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Provenance of Würmian loess and loess-like sediments of Moravia and Silesia (Czech Republic): a study of zircon typology and cathodoluminiscence

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Abstract: A detailed zircon study (typology and cathodoluminiscence) of late Pleistocene (Würmian) loess sediments from Moravia area, Czech Republic shows a significant western provenance from magmatic (mainly granitic) rocks of Bohemian Massif together with contributions from metamorphic rocks. Zircon typology is applicable only for well-preserved magmatic zircon crystals, which usually occupy a part of the whole zircon population. Zircon typology indicates a dominant provenance from calc-alkaline I-type granites, whereas important contributions of material from S-type granites (Moldanubian pluton?) is not documented. The provenance material of the Velká Bíteš locality is derived from the adjacent melanosyenitic rocks (durbachites) of the Třebíč Massif and in this case confirms transport over a short distance as well as provenance from the west. Cathodoluminiscence images indicate both magmatic and metamorphic origin of the studied zircon.

Key words: Pleistocene, Würmian, Czech Republic, Moravia, cathodoluminiscence, loess sediments, zircon typology, zircon.

Introduction

Loesses and loess-like sediments occupy large areas, more than 20 % of the total surface of the Quaternary surface area in Moravia, the eastern part of the Czech Republic (Fig. 1). Eolic sedimentation of most of these accumulations is determined during the last Pleistocene glacial age, Würmian/Upper Weichselian (Frechen et al. 1999). The average thickness of Würmian loesses is about 1 to 1.5 m.

Würmian loess and loess-like sediments in the Moravia and Silesia area were studied by many authors. The oldest studies classified the loesses on the basis of granulometry, carbonate and humus content. Their provenance was determined mainly according to Quaternary geomorphology and recent wind directions (Ambrož 1947; Pelíšek 1949). Later published contributions were based mostly on stratigraphy or climatology (Musil & Valoch 1956; Ložek 1958; Kukla 1961; Havlíček & Smolíková 1993). In the last ten years provenance studies have only been carried out in small areas (Adamová & Havlíček 1997; Frechen et al. 1999; Adamová et al. 2002; Kvítková & Buriánek 2002; Kvítková & Chadima 2002; Lisá 2004). The most recent loess study based on heavy mineral associations divided Moravian Würmian loess and loess-like sediments into five main provenance areas (Lisá 2004; Lisá et al. 2005).

The material of Moravian loess sediments is composed mainly of quartz (Cílek 2001), feldspars, calcite and dolomite (Pécsi 1991). Dominant heavy minerals are represented by amphibole- and garnet-group minerals (Lisá 2004; Lisá et al. 2005). Prevailing W, NW and SW winds are documented by the orientation of loess banks and the presence of particles from neighbouring rocks. Microstructures of quartz grains are typical for different regions, where angular grains are typical for loess from the western part of Moravia with crystalline basement provenance, whereas more rounded grains with fluvial microstructures are common in loess with a Miocene sediment provenance (Lisá 2004).

Fig. 1. Map of the Quaternary cover with studied localities, average depth of the cover is 20–40 m (Žebera 1966, modified).

Results based on the detailed study of heavy minerals, especially garnet composition, represent a valuable source for provenance determination (Lisá 2004; Lisá et al. 2005). Zircon typology and cathodoluminiscence are part of this complex research of Pleistocene loess and loess-like sediments from Moravia area and the aim of this study is to contribute to the provenance of loess material using these techniques.

Methods

Samples were collected from typical loess profiles, which had been described in previous studies (Macoun et al. 1965; Havlíček 1985; Havlíček & Smolíková 1993; Adamová & Havlíček 1995, 1997, etc.). Samples are taken from the Würmian layers, below the 20–60 cm Holocene layer. In total, 9 localities were selected for detailed zircon studies and are presented in Fig. 1 and the Appendix.

After sampling and quartation of the loesses, the size fraction of 0.063–0.250 mm was prepared for heavy mineral separation in heavy liquid, tetrabromethane with $D=2.96\ g/cm^3$. A low-intensity U-shaped magnet was used to separate ferromagnetic minerals. A final selection of detrital zircons was performed by hand picking under the binocular stereomicroscope and observed in the scanning electron microscope at the Department of Biology, Masaryk University, Brno. Observations were evaluated according to the zircon typology method (Pupin 1980, 1985). One hundred well-developed zircon crystals were used for the typology measurements from each studied locality.

Samples for the cathodoluminiscence observations (CL) were separated by similar methods. Polished samples were then studied at Dionýz Štúr State Geological Institute, Bratislava, on the cathodoluminiscence microscope as part of the Cameca SX 100 electron-microprobe apparatus. The following analytical conditions were used: accelerating voltage 8 kV and beam current 1×10^{-3} nA.

Results

Zircon typology

Detritus from Moravian loess and loess-like sediments contain four main zircon groups: (1) rounded crystals or fragmented grains, (2) prismatic zircons but with edges rounded to varying degrees (grains are partly broken, but without fresh cracks), (3) prismatic zircon with morphology not typical for common magmatic rocks, and (4) zircon with distinct typology characteristic for magmatic rocks (according to Pupin 1980; Table 1, Figs. 2 and 3).

The amount of magmatic zircon with well-preserved crystal morphology (population 4) is widely variable (Table 1). Rounded zircon crystals without distinctive crystal faces (groups 1 and 2) are widespread mainly in South-Moravian loesses (Modřice, Horní Dunajovice, Dolní Věstonice and Ořechov). Only up to 10 % of the zircons have well-preserved crystal faces applicable for the typology method. Higher amounts of magmatic well-preserved zircon crystals were revealed in the loess sediments from the northern part of Moravia (Hranice I, Hranice II, Leština and Osoblaha (15 to 50 %)). Almost 100 % of well-preserved magmatic zircon crystals without visible eolic and/or sedimentary transport features occur in Velká Bíteš loess in the SW part of Moravia.

Typology results from well-preserved crystals (population 4) indicate a relatively uniform distribution of zircon types and subtypes for almost all the studied samples. The S_{12}, S_{13}, S_{16}, S_{17}, S_{18} and S_{19} subtypes are the most widespread (Table 1, Figs. 2 and 3). Modřice and Horní Dunajovice localities did not contain sufficient amounts of well-preserved zircons, only scarce S_{17} and S_{18} subtypes in Modřice and S_6 and S_8 subtypes in Horní Dunajovice were observed. On the other hand, different zircon typologies were found in Velká Bíteš loess sediments, for which S_{23}, S_{24} and S_{25} subtypes are characteristic (Table 1, Figs. 2 and 3).

Zircon cathodoluminiscence

Zircon from the studied loesses show wide variability of internal zoning under CL (Fig. 4). A fine regular oscillatory zoning pattern (Fig. 4A,B) is characteristic mainly for Velká Bíteš, Leština, Osoblaha and Hranice I and II zircons. However, the most widespread pattern is irregular zoning or complex combinations of regular oscillatory and irregular zoning; the crystals with oscillatory zoning are corroded along their rims by younger embayed zones (Fig. 4C,D) or older oscillatory zonal cores are surrounded and corroded by rims with irregular zoning (Fig. 4E,F). This texture is characteristic mainly for the Horní Dunajo-

Table 1: Distribution of observed zircon subtypes (Pupin 1980) in loess sediments (in %).

	S_4	S_6	S_8	S_{11}	S_{12}	S_{13}	S_{14}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}	S_{23}	S_{24}	S_{25}	% content of euhedral zircons
Velká Bíteš	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.2	67.0	6.8	100
Hranice I.	0.0	0.0	15.8	0.0	19.4	1.6	10.9	0.0	13.4	34.0	4.9	0.0	0.0	0.0	0.0	20
Hranice II.	0.0	0.0	0.0	8.7	30.6	0.5	0.0	0.0	18.6	36.1	5.5	0.0	0.0	0.0	0.0	15
Leština	0.0	0.0	0.0	0.0	4.3	0.5	0.0	15.0	37.4	29.9	10.7	2.1	0.0	0.0	0.0	50
Ořechov	11.0	0.0	0.0	22.1	38.7	0.6	5.5	0.0	5.5	5.5	0.0	0.0	0.0	11.0	0.0	10
Osoblaha	0.0	0.0	0.0	0.0	13.3	0.0	3.3	6.7	30.0	33.3	13.3	0.0	0.0	0.0	0.0	25
D. Věstonice	0.0	0.0	0.0	0.0	40.1	1.4	0.0	0.0	35.6	13.8	9.2	0.0	0.0	0.0	0.0	5
H. Dunajovice		3	2													3
Modřice									3	3						3

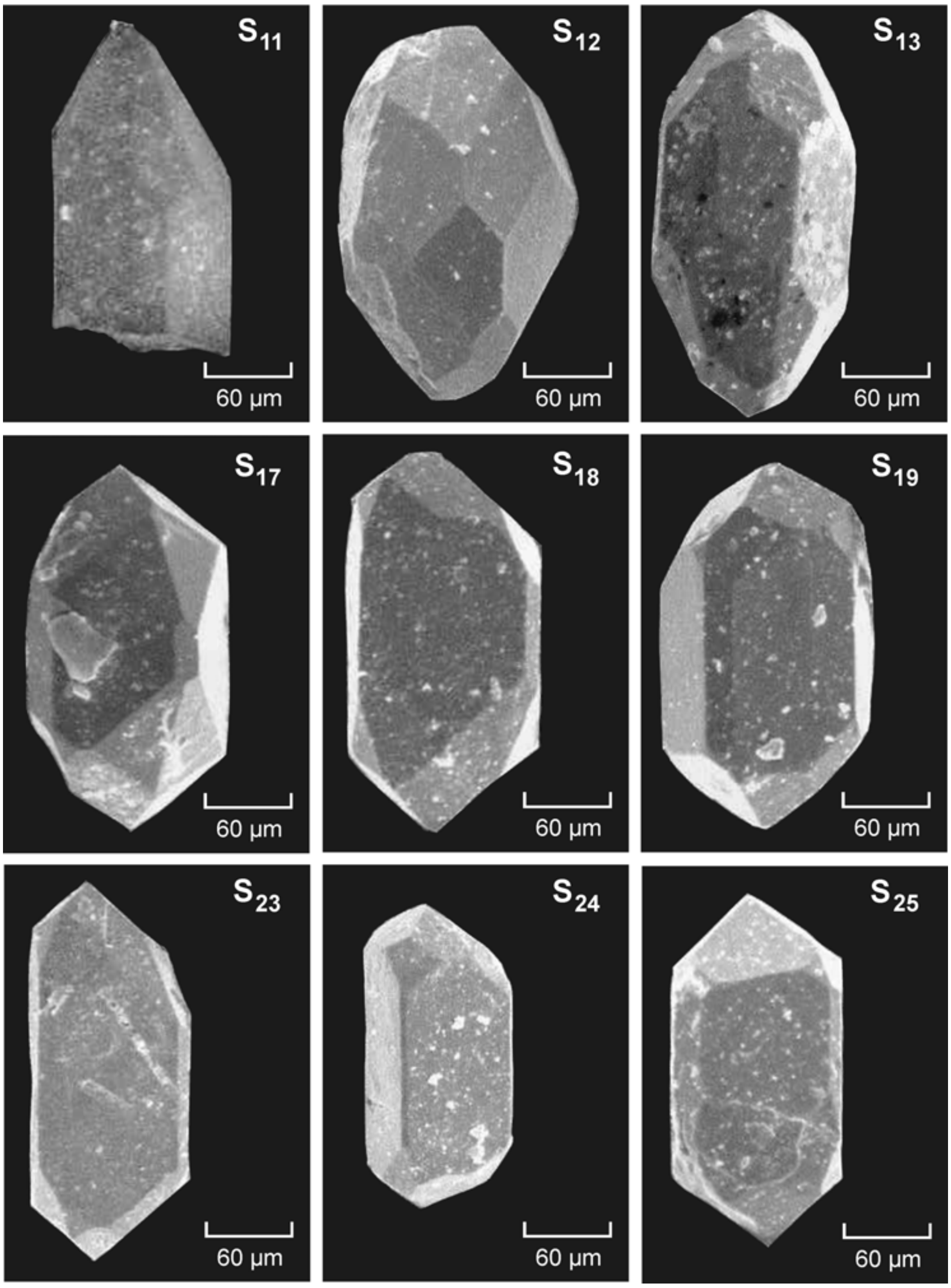

Fig. 2. Typical zircon subtypes (after Pupin 1980) observed in loess sediments.

vice, Modřice, Dolní Věstonice, Hranice I, and Osoblaha zircon. Rarely, unzonal zircon crystals were found in the studied localities.

Discussion

Our results of zircon typology and cathodoluminiscence revealed some differences in these features as a consequence of various source rocks and provenance areas.

Although zircon typology (Pupin 1980, 1985) was applied widely as a usefull provenance method for clastic sediments (e.g. Uher & Kováč 1993; Loi & Dabard 1997; Fekkak et al. 2000; Willner et al. 2003), data from the clastic sediments of the Moravia area are still scarce and incomplete (e.g. Král 2002). Moreover, zircon typology is applicable only for well-preserved euhedral magmatic or metaigneous zircon crystals, unaffected by extensive sedimentary transport. The presence of common rounded zircon grains without well-preserved crystal faces indicates a distinctive pre-eolic sedimentary transport of zircon in clastic source rocks. However, an irregular oval shape of zircon could also be a result of metamorphic (re)crystallization (e.g. Broska & Caňo 1987; Corfu et al. 2003).

The zircon typology of the studied loess sediments show the clear dominance of zircon subtypes with medium

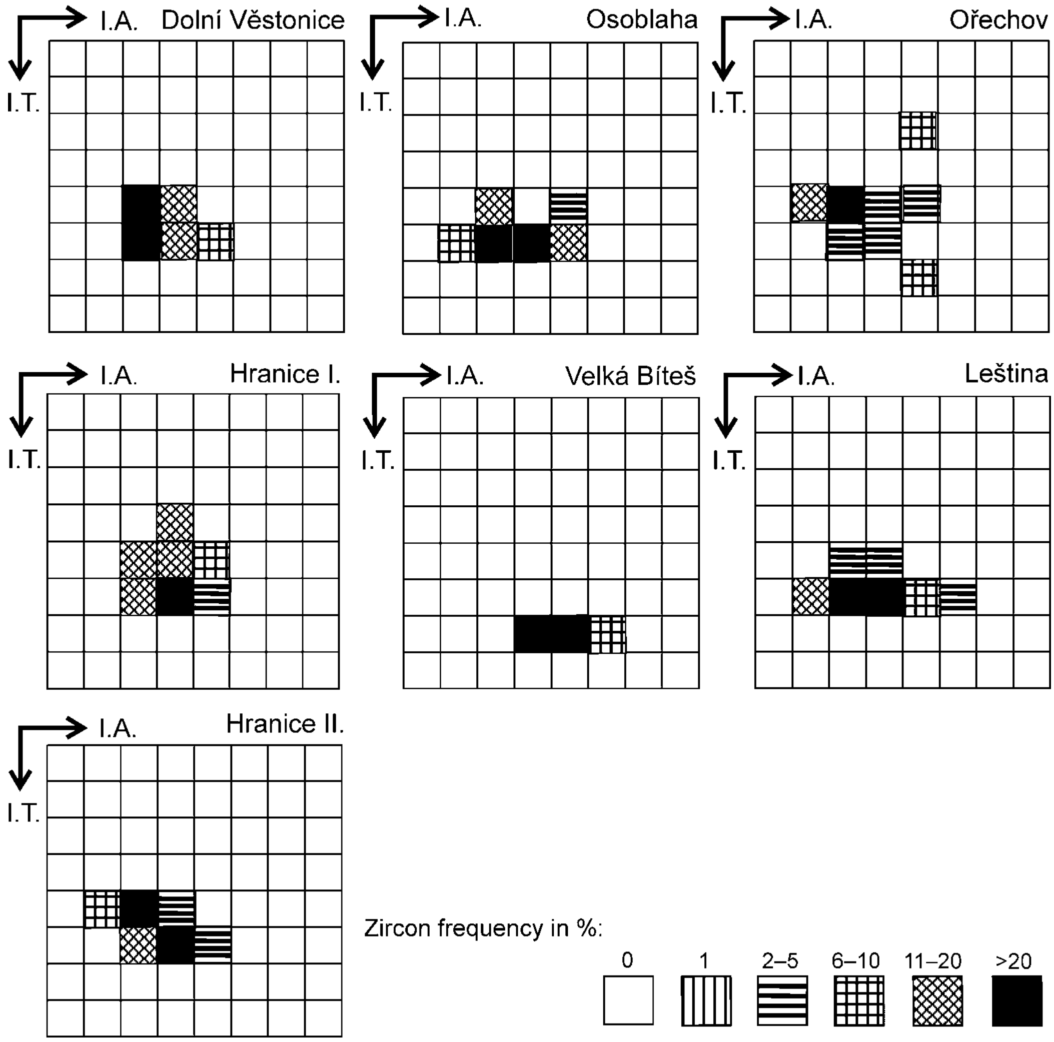

Fig. 3. Zircon typograms (Pupin 1980) for loess sediments.

I.A. (agpacity index) and medium to high I.T. (index of temperature) parameters (Fig. 3). Zircon from Dolní Věstonice, Osoblaha, Ořechov, Hranice and Leština reveal very similar typograms with a majority of medium-temperature S_{12}, S_{13}, S_{16}, S_{17}, S_{18} and S_{19} subtypes. Such subtypes are typical for aluminous to calc-alkaline allanite-bearing I-type granitic suites rather than lower temperature monazite-bearing S-type suites (cf. Pupin 1985; Broska & Uher 1991). The possible source for such zircons could be magmatic suites with I-type character from the eastern part of the Bohemian Massif, probably from Precambrian magmatic rocks of the Brno Massif, eventually from probably pre-Hercynian granodiorites of Svinov-Vranová Crystalline Complex (Dolní Věstonice, Ořechov, Hranice I and Hranice II loesses). A potential source rock for zircon from Leština and Osoblaha loesses could be the Šumperk Massif, a Hercynian allanite-bearing I-type granodiorite (Zachovalová et al. 2002). Unfortunately, there are missing zircon typology data for the above mentioned possible primary rocks, which would serve as material for comparison. Another source for the zircon Leština and Osoblaha could be Děsná gneiss, containing partly deformed pre-Variscan granitoids.

On the contrary, zircon typology of the studied Moravian loesses is distinctly different from typology of Hercynian S- and I-type granitic rocks of the Moldanubian pluton where low-temperature zircon subtypes dominated (Finger et al. 1991; Jalovec et al. 1993; Uher et al. 1998). Moreover, in the Moldanubian pluton high-temperature and (sub)alkaline members occur locally (Karlstift granite; Finger et al. 1991) or highly-evolved leucogranites with dominant low-temperature and high-alkaline G_1 zircon subtype (Homolka granite; Uher et al. 1998), both different from loess zircons.

The only unambiguous example represents zircon from Velká Bíteš loess. Zircon typology shows the dominance of S_{23}, S_{24} and S_{25} subtypes (Fig. 3), entirely analogous to zircon typology from the adjacent melanosyenitic rocks (durbachites) of the Hercynian Třebíč Massif (Holub et al. 1997; Král 2002; Dosbaba & Sulovský 2004).

For provenance studies it is important to distinguish zircon derived from magmatic versus metamorphic rocks. It

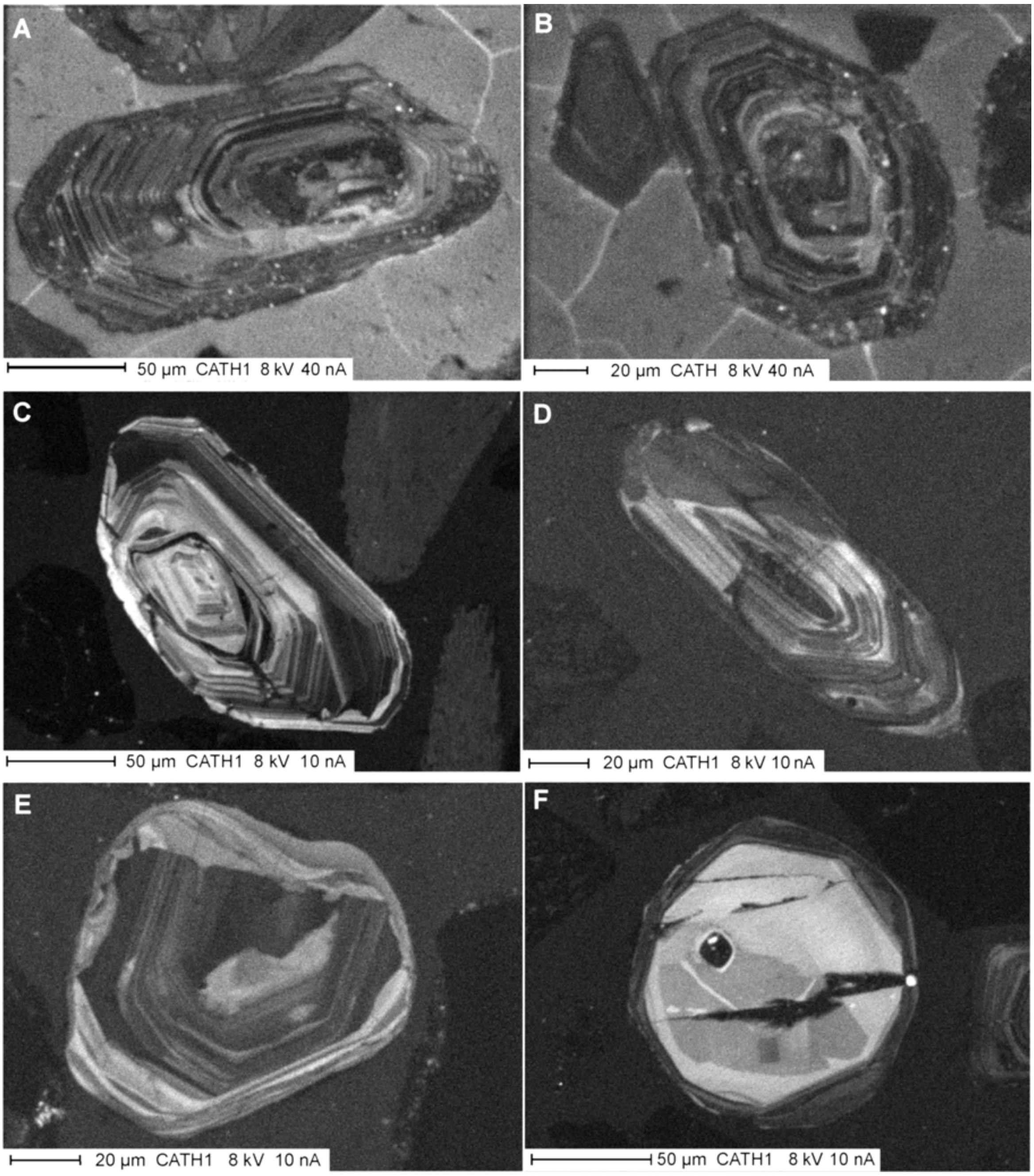

Fig. 4. Representative CL images of zircons observed in loess sediments. **A–D** — fine oscillatory zoning, locally with embayments due to partial resorption (**C–D**). **E** — core with regular oscillatory zoning overrimmed by domain with irregular oscillatory zoning. **F** — irregularly zoned core surrounded by darker rim with irregular zoning. Location: Velká Bíteš (A, B), Dolní Věstonice (C, D), Hranice II (E), Hranice I (F).

is a complex problem because of similarities in morphology as well as internal zoning of the magmatic versus metamorphic (especially metaigneous) zircon. However, a study of zircon internal zoning by high-resolution cathodoluminiscence (CL) images distinguishes some characteristic patterns of magmatic versus metamorphic zircon. Magmatic zircons show characteristic fine and regular oscillatory zoning whereas metamorphic zircons reveal irregular zoning, commonly with the presence of older, partly resorbed or recrystallized cores and embayed or mozaic patterns (e.g. Vavra 1994; Rubatto & Gebauer 2000; Corfu et al. 2003).

The studied zircons from Moravian loesses show both regular magmatic as well as irregular metamorphic patterns (Fig. 4). The typical fine oscillatory magmatic zoning is characteristic mainly for zircon from Velká Bíteš loess (Fig. 4A,B) where the adjacent Třebíč melanosyenite (durbachite) is assumed as the source rock and the zircon typology clearly supports this.

However, CL images of zircon from other studied loesses indicate the presence of both magmatic and metamorphic patterns. The common presence of oscillatory zonal cores corroded by irregular embayed rims indicates post-magmatic, probably metamorphic processes during zircon evolution; such patterns were observed mainly in the Dolní Věstonice, Horní Dunajovice, Modřice and Hranice loesses. Analogous zircon CL patterns were observed from high-grade metamorphic rocks, such as orthogneisses, metagabbros, or metasediments (Rubatto & Gebauer 2000; Corfu et al. 2003). Moreover, results of heavy mineral assemblages, especially garnet compositions of the loess, indicates at least a partial metamorphic source of the loess material, probably from crystalline complexes of the eastern part of the Bohemian Massif (Kvítková & Buriánek 2002; Kvítková 2004; Lisá et al. 2005). This assumption also supports analysis of Würmian winds with prevailing W, NW and SW directions as documented by loess dune orientation, the presence of particles from neighbouring rocks and microstructures of quartz grains (Cílek 2001; Lisá 2004).

Conclusions

The following main conclusions can be derived from the presented data:

Zircon typology is applicable only for well-preserved magmatic zircon crystals, which usually form only a part of the whole zircon population from Würmian Moravian loess sediments. The typology of the studied samples indicated dominant provenance of calc-alkaline I-type granites, probably from various source regions (possibly the Brno, Svinov-Vranová and Šumperk Massifs), material from S-type granites (mainly Moldanubian pluton) contributed probably only in negligible amounts.

The provenance material of the Velká Bíteš locality is significantly different; their zircon population was unambiguously derived from the adjacent melanosyenitic rocks (durbachites) of the Třebíč Massif.

Internal zoning (cathodoluminiscence images) indicates both magmatic and metamorphic origins of zircon in the Würmian loess sediments of Moravia.

Generally, zircon typology and cathodoluminiscence patterns in our study evidently indicate the presence of magmatic, probably mainly granitic as well as metamorphic source rocks for Würmian loesses in the Moravia area, most probably from Precambrian to Hercynian crystalline complexes of the Bohemian Massif. However, some admixture from younger clastic sedimentary rocks (mainly Neogene sandstones) in eolic material of Moravian loess sediments is not excluded.

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Appendix: sample location

Osoblaha. NE border of Bohušov village. 2300 m SSW from the Osoblaha railway station.

Hranice I. Outcrop over "Vápenka" motorway restaurant; 1500 m SE from the Hranice na Moravě railway station.

Hranice II. Upper part of the Skalka quarry; 2500 m NE from the Hranice na Moravě railway station.

Leština. E border of the Leština village, 800 m SW from the elev. point 524, Trlice.

Modřice. 3750 m SE from the elev. point 307, Rovný.

Horní Dunajovice. Centre of Horní Dunajovice village, 950 m ESE from the elev. point 287, Šibeniční Kopec.

Dolní Věstonice. E border of the Dolní Věstonice village; 2000 m N from the elev. point 550, Děvín.

Ořechov. West border of the Ořechov village; 3000 m SE from the elev. point 389, Záhumenice.

Velká Bíteš. NW border of the Jestřabí village; 1800 m SSE from the elev. point 516, Chocholáč.

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