish-gray calcareous clay with mollusc assemblage. At the margins of the basin they are composed of gray, pale gray conglomerate, sand and sandstone, locally sandy limestone with serpula-lumachella which are assigned to the Karlova Ves Member (Nagy et al., 1993).

Abrupt flooding of the area including Hradište Bay as well as characteristics of dispersion system documented by carbonate facies enable to assign described sediments into the transgressive deposition system of beach sand bars and at the northern margins of the Vienna Basin into transgressive deposition system of barrier, lagoon and estuary type. A complex of described depositional systems defines transgressive depositional system at the boundary of foraminifera zones *Elphidium reginum* and *Elphidium hauerinum*. The zone *Elphidium hauerinum* shows in the sedimentary record from the surroundings of Suchohrad and Gajary villages marly horizon thick 30–50 m (Jiříček, 1985) probably representing maximum flooding surface.

In the Upper Sarmatian sediments from surroundings of Gajary the sandy facies of deltaic origin again occur. Similar facies with similar interpretations are known from Holíč and Hodonín (Fig. III.27). The described prograde sands may be assigned to the regressive deposition systems of deltaic mouth bars.

Danube Basin and intramountain depressions

At the beginning of the Sarmatian (Figs. III.19 and III.20) the sea level dropped in the entire area of the Alpine–Carpathian zone. Because of it the Badenian marginal sediments were removed by erosion (Hudáčková and Kováč, 1993; Baráth, 1993).

In Danube Basin the Sarmatian sediments are represented by Vráble Formation (Priechodská and Harčár, 1988; Vass, 1989). The formation is lithologically variable. In Želiezovce Depression it consists at the base mainly of conglomerate, sandy, oolitic and lumachella limestone, sandstone and sand as well as acid biotitic tuff (Malá Member, Seneš in Steininger et al., 1985). Toward the centre of depression the volume of gray, calcareous, locally tuffitic clay increases. The upper part of the formation is composed of sands with clay intercalations (Seneš, 1962).

At margins of basin the deltaic sediments are developed (Nagy, 1998). Shallow-water environment originated mainly in the area of partly emerged pre-Tertiary basement, particularly southeast of Santovka–Levice Horst. In this area at periphery of the Štiavnica Stratovolcano the coarse-detritic, sandy and pelitic sediments with redeposited volcanic material, tuff and tuffitic sandstone and rarely layers of diatomite and organodetritic limestone were deposited. These sediments comprise Vráble Formation. Accumulation of volcanoclastic sediments delivered by rivers and torrential floods resulted in shallowing and emerging of some nearshore areas.

The sedimentary fill of Komjatice Depression consists of clays and sands, at the southeastern and eastern margin coal seams also occur (Gaža, 1961, 1971, in Biela, 1978; Gaža and Beinhauerová, 1976; Vass and Gašparik, 1978).

In the sedimentary fill of Blatné Depression predominating calcareous silt and clay occur. At the western margin the gravel and organogenic limestone occur. The upper part of the formation is composed of sands, variegated and gray calcareous clay, coal clay with lenses and seams of coal (Gaža, 1961, 1971; Homola, 1955; Biela, 1978). The formation originated in littoral zone and shelf of hyposaline sea. Coal lenses and seams suggest depositional environment of delta plain (Vass in Keith et al., 1989, 1994). Thickness of formation is according to Hrušecký et al. (1991, 1996) 300 m (Želiezovce Depression), 500 and 700 m (Blatné and Komjatice depressions).

In the northern part of Rišňovce Depression the eustatic sea level fall and tectonic subsidence of the central part of Danube Basin resulted in regression. During the Sarmatian and Lower Pannonian the fresh-water deltaic sediments of Ripňany Formation were deposited (Fordinál and Elečko, 2000). The Závada–Bielice Rise confines the formation of northern margin. The rise separates the Bánovce and Rišňovce depressions (Vass et al., 2002). The formation consists of greenish-gray, prevailingly sandy and calcareous clay. The clay is locally yellow, brown and violet spotted and may contain coalified remnants of plants and several cm thick intercalations of lignite. The thickness and number of sand beds passing to gravel increase toward the basin margin. The clay changes to pale gray, greenish gray and rusty yellow spots. At the base of the formation the calcareous sandstone occurs. Based on litho – and biofacies development Fordinál and Elečko (l. c.) assume that Ripňany Formation represents a river delta environment. The deltaic sediments were deposited in fresh-water environment (Gaža, 1968). The thickness of the formation is about 1400 m. The age of the formation is estimated on the base of superposition: it is underlain by Upper Badenian marine sediments and overlain by sediments of the Pannonian, Zone C.

In Bánovce Depression at the base of the Middle Sarmatian the conglomerates occur. The conglomerate clasts consist of andesite, quartz, granitoids and crystalline schists. The conglomerate passes upward into pelitic sediments with variable content of volcanoclastics, sands and tuffitic sandstones alternating with tuff and conglomerate (Kováč et al., 1993). The sediments were assigned to the Vtáčnik Formation as Ruskov Member (Šimon in Fordinál et al., 2001). The Ruskov Member represents sediments of prograding alluvial fans which were transported by grain flows and debris flows from the area of current Vtáčnik Mts. into swamp–lacustrine environment in the area of current Bánovce Depression. Several types of andesites in gravity flows point to several volcanic phases. Interconnection between Bánovce and Horná Nitra depressions was probably across the southern part of "Chalmová island" and across the surroundings of town Partizánske.

In the Horná Nitra Depression the Sarmatian sediments consist of gravelly sands belonging to the fluvial sediments of above described Lehota Formation.

As a result of isolation due to accumulation of volcanic rocks during the activity of Kremnica Stratovolcano, the Sarmatian deposits in Turiec Depression in fresh-water conditions originated. The main volume of Neogene Depression fill consists of pelitic sediments of Martin Formation (Buday, 1962; Hók and Rakús, in press) representing basinal facies of shallow lake and local swamps. The formation is lithofacially variable and the main part is represented by gray clays with variable sand admixture. The clay sometimes contains sandy intraclasts and concretions. The clay layers sandwiching the lignite seams are commonly enriched in coalified plant remnants accumulated in laminae. The clayey sand and sand, occasionally sandstone, fine-grained carbonate conglomerate and fresh-water limestone as well as redeposited tuff are present, too. The age of the formation ranges from Middle Sarmatian up to the Pliocene. The thickness of the formation varies from several tens of meters up to several hundreds of meters. The maximum thickness, described from the borehole ZGT-3, is 1025 m.

In the southern part of the Turiec Depression lateral member of Martin Formation was described by Hók and Rakús (in press) as Kalamenová Formation. The lithology of sediments is the same like in the Martin Formation, however, the Kalamenová Formation contains more volcanic rocks. Tuffitic claystones are pale, beige, pale-brown and light-gray. They predominate in the profile. The formation is some 500 m thick (borehole HGB-3a). Westward, close to the Lúčanská Malá Fatra Mts. the thickness of the formation rapidly decreases to about 50 m (Gašparik et al., 1989).

The main basin fill interfingers with coarse-clastic sediments entering the basin laterally. These sediments comprise several lithostratigraphic units.

The Slovany Formation (Gašparik et al., 1995; Hók and Rakús, 2004) is represented by breccia, poorly sorted conglomerate (near marginal fault and at the base), boulder conglomerate and sand layers. The sediments, which basinward become finer and better sorted, were deposited in alluvial fan environment by dense, water saturated gravity flows to short distance. The conglomerate is composed of Triassic limestone and dolomite and its clasts are subangular. The conglomerate matrix consists of sandy clay of ochreous and rusty brown colour and contains illite, quartz, calcite, dolomite and montmorillonite

(Gašparik et al., 1989). The age of the formation is based on its spatial position: distal parts of the alluvial fan interfingers Martin Formation (e. g. in the borehole KM-1 or at locality Stráža near Socovce) of Sarmatian–Pannonian age. The thickness of the formation is variable and at the western margin of the depression is of 360–400 m.

The Budiš Formation (Gašparik et al., 1995; Hók and Rakús, 2004) occurs in the southern part of the depression on the northern foothill of Žiar Mts. Similarly to the Slovany Formation the sediments of Budiš Formation probably represent alluvial fan environment (sediments of plain floods), however, petrographic composition is different. The main petrographic type-disintegrated weathered granite colluvium was transported on short distance. It is mainly represented by arcosic sand – sandstone of variable lithification degree. The clastic material is mainly composed of angular quartz grains 3–4 mm in diameter, feldspars, mica, mainly muscovite (Gašparik et al., 1995). The sandstone contains subangular blocks (up to several m^3) of coarse-grained Žiar granodiorites as well as of Mesozoic cover rocks. The thickness of the formation, recovered by HGB-1 borehole, is 908.7 m and by HGB-2 more than 600 m without encountering the basement. In contrast, at the western margin of the basin the thickness of the formation is only 70 m. The Sarmatian age is proven by ostracods and flora (Sitár in Gašparik, 1974) as well as by spatial position of sediments (Hók and Rakús, in press).

The Abramová Member (Gašparik et al., 1995; Hók and Rakús, in press) consists of coarse-clastic sediments of subaerial and subaquatic gravity flows (debris flows) deposited in alluvial fans and fan deltas. The coarse-clastic sediments gradually fines-up basinward and they interfinger with fine-grained sediments of Kalamenová Formation.

The formation is predominantly composed of friable carbonatic conglomerate. The clasts are subangular and poorly sorted. The sediments resemble Slovany Formation by spatial position, genesis and lithology. It differs by composition of the matrix, which does not contain red and bauxitic clays. Because it interfingers with sediments of depression fill, we assume its contemporary age. The thickness of the formation at the western margin is 500 m and basinward rapidly decreases.

The Sarmatian basin fill of Žiar and Zvolen–Slatina depressions is lithologically similar to the Badenian one. It is composed of volcanic and volcanoclastic rocks derived from volcanic centres of Vtáčnik Mts., Kremnické vrchy Mts., Poľana and Javorie Mts. as well as from Štiavnica Stratovolcano.

In the Horehronské podolie Depression the fresh-water sediments of Brezno Formation are preserved. They were deposited during the Badenian and Lower Sarmatian.

In the Orava Depression after tectonic movements the fresh-water deposits of Orava Formation (Wozny, 1976; Vass, 2002) started to accumulate in an isolated basin in Middle Sarmatian. The formation is represented by lacustrine gray clay and silt with variable content of sand and occasional sand layers. Bentonite and acid tuff are rare. The formation also contains seams and lenses of brown coal with coal shale and dark coal clay. The coal originated in marginal swamps of a lake. The basal and marginal facies of the formation are composed of coarse-grained deposits, fine-grained gravels with clasts composed of prevailing Paleogene rocks as well as coarse-grained sand and clay. These sediments represent environment of alluvial fans. The gravel gradually disappears basinward and may be observed only in lenses (Watycha, 1976; Pulec, 1974, 1976; Pulec et al., 1976; Nagy et al., 1996). The formation transgressively and with unconformity overlies basement composed of Paleogene and Miocene rocks of Magura Unit and of Mesozoic rocks of the Klippen Belt. It is disconformably overlain by the Pliocene sediments of Čimhov Formation. The assumed thickness of the formation is 750 m (Nagy in Gross et al., 1993). The age of the formation ranges from Middle Sarmatian to Upper Miocene.

Central Slovakia Volcanic Field

The Lower and Middle Sarmatian were characterized by the revival of explosive-effusive volcanic activity giving rise to several smaller stratovolcanoes and stratovolcano complexes on surface of older, partly denudated Badenian stratovolcanoes.

In the Javorie area the complex Javorie Stratovolcano was formed with the central zone in the area of Kalinka–Stožok and a smaller volcano more to the west with the central zone in the surroundings of the village Králová. In the Poľana area a younger, mostly effusive stratovolcano (Veľká Detva Formation) evolved covering the Early Sarmatian caldera with rhyodacite volcanics.

In the northern part of the region at the margins of the Kremnica Graben an entire array of smaller volcanoes originated – Markov vrch, Vtáčnik, Zlatá Jedľa and Remata volcanoes at the west, Flochová Volcano at the north and Sielnica and Turová volcanoes at the east. The products of the described stratovolcanoes at the west covered the sedimentary fill of the Handlová–Nováky coal basin and terminated its evolution.

Important changes affected the Štiavnica Stratovolcano where several smaller volcanoes and stratovolcanic complexes originated in the caldera and on the stratovolcano slopes. The activity commenced by explosive eruptions of amphibole-pyroxene andesite with biotite. Pumice and ash were deposited at the caldera area on SW slope of the stratovolcano at the bottom of paleovalleys extending southward to the area of Ladzany and Hontianske Moravce as the Ladzany Formation. Products of the following explosive-effusive activity of pyroxene andesites (Badan Formation) comprise the upper part in the fill of described paleovalleys, which southward widened and passed into a flat coastal relief (Konečný et al., 1998). Lava flowing in the coastal area reached a considerable areal extention forming lava plateau.

Pumiceous tuffs of subsequent explosive eruptions of biotite-amphibole-pyroxene andesites were partly depo-

sited in the southern part of the caldera as the Biely Kameň Formation and partly they were transported on the stratovolcano slope where they form fill of radial paleovalleys. Subsequent effusions of amphibole-pyroxene andesite with biotite of the Sitno Complex, filled the southern and southwestern part of the caldera and continued on stratovolcanic slopes restricted by paleovalleys. They form the uppermost part of their fill.

Subsequent explosive activity of biotite-amphibole--pyroxene andesites gave rise to ignimbrite deposits in the SW and W parts of the stratovolcano (Drastvica Formation).

In a marine bay at the SW margin of stratovolcano the tuffaceous sediments with coal intercalations were deposited in partially isolated brackish–lagoonal environment. Thickness of sediments reached over 130 m as indicated by boreholes (Brestenská, 1955; Blaško et al., 1989). Based on marine fauna the formation was assigned to the lowermost ervilia beds i. e. to the Lower Sarmatian (Váňová, 1960). It underlies lava flows and hyaloclastite breccias of coarse-grained amphibole-pyroxene andesites of the Priesil Formation.

During the Middle and Upper Sarmatian the effusive activity of pyroxene and leucocrate andesites of the Inovec Formation occurred at the western slope of the Štiavnica Stratovolcano. In the southeastern part of the Štiavnica Caldera a smaller stratovolcano Jabloňový vrch was formed.

Upper Sarmatian and Pannonian are characteristic by block movements along NNE–SSW faults in the western part of the region. The amplitude of block movements reached 2000–3000 m. Asymmetric uplift of the basement resulted in formation of 10 x 17 km large Hodruša–Štiavnica Horst in the central part of the Štiavnica caldera. The formation of the horst was accompanied by the subsidence of the Žiar Depression. The fault system at the western margin of the horst and at the boundary between the horst and subsiding Žiar Depression was used for ascent of rhyolites to the surface. Products of explosive--extrusive volcanic activity were assigned to the Jastrabá Formation of the Later Sarmatian age. The formation consists of tuffs, extrusive domes, lava flows and laccoliths mainly accumulated at southeastern, eastern and northern margins of the Žiar Depression. The western, more subsiding part of the depression was filled by tuffitic sandstones, siltstones and clays and finer-grained epiclastic volcanic material. Rhyolite extrusions and dykes follow also the N–S trending fault system – Nová Baňa–Kľakovce.

Calc-alkaline volcanism was terminated by activity of basaltic andesites giving rise to maars, lava flows, intrusions, dykes and sills east of the Žiar Depression. These products are assigned to the Šibeničný vrch Complex.

East Slovakian Basin

During the Early Sarmatian in the East Slovakian Basin the process of Central Paratethys separation from the open sea was evident. The separation resulted in decrease of salinity and gradual development of brackish environment. However, in spite of isolation, the Lower Sarmatian sediments record transgression from the Pannonian realm located in the south (Fig. III.28). The Lower Sarmatian sediments are represented by the Stretava Formation (Vass and Čverčko, 1985) consisting of gray calcareous clay, sand and gravel, acid tuff of the Olšava and Rankovce Tuff. In the basin central and eastern part there are buried andesite stratovolcanoes (Malčice Volcanics; Ďurica, 1965; Rudinec and Magyar, 1980), Myšľa Members (Švagrovský, 1956; Seneš, 1955). Rhyodacites of Lipová (Vass and Kaličiak in Baňacký et al., 1987) consist of the intrusive bodies or necks cropping out at the northern margin of the basin NW of Vranov. At the western margin of the basin coarse-grained sediments known as Košice Gravel are exposed (Švagrovský, 1956; Vass, 1989; Janočko et al., 1991, 1998). They were deposited in deltaic and inner shelf environments. The gravel is polymict and alternates with sand and clay. Wider basinward extension of the gravel was restricted by rising volcanic chain of Slanské vrchy Mts. Deltaic sediments were also deposited at the northern margin of the basin by paleoflows of Laborec and Topľa rivers.

The Late Sarmatian represents beginnig of a new sedimentary cycle – a phase of gradual transition from brackish to fresh-water regime. The lower part of sedimentary succession still contains brackish foraminifers assemblage. In the upper part only crashed fresh-water mollusc fragments occur. The basin was entirely open toward the Pannonian basin in the south and toward the Ukraine part of the Transcarpathian Depression. The sediments of the Upper Sarmatian are extended in Moldava Depression, southern part of Prešov Depression and in Trebišov Depression.

In the western part of the basin Middle and Upper Sarmatian is represented by fresh-water Kochanovce Formation (Vass and Čverčko, 1985). The formation is characteristic by predominance of gray, light gray calcareous clay and claystone with intercalation of volcanoclastics. The volcanoclastics are concentrated in the surroundings of the Slanské vrchy Mts. as a part of peripheral zone of individual stratovolcanoes. In the east the brackish Ptrukša Formation is developed. It is subdivided in Lúčky Volcanoclastics and Závadka Member. The thickness of the formation does not exceed 200 m. The formation is composed of sand and friable sandstone with intercalations of calcareous clay and occasional tuff (Vass and Čverčko, 1985). The equivalent to the Kochanovce Formation in the Roňava Bay is the Galgavőlgy Tuff.

The Sarmatian was a period of an eventful volcanic activity. Except the above mentioned volcanics, which comprise a part of the basin fill (andesites and rhyolite tuffs), the main mass of volcanics forming the Slanské vrchy Mts. and Vihorlat Mts. was formed during the Sarmatian. The radiometric ages of the volcanic rocks from the Slanské vrchy Mts. vary from 10.0 to 13.6 Ma (Bagdasarjan et al., 1971; Slávik et al., 1976; Ďurica et al., 1978). The stratovolcano Ošvárska in the northern

part of the mountains faded during the Early Sarmatian. At that time also new and main andesitic stratovolcanoes formed in the Slanské vrchy Mts. Several isolated andesite and rhyolite bodies on the basin margin, rhyolite ignimbrite and perlite (with radiometric age varying from 11.1 to 12.1 Ma) were also formed during Sarmatian (Vass, 1967; Bagdasarjan et al., 1968, 1971; Pulec and Vass, 1969; Konečný, Lexa and Dublan in Baňacký et al., 1989).

According to the radiometric ages the Vihorlat and Popriečny volcanic mountains commenced to form during the Middle and mainly Late Sarmatian. During the Middle Sarmatian the andesite Vinné Complex originated. During the Sarmatian a number of stratovolcanoes erose. Their activity terminated during the Pannonian (e. g. Bagdasarjan et al., 1971).

Rhyolite and rhyodacite volcanoes Veľký and Malý Kamenec and Viničky (S of Trebišov town) were formed on the Zemplín Horst during Late Sarmatian. Their lava flows are accompanied by various types of volcanoclastics and tuffs which form an important part of Galgavőlgy Formation on the southern foothill of the Zemplín Hills.

Pannonian

Vienna Basin

The Pannonian sediments are represented by Bzenec Formation (Čtyroký, 2000) including the so-called Big Pannonian Sand in the Vienna Basin. The sand upward fines up and passes into silts and clays. Deposition occurs in extremely shallow-water environment and in deltaic environments.

Danube Basin and intramountain depressions

Uplift of the Carpathians at the end of Sarmatian and at the beginning of Pannonian resulted in separation of the Pannonian area from the other part of Paratethys. This determined formation of Pannonian lake with gradual drop of salinity due to input of fresh-waters from mainland (Kázmer, 1990). The Pannonian sediments (Figs. III.22 and III.23) in the Danube Basin were deposited in shallow lake of Kaspibrackish character, which was filled by deposits transported by rivers from uplifted Alpine–Carpathian Orogene. These sediments are assigned to the Ivanka Formation (Priechodská and Harčár, 1988; Vass, 1989).

In the southern part of the Danube Basin, in Blatné and Rišňovce depressions, a dominant part of the formation is composed of sand. In Želiezovce Depression the calcareous clay and silt prevail. In Komjatice Depression and in the northern part of Gabčíkovo Depression the sand, calcareous clay and silt alternate (Pagáč et al., 1991; Hrušecký et al., 1996). In the upper part of the formation coal clay and lignite seams occur (Vass and Gašparik et al., 1978). The sediments originated in deltaic environment similarly to contemporaneous deposits in Hungary. The thickness of the formation is about 2000 m.

The lake level fall at the Sarmatian/Pannonian boundary resulted in the northern part of Rišňov Depression in continuing progradation of delta i. e. the Ripňany Formation during the Lower Pannonian (zone A-B). The delta prograded southward into lake (approx. as far as line Sered'–Veľké Zálužie). It is suggested by occurrence of fresh-water Ripňany Formation overlying sediments of Vráble Formation with Sarmatian brackish fauna. Deltaic sediments represent greenish-gray, violet, red and rusty-yellow spotted calcareous clay with intercalations of conglomerate. The conglomerate contains well-rounded clasts and pale-red matrix. The sediments probably originated in delta plain environment.

Lacustrine sediments of Hlaviná Member, occurring in Rišňovce Depression, are also of Pannonian age (Fordinál and Nagy, 1997). They belong to the lower part of Beladice Formation described below. The member consists of pale and white friable limestones and solid fresh-water limestones. The unlithified limestone passes into green, rusty spotted clay with sand layers and intercalations (up to 5 cm) of lignite (Fordinál and Nagy, l. c.). The thickness of the member is 50–60 m. The age is the Pannonian, zone H (sensu Rögl et al., 1993).

In the Upper Pannonian the Závada–Bielice Elevation vanished function of a barrier and Bánovce Depression became a part of the Danube Basin (Vass et al., 2002). Sediments of the Upper Pannonian Beladice Formation were deposited in lake and swamps in this part of the basin.

In the Turiec Depression deposition continued by fresh-water lacustrine sediments of Kalamenová and Martin formations. Amidst of Martin Formation during Pannonian the fresh-water clayey Dolina Limestone deposited (Hók and Rakús, in press). The limestone is pale, beige and sometimes brown and gray-brown in colour. The limestone is stratified, lithified with transition into calcareous clay and marl. Commonly two or three limestone layers are separated by calcareous clay. The Dolina Limestone is an important correlation horizon. It is possible to observe it even as denudation remnants in the entire depression. The limestones are characteristic by abundance of fresh-water gastropods and molluscs forming coquinas. They probably originated in lagoonal environment.

Input of clastic material continued at that time and alluvial fan sediments of Slovany, Budiš and Abramovce Formations continued to develop.

In Žiar Depression and probably also in the southern part of Zvolen–Slatina Depression the fresh-water sediments of Trubín Formation were deposited (Vass, 2002). The formation consists of tuffitic claystone alternating with sandy claystone, fine-grained sandstone, lenses of fine-grained gravel and seams and lenses of lignite or brown coal (fide Nagy et al., in Konečný, ed., 1998). Sediments originated in intravolcanic lake with high overflow. The thickness of the formation is 270–300 m. Planderová (in Konečný et al., 1983) described from the formation pollen and spores suggesting Pannonian and Pontian ages.

At the Pannonian and Pontian boundary the Kosorín Member (Vass, 2002) developed in the Trubín Formation.

The member contains coal seams thick 1.8 to 7.2 m. The seams are separated by silt and clay with various content of coal matter. In the surroundings of Trubín the coal is substituted by clayey lignite. Kosorín coal-bearing Member originated in swamp at the margin of a shallow lake. Its maximum thickness is 85 m. The area of extension is in the northern part of Žiar Depression, in the surroundings of villages Kosorín and Trubín.

In the Orava Depression the sedimentation of Orava Formation continued.

Central Slovakian Volcanic Field

Alkali basalt volcanism was active in the region during the Late Pannonian to Quaternary time. Denudation remnants of a lava flows Ostrá Lúka (SW of Zvolen) were dated to 8.0 resp. 6.59 Ma. Relics of lava necks near Banská Štiavnica dated to 7.29 and 6.88 Ma (Kantor et al., 1981) represent feeder systems to surface volcanic structures removed by erosion.

The youngest volcano Putikov vŕšok near Nová Baňa comprises relics of scoria cone and lava flows directed northward into the Hron valley. They overlie the terrace of the Riss age corresponding to the age 140–130 ka (Šimon and Halouzka, 1996; Šimon, 2000). Radiometric dating (Balogh in Konečný et al., 1999) yielded the age 0.53 ± 0.16 Ma.

East Slovakian Basin

Deposition in the East Slovakian Basin continues after hiatus by transgression of Sečovce Formation (Vass and Čverčko, 1985) Pannonian in age. The fresh-water, up to 1300 m thick formation extended in Trebišov and Moldava depressions. Maximum thickness of the formation occur between Sečovce and Trebišov. Besides claystone and siltstone with frequent sand layers the intercalations of volcanoclastics as a product of fading volcanic activity in the Slanské vrchy Mts. and Vihorlatské vrchy Mts. are typical. The most conspicuous volcanoclastic horizon is the Hažín Tuff covered by the clay, claystone and lignite seams of the Hnojné Member.

Small deltas entering the basin from the north (probably paleorivers of Laborec and Ondava) delivered coarse-grained sediments. Similarly in the Moldava Depression on the foothill of the Spišsko-gemerské rudohorie Mts. the coarse-grained deposits of alluvial fans originated (Janočko and Šoltésová, 1993).

During Pannonian, the activity of the Slanské vrchy Mts. andesite volcanoes as well as the activity of the most Vihorlat Mts. stratovolcanoes ceased. The youngest volcanics of the Vihorlat Mts. are about 9 Ma old (Slávik et al., l. c.). The Pannonian radiometric ages (9 Ma) are reported from some andesites and dacides at locality Dubník in the Slanské vrchy Mts. (e. g. Slávik et al., 1976; Kaličiak et al., 1991, 1996). The products of coeval explosive andesite volcanism are represented by the Albinov Tuff exposed NW of Sečovce town. Acid volcanism was active on southern periphery of the Vihorlat Mts. The rhyolite of Hrádok Hill near Michalovce town seems to be also Pannonian in age (Márton et al., 2000).

Pontian

Danube Basin and intramountain depressions

The Pontian sediments (Figs. III.22 and III.23) extend in the entire Danube Basin and in the Bánovce Depression. They are represented by Beladice Formation (Priechodská and Harčár, 1988; Vass, 1989). The prevailing lithotype is greenish-gray clay with varying content of silt and sand admixture and intercalations of sand. Typical are dark coal clay and lignite seams. At the margin of the basin gravel and conglomerate as well as fresh-water limestone occur (Buday, 1962; Buday in Buday et al., 1967; Priechodská and Harčár, 1988; Hrušecký et al., 1991, 1996; Fordinál and Nagy, 1997). The predominating part of the formation originated in deltaic and lacustrine environments. The coal seams were deposited on delta plain (Vass in Keith et al., 1994). The thickness of the formation is several hundreds metres, in the borehole D-1 the thickness is up to 1165 m.

In Hornonitrianska kotlina Depression the Pontian sediments are represented by Lelovce Formation (Gašparik, 1957; Slávik, 1959). The formation is composed of clayey--sandy sediments with layers of gravel, conglomerate and fresh-water limestone. The clay is of variegated colour. The formation, thick up to 100 m, originated in fluvial environment, probably as a channel fill. The age of the formation was proved by pollen spectra (Planderová fide Šimon et al., 1997) and it may be correlated with Poltár Formation of South Slovakia.

In Turiec Depression the deposition of fresh-water lacustrine sediments of Martin Formation continued.

Already at the end of Pannonian deposition of Bystrička Formation commenced (Gašparik et al., 1995; Hók and Rakús, 2003). The formation extends at the western margin of the depression. It consists of coarse-clastic sediments of subaeric and subaquatic gravity flows (debris flows) in alluvial fan environment. In contrast to the Slovany and Abramovce formations, the petrographic composition of Bystrička Formation is variegated. The clasts of crystalline, Mesozoic and Paleogene rocks are of various roundness. There is no direct biostratigraphic evidence of the formation age, however, the position on the Martin Formation suggests Upper Pannonian and Pontian ages. The thickness of the formation is 200 m.

At the end of the Pannonian in the southern part of the basin the Pravno Member was deposited (Gašparik et al., 1995; Hók and Rakús, in press). The member consists of light gray, bluish and greenish calcareous clays with accumulations of plant fragments and shells of fresh--water gastropods.

In the Žiar Depression and probably also in the southern part of Zvolen–Slatina Depression there continued the deposition of Trubin Formation being described above.

In the Orava Depression the deposition of Orava Formation terminated.

Area of South Slovakian Depressions

The area of South Slovakian Depressions and Cerová vrchovina Mts. was after the Badenian uplifted and eroded. During the Pontian the subsidence in the northern part of Lučenec Depression revived resulting in deposition of Poltár Formation. The formation fills also the river valleys on the foothill of Slovenské rudohorie Mts. During deposition the basaltic volcanism was active comprising Podrečany Formation. The sediments and volcanics mutually interfinger.

The Poltár Formation (Andrusov and Zorkovský, 1950) originated in fluvial and lacustrine environments. It consists of gravel, sand and variegated clay. Characteristic is kaolinite clay with kaolinitized clasts of phyllites and other pre-Tertiary rocks. Another type of kaolinite clay contains angular clasts of quartz. The clays represent weathering crust redeposited on short distance. The only relic of original rock is insoluble remnant of quartz veins forming small angular clasts of quartz in the clay. The thickest sediments were found in the northern part of the Rimava Depression (more than 100 m). In the Lučenec Depression the formation thickness is maximum 100 m.

In depression the relics of lacustrine deltas and maar lake sediments are preserved. The sediments of a lake into which river network mouthed have been completely removed by erosion.

Deltaic sediments occur at the southern margin of recent distribution of Poltár Formation in Lučenec Depression. The sediments are coarse-grained suggesting deposition in fan deltas supplied by rivers with high traction ability.

Maar craters originated by phreatomagmatic activity of Podrečany Basalt Formation. After fading out of volcanic activity they were filled by precipitation water and small lakes originated. In the lakes laminated alginite and diatomite were deposited (Vass et al., 1998a, 1998b). The Podrečany Formation is built up by basalt lava flows and maars (Vass and Kraus, 1985; Konečný and Lexa in Vass and Elečko, 1992).

East Slovakian Basin

In the central and southeastern part of the basin 600 m thick Senné Formation developed (Vass and Čverčko, 1985). The Senné Formation overlies Sečovce Formation. Depositional hiatus is assumed between both formations (Vass et al., 2000). The formation consists mostly of kaolinitic clay, conglomerate/gravel (Pozdišovce Member; Mišík, 1954) and lignite seams (Krajné Member; Kocák and Čverčko, 1965).

Pliocene, Dacian and Rumanian

Danube Basin and intramountain depressions

The Pliocene–Dacian sediments are known from the entire Danube Basin and occur also in the intramountain depressions. They represent terminal parts of Neogene sedimentation occurring in fluvial and partly also in lacustrine environment. At that time the river network resembling recent network was formed.

In the Danube Basin the Dacian sediments are represented by Volkovce Formation (Priechodská and Harčár, 1988; Vass, 1989). In the central part of the basin it consists of variegated clay, silt and sand deposited in fresh-water fluvial and lacustrine environment. At the marginal parts of the Danube Basin the formation is mostly composed of gravel and sand and on carbonate basement also fresh-water limestone. The thickness of the formation is 1200–1400 m.

In Komjatice Depression the Nemčiňany Gravel is developed (Brestenská in Kuthan et al., 1963) representing fill of pre-Hron river distributary channels of Gilbert-type delta (Baráth and Kováč, 1995). The thickness of the member is several tens of metres.

In Blatné Depression near Piešťany the variegated (violet, yellow, pink) fine- and medium-grained kaolinic quartzose sandstone and conglomerate occur. The sediments also contain red and light gray kaolinic clay with pyrite concretions. The conglomerate clasts are mostly composed of quartz, minor occurrence have limestone and cherts. In fissures of kaolinic sandstones crystallized kaolinite and halloyzite. The red colour is caused by admixture of fine-grained hematite. Correlation with Volkovce Formation is only done on the base of variegated colouration typical for clay of Volkovce Formation.

In all intramountain depressions with exception of Hornonitrianska kotlina Depression the Pliocene sediments are of variegated development and they originated in fresh-water environment.

In Trenčín and Ilava depressions the upper part of the fill consists of gravel and sand with clay intercalations (Buday in Maheľ et al., 1962). These sediments represent equivalents of Volkovce Formation.

In Žiar and Zvolen–Slatina depressions and in the Horehronské podolie Depression the Pliocene sediments are represented by Banská Bystrica Formation (Andrusov, 1954). The formation consists of light gray sand, clayey sand, gravel with large blocks and pebbles of quartz, quartzite and crystalline rocks. The thickness of the formation is several metres. It extends above the valley of middle and upper Hron river from Pohorelá as far as Hronská pahorkatina Upland in the Danube Basin. The age of the formation is Pliocene (Late Pliocene?) as suggested by relationship to the Quaternary terraces of the Hron river.

In Turiec Depression the Pliocene sediments are represented by several sedimentary units or their parts. The main part of the depression fill consists of clayey sediments deposited in lakes belonging to the above mentioned Martin Formation. At the depression margins the coarse-clastic sediments interfinger the clay. In the southern part of the depression they are represented by already described Pravno Member. This is overlain by Diviaky Member (Buday, 1962) mostly consisting of clay and

minor gravel. The clay is light-gray, greenish-gray and yellowish-brown, plastic. Occasionally it contains the intercalations of fine-grained micaceous quartzose sand. The gravel mainly consists of dark andesite clasts and less quartz, granitoids, quartzite, dolomitic limestones, metaquartzite and Paleogene sandstone. The Diviaky Member represents an alluvial fan probably supplied by paleochannels of the Turiec river. The thickness of the member does not exceed 40–60 m and northward it decreases to 5 m.

In the NW part of Turiec Depression the fresh-water sediments of the upper part of Dubná Skala Formation originated since the end of Pontian and during the Pliocene (Hók and Rakús, in press). The sediments consist of fresh-water limestone, travertine and in the lower part of sandy clay and claystone with occasional laminae of carbonate conglomerate.

The clay is plastic greenish-gray, darkish-gray and black (coal clay). It comprises up to 7 m thick layers of limestone. The volume of sandy admixture varies. The conglomerate clasts are composed of dolomites and limestones and reach in diameter up to 1 cm. The thickness of the formation is about 150 m. In the Orava Depression the Čineková Formation (Vass, 2002) covers unconformably the Orava Formation. The Čineková Formation consists the gray-green clay and silt with intercalation of sand, lignite stones and gravel (Pulec, ed., 1976).

In the Danube Basin the entire sedimentary succession is terminated by fluvio-lacustrine deposits of Kolárovo Formation (Dlabač, 1960; Vass, 1989; Vass in Keith et al., 1989, 1994). The formation consists of micaceous sand and fine-grained gravel alternating with sandy, gray, rusty and greenish-gray clay which is occasionally calcareous. The thickness of the formation is 100–150 m. On the base of spatial distribution of the sediments as well as on magnetostratigraphy (borehole Čuňovo-1, Vass et al., 1992) the age of the formation is the uppermost Pliocene – Romanian.

Area of the Southern Slovakia – Cerová vrchovina Highland

During Pliocene – Pleistocene, the volcanic activity spread to the southern part of the Lučenec Basin and to Cerová vrchovina Highland – Northern Hungary (Šalgótárján area). Southern part of Cerová vrchovina Highland uplifted and transformed into a dome structure indicated by geomorphologic evidence and by change of hydrodynamic regime during Early Pliocene up to Late Pleistocene (Vass et al., 1986). Volcanic activity of the Cerová Basalt Formation created a number of scoria cones accompanied with lava flows and/or lava complexes built at their foot by lava plateau. Phreatomagmatic activity resulted in formation of maars, tuff rings and tuff cones. Volcanic activity according radiometric data occurred during several volcanic phases from 5.43 Ma up to 1.16 Ma (Balogh in Konečný et al., 1999).

East Slovakian Basin

The Neogene evolution of the East Slovakian Basin terminates in the Pliocene by Čečehov Formation (Vass and Čverčko, 1985). The formation overlies unconformable Senné Formation and has thickness of some 200 m. It consists of variegated clays containing layers of andesite gravel and sand as well as redeposited tuff. The sediments were delivered into the fresh-water lake from the Vihorlatské vrchy Mts.

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IV. GEOLOGIC STRUCTURE AND EVOLUTION OF INTRAVOLCANIC DEPRESSIONS IN THE AREA OF NEOGENE VOLCANISM IN CENTRAL SLOVAKIA

VLASTIMIL KONEČNÝ[1], JAROSLAV LEXA[1] and LADISLAV ŠIMON[1]

Geotectonic position of the Neogene volcanism

During Neogene the Carpathians formed a continental margin or a true island arc including part of older continental crust. The arc migrated northward, northeastward and eastward powered by the subduction of oceanic and suboceanic crust of the Flysch basins until it collided gradually from the west to the east with the margin of the European Platform. While the continent/continent type collision in the Alpine realm stopped relative motion of the African and European plates, the arc retreat into the area of Flysch basins was compensated by the formation of intra-arc and back-arc extensional basins and by the escape of lithosphere from the Alpine collisional zone into the area of back-arc extension (Csontos et al., 1992). The crust and lithosphere extensions in the area of the Pannonian basin and its northern margin were accompanied by an ascent of asthenosphere up to relatively shallow levels.

The above mentioned geotectonic framework and distribution of blocks of older continental crust influenced substantially the spatial and time distribution of Neogene volcanic formations and their geochemical evolution (Fig. IV.1).

Concerning the spatial distribution and geochemical characteristics, the Neogene volcanic formations of the Carpathian–Pannonian region are subdivided into four groups (Lexa et al., 1993):

1 – Areally distributed dacite and rhyolite volcanism of prevailingly explosive type characterized by great volumes of ash/pumice tuffs deposited in the area of Pannonian and Transylvanian basins, covering an area of ca. 125 000 km^2. The explosive products in the source areas are accompanied by extrusive domes. From the petrological point of view these rocks represent magmas of prevailingly crustal origin (Salters et al., 1998) generated by anatexis of crustal material due to overheating by diapiric ascent of asthenosphere in the extensional regime and an assumed underplating by magma from a mantle source (Póka, 1988). This type of dacite and rhyolite volcanism, related to the formation of crustal magma reservoirs, is mainly characteristic for initial stages of back-arc extension in the environment of a relatively thick continental crust.

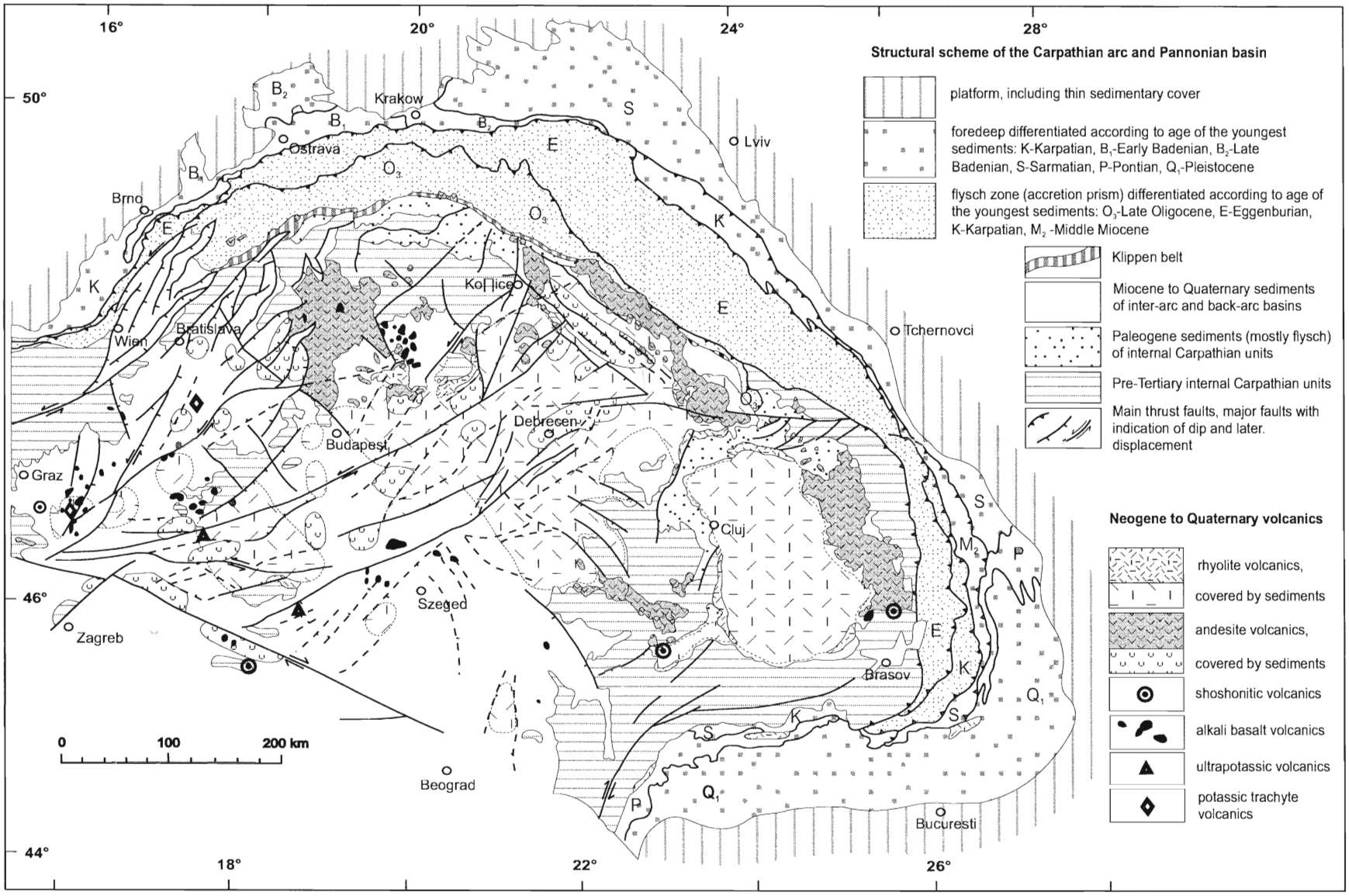
Products of areally distributed explosive dacite and rhyolite volcanism in the area of Slovakia are represented by ash/pumice tuffs and ignimbrites deposited in the Lower Miocene sediments in the area of Southern Slovakia (position and lithology is discussed in the section of South Slovakian Basin) and in the area of Eastern Slovakia in the East Slovakian Basin.

2 – Areally distributed andesite volcanism represents an association of intermediate, basic and acid andesites of calc-alkaline type characterized by the evolution of andesite stratovolcanoes with a substantial occurrence of differentiated rocks and subvolcanic intrusions. Besides stratovolcanoes also the extrusive domes and effusive complexes occur in the fill of volcanotectonic grabens. Typically there is a close time and space relationship with extensional tectonics of the back-arc area, mainly with its more advanced phase related to the evolution of a horst/graben system. The geochemical characteristics of rocks suggests mantle magmas affected by previous subduction processes and influenced by crustal material (Salters et al., 1998). The ascent of mantle magmas representing the source of andesite volcanism is related to the processes of diapirism in conditions of back-arc extension (Lexa and Konečný, 1974, 1998). After the ascent into shallow subsurface reservoirs they further evolved through processes of fractional crystallization and magma mixing.

The products of calc-alkaline andesite volcanism form expressive volcanic mountains with relics of andesite stratovolcanoes, monogenous volcanoes, extrusive domes and complexes of volcanoclastic and volcanosedimentary rocks (Fig. IV.2).

3 – Basaltic-andesite and andesite volcanism of the arc type is represented by andesite stratovolcanoes of small and medium size with minor occurrence of differentiated rocks and subvolcanic intrusions. A characteristic feature is the alignment of volcanoes in well-defined segments subparallel to the Carpathian arc or orientation of the

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Structural scheme of the Carpathian arc and Pannonian basin
platform, including thin sedimentary cover
foredeep differentiated according to age of the youngest sediments: K-Karpatian, B1-Early Badenian, B2-Late Badenian, S-Sarmatian, P-Pontian, Q1-Pleistocene
flysch zone (accretion prism) differentiated according to age of the youngest sediments: O3-Late Oligocene, E-Eggenburian, K-Karpatian, M2 -Middle Miocene
Klippen belt
Miocene to Quaternary sediments of inter-arc and back-arc basins
Paleogene sediments (mostly flysch) of internal Carpathian units
Pre-Tertiary internal Carpathian units
Main thrust faults, major faults with indication of dip and later. displacement
Neogene to Quaternary volcanics
rhyolite volcanics, covered by sediments
andesite volcanics, covered by sediments
shoshonitic volcanics
alkali basalt volcanics
ultrapotassic volcanics
potassic trachyte volcanics
16°
20°
24°
28°
50°
46°
44°
18°
22°
26°
Krakow
Lviv
Ostrava
Brno
Wien
Bratislava
Kosice
Tchernovci
Budapest
Debrecen
Graz
Cluj
Szeged
Zagreb
Brasov
Beograd
Bucuresti
0
100
200 km

subduction zone. Geochemical characteristics matches volcanic rocks of evolved island arcs and continental margins. The time and spatial distribution of volcanic rocks was directly related to the subduction of oceanic crust of former flysch basins.

The arc-type andesite volcanoes form on our territory the northern part of Slanské vrchy Mts. and Vihorlat Mts. They represent the western margin of a volcanic chain that continues into Western Ukraine and onto the territory of Northern and Eastern Romania over a total length of 500 km.

4 – Alkali basalt and basanite volcanism, following immediately the calk-alcaline andesite volcanism indicates a continuing extension of the back-arc area. It is related to diapiric ascent of asthenospheric mantle which was not contaminated by subduction processes. Characteristic volcanic forms there are diatremes, maars, tuff cones and separated or clustered cinder cones accompanied by lava flows.

In Central Slovakia the alkali basalt volcanism is represented by sporadic lava flows near Ostrá Lúka (SW of Zvolen), two necks near Banská Štiavnica and a cinder cone with lava flows near Nová Baňa. More extensive relics of basaltic volcanism in Southern Slovakia are in the area of Lučenec Depression and Cerová Highland with continuation on the territory of Northern Hungary into the area of Salgótarján. The alkali basalt volcanism of Southern Slovakia is discussed in the section of South Slovakian Basin.

Areally distributed andesite volcanism in Central Slovakia

Origin of the areally distributed andesite volcanism in Central Slovakia was indirectly related to the subduction of the oceanic basement of the Krosno flysch zone. Its spatial and time distribution was controlled by processes of diapiric ascent of the mantle in an extensional regime of the back-arc area (Lexa and Konečný, 1974, 1979a, 1998; Póka, 1988; Lexa et al., 1993, 1995). Volcanism developed in the area of the continental block of Central Western Carpathians over Hercynian crust that underwent metamorphic and granitization processes in conditions of the Andean type orogene and subsequently was affected together with Paleozoic and Mesozoic sediments by processes of continental collision (Tomek et al., 1989, Bezák et al., 1997). This fact is reflected also in the geochemical composition of volcanic rocks resembling closely the Andean type calc-alkaline associations of continental margins.

The Central Slovakian Volcanic Field with an area of 5600 km^2 developed in Middle and Late Miocene in the period since 16 to 9 million years. Dominant volcanic structures are represented by stratovolcanoes and minor extrusive domes and effusive complexes. In the southern part of this area the volcanic products were deposited in marine and brackish environments while in the central and northern sectors the products were deposited in fluvio-limnic and subaerial environments.

Main building units of the Central Slovakian Volcanic Field include following volcanoes (Fig. IV.2):

In the south of the region, near the southern edge of the Krupina plateau, products of submarine extrusive volcanism of the Vinice Formation are represented by extrusive bodies and related volcanoclastic rocks, Čelovce pyroclastic volcano and Lysec pyroclastic volcano with a central extrusion.

In the central and northern sectors of the volcanic field there occur the more extensive Štiavnica, Kremnica, Javorie and Poľana stratovolcanoes evolved during the Badenian time. Their evolution was terminated during the Upper Badenian and Lower Sarmatian time by the formation of volcanotectonic depressions – grabens and calderas. Prominent among these there are the Štiavnica Caldera, graben-type depressions of Javorie, caldera of Poľana and Kremnica Graben. The upper structure of these stratovolcanoes consists of relics of smaller Sarmatian andesite stratovolcanoes and effusive complexes deposited on top of older, partly eroded Badenian volcanic formations. In the case of the Štiavnica Stratovolcano the centers of these smaller volcanoes were located in the area of caldera near the caldera fault and partly on stratovolcanic slopes. In the northern part of the region smaller andesite stratovolcanoes are situated at marginal faults of the Kremnica Graben (Remata, Flochová, Vtáčnik, and Markov vrch volcanoes). On southeastern slopes of the Kremnica Stratovolcano these are represented by remnants of the Sielnica and Turovce volcanoes. The upper structures of the Javorie and Poľana stratovolcanoes are composed of remnants of Sarmatian volcanoes (Veľká Detva and Javorie Formations). Products of Sarmatian andesite volcanism cover to a great extent structures of older, Badenian stratovolcanoes.

The younger structural elements in the volcanic field are represented by Late Sarmatian products of rhyolite volcanism related to strong block movements during the development of the Žiar Depression and the Hodruša–Štiavnica Horst, formed in the framework of older caldera. Products of rhyolite volcanism associate with a fault system at the boundary between the depression and the horst with a high amplitude of vertical displacement. Rhyolite volcanism associated also with subparallel N–S fault systems, west and north of the Žiar Depression.

Basaltic andesite volcanism of the Pannonian age concluded calc-alkaline volcanic activity in Central Slovakia. Relics of this volcanism (dykes, intrusions, tuff cones and shallow intrusions) are associated with the fault system at the eastern margin of the Žiar Depression (Šibeničný vrch complex). In the area of Kremnické vrchy Mts. a smaller stratovolcano Vlčí vrch, consisting of basaltic andesites, is located at the fault system of the eastern margin of the Kremnica Graben. In the southern part of Vtáčnik Mts. remnants of basaltic andesite volcanism are represented by a group of dykes and a lava neck Ostrovica.

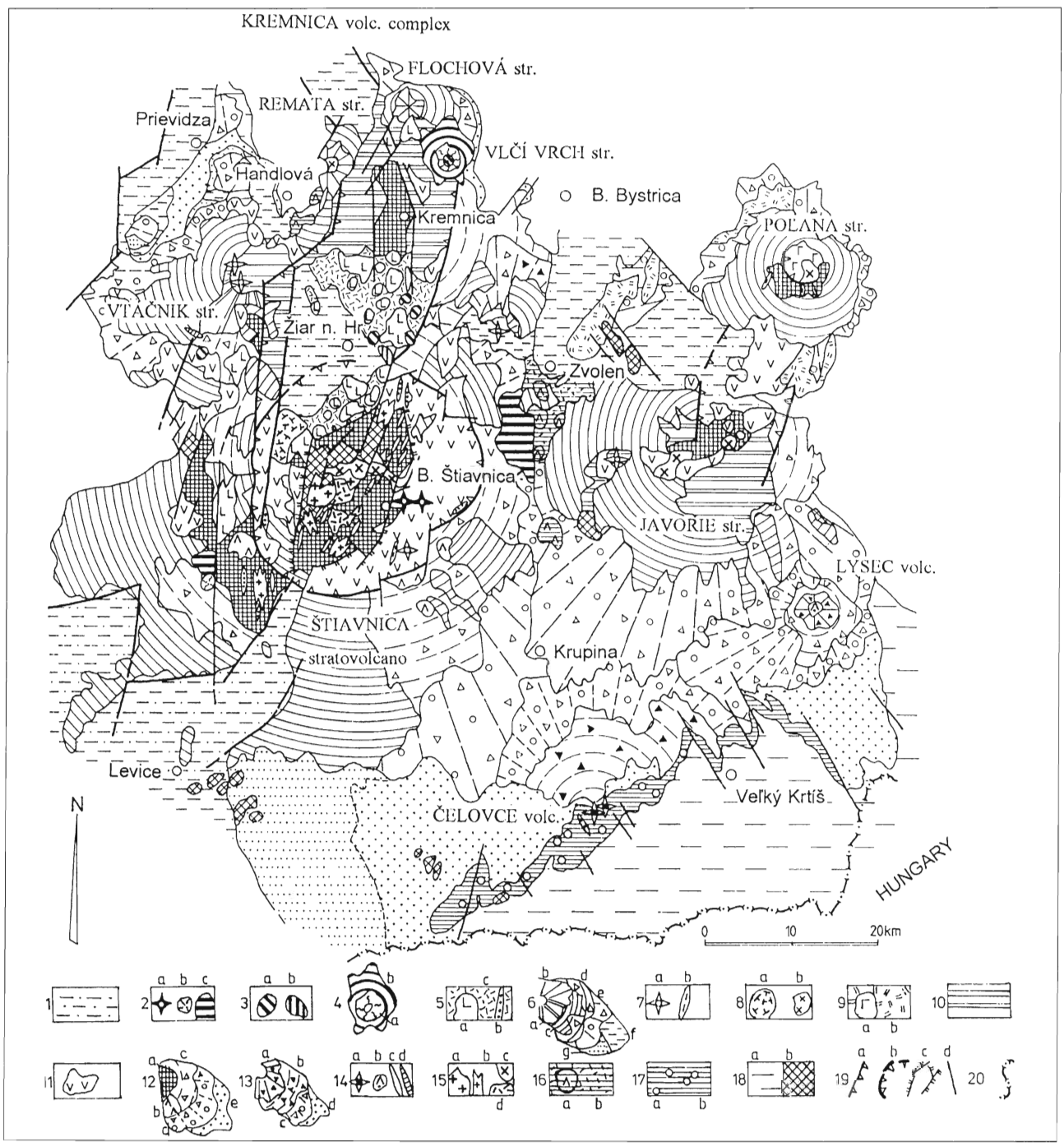
◀**Fig. IV.1.** Structural scheme of the Carpathian arc and Pannonian basin showing the extent of Neogene to Quaternary volcanic formations (Lexa and Konečný, 1998).

Volcanic activity in the Central Slovakian Volcanic Field was terminated by alkali basalts in the form of lava flows (Devičie, Ostrá Lúka), necks (Banská Štiavnica) and a cinder cone with lava flow near Nová Baňa.

Morpho-tectonic structure of the basement

Structural boreholes that encountered pre-volcanic basement, as well as geophysical surveys confirmed a complicated morphology of the pre-Tertiary basement relief characterized by elevations and depressions (Fusán et al., 1969). Interpretation of gravimetry and results of structural boreholes enabled to define a horst and graben structure of the basement and its relation to the evolution of volcanism (Konečný et al., 1973, 1978).

The horst and graben system in Central Slovakia evolved in the region of back-arc extension in a close time and space relation to evolution of volcanic activity. The structure shown in Fig. IV.3 resulted from a multi-stage development. Main features of the horst and graben system are characterized as follows:



– in the central and western sectors of the region N–S and NNE–SSW striking fault zones are predominant. Amplitudes of vertical displacement have maximum values of 2000–3000 m,

– in the central and western sectors of the region N–S and NNE–SSW striking fault zones dominate. Amplitudes of vertical displacement reach maximum values of 2000–3000 m,

– in the eastern part of the region NE–SW striking faults dominate in combination with NW–SE striking faults controlling the formation of horsts and grabens,

– volcanotectonic depressions represent a specific type of structures affected by magmatic processes – calderas and volcanotectonic grabens found in the basement of more extensive stratovolcanoes were formed by the collapse of crustal blocks into upper, depleted parts of magmatic reservoirs.

The first manifestations of extension forces and graben and horst formation along NW–SE striking faults coincided with the Early Badenian andesite volcanism of prevailingly extrusive type. Maximum subsidence related to the evolution of grabens along N–S and NNE–SSW striking faults took place during the Late Badenian time, including the formation of volcanotectonic depressions (Kremnica Graben, Štiavnica Caldera) in the central and western sectors of the volcanic field (products of younger Sarmatian andesite volcanism cover their marginal faults). During Late Sarmatian and Pannonian mainly NNE–SSW and NE–SW striking fault systems were reactivated accompanied by the ascent of rhyolites and the formation of horst and graben structures in the central and western parts of the region (Štiavnica Horst, Žiar Depression, Handlová Horst) and the formation of grabens near SW margins of Štiavnica Stratovolcano (Bátovce–Pukanec, Volkovo and Zlaté Moravce grabens).

Structural analyses of the Carpathian arc evolution and back-arc extension, including horst and graben structure of the Central Slovakian Volcanic Field (Nemčok and Lexa, 1990; Nemčok et al., 1993; Hók et al., 1995) showed that stress field changed during the Neogene in relation to the gradual collision of the Carpathian arc with the platform margin from the west to the east. While in the Early and Middle Badenian NW–SE compression (with NE–SW extension) prevailed, during the Late Badenian (e. g. during the period of maximum subsidence) the compression direction rotated to N–S and NE–SW (extension direction was E–W and NW–SE). The maximum stress acted variably in horizontal and vertical directions as reflected in horizontal and vertical movements and in combination of the two. During Sarmatian the stress field with a strong NW–SE extension persisted. Since Pannonian till recent the compression direction changed to N–S.

IV.I GEOLOGICAL STRUCTURE AND LITHOLOGY OF INTRAVOLCANIC DEPRESSIONS

In times of volcanic activity the intravolcanic depressions and grabens provided space for the deposition of coarse- and fine-grained volcanoclastic material. Deposition in fluvial-limnic or marine and brackish environments compensated their subsidence while the thickness of deposited volcanosedimentary material often reached several hundreds to over one thousand meters. A number of structural boreholes drilled into volcanosedimentary fill of intravolcanic depressions and grabens provided important information in respect of the geological structure, lithology, petrography and biostratigraphy as well as in respect of the evolution of neighbouring volcanic structures.

Evaluation and interpretation of gravimetric maps suggest that besides few depressions with obscure tectonic limits predominating graben structures are controlled by subparallel faults or fault zones with vertical displacement of hundreds of meters. Graben structures are often characterized by an autonomous sedimentary regime. Some depressions, limited by fault zones at one side only, represent asymmetric partial grabens or halfgrabens (Zvolen Depression, Turiec Depression, Horná Nitra Depression etc.). Time coincidence between subsidence and volcanic activity is proven in most of the depressions of the graben type. In some cases marginal faults were used for ascent of magma to the surface.

Besides depressions discussed above other specific types of depressions have been identified. They resulted from the subsidence of blocks into upper, depleted parts of magmatic reservoirs giving rise to calderas and volcano-

Fig. IV.2. Structural scheme of the Central Slovakia Volcanic Field (Konečný and Lexa, 1999). *Pannonian to Quaternary*: 1 – sediments of intravolcanic depressions, 2 – products of the alkali basalt volcanism: a – necks, b – cinder cones, c – lava flows. *Pannonian*: 3 – lava flows and sills of aphanitic calc-alkali basalts/basaltic andesites (a) and pyroxene andesites (b), 4 – stratovolcano of porphyritic calc-alkali basalts/basaltic andesites, a – volcanic cone, b – effusive complex. *Middle to Late Sarmatian:* 5 – rhyolite domes/dome flows (a), dykes (b) and pyroclastic and epiclastic rocks (c) of the Jastrabá Formation. *Early to Middle Sarmatian:* 6 – andesite stratovolcanoes, a – effusive cones, b – stratovolcanic cones, c – stratovolcanic complex of the proximal zone, d – epiclastic volcanic breccias of the proximal zone, e – epiclastic volcanic breccias and conglomerates of the proximal/distal zone, f – epiclastic conglomerates and sandstones of the distal zone, g – tuffaceous sediments, 7 – andesite necks (a) and dykes (b), 8 – andesite extrusive domes (a) and diorite porphyry intrusions (b), 9 – rhyodacite domes/dome flows (a) and related pumice tuffs and reworked tuffs (b) of the Strelníky Formation. *Late Badenian:* 10 – basaltic andesite/andesite effusive complexes with hyaloclastites and phreatomagmatic pyroclastic rocks filling grabens, 11 – dome/flow complexes and related breccias of intermediate to acid andesites filling grabens and caldera. *Early to Middle Badenian:* 12 – andesite stratovolcanoes: a – propylitized complex of the central zone, b – stratovolcanic complex of the proximal zone, c – epiclastic volcanic conglomerates and sandstones of the distal zone, 13 – andesite pyroclastic volcanoes, a – pyroclastic cones, pyroclastic complexes of the proximal zone, c – epiclastic volcanic breccias and conglomerates of the proximal/distal zone, 14 – andesite necks (a), quartz-diorite porphyry sills (b), and dykes (c), andesite dykes (d), 15 – subvolcanic intrusions, a – granodiorite, b – granodiorite porphyry, c – diorite and diorite porphyry, d – quartz diorite porphyry sills. *Early Badenian:* 16 – extrusive domes (a) and related breccias (b) of garnet-bearing andesites in the terrestrial environment, 17 – andesite extrusive domes (a) and volcanoclastic rocks of the Vinica Formation, 18 – *pre-volcanic basement:* a – Early Miocene sediments, b – older rocks, 19 – *faults:* a – marginal faults of volcanotectonic grabens, b – marginal faults of the caldera, c – marginal faults of volcanotectonic horsts, d – other faults, 20 – state boundary.

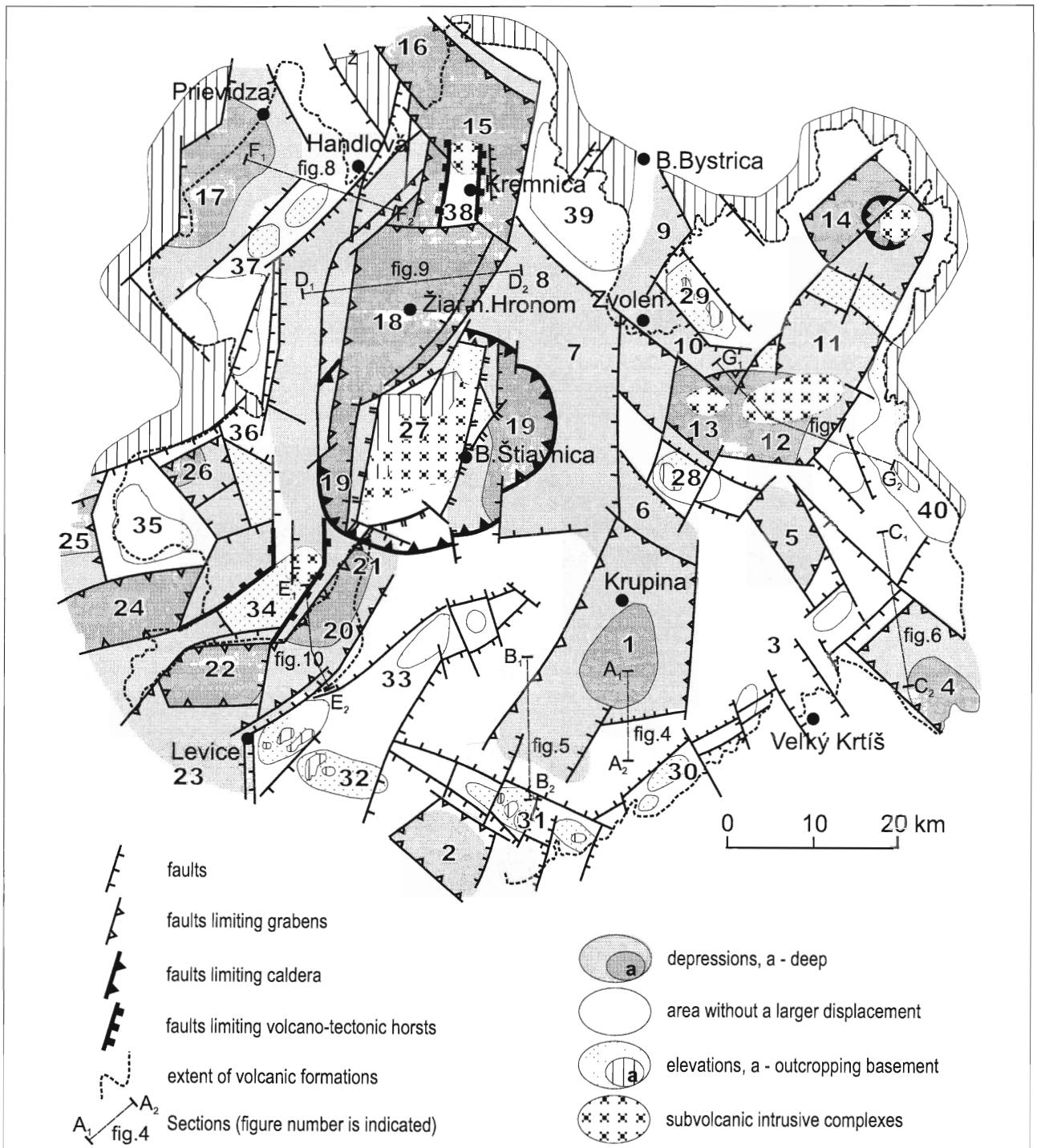
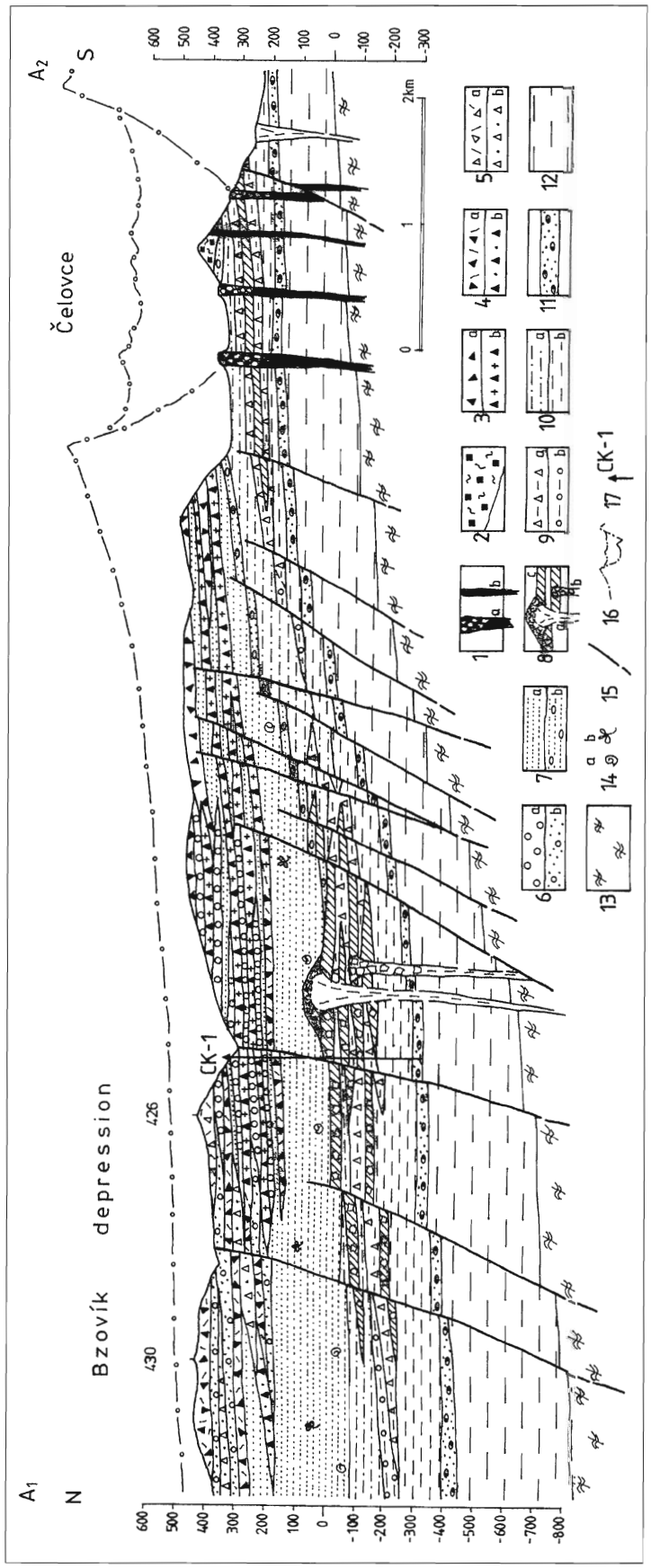


Fig. IV.3. Structure of pre-volcanic basement in the area of the Central Slovakia Volcanic Field (according Konečný et al., 1975, 1978). Explanations: 1 – faults, 2 – faults limiting grabens, 3 – faults limiting caldera, 4 – faults limiting volcano-tectonic horsts, 5 – depressions, a – deep, 6 – area without larger displacement, 7 – elevations, a – outcroping basement, 8 – subvolcanic complexes, 9 – extent of volcanic formations, 10 – sections in figures. List of basement structures. Depressions and grabens: 1 – Bzovík Depression, 1a – Rykynčice Depression (southern part of Bzovík Depression), 2 – Semerovce Depression, 3 – Dačov Lom Depression, 4 – Strháre–Trenč Depression, 5 – Turie pole Depression, 6 – Čekovce Depression, 7 – Bacúrov Depression, 8 – Kľačany Depression, 9 – Zvolen Depression, 10 – Slatina Depression, 11 – Vígľaš Depression, 12 – Javorie Graben; 13 – Kráľová Graben, 14 – Poľana Graben, 15 – Kremnica Graben, 16 – Turčianska kotlina Depression, 17 – Horná Nitra Depression, 18 – Žiarska kotlina Depression, 19 – Štiavnica Caldera, 20 – Bátovce Depression, 21 – Pukanec Depression, 22 – Čajkov Depression, 23 – Tekov Depression, 24 – Volkovce Depression, 25 – Zlaté Moravce Depression, 26 – Veľká Lehota Depression. Horsts and elevations: 27 – Hodruša–Štiavnica Horst, 28 – Pliešovce Horst, 29 – Lieskovský chrbát Horst, 30 – Šahy Elevation, 31 – Túrovce Horst, Elevation, 32 – Santovka Horst, Elevation, 33 – Krškany–Krnišov Elevation, 34 – Tatiar Horst, 35 – Pohronský Inovec Horst, Elevation, 36 – Župkov Elevation, 37 – Handlová Ridge Horst, 38 – Kremnica Horst, 39 – Malachov Ridge Elevation, 40 – Ábelová Elevation.



tectonic grabens. Volcanic products such as effusive and extrusive complexes and eventually, pyroclastic or hyaloclastite volcanoclastic rocks dominate in their fill. In some volcanotectonic grabens local fluvio-limnic deposition took place in relation to younger subsidence (Žiar Depression, Vígľaš Depression).

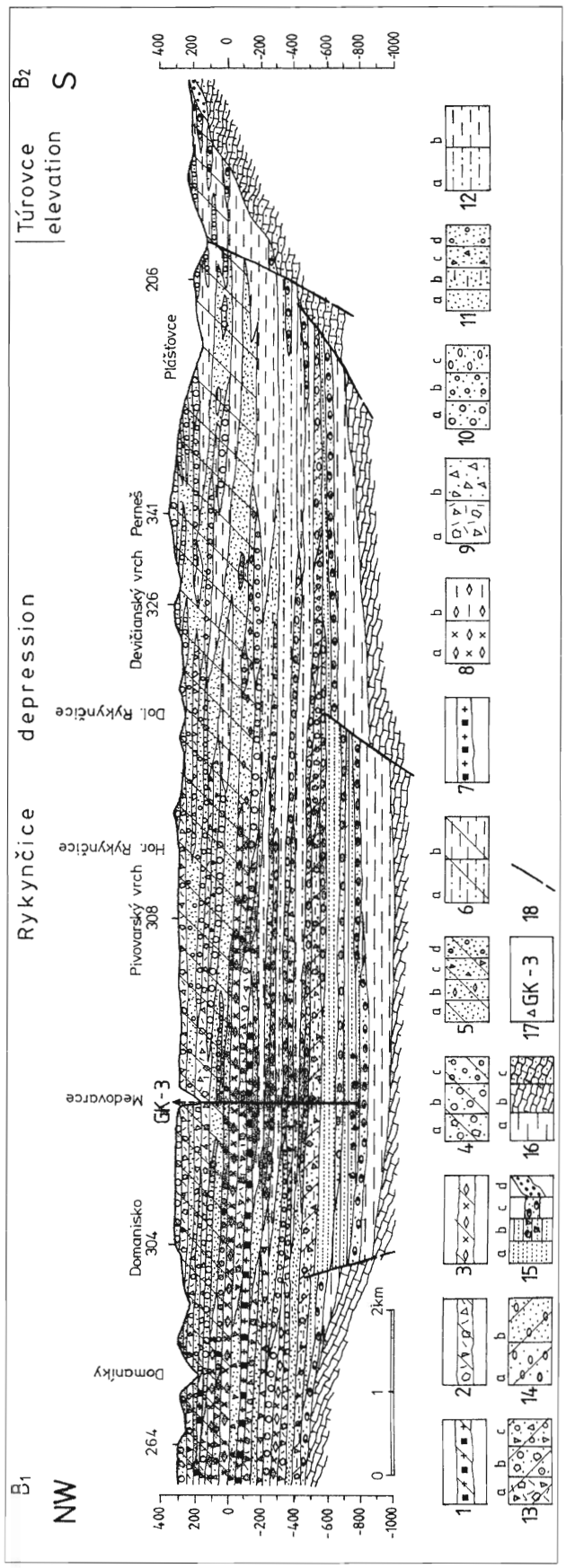
As regards the evolution in time the subsidence of some depressions started already in the Early Badenian, eventually, their subsidence was inherited from Early Miocene and Oligomiocene sedimentary basins (Bzovík Depression, Bacúrov Depression). During the subsequent evolution these depressions were often buried beneath younger volcanic products and information about their existence comes only from drillings and gravimetric surveys.

Evolution of most of the depressions and grabens during Badenian and Sarmatian was closely related with volcanic activity. Depression subsidence was compensated by deposition of volcanoclastic material transported from volcanic slopes by mass transport processes – debris flows, lahars, hyperconcentrated flows, grain flows as well as by ephemeral rivers etc. Some depressions also contain other facies of volcanic material such as pyroclastic flows, ash/pumice tuffs or complexes of lava flows and hyaloclastites.

Some of the depressions evolved further in the terminal period of volcanic activity and eventually, also in the post-volcanic period as a result of continuing subsidence. Morphology of these depressions is also conspicuous in the present relief (Žiar Depression, Slatina and Vígľaš depressions, Turiec Depression, Horná Nitra Depression as well as depressions system near southwestern margin of the volcanic field – Čajkov, Bátovce–Pukanec depressions, etc.).

Elevation structures of the pre-volcanic basement take also a part in its morphotectonic structure and crop out in the areas of volcanic rocks as "islands". These basement elevations represent relics of older

Fig. IV.4. Geological section A_1–A_2 through Bzovík Depression (according to Konečný, 1979). *Čelovce pyroclastic volcano* (Middle Badenian): 1 – a – explosive neck, b – dyke, 2 – a – volcanic breccia, 3 – a – agglomerates and pyroclastic breccias of the proximal zone complex, b – block and ash pyroclastic flow deposits, 4 – a – hot lahar deposits, b – reworked pyroclastic rocks, 5 – a – cold lahar deposits, b – epiclastic volcanic breccias, 6 – epiclastic volcanic conglomerates: a – coarse, b – fine, 7 – a – epiclastic volcanic sandstones, b – tuffitic sands and gravels with volcanic and nonvolcanic material. *Vinica Formation* (Early – Middle Badenian): 8 – a – submarine andesite dome, b – andesite bodies with underground brecciation, c – submarine pyroclastic flow deposits, 9 – a – epiclastic volcanic breccias, b – epiclastic volcanic conglomerates and tuffitic siltstones, 10 – a – tuffitic siltstones and sandstones, b – tuffitic siltstones, 11 – basal tuffitic sands with pebbles of nonvolcanic rocks, 12 – Early Miocene sediments (undivided), 13 – basement undivided pre-Tertiary rocks, 14 – a – shells of marine fauna, b – imprints of flora, 15 – fault, 16 – supposed extent of original pyroclastic volcano, 17 – borehole.



relief which persisted during volcanism as prominent morphological elements. Overlying volcanic complexes are markedly reduced or, eventually, they are absent as these basement elevations occasionally appeared as emerged belts (Santovka–Turovce Elevation). Some basement elevations were dynamically formed (uplifted) during the volcanic and post-volcanic period like horsts (Hodruša–Štiavnica Horst, Kremnica Horst).

In the eastern part of the Central Slovakian Volcanic Field the basement structures are controlled by faults and fault zones of prevailingly NW–SE and NE–SW orientation. In the western sector also NNE–SSW and N–S striking faults occur.

Eastern sector of the Central Slovakian Volcanic Field

Eastern part of the volcanic field includes elevation and depression systems occurring in basement of Krupina plateau volcanosedimentary complexes and in basement of Javorie and Poľana stratovolcanoes.

Bzovík Depression (1)

At the west the depression (Fig. IV.3/1) is separated from the Ladzany Elevation along a NE–SW trending fault zone and the south it borders the NW–SE oriented Turovce Elevation (Fig. IV.1). Its eastern boundary is formed by NE–SW oriented Šahy Elevation. In the north it neighbours the NW–SE oriented Pliešovce Elevation with a surface exposure of pre-Tertiary basement. Bzovík Depression is asymmetric. The basement dips westward. It is at ca. 500 m b.s.l. at the east, reaching a level of some 800 m b.s.l. at the west.

The GK-4 borehole near the village Bzovík (Konečný et al., 1970) encountered in the lowermost level Triassic

Fig. IV.5. Geological section B_1–B_2 through Rykynčice Depression – southern part of the Bzovík Depression (according to Konečný, 1998). *Sebechleby Formation* (Early to Middle Badenian) – volcanosedimentary complex of the Štiavnica Stratovolcano. 1 – pyroclastic flow breccia, 2 – lahar breccia, 3 – autochtonous and reworked pumice tuffs, 4 – epiclastic volcanic rocks: a – coarse to blocky breccias/conglomerates, b – coarse to blocky conglomerates, c – medium conglomerates with sandstones, 5 – a – epiclastic volcanic sandstones, b – sandstones with pumice, c – sandstones with fine breccia, d – sandstones with fine conglomerates, 6 – a – epiclastic volcanic sandstones and siltstones, b – siltstones. *Volcanic complex underlying Sebechleby Formation:* 7 – pyroclastic flow breccia, 8 – a – pumice tuffs, b – epiclastic volcanic siltstones with pumice, 9 – a – lahar brecias, b – epiclastic volcanic breccias, 10 – epiclastic volcanic conglomerates: a – coarse, b – medium, c – fine, 11 – a – epiclastic volcanic sandstones medium to coarse, b – with siltstones, c – with fine breccia, d – with fine conglomerates, 12 – a – fine epiclastic volcanic sandstones and siltstones, b – tuffaceous siltstones. *Volcanics of garnet-bearing hypersthene-amphibole andesites* (Early Badenian): 13 – a – lahar breccias, b – coarse to blocky epiclastic volcanic breccias/conglomerates, c – medium epiclastic volcanic breccia/conglomerates, 14 – a – fine epiclastic volcanic conglomerates, b – epiclastic volcanic sandstones with rare volcanic pebbles, 15 – a – tuffitic sandstones/sands, b – tuffaceous claystones and siltstones with sandstone intercalations, in some places are breccias of Mesozoic carbonates, c – tuffitic sand with gravels of underlying rocks. *Pre-volcanic basement* 16 – a – undivided Early Miocene sediments, b – undivided Mesozoic carbonate rocks, c – metamorphosed rocks of the Federata group (Triassic – Permian), 17 – borehole, 18 – fault.

(eventually Jurassic?) limestones and dolomites overlain by deposits of early molasse (Cretaceous and Paleogene) in thickness 184 m. These are, in turn, overlain by 273 m thick Early Miocene deposits laid down in the brackish and hypersaline environments. Deposition during the early molasse and Early Miocene was controlled by faults of the meridional direction (Vass et al., 1979). The most intensive subsidence occurred during the Early and Middle Badenian as shown by 822 m of volcanosedimentary rocks intersected in the borehole GK-4. A maximum thickness of volcanosedimentary rocks indicated by gravimetric surveys is about 1150 m in the central part of the depression (south of the GK-4 borehole). At the southern part of the depression borehole GK-3 intersected 981 m thick complex of volcanosedimentary rocks of the Badenian age (Konečný et al., 1966). This borehole did not encounter basement (Fig. IV.5).

The fill of the Bzovík Depression is lithologically heterogenous (Fig. IV.5). In the lower level of the depression variegated, continental fluvio-limnic formation rests over Early Miocene deposits. The 125 m thick formation consists of siltstones with conglomerate beds and breccias of Mesozoic rocks (borehole GK-3). Subsequently, following a marine transgression a deposition of tuffitic sandstones (thickness 20–50 m) and coarse-grained epiclastic volcanic rocks took place. Lahars and submarine breccia flows of the Vinice Formation were transported into the southern sector of the depression from centers in the area of the Šahy Elevation. These deposits attain a thickness over 300 m. In the southern sector of the depression the above mentioned deposits are overlain by a volcanosedimentary complex of the Middle Badenian Čelovce Formation in thickness up to 280 m (Konečný, 1969). The formation consists in the lower levels of a 150 m thick sequence of epiclastic volcanic sandstones with intercalations of fine conglomerates and abundant remnants of marine fauna. In upper levels the layers of pumice tuffs and pyroclastic flows prevail, transported here from the Čelovce Volcano.

During the Middle and Late Badenian, as well as during the Sarmatian volcanoclastic material was transported into the central and southern parts of the Bzovík Depression from northwest and northeast, from slopes of the Štiavnica and Javorie stratovolcanoes.

Semerovce Depression (2)

The Semerovce Depression (Fig. IV.3/2) in the southern part of the Central Slovakian Volcanic Field, separated from the Bzovík Depression by the WNW–ESE oriented Turovce Elevation, represented during the Badenian time an isolated sedimentary area formed by the intense subsidence of a crustal block outlined by NW–SE striking faults. The basement occurring at depth of 386 m (borehole ŠV-8) consists of Early Triassic quartz sandstones and schists. At the base of the depression, above the Triassic rocks, a continental sequence of the Early Badenian age is development. It is composed of 12 m of conglomerates containing clasts of Early Triassic basement rocks followed by 56 m of variegated claystones designated as Turovce Member (Vass, 1981). The depression subsidence during Early to Late Badenian was compensated by the deposition of ca. 520 m thick sequence of siltstones, sandstones and claystones. The absence of volcanoclastic material suggests isolation of this depression from the source areas with volcanic structures (Vass, 1981). Sarmatian sediments in the uppermost part of the depression (21 m in the borehole ŠV-8) suggest that in the given time the depression became to be an integral part of the marine-brackish environment.

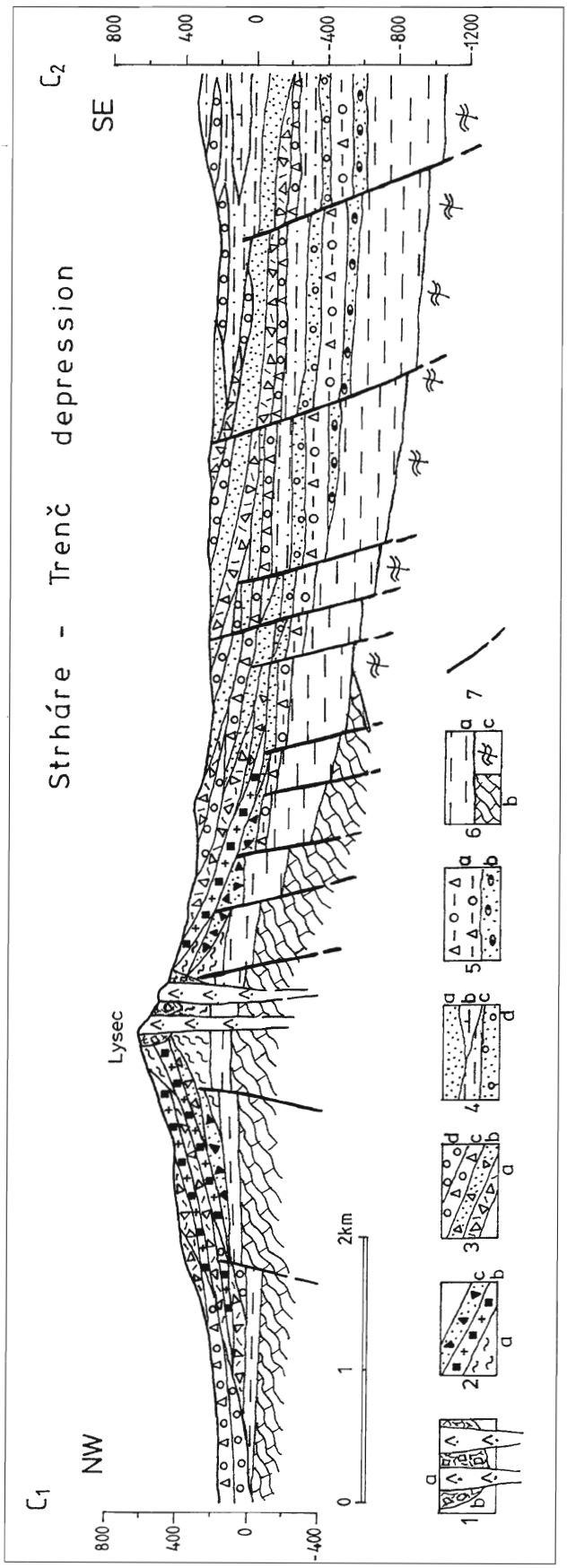
Dačov Lom Depression (3)

The Dačov lom Depression (Fig. IV.3/3) is located east of Bzovík and north of the buried Šahy Elevation. Its northern boundary forms the exposed basement of the Pliešovce Elevation. At the east it is bordered by the narrow Turie pole Graben. As suggested by geophysical data the basement is assumed to be ca. 500 m b.s.l. During Early Miocene the Dačov Lom Depression represented a structure breaking through the Šahy Elevation and formed as a subsidence zone with greatest thickness of Rupelian, Eggerian and Karpatian sediments. Between Badenian and Karpatian the extent of coal seams in the depression was reduced by erosion (Vass, 1979).

During Early and Middle Badenian the depression appears to have been more stabilized as compared to the Bzovík Depression that subsided more intensively. Volcanoclastic material was transported into Dačov Lom Depression from the south from centers of extrusive volcanism of the Vinica Formation and subsequently from the pyroclastic Čelovce Volcano. At the north volcanoclastic material was derived from slopes of the Javorie Stratovolcano. The borehole MV-14 located near Dačov Lom intersected 425 m thick volcanosedimentary complex.

Strháre–Trenč Depression (4)

The Strháre–Trenč Depression (Fig. IV.3/4), located in the SE sector of the volcanic field, is of the graben type developed between subparallel NW–SE striking faults. At the north the depression is limited by a NE–SW striking fault zone. The pre-Tertiary basement gradually sinks southward from ca. 400 m to 800–1200 m b.s.l (Fig. IV.6). During Early Miocene, as in the case of the Dačov Lom Depression, it was a site of intense subsidence with a considerable accumulation of sediments (Rupelian – Karpatian). Following sea regression at the end of Karpatian a reduction down to the Ottnangian coal formation occurred. During Early Badenian, after a return of marine transgression, the initial subsidence of the depression was slow (the thickness of volcanosedimentary material of Vinice Formation attains 80–100 m). More intense subsidence occurred during the period of activity of the Lysec Volcano (Middle – Late Badenian), which was located north of the depression edge. Eruptive centre of the Lysec Volcano lays at the continuation of a fault belt limiting the depression from the eastern side (Konečný



et al., 1973). Volcanoclastic material transported from slopes of the Lysec Volcano into subsiding depression reached a thickness over 300 m. Subsidence also continued at the western side of the depression (the Plachtince potok fault) in the post-volcanic period resulting in asymmetry of the depression with greater subsidence along the western margin.

Turie Pole Depression (5)

It represents a narrow depression (Fig. IV.3/5) of the graben type located east of the Dačov Lom Depression. The depression is controlled by subparallel NW–SE striking faults. On the regional structural plan it appears as a continuation of the Strháre–Trenč Depression cut-off by uplifted block of the Šahy Elevation in the area of Suché Brezovo–Veľký Lom. At the north the depression approaches the Javorie volcanotectonic Depression. Pre-Tertiary basement of the depression subsided to 600–1000 meters b.s.l. Early Miocene sedimentary rocks occur in the southern part of the depression. South of the depression, in the area of the relatively uplifted block Veľký Lom–Suché Brezovo, a coal-bearing formation occurring about 100 m b.s.l., is believed to be of the Ottnangian age (Bartek et al., 1998). During Badenian the depression was fed mainly by volcanoclastic material coming from slopes of the Javorie Stratovolcano. The formation is 500–550 m thick.

Čekovce Depression (6)

In the central part of the volcanic field, between the Ladzany and Pliešovce elevations, a narrow subsided block is indicated by geophysics (Fig. IV.3/6). The depression, previously called Babiná Depression, forms an asymmetric graben dipping westward with basement 1000 m b.s.l. The depression is bordered at the west by a N–S trending fault and at the north-east separated from the Pliešovce Horst elevation by a NW–SE trending fault zone with displacement over 1000 m. On the structural plan the depression appears as a northern continuation of the Bzovík Depression in the form of a communication channel between the Bzovík and Bacúrov depressions that existed already during the deposition of early molasse (Late

Fig. IV.6. Geological section C_1–C_2 through Strháre–Trenč Depression (according to Konečný, 1979). *Lysec pyroclastic volcano:* 1 – central zone: a – pyroxene amphibole andesite tholoids, b – marginal breccia, 2 – a – agglomerates, lapilli tuff (central zone), b – pyroclastic flow breccias, c – hot lahars breccia (proximal zone), 3 – proximal/distal zone: a – lahar breccia, b – epiclastic volcanic breccia, c – epiclastic volcanic breccia/conglomerate, d – coarse epiclastic volcanic conglomerates, 4 – a – epiclastic volcanic sandstones, b – claystones, c – siltstones, d – epiclastic volcanic sandstones with medium-fine conglomerates. *Vinica Formation:* 5 – a – epiclastic volcanic breccias/conglomerates, sandstones and silstones, b – basal beds, tuffaceous sands with pebbles of nonvolcanic rocks. *Underlying rocks:* 6 – a – Early Miocene sediments (undivided), b – Triassic rocks (undivided), c – Hercynian basement of Veporicum formed of metamorphic rocks, 7 – fault.

Cretaceous – Paleogene). We assume that during the Early Badenian period the sea penetrated into the Bacúrov and Žiar depressions via the Čekovce channel bringing along the marine-brackish and lagoonal sedimentation later developing into lacustrine and limnic one. During Early and Middle Badenian the depression was filled by products of extrusive volcanism of garnet-bearing andesites (extrusions and laccoliths near Babiná) in the form of breccias and massive lava bodies. During Late Badenian and Sarmatian the upper levels of the depression were filled by products of the Štiavnica Stratovolcano.

During Badenian and Sarmatian the evolution of sedimentary basins of Zvolen, Bacúrov and Kľačany block depressions took place in the northern sector of the area between Štiavnica, Kremnica and Javorie stratovolcanoes. These basins received volcanoclastic material transported from slopes of the above mentioned stratovolcanoes. Accumulation of volcanoclastic material compensated a continuing subsidence of these depressions. Tectonic block movements during Badenian, Sarmatian and Pliocene resulted in the observed morphotectonic basement structure recognized on gravimetric map as more or less pronounced depressions or interblocks.

Bacúrov Depression (7)

The Bacúrov Depression (Fig. IV.3/7) (west of Zvolen) is separated from the Zvolen Depression by a NW–SE striking fault zone. At the eastern side its contact with the deeper Kráľová volcanotectonic Depression runs along an N–S striking fault (Neresnica fault zone). At the west it borders the Štiavnica Caldera and at the northeast it is limited by a relatively uplifted Kľačany interblock. The depression is slightly asymmetric deepening northwestward. Pre-volcanic basement intersected by the borehole GK-8 820 m b.s.l. consists of Eocene (Lutetian) sedimentary rocks in the Buda facies development (Gross in Karolus et al., 1974; Gross et al., 1976).

The 115 m thick Lower Badenian formation at the base consists of tuffaceous clays with dolomitic breccia and conglomerate intercalations, showing deposition in the lagoonal and lacustrine environments. Subsidence of the depression during Early and Middle Badenian was compensated by the deposition of 580 m thick sequence of coarse-grained volcanoclastic breccias derived from garnet-bearing andesites of the Neresnica Formation (borehole GK-8). Extrusive bodies of garnet-bearing andesites and breccias are exposed southwest of Zvolen.

Higher up the Bacúrov Depression contains 315 m of products derived from the lower levels of the Štiavnica Stratovolcano (pyroclastic and epiclastic rocks, lava flows) as well as 70 m of products derived from the Studenec Formation (period of the Štiavnica Caldera formation). The upper part of the Bacúrov Depression fill in thickness up to 115 m consists of Sarmatian volcanosedimentary rocks – the Breznica Complex. The depression fill is capped by 62 m of Pliocene lacustrine clays, gravels and sands (borehole GK-8) and Pliocene alkali basalt lava flows in the form of northwesterly dipping sheets.

Kľačany "interblock" (8)

The so called Kľačany "interblock" (Fig. IV.3/8) represents a relatively uplifted block in the present basement configuration in the area of a former depression. The "interblock" is separated from the Bacúrov Depression by a NE–SW striking fault. At the northern side it is limited by a continuation of the NW striking fault zone separating the Bacúrov Depression from the shallow Zvolen Depression. At the west the "interblock" is cut by the marginal fault zone of the Kremnica Graben.

Information about the evolution of the Kľačany "interblock" sedimentary area is provided by the borehole JP-1 located at its western edge near the Jastrabá village. Pre-Tertiary basement (Upper Paleozoic of the Hronicum) was intersected across a fault at the depth of 1021 m (653 m b.s.l.). The deposition during Early Badenian is represented by a 320 m thick succession of siltstones, claystones and coal-bearing clays alternating with sand layers. The occurrence of garnet-bearing andesite fragments suggests a contemporaneous volcanic activity. During Middle Badenian the siltstone and claystone sedimentation continued including coal and fine-grained conglomerate intercalations as well as rare horizons of epiclastic volcanic conglomerate, hyaloclastite and andesite – an equivalent of the Zlatá studňa Formation of the Kremnica Stratovolcano (interval 700–400 m). Higher up there is a succession of the Kremnica Graben fill. Sedimentation during the Late Badenian and Early Sarmatian time continued at the eastern side of the "interblock". It is recorded by a volcanosedimentary succession at the base of the borehole FŽB-1 near Železná Breznica (Forgáč et al., 1979; Konečný et al., 1983). Former sedimentary basins of the "interblock" are covered by a thick Sarmatian volcanic complex – Sielnica and Turová Formations of Kremnické vrchy and Breznica Complex of the Štiavnica Stratovolcano.

Zvolen Depression (9)

The N–S oriented depression (Fig. IV.3/9) is separated from the Lieskovec Horst by a NE–SW striking fault zone and at the southern side it is separated from the Bacúrov Depression and Kľačany "interblock" by a subparallel NW–SE striking fault zone. The depression basement dips southeastward. At the southeast the depression neighbours with the deeper Kráľová volcanotectonic Depression along an E–W striking fault zone. The depression in its northwestern part shallows gradually and passes into the Malachov Elevation.

The borehole PK-1 (west of Zvolen) encountered pre-volcanic basement at the depth 724.8 m, i.e. 378 m b.s.l., consisting of Veporic granodiorites (Biela, 1978). The basal part of the depression fill (borehole interval 724–580 m) with sandy sediments with conglomerate layers composed of pre-volcanic basement rocks and coal-bearing clay intercalations occur. It is overlain (580–487 m) by sandstones alternating with intercalations of siltstones, fine-grained conglomerates and epiclastic volcanic rocks. Overlying coarse epiclastic volcanic breccias corre-

lated with the pre-caldera stage of the Štiavnica Stratovolcano (487–366 m) are followed by a sequence of epiclastic volcanic breccias, conglomerates and sandstones, redeposited tuffs and rare conglomerates and claystones with lignite (366–259 m). This are, in turn, overlain by a complex of fine-grained epiclastic volcanic breccias, conglomerates, sandstones and redeposited tuffs with clasts of hornblende pyroxene andesites and hypersthene-pyroxene andesites (259–134 m) correlated with Badenian volcanic activity of the Javorie Stratovolcano. In the upper levels of the depression (24–134 m) the borehole intersected pumice tuffs, redeposited tuffs and fine-grained epiclastic breccias containing pyroxene-biotite-amphibole andesite fragments corresponding to the Late Badenian Studenec Formation (caldera stage of the Štiavnica Stratovolcano). Pollen analyses of tuffaceous-clay deposits, intersected by boreholes east of Zvolen (P-2 at 96–97 m, P-9 at 62–207 m) indicate the Late Badenian to Early Sarmatian age (Planderová in Konečný et al., 1983).

In the northern and northwestern parts of the Zvolen Depression Badenian volcanic complex is substantially reduced by erosion to just several meters or tens of meters as indicated by boreholes (P-19, B-2, B-1, VS-19) from surroundings of Sielnica, Sliač and boreholes (HP-20, VS-13) west of Malachov. Polymict conglomerates of the Early Badenian Kordíky Formation are overlain by tuffaceous claystones and siltstones with lignite intercalations indicating lacustrine-paludal depositional environment.

Information on the evolution in the NW part of the depression is provided by the borehole FŽB-1 (Forgáč et al., 1972). The borehole encountered Mesozoic basement in depth 527 m (i. e. 100 m a.s.l.). The base of the volcanosedimentary complex consists of non-volcanic material conglomerates and breccias. These are covered by tuffaceous claystones, sands and gravels interpreted as transgressive deposits. These, in turn, are overlain by fine-grained sandstones with intercalations of siltstones, claystones and fine-grained conglomerates of the probable Late Badenian age. Further upward there follow fine-grained sandstones, siltstones and claystones including a lava flow of biotite–amphibole–pyroxene andesite (Sitno type?) and a bed of conglomerate. Microflora analyses indicate the Late Badenian to Early Sarmatian age of the complex (Planderová in Forgáč et al., 1980). The upper borehole section (0–170 m) consists of epiclastic breccias and lava flows of pyroxene-amphibole and pyroxene andesites which are correlated to the products of Sarmatian volcanism. Pollen analyses from FŽB-1 borehole (169.5–170 m) sample yielded the Middle to Late Sarmatian age (Planderová in Forgáč et al., 1980).

The sedimentary fill in the surroundings of Badín, Sielnica and Sliač, located in northern and northwestern parts of the Zvolen Depression, consists of volcanosedimentary sequences with predominance of epiclastic volcanic sandstones with intercalations of claystones, fine-grained conglomerates and tuffs, that are correlated with Sarmatian Sielnica and Turová Formations. The thickness of Sarmatian volcanosedimentary sequences varies from several tens of meters to 200–300 m (borehole BO-9 near Sielnica) and suggests subsidence during Middle and Late Sarmatian. Pliocene fluvial gravels and sands in the thickness up to 100 m represent the youngest part of the depression fill.

Slatina Depression (10)

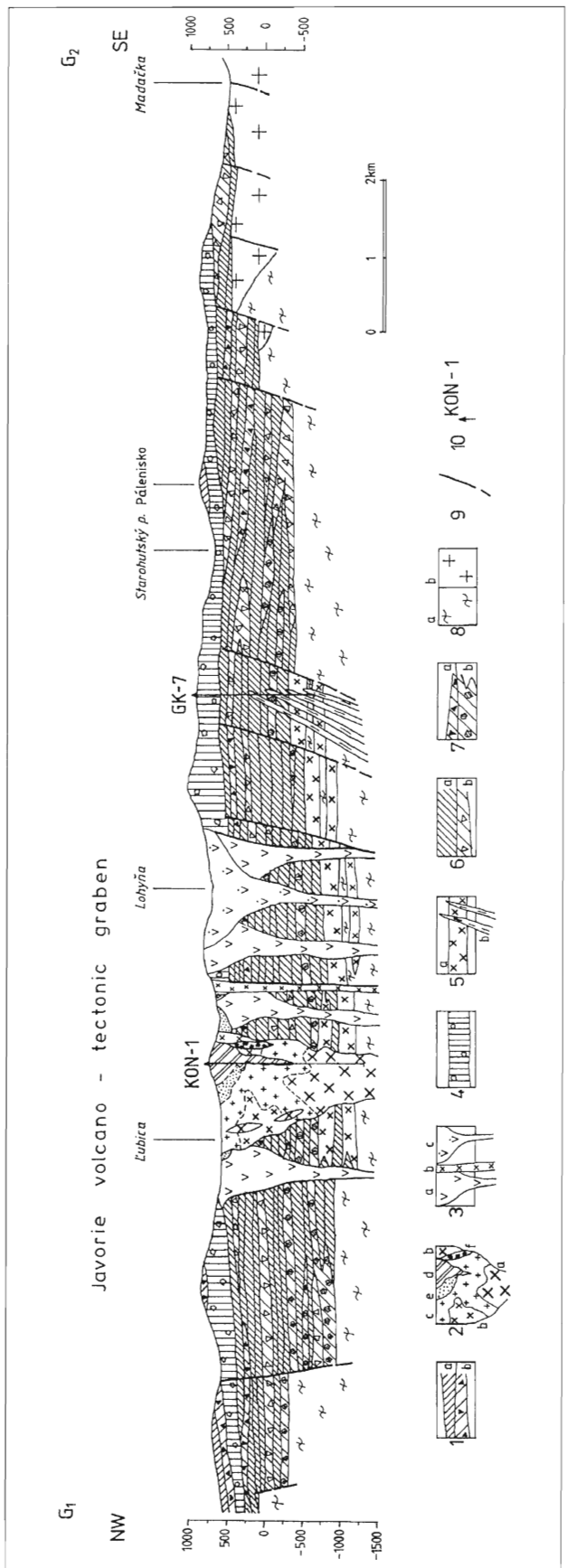
The depression at the northern perimeter of the Javorie Stratovolcano is bordered at the north by the Lieskovec Horst (Fig. IV.3/10). At the eastern margin it is separated from the deeper Vígľaš volcanotectonic Depression by a NE–SW striking fault zone. At the north the depression is limited by a shallow basement. At the southern side the depression is separated from the deeper complexes of the Javorie Stratovolcano by an E–W striking fault. The depression shows a flat and shallow basement configuration dipping from the elevation 200 m a.s.l. at the north to 0 m at its southern margin. The borehole KJ-40, situated north of Zvolenská Slatina, encountered basement at 160 m a.s.l., consisting of crystalline schists. The weathered surface of crystalline rocks is overlain by a thin bed of redeposited tuff followed by a 500 m thick sequence of clays with intercalations of sandstones and fine-grained conglomerates. Pollen analyses of the sequence indicate the Pliocene age (Planderová in Konečný et al., 1983). The Slatiná Depression commenced in Pliocene by the subsidence of the eastern segment of the Lieskovce Horst providing conditions for the fluvio-limnic sedimentary environment.

Vígľaš volcanotectonic Depression (Graben) (11)

The Vígľaš volcanotectonic Depression (Fig. IV.3/11) of the graben type represents a subsided block of volcanic structure at the northern slopes of the Javorie Stratovolcano. The depression is controlled by subparallel NNE–SSW striking faults. At the north it is limited by a relatively uplifted basement block of the Dúbrava–Detva Elevation and at the south it joins the deeper Javorie volcanotectonic Depression from which it is separated by an E–W striking fault. Basement of the Vígľaš Depression consisting of Veporicum crystalline rocks was intersected by the borehole D-24 (Dublan et al., 1984) at 370 m b.s.l. The depression subsidence was during Late Badenian and Early Sarmatian compensated by effusions of pyroxene andesite lavas and subsequent extrusions of more differentiated hypersthene-amphibole andesites reaching thickness over 700 m. Reactivated subsidence during Pontian and Pliocene resulted in extension of the fluvio-limnic environment from the Slatiná Depression into western part of the Vígľaš Depression and the deposition of 60–80 m thick succession of sandy clays, gravels and sands (boreholes P-6 and KJ-2; Konečný et al., 1933).

Javorie and Kráľová volcanotectonic depressions (12, 13)

These volcanotectonic depressions of the graben type (Fig. IV.3/12, 13), buried below the Javorie Stratovolcano, were identified by the interpretation of gravimetric surveys.



The Javorie Depression was intersected by the structural borehole GK-7 (Konečný et al., 1972). The depression, elongated in ENE–WSW direction, includes an area of the central volcanic zone of the Javorie Stratovolcano with bodies of intrusive rocks (Fig. IV.7). In the northern part it continues into the shallower Vígľaš Depression, from which it is separated by a fault zone. At the west it is attached to the deeper Kráľová Depression. In the area of contact near the Kalinka village an intrusive complex of quartz-diorite porphyry to monsodiorite; appears (borehole KON-1; Konečný et al., 1979). According to gravimetric surveys the basement in the central part of the depression is at the depth of 1200 m. Basement, encountered by the borehole GK-7 at southern side of the depression at the depth of 836 m b.s.l., consists of migmatized gneisses and amphibolites belonging to the Veporicum.

The Kráľová Depression, elongated in an E–W to NW–SE direction, is located more to the west. It shows a more subsided basement found at depth of more than 2000 m b.s.l. (basement has not been reached by drilling). The area of Kráľová Depression hosts the central volcanic zone with intrusive complexes of diorite porphyry (Kráľová intrusive complex).

The described depressions contain in their lower part the collapsed complexes of lower levels of a Badenian stratovolcano. Their subsidence was compensated by effusions of basaltic and intermediate pyroxene andesite lavas accompanied by the formation of hyaloclastite breccias (Blýskavica Formation), extrusions of differentiated hypersthene-amphibole andesites and intrusions of diorite porphyry. Products of younger Sarmatian volcanic activity (Javorie Formation) appear at the upper parts of the Javorie Stratovolcano and cover deposits in the depressions without suffering any faulting.

Poľana volcanotectonic Depression (14)

The depression outlined on the basis of gravimetric surveys is divided into a deeper western and shallower eastern segments (Fig. IV.3/14). Basement in the western part lies at some 100 m b.s.l. while in the eastern part it lies at 230 m a.s.l. (at the eastern side of the Poľana Stratovolcano basement crops out at 800–900 m a.s.l.). In the western part the basement consists of diaphtorized paragneisses of the Veporicum as shown by the borehole D-8

Fig. IV.7. Javorie volcanotectonic Graben (Konečný, 1998). 1 – Javorie Formation: a – lava flows of pyroxene and amphibole-pyroxene andesites, b – volcanoclastic rocks (Sarmatian), 2 – Kalinka intrusive complex: a – quartz monzodiorite, b – diorite porphyry, c – quartz diorite porphyry, d – secondary quartzites, e – argillites, f – hydrotermal explosive breccias, 3 – Syroň Formation: a – amphibole andesite extrusion, b – rhyodacite intrusion, c – biotite-hyperstene dacite extrusion (Late Badenian), 4 – Blýskavica Formation, basalto-andesite lava flows, hyaloclastite breccias (Middle Badenian), 5 – a – sill of diorite porphyry, b – amphibole andesite dykes, 6 – Stará Huta Formation: a – pyroxene, amphibole andesite lava flows, b – epiclastic volcanic rocks, 7 – a – pyroclastic rocks, b – hyaloclastite breccias, 8 – basement rocks of Veporicum: a – hybridic granitoids with gneisses, b – porphyric granitoids, 9 – fault, 10 – borehole.

(Dublan et al., 1997). The fill of the volcanotectonic depression and caldera, in the eastern part, consists of a sunken Badenian stratovolcano and products of Early Sarmatian rhyolite volcanism (caldera fill). The older volcanic structure, including the caldera fill, is buried under younger, Sarmatian stratovolcano (Veľká Detva Formation) and penetrated by subvolcanic intrusions of diorite porphyry.

Western sector of the Central Slovakian Volcanic Field

The western part of the volcanic field suffered the most intensive block movements during Late Badenian and Sarmatian. These resulted in the formation of prominent horst and graben structures. Between eastern and western belts of depressions occurs a NE–SW oriented belt of topographic elevations – the Santovka and Turovce elevations with outcropping bedrocks merging northward into the Krškany–Ladzany Elevation with basement at 0–200 m b.s.l. The belt of elevations represented during Badenian and Sarmatian a shallowing and emerging zone without appreciable accumulations of volcanosedimentary rocks.

West of the elevated zone the most prominent depressions include: Kremnica Graben, Žiar Depression, Štiavnica Caldera, Turiec, Horná Nitra and Bánovce depressions. At the SW perimeter of the Štiavnica Stratovolcano there are the Čajkov, Bátka and Pukanec depressions and yet more western Volkovce and Zlaté Moravce depressions. Besides depressions in the western part of the volcanic field there is a number of elevations and horst structures that will not be discussed here because they do not contain more extensive accumulations of volcanoclastic rocks.

Kremnica Graben (15)

The Kremnica Graben (Fig. IV.3/15), controlled by NNE–SSW striking faults, represents a dominant structure in the Kremnické vrchy Mts. At the north the graben joins the Turiec Depression and at the south it merges with the Žiar Depression. Pre-volcanic basement in the eastern part of the graben, encountered by the borehole Lx-5 some 640 m b.s.l., consists of Paleogene sedimentary rocks (Lexa et al., 1979b). Amplitude of the graben subsidence at the eastern margin is over 1000 m (data from the boreholes Lx-5 and Lx-7). Total thickness of the graben fill, consisting of products of contemporaneous volcanic activity, is about 1500 m. The lower part of the graben fill in thickness about 500 m is represented by Badenian volcanosedimentary and volcanic rocks pre-dating subsidence of the graben. The Kordíky Formation at the base consists of tuffaceous claystones, siltstones and sandstones with conglomerate intercalations grading upward into redeposited tuffs, epiclastic volcanic sandstones, claystones and fine-grained tuffs. In the southwestern and southern parts of the graben the sediments were deposited in the marine environment confirmed by findings of Early Badenian marine fauna (Gašpariková in Blaško et al., 1989). In contrast, in the northern part of the graben and east of the graben boundary the Kordíky Formation was deposited in the fluvio-limnic environment.

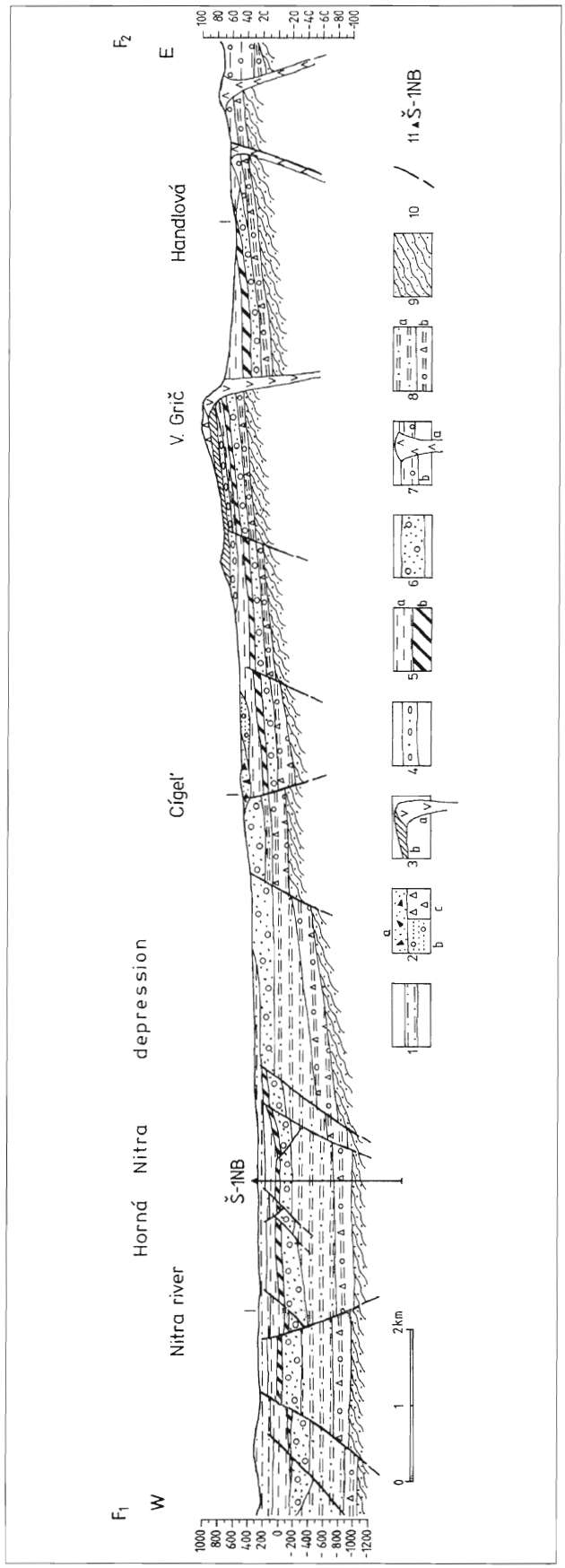
Above the Kordíky Formation there are scattered products of garnet-bearing hypersthene-amphibole andesite volcanic activity in the form of extrusive domes and epiclastic volcanic breccias, conglomerates and sandstones. The pre-graben succession is completed by volcanic complex of a Badenian andesite stratovolcano – the Zlatá Studňa Formation. In the Kremnica Horst area it consists of a propylitized complex of lava flows and sills of pyroxene and amphibole-pyroxene andesites and andesite porphyries, including intrusions of diorite porphyries, diorites and gabbrodiorites (Böhmer, 1979). In the marginal parts of the graben and beyond its marginal faults the Zlatá Studňa Formation is represented by a stratovolcanic complex.

The Zlatá Studňa Formation in the Kremnica Graben is covered in the thickness 1000 m by the graben fill sensu stricto (contemporaneous with the graben subsidence). The 400–500 m thick Turček Formation in the lower part consists of lava flows of pyroxene andesites, leucocratic andesites and basaltic andesites, hyaloclastite breccias, redeposited phreatomagmatic tuffs, rare pyroclastic flow deposits and reworked material in the form of epiclastic volcanic breccias and sandstones. In the upper part the graben is filled by 500 m thick Kremnický štít Formation represented by the effusive complex of amphibole-pyroxene andesites. Based on the stratigraphy and radiometric dating (Ft method, Repčok, 1981) the graben fill is considered to be of the Late Badenian age. Rare extrusive domes of biotite-amphibole andesite (correlated with the Studenec Formation of the Štiavnica Stratovolcano) form the youngest part of the graben fill.

The Kremnica Graben subsidence was coeval with volcanic activity of the Late Badenian age. Products of Sarmatian volcanic activity cover marginal faults and mostly are not affected by younger displacement. The formation of the Kremnica Horst in the central sector of the graben took place during Late Sarmatian, at the same time as rhyolite volcanism.

Turčianska kotlina Depression (southern part) (16)

The Turčianska kotlina Depression (Fig. IV.3/16) at the northern margin of Kremnické vrchy Mts., limited by NW–SE striking faults, may be considered as a northern continuation of the Kremnica Graben. It is strongly asymmetric, its fill dipping westward. A total displacement on marginal faults at the west has reached over 3000 m. Basement, consisting of Mesozoic rocks, was intersected by the borehole GHŠ-1 near Turčianske Teplice at the depth of 847 m b.s.l. (Gašparik et al., 1974). At the base there are volcanosedimentary rocks of the Late Badenian age (GHŠ-1; Gašparik et al., 1974; Lexa et al., 1982), followed by 400 m thick complex of redeposited pyroclastic rocks, epiclastic volcanic rocks and andesite lava flows of the Turček Formation (Late Badenian – Early Sarmatian?). These are, in turn, overlain by 300–400 m of Sarmatian sands and clays containing beds of gravel with two horizons of Late Sarmatian rhyolite tuffs and epiclastic volcanic sandstones at the top. Pannonian to



Pontian clays, tuffitic sands and gravels form the upper part of the depression fill in thickness up to 500 m.

Characteristics of the depression fill suggest subsidence since Late Badenian till Pannonian or Pontian.

Horná Nitra Depression (17)

The Horná Nitra Depression (Fig. IV.3/17) is an asymmetric westward dipping graben located at the northwestern margin of the Central Slovakian Volcanic Field. The borehole Š-1 NB, drilled near the Koš village, intersected below volcanic rocks at 181 m b.s.l. a thick sedimentary succession of the Central Carpathian Paleogene resting upon Triassic dolomites of the Hronicum (Fig. IV.8). The Horná Nitra Depression is at the west limited by a fault zone with vertical displacement over 1400 m (the Bojnice fault hosting thermal springs). It becomes shallower eastward where it passes gradually into the Handlová ridge elevation with basement at 200–400 m a.s.l. Between Handlová and Prievidza erosion relics of Eggenburgian sediments are preserved immediately beneath the volcanic complex.

Subsidence of the depression started in the Early Badenian time. At the base of the depression fill there is the Kamenec Formation consisting mostly of epiclastic volcanic conglomerates and sandstones with nonvolcanic admixture. Minor claystones and coal seams have been observed locally. Its thickness varies from several meters up to 200 m. Its lower part with material of garnet-bearing andesites of the Early Badenian age corresponds to the Kordíky Formation in Kremnické vrchy Mts. Lithofacial characteristics indicate that the sediments were laid down in the fluvial and locally also limnic environments. Petrographic composition of clastic material in its upper part of the Middle Badenian age points to the Štiavnica and Kremnica stratovolcanoes as source areas.

The Kamenec Formation is overlain by the Handlová and Nováky Formations represented by 30–50 m thick tuffaceous sand, silt and clay deposits containing coal seams. The Handlová Formation extends in the area of Handlová and Cígeľ coal deposits and from the Nováky

Fig. IV.8. Geological section F_1–F_2 through Horná Nitra Depression (according to Šimon, 1997). 1 – gravels, sands, clays, Čelovce Formation (Pontian), 2 – volcanoclastic rocks, Vtáčnik Formation (Sarmatian): a – autochtonous and reworked pyroclastic rocks, b – epiclastic volcanic conglomerates and sandstones, c – coarse epiclastic volcanic breccias, 3 – basaltic andesite Klakovská dolina Formation (Late Badenian): a – extrusive dome, b – lava flow, 4 – gravels dominantly of Mesozoic carbonates, sands and sandy clays Lehota Formation, 5 – a – clays, marly clays, diatomites, diatomitic clays, Koš Formation, b – coal, coaly clays, claystones, tuffaceous intercalations, Handlová, Nováky Formation (Late Badenian), 6 – epiclastic volcanic conglomerates and sandstones with breccia, coal and tuff intercalations (Early – Middle Badenian), 7 – a – extrusions of hypersthene–amphibole andesite with garnet, b – tuffaceous claystones, siltstones and gravels with nonvolcanic material, Kordíky Formation (Early Badenian). *Underlying rocks:* 8 – a – sandstones and siltstones, Huta and Zuberec Formation (Oligocene), b – claystones, calcareous breccias and conglomerates, limestones, Terchová and Borové Formation (Eocene – Oligocene), 9 – metamorphosed sediments of Carboniferous and Permian, Choč nappe, Hronicum, 10 – fault, 11 – borehole.

Formation in the area of the Nováky coal deposit it is separated by a zone of subsequent erosion. Both formations show a gradual evolution from underlying epiclastic volcanic sandstones and gravels. In the lower part they consist of tuffaceous sands and silts passing upward into brownish, dark-grey and black clays with coal seams. The coal seam, having a mean thickness 7–9 m, often contains thin layers of claystones and siltstones. In the north-eastern part of the Handlová coal deposit two seams are developed, separated by a 30–35 m thick interval of clays, tuffaceous clays, tuffaceous sandstones, and reworked tuffs. The Handlová and Nováky Formation were laid down in taxodont swamps (Planderová in Konečný et al., 1983). Macroflora analyses yielded the Late Badenian age of the Handlová Formation (Němejc, 1958). Based on pollen analyses (Planderová in Konečný et al., 1983) the revised age is Late Badenian for the Nováky Formation and Late Badenian to Early Sarmatian for the Handlová Formation. The younger age of the Handlová Formation implies a gradual transgression (eastward progradation) of the lacustrine environment on inclined surface of the Kamenec Formation alluvial fans.

The Koš Formation, overlying the Handlová and Nováky Formations, consists of pale- and dark-grey clay and marly clay with thickness from several meters up to 300 m. Immediately above the main coal seam of the Nováky Formation the discontinuous layers of diatomaceous earth are recorded (Gašparik and Planderová, 1970). The upper part of the formation contains lenses of fluvial sands and gravels, including rare thin coal seams (Čechovič, 1959). Microflora from clays of the Koš Formation suggest the same age as microflora from the Handlová Formation. The Koš Formation was deposited in the fresh-water limnic environment and indicates a progressive deepening of the subsiding depression.

Following tectonic activity related to the uplift of the Handlová Ridge and contemporaneous subsidence of the Kremnica and Žiar grabens resulted in expressive changes of paleorelief and denudation of uplifted blocks. Tectonic activity was accompanied by extrusions of hypersthene-amphibole andesites of the Plešina Formation and rare rhyolites of the Nová Lehota Formation (Šimon et al., 1991). Deposition of the younger Lehota Formation, which overlies the Koš Formation, took place in paleovalleys on a denudated relief. The Lehota Formation consists of coarse- and fine-grained fluvial gravels and sands composed of Mesozoic carbonate and quartzite clasts and minor granodiorites, crystalline schists and Paleogene sediments. Sporadic andesite pebbles are present too. Gravels and sands include lenses of sandy clays and clays locally. Sedimentary material transported from exposed pre-Tertiary basement at the north and northwest formed a delta-like accumulation at the entrance to the subsiding Žiar Graben at the southeast.

Western margin of the Kremnica and Žiar grabens extends into the eastern part of Vtáčnik Mts. Their marginal faults cut the south-eastern continuation of the Handlová and Koš Formations implying a younger age of the graben subsidence. Volcanics at the base of the graben fill are eventually interbedded with gravels of the Lehota Formation. In the basal part of the graben fill there are lava flows of leucocratic, pyroxene and basaltic andesites alternating with autochthonous and redeposited pyroclastic rocks of the Kľakovská dolina Formation – an equivalent of the Turček Formation in the Kremnica Graben. The formation attains maximum thickness of 500 m at the western side of the Žiar Depression (Graben). Amphibole-pyroxene andesites of the Stráň Effusive Complex (an analogue of the Kremnický štít Formation in the Kremnica Graben) make up the upper part of the graben fill in thickness 300–400 m.

During the Sarmatian time a renewed pyroxene andesite volcanic activity gave rise to a stratovolcano of the Vtáčnik Formation. Volcanic products covered former sedimentary basins. During the Late Sarmatian and Pannonian time the Horná Nitra Depression and Handlová Ridge were again tilted about 10° westward, attaining their present position. Coal-bearing formations are at 400 m a.s.l. in the central part of Vtáčnik Mts. while they rest below the seal level in the Nováky area.

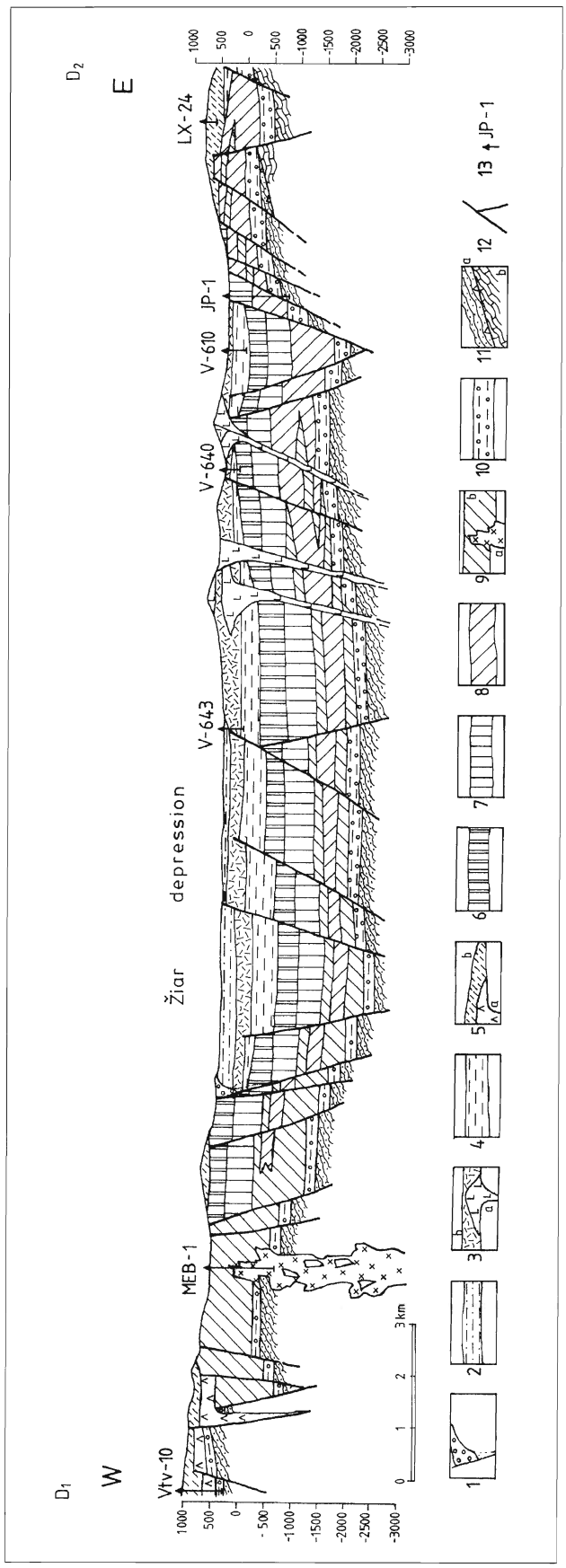
Subsidence of the north-western part of the Horná Nitra Depression continued during Pontian as documented by the 200 m thick sedimentary succession of the Čelovce Formation consisting of fluvial gravels, sands and clays with intercalations of lacustrine limestones and travertines (Elečko in Šimon et al., 1997).

Bánovce Depression

The Bánovce Depression (Fig. IV.3), situated west of the Horná Nitra Depression, represents a northern promontory of the Danube Basin. During Middle and Late Miocene the depression represented a sedimentary area evolving along with the Horná Nitra Depression. During Badenian and Sarmatian it received episodically volcanoclastic material from volcanic mountains situated at the western margin of the volcanic field.

The oldest sediments in the depression there are those of the Čausa Formation (Eggenburgian) represented by schlier facies (pelites, siltstones) with variable sand admixture and conglomerate at the base. It is overlain by the Bánovce Formation (Ottnangian) consisting of sands, silts and clays with intercalations of fine-grained conglomerates. The Lakšár Formation (Karpatian), lying unconformably on the Bánovce Formation, is formed in the basal part by medium- to coarse-grained sandstones with conglomerates that are overlain by flysch-like sediments of calcareous claystones and sandstones.

After a sedimentary hiatus a subsidence of the depression in its present form started in Early Badenian. The Early to Middle Badenian Svinná Formation consists of claystones with intercalations of fine-grained sandstones that are believed to be deposited in the fresh-water environment with signs of marine ingressions. Above there are andesite epiclastic volcanic sandstones and conglomerates containing clasts of garnet-bearing amphibole-pyroxene and hypersthene-amphibole andesites correlated to the Kamenec Formation of the Horná Nitra Depression. Besides clasts



of volcanic rocks the conglomerate contains clasts of crystalline schists and Mesozoic sedimentary rocks. Higher up there are tuffaceous sands, silts and clays including horizons of carbonaceous clays correlated to the Nováky and Handlová Formations of the Horná Nitra Depression (Šimon in Fordinál et al., 2001).

The sedimentary succession continues by tuffaceous claystones and siltstones with andesite epiclastic volcanic conglomerates and by reworked tuffs of the Ruskovce Member. This member is correlated with the Sarmatian Vtáčnik Formation (Šimon in Fordinál et al., 2001). Volcanoclastic material was transported and deposited by rivers and mass flows like lahars, debris flows and hyperconcentrated flows. The Beladice Formation of the Late Pannonian and Pontian age (Fordinál et al., 2001), deposited in the area of the Závada–Bielice Elevation on Paleogene sediments, consists of dark brown claystones with lignite intercalations. Fresh-water limestones represent marginal parts of the formation. The youngest Volkovce Formation of the Pliocene age is composed of fluvial sands and gravels.

Žiar Depression (Graben) (18)

The Žiar Depression (Fig. IV.3/18) represents a conspicuous structure of the graben type in the western part of the Central Slovakian Volcanic Field, situated among the Vtáčnik, Kremnické vrchy and Štiavnické vrchy volcanic mountain ranges (Fig. IV.2). The depression is at the west and east limited by N–S to NNE–SSW trending faults with the amplitude of displacement reaching 1000–1500 m. In the western part the depression defined by gravimetry corresponds to the present-day morphological depression while in the eastern part it includes products of rhyolite volcanism showing a hilly relief. The Žiar Depression represents a younger structure superimposed over the southern extension of the Kremnica Graben. At the north it is separated from the Kremnica Graben fill by NE–SW and E–W striking faults. At the southeast and south the depression is limited against the Hodruša–Štiavnica resurgent horst by a NE–SW

Fig. IV.9. Geological section D_1–D_2 through Žiar Depression (according to Konečný and Lexa, 2000). 1 – limnoquartzites, 2 – Neogene sediments, clays, silts with sandstone intercalations (Pannonian – Pontian), 3 – rhyolite volcanism: a – extrusive dome, b – tuffs (Late Sarmatian), 4 – claystones, sandstones and conglomerates with partly nonvolcanic material (Middle to Late Sarmatian), 5 – a – extrusive dome of hypersthene-amphibole andesite (Early Sarmatian), b – pyroxene and amphibole pyroxene andesite (Sarmatian), 6 – effusive complex of amphibole-pyroxene andesite ± biotite, Stráň effusive complex, Kremnický štít Formation (Late Badenian to Early Sarmatian), 7 – effusive complex of pyroxene andesite and volcanoclastic rocks (hyaloclastites, pyroclastic and epiclastic volcanic rocks), Kľakovská dolina Formation, Turček Formation (Late Badenian), 8 – stratovolcanic complex of pyroxene andesite, Zlatá Studňa Formation (Badenian), 9 – Štiavnica Stratovolcano (Badenian): a – intrusion of hornblende-pyroxene andesite porphyry, b – stratovolcanic complex, lava flows of pyroxene and pyroxene-amphibole andesites and volcanoclastic rocks, 10 – tuffitic sandstones and siltstones, conglomerates with nonvolcanic material, Kordíky Formation (Early Badenian), 11 – pre-volcanic basement: a – Paleozoic rocks, b – undivided Triassic rocks of the Hronicum), 12 – fault, 13 – borehole.

trending fault system (Vyhne–Ihráč fault zone) with the integrated amplitude of displacement over 3 000 m. This fault system continues in the NNE–SSW direction as marginal fault system of the Kremnica Graben.

The pre-Tertiary basement in the central part of the depression has not been verified by boreholes. Boreholes located at margins of the depression recovered Paleozoic and Mesozoic rocks belonging to the Hronicum and denudation relics of Paleogene deposits capping older rocks (Fig. IV.9). Gravimetric investigation suggests an asymmetric character of the depression with maximum subsidence (basement at 2200 m b.s.l.) in its north-western part (Kosorín area). The boreholes aimed at coal prospection located at the north-western margin of the Žiar Depression (near Jánova Lehota; Blaško et al., 1989) indicate at the base of fill 300–500 m thick Early Badenian formation analogous to the Kordíky Formation, including coal seams at the base and overlying nonvolcanic sandstones, siltstones and claystones with marine fauna (Gašpariková in Blaško et al., 1989). In the upper part of the formation volcanoclastic material including garnet-bearing hypersthene--amphibole andesites prevails. In northern and north-western part of the depression the Kordíky Formation is covered by a thick andesite stratovolcanic complex of the Early to Middle Badenian Zlatá Studňa Formation (borehole JP-1). A thick volcanic complex (over 2000 m) including pre-caldera and caldera stage formations of the Štiavnica Stratovolcano occurs in the subsided position in the southern part of the Žiar Depression. In the middle and northern parts of the depression the mentioned Early to Middle Badenian volcanic formations are buried by the Kremnica Graben fill (described above) in thickness 1000–1200 m. Badenian volcanic formations are covered by Early Sarmatian andesite volcanic formations of the Štiavnica and Vtáčnik stratovolcanoes in the southern and western parts of the Žiar Depression.

Volcanosedimentary succession of the Sarmatian age, representing a younger part of the Žiar Depression fill, consists of claystones, siltstones, micaceous sandstones, reworked tuffs, epiclastic volcanic sandstones with intercalations of fine-grained conglomerates and rare layers of gravel composed of nonvolcanic clasts. Their lithology corresponds to the evolution in the fluvial/limnic environment with a sustainable input of nonvolcanic material. Maximum verified thickness of the Sarmatian volcanosedimentary fill is 850 m (the borehole Kríž-1 near Žiar nad Hronom). Stratigraphic assignment to the Early to Late Sarmatian is based on pollen analyses from sediments recovered by the boreholes HF-1 and V-643 (Planderová in Konečný et al., 1983). Garnet-bearing rhyodacite material in the lower part of the volcanosedimentary succession correlates with the Early Sarmatian Strelniky Formation of the Poľana Stratovolcano.

In the upper part of the Žiar Depression fill products of rhyolite volcanism of the Late Sarmatian Jastrabá Formation occur in the thickness 300–400 m. The formation consists of exogenous and endogenous extrusive domes, dome flows, lava flows and wide variety of pyroclastic and epiclastic volcanic rocks. In the south-western and western parts of depression the epiclastic conglomerates and sandstones prevail, including reworked tuffs and tuffaceous sandstones, siltstones and claystones with lenses of limnic quartzites containing remnants of flora and fauna.

Due to asymmetric subsidence of the Žiar Depression products of rhyolite volcanism are in its western part overlain by Pannonian and Pontian sediments in the thickness 50–300 m. They are represented by alternating limnic silts and sandy clays with fluvial gravels and sands and lacustrine carbonaceous clays, lignite seams and rare dark limnic quartzites (Blaško et al., 1987). During the Pannonian time the Žiar Depression was also a place of minor basalt and basaltic andesite volcanic activity giving rise to dykes, sills, lava flows, and phreatomagmatic tuff cones.

Subsidence of the Žiar Depression did not continue during Pliocene time. Pliocene deposits consist of the Hron river high terraces and boulderly alluvial fans in front of major valleys entering the depression.

Štiavnica Caldera (19)

The Štiavnica Caldera (Fig. IV.3/19), situated in the central part of the Badenian stratovolcano, extends on the area 18 x 22 km and is confined by a curved, approximately elliptic caldera fault. On gravimetric map it is indicated by a girdle of negative anomalies surrounding the centrally located Hodruša–Štiavnica Horst. Thickness of the Badenian pre-caldera stage andesite complex varies from 300–1000 m implying an extensive erosion of Badenian volcanic formations prior to the caldera subsidence. Amplitude of the caldera subsidence is estimated at 400–500 m. At the base of the caldera fill there are variably epiclastic volcanic breccias along its margins and epiclastic volcanic sandstones, reworked tuffs and tuffaceous silts and clays with lignite intercalations in its central part, marked as the Červená studňa Formation. The formation, which is 80–90 m thick, is though to be deposited in the lacustrine–paludal environment. Pollen assemblage in sediments, suggesting subtropical and mild climate, yielded the Late Badenian age in the transitional microfloristic zone of "Late Badenian – Early Sarmatian" (Planderová in Konečný et al., 1983). The Červená studňa Formation is overlain variably by products of explosive and extrusive activity of differentiated biotite-hornblende andesites (the Studenec Formation) – extrusive domes, dome-flows, flows, pyroclastic flow breccias, pumice tuffs and epiclastic volcanic breccias. The uppermost parts of the caldera fill correspond to the post-caldera stage andesite volcanic activity. Reworked tuffs, tuffaceous silts and clays, and diatomaceous clays and diatomites were deposited in a local limnic basin in the northern part of the caldera (north of Močiar). Remnants of macroflora suggest the Early to Middle Sarmatian age (Sitár, 1970).

Gravity anomalies and structural boreholes revealed a system of graben-like depressions also along the south-western margin of the Central Slovakian Volcanic Field. The depressions are mainly confined by NE–SW trending

faults. West of the Krškany–Ladzany Elevation there are following partial depressions: Bátovce–Pukanec and Čajkov depressions, more to the south Tekov Depression and westward Volkovce and Zlaté Moravce depressions. Evolution of these depressions took place during Sarmatian except the Bátovce Depression being already formed by subsidence during the Early and Middle Badenian time.

Bátovce Depression (20)

The Bátovce Depression (Graben) (Fig. IV.3/20) is confined by subparallel NE–SW and NNE–SSW striking faults with the amplitude of displacement 1000–1400 m. Basement consisting of Permian sedimentary rocks assigned to the Hronicum was verified by the borehole PKŠ-1 (Karolus et al., 1979) at the depth 1200 m, i.e. 1000 m b.s.l. At the base of the depression fill there are developed the sedimentary rocks reaching the thickness of 400 m – conglomerates composed mostly of clasts from underlying Permian basement overlain by dark silty and sandy clays and carbonaceous clays interbedded with sandstones and fine-grained conglomerates (Fig. IV.10). These sediments are thought to be deposited in the fluvial/limnic environment. Foraminifera fauna with Spiroplectamina carinata suggests the Middle Badenian age (Brestenská in Karolus et al., 1975). Badenian and Sarmatian stratovolcanic complexes of the Štiavnica Stratovolcano make up the main part of the depression fill. The uppermost part of the depression fill consists of sandy clays and clays assigned to Middle and Late (?) Sarmatian.

Lithology of sediments recovered by the borehole PKŠ-1 indicates a fast subsidence during the Early Badenian time, with a partial isolation of the sedimentation area. The subsidence continued during Middle Badenian causing marine ingressions and the marine bay environment. After a sedimentary hiatus during the late Middle Badenian to Early Sarmatian time, when the area became a part of the Štiavnica Stratovolcano, the deposition of sedimentary rocks started again during Middle Sarmatian in the brackish environment due to the block movements along NE–SW trending faults that formed the Bátovce Graben in its present extent.

Pukanec Depression (21)

The Pukanec Depression (Graben) (Fig. IV.3/21) occurs in the north-east continuation of the Bátovce Depression. Its subsidence took place during Pannonian and Pontian. The depression fill rests upon Badenian and Sarmatian volcanic complexes of the Štiavnica Stratovolcano. It consists of grey bituminous and sandy clays with lignite seams in thickness up to 50 m.

Čajkov Depression (22)

The Čajkov Depression (Fig. IV.3/22) is confined by subparallel E–W trending faults south of the Tatiar Horst. Its basement (Permian rocks of the Hronicum) was encountered by the borehole GK-6 at 1745 m (Karolus et al., 1971) i. e. 1570 m b.s.l. The borehole shows in the lower part of the depression fill subsided Badenian complexes of the lower structure of the Štiavnica Stratovolcano – lava flows, epiclastic volcanic breccias and hyaloclastite breccias with total thickness 770 m. Hyaloclastite brecciation implies the subaquatic environment. Badenian volcanic formations are covered by andesite stratovolcanic complex of the Early Sarmatian age. Subsidence continued during Middle and Upper Sarmatian when tuffaceous sandy silts and clays accumulated in the thickness up to 400 m. A continuing subsidence during Pannonian and Pliocene is indicated by 95 m thick clays and sands.

Tekov Depression (23)

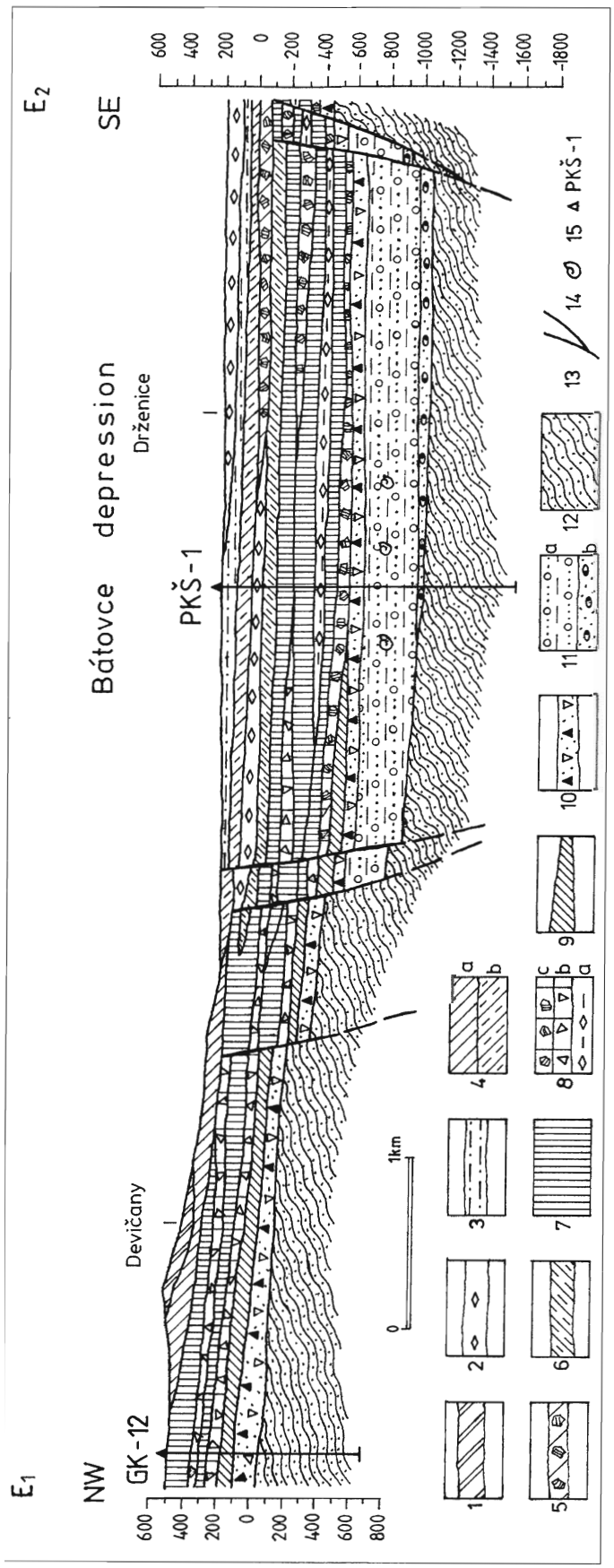
The Tekov Depression (Fig. IV.3/23) represents a system of NE–SW oriented grabens south of the Čajkov Depression. Based on geophysical investigation the altitude of basement in the depression is 800–1000 m b.s.l. (basement has not been encountered by a borehole). Magnetic anomalies suggest a thick volcanic complex in the lower part of the depression fill. In its upper part there are tuffaceous and sandy sediments. Molluscs (Fordinál in Nagy et al., 1998) and imprints of macroflora (Sitár in Nagy et al., 1998) suggest the Middle to Late Sarmatian age.

Volkovce Depression (24)

The narrow Volkovce Depression (Fig. IV.3/24) (graben) is separated from the Tekov Depression by a horst of Kozmálovce hills where a Sarmatian, mostly effusive type volcanic complex is exposed. The depression was shaped by intensive subsidence along NE–SW trending faults (based on gravimetry the basement is assumed at the level 2300 m b.s.l.). At the north it is bounded against the uplifted block of Pohronský Inovec Mts. by a NE–SW trending fault zone with the amplitude of displacement over 3000 m. The depression fill is most probably equivalent to the Zlaté Moravce Depression.

Zlaté Moravce Depression (Komjatice Depression) (25)

The depression is at the east bounded against the uplifted block of Pohronský Inovec Mts. by the N–S trending fault zone (Fig. IV.3/25). At the northwest it is separated from the horst of Tribeč Mts. by the NE–SW trending fault zone. According to interpretation of gravimetric map the depression is subdivided along NE–SW trending fault into the northern, deeper part with basement at 1600 m b.s.l. and southern, shallower part with basement at 1200 m b.s.l. Basement, encountered by the borehole ZM-1, is represented by Late Paleozoic sedimentary rocks of the Hronicum. A 400 m thick complex of volcanosedimentary rocks at the base of the depression fill including conglomerates, epiclastic volcanic rocks, reworked tuffs and tuffaceous clays is of the Middle Badenian age. A similar 200 thick volcanosedimentary package higher up is of the



Late Badenian age. Overlying conglomerates, sandstones and clays were deposited during the Sarmatian time. Volcanosedimentary successions in the Zlaté Moravce and Volkovce depressions are capped by Late Sarmatian calcareous clays with sands and fine-grained gravels of the Vráble Formation, Pannonian clays with sand and gravel layers of the Ivánka Formation and Pliocene gravels and sands of the Volkovce Formation (Priechodská and Harčár, 1988).

Veľká Lehota Graben (26)

The Veľká Lehota Graben (depression) (Fig. IV.3/26) is situated in the western part of the Central Slovakian Volcanic Field. Pre-volcanic basement formed of Late Paleozoic rocks of the Hronicum is at the level 570 m b.s.l. (borehole GK-5 Veľká Lehota; Karolus et al., 1969). The lower part of the graben fill in the thickness of 460 m is occupied by extrusive dome of garnet-bearing hypersthene-amphibole andesite. Higher up there rests Badenian andesite stratovolcanic complex in the thickness of 500 m. Sarmatian post-graben ignimbrites of the Drastvica Formation and andesite lava flows of the Inovec Formation cover the graben fill and its marginal faults. Subsidence of the graben took place during the Badenian time.

IV.II TECTOGENETIC EVOLUTION OF INTRAVOLCANIC DEPRESSIONS IN CENTRAL SLOVAKIA DURING BADENIAN – SARMATIAN – PANNONIAN PERIOD

Following the retreat of Karpatian sea from the area of the South Slovakian Depression, the erosion of pre-Tertiary rock units continued, including Paleogene and Early Miocene sequences. The erosion resulted in a further substantial reduction of the area covered originally by Early Miocene sediments as well as those of the early molasse (Late Cretaceous – Paleogene).

In the northern sector of the volcanic field, Eocene sediments reduced by erosion (Borové, Huty and Zuberec

Fig. IV.10. Geological section E_1–E_2 through Bátovce Depression (according to Konečný, 1998). *Upper stratovolcanic structure* (Sarmatian): 1 – lava flow of amphibole-pyroxene andesite (± biotite), Sitno Complex (Sarmatian), 2 – pumice tuffs, 3 – tuffitic claystone and siltstone, 4 – lava flows of: a – pyroxene andesite, b – leucocrate and glassy pyroxene andesite, Badan Formation (Early Sarmatian), 5 – hyaloclastite breccias. *Lower stratovolcanic structure* (Badenian): 6 – lava flows of amphibole-biotite-pyroxene andesite (Late Badenian), 7 – lava flows of glassy and leucocrate pyroxene andesite, 8 – a – epiclastic volcanic sandstones with pumice, b – epiclastic volcanic breccia, c – hyaloclastite breccia, 9 – pyroxene andesite lava flow. *Volcano-sedimentary complex underlying Sebechleby Formation* (Early to Middle Badenian): 10 – pyroclastic and epiclastic volcanic breccias and sandstones, 11 – a – tuffaceous sandstones, siltstones and claystones, gravels with nonvolcanic material, tuff intercalations, b – basalt beds, tuffaceous sands with pebbles of nonvolcanic rocks. *Pre-volcanic basement:* 12 – Paleozoic rocks of the Hronicum, 13 – fault, 14 – shells of marine fauna, 15 – borehole.

Formations) were preserved in the E–W oriented Bánovce–Handlová–Kremnica–Banská Bystrica–Brezno Depression. In the areas between Handlová and Prievidza as well as in the Bánovce Depression (Ruskovce vicinity) preserved Eocene deposits are overlain by erosion remnants of Eggerian and Eggenburgian sedimentary rocks (Fig. IV.11).

Sedimentary rocks of the Late Cretaceous to Paleocene age were further encountered in another N–S oriented depression near Bzovík (intersected by the borehole GK-4) and a basal Eocene sequence (Lutetian) represented by the Budín transgressive facies (Gross and Váňová, 1976) was found SW of Zvolen in the borehole GK-8. Eocene breccias, conglomerates and sandstones occur as relics also in the area of the Hodruša–Štiavnica Horst.

In the area of Krupina plateau the northern extent of Early Miocene sedimentary rocks is preserved underneath Badenian volcanosedimentary complexes. It is limited along a line running approximately between Krupina–Červeňany, Ábelová and Luboreč town strips.

Early Badenian

Before the onset of the Early Badenian sea transgression (due to the back-arc extension process) a series of smaller sedimentary basins was formed in the area under discussion. The basins were filled with fluvio-limnic sediments in some cases including interesting coal measures (Fig. IV.12). The bulk of the material transported into these basins and local depressions came from the rocks eroded

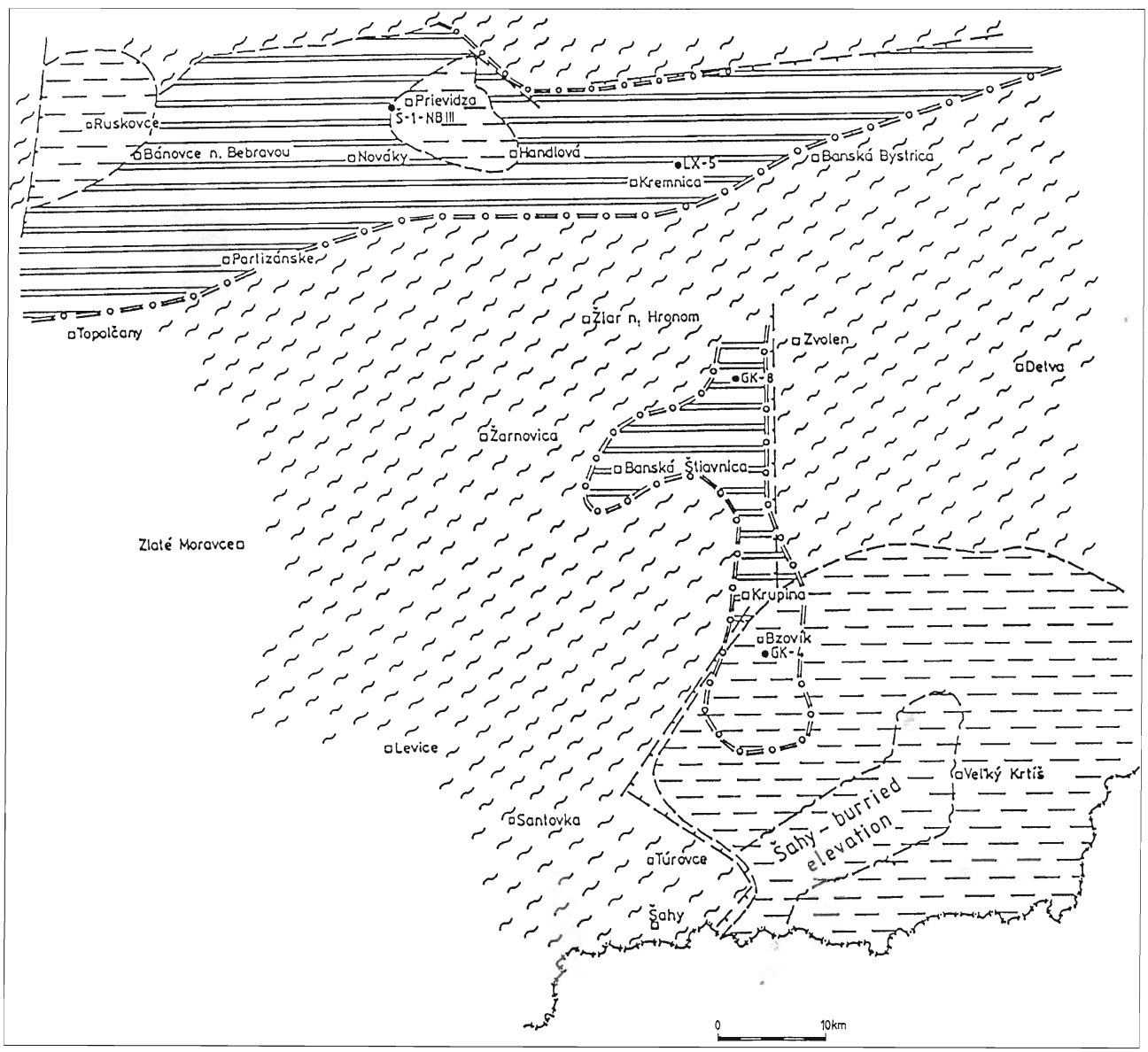


Fig. IV.11. Paleogeographic situation after regression of the Karpatian sea (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

in the adjacent areas of pre-Tertiary basement and Paleogene–Early Miocene sediments.

Active NW–SE oriented stress forces produced predominantly likewise striking graben and horst structures. In the area south of the Turovce Elevation (Horst), the Semerovce Depression controlled and limited by NW–SE trending faults started its subsidence. It was filled with mixed, fresh-water sedimentary sequences up to 40 m thick composed of basal breccia, reddish-brown sandy claystones and sandstones.

Farther, near Turovce the Turovce Formation appears in a similar stratigraphic position (Vass, 1981), composed of quartz sandstones and gravels some 50 m thick. Correspondingly, in the Bzovík Depression, a 125 m thick variegated sequence of reddish-brown sandy claystones occurs with beds of conglomerates and carbonate rock breccias, intersected by the borehole GU-3. The lithology and remnants of flora indicate fluvio-limnic to limnic sedimentary conditions.

A formation of a similar type is reported also from the borehole GK-8 near Zvolen, located to intersect a channel leading into the Bacúrov Depression. This formation consists of mixed reddish-brown clay-sandy strata passing upwards into beds of conglomerate and coarse to blocky breccia showing a transport from steep slopes build of Mesozoic carbonate rocks.

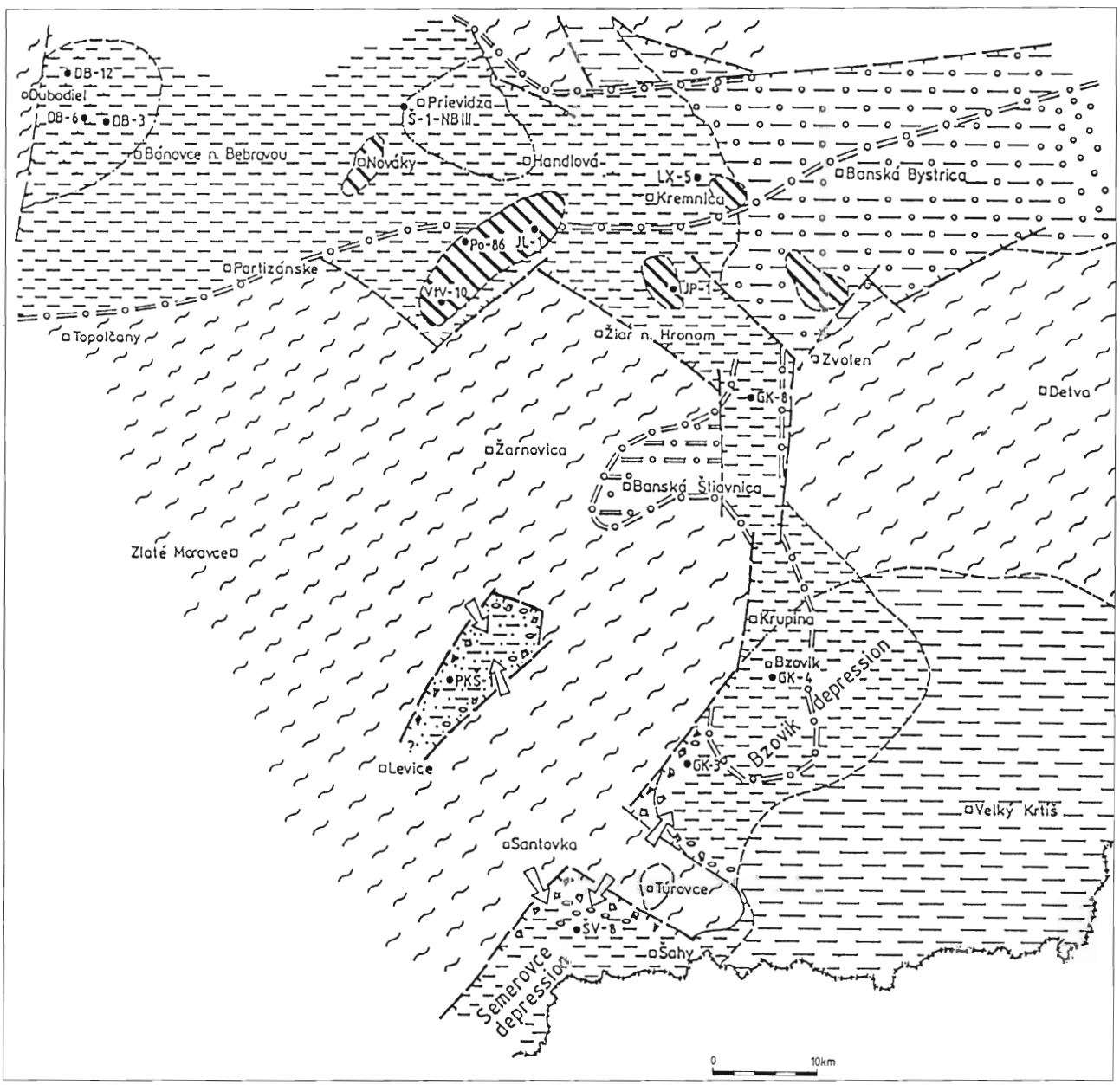


Fig. VI.12. Early Badenian sedimentation in continental fluvial/limnic basins (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

Meantime in the northern part of the volcanic field the sedimentation took place in a limnic to marshy environment, conglomerates are the prevailing rock types in the east (Kordíky Formation). The sedimentary basin was deeper westwards characterized by predominantly fine-grained sediments – sandy aleurites, sandstones, siltstones and claystones. Marshy deposits contain frequently coal seams, some of them of economic interest (Handlová area – boreholes JL-1, PO-86, VTV-10). The coal-bearing sedimentation continued farther SW of Prievidza (borehole Š-1 – NB-III). The important lower coal seam at Nováky deposit is in fact in the equivalent stratigraphic position. Due to an intense subsidence a coeval sedimentary complex in the Bánovce Depression contains mostly siltstones and claystones with only local coal intercalations (boreholes DB-6, DB-12, DB-3).

In the area NE of Levice a local depression formed on a subsiding block of the basement. A structural borehole (PKŠ-1) intersected here a sequence composed of coarse, clastic sediments (coarse breccia and conglomerates at the bottom followed by a sequence of sandstones, sandy claystones and carbonaceous clays).

A sea transgression which during Early Badenian reached the Semerovce (borehole ŠV-8) and Zbrojníky Depressions (borehole HGŽ-3) from the south extended further into the interior of the Krupina Plateau. At the transgression level the tuffaceous sands with conglomerate intercalations appear, some 15–25 m thick (Fig. IV.13). In outcrops, along southern edges of the Krupina Plateau, they have been described as the Príbelce Formation (Vass et al., 1979). The type of sedimentation within depression changes eastwards – the shallowing of the water is reflec-

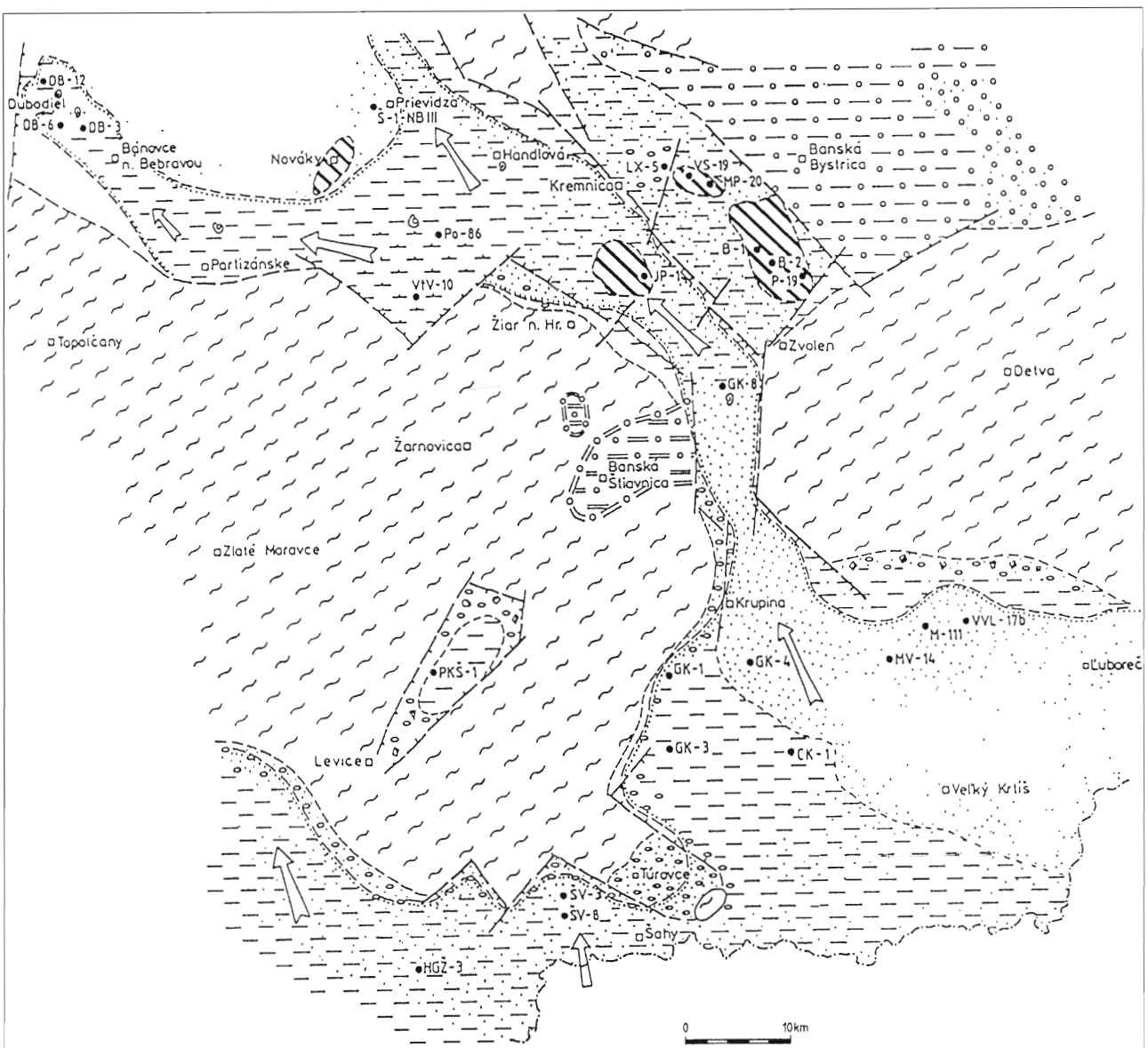


Fig. IV.13. Sediments of the marine transgression during Early Badenian (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

ted in the increased content of clastic material – mainly coarser conglomerates in littoral facies, tuffaceous sands and further even fluvio-limnic to continental sedimentary rocks. In the opposite direction (W, SW) the depressions deepen and the sediments are composed predominantly of aleurites and siltstones (boreholes ŠV-8, ŠV-3, HGŽ-3). Similar conditions have been encountered in the inner sector of the Bzovík Depression where the strata of tuffaceous sands and conglomerates are followed by much finer-grained aleuritic to areno-aleuritic sediments in increasing thickness (boreholes GK-3, GK-1, CK-1).

The northern sector of the region was affected by the sea believed to have penetrated into the area via a narrow channel of the Bacúrov Depression, from where the marine environment extended further westwards into the Žiar and Handlová basins. A marine environment was confirmed in the borehole GK-8 that intersected marine fauna hosting tuffaceous-sandy sediments with blocks of carbonate rocks. Marine macro- and microfauna is reported from near Handlová (Lehotayová, 1959) and foraminifera and nanoflora from the borehole HV-9 near Jánova Lehota (Gašpariková in Blaško et al., 1987).

In the eastern sector of the sedimentary area the marshy environment is documented by the formation of carbonaceous clays and coal seams intersected in a number of boreholes: B-1, B-2, and P-19 near Badín north of Zvolen VS-19, MP-20 northwest of Malachov. Brown coal seams appear in the borehole JP-1 near Jastrabá. The coal-

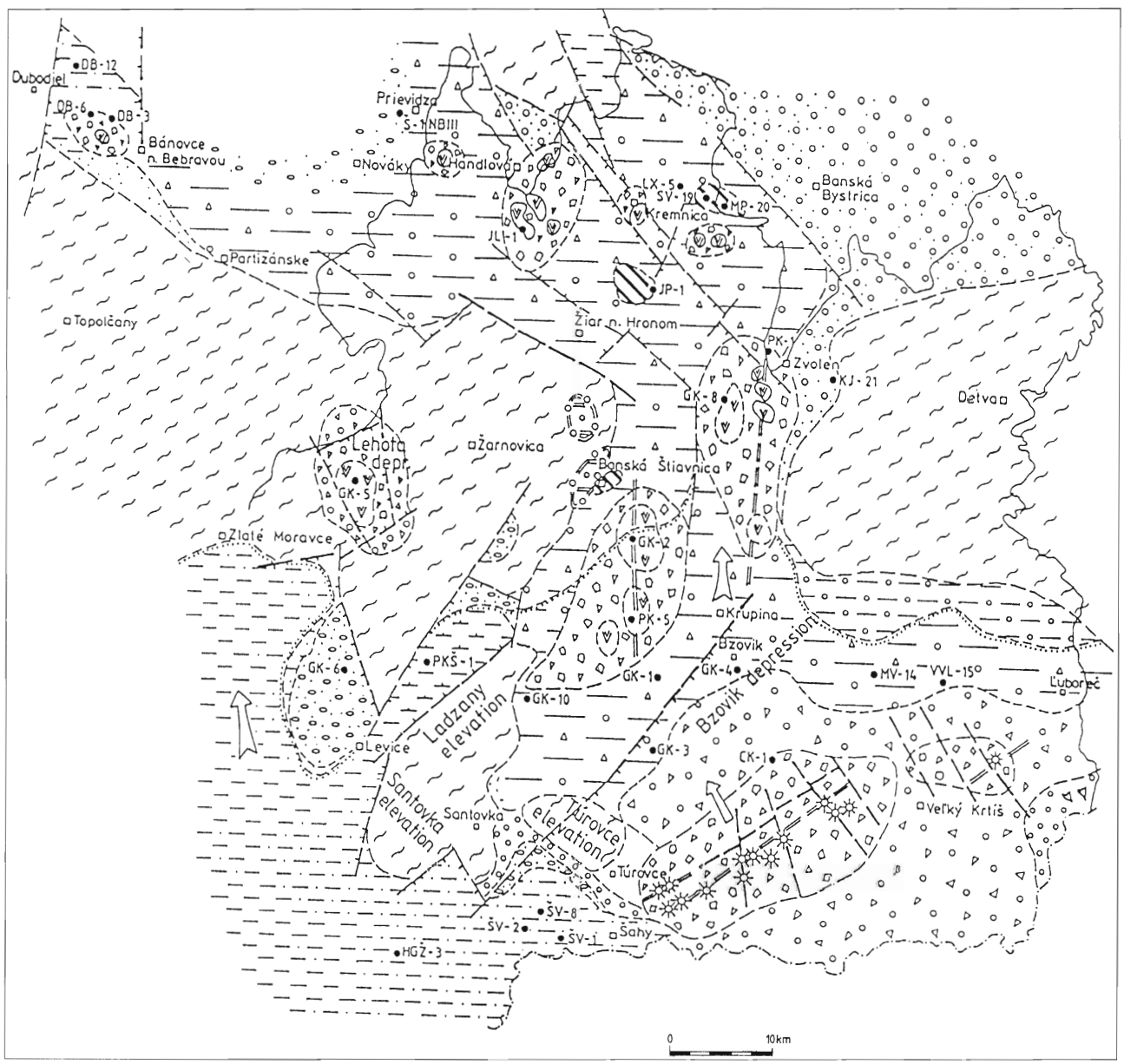


Fig. IV.14. Early-Middle Badenian extrusive volcanism of hypersthene-amphibole andesite ± garnet (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

-bearing sediments in the area south of Handlová were subsequently covered by tuffaceous sands and sandy claystones (boreholes JL-1, PO-86 and VZJ-10). Incursions of the marine environment farther to the west into the subsiding Bánovce Depression are confirmed by the occurrence of marine fauna in sandy claystones with conglomerate intercalations (boreholes DB-12, DB-6, DB-3).

Extension processes taking place in the period of Early Badenian were instrumental in the formation of predominantly NW–SE oriented horst-graben structures triggering simultaneously the extrusive andesite volcanism (Fig. IV.14).

During this time the buried Šahy Elevation was dislocated into partial blocks. The eruptive centers of hornblende-pyroxene andesites of the Vinica Formation, as a part of the NE–SW trending Šahy–Lysec volcanotectonic zone (Konečný, 1969) often appear at intersections with NW–SE trending cross faults. Andesite extrusions, in the marine environment, were subject to brecciation and explosive destruction. Clastic material was transported predominantly north-westward into the subsiding Bzovík Depression, accumulating in a thickness up to 300 m. Extrusions of garnet-bearing hornblende-hypersthene andesites were taking place in the north-central part of the volcanic field. These andesites form mostly extrusive domes and crop out SW of Zvolen along the N–S striking Neresnica fault zone as well as SE and W of Kremnica and in the northern part of Vtáčnik Mts. Extrusive bodies of andesite are surrounded by coarse breccias. In the western sector of the volcanic field garnet-bearing andesite extrusions were confirmed underneath the Štiavnica Stratovolcano at the base of volcanic complex by drilling. In the vicinity of Veľká Lehota, near the western margin of the region, a buried 465 m thick extrusive body (laccolith?) of garnet-bearing hornblende-hypersthene andesite was intersected by the borehole GK-5, emplaced among beds of epiclastic volcanic breccias.

Material derived from the desintegrating extrusive domes was transported into at that time intensively subsiding Bátovce Depression. In the borehole PKŠ-1 the sediments intersected at a depth 1031 m show substantial enrichment of clastic mineral in hornblende, biotite and garnet. At the higher levels these sediments contain foraminifera as well as littoral macrofauna thus indicating a connection of this area with the marine environment. In general volcanoclastic material during this time was redeposited in the marine environment at the south and in the limnic, lacustrine or fluvial environments at the central and northern sectors of the volcanic field. The type of shallow, marshy environment continued in the northern sector in the area W of Kremnica (boreholes VS-9, MP-20) and at the eastern border of the Žiar Basin (borehole JP-1). The limnic and lacustrine sedimentation at the north was interrupted by the inflow of clastic material in the form of conglomerates and sandstones (boreholes P-86, VTV-10). Clastic derivatives of garnet-bearing andesites intersected by drilling (DB-6) in the subsiding Bánovce Depression are probably related to extrusive volcanic bodies indicated in the area by geophysical survey.

Along the eastern border of the sedimentation area the Kordíky Formation continued its evolution in a fluvio-limnic environment with conglomerates and sandstones. The material derived from garnet-bearing hornblende-hypersthene andesites yielded the age of 16.2 ± 0.6 Ma (Repčok, 1981) corresponding to Early Badenian.

The Early Badenian transgression was terminated by an emergence of the sedimentation area at the east (neritic conditions documented near Hrušov by Ammulsia denudata) and deepening of the area at the west due to a shifting of deposition centers.

Late Early – early Late Badenian

The younger stage in evolution of the Central Slovakian Volcanic Field is marked by the formation of medium to very large andesite volcanoes (Fig. IV.15).

Following the partial retreat of the sea from the eastern areas the southern emerged sector suffered a severe erosion, mainly of the Vinica Formation the thickness of which was reduced to only several tens of m (Intra-Badenian erosive phase). During the following phase of renewed marine advancement eastwards the Čelovce pyroclastic volcano started emerging in the littoral zone of the buried Šahy Elevation. Its pyroclastic flows and lahars descended mainly in the N to NW direction into the subsiding Bzovík Depression, leading to accumulations in thickness over 300 m. The Čelovce Volcano was developing asymmetrically, its western slopes being simultaneously destructed in the littoral zone producing deposits of epiclastic volcanic sandstones and conglomerates. The rising Čelovce Stratovolcano gradually separated the eastern areas from the marine environment. The slightly younger Lysec pyroclastic volcano was evolving in the NE extension of the Šahy–Lysec volcanotectonic zone already in the continental subaerial environment. Its volcanoclastic products were transported predominantly southwards into the intensively subsiding Strháre–Trenč Depression. The environment in the volcano surroundings was fluvial to limnic, dominated by epiclastic volcanic sandstones, conglomerates and siltstones.

During the same time the NE sector of the volcanic field saw the emergence of two andesite stratovolcanoes – the larger at Javorie and the smaller at Poľana mountain range. The deposits at the base of Javorie Volcano imply wet, probably limnic environment (hyaloclastites with lignite intercalations). Further upwards the volcanic structure was developing in a dry-land, subaerial environment. There are indications of similar conditions also at the Poľana Volcano.

Another important andesite stratovolcano was formed at Kremnica in the northern sector of the volcanic field. The Kremnica Volcano started developing in a shallow water, sublitoral environment as witnessed by hyaloclastite breccias and products of phreato-magmatic eruptions. Later subaerial effusive activity took over in a dry land environment. Meantime in the space between these large stratovolcanoes in the areas of Zvolen and Bacúrov depressions the sedimentation in a fluvio-limnic environment conti-

nued bringing in a variety of volcanogenic materials, mainly volcanoclastic rocks with occasional lava flows from the slopes of surrounding volcanoes (boreholes GK-8, FŽB-1, JP-1, and PK-1).

At the west of the volcanic field the dominant feature was the growing andesite Štiavnica Stratovolcano. Its southern footing was evolving in a littoral to sublitoral marine environment and lava flows reaching the sea shore were subject to hyaloclastite brecciation. At an early stage the SE shore line of the stratovolcano extended in to the Krupina–Pliešovce area and continued westwards, approximately in the direction of Sitnianska Lehôtka–Badan–Pukanec–Tekovská Breznica–Zlaté Moravce. The areas emerged above water along the western margin of the stratovolcano included the Pohronský Inovec Horst and probably the horst of Tribeč Mts. as well. Farther to the north of the horst a marine bay incursion was reaching into the Topoľčany area. Shallow and emerged areas along the southern perimeter of the Štiavnica Stratovolcano were formed by the Santovka and Turovce elevations.

During Badenian the SW segment of the Štiavnica Stratovolcano was gradually subsiding being covered by masses of volcanoclastic material and lava flows brecciated at the contact with water in accumulations reaching 720–760 m in thickness (boreholes PKŠ-1, GK-6 located in Bátovce and Čajkov depressions). The Bzovík Depression was at the same time filled mainly by volcanoclastic material derived from the Čelovce Volcano located at the south of Štiavnica.

The increase in mass and the areal expansion of the stratovolcano pushed its outer perimeter facies gradually outwards form the centre into more external zones. The border facies, characterized by very coarse conglomerates often with blocky fragments, migrated farther south following the line connecting the present localities of

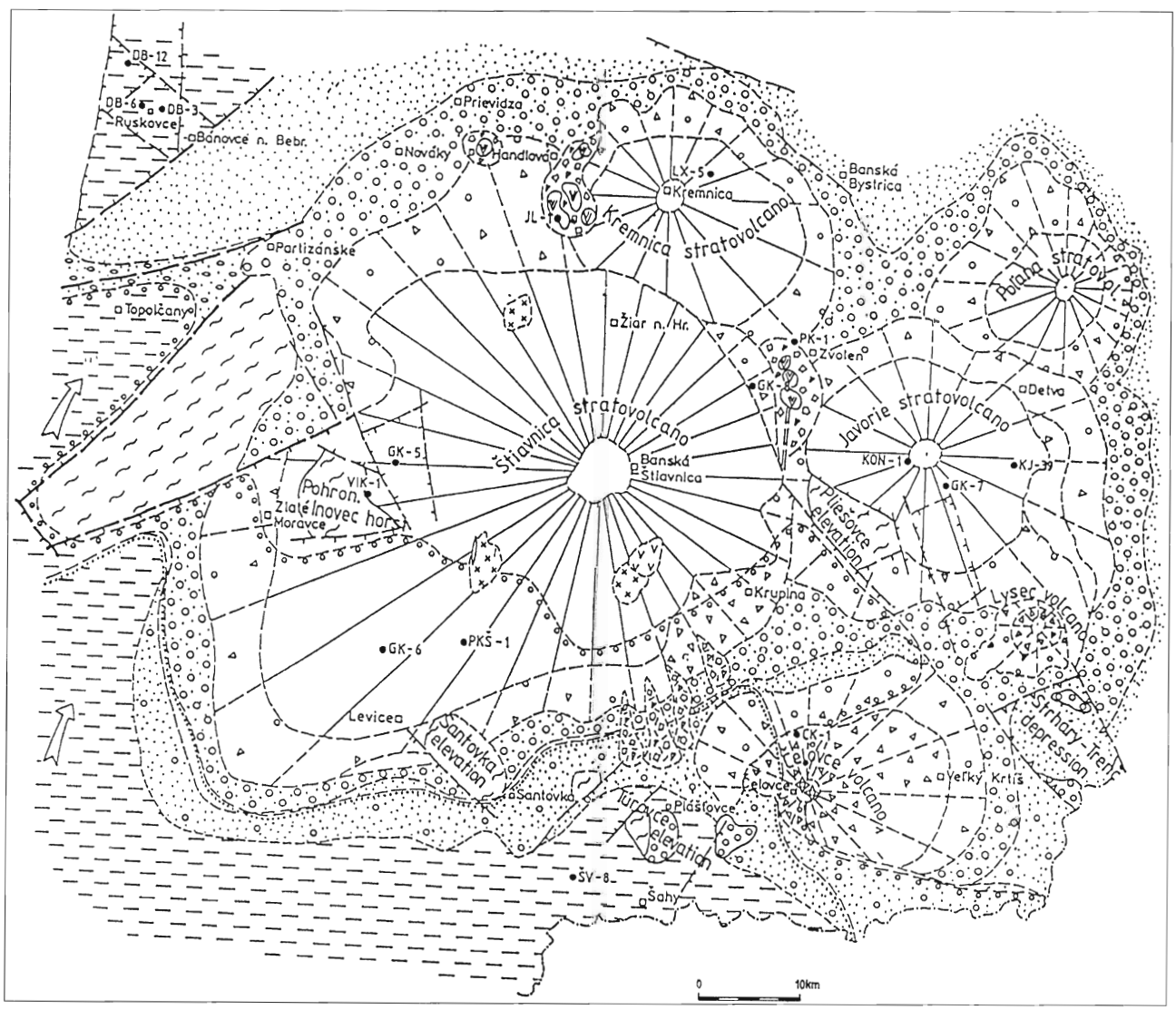


Fig. IV.15. Middle-Late Badenian: evolution of andesite stratovolcanoes (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

Bzovík–Hontianske Ladzany–Levice. South of the littoral zone i.e. in the sublitoral zone the finer-grained sedimentation gradually prevailed with only intermittent mass incursions of coarse-fragmented products. The finer sediments are represented by epiclastic volcanic sandstones with thin intercalations of conglomerates and siltstones. The episodic coarse products include pyroclastic flows, debris flows as well as slumping turbidites. As the Turovce Elevation in the south at that time presented a barrier, the southward flowing turbidity currents could not reach the Semerovce Depression and ended at the northern boundary of the elevation (Vass et al., 1971).

The areas north of the Štiavnica and west of the Kremnica Stratovolcanoes (i. e. between Handlová–Nováky–Prievidza and Partizánske) during this period were accommodating distal sedimentary facies of these stratovolcanoes composed of sand and gravel deposited in the fluvial and limnic environments (Kamenec Formation). In the Bánovce Depression the sedimentation was taking place also in the fluvial and limnic environments following the separation from the sea.

Late Badenian – Early Sarmatian

During this period the retreat of marine environment from the SE sector of the volcanic field continued in connection with the shifting of deposition centers farther westwards into the Danube Basin. Meantime the evolution of stratovolcanoes underwent some dramatic changes (Fig. IV.16). Volcanotectonic grabens (Javorie and Vígľaš) developed in the upper part of the Javorie Stratovolcano. They were, however, simultaneously compensated by basaltic and pyroxene andesite lava effusions. The lava flows in contact with water in the depressions were subject to hyaloclastite brecciation. The collapsing volcanic structures were penetrated by hornblende andesite and rhyodacite extrusions and intruded by diorite porphyry bodies. A smaller caldera was formed in the summit part of the Poľana Stratovolcano, subsequently compensated by extrusions and effusions of rhyodacite lavas while rhyodacite tuffs covered the western and southern slopes of the stratovolcanic structure.

During the Late Badenian in the northwest sector of the region (i.e. west of the Kremnica Stratovolcano and along the northwest rim of the Štiavnica Stratovolcano) the Handlová–Nováky coal basin started to develop over the conglomerates of the Kamenec Formation. The boundaries of the basin were the two stratovolcanoes at the south and east, the rising pre-volcanic basement at the north and Závada–Bielice basement elevation at the west. Due to continuing subsidence the coal-bearing strata of the Handlová–Nováky Basin were overlain by some 300 m of limnic clays of the Koš Formation. Extrusive volcanism of hypersthene–amphibole andesites (Plešiny Formation) was activated on the NW slopes of the Štiavnica Stratovolcano due to block movements. In the following stages the sediments of the basin, both limnic clays and coal-bearing strata, were partially eroded and an extensive delta-like fluvial cone composed mainly of conglomerates accumulated south of the sedimentation area at the entrance to the subsiding Žiar Depression (Lehota Formation). The cone extended also southwestward between Považský Inovec and Tribeč elevations merging further in the area of the Rišňovce Depression with deltaic sediments (Vass et al., 2002).

A large graben was formed in the area of Kremnica along controlling NNE–SSW trending fault lines. The graben extended southward far enough to incorporate the northern slopes of the Štiavnica Stratovolcano. The graben subsidence was compensated by lava effusions and masses of volcanoclastic rocks in a thickness over 1000 m. The lower levels of the graben bear witness to subaquatic environment causing hyaloclastite brecciation of lava flows and phreatomagmatic explosive eruptions. The faults along the western side of the graben displaced the Handlová Basin sediments thus confirming a younger age of the graben-forming tectonics. The graben faults located a series of smaller phreato-pyroclastic cones and minor stratovolcanoes and extrusions of basaltic andesites (e. g. Veľký and Malý Grič west of Handlová). The Kremnica Graben extended northward as the Turiec Depression (Graben) accommodating quantities of volcanoclastic material with few lava flows to an approximate thickness of 300–400 m (borehole GHŠ-1).

During the Late Badenian–Early Sarmatian (?) period a large caldera began forming in the central part of the Štiavnica Stratovolcano. The initial subsidence phase produced an isolated, lacustrine–swampy sedimentation basin with sandy–silty deposits including lignite intercalations (Červená studňa Formation). This initial subsidence of the caldera was probably caused by a lateral outflow of magma from the shallow reservoir into the subsiding Kremnica Graben north of the volcano, creating 500 m thick effusive complex of amphibole-pyroxene andesites in the upper part of the graben fill. Further collapse of the caldera was compensated by the inflow of biotite-amphibole andesite lava forming a dome/flow complex in the thickness of 300–500 m. A part of volcanic products passed over the caldera margins and filled radially oriented valleys on slopes of the volcano.

Minor, isolated lacustrine basin formed also in local depressions between the stratovolcanoes. Finer-grained sediments often with carbonaceous clays were the major component of the basin fills. The age of these sediments was determined by palinologic studies as Late Badenian–Early Sarmatian correlating well with that of the Nováky coal basin (Planderová in Konečný et al., 1983). Sedimentary sequence of this type were formed at a number of places and confirmed by drilling: at the eastern limit of the Žiar Basin (boreholes JP-1 at 673–460 m and FŽB-1 at 520–445 m), within the Žiar Basin (borehole HF-1 at 217–188 m), in the eastern part of Kremnické vrchy (borehole LX-5 at 435–424 m), in the Turiec Depression (borehole GHŠ-1) and at the east near Detva (borehole D-1 at 207 m) a lacustrine sedimentation at the NW sector of the volcanic field (Bánovce Depression) yielded tuffaceous siltstones equally with coal-bearing claystones, correlated

well with the Handlová coal basin formation (Šimon in Fordinál et al., 2000; boreholes DB-12, DB-6 and DB-3). At the western part of the Štiavnica Stratovolcano a minor, isolated basin containing lignite and carbonaceous sediments developed close to the marine bay promontory north of Zlaté Moravce.

During the Late Badenian–Early Sarmatian (?) period the region of Central Slovakian stratovolcanoes provided a favorable environment for the formation of minor coal-bearing basins. It was in particular their location around the perimeter of the volcanoes emerging from the marine environment gradually giving way to isolated lakes with brackish conditions with ever more inflow of fresh water turning them at the end into fresh water basins and swamps overgrown with coal-yielding marshy vegetation. With a mild to warm subtropical climate the conditions were highly favorable for the growth of appropriate plants–mainly Taxodiaceae, Nyssaceae and Myriaceae which became the bulk material for the formation of coal seams (Planderová in Konečný et al., 1983).

Early to Middle Sarmatian

In the Central Slovakian Volcanic Field the Early to Middle Sarmatian period was characterized by an intense explosive/effusive volcanic activity resulting in a considerable number of smaller stratovolcanic structures formed upon denuded Badenian volcanic formations. In the Javorie area a complex volcano was strapping up with the central zone situated between the present day Kalinka and Stožok and another, smaller one west of the former with its central zone near Kráľová. The younger volcanic products buried

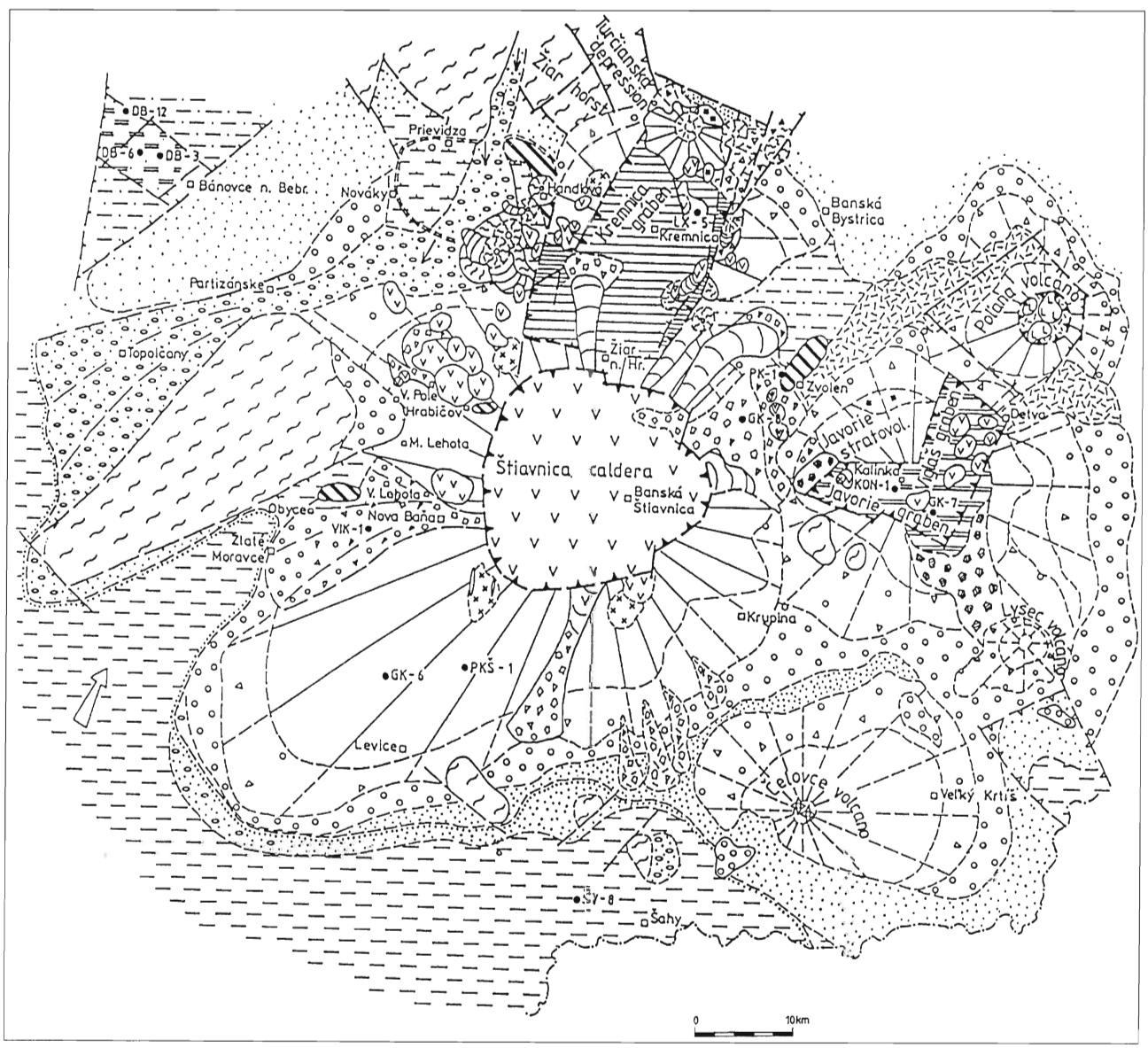


Fig. IV.16. Late Badenian – Early Sarmatian: closing stage in the evolution of stratovolcanoes – origin of calderas and grabens (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

the older and partially eroded Badenian stratovolcano together with adjacent volcanotectonic depressions. In the area of Poľana over the remnants of the Badenian stratovolcano a formation of a new stratovolcano began.

In the northern sector of the volcanic field at the western and northeastern marginal faults of the Kremnica Graben Markov vrch, Vtáčnik, Remata and Flochová andesite stratovolcanoes grew up. Material discharged from these volcanic structures covered to a substantial degree the Handlová–Nováky coal basin.

In the area of the extensive Štiavnica Stratovolcano a considerable number of minor stratovolcanoes came into being in the vicinity of the caldera fault or inside the caldera itself. Their volcanic products – pumice tuffs, pyroclastic flows and lava flows were transported south to southwestward into a widening delta which opened south of the circumferential caldera fault (at present day Počúvadlo village). Lava flows at the southern to southwestern slopes of the stratovolcano reached the littoral zone of the Sarmatian sea where they were subject to hyaloclastite brecciation (Badan Formation).

Toward the termination of volcanic effusions a large 90–100 km^2 plateau of lava developed at the SW foot of the stratovolcano. The lava flows and hyaloclastite breccia having reached the littoral zone suffered destruction through wave action and were transformed into deposits of conglomerates, sandstones and redeposited hyaloclastites. Ash-pumice tuffs following the aerial or lahar transport were deposited in the marine environment along the northern and southwestern rim of the stratovolcano. Pumice flows

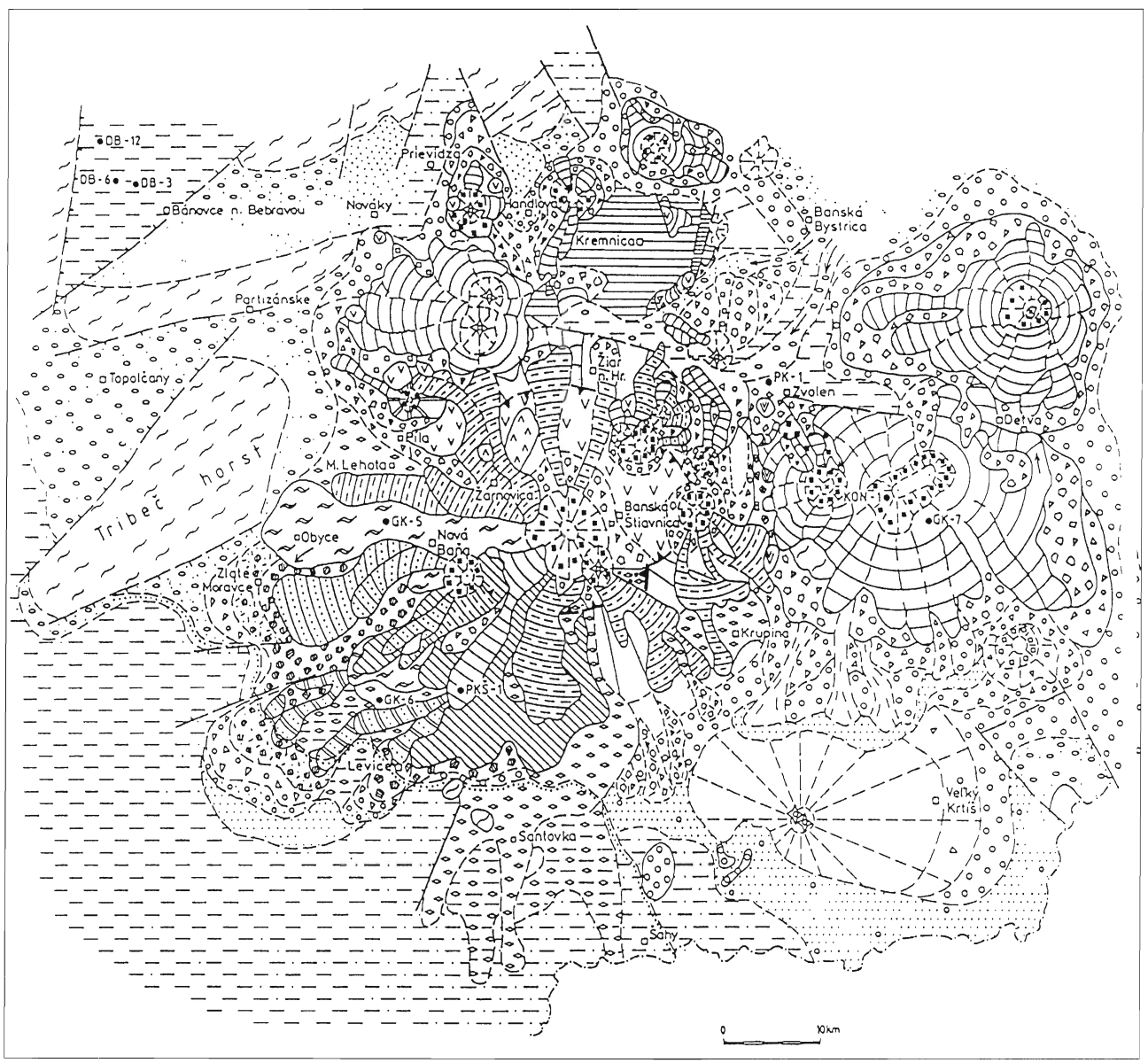


Fig. IV.17. Early – Middle Sarmatian: origin of andesite stratovolcanoes related to caldera and graben fault systems (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

deposited in paleovalleys around the stratovolcano became welded under favorable thermodynamic conditions producing ignimbrites. A major ignimbrite body some 25 km long can be found near Obyce village where the pumice--ash flows of the Drastvica Formation accumulated in paleovalleys burying a local pan of coal-bearing sediments.

The previously retreated marine environment reappeared in a new transgressive phase of Early Sarmatian invading the SW perimeter of the Štiavnica Stratovolcano. In one of the new marine incursions into the area a sequence of tuffaceous-sandy claystones with lignite intercalations was deposited in a semi-isolated lagoonal-brackish environment. The sequence situated in the neighbourhood of Hronský Beňadik–Orovnica–Tekovská Breznica, is some 130 m thick with 0.5–2 m lignite intercalations (Brestenská, 1955; Brlay, 1964; Blaško et al., 1989). Its age, based on mollusc fauna, was established as Early Sarmatian (Váňová, 1960). Similar tuffaceous-sandy and sandy-clay sediments containing marine fauna of Early Sarmatian age occur frequently along SW perimeter of the Štiavnica Stratovolcano, e. g. around Tlmače and Lipník (Váňová, 1960; Brestenská, 1965). The above mentioned sequence as well as the overlying strata host hyaloclastite breccia and brecciated lava flows of coarse-porphyric hornblende--pyroxene andesites of the effusive Priesil Complex. The gradual filling of the paleovalley and of the adjacent marine bay by products of the Priesil Complex pushed the shore line further SW toward Kozmálovské kopce Hills. Its position is indicated by the occurrence of coarse conglomerates deposited along the shore line.

Minor local depressions developed around the perimeter of the Štiavnica Stratovolcano. Their fluvio-lacustrine sediments yielded frequently fossil remnants enabling age determinations. A small pan with tuffaceous, lignite-bearing sediments near Hrabičov at the NW slopes of the stratovolcano yielded microflora (borehole VTV-26) corresponding to the upper levels of Early Sarmatian (Planderová in Konečný et al., 1983). Another small fresh-water basin located within the caldera near Močiar contains diatomite sediments with macroflora indicating also the Early Sarmatian age (Sitár, 1970).

Other minor fluvio-lacustrine basins are found near Zvolen. Boreholes PK-1 at 151–138 m and Bo-7 at 187–188 m confirm the Lower Sarmatian age of sediments based on microflora (Planderová in Konečný et al., 1983). The Zvolen Depression opened westward into the Žiar Depression via a fresh-water fluvial channel. Lacustrine sediments occur near Železná Breznica and tuffaceous claystones/siltstones with sandstone, lignite and diatomite intercalations occur near Turová village (Blaško et al., 1989).

Middle to Late Sarmatian

Andesite volcanism giving rise to smaller stratovolcanoes continued through the Middle Sarmatian and perhaps even into the Late Sarmatian, accompanied by a simultaneous retreat of the sea from the SW sector of the volcanic field (Fig. IV.18).

Further effusions poured down the western slopes of the Štiavnica Stratovolcano in the form of pyroxene and leucocratic andesite lava flows (Inovec Formation). As in previous cases after reaching the water they underwent a transformation into hyaloclastite breccias. On the opposite (SE) side of the stratovolcano a minor pyroxene andesite volcano developed near Jabloňový vrch hill. Pyroclastic/effusive Sielnica and Turová volcanoes in the SE sector of Kremnické vrchy Mts. covered Early Sarmatian volcanic formations of the Štiavnica Stratovolcano as well as fluvial and limnic sediments connecting the Zvolen and Žiar depressions.

The Žiar Depression together with northern slopes of the Štiavnica Stratovolcano were affected by the subsidence of a narrow basement block along the Kremnica Graben NNE–SSW fault lines. The opening space was filled by 500 m of fluvio-limnic sediments composed basically of alternating claystones, siltstones and sandstones with intercalations of conglomerates, reworked tuffs and lignite. Palinologic investigations of the borehole HF-1 and V-643 intersections (Planderová in Konečný et al., 1983) showed the Middle to Late Sarmatian age.

In the NE sector of the region, a fluvio-limnic system started developing in the area of Banská Bystrica–Zvolen Basin with a communication opened into the Žiar Basin. This new sedimentation space was filled by fluvial sediments with debris of rocks derived from denudated Veporicum basement. It is suggested that at the time, the eastern boundary of the Zvolen Depression was formed by the uplift of the Lieskovec Horst along NW–SE trending fault lines.

At the north of the volcanic field the subsidence of the Turiec Depression, cut along NW–SE striking fault lines was compensated by accumulation of volcanic debris eroded from the Flochová Stratovolcano and subsequently deposited in the depression as a 150 m thick volcanosedimentary sequence (borehole GHŠ-1; Gašparik, 1974; Lexa, 1982). In a similar fashion the deposition of a volcanosedimentary sequence derived from the Vtáčnik and Zlatá Jedľa stratovolcanoes provided compensation for the asymmetrically subsiding block of the Horná Nitra Depression.

The marine environment near the SW border of the volcanic field, continued its retreat westwards in connection with the migration of deposition centers into the area of Danube Basin. The gradual shallowing of the marine environment along the SW perimeter of the Štiavnica Stratovolcano lead to its change into the brackish-lacustrine and limnic type. The process of this change was subsequently completed during Late Sarmatian, Pannonian and, finally, Pontian.

The subsidence of grabens along the SW foot of the Štiavnica Stratovolcano, operating along NE–SW and ENE–WSW trending fault lines with displacements of several hundred meters, was compensated by the deposition of volcanosedimentary sequences in the Čajkov Depression, and in even more pronounced way in a system of smaller Tekov Depression and Volkovce Depression. The depth of the subsiding Volkovce Depression is a remarkable

2000 m b.s.l. The Zlaté Moravce Depression farther to the NW shows equally great depth (1200–1600 m b.s.l.). Compensatory deposits include the Vráble Formation (Priechodská and Harčár, 1988) of sandy to calcareous clays with intercalations and beds of tuffaceous sandstones. As coeval in the Štiavnica area there are considered occurrences of pumice tuffs. During this period the strongly subsiding Čajkov Depression, has been filled with tuffaceous clays and silts reaching 265 m in thickness. Borehole GK-6 between 95–360 m yielded microfauna of foraminifers determined as Middle to Late Sarmatian (Brestenská in Karolus et al., 1971). A complex of Early Sarmatian lava flows composed of leucocratic pyroxene and pyroxene-biotite andesites is emplaced in the upper levels of the Bátovce Graben. This volcanic complex was intersected by the borehole PKŠ-1 between 95–273 m, it did not, however, encounter any sedimentary derivatives of the Middle to Late Sarmatian age.

Sediments of a similar lithology and stratigraphic position such as those of the Čajkov Depression were found farther west in the boreholes Bi-1 and Le-4 as well as NW of Kozárovce. An outcropping sequence of Late Sarmatian tuffaceous sandstones and claystones located south of Levice, near Hontianska Vrbica, contains a fauna of Molluscs (Fordinál, 1997, in Nagy et al., 1997). The same sequence yielded from siltstone intercalations macrofauna indicating the Middle to Late Sarmatian age and, simultaneously, an environment proximal to the continent (Sitár, 1997, in Nagy, 1997). The sedimentary sequence described above is extruding to the SW into the area of Komjatice–Želiezovce



Fig. IV.18. Middle – Late Sarmatian: evolution of smaler volcanoes and early subsidence of the Žiar Depression (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

Depression turning into deep-water deposits in correspondence to the deepening of the sedimentary environment. Their thickness determined by a drilling near Pozba attains 250–300 m. In the same period a horst block of Kozmálovské kopce hills was emerging form the sedimentary area at the SW foot of the Štiavnica Stratovolcano. The block is built mainly of lava effusions, hyaloclastite breccias as well as coarse epiclastic volcanic breccia and conglomerates in near-shore facies. The northern border of the Zlaté Moravce Depression and its sedimentation area was, at that time, represented by the Tribeč Horst structure.

In the area of the Rišňovce Depression, bordered by the Závada–Bielice Elevation at the north and Tribeč Horst at the south, the sedimentation during Sarmatian was characterized by deltaic facies with prevalence of gravel and sand deposits (Ripňany Formation).

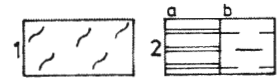
Late Sarmatian, Pannonian and Pliocene

The closing phases of the Tertiary period involved extensive block movements in the western sector of the volcanic field, mainly along NNE–SSW striking fault lines with displacements exceeding 3000 m. The formation of the Hodruša–Štiavnica Horst attaining surface dimensions of 17 x 10 km (Fig. IV.19) began in the central and western parts of the caldera due to the asymmetric rise of the block. Subsequent erosion in the western part of the horst structure exposed rocks of the pre-Tertiary basement and



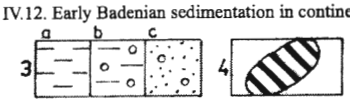
Fig. IV.19. Late Sarmatian – Pannonian and Pliocene: rhyolite, basaltic andesite and alkali basalt volcanism, uplift of resurgent horst, subsidence of intravolcanic/marginal basins (for explanations see Fig. IV.20 with common explanations to all paleogeographic schemes).

Fig. IV.11. Paleogeographic situation after regression of the Karpatian sea.



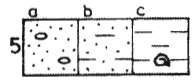
1 – pre-Tertiary basement (undivided),
2 – Tertiary basement: a – Paleogene sediments, b – Early Miocene sediments.

Fig. IV.12. Early Badenian sedimentation in continental fluvial/limnic basins.



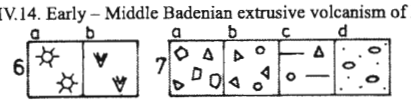
3 – a – siltstones, claystones, b – sandstones, siltstones, conglomerates, c – conglomerates and sandstones,
4 – coal sediments, coal.

Fig. IV.13. Sediments of the marine transgression during Early Badenian.



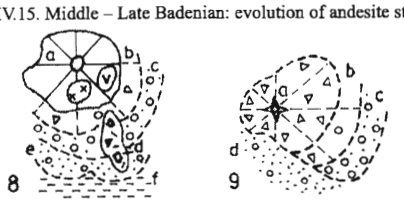
5 – a – tuffaceous sands, b – tuffaceous sands and claystones, c – siltstones and claystones.

Fig. IV.14. Early – Middle Badenian extrusive volcanism of hypersthene-amphibole andesite (± garnet).



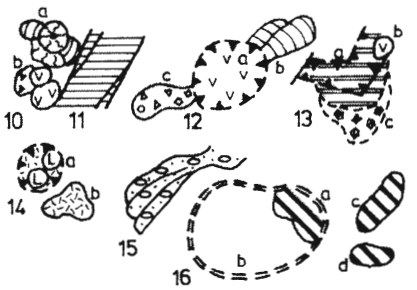
6 – eruptive centers: a – submarine extrusive domes of the Vinica Formation, b – extrusive domes of Neresnica Formation,
7 – volcanoclastic rocks: a – coarse to blocky breccias, b – breccias - conglomerates, c – siltstones, breccias, d – sandstones, fine conglomerates.

Fig. IV.15. Middle – Late Badenian: evolution of andesite stratovolcanoes.



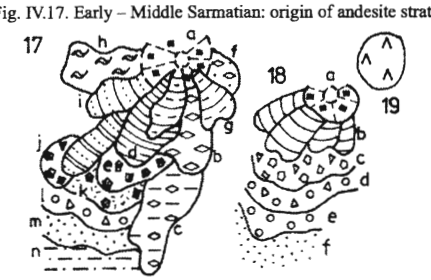
8 – a – central and proximal zone (lava flows, pyroclastic rocks, intrusion and extrusions), distal zone: b – epiclastic volcanic breccias, conglomerates, c – conglomerates, d – lahars, e – epiclastic volcanic sandstones and conglomerates, f – sandstones and siltstones,
9 – pyroclastic volcano: a – central and proximal zone (neck, pyroclastic rocks), distal zone: b – epiclastic volcanic breccias, conglomerates, c – epiclastic volcanic conglomerates, d – epiclastic volcanic sandstones.

Fig. IV.16. Late Badenian – Early Sarmatian: closing stage in the evolution of stratovolcanoes – origin of calderas and grabens.



10 – a – phreatopyroclastic cones with lava flows, b – extrusions of hypersthene amphibole andesites and breccias,
11 – lava complex within Kremnica Graben,
12 – a – Štiavnica Caldera filling, b – lava flow, c – epiclastic volcanic breccias, conglomerates,
13 – grabens related to Javorie stratovolcano: a – basalt-andesite lava flows and hyaloclastite breccias, b – extrusive dome of hypersthene amphibole andesites, c – hyaloclastite breccias and reworked hyaloclastites,
14 – Poľana Caldera: a – rhyodacite extrusions, b – tuffs,
15 – alluvial fan,
16 – coal seams and coal sediments: a – Handlová–Nováky deposits, b – extent of coal deposits, c – coal deposit at Badín village, d – coal deposit at Obyce village.

Fig. IV.17. Early – Middle Sarmatian: origin of andesite stratovolcanoes related to caldera and graben fault systems.



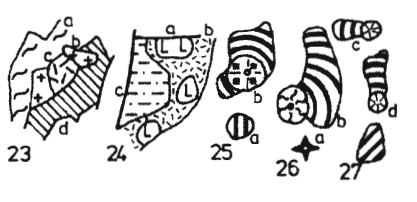
17 – Štiavnica Stratovolcano: a – pyroclastic cone, b – pumice tuff of the Ladzany Formation. Pyroxene andesite volcanic activity – Baďan Formation: c – pumice tuffs, d – lava flows, e – hyaloclastites. Amphibole-pyroxene andesite (± biotite) volcanic activity: f – pumice tuff of Biely Kameň Formation, g – lava flows of Sitno Complex. Explosive volcanism of biotite-amphibole-pyroxene andesite – Drastvica Formation: h – pumice tuffs and ignimbrites. Amphibole-pyroxene andesite volcanic activity – Priesil Formation: i – lava flows, j – hyaloclastite breccias, k – reworked hyaloclastites, l – epiclastic-volcanic breccias – conglomerates, m – epiclastic volcanic sandstones, n – epiclastic volcanic sandstones and siltstones,
18 – Javorie, Poľana, Vtáčnik stratovolcanoes, a – pyroclastic cone, b – pyroxene andesite (± amphibole) lava flows, c – coarse epiclastic volcanic breccias, d – epiclastic volcanic breccias – conglomerates, e – epiclastic volcanic conglomerates, f – epiclastic volcanic sandstones,
19 – amphibole-biotite-hypersthene extrusive andesite domes.

Fig. IV.18. Middle – Late Sarmatian: evolution of smaler volcanoes and early subsidence of the Žiar Depression.



20 – pyroxene leucocrate andesite lava flows – Inovec Formation,
21 – pyroxene andesite volcanic activity: a – Turová pyroclastic cone, b – Jabloňový vrch volcano,
22 – tuffaceous sediments in Žiar Depression.

Fig. IV.19. Late Sarmatian – Pannonian and Pliocene: rhyolite, basaltic andesite and alkali basalt volcanism, uplift of resurgent horst, subsidence of intravolcanic/marginal basins.



23 – Hodruša–Štiavnica Horst: a – pre-Tertiary basement, b – Hodruša–Štiavnica intrusive complex, granodiorite, diorite, c – quartz-diorite porphyry sills – Banisko Complex, d – lower volcanic structure of Badenian age,
24 – Žiarska kotlina Depression: a – rhyolite extrusive domes and lava flows, b – rhyolite tuffs,
25 – basaltic-andesites: a – lava flows, intrusions, Šibeničný vrch Complex, b – Vlčí vrch Volcano,
26 – alkali basalt volcanism: a – lava necks, Kalvária and Kysihýbel (at the Banská Štiavnica town), b – scoria cone and lava flows – Ostrá Lúka Complex (to SW of Zvolen town), c – scoria cone and lava flow at Devičie village, d – scoria cone and lava flows of Pútikov vŕšok volcano (to south of Nová Baňa town),
27 – lignite seams (at Pukanec town).

Fig. IV.20. Common explanations to paleogeographic schemes in Figs. IV.11–19.

the subvolcanic intrusive complex. In the same period the similar horst structures were developing in the areas of Pukanec and in the central sector of the Kremnica Graben.

The formation of the Hodruša–Štiavnica Horst was accompanied by the Žiar Depression subsidence. The fracturing at the contact of the two adjacent blocks – so-called Vyhne fault zone served as an important conduit for the ascent of the rhyolite magma to the surface. Products of rhyolite volcanism of the Jastrabá Formation accumulated along the SE border of the Žiar Depression include mainly extrusive domes, lava flows and laccolith appearing within the rhyolite tuff masses. The fine-grained material, however, migrated further and was deposited as epiclastic volcanic conglomerates, sandstones, tuffites, tuffaceous siltstones and claystones in the more central and western sectors of the basin.

The N–S striking Nová Baňa–Kľak volcanotectonic zone became equally an important milieu for the rise of rhyolite magma to the surface and emplacement of extrusive volcanic bodies.

The later development, during Pannonian, saw the emergence of basaltic andesite volcanism in the form of maars, lava flows, dykes and sills predominantly at the eastern side of the Žiar Depression (Šibeničný vrch Complex). Few dykes and necks occur also west of Kľak in the Vtáčnik Mts. The Vlčí vrch Stratovolcano of basaltic andesites grew up in the northeastern part of Kremnické vrchy Mts., at the eastern marginal fault of the Kremnica Graben.

The period from Late Sarmatian through Pontian saw a further asymmetric subsidence of the Žiar Depression. It was compensated by accumulation of tuffaceous claystones and siltstones with intercalations of conglomerates and coal-bearing clays deposited in a thickness up to 390 m (borehole T-1 near Turbín).

Between Pannonian and Pontian also the development of the Horná Nitra Depression came to conclusion. Its asymmetric configuration was further emphasized by strong subsidence of its NW part with simultaneous uplift of the Handlová crest resulting in a block tilting in the NW direction. This process affected quite negatively the Handlová coal deposit, which, due to this event was lifted into the elevation of 400 m a.s.l., while subsidence in the W part of the depression took coal measures to the level of zero to 100 m b.s.l. In this area the Pontian is represented by freshwater clays, sands and gravels (Lelovce Formation) reaching a thickness of 100–200 m in the central and western parts of the depression. The fault zone along the western edge of the Horná Nitra Depression remained active through Quaternary to the present (Bojnice fault) and is nowadays a site of the important thermal water source of Bojnice spa.

Asymmetric subsidence of the Turiec Depression, along the controlling NW–SE trending fault lines, continued further during Pannonian through Pliocene. The depression was filled by clays, silts, sands and gravel in thickness up to 500 m (borehole GHŠ-1).

In the NE sector of volcanic field the evolution of the Slatina Depression took place. Subsidence was accompanied by deposition of fluvio-limnic sediments composed of tuffaceous clays with sand and gravel intercalations, reaching thickness of 170 m (borehole KJ-40) at lower levels the sequence encloses kaolinite and montmorillonite strata locally with lignite intercalations (Kraus in Pulec, 1966). The spreading of the subsidence eastward into the Vígľaš Depression (controlled by N–S trending faults) was followed by a similar type of sedimentation in this area, leading to a deposition of sands, tuffaceous siltstones and tuffaceous sandstones with gravel intercalations. The sequence about 70 m thick (borehole KJ-1) yielded fossilized pollen associations of the Late Pannonian to Early Pliocene age (Planderová in Konečný et al., 1983).

Pannonian alkaline basalt volcanism

The Pannonian period was in the Central Slovakian Volcanic Field marked by the onset of alkali basalt volcanism. Its age, determined on the basis of K/Ar dating, is 8.0 ± 0.5 Ma. The sample was taken from the base of a lava flow SW of Krupina near the Devičie village. The alkali basalt appears here in the form of an erosion relic in a former paleovalley, at present some 25 m above the bottom of the Krupinica river.

Another lava complex (Ostrá Lúka) near Zvolen, dated to 6.59 ± 0.28 Ma, consists of several lava flows comming out of the eruptive centre (scoria cone) believed to have been located south of the flows. Northward flowing lava flows placed a barrier into the paleovalley causing its damming and subsequent filling with limnic and fluvial sediments, mainly lacustrine clays and sandy clays with gravel intercalations. The 15.5 m thick sequence intersected by the borehole KJ-36 yielded pollen associations indicating the age younger than Pontian and older than Early Pliocene (Planderová in Konečný et al., 1986). The fluvio-limnic sediments beneath the discussed lava flows intersected by the borehole GK-8 near Ostrá Lúka are some 62 m thick and are believed to be of the Pannonian age.

Two alkaline basalt necks near Banská Štiavnica (Kalvária hill and Kysihýbeľ) yielded radiometric ages of 7.29 ± 0.41 Ma for the former and 6.77 ± 0.48 Ma for the latter (Kantor and Wiegerová, 1981). The necks are considered to be lava conduits to the surface volcanic structures (tuff and/or scoria cones) subsequently removed by erosion.

During Pannonian, the area along the SW perimeter of the Štiavnica Stratovolcano was the site of fresh-water sedimentation in two adjacent depressions. In the Bátovce Depression the thickness of bituminous clays reached about 95 m while in its northern continuation, the Pukanec Depression, the sequence includes a 30 m thick bed of lignite emplaced between clay strata. Similar sedimentary environment is found in the adjacent Čajkov Depression where 90 m of clays and sandy clays was intersected by the borehole GK-6. In the area north of Hronské Kosihy Brestenská (1963b) found Ostracoda fossils in sandy clay strata and determined them as belonging to the Ostracoda B zone of Early Pannonian.

From the area of above described depressions the Pannonian fresh water sedimentation extended farther SW into the depression of Želiezovce where the microfauna assemblages show the Pannonian age (Zones A–E; Papp, 1951, in boreholes Pozba 3 and 4) and continuing to Beladice (Beladice Sequence) with an increased number of lignite intercalations corresponding to the F zone of Pannonian.

Interesting topomorphic imprints from this stratigraphic period are the first documented traces of Hron river paleoflow. Remnants of terrace sediments were found in the upper reaches of the Hron valley near Nová Baňa (Krahulčie 437 m a.s.l. and Klič 430 m a.s.l.). The sediments consist of coarsely faceted material of large rhyolite and ignimbrite blocks (0.5–4.0 m in diameter). According to their stratigraphic position the terraces are considered to be of the Pannonian age (Late Pannonian to Pontian).

Another location of gravels and sandy–gravel sediments north of Kozárovce described as Pliocene Volkovce Formation (Priechodská and Harčár, 1988) is nowadays believed to be the paleodelta of the Hron river (Baráth and Kováč, 1995). Deposits of Pontian–Pliocene age cover important areas in the SW sector of the region mainly as variegated clays with sandy intercalations attaining thicknesses up to 200 m (Nagy et al., 1998). These sediments locally contain fresh water limestones and travertine masses (Levice, Mýtne Ludany) often related to hot mineral springs (Dudince, Santovka).

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