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Lower Miocene Volcaniclastics in South Moravia and Lower Austria

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16 Text-Figures and 3 Tables

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Untermiozäne Vulkanoklastika in Südmähren und Niederösterreich

Zusammenfassung

Die vulkanoklastischen Ablagerungen aus untermiozänen Sedimenten der Karpatischen Vortiefe in Südmähren und der Molassezone in Niederösterreich entstammen einem sauren, rhyodazitischen Vulkanismus. Das vulkanische Material ist einer kalkalkalischen Provinz eines vulkanischen Bogens zuzuordnen. Die geschätzte Eruptionstemperatur liegt zwischen 720°C und 780 °C. Das Auswurfmaterial wurde vermutlich von dem neogenen, dazitischen und rhyolithischen Vulkanismus in der Karpato-Balkanischen Region, wahrscheinlich in Nordungarn und der Ostslowakei produziert.

Die untersuchten Vulkanoklastika entstanden durch distale Ascheregen. Umlagerungsprozesse hatten z.T. großen Einfluss auf Zusammensetzung, Struktur und Textur der Vulkanoklastika.

Aufgrund von Zirkonstudien können zwei Horizonte (Horizont I und II) unterschieden werden. Die Existenz von verschiedenen Horizonten wird durch mehrere Eruptionsphasen im gleichen Liefergebiet mit einer vertikal differenzierten, magmatischen Kammer erklärt.

Der tiefere Horizont (Horizont I) wird in das Obere Eggenburgium gestellt. Das durchschnittliche absolute Fission-Track-Alter beträgt 20.3±2.4 Ma. Der höhere Horizont (Horizont II) kann mit vulkanischen Einschaltungen in der Zellerndorf-Formation und Langau-Formation des Ottnangium korreliert werden.

Vulkanoklastika von Herrnbaumgarten im Wiener Becken, die bisher mit dem oben beschriebenen Auswurfmaterial in Verbindung gebracht wurden, zeigen unterschiedliche Charakteristika der vulkanischen Zirkone. Ein anderes Liefergebiet ist daher wahrscheinlich.

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Abstract

The Lower Miocene volcaniclastics from the Carpathian Foredeep in South Moravia and the Molasse Zone of Lower Austria have an acidic character (rhyodacites). The source of volcanic material was from a calc-alkaline volcanic suite of a volcanic arc. The estimated eruption temperature lies between 720 °C and 780 °C. Tephra was produced by the Neogene aerial type of dacite and rhyolite volcanic activity in the Carpatho-Pannonian region. The volcanic source is probably located in Northern Hungary and Eastern Slovakia. Studied volcaniclastics belong to the distal fallout tephra. Postdepositional processes partly highly influenced composition, texture and structure of the volcaniclastics. Based on zircon studies two horizons of volcaniclastics (horizon I and II) have been recognized. The existence of different horizons is explained by several eruptional phases in the same source area and a stratified magmatic chamber. The lower horizon (horizon I) is Upper Eggenburgian in age. Its average absolute age (Fission-track-dating) is 20.3±2.4 Ma. The upper horizon (horizon II) can be correlated with tephra layers of the Zellerndorf Formation and Langau Formation (Molasse Zone of Austria). These rocks are Ottnangian in age.

Volcaniclastics from the locality Herrnbaumgarten (Vienna Basin) which were formerly assumed to correlate with the above mentioned tephra layers show different characteristics of volcanic zircons. For that reason a different source is most probable.

1. Introduction

Tephra studies are often used to correlate marine and terrestrial environments. They can be an important tool for the definition of correlative surfaces, especially in basins without extensive outcrops. Occurrences of volcaniclastics are reported from many Neogene basins in Central Europe.

In South Moravia (Czech Republic) and Lower Austria volcaniclastics occur in Lower Miocene sediments along the Bohemian Massif. Volcaniclastics in South Moravia are connected with the Eggenburgian-Ottnangian boundary (ČTYROKÝ, 1982, 1991). Volcaniclastics reported from Lower Austria are mainly part of the Weitersfeld Formation, Langau Formation and Zellerndorf Formation (ROETZEL, 1991, 1993, 1994), all of Ottnangian age.

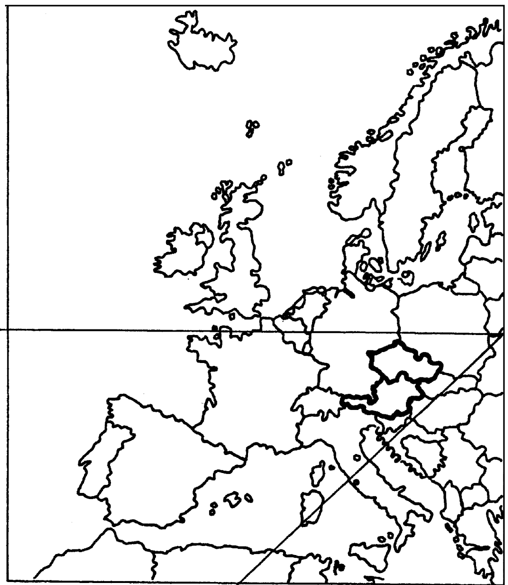
In the studied area only distal fallout tephra was recognized. Such deposits can be easily reworked by various processes. Redeposition usually affects the actual thickness and composition of the layer (HUANG et al., 1973; RUDDIMAN & GLOVER, 1972). The studied volcaniclastic rocks have very different petrographical and mineralogical compositions. Reliable tephrostratigraphic data from these rocks were missing so far, thus the opportunity for broader stratigraphic correlations has not been utilized.

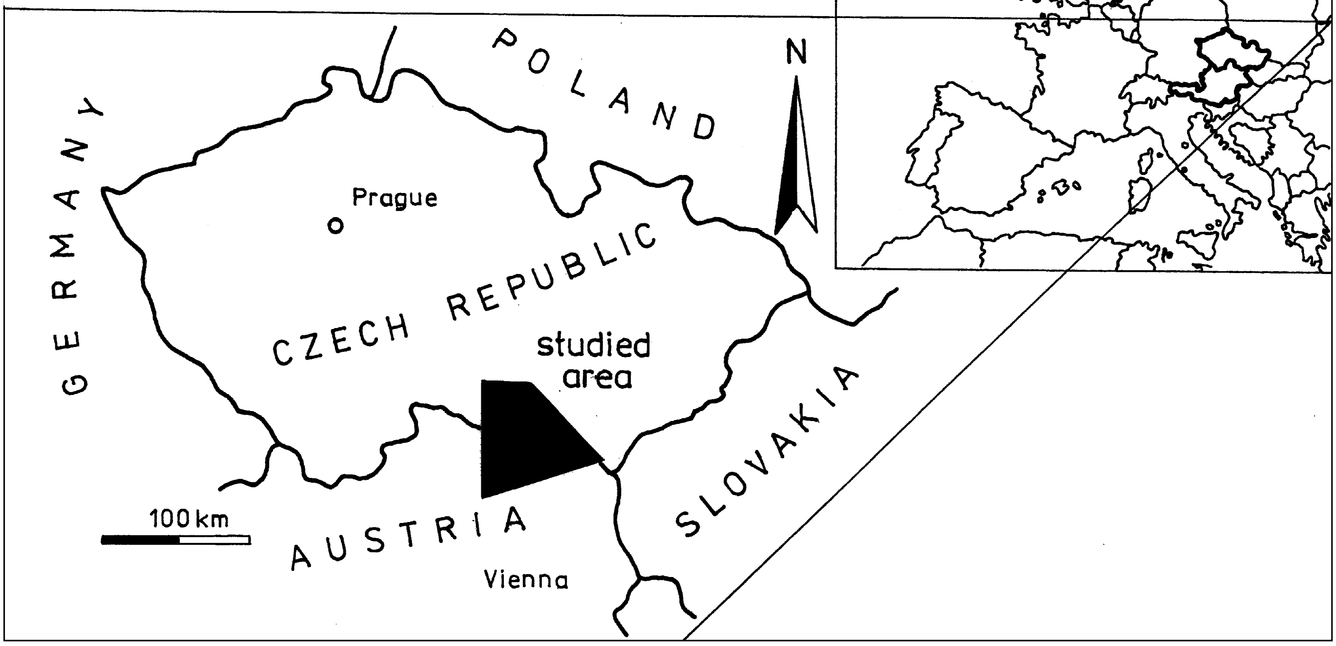
The classification of volcaniclastic rocks is a subject of discussion (ALLEN, 1991; CAS, 1991; ZUFFA, 1991). In the study area pyroclastics, tuffites or bentonites and smectitic clays have been found.

A reliable correlation of volcaniclastics requires a multiple criteria approach of tephra characterization (IZETT, 1981; WESTGATE & GORTON, 1980; WILCOX, 1965). This is especially important for distal tephra deposits. In our Neogene deposits the physico-chemical properties of glass shards and primary phenocrysts (zircon) together with bulk rock geochemistry and grain size were studied.

Various earlier data are available for the volcaniclastics of South Moravia and Lower Austria. Mainly geochemical data were produced by different laboratories and incompatible methods. For that reason their value for the tephrostratigraphy is limited.

Samples from South Moravia derive from outcrops at Znojmo-Pražská street, Chvalovice, Přímětice, Višňové, Plaveč, Horní Dunajovice, Ivančice-Réna and Žerotice and from cores from the drillings Únanov V 14, V 15, V 16, Znojmo-Hradiště H 32, H 36, Ivančice-Réna V 2, Strachotice V 1, V 2,





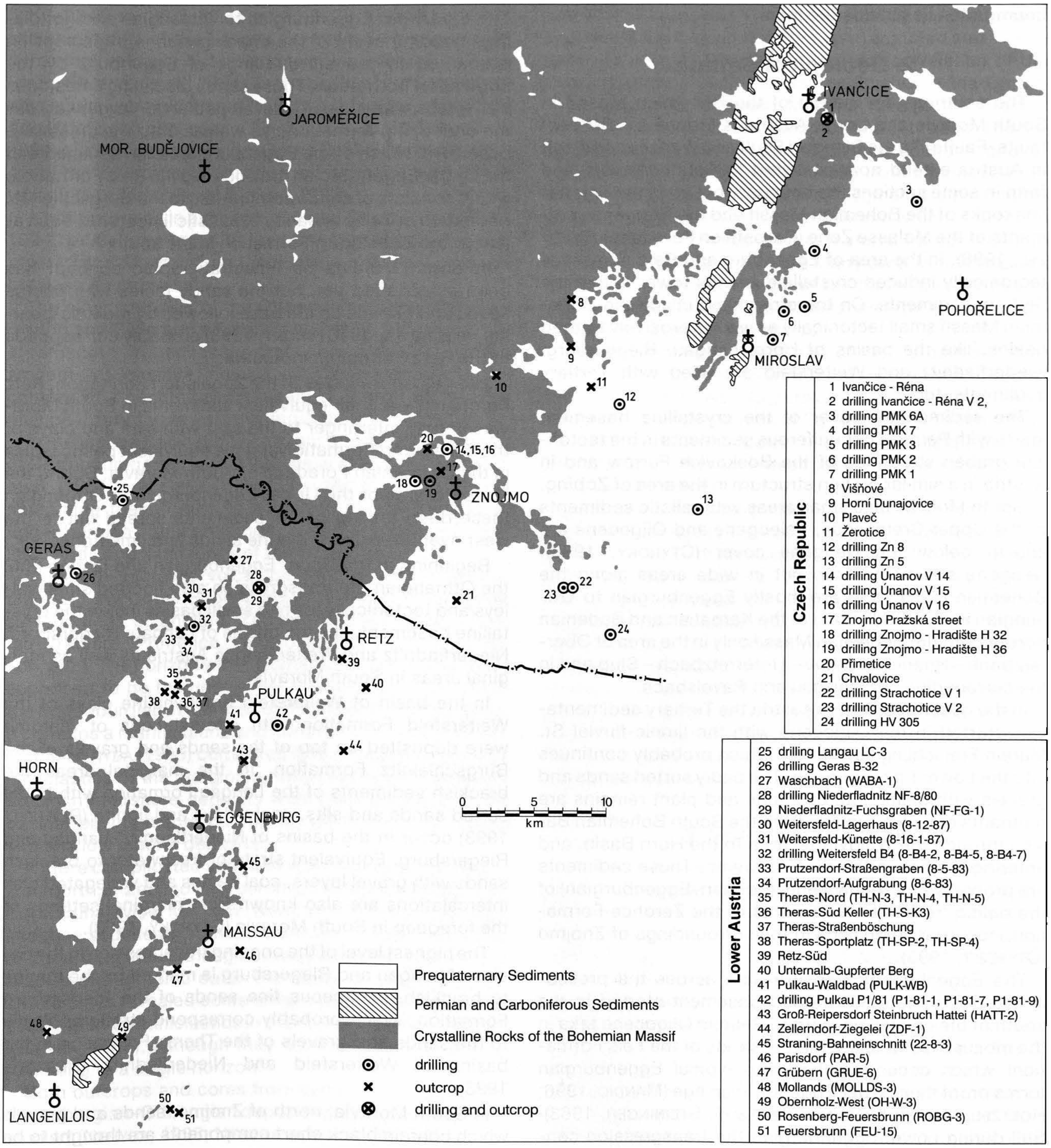
Text-Fig. 1.
Location of the study area in South Moravia and Lower Austria.

Ždánice 66, PMK 1, PMK 2, PMK 3, PMK 6A, PMK 7, Zn 5, Zn 8 and HV 305. Geochemical data (bulk rock analyses) were produced by the chemical laboratory of the Czech Geological Survey in Prague. Volcanic glasses were analysed by the chemical laboratory of the Institute of Mineral Resources in Kutná Hora. Fission-track-datings of zircon were elaborated at the laboratories of the Geological Institute of Dionýz Štúr Bratislava.

Lower Austrian samples of the Molasse Zone derive from the outcrops Groß-Reipersdorf/Steinbruch Hattei, Theras/Straßenböschung, Weitersfeld/Lagerhaus, Prutzendorf/Straßengraben, Retz-Süd, Unternalb/Gupfferter Berg and from the drilling Geras B-32. Samples from outcrops near Herrnbaumgarten (HBG-5, HBG 7) which were also studied, are from the Vienna Basin.

Zircons from these samples were studied at the Department of Geology, Masaryk University Brno.

Geochemical data of volcaniclastics from the area of Lower Austria, analysed by the chemical laboratory of the Geological Survey in Vienna, came from the following outcrops and drillings: Prutzendorf/Aufgrabung (8-6-83), Weitersfeld-Lagerhaus (8-12-87), Weitersfeld/Künette (8-16-1-87), drilling Weitersfeld B4 (8-B4-2, 8-B4-5, 8-B4-7), Grübern (GRUE-6), Feuersbrunn (FEU-15),



Text-Fig. 2.
Location of the studied samples in drillings and outcrops.
The locations of the drilling Ždánice 66 and the outcrop Herrnbaumgarten lie outside the map.

Groß-Reipersdorf/Steinbruch Hattei (HATT-2), Mollands (MOLLDS-3), Niederfladnitz/Fuchsgraben (NF-FG-1), Obernholz-West (OH-W-3), drilling Pulkau P1/81 (P1-81-1, P1-81-7, P1-81-9), Parisdorf (PAR-5), Pulkau/ Waldbad (PULK-WB), Rosenberg-Feuersbrunn (ROBG-3), Theras-Nord (TH-N-3, TH-N-4, TH-N-5), Theras-Süd/Keller (TH-S-K3), Theras/Sportplatz (TH-SP-2, TH-SP-4), Waschbach (WABA-1) and Zellerndorf/ Ziegelei (ZDF-1). In addition data from Austrian samples published in UNGER et al. (1990) were used.

The study area is presented in Text-Fig. 1, the localization of the studied samples is shown in Text-Fig. 2. The locations of the drilling Ždánice 66 and the outcrop Herrnbaumgarten lie outside the map.

2. Geological Setting

The southeastern margin of the Bohemian Massif in South Moravia and Lower Austria is formed by different faults. Faults like the Diendorf Fault and Waitzendorf Fault in Austria extend northeastward to South Moravia and form in some sections the boundary between the crystalline rocks of the Bohemian Massif and the Neogene sediments of the Molasse Zone (Carpathian Foredeep) (ROETZEL, 1996). In the area of Eggenburg and Retz numerous tectonically induced crystalline islands tower above the Tertiary sediments. On the other hand inside the Bohemian Massif small tectonically as well as erosively formed basins, like the basins of Horn, Langau, Riegersburg, Niederfladnitz and Weitersfeld are filled with Tertiary sediments, too.

The sedimentary cover of the crystalline basement starts with Permo-Carboniferous sediments in the tectonical graben structures of the Boskovice Furrow and in Austria in a similar graben structure in the area of Zöbing. In South Moravia also small areas with relictic sediments of the Upper Cretaceous, Paleogene and Oligocene are known below the Neogene cover (ČTYROKÝ, 1993). Neogene sediments crop out in wide areas along the Bohemian Massif and are mostly Eggenburgian to Ottnangian in age. Sediments of the Karpatian and Badenian border onto the Bohemian Massif only in the area of Oberretzbach – Hnánice – Šatov – Unterretzbach – Slup and in the surroundings of Maissau and Ravelsbach.

In the described area in Austria the Tertiary sedimentation started in the Oligocene with the limnic-fluvial St. Marein Freischling Formation, which probably continues into the Lower Eggenburgian. The badly sorted sands and gravels with pelitic intercalations and plant remains are remnants of a river running from the South Bohemian Basins through the Waldviertel area to the Horn Basin, and entering the sea in the area of Krems. These sediments are probably time-equivalents (Egerian–Eggenburgian) of the pelitic freshwater-sediments of the Žerotice Formation, occurring in drillings in the surroundings of Znojmo (ČTYROKÝ, 1993).

The Eggenburgian transgression across the presedimentarily formed and eroded basement started in the south of the crystalline margin. Relictic Oligocene taxa in the mollusc fauna of the marine sands of the Fels Formation, which occur together with typical Eggenburgian forms proof their Lower Eggenburgian age (MANDIC, 1996; ROETZEL, MANDIC & STEININGER, 1999; STEININGER, 1963). Still during Lower Eggenburgian the transgression continued into the Horn Basin leaving the brackish deposits of the Mold Formation in the estuary of the Horn river. The overlying sands of the Loibersdorf Formation, which contain a fully marine mollusc fauna, document the northward continuation of the transgression. During the Upper Eggenburgian the area of Eggenburg was flooded by the sea. Sedimentation starts with brackish-marine silts, sands and gravels of the Kühnring Member, enclosing a typical mollusc-fauna, indicative for reduced salinity conditions. The overlying and laterally interfingering sands of the fully marine Burgschleinitz Formation are shallow water-deposits of an eulitoral to sublitoral environment. The laterally interfingering silts and fine sands of the Gauderndorf Formation with typical burrowing molluscs can be interpreted as a muddy facies of a calm, relatively deeper, sublitoral environment.

In the Upper Eggenburgian to Ottnangian another distinct flooding event of the ongoing marine transgression is marked in the surroundings of Eggenburg by the Zogelsdorf Formation. These sandy bioclastic limestones transgress with a clearly developed unconformity across the underlying formations as well as onto the crystalline basement. North of the Eggenburg area the sediments of the Upper Eggenburgian are added to the Retz Formation, which consists of sands comparable to the Burgschleinitz Formation but also of sandy bioclastic limestones equivalent to the Zogelsdorf Formation in the south.

In South Moravia no lithostratigraphic concept has been established yet, but the sandy facies with coarse sands and gravels on the base followed by mollusc-bearing, marine sands (ČTYROKÝ, 1993) probably corresponds to the Retz Formation in Austria.

The nearshore facies of the Zogelsdorf Formation, Retz Formation and their equivalent sediments in South Moravia laterally interfinger to the east with silts and clays of the Zellerndorf Formation and the equivalent pelitic facies in the Carpathian Foredeep of South Moravia. During the transgression of the Upper Eggenburgian to Ottnangian these deep marine pelitic sediments spread out to the west over the shallow marine sands and limestones.

Beginning in the Upper Eggenburgian and lasting until the Ottnangian the transgression also flooded small valleys and tectonically formed small basins inside the crystalline basement, like the basins of Langau, Riegersburg, Niederfladnitz and Weitersfeld in Austria as well as marginal areas in South Moravia.

In the basin of Weitersfeld brachyhaline clays of the Weitersfeld Formation with intercalations of diatomit were deposited on top of the sands and gravels of the Burgschleinitz Formation. In the marginal areas the brackish sediments of the Langau Formation with badly sorted sands and silts, coaly clays and lignite (ROETZEL, 1993) occur in the basins of Niederfladnitz, Langau and Riegersburg. Equivalent strata of freshwater to brackish sands with gravel layers, coal seams and variegated clay intercalations are also known from marginal settings of the foredeep in South Moravia (ČTYROKÝ, 1993).

The highest level of the ongoing transgression in the basins of Langau and Riegersburg is marked by the marine to brackish, micaceous fine sands of the Riegersburg Formation, which probably correspond stratigraphically to the sands and gravels of the Theras Formation in the basins of Weitersfeld and Niederfladnitz (ROETZEL, 1993).

In South Moravia, north of Znojmo, sands and gravels which contain black chert components are thought to be Ottnangian in age too. West of the Miroslav fault-block the Upper Ottnangian is represented by the brackish, sandy to silty Rzehakia (Oncophora) beds (ČTYROKÝ, 1993).

Smectitic clays and tuffitic intercalations in the Zellerndorf Formation, Weitersfeld Formation and Langau Formation in Austria (ROETZEL, 1994; ROETZEL et al., 1994; ROETZEL & ŘEHÁKOVÁ, 1991) and in the equivalent sediments in South Moravia (ČIŽEK et al., 1990; ČTYROKÝ, 1993; KRYSTEK, 1959; NEHYBA, 1997) show the influence of volcanic activity during the Upper Eggenburgian and Ottnangian.

In Austria tuffitic layers in sediments of Upper Eggenburgian and Ottnangian age are very rare.

In the basin of Niederfladnitz tuffitic layers were found in two drillings (NF-8/80, NF-16/80) nearby Niederfladnitz. The drilling NF-8/80 exposed three thin tuffitic layers (22.0–22.07 m, 30.7–30.74 m, 31.9–32.1 m) in sandy to silty sediments of the Langau Formation. Hexagonal bipyramidal volcanic quartz crystals were found in these layers (ROETZEL et al., 1994). In the basin of Langau bentonitic layers were recovered from two drillings, where they occur between coal seams (Langau LC-3; ROETZEL et al., 1994) and inside sandy silts (Geras B-32). Bentonitic layers of the Zellerndorf Formation are exposed east of Unternalb (Gupferter Berg) (NOVÁK, 1991).

A tuffit exposed in a railway-cut near Straning (ROETZEL, 1994; 1999) is younger. At the base silty clays with ?*Silicoplacentina* ("*Saccamina*" sp.) indicate a shallow, probably brackish environment.

The clays and silts of the Ottnangian Weitersfeld Formation and Zellerndorf Formation contain a high content of smectite in their clay fractions. Besides various amounts of kaolinite, fireclay, illite and vermiculite the content of smectite lies between 41 % and 96 %. This may be attributed to volcanic input during deposition.

In the Vienna Basin tuffits crop out southwest and north of Herrnbaumgarten with a thickness of about 1 m. GRILL et al. (1961) and GRILL (1968) regarded these sediments containing these tuffits to belong to the Ottnangian to Eggenburgian "Schliermergel", which is overlain by pelits, sands and limestones of the Badenian.

In South Moravia volcaniclastics were recognized mainly in the Upper Eggenburgian deposits of the wider surroundings of Znojmo (Znojmo-Pražská street, Znojmo-Hradiště, Přímětice, Chvalovice, Strachotice, Únanov, etc.). The horizon with rhyolite tuffite and bentonite is supposed to be the uppermost lithostratigraphic unit of the Eggenburgian in this area of the Carpathian Foredeep. It contains a marine fauna and continental flora (ČTYROKÝ, 1993). NEHYBA (1995) correlated in the Eggenburgian volcaniclastics of the marginal environments with generally brackish nearshore deposits with volcaniclastics of the basinal environments containing generally fully marine and shallow marine deposits.

A more complicated situation was recognized in the region north of Znojmo (surroundings of Višňové, Žerotice, Horní Dunajovice, Miroslav, Ivančice – Réna, etc.). Lower Miocene sediments in these areas are usually described as Eggenburgian–Ottnangian in age due to the lack of more precise stratigraphic data. The study of bentonites and tuffitic clays revealed some differences to the Upper Eggenburgian volcaniclastics in the surroundings of Znojmo (NEHYBA, 1995), although they were originally supposed to belong to a single horizon.

Both outcrops and cores from various drill-holes from Eggenburgian–Ottnangian deposits north of Znojmo were studied (NEHYBA, 1995; NEHYBA et al., 1995). Sedimentological, tephrostratigraphical, paleontological and palynological studies allow to distinguish three main "segments" in this area. A "segment" indicates a three-dimensional body of sediments defined by its position within the depositional cycle. Their deposition results from changes in relative sea-level and sediment supply. The basal segment (segment I) comprises alluvial-fluvial deposits. The rarely occurring volcaniclastics of segment I are correlatable with the Upper Eggenburgian tuffits in the surroundings of Znojmo. The middle segment (segment II) is a product of deltaic deposition. Some volcaniclastic layers were recognized within this segment. The upper segment (segment III) is represented by shallow-marine deposits. The Oncophora beds are part of segment III. The regional distribution of the higher segments (segment II and III) is strongly influenced by the basement structures (important role of Vranovice Trough). Especially the deposits of segment II were recognized only in a restricted area northeast and east of Miroslav. A regional correlation of the Eggenburgian and Ottnangian sediments in the Carpathian Foredeep of South Moravia reveals the gradual north- to northwestward transgression of the sea. The described segments I–III reflect local progradational and retrogradational phases (relative sea level changes). Individual depositional patterns of segments were mainly governed by the rate of sedimentation, which is function of the amount and character of material transported into the basin. The position of the study area, which was not far from the western margin of the basin, also played an important role for the depositional architecture and preservation of various lithofacies.

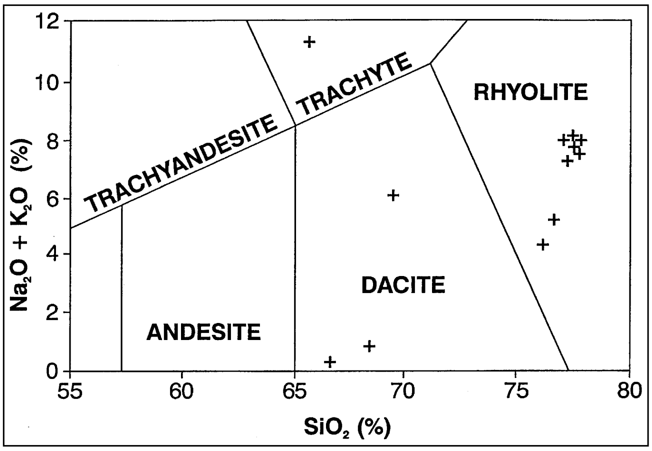
Volcaniclastics from that part of the Carpathian Foredeep which has been overthrusted by the flysch nappes are rarely described. HOLZKNECHT & ZAPLETALOVÁ (1974) mentioned volcaniclastics in Eggenburgian sediments of the well Dunajovice-1. Lower Miocene rhyodacite and dacite tuffs and tuffits were described from the well Ždánice 66 (ZÁDRAPA, 1988).

Sediments of the Karpatian (Laa Formation) and Lower Badenian (Grund Formation, Gaindorf Formation) occur in position close to the Bohemian Massif in the border area of Oberretzbach Hnánice – Šatov – Unterretzbach – Slup, and in the surroundings of Maissau, Ravelsbach and Mühlbach (CICHA & RUDOLSKÝ, 1995; ČTYROKÁ & ČTYROKÝ, 1991; ROETZEL, 1996). They typically consist of alternating calcareous silt, sand and gravel of a shallow marine environment. Especially in South Moravia the transgression of the Lower Badenian extended far to the west onto the Bohemian Massif leaving basal sands and gravels in the vicinity of Brno, Oslavany and Ivančice and more widespread calcareous silts and clays.

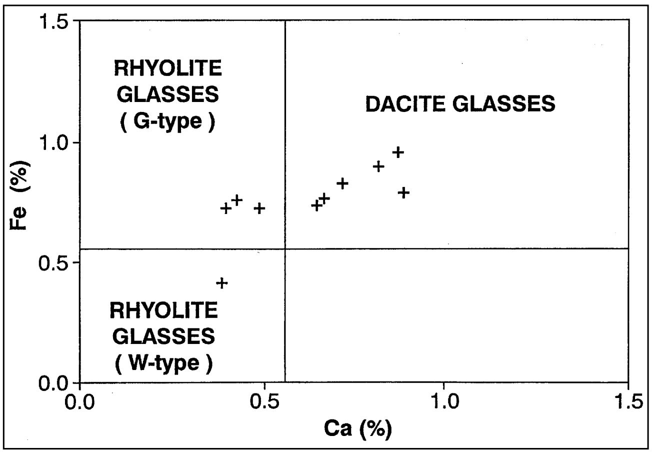
3. Volcanic Glasses

Tephra beds are commonly distinguished by the properties of their volcanic glass. However, proneness to alteration limits or prevents the use of volcanic glass studies for stratigraphically older tephra deposits (IZETT et al., 1970; PREECE et al., 1992; SMITH & WESTGATE, 1969). Results from volcanic glass studies are only available from the area of South Moravia (NEHYBA, 1997).

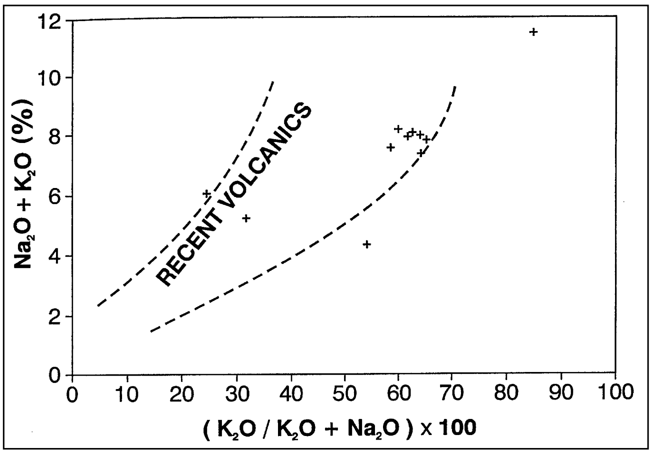
The studied samples contain acidic volcanic glasses, derived from calc-alkaline volcanic source (Text-Fig. 3) (NEHYBA, 1997). They can be classified as dacitic or rhyolitic glasses (Text-Fig. 4). The highest degree of alteration of volcanic glasses can be observed in samples from Višňové, Ivančice-Réna, Strachotice and Chvalovice. Intensive alteration of tephra at these localities was confirmed by the study of volcanic biotite (NEHYBA, 1995). The intensity of postdepositional changes is variable (Text-



Text-Fig. 3.
$Na_2O + K_2O$ vs. SiO_2 diagram for studied Upper Eggenburgian volcanic glasses.



Text-Fig. 4.
Classification diagram for studied Upper Eggenburgian volcanic glasses (diagram after IZETT, 1981).



Text-Fig. 5.
$Na_2O + K_2O$ vs. ($K_2O/K_2O + Na_2O$) x 100 diagram for studied Upper Eggenburgian volcanic glasses (diagram after HUGHES, 1973).

Fig. 5, according to HUGHES, 1973). Different postdepositional processes occurred in the various depositional environments, into which the primary volcanic material was deposited from the air column or redeposited from the adjacent terrestrial environment.

The morphology of glass shards can be used both for classification and correlation (CAS & WRIGHT, 1984; HEIKEN, 1972; IZETT, 1981). Two types of glasses were recognized in all studied samples of Lower Miocene age.

Type 1 shards are flat, cuspate or lunate-shaped fragments originating from destructed bubbles of magmatic melt or the remnants of bubble junctions (Y-shaped in cross section). Small pits and other imperfections were recognized on almost smooth flat shard surfaces. Glass shards of type 1 can presumably be ascribed to magmatic eruptions of low viscosity rhyolitic magma at temperatures exceeding 850°C (IZETT, 1981).

Type 2 shards are blocky pieces of pumice. They show a fibrous to cellular structure composed of minute elongated or circular cavities enclosed by glass walls. Their surface relief is very irregular. Pumice shards tend to develop from relatively high viscosity rhyolitic magmas at temperatures below 850 °C (IZETT, 1981). Different quantities of shard type 1 and 2 were found in studied samples. Prevalence of type 1 shards correlates with a higher content of volcanic quartz. Chemical analyses of both types of shards at the locality of Chvalovice show that type 1 shards have a higher content of SiO_2 (76.9 %) than type 2 shards (69.4 %). The presence of two types of shards can be explained by magmatic melt mixing or by the contact of the magma with external water (CAS & WRIGHT, 1984). For example both of these processes are assumed to have been active in case of the Miocene volcanism of Northern Hungary (PANTÓ & DOWNES, 1994).

Another explanation of the occurrence of two types of shards could be syndepositional mixing of tephra from different sources or their redeposition. Various types of shards have been affected in different ways by postdepositional alteration.

Because of the results of the study of volcanic minerals and bulk rock chemistry (see further) we assume a common source of studied volcaniclastics from a stratified magmatic chamber. The origin of some differences in shard characteristics can be explained mainly by postdepositional processes.

CAREY & SIGURDSSON (1978) described the changing of chemical composition of pyroclastics (rhyolite to dacite) during a single eruption phase. MARZA et al. (1991) presented a model of submarine rhyodacitic explosive volcanism (freatic and freatomagmatic eruptions) with a gradual evacuation of the stratified magmatic chamber for the Lower Badenian of the Simleu area (Romania).

4. Study of Pyrogenic Minerals

Pyrogenic minerals occur as intratelluric phenocrysts and microlites, which are deposited as complete or broken crystals (FISHER & SCHMINCKE, 1984). The study of these minerals, especially in ancient tephra beds, is highly recommended by their stability according to postdepositional changes and because they perfectly reflect the initial crystallization conditions (EWART, 1963; FISHER & SCHMINCKE, 1984). The most stable minerals of volcanic origin are often found in the "heavy mineral suite" (LOWE et al., 1990; MORTON, 1985). Moreover, the study of heavy minerals gives information about the magma composition and development during the preeruptional period. They can show up the relationship of isolated tephra layers, whose glass characteristics are different because of a different postdepositional history or the stratification of the magmatic chamber (CAREY & SIGURDSSON, 1978).

Various pyrogenic minerals have been studied by ALEXANDROWICZ (1957), AOKI (1980), CAS & WRIGHT (1984), EWART (1963), FISHER & SCHMINCKE (1984), FREUNDT &

SCHMINCKE (1992), GILBERT & ROGERS (1989), KSIAZEK et al. (1980), LERBEKMO et al. (1975), LETERRIER et al. (1982), MUNKSGAARD (1985), WESTGATE & GORTON (1980), WILCOX (1965). Grain-discrete methods are prefered to bulk separate techniques because they allow the detection of postdepositional changes, contamination effects, and the recognition of more than one indigenous phase during crystallization of a special mineral (SAKUYAMA, 1979; WESTGATE et al., 1977). The advantage of single grain-methods is the possibility to distinguish between volcanic and nonvolcanic (detritic) origin and more generations of the studied minerals.

The main results in tephrostratigraphy of the studied Neogene volcaniclastics have been obtained by zircon studies.

4.1. Zircon Studies

The high stability of zircon with regard to postdepositional changes as well as its relative abundance in tephra deposits, strongly suggest the study of this mineral in tephrostratigraphic consens (KOWALLIS et al., 1989; WINKLER et al., 1985; WINTER, 1981, 1984). Though the study of zircon typology (according to PUPIN, 1980) has already produced important results, this method is still under discussion (BENISEK & FINGER, 1993; VAVRA, 1990).

Various zircon characteristics were studied in the grain size fraction 0,063 mm–0,125 mm. Outer morphology, zonality, elder cores and inclusions were studied in the whole zircon spectra (volcanic and nonvolcanic zircons). Typology, measurement of elongation and Fission-track-dating were done only for the volcanic zircons.

4.1.1. Outer Morphology

Morphology (outer morphology) of a mineral grain denotes the general description of the minerals outer shape (HOPPE, 1962). By morphologic studies different sources or depositional processes easily can be detected. The euhedral shape of zircons often is considered to give evidence of their magmatic or volcanic origin (POLDERVAART, 1950), whereas rounded grains, in a simplified way, are explained to be detritic in origin. However, they also can be of magmatic origin (MADER, 1980; WINTER, 1981).

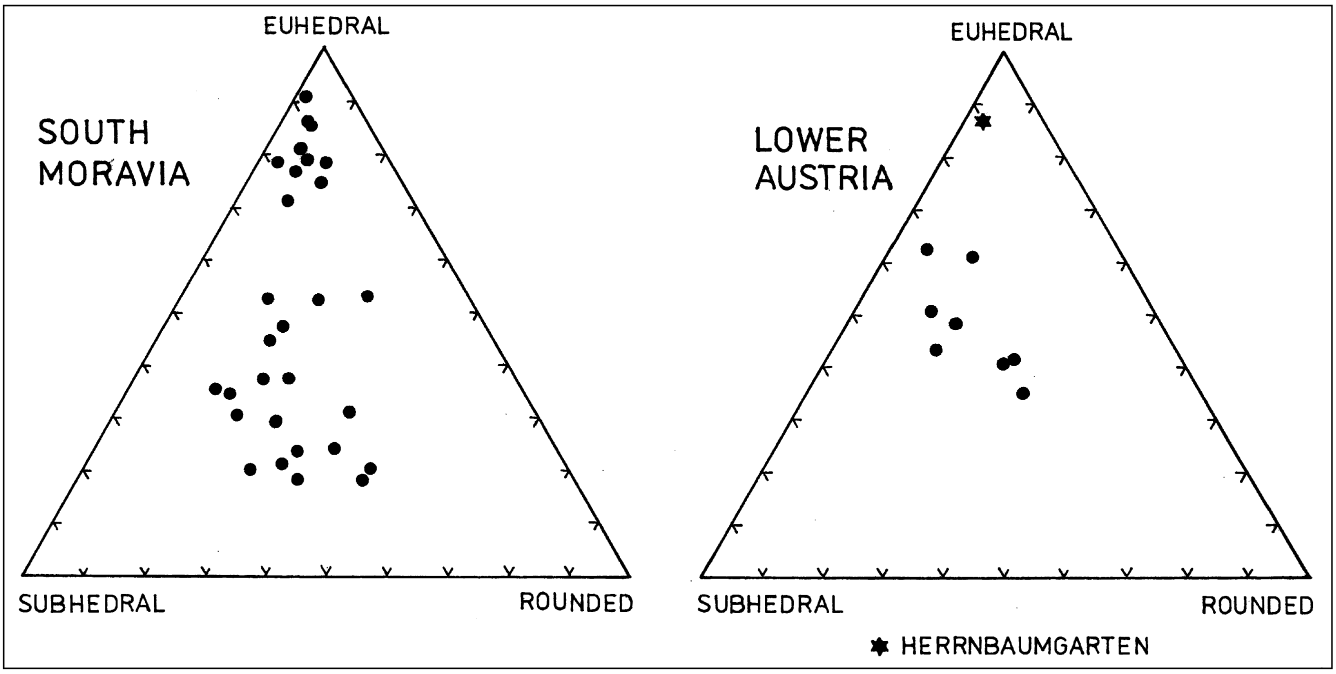
The results of the morphologic study (Text-Fig. 6) show that the amount of volcanic material in the studied deposits is variable. Samples from Lower Austria generally have a lower amount of euhedral zircons. Nonvolcanic zircons are generally more abundant in the surroundings of Miroslav (South Moravia). An explanation for this could be a higher rate of redeposition and mixing.

Volcanic zircons show great differences in surface texture even on a single crystal. A typical surface texture are glass rinds coating the crystals. Irregular and rough faces, broken crystals, sharp irregularities of crystal planes and edges, great amounts of buildups of smaller crystals, irregular crystal intergrowths in various stages of disintegration, various plane imperfections, minute pits, traces of corrosion and intergrowths with biotite or apatite often were recognized. The great majority of observed structures on mineral faces can be explained by rapid cooling during magma ascent and eruption or by transport processes in the tephra cloud. Irregular mineral intergrowths and other evidences of polyphase generation of zircons, together with the different crystallographic development of the opposite pyramides or prisms of a single crystal, support the idea of a stratified parental magmatic chamber. In some samples, euhedral crystals of several other mineral phases, like apatite, garnet and hornblende were observed.

4.1.2. Zircon Typology

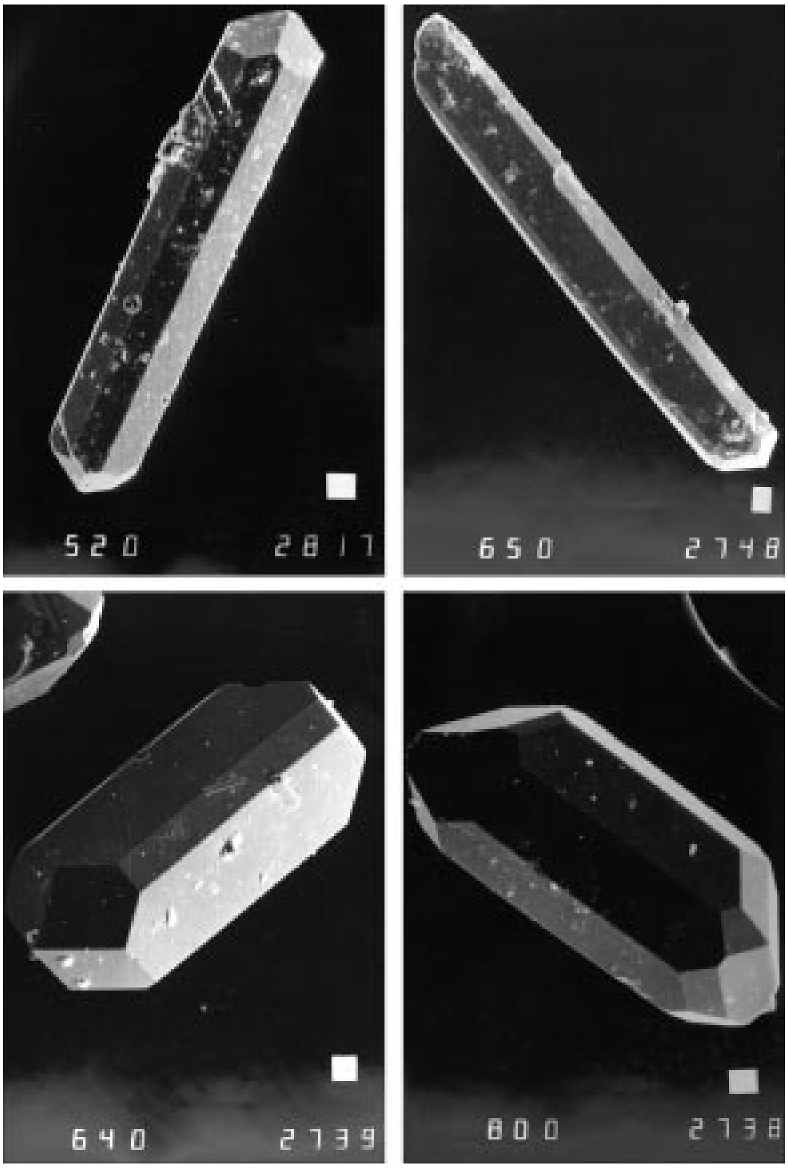
Zircon typology (PUPIN, 1980) describes the presence or absence of certain crystal planes, which is expressed in crystallographic symbols. This is an effective tool in tephra correlation.

Various magmatic chambers could produce a different zircon typology (BROTZEN, 1952; PUPIN, 1980, 1985; WINTER, 1981, 1984). The diagrams of PUPIN give evidence about the conditions during zircon crystallization (coordinates of the relative development of various prisms (I.T. value) and pyramids (I.A. value) are reflecting the crystal-



Text-Fig. 6.
Ternary diagrams of euhedral, subhedral and rounded zircons for studied volcaniclastics.

Text-Fig. 7.
Scanning electronic microscope images of studied volcanic zircons (white bar for scale is 10 μm).



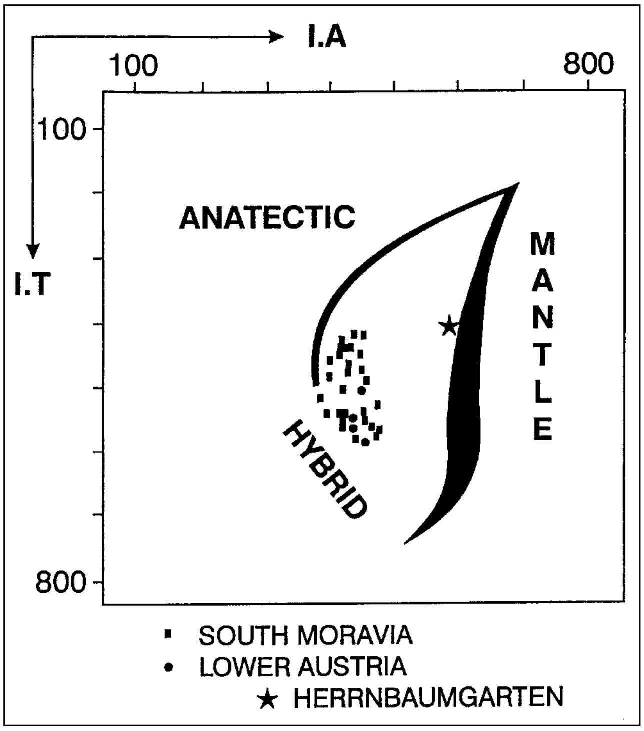
lisation condition – chemistry and temperature. Scanning electronic microscope images of some selected zircons are presented in Text-Fig. 7.

The position of the "typology mean point" in the diagram gives evidence about the origin of the magma (PUPIN, 1980, 1985). The parental magma of the studied Lower Miocene volcaniclastics has a hybrid character, very close to an anatectic source (Text-Fig. 8). This position is typical for all but one studied sample. This one is the sample from the locality Herrnbaumgarten. Typology of zircons from Herrnbaumgarten show that their parental magma was very close to mantle origin. The hybrid character of the Carpatho-Pannonian volcanism has been proved by PANTÓ & DOWNES (1994) or SEGHEDI et al. (1994). The mean points are located in the typical position for volcanic zircons, i.e. in the lower part of the evolution trend of the magma (PUPIN, 1980, 1985). Such a position is the result of a break in magma evolution due to a rapid decrease of temperature during eruption. A different development of opposite pyramides on single crystals or irregularities of prismatic planes were recognized in the studied samples.

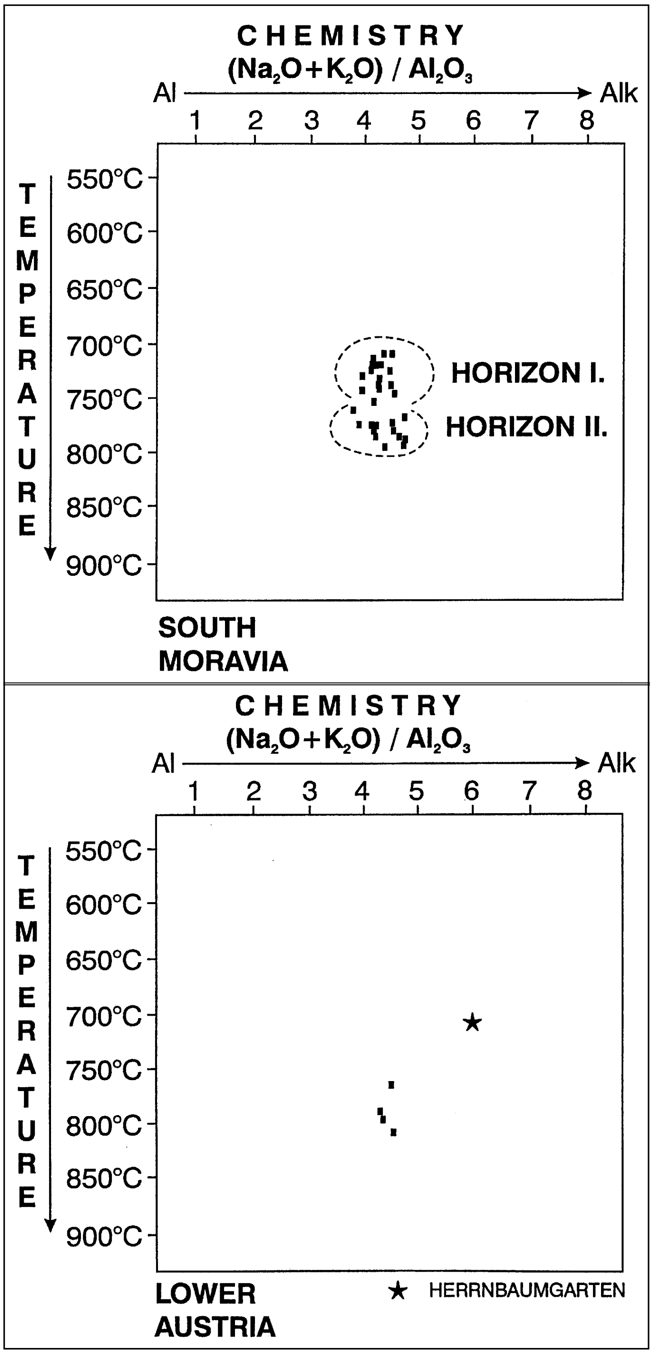
The estimated eruption temperature (I.T. value see KOWALLIS et al., 1989; PUPIN, 1985) for the studied tephra lies between 720 °C and 780 °C. Typical eruptional temperatures for rhyolites are between 700 °C and 900 °C and for dacites between 800 °C and 1000 °C (CAS & WRIGHT, 1984).

By detailed studies of volcanic zircons in South Moravian tephra beds together with the position in cores two different volcanoclastic horizons can be recognized (horizon I and II, Text-Fig. 9).

The samples of horizon I come from the wider surroundings of Znojmo (Hradiště, Strachotice, Chvalovice, Únanov, Znojmo-Pražská street), from the drilling PMK 1 (87.4 m) and from the well Ždánice 66 (745–750 m). Typical for horizon I is a generally lower I.T. value (below 740 °C). Typology proves the correlation of tephra in "basinal" and "marginal" Eggenburgian deposits in the surroundings of Znojmo (ČTYROKÝ, 1982). Several thin tephra layers (usually about 1 cm thick) without significant differences in zircon typology were recognized in this area. Tephra layers are separated by thin intercalations of clastic sediment. The maximum thickness of the sequence with tephra layers is 2 m. Such layers represent both the period of tephra fallout and the period of tephra redeposition from the adjacent terrestrial environment. Especially thick tephra layers (Znojmo-Pražská street) can be explained by processes of redeposition. Nonvolcanic clastic deposits



Text-Fig. 8.
Plot of average Pupin indices for studied volcanic zircons (diagram after PUPIN, 1980).



Text-Fig. 9.
Mean point distributions in the main domains of the typologic diagram for studied volcanic zircons.
Diagram after PUPIN (1980).

show sedimentary structures reflecting high sedimentation rates and redeposition in a shoreline environment. The results of zircon typology and volcanic glass studies from the Ždánice 66 core give evidence for an Upper Eggenburgian age instead of the Karpatian age, postulated until now (ZÁDRAPA, 1988). Karpatian volcaniclastics within the deposits of the Carpathian Foredeep were not clearly recognized until yet (cf. NEHYBA & PETROVÁ, 1995).

Samples of horizon II derive from an area further to the north (outcrops in Plaveč, Žerotice, Horní Dunajovice, Višňové, Ivančice-Réna and from PMK drill-holes). Typically higher I.T. values were recognized by zircon typology (more than 750 °C) in this horizon. The I.A. values are very similar in both horizons. Stratigraphically important is the position of horizon II higher up in the sedimentary succession than horizon I, which can best be seen in the drilling PMK 1. Horizon I occurs at a depth of 87.4 m in alluvial-fluvial deposits whereas several thin tephra layers, representing horizon II, were found at depths between 73 m to 78 m in deltaic deposits. Together with sedimentological studies (NEHYBA, 1995) this result shows that horizon II represents a younger period of tephra deposition than horizon I.

Statistically expressive results from the study of zircon typology are available for five Lower Austrian localities (Text-Fig. 9). Typologic characteristics from the localities Groß-Reipersdorf – Steinbruch Hattei, Retz-Süd, Unternalb-Gupferter Berg (Zellerndorf Formation) and the drilling Geras B-32 (Langau Formation) are identical with the results of horizon II in South Moravia. This correlation, together with sedimentologic studies allows to draw some conclusions about the Lower Miocene depositional processes in the study area. The volcaniclastics of horizon I represent the last lithostratigraphic unit (Rhyolite Tuffite and Bentonite) of the Eggenburgian period, containing a marine fauna and continental flora, in the surroundings of Znojmo (more details in ČTYROKÝ, 1991, 1993). Time equivalent sediments are alluvial-fluvial deposits in the surroundings of Miroslav (deposits of segment I, NEHYBA, 1995). The Zellerndorf Formation and Langau Formation and the mainly deltaic deposits in the surroundings of Miroslav (deposits of segment II, NEHYBA, 1995), which both contain volcaniclastics of horizon II, represent a younger period of deposition. Deposits of the Zellerndorf Formation and Langau Formation are Ottnangian in age (STEININGER & ROETZEL, 1991). Tephrostratigraphy proved that the deposits of segment II in the surroundings of Miroslav are correlative. Tephra of horizon II has Ottnangian age and so at least parts of deposits of segment II have the same age. Deposits of segment III (shallow marine deposits) were recognized in superposition of segment II. Segment III contains the Rzehakia beds with brackish molluscs and the bivalve *Rzehakia socialis* as index fossil. The Rzehakia beds are Ottnangian in age (ČTYROKÝ, 1993).

Differences in Lower Miocene zircon typology can be explained by two models:

1) zircons with different typology originate from various magmatic chambers,
2) zircons originate from a common source, which underwent some changes.

Two eruptional phases of one parental magma chamber are more probable because of the I.A. values of zircon typology, the results of the study of volcanic glass and pyrogenic minerals, and the position of the tephra layers in drill-holes. In a stratified magmatic chamber evacuated during several eruptive phases it is quite common that a slightly cooler part is erupted at first followed by a slightly hotter melt (BARDINTZEFF, 1992; FISHER & SCHMINCKE, 1984; LIRER et al., 1973).

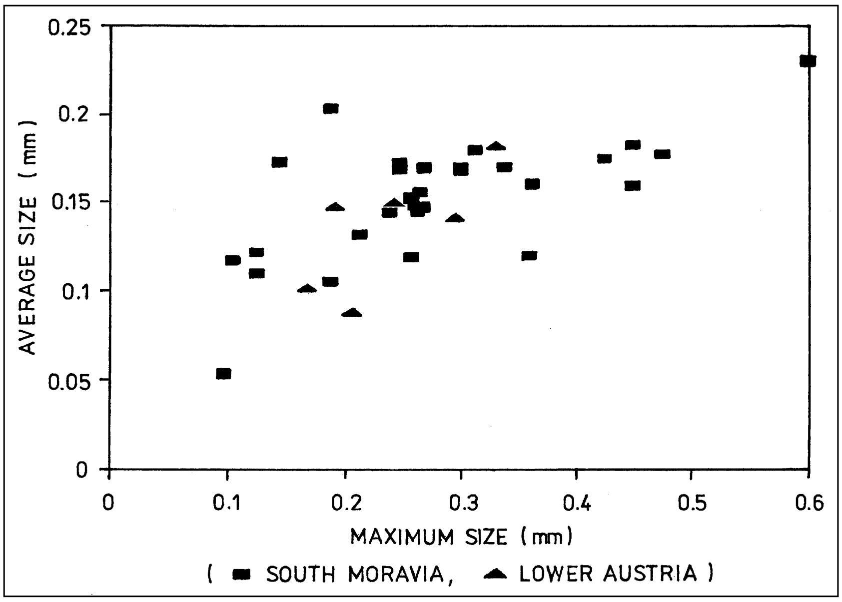
The samples from the locality Herrnbaumgarten (Vienna Basin) have different typologic characteristics. For these volcaniclastics a different source of volcanic material has to be assumed. The results of the typologic study of this locality resemble the results obtained from Lower Badenian volcaniclastics of the Carpathian Foredeep (NEHYBA, 1995).

4.1.3. Zircon Elongation

The study of elongation (the relation of length to width of the crystals) can help to trace the source of deposits (POLDERVAART, 1950; WINTER, 1981, 1984; ZIMMERLE,

Table 1.
Results of elongation studies of zircons.
n: number of studied grains.

Samples	n	Absolute value of elongation	Average elongation	Elongation over 3	Elongation over 4
Horizon I (Moravia)	2001	1.0 - 10	2.4 - 2.9	13 % - 28.4 %	2.9 % - 12.3 %
Horizon II (Moravia)	952	1.1 - 12	2.0 - 3.1	6 % - 30.3 %	0 % - 18 %
Lower Austria	272	1.1 - 8.3	1.9 - 2.9	0 % - 30.6 %	0 % - 16.5 %



Text-Fig. 10.
Maximum size vs. average size diagram for zircons of studied samples.

1979). DOPITA & KRÁLÍK (1977) showed that the size of zircon crystals directly depend on the thickness of the tephra layer. This means that volcanic zircons from the same fallout tephra layer can have different values of elongation at various localities. The results of more than 3000 measurements of unbroken euhedral crystals are presented in this article.

Elongation of the studied volcanic zircons is very variable. ZIMMERLE (1979) postulates that the value of elongation directly depends on the size of the crystal. A positive correlation between maximum size and average size was recognized (Text-Fig. 10) both for samples from the area of South Moravia and Lower Austria. The lowest average size of zircons has been found for the samples from Herrnbaumgarten.

Some differences in the values of elongation (Tab. 1) were observed at various localities. The lowest value of average elongation has been recognized in a sample from Herrnbaumgarten. The values of average elongation and maximum elongation are proportional.

Zircons with an elongation of more than 3 or 4 ("highly elongated zircons") are supposed to be typical for volcanic rocks. In the studied samples (Tab. 1), mainly long prismatic crystals with reduced pyramides show higher values of elongation. Positive correlation between the presence of zircons with higher values of elongation and average value of elongation has been recognized. The results of ZIMMERLE (1979) are similar. The lowest portion of highly elongated zircons was recognized in the samples from Herrnbaumgarten. The abundancy of such highly elongated zircons usually depends on the role of redeposition. However, recognized differences could also be connected with the magma development. The upward movement of magma into shallower depths, changes in the extent of the magmatic chamber and changes in composition could explain these differences (LYAKHOVICH, 1963; YUSHKIN et al., 1966). In studied samples, some fragments of prisms which had originated in crystals with higher value of elongation, were recognized.

4.1.4. Zonality, Elder Cores and Inclusions in Zircons

Zonality, the presence of elder cores and inclusions are the most important features of the inner fabric. Zonality is very common in volcanic zircons and can be explained by the rapid drop of temperature during crystallization (HOPPE, 1962). DOPITA & KRÁLÍK (1977) observed in the Carboniferous coal tonstein, that between 18 % and 90 % of the zircons show zonality. However, ZIMMERLE (1979) only rarely found zoned zircons in rhyolites. DOPITA & KRÁLÍK (1977) observed in coal tonstein between 13 % and 21 % of zircons with elder cores. A higher content of inclusions is typical for zircons from volcanic rocks (DOPITA & KRÁLÍK, 1977; ZIMMERLE, 1979).

Results from the study of the inner fabric of our samples are presented in Table 2. The proportion of zoned zircons and zircons with elder cores is generally low. This indicates stable conditions of crystallization. Differences between samples can largely be explained by different post-depositional processes, e.g. redeposition and mixing with detritic zircons from other sources.

The studied volcaniclastics show a high proportion of zircons with inclusions, which are mainly elongated and oval. Tiny needles, columnar and cylindrical shapes of in-

Samples	n	Zoned zircons	Zircons with elder cores	Zircons with inclusions
Horizon I (Moravia)	3260	0.2 % - 14.9 %	0.2 % - 5.0 %	96.1 % - 100 %
Horizon II (Moravia)	1885	2.8 % - 22.1 %	0.8 % - 8.6 %	96.1 % - 100 %
Lower Austria	533	1.6 % - 23.7 %	1.2 % - 13.9 %	94.1 % - 100 %

Table 2.
Abundance of zoned zircons, zircons with elder cores and inclusions in studied samples.

clusions often were recognized. Inclusions within crystals usually have a light colour although dark inclusions were observed too. Inclusions of crystals are rare. Typically various kinds of inclusions can be observed in one grain.

4.1.5. Fission-Track-Dating

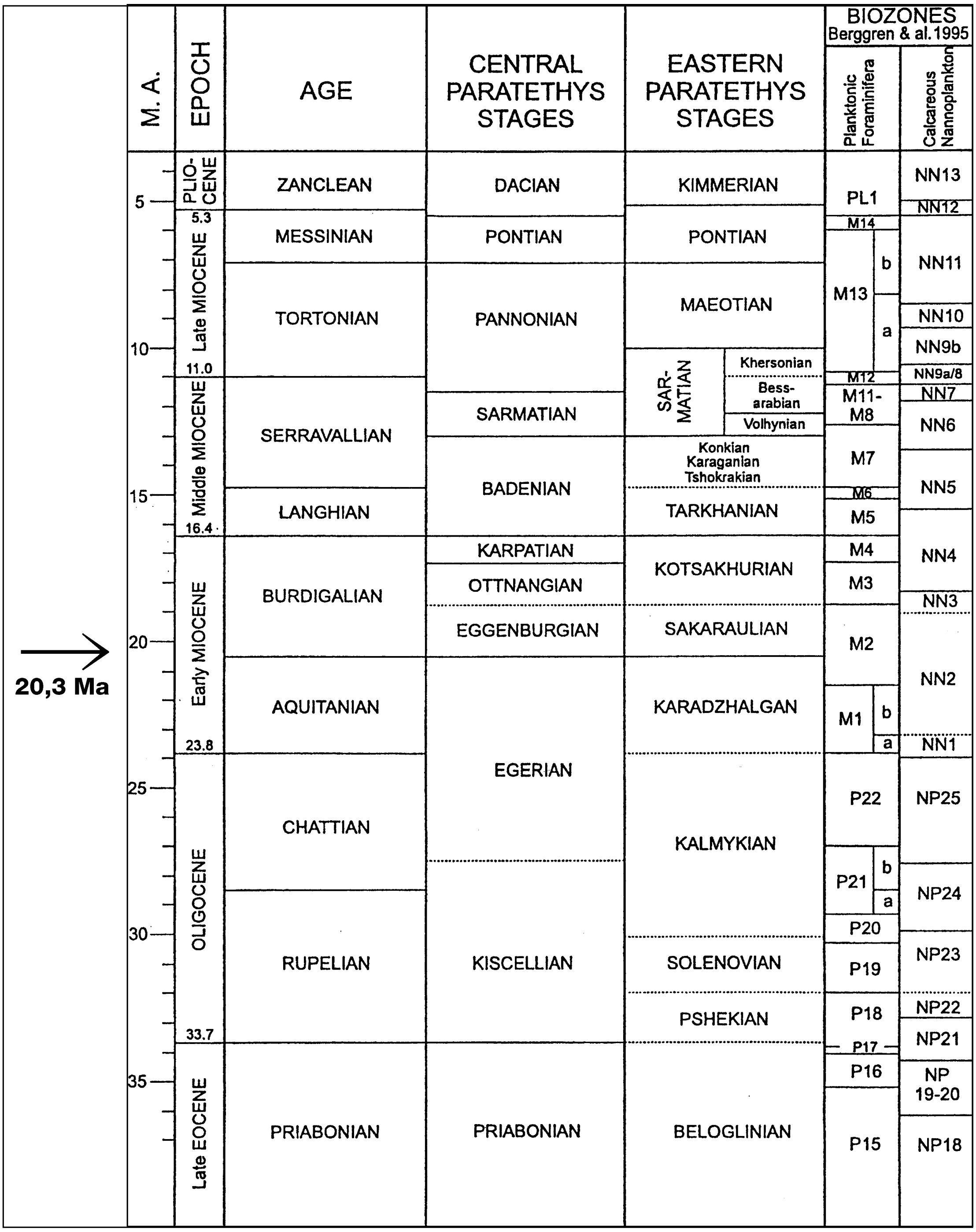
Volcanic layers provide an excellent opportunity for radiometric dating. Volcanic zircons from the localities Strachotice, Chvalovice, Únanov and Znojmo-Hradiště (all samples from horizon I) were dated, employing the Fission-Track method (more details in NEHYBA, 1995).

The average radiometric age of these samples is 20.3±2.4 Ma. The stratigraphic position of the dated volcaniclastics in the Neogene stratigraphic correlation table (RÖGL, 1998) is presented in Text-Fig. 11.

Results of Fission-track-dating also show the uranium content in studied minerals. The studied Lower Miocene volcanic zircons have an average concentration of Uranium of 947 ppm (max. value 1935 ppm, min. value 341.5 ppm). Results from the typologic study can be related to differences of the uranium content in the source magma (BENISEK & FINGER, 1993). According to BARDINTZEFF (1992) in a magmatic chamber with differentiated granitic melt cooler zones relatively enriched by U, Th, Y (REE) can exist, which could lead to the formation of zircons with [110]-prisms (BENISEK & FINGER , 1993). This supports the assumption of a common source of tephra horizons I and II.

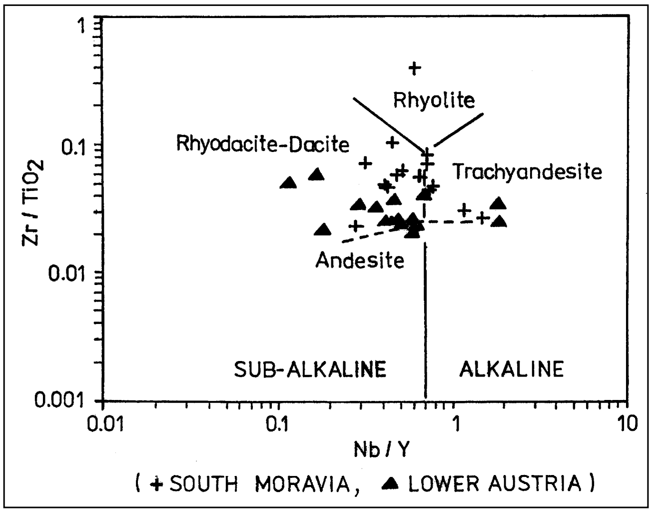
5. Bulk Rocks Studies

The most useful parameters for tephra characterisation are those that remain constant over the whole fall out zone. Bulk rock analyses do not fulfill this requirement in many cases, because the tephra has been subjected to



Text-Fig. 11.
Stratigraphic position of studied volcaniclastics in the Neogene stratigraphic correlation table (after RÖGL, 1998).

various alteration processes. The important role of the postdepositional history could be proved for the studied Neogene volcaniclastics. Bulk rock tephra analysis suffers not only from postdepositonal changes, but also from various differentiation processes in the magmatic chamber, processes in the eruptional column and processes of eolian fractionation (BARDINTZEFF, 1992; CAREY & SIGURDSSON, 1980; EWART, 1979; FISHER & SCHMINCKE, 1984; GILBERT et al., 1991; HINKLEY et al., 1987; KELLER et al., 1978; LERBEKMO & CAMPBELL, 1969; LERBEKMO et. al., 1975; LIPMAN et al., 1981; LIRER et al., 1973; SARNA-WOJCICKI et al., 1981a, 1981b; WALKER, 1971). For this reason, results of major element study are not very suitable for tephrostratigraphic studies. The study of immobile minority and trace elements or isotopic studies usually give better results. In this article only basic results of geochemical studies are presented by selected diagrams. An important part of bulk rock studies was the investigation of grain size distributions.

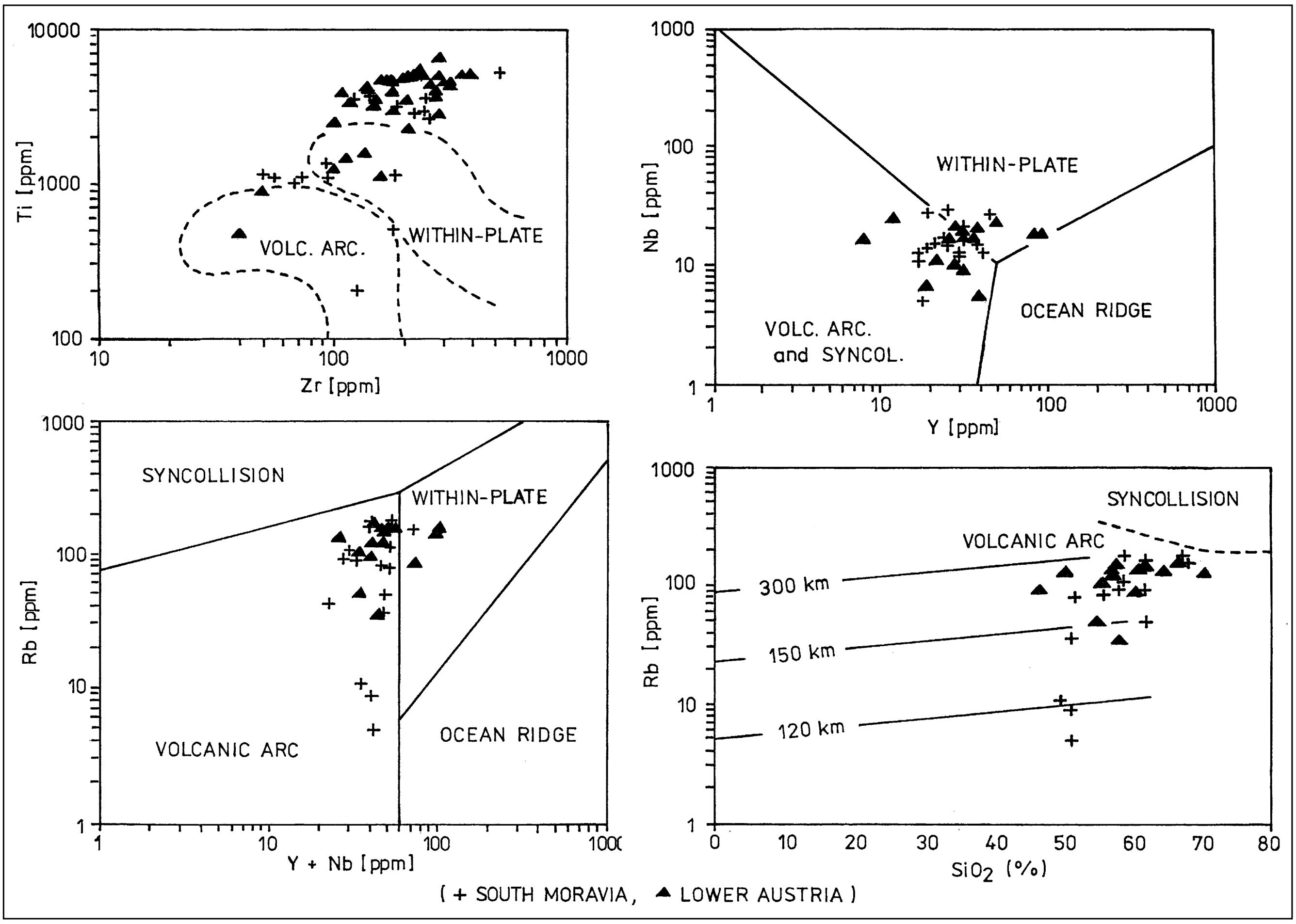


Text-Fig. 12.
Nb/Y vs. Zr/TiO_2 diagram (diagram after WINCHESTER & FLOYD, 1977).

5.1. Geochemistry of Volcaniclastics

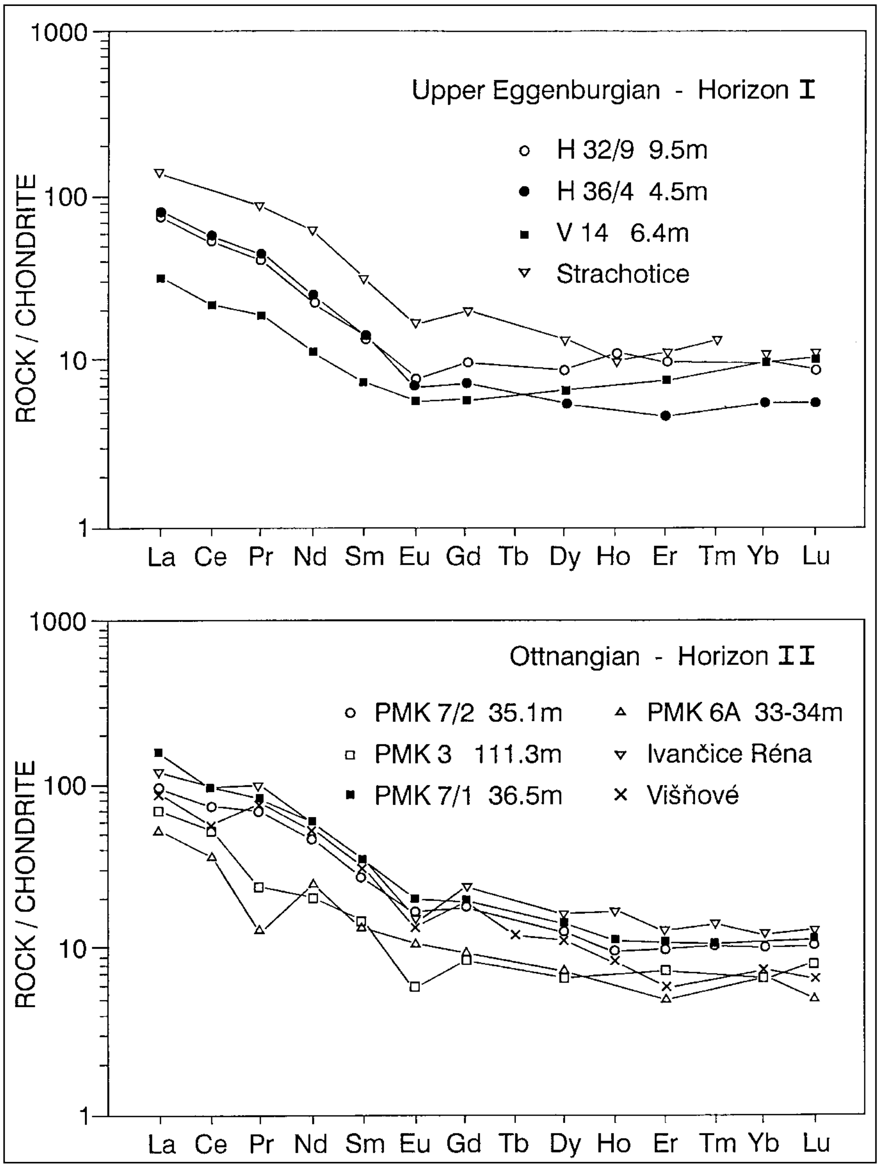
Results of the study of major und minor element composition of the Neogene volcaniclastics are quite variable. This is due to various petrographic compositions of studied samples (tuffites, bentonites and smectitic clays). Published (NEHYBA, 1995; UNGER et al., 1990) and unpublished results of chemical analyses were produced by various laboratories and techniques. They were often carried out without a study of the mineralogical composition of the samples. Thus only a rather general information to tephrostratigraphy can be expected by these studies.

Geochemical data for volcaniclastics of the Carpathian Foredeep (Czech Republic) have been produced for all localities mentioned above (introduction). In Lower Austria the following outcrops and drillings were incorporated into geochemical studies: Prutzendorf/Aufgrabung (8-6-83), Weitersfeld/Lagerhaus (8-12-87), Weitersfeld/Künette (8-16-1-87), drilling Weitersfeld B4 (8-B4-2,



Text-Fig. 13.
Trace element discrimination diagrams for volcaniclastics of the Carpathian Foredeep (tectonic setting-composition boundaries after HOLLOCHER, 1993; FLOYD et al., 1992; RICHARDSON & NINKOVICH, 1976).

Text-Fig. 14.
Chondrite-normalized REE patterns for studied Neogene volcaniclastics.



8-B4-5, 8-B4-7), Grübern (GRUE-6), Feuersbrunn (FEU-15), Groß Reipersdorf/Steinbruch Hattei (HATT-2), Mollands (MOLLDS-3), Niederfladnitz/Fuchsgraben (NF-FG-1), Obernholz-West (OH-W-3), drilling Pulkau P1/81 (P1-81-1, P1-81-7, P1-81-9), Parisdorf (PAR-5), Pulkau/Waldbad (PULK-WB), Rosenberg/Feuersbrunn (ROBG-3), Theras-Nord (TH-N-3, TH-N-4, TH-N-5), Theras-Süd/Keller (TH-S-K3), Theras/Sportplatz (TH-SP-2, TH-SP-4), Waschbach (WA-BA-1) and Zellerndorf/Ziegelei (ZDF-1) (Text-Fig. 2). In addition analyses from Austrian samples published in Unger et al. (1990) were used for further interpretation (drilling Niederfladnitz NF-8/80-11, Prutzendorf PRU/01, PRU/02, Theras TH-N/4, TH-N/5, TH-SP/02, TH-SP/04 and Herrnbaumgarten Rö15-84).

Position of the sample points in the diagram Nb/Y vs. Zr/TiO_2 (Text-Fig. 12) (Winchester & Floyd, 1977), confirms that the studied samples can be classified as rhyodacites, deriving from an subalkaline volcanism. The varying position of some samples is most probably connected with the admixture of nonvolcanic material.

The diagrams Ti vs. Zr, Nb vs. Y (Hollocher, 1993), Y + Nb vs. Rb (Floyd et al., 1992) and SiO_2 vs. Rb (Richardson & Ninkovich, 1976) support our claim, that the studied rocks contain volcanic material of a volcanic arc (Text-Fig. 13). Interpretation of the melting depth from the diagrams mentioned above is not easy. However, a depth of about 200 km generally can be assumed.

The content and distribution of Rare Earth elements (REE), which were normalized to chondrites, is presented in Text-Fig. 14. Samples generally show a low content of REE (mainly HREE) and only a slightly developed negative Eu-anomaly. The REE profile is generally very flat, which can be related to a poorly differentiated magmatic source. The profile shows significant absolute differences in contents of REE elements for various Lower Miocene samples.

These results can be explained by slightly different stratigraphic positions (several tephra layers), varying localities (orientation towards the volcanic source and eolian fractionation), and a different postdepositional history.

5.2. Grain Size Studies of Volcaniclastics

Grain size studies of fallout tephra are employed for estimation of the eruptional processes, for determination of the direction of the source and in order to get information about transportational and depositional processes (Fisher & Schmincke, 1984). Methods of grain size analysis must be carefully chosen to exclude the presence of non-volcanic grains. In this article only selected samples from cores in South Moravia were used for the study (Nehyba, 1995). Tephra was separated under the microscope and laser equipment was used for grain size analyses.

Only fine grained sediments were recognized in the 13 samples studied. They can be classified mainly as silts (clayey silt, clayey-sandy silt, sandy silt, silt). Only one sample of very fine sand was recognized. Frequency curves and grain size histograms mainly show a normal (Gaussian) distribution. Sometimes a minor undulation of the fequency curve, which is typical for mixed sediments, occurs. These features are typical for distal fallout tephra.

The numerical parameters of grain size analyses are presented in Table 3 (for details of selected parameters see Fisher & Schmincke, 1984). The value of the median (in μm) typically decreases with the distance from the source (Fisher & Schmincke, 1984; Walker, 1971). Tephra fallout sediments usually show good sorting. The interrelation between better sorting and growing distance from the source is not so simple as it seems, due to eolian fractionation (Fisher & Schmincke, 1984). Walker (1971) and Fisher & Schmincke (1984) claim a value of δ_ϕ usually

Table 3.
Grain size parameters of studied volcaniclastics.

sample	depth (m)	Md (μm)	Md ϕ	perc.99 (μm)	perc.90 (μm)	So	δ_ϕ	Sk
Únanov V14	6.1	22.5	5.45	140	65.5	2.6	2.20	0.73
Únanov V14	6.2	24.5	5.40	111	66.5	3.0	0.50	0.65
Únanov V15	4.9	31.5	5.00	178	95.0	2.3	2.05	0.87
Únanov V15	5.6	13.5	6.20	105	46.0	2.5	2.03	0.85
Únanov V15	6.9	10.1	6.50	24	15.5	2.4	1.70	0.53
Únanov V15	7.0	8.1	6.90	51	26.0	2.4	1.95	0.85
Únanov V15	7.9	9.2	6.80	109	38.0	2.7	2.20	0.85
Únanov V15	9.8	8.2	6.90	78	37.0	2.9	2.25	0.88
PMK 7	35.0	22.0	5.50	110	58.0	1.9	1.45	0.85
Hradiště 36/4		90.0	3.50	195	143.0	1.3	0.65	0.94
Hradiště 36/4		27.7	5.15	228	114.0	2.5	2.23	0.94
PMK 2	58.5	22.9	5.45	83.6	40.5	2.2	1.85	0.67
Chvalovice		9.4	6.70	36.7	23.7	2.1	1.63	0.85
mean		23.05	5.80	111.49	59.13	2.37	1.75	0.80
st.deviation		20.87	0.95	58.60	36.31	0.42	0.55	0.12

between 1 and 2 for fallout tephra (typically 1.4). Sorting is less good in samples with two subpopulations in the grain size distribution. For some samples, the average value of skewness (Sk) reflects a higher discharge of particles smaller than the median or an almost symmetrical distribution of particle sizes. The lower symmetry of curves with two subpopulations reflects redeposition of the volcanic material (MC LAREN & BOWLES, 1985).

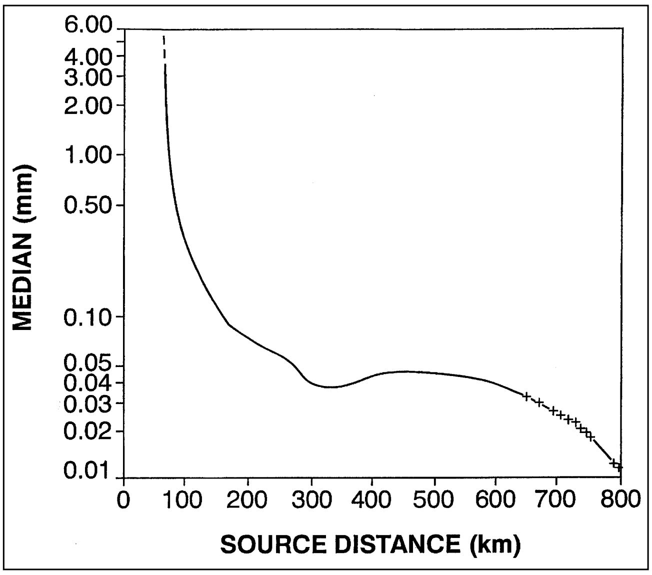
Grain size parameters can be used for various scatterplots (FISHER & SCHMINCKE, 1984; LERBEKMO & CAMPBELL, 1969; LIRER et al., 1973; LIRER & VINCI, 1991; WALKER, 1971). The studied samples correspond to characteristics of the distall fallout tephra. A typical application of tephra grain size studies is to determine the distance from the volcanic source. Results from the Carpathian Foredeep, presented in Text-Fig. 15 and Text-Fig. 16, show that the source was 200 km to 1000 km away. Probably the distance was closer to the upper limit, we can assume about 600 km (FISHER & SCHMINCKE, 1984; SARNA-WOJCICKI et al., 1981b; Text-Fig. 15 and 16). The thickness of tephra layers for distance estimations (FISHER & SCHMINCKE, 1984) could not be employed because of the postdepositional history (resedimentation) and missing data about eruption processes.

6. Volcanic Source of Tephra

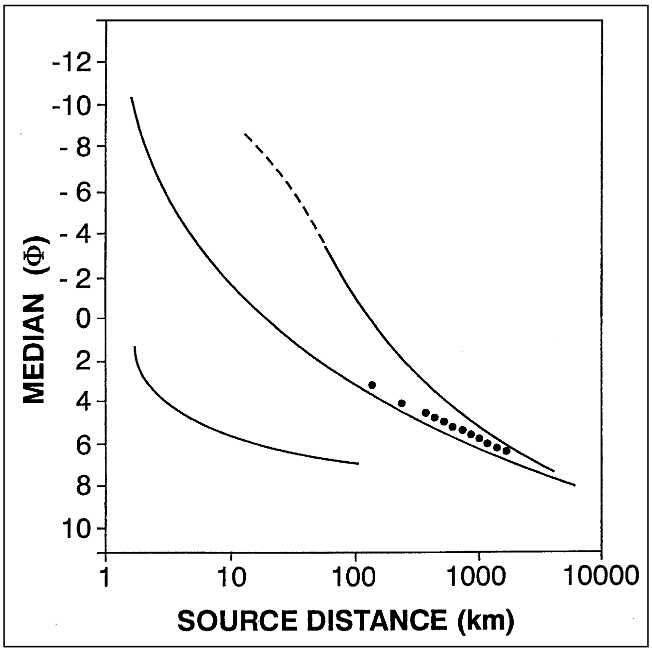
The presented results help to identify the possible source of tephra layers in the studied deposits. Only thin distal volcaniclastic layers have been recognized in the study area. Several factors influence the quality of preservation of the fallout tephra layers.

However, only eruptions with high intensity produce distal fallout tephra layers with a thickness sufficient for preservation. A single eruption can produce several tephra layers with different grain size distributions and even slightly different chemistry, due to eolian fractionation (FISHER & SCHMINCKE, 1984).

Thin layers of Eggenburgian–Ottnangian rhyodacitic tephra are known from South Moravia (NEHYBA, 1995), Lower Austria (ROETZEL, 1994; ROETZEL et al., 1994; ROETZEL & ŘEHÁKOVÁ, 1991), Slovenia (RIJEVEC, 1976) and South Poland (NOWAK, GEROCH & GASINSKI, 1985). Greater thicknesses of similar tephra layers are known from Southern Slovakia and especially from Northern Hungary and Eastern Slovakia. If all these volcaniclastic layers were pro-



Text-Fig. 15.
Median diameter (Md) vs. distance from source for various tephra sheets (diagram after SARNA-WOJCICKI et al., 1981b).



Text-Fig. 16.
Median diameter (Mϕ) vs. distance from source for fallout tephra sheets (diagram after FISHER & SCHMINCKE, 1984).

duced by one source, it had to be a highly explosive volcanism with a thick proximal tephra facies (Plinian or Phreatoplinian eruptions [CAS & WRIGHT, 1984]).

An island volcano, now deeply buried under flysch nappes or Neogene deposits, was thought to have existed during the Neogene in today's Austria or Moravia. This volcano was formerly assumed to be the source of the studied tephra layers (BŘEZINA, 1959, 1967; KRYSTEK, 1959). However, the results of grain size analyses, thickness of tephra layers, sedimentary structures, the absence of a proximal volcanic facies (the thickness of such a facies should be at least several tens of meters for acid volcanism), and the absence of geophysical structures of volcanic origin in the study area (c.f. RUDINEC & MAGYAR, 1980 for the East Slovakian basin) strongly argue against the existence of such a volcano.

Another possible source has been located in Styria or Burgenland. However, the Miocene volcanism of the Styrian Basin is Karpatian and Lower Badenian in age (EBNER & GRÄF, 1982; HÖLLER et al., 1976; KOLLMANN, 1965; SACHSENHOFER, 1992).

The most likely volcanic source area of the studied tephra layers is Northern Hungary or Eastern Slovakia (KRYSTEK, 1983). In Hungary Miocene volcanism is very important for stratigraphic correlations. Three major groups of pyroclastics (Upper, Middle and Lower rhyolite tuff) have been recognized (HÁMOR et al., 1979; HORUSITZKY, 1965; PANTÓ, 1965; TRUNKÓ, 1969) and defined in their stratigraphic position. The studied volcaniclastics can be correlated with the Lower rhyolite tuff-group. This tuff has a wide stratigraphic range and a variable mineralogical and chemical composition. The production of rhyodacites is related to a time of maximal volcanic activity. Volcanic activity in Eastern Slovakia started in the Eggenburgian (KALIČIAK et al., 1989; RUDINEC, 1978; SLÁVIK et al., 1968).

In the Carpatho-Pannonian region Miocene volcanism was distributed over a wide area (KALIČIAK et al., 1989; LEXA & KONEČNÝ, 1979; LEXA et al., 1993). The majority of Lower Miocene rhyolites and rhyodacites were produced by the areal type of volcanic activity, which started in the Eggenburgian–Ottnangian period. Volcanic rocks have a dominantly crustal origin. The Lower rhyolite tuffs in Hungary and Eastern Slovakia belong to this type (LEXA et al., 1993).

Radiometric ages, which have been obtained by the Fission-Track method, can be compared with published data. Unfortunately these data were produced by various laboratories and dating techniques. Similar results as those for Upper Eggenburgian volcaniclastics in the Carpathian Foredeep exist for rhyodacite tuff (Lipovany): 20,6±0,5 Ma; 20,1±0,4 Ma (VASS et al., 1987) and for tuff in the Upper Krosno Formation (Silesian unit): 20,5±0,9 Ma (NOWAK, GEROCH & GASINSKI, 1985). The average age of the "Lower rhyolite tuff" is 19,6±1,4 Ma (HÁMOR et al., 1979) but the actual results are affected by the long-term existence of the source volcanism. UNGER et al. (1990) presented an age of 20,6±3,2 Ma for rhyolite tuff from Magyárkút and an age of 19,7±1,4 Ma for rhyolitic ignimbrite from Kistbattyán.

Our results favour a position of the volcanic source of the Neogene volcaniclastics in Northern Hungary and Eastern Slovakia.

7. Conclusions

Lower Miocene volcaniclastics from the Carpathian Foredeep in South Moravia and the Molasse Zone of Lower Austria can be correlated. The volcaniclastics have an acidic character (rhyodacites). The source of volcanic material was from the calc-alkaline volcanic suite of a volcanic arc. The estimated eruption temperature lies between 720 °C and 780 °C. Tephra was produced by the Neogene aerial type of dacite and rhyolite volcanic activity in the Carpatho-Pannonian region. The volcanic source is probably located in Northern Hungary and Eastern Slovakia. Studied volcaniclastics belong to the distal fallout tephra. The important influence of postdepositional processes on chemical composition, texture and structure of the volcaniclastics has been documented. The tephrostratigraphic correlation of the studied volcaniclastics is based on zircon studies.

Two horizons of volcaniclastics (horizon I and II) have been recognized in the Carpathian Foredeep. The existence of different horizons is explained by several eruptional phases in the same source area and a stratified magmatic chamber. The lower horizon (horizon I) is Upper Eggenburgian in age. Its average absolute age (Fission-track-dating) is 20.3±2.4 Ma. The upper horizon (horizon II) which was recognized in the surroundings of Miroslav (Carpathian Foredeep of Czech Republic) can be correlated with tephra layers of the Zellerndorf Formation and Langau Formation (Molasse Zone of Austria). These rocks are Ottnangian in age.

Volcaniclastics from the locality Herrnbaumgarten (Vienna Basin) which were formerly assumed to correlate with the above mentioned tephra layers show different characteristics of volcanic zircons. For that reason a different source is most probable.

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