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Exoscopy of Moravian eolian sediments

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Abstract. Loess and related eolian sediment samples from selected localities in southern and central Moravia were studied using exoscopy combined with the study of heavy minerals, toward determining the provenance of their source rocks. The loess sediments from selected localities were divided into four sub-groups based on the characteristics of their heavy mineral fractions. Material of the first sub-group was deflated solely from the weathering horizons of nearby magmatic or metamorphic rocks to the west. The material of the other loess sub-areas was predominantly deflated from sedimentary rocks to the west, southwest, and northwest of their present sites. The sediments with a predominant fine-grained fraction contain exceedingly minimum quartz grains lacking distinctive transport evidence. Nonetheless, it has been possible to use other methods in determining their source rocks.

Keywords: exoscopy, microstructure, heavy minerals, loess, Last Glacial

Introduction

The determination of sediment origins by the method of exoscopy has been in use since the classic studies of Smalley and Cabrera (1970) and Krinsley and Doornkamp (1973). Exoscopy enables one to discern the differences between eolian and fluvial origins for sands, by studying the polished surfaces of quartz grains. However, such distinctions are not entirely clear for fine-grained sediments. The origin of fine-grained sediments has instead been determined by the study of surface morphology and the mineralogical composition of the sediment.

Geological setting

Loess and loess-like sediments occupy about 20% of the entire area of southern and central Moravia. Most of these accumulations are considered to have been deposited during the Last Glacial – Würmian/Upper Weichselian (Frechen et al. 1999). The average thickness of Würmian loesses is about 1–1.5 m. Both loess and loess-like sediments have been studied by other authors (Šajgalík and Modlitba 1983).

There has been growing interest in loesses and their origins in Moravia since the late 1940s. Ambrož (1947) and Pelíšek (1949) evaluated loess sequences by granulometry, mineral composition, $CaCO_3$ content, humus content, and geomorphology. These authors eventually inferred prevailing wind directions and a western source for the loess material. Many contributions dealing with the stratigraphy or pedology of the Moravian deposits have been published since that time (Musil and Valoch 1956, Ložek 1958, Kukla 1961, Havlíček and Smolíková 1993). Recent research has been focused on loess origins (Adamová and Havlíček 1997, Cílek 1999, Adamová et al. 2002, and Kvítková 2003).

Methods

Ten samples of 500 g each were collected from localities containing loess of a presumed eolian origin. The collection sites are shown in Fig. 1. All of these samples were collected from deposits of the Last Glacial cycle. The samples were first divided according to particle size (see Table 1) by Kopecký separator at the Department of Geology and Pedology, Faculty of Forestry, Mendel University. The 0.063–0.250 mm fraction was then separated by wet sieving and by heavy liquid (1,1,2,2, tetrabrommethan, D = 2.964 g/m^3; Rost 1956). Heavy minerals were prepared for study under a polarising microscope, while the light mineral fraction was boiled in HCl. The samples of the light mineral fraction were then glued to carbon tape, coated with gold, and observed by scanning electron microscope

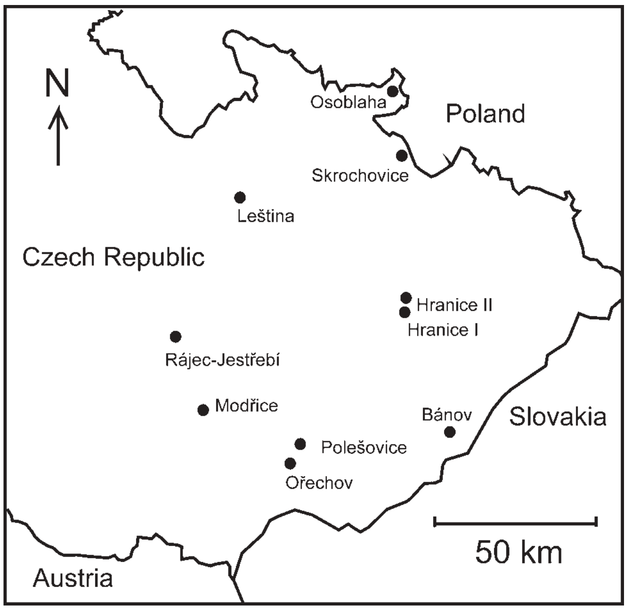

Figure 1. Site locations.

Table 1. Grain-size analyses of the samples

Sample No.	Site	I. (< 0.01 mm)	II. (0.01–0.05 mm)	III. (0.05–0.1 mm)	IV. (0.1–2.0 mm)
1	Modřice	20.3	56.7	22.4	0.6
2	Leština	15.0	48.0	31.3	5.7
3	Rájec-Jestřebí	14.1	28.0	39.8	18.1
4	Ořechov	23.2	39.8	19.4	17.6
5	Hranice I	29.1	35.5	17.0	18.4
6	Hranice II	33.3	49.3	14.6	2.8
7	Skrochovice	18.7	60.5	11.8	9.0
8	Osoblaha	29.2	29.5	13.4	27.9

at the Department of Biology, Faculty of Science, Masaryk University. Exoscopy has previously been applied to the study of loesses by several authors, e.g. by Smalley and Cabrera (1970) and Rywocka-Kenig (1997). Exoscopy atlases were used for comparing the quartz microstructures of the grains in our samples with those of previous authors (Krinsley studied Doornkamp 1973, Ribault 1977, Rywocka-Kenig 1997).

Results

The samples from Modřice, Rájec-Jestřebí, Ořechov, Skrochovice, and Osoblaha are classified as typical calcareous loesses in accordance with the INQUA 1975 classification (Šajgalík and Modlitba 1983), with a prevalent size fraction of 20–50 micrometers (Table 1). This sediment is massive, non-bedded, and of a primarily carbonaceous content, with capillary porosity, and is of yellow or dark yellow colour according to the Munsell colour chart. The other sediments are considered to be only loess-like because of their absence of carbonaceous content. In terms of the second order classification scheme of Ambrož (1947) and Pelíšek (1954), the loesses from Modřice, Rájec Jestřebí, Skrochovice, Osoblaha, and Ořechov are classified as well-sorted calcareous loesses. The loesses from Leština, Hranice I, Hranice II, and Štemberk are classified as typical well-sorted, non-calcareous loesses. The sediments from the Bánov locality are comprised of Holocene aeolian soils, while the sediments from the Polešovice locality are comprised of aeolian sands.

Modřice, Leština

These two very similar localities are situated in the eastern part of the Bohemian Massif. The main constituents of the transparent heavy mineral fraction are amphibole and garnet (see Table 2), with lesser quantities of epidote, apatite, zircon, sillimanite, and rutile (Lisá in print). Polished, angular quartz grains comprised about 50% of the samples from both localities. The remainder of the quartz fraction is comprised of subangular grains with only slightly rounded edges, and with traces of chemical weathering and precipitation. The occurrence of characteristic eolian surface textures (such as eolian pitting) was sporadic (up to 1% from the fraction studied, see Plate 1A, B). The total carbonate content of 5 to 8.5 wt% for the Modřice locality was determined by point-counting. Quartz comprises 99.67 wt% of the light fraction. The total carbonate content of the samples from the Rájec-Jestřebí locality varies between 0.1 and 1 wt%, while the light fraction comprises up to 93% of the material.

Ořechov

The Ořechov locality is situated in the northern part of the Dolnomoravský úval Valley. The transparent heavy mineral fraction is dominated by amphibole, zircon, and rutile (see Table 2), with lesser proportions of garnet, tourmaline, staurolite, and epidote. About 60% of the quartz grains in this fraction are subangular, 30% are subrounded, while the remaining10% are polished and angular. 20% of the subrounded grains have surface textures that are characteristic of fluvial transport (see Plate 1H). Less than 1% of the grains show surface textures indicative of eolian transport (eolian pitting) and/or of having been affected by chemical weathering (see Plate 1E). The total carbonate content, based on point-counting, varies between 0.7 and 5.3 wt%. The light fraction in this sample, in which quartz is the predominant component, amounts to 99.84 wt%.

Hranice I and Hranice II

Although these two localities are very near each other, they have widely different appearances. Both localities lie in the area between the Vyškov and Morava gateways. Garnet, zircon, rutile, and tourmaline comprise most of the transparent heavy mineral fraction, with lesser proportions of epidote, amphibole, and kyanite (Table 2). Semiquantitative analysis of the transparent heavy mineral fraction has revealed other differences as well.

Our samples from the Hranice I locality consist mainly of zircon and garnet. About 70% of the quartz grains are subangular, 20% display clear polished surfaces, while the remaining 10% are subrounded. 30% of the subrounded grains show the characteristic surface textures of fluvial transport (see Plate 1C). Less than 1% of all the grains show the kinds of surface textures indicative of eolian transport or chemical weathering. The carbonate content varies from 0 to 0.3 wt%. The light fraction comprises 98.5 wt% of this sample, and consist mainly of quartz.

Table 2. Semiquantitative analyses of the transparent heavy mineral fraction

Site	Amf	Grt	Zrn	Ep	Ap	Sil	Ttn	Ky	St	Rt	Mnz	Tur
Modřice	39.8	39.5	1.9	3.8	5.1	1.9	0.9	1.2	1.9	2.6	0.3	1.2
Leština	60.6	24.4	1.9	2.5	3.5	2.0	0.3	0.9	0.7	2.5	0.3	0.3
Rájec-Jestřebí	72.7	2.0	8.0	12.2	1.0	2.4	1.3	0.0	0.0	0.0	0.2	0.0
Ořechov	50.3	5.4	16.1	2.0	1.4	0.0	0.0	4.1	4.0	11.5	0.6	4.7
Hranice I	8.4	30.8	32.6	9.8	0.0	0.0	0.0	1.4	0.0	8.4	0.1	8.4
Hranice II	0.0	53.1	11.0	0.0	0.0	0.0	0.0	2.7	0.0	13.8	0.1	19.2
Skrochovice	6.9	40.4	8.1	0.0	0.0	0.0	0.0	4.3	13.1	10.8	0.1	16.2
Osoblaha	9.5	35.8	17.6	0.0	3.5	0.0	1.6	0.0	21.1	7.1	0.2	3.8

Amf – amphibolite, Grt – garnet, Zrn – zircon, Ep – epidote, Ap – apatite, Sil – sillimanite, Ttn – titanite, Ky – kyanite, St – staurolite, Rt – rutile, Mnz – monazite, Tur – tourmaline

The transparent heavy mineral fraction of the Hranice II sample is comprised predominantly of garnet, tourmaline, and rutile. Amphibole is absent. 90% of the quartz grains are subangular, while the remaining 10% have polished textures and angular shapes. 30% of the subangular quartz grains display characteristic textures of fluvial transport. Grains with typical eolian textures occur in less than 0.5% of the observed grains, though surface textures indicative of chemical weathering occur on 50% of the grains (see Plate 1G). The carbonate content varies between 0 and 0.3 wt%. Quartz comprises 99.95 wt% of the light fraction.

Skrochovice, Osoblaha

These two localities in northern Silesia, close to the Polish border, represent an area that was affected by the north European continental glacier (Macoun et al. 1965, Macoun and Králík 1995). The transparent heavy mineral fraction of the samples from these sites is dominated by garnet, staurolite, tourmaline, zircon, and amphibole (Table 2), with lesser amounts of apatite, monazite, and titanite. 70% of the quartz grains from these samples are subangular, 20% are subrounded, while only 10% are polished and angular. Microstructures typical for glacial transport were observed on 10% of the grains (see Plate 1D). 20% of the subrounded grains show textures typical of fluvial transport. Less than 1% of the grains show textures indicative of eolian transport (eolian pitting) and/or chemical weathering (see Plate 1F). The total carbonate content was determined by point-counting to vary between 0.3 and 3.0 wt%. The light fraction, in which quartz is the predominant component, amounts to more than 99 wt% for samples from both localities.

Bánov and Polešovice

The exoscopy of grains from these two localities was included only for the sake of comparison. The Bánov locality is represented by recent aeolian soils (Švehlík 1996). Most of the quartz grain surface textures have been removed by chemical weathering. Most of the quartz grains are subrounded. Pedogenic processes have been so intense at this site, that the primary microstructures have not been preserved.

Aeolian calcareous sands were sampled at the Polešovice locality. 60% of these grains are subangular, 30% are subrounded, and 10% are polished and angular. Typical surface textures of fluvial transport are present on 10% of the quartz grains, while 20% show surface textures indicative of eolian transport (eolian pitting).

Discussion

Four main sub-groups have been differentiated based on the composition of the transparent heavy mineral fraction (Lisa in print.). The first sub-group includes the Modřice, Leština, and Rájec localities. The sources of the sediments from these three localities are magmatic and metamorphic rocks to the west and northwest (Štelcl et al. 1977, Kodymová and Kodym 1984, Abraham 2001). According to Smith et al. (2002), the degree to which some of the grains are subrounded corresponds to four hours of transport. We assume that the wind which caused the accumulation of these loesses during the Last Glacial cycle was of the same velocity as that which resulted in the sedimentation of the recent aeolian Bánov soils: 4 m/s (14.4 km/h; Švehlík 1996). This wind velocity for a duration of 4 hours corresponds to a transport distance of 58 km.

According to these assumptions, 50% of the loess material at the Modřice locality was probably transported there from a distance of less than 58 km. The rest of the material was deflated from the close vicinity. This would indicate that the source rocks for the Modřice loesses are the granitoids of the Brno Massif, the Býteš gneisses, and the rocks of Třebíč Massif. These assumptions are supported by small increas in radioactivity in the loess material at the Modřice locality (Kvítková 2002). These data support the conclusion of the western origin of the source material for this deposit during the Last Glacial cycle.

The situation for the Leština locality is much different. The calcareous sediments to the west of this area are of a diverse mineralogical composition (Abraham 2001), and our exoscopic analysis does not support a western origin for the transported material. The length of transport could be regarded as similar to that of the Modřice sediments, about 60 km. This assumption would locate the provenance of these deposits in the metamorphic and magmatic rocks of the Silesicum (Otava 1988, Abraham 2001) to the northwest. The minor carbonate component is probably the result of the high degree of weathering (Kvítková 2003).

Based on the degree of roundness and particle-size analysis, the quartz grains of the Rájec-Jestřebí locality would seem to be from the close vicinity. The increased radioactivity observed in this sample could support the conclusion that this material originated from the durbachites of the Třebíč Massif. The rest of the material originated from the granitoids of the Brno Massif. It is possible that a small carbonate content was affected by subsequent weathering or leaching (Kvítková 2003), but we cannot reliably define the reasons for positive or negative carbonate content. The carbonate content of this loess is perhaps strongly dependent on particle-size distribution and the length of transport.

We presume a mainly sedimentary rock origin for other established sub-groups (Lisá in print), based the composition of their transparent heavy mineral fraction and exoscopic analyses. Unfortunately, degree of roundness cannot be used as an indicator of transport length for these localities; instead, we must use the heavy mineral fraction and the surface textures of the quartz grains as indicators of provenance rocks.

The sediments from the Ořechov locality comprise the second sub-group (Lisá in print). If we would presume that the primary material has its origins from the weathering horizons of magmatic or metamorphic rocks, their provenance would be more than 150 km away. In spite of this, other loess deposits of the same age as that of Modřice or Rájec-Jestřebí in this direction have a different mineral composition and do not show enough microstructure for exoscopic analysis. The material must therefore come from the nearby Tertiary sediments (Hypr 1975, Studený 1976, Abraham 2001).

The sediments of the Drahany Upland have been determined as the main source of the third sub-group, which is comprised of the Hranice I and Hranice II loess deposits (Lisá in print). The degree of roundness of these grains corresponds to the presence of fluvial sediments in the primary rocks. A higher content of chemical weathering textures, typical for the Hranice II locality, corresponds to the absence of unstable minerals (such as amphibole or epidote). The degree of weathering probably depends on precipitation (Kvítková 2003). Though there are other ways to explain these differences, no other suitable rock sources could be found in the vicinity. It is therefore proposed that the source of loess material for the Hranice I and Hranice II localities was the same, but the material was differently affected by subsequent chemical weathering. The presence of more stable minerals, higher fine fraction proportions, the absence of carbonate, and the increased content of opaque minerals in the more weathered loesses of the Hranice II locality, in contrast to the Hranice I locality, supports this explanation.

The loesses of the Skrochovice and Leština localities comprise the last sub-group, the source of which are probably in the Tertiary sediments of Poland (Lisá in print). The presence of glacial and fluvial surface textures supports the assumption that these primarily fluvial sediments were affected by north European glaciation. We can say accordingly that the degree of roundness and the nature of the surface textures of the quartz grains correspond to the types of sedimentary rocks in the studied area.

Our study of the Bánov deposits demonstrates that sediments, which have undergone intensive post-sedimentary processes are not well suited for exoscopic studies. On the other hand, the data from the Polešovice locality show that not all eolian sediments display surface textures characteristic of eolian transport. A large population of quartz grains is therefore necessary for a reliable exoscopic investigation.

Conclusions

The loess material of the studied localities has been divided into four sub-groups according to the semiquantitative analysis of their heavy mineral fractions (Lisá in print), and to the identification of surface-wear patterns on individual grains. Loess material of the first sub-group appears to have been deflated from the weathering horizons of magmatic or metamorphic rocks to the west of the deposit. This material was thus transported from the west or northwest, and from less than 60 km away. The material of the other sub-groups was predominantly deflated from sedimentary rocks located to the west.

It is possible to estimate the distance of transport based on the degree of roundness of quartz grains only when the material originates from the weathering horizons of magmatic or metamorphic rocks, i.e. non-transported regolith. Sediments comprised predominantly of a fine fraction display few eolian surface textures. However, the type of source rocks can still be determined by other methods.

It is generally the case with typical eolian sediments that about 10% of the fraction studied will not show any surface textures typical of eolian transport. For a reliable interpretation, it is therefore necessary to utilize a large population of at least 100 quartz grains.

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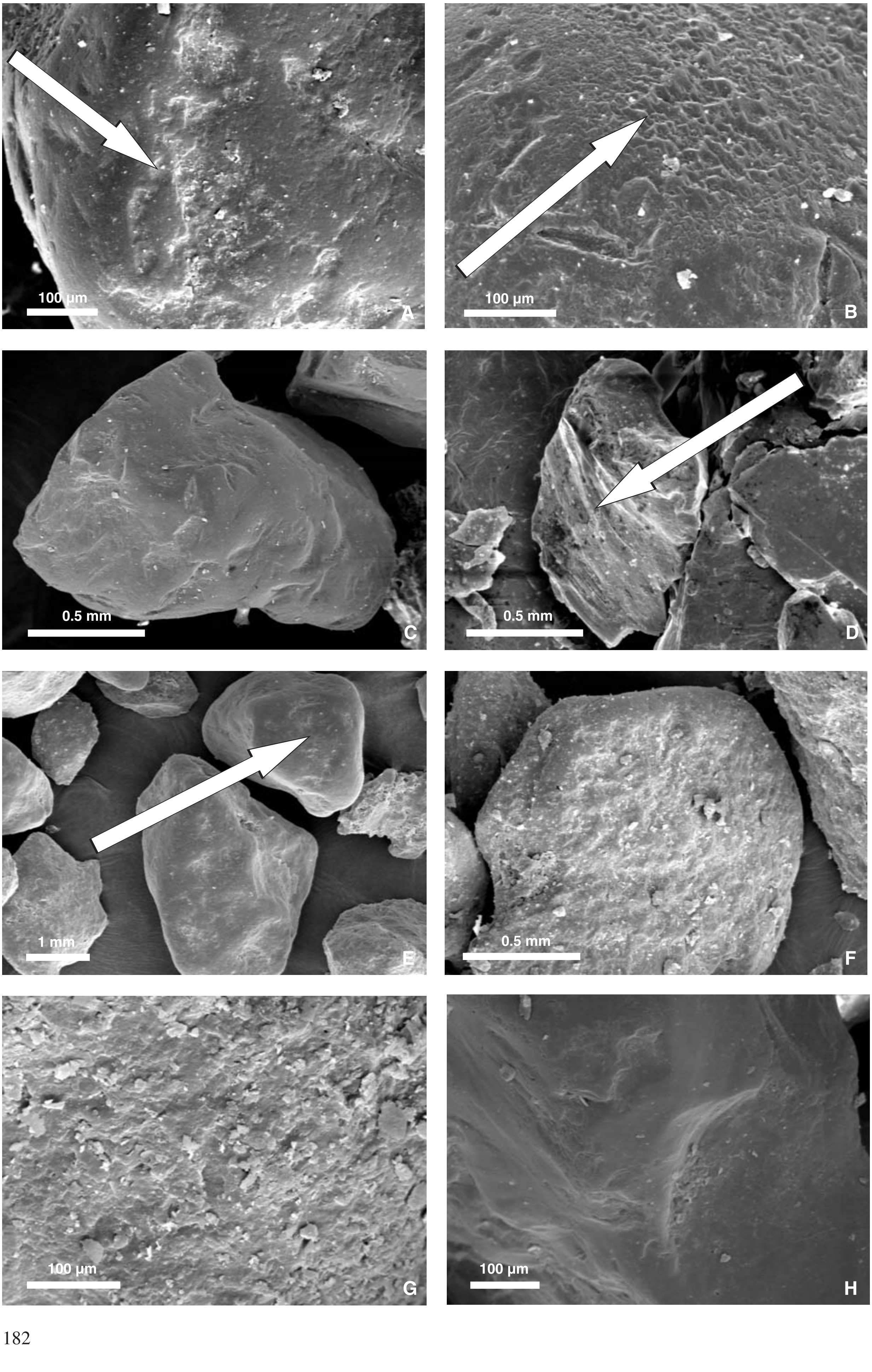
Plate I. Microstructures and surface features of quartz grains.
A – impact depressions with surfaces smoothed by silica precipitation indicated by the arrow; Modřice locality. B – rounded aeolian grain showing impact depressions; the surface indicated by the arrow has been smoothed after silica precipitation; Modřice locality. C – subrounded grain with partly smoothed mechanical grooves resulting from fluvial transport; Hranice locality. D – Angular grain with sharp edges and traces of glacial crushing; Osoblaha locality. E – Subrounded grain with traces of eolian transport; Ořechov locality. F – Subrounded grain with traces of eolian transport, strongly affected by chemical weathering and precipitation; Skrochovice locality. G – Strong chemical precipitation; Hranice locality. H – Mechanical grooves, mostly parallel to the elongation of the grain, caused by fluvial transport; Ořechov locality.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