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Texture and petrography of glacial deposits in the northern foothill of the Hrubý Jeseník and Rychlebské Mts., Czechia

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The petrographic and mineralogical characteristics of glacial deposits from the localities in the northern foothills of the Hrubý Jeseník and Rychlebské Mts. have been studied. Grain-size, petrographic composition, heavy minerals, clast shape and roundness have been investigated. The data obtained have been used to create a probability model to differentiate the stratigraphy of particular accumulations and for partial reconstruction of the advance direction of the ice sheet in the area. The main advance direction of the ice sheet was presumed to be from the NW to SE in this region. The erratic material was probably predominantly transported in the basal ice layers according to the clast shape and roundness. An Elsterian age of the sedimentary bodies investigated is suggested by correlation with analogous deposits in adjacent parts of Poland. This model contradicts previous correlations. However, further constraints on the stratigraphic position of these deposits would require the application of dating techniques.

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Key words: Northern Moravia, clast shape, provenance, glaciofluvial sediment, heavy minerals.

INTRODUCTION

The northern part of Moravia was affected by continental glaciation during the Mid Pleistocene (e.g. Macoun *et al*., 1965; Prosová, 1981; Macoun and Králík, 1995; Nývlt, 1998). In this paper we focus on the glaciated region in the northern foothills of the Rychlebské Mts. and the Hrubý Jeseník Mts. This region extends from the Rychlebské Mts. and Hrubý Jeseník Mts., ranging into the Žulová Uplands in the W and the Vidnava Lowland in the E. The study area is geologically very complicated. Precambrian to Palaeozoic rocks comprise mainly the Orlice-Sněžník Unit and the Desná Unit of the Silesian Metamorphic Unit (Žáček *et al*., 2004; Pecina *et al*. in press). The Žulová Massif of Late Carboniferous to Early Permian age is formed mainly of granite and granodiorite (Zachovalová *et al*., 2002; Pecina *et al*. in press). Tertiary deposits cover the NE part of the area (Žáček *et al*., 2004; Pecina *et al*. in press).

The former presence of ice masses has made characteristic changes to the local relief and deposited substantial accumulations of glacigenic and glaciofluvial sediments. These deposits contain local as well as far-travelled material, which may have originated either from the Central European Lowland in Poland and/or Germany or may be of Baltic or Fennoscandian origin. The provenance of the material deposited by glacial processes in the area studied has already been analysed (e.g. Gába, 1974, 2001; Kopečný and Pek, 1974; Gába and Pek, 1999; Pecina *et al*. in press).

Exposures of glacial deposits were chosen for sedimentary-petrological analyses in this study. Grain-size, gravel clast petrography, heavy minerals, clast shape and roundness have been investigated. The results have been used to define and compare the lithologies of particular accumulations and establish their stratigraphy. These sedimentary-petrological methods are sensitive to the nature of the palaeogeographic reconstruction; e.g. for the partial reconstruction of the advance direction of the ice sheet in the area.

FIELD SITES

Samples were taken from localities at Kolnovice, Supíkovice, the Vidnava former kaolin mine (marked here as

Vidnava), Dolní Červená Voda, Bernartice and Javorník (Fig. 1, Table 1).

The exposures studied at Kolnovice, Supíkovice, Vidnava, Dolní Červená Voda and Bernartice localities are situated within proglacial glaciofluvial sediments. A complex profile of subglacial and supraglacial melt-out tills may be seen at the Javorník locality (Pecina *et al*. in press).

Seven samples for grain-size analysis and three additional samples for petrographic analysis were taken at the Kolnovice locality. The particle size coarsens upwards from gravely sands in the lower part of the accumulation towards sandy gravels higher up. Seven further samples for petrographic analysis were taken at Supíkovice. The oscillation between sandy gravels and gravely sands is similar to that at the previous locality. At Vidnava two samples of medium-grained sand were taken. The Bernartice locality was sampled for two samples at the same depth, but from different sections; the particle size of these two samples varies from gravel to sand. Three samples were taken at Dolní Červená Voda, that shows a similar coarsening-upwards trend as at the other localities sampled. The last locality sampled is at Javorník, where two samples of supraglacial melt-out till were taken, both of them being sandy gravels.

METHODS

Samples were collected from cleared sections. The relative depth from the surface was measured by tape. The size of samples ranged between 1 and 6 kg depending on the particle size distribution of the deposit sampled. The samples were dried.

Individual samples were dry-sieved using coarse woven wire to micromesh sieves and a sieve shaker. The particle size fractions obtained were weighed by a precise digital balance with decimal accuracy, at the Laboratory of Physical geography and geoecology, Faculty of Science, Charles University in Prague and at the Department of Geological Science, Masaryk University in Brno. The methodology of sampling and laboratory analyses follows the methodology of Gale and Hoare (1991). The raw data were plotted on a histogram and a cumulative frequency distribution curve. The cumulative frequency curves provided values for calculations of statistical parameters of particle size following Folk and Ward (1957) as: Graphic Mean (Mz), Graphic Standard Deviation (σ), Graphic Skewness (S_k), Graphic Kurtosis (K_G), and Median (M_d). For further details on the methodology of particle size analyses used in this study see Folk and Ward (1957) and Gale and Hoare (1991).

For petrographic analysis the 8–16 and 16–64 mm fractions from the particle size analyses were used. Further samples of the coarser units were taken at some localities. These samples were sieved *in situ* and used only for petrographical analysis, and so have the prefix "S" (Table 1). On the basis of the initial petrographic analyses categories reflecting different provenances were determined. The local categories are: Žulová Granite, gneiss, quartzite, phyllite and silicite. Categories of Sudetes porphyry, basalt and sandstone of "near" provenance were identified. Granitoids, porphyries, sandstone and flint regarded as Nordic in origin were also recognized, though some flint clasts may also originate from Mesozoic sedimentary units in Poland. Quartz and undetermined rocks do not fall into any of the categories noted above (Gába and Wójcik, 1990; Gába and Pek, 1999) and are marked here as of indetermined provenance. Amounts of individual categories were calculated and converted into percentages. The O/K coefficient showing the proportion of sedimentary to crystalline rocks was calculated. The other petrographical coefficients (K/W, A/B) commonly used in Poland were not calculated, because limestones and dolomites have not been detected at the localities examined. Due to the absence of limestones and dolomites we were restricted to the use of the O/K coefficient for comparison with Polish data.

Long (a), intermediate (b) and short (c) particle axes were measured using a vernier calliper on selected petrographic categories for particle shape analyses. Ternary diagrams, which follow the Benn and Ballantyne (1993) modification of the diagram of Sneed and Folk (1958), were used for presentation of the data and analyses of the particle shapes. Ideal particle shapes are shown in Figure 2. Individual measured values were projected on to triangular diagrams by using the TRI-PLOT spreadsheet method of Graham and Midgley (2002).

Separation and identification of heavy minerals was carried out an 200–250 ml samples of material. These samples were sieved on a 0.5 mm mesh. The <0.5 mm fraction was washed to get remove the silt and clay fraction and was then dried. 1,1,2,2–tetrabromethan ($C_2H_2Br_4$) with a density of 2.96 g/cm^3 was used for the separation of the samples. Separation of heavy

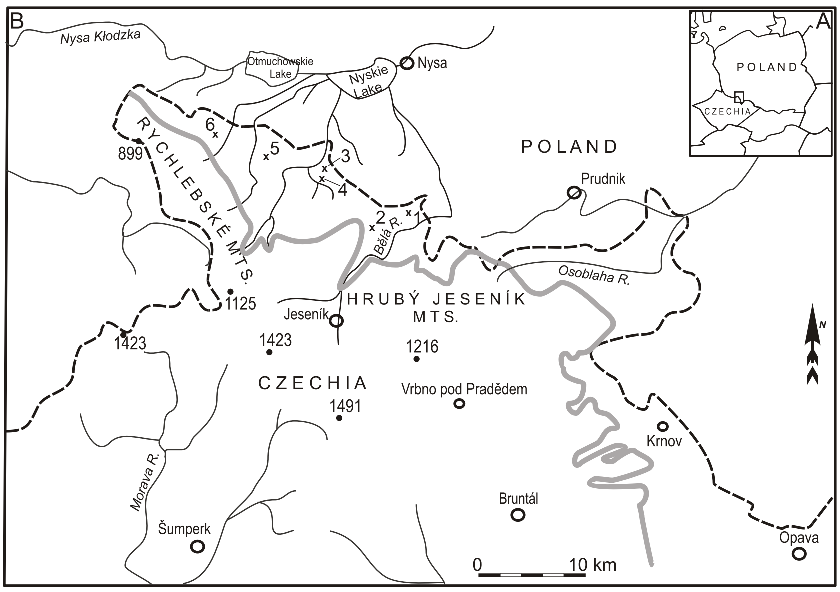

Fig. 1. Sketch map of the area studied with individual localities

1 — Kolnovice, 2 — Supíkovice, 3 — Vidnava, 4 — Dolní Červená Voda, 5 — Bernartice, 6 — Javorník; solid line shows maximum extent of continental glaciation; the dashed line shows the boundary between Poland and the Czech Republic

Table 1

Table of localities with altitudes, sample names and their depths from the undisturbed surface

Locality (altitude)	Symbol of sample	Depth [m]
Kolnovice (388 m)	1K	4.5
	2K	6.5
	3K	7.1
	4K	8.0
	5K	8.2
	6K	14.6
	7K	15.1
	S1K	5.1
	S2K	7.5
	S3K	8.2
Supíkovice (397 m)	1S	6.4
	2S	8.0
	3S	15.4
	4S	17.5
	5S	21.1
	S1S	14.6
	S2S	16.1
Vidnava (278 m)	1V	1.3
	2V	8.4
Bernartice (308 m)	1B	1.5
	2B	1.5
Dolní Červená Voda (311 m)	1D	1.4
	2D	1.8
	3D	2.5

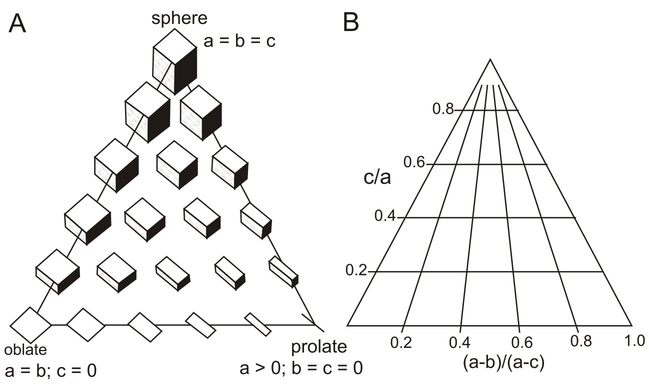

Fig. 2. Ternary diagrams used by Sneed and Folk (1958); A — definition of apices of triangular diagram and positions of selected idealized shapes; B — the scaling of triangular diagrams

For explanations see the text

minerals was done at laboratories of Czech Geological Survey in Prague. Heavy mineral samples were studied by binocular and polarization microscopes. Semi-quantitative method was used to determine the distribution of individual minerals or mineral groups.

RESULTS

Sampling at Kolnovice was between 4.5 and 15.1 m below the surface. The grain-size characteristics here vary from very well sorted medium-grained sands in the lower part, through poorly sorted gravely sands in the middle part to very poorly sorted sandy gravels in the upper part. Graphic skewness is nearly symmetrical in the samples; only two gravely sand samples (3K, 5K) from the middle part are coarse-skewed. The overall graphic kurtosis of the samples is rather flat-peaked (platikurtic) rather than neutral. All histograms of samples from Kolnovice locality were unimodal. The statistical variables of the samples studied are shown in Table 2.

At the Supíkovice locality five samples were taken in depth range of 6.4 to 21.1 m. The grain-size characteristics grade negatively from moderately sorted medium-grained sands to very poorly sorted sandy gravels analogous to those at Kolnovice. Graphic skewness is nearly symmetrical, only sample 4S is very coarse-skewed due to the absence of fines. Graphic kurtosis varies significantly between slightly platikurtic samples and very leptokurtic ones with marked peaks due to significantly better sorting in the centre of the distribution. Histograms of the samples from the Supíkovice locality are unimodal, except for the bimodal uppermost sample 1S.

At the Vidnava locality two samples from depths 1.3 and 8.4 m were taken. The upper sample is poorly sorted sandy gravel that produced a nearly symmetrical, flat-peaked and unimodal histogram. The lower sample is a nearly symmetrical moderately sorted medium-grained sand giving a markedly peaked unimodal histogram. Two samples were taken from the same depth (1.5 m), but from different exposures at the Bernartice locality. One sample is a poorly sorted sandy gravel with a nearly symmetrical, normal histogram with a bimodal distribution. The other is a very poorly sorted gravely sand, coarse skewed, flat-peaked with a unimodal distribution. Three samples were taken at depth range of 1.4 to 2.5 m at Dolní Červená Voda. All samples are poorly sorted with normal and unimodal histograms. Two samples from the upper part are gravely sands with nearly symmetrical distributions; the lowest sandy sample is slightly coarse skewed. Two samples from depths of 0.8 and 1.2 m were sampled at the Javorník locality. Both samples are sandy gravels with reasonably flat-peaked and bimodal histograms. The upper sample is poorly sorted and nearly symmetrical, the lower sample is very poorly sorted and fine-skewed.

The amounts of individual petrographic categories were calculated and transferred into percentage shares (Table 3). The O/K petrographic coefficient is quite low for all the studied samples, lying between 0.12 and 0.40.

Clasts of Nordic granitoid, Nordic porphyry, Nordic sandstone, "near" sandstone, Sudetes porphyry, Žulová Granite and quartz from petrographical analysis in the 8–16 mm fraction

Table 2

Statistic parameters of grain-size distributions of the samples using the statistical indices of Folk and Ward (1957)

Locality/sample		Depth [m]	M_Z [ϕ]	Md [ϕ]	σ [ϕ]	S_k	K_G	Histogram	Classification
Kolnovice	1K	4.5	–2.71	–2.60	2.25	–0.03	0.77	unimodal	sandy gravel
	2K	6.5	–2.15	–2.30	2.13	0.00	0.86	unimodal	sandy gravel
	3K	7.1	–0.76	–0.48	1.55	–0.29	1.09	unimodal	gravely sand
	4K	8.0	–1.50	–1.20	2.11	–0.01	1.01	unimodal	sandy gravel
	5K	8.2	–1.01	–0.73	1.84	–0.22	0.78	unimodal	gravely sand
	6K	14.6	1.53	1.50	0.31	0.09	0.81	unimodal	medium-grained sand
	7K	15.1	1.53	1.53	0.36	0.08	0.97	unimodal	medium-grained sand
Supíkovice	1S	6.4	–2.30	–2.05	2.34	–0.01	0.83	bimodal	sandy gravel
	2S	8.0	–1.77	–1.80	1.84	0.00	0.94	unimodal	sandy gravel
	3S	15.4	2.54	2.55	0.67	0.09	1.59	unimodal	medium-grained sand
	4S	17.5	1.15	1.28	0.83	–0.38	1.46	unimodal	medium-grained sand
	5S	21.1	1.41	1.41	0.58	–0.08	1.24	unimodal	medium-grained sand
Vidnava	1V	1.3	–1.76	–1.81	1.96	0.04	0.82	unimodal	sandy gravel
	2V	8.4	1.39	1.40	0.76	–0.04	1.16	unimodal	medium-grained sand
Bernartice	1B	1.5	–1.95	–1.90	1.94	0.00	1.06	bimodal	sandy gravel
	2B	1.5	–1.00	–0.63	2.03	–0.25	0.82	unimodal	gravely sand
Dolní Červená Voda	1D	1.4	–0.01	0.10	1.52	–0.10	0.92	unimodal	gravely sand
	2D	1.8	–0.03	0.20	1.24	–0.03	1.10	unimodal	gravely sand
	3D	2.5	0.55	0.60	1.33	–0.11	1.10	unimodal	sand
Javorník	1J	0.8	–2.18	–2.00	1.82	–0.01	0.71	bimodal	sandy gravel
	2J	1.2	–2.04	–2.43	2.41	0.2	0.68	bimodal	sandy gravel

For other explanations see the text

Table 3

Results of petrological analysis; percentage shares of clasts divided into local, "near", Nordic and indetermined provenances from the localities studied

Locality	Sample	Fraction [mm]	Depth [m]	Number of clast	Provenance [%]				O/K
					Local	Near	Nordic	Indet.	
Kolnovice	S1K	8–16	5.1	805	62.2	2.7	8.9	26.1	0.165
	S2K	16–64	7.5	403	61.3	7.7	9.4	21.6	0.202
	S3K	8–16	8.2	490	59.6	3.1	7.6	29.8	0.206
Supíkovice	1S	16–64	6.4	581	49.4	10.3	14.5	25.8	0.337
	2S	16–64	8.0	288	71.1	4.7	11.8	12.4	0.401
	S1S	8–16	14.6	359	73.8	1.4	8.7	15.9	0.117
	S2S	8–16	16.1	583	68.6	2.2	5.5	23.7	0.237
Vidnava	1V	8–16	1.3	342	42.4	7.0	14.6	36.0	0.143
Bernartice	1B	16–64	1.5	267	50.2	12.7	7.1	30.0	0.162
	2B	8–16	1.5	180	43.9	11.1	13.3	31.7	0.188
Dolní Èervená Voda	2D	16–64	1.8	333	40.8	12.9	19.8	26.4	0.301
Javorník	1J	16–64	0.8	206	51.5	10.7	16.5	21.4	0.189
	2J	8–16	1.2	253	48.2	6.7	16.2	28.9	0.248

For other explanations see the text

were taken for shape analysis. The lengths of the three measured axes were put into the TRI-PLOT spreadsheet diagram of Graham and Midgley (2002); see Figure 3. The shape analysis was carried out for the whole study area collectively.

Andalusite, apatite, biotite, epidote group, Fe secondary minerals group, garnet group, hornblende group, illmenite, kyanite, magnetite, pyrite, pyroxene group, rutile, sillimanite, titanite, tourmaline and zircon were determined in selected samples. Percentage shares of contents of individual minerals or mineral groups were determined by a semi-quantitative method and the garnet-hornblende ratio was calculated (see Table 4).

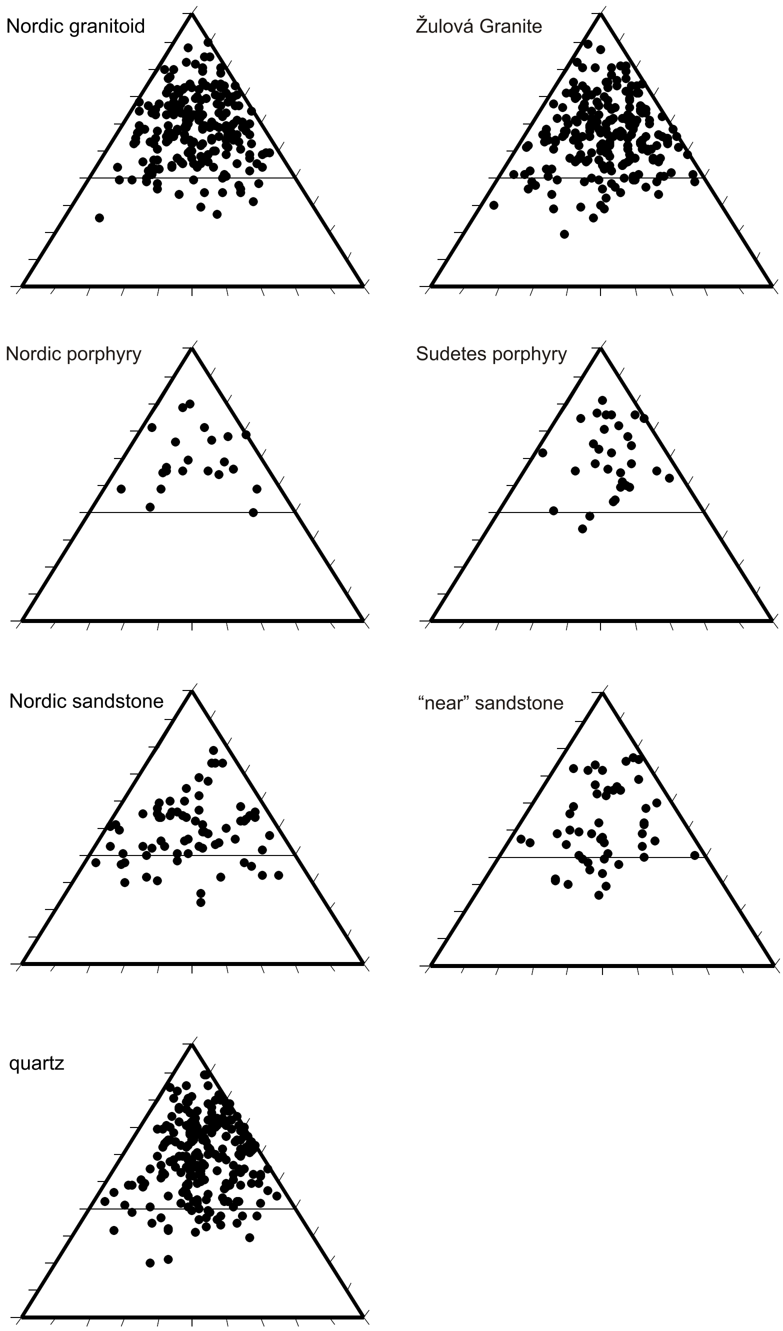

Fig. 3. TRI-PLOT diagrams of Nordic granitoid, Žulová Granite, Nordic prophyry, Sudetes porphyry, Nordic sandstone, “near” sandstone and quartz clasts in the 8–16 mm fraction

DISCUSSION

Particle size analysis was used as one of the criteria to constrain the genesis of deposits from the localities studied. A unimodal distribution with a symmetrical to coarse-skewed histogram is typical of glaciofluvial sediments while a polymodal (bimodal is the most common) distribution with fine-skewed histograms is more typical of tills (see Dreimanis and Vagners, 1971, 1972; Haldorsen, 1981; Rzechowski, 1982).

A bimodal distribution is seen on histograms of both samples from the Javorník locality and in the uppermost samples from Supíkovice and Bernartice. Samples from Javorník were taken from supraglacial melt-out till and were rich in the fine fraction, which together with positive skewness and platikurtic kurtosis is typical of tills (Růžičková *et al.*, 2001). The uppermost samples from Supíkovice and Bernartice were probably deposited in a proximal glaciofluvial setting. Though the samples are poorly sorted, the low contents of fines are not typical of tills. The uppermost sample from Kolnovice is except for being unimodal, very similar to the uppermost samples from Supíkovice and Bernartice and was probably deposited in a similar environment.

Other samples show a unimodal distribution and their partical size characteristics are typical of glaciofluvial sediments. The diagram of graphic mean versus graphic standard deviation of the samples studied compared with unpublished data of Z. Gába from the same study area is given in Figure 4. The measured particle size and graphic mean deviation of samples from Javorník locality should lie higher in both cases. Our samples have not contained large clasts, the long axes of which can exceed 1 m at this locality.

A difference between the material of local, near and Nordic provenance was recognized in the study area by means of petrographical analyses. The highest amounts of Nordic material were at the Javorník and Dolní Červená Voda localities (>16%). Samples from Vidnava, Supíkovice and Bernartice contain 5–15% of Nordic material. All samples from the Kolnovice locality are characterized by less then 10% of Nordic material.

In localities where more than one sample was taken for petrographical analysis, an enrichment in Nordic material upwards has been observed. This phenomenon was described by Nývlt and Hoare (2000) from northern Bohemia and was explained as due deposition during glacier retreat, when far-travelled material comes later into the proglacial outwash depositional system.

Petrographic analysis of material from the Bernartice and Kolnovice localities carried out by Gába (1974, 2001) show some 5% more

Table 4

Percentage content of heavy minerals and garnet-hornblende ratios for selected samples from the localities studied

Locality		Semi-quantitative percentages [%]																		Garnet/Hornblende
Sample	Depth [m]	Hornblende	Andalusite	Apatite	Biotite	Fe sec. min.	Garnets	Illmenite	Kyanite	Magnetite	Pyrite	Pyroxenes	Rutile	Sillimanite	Epidotes	Staurolite	Titanite	Tourmaline	Zircon	
Kolnovice																				
1K	4.5	18	0	3	2	26	7	10	1	2	0.5	9	2	0.5	3	9	1	1	5	0.40
3K	7.1	19	0	3	2	21	6	7	4	1	0	10	1	2	1	9	2	2	10	0.30
5K	8.2	21	0	0.5	2	25	6	6	0	1	2	21	0.5	2	2	4	2	1	4	0.30
6K	14.6	24	0	2	3	27	3	8	0.5	1	0.5	20	1	2	2	1	2	2	1	0.10
7K	15.1	15	2	0.5	2	28	7	8	4	2	1	8	2	0	2	4	0.5	5	9	0.45
Supíkovice																				
3S	15.4	13	0	2	4	19	6	13	5	1	0	5	2	3	2	6	1	6	12	0.45
4S	17.5	14	0	0	1	28	9	9	2	0.5	1	8	0	3	4	8	1	0.5	11	0.65
5S	21.1	12	0	1	1	25	9	16	5	0.5	0	4	1	2	3	5	0.5	3	12	0.75
Vidnava																				
1V	1.3	21	0	4	0.5	24	12	8	0	1	1	9	1	1	3	7	0	0.5	7	0.55
Bernartice																				
2B	1.5	19	0	3	0.5	25	9	10	3	1	0.5	10	1	1	2	8	0	2	5	0.45
Dolní Červená Voda																				
1D	1.4	13	0.5	3	2	29	7	10	4	2	0.5	7	2	3	2	6	0	2	7	0.55
3D	2.5	13	0	3	2	27	9	10	4	2	1	7	2	3	2	5	0	1	9	0.70
Javorník																				
2J	1.2	18	0	4	1	27	7	7	3	1	0.5	10	1	0.5	2	7	0	4	7	0.40

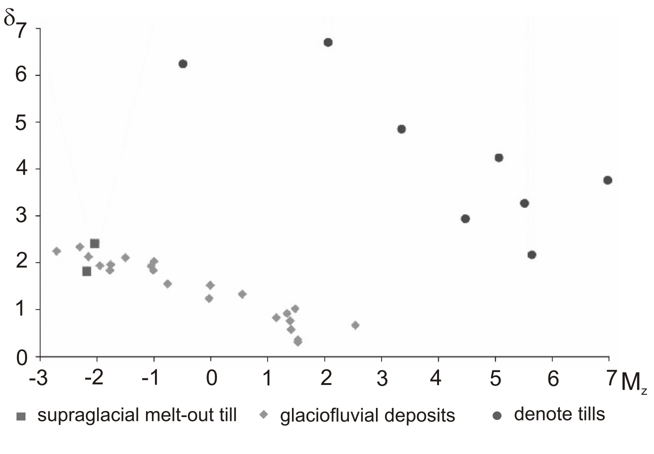

Fig. 4. The diagram of graphic mean (M_Z) to graphic standard deviation (δ) ratio of the samples studied

Nordic material in comparison with our results. This enrichment can be explained by using a finer fraction and/or by sampling from the upper parts of the sections. Petrological analyses in the area studied have shown a decrease in the relative amount of Nordic material in a NE–SW direction. This pattern is consistent with conclusions of the direction of the ice sheet advance and/or glacier meltwater discharge by Gába (1972) and Gába and Wójcik (1990) in the study area and is analogous with the concept of the ice sheet advance in the near Polish area during the Elsterian stadials (Czerwonka and Krzyszkowski, 1992, 1994; Krzyszkowski and Ibek, 1996). This may be also supported by the lower values of the O/K coefficient, which correspond only with those of the Pietrzykowice Till Formation of the South Polish Glaciation (Elsterian) in nearby parts of Poland (Czerwonka, 2004), in spite of using a coarser fraction than is commonly used in Polish studies. The younger glacial deposits of Poland contain a higher amount of sedimentary rocks as a result of higher input of that material into the system. Alternatively they have not been affected by weathering processes for long enough to remove sedimentary clasts from the fractions studied.

Shape analysis was carried out on selected categories from the material used for petrographic analysis. Similar categories with different origins were chosen for comparison. The couples: Nordic granitoid — Žulová Granite, Nordic porphyry — Sudetes porphyry, Nordic sandstone — "near" sandstone and category of quartz were measured. It is possible to place TRI-PLOT diagrams of selected categories in the sequence: Nordic porphyry, Nordic granitoid, Sudetes porphyry and Žulová Granite, with increasing area scatter. The sequence follows the rule that the longer the transport distance, the more spherical-shaped the transported material and the smaller the scatter (see Benn and Ballantyne, 1993, 1994; Huddart, 1994). Diagrams of Nordic and "near" sandstones are very similar and they could not be differentiated using their shapes. The lower possibility of comparing Nordic sandstones to "near" sandstones may be due to the similar lithologies of these sandstones.

Diagrams of Nordic granitoid, Nordic and Sudetes porphyries and quartz show a slight clustering to the right side of the diagram field. This clustering is caused by the shortening of the *b*-axis. Such *b*-axis shortening is usually caused by active subglacial transport of glacial material (Benn and Ballantyne, 1993, 1994; Bennett *et al*., 1997).

A typical association of clearly glacially-derived heavy minerals has been determined in selected samples, with garnets, epidote group minerals and hornblendes considered as being "typical Nordic heavy minerals" (Choma–Moryl *et al*., 1991; Otava *et al*., 1991; Czerwonka and Krzyszkowski, 1992; De Jong, 1993; Krzyszkowski and Ibek, 1996; Skupin and Speetzen, 1998).

A pyroxene-bearing horizon was found in the middle part of the section sampled at Kolnovice. This horizon is very similar to the Oleśnice Pyroxene Formation, which was described near Wrocław by Czerwonka and Krzyszkowski (1992). The Oleśnice Pyroxene Formation was probably deposited during the Elsterian interstadial. The higher amounts of pyroxene and hornblende in the middle part of the Kolnovice section is exceptional within the samples studied. It is possible to categorize localities into those enriched in Nordic heavy minerals (garnet-hornblende-epidote) group (Vidnava and Bernartice localities) and those impoverished in them (Supíkovice and Dolní Červená Voda localities), with the Kolnovice and Javorník localities showing an intermediate amount of Nordic heavy minerals. Czerwonka and Krzyszkowski (1992) also described a slight difference in the garnet-hornblende ratio between the Pietrzykowice till of an older Elsterian stadial and the Wierzbno till from a younger Elsterian stadial. The samples from Supíkovice and Dolní Červená Voda localities have the highest garnet-hornblende ratios; samples from the Kolnovice locality have by contrast the lowest garnet-hornblende ratio. However, considering that differences in the garnet-hornblende ratio of all the samples studied are slight, it is not possible to make a distinction between these deposits on the basis of the garnet-hornblende ratio.

CONCLUSIONS

The presence of typical sedimentary structures (though not discussed in this paper) and particle size characteristics in the study area indicate the presences of glacial deposits. Those of the Kolnovice, Supíkovice, Dolní Červená Voda, Bernartice and Vidnava localities have accumulated as glaciofluvial sediments, while the material from the Javornik locality formed as subglacial melt-out till.

On the basis of petrographic analysis it is possible to observe a decrease in the relative amount of Nordic material in a NW–SE direction. This direction is considered as being the main course of glacial movement and melt-water runoff during the Elsterian. A greater content of Nordic material stratigraphically upwards is a feature of sedimentation during the retreat stage of this glaciation. Shape analysis of igneous rocks indicates an increase of roundness with the greater transport and suggests mostly subglacial transport of the material.

A pyroxene-bearing horizon was found at the Kolnovice locality. This enrichment in pyroxene and hornblende may correlate with the Oleśnice Pyroxene Formation in Poland, which is of the fluvial origin and was deposited during Elsterian interstadial. Garnet-hornblende ratios and the low O/K coefficients from upper and lower samples from the Kolnovice locality coincide with those from tills (Pietrzykowice and Wierzbno) from the adjacent Polish area from older and younger Elsterian stadials respectively. Nevertheless all measured ratios are very similar and it is not possible to use them as the sole distinguishing method.

Our study modifies the interpretion of the Mid Pleistocene glaciation in the area studied. Ice sheet masses entered the study area probably during both Elsterian stadials. Most of the material was deposited during the retreat stages of both glaciations. The material was actively transported in the subglacial zone at least for some part of the transport path. The final stratigraphic correlation of the glacial deposits of the study area needs further sedimentary-petrological, stratigraphic and dating studies. The increase in Nordic material to the NW and stratigraphically upwards supports the hypothesis of glacier advance from the NW to the area of study and the prevalence of proglacial sedimentation during the retreat phases of each glaciation. Sedimentary-petrological data could serve for correlation of glacial deposits in the border zone of the Czech Republic and Poland.

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