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A Carboniferous/Permian, calc-alkaline, I-type granodiorite from the Małopolska Block, Southern Poland: implications from geochemical and U-Pb zircon age data

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A granodiorite from borehole WB-102A in the Dolina Będkowska, the Małopolska Block (MB), Southern Poland, yielded a mean U-Pb zircon age of 300 ±3 Ma with SHRIMP II. No inherited older component was detected. Geochemically, it is a K-rich, I-type, calc-alkaline granodiorite with supra-subduction characteristics (negative Nb and Ti anomalies). Silicic igneous rocks are abundant at the MB margin along the Kraków–Lubliniec Fault Zone (KLFZ) across which it adjoins to the Upper Silesian Block (USB) where such rocks are scarce. Both blocks belong to the Variscan foreland. Granitic rocks cannot, however, generate at foreland settings. Thus, the hypothesis is put forward that the parent melt for the silicic rocks was derived from the thickened lower crust of the Variscan orogenic belt owing to extensional decompression melting, and transported away towards pull-apart openings developed along the crustal-scale fault zone (KLFZ) that underwent a complex strike-slip history around the Carboniferous/Permian boundary.

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INTRODUCTION

In Southern Poland, the NW-trending, crustal-scale Kraków–Lubliniec Fault Zone (KLFZ) separates, in the subsurface, the Upper Silesian Block (USB) of the composite Brunovistulian Block (BB) from the SW from the Małopolska Block (MB) to the NE, both concealed under Mesozoic-Cenozoic platform cover and Carpathian nappes (Fig. 1). The two blocks differ markedly in the velocity structure of the crust as shown by seismic refraction profile CEL-02 of the CELEBRATION 2000 experiment (Malinowski *et al.*, 2005). Such seismic data is consistent with earlier interpretations of the Kraków–Lubliniec Fault Zone as a terrane boundary (Brochwicz-Lewiński *et al.*, 1986; Harańczyk, 1994; Dadlez, 1995; Buła *et al.*, 1997, Nawrocki *et al.*, 2004). Based on different lines of evidence, this prominent crustal feature is assumed to have originated in Neoproterozoic-Cambrian times and then repeatedly rejuvenated during the Palaeozoic (Dudek, 1980; Dadlez, 1995; Żelaźniewicz, 1998; Żaba, 1999; Nawrocki *et al.*, 2004). On the pre-Mesozoic surface, the feature is confined to a *ca*. 500 m wide zone of intensely brittle deformation (Buła *et al.*, 1997; Żaba, 1999) observed in Palaeozoic rocks of the MB and USB. Another conspicuous subsurface manifestation of the KLFZ is a demarcation of the Lower to Middle Cambrian shallow-water sandstone succession on the Upper Silesian Block (Buła, 2000) which does not pass across the fault (Fig. 1A). In contrast, on the MB side, unmetamorphosed to anchimetamorphosed Neoproterozoic pelites (Jachowicz, 1994; Jachowicz *et al.*, 2002), overlain by Ordovician and Silurian carbonates and pelitic to psammitic rocks, adhere to the Kraków–Lubliniec Fault Zone (Buła, 2000). On the two blocks, Devonian carbonates are covered by Carboniferous clastic rocks. The Kraków–Lubliniec Fault Zone, which dips steeply to the NE or SW (Żaba, 1999) in its near-surface sections, likely becomes a widely distributed feature deeper in the crust (Malinowski *et al.*, 2005).

In both walls of the Kraków–Lubliniec Fault Zone, igneous rocks are in evidence (Fig. 1). They are much less abundant on the USB side. K-rich rhyolites to dacites intruded in the form of

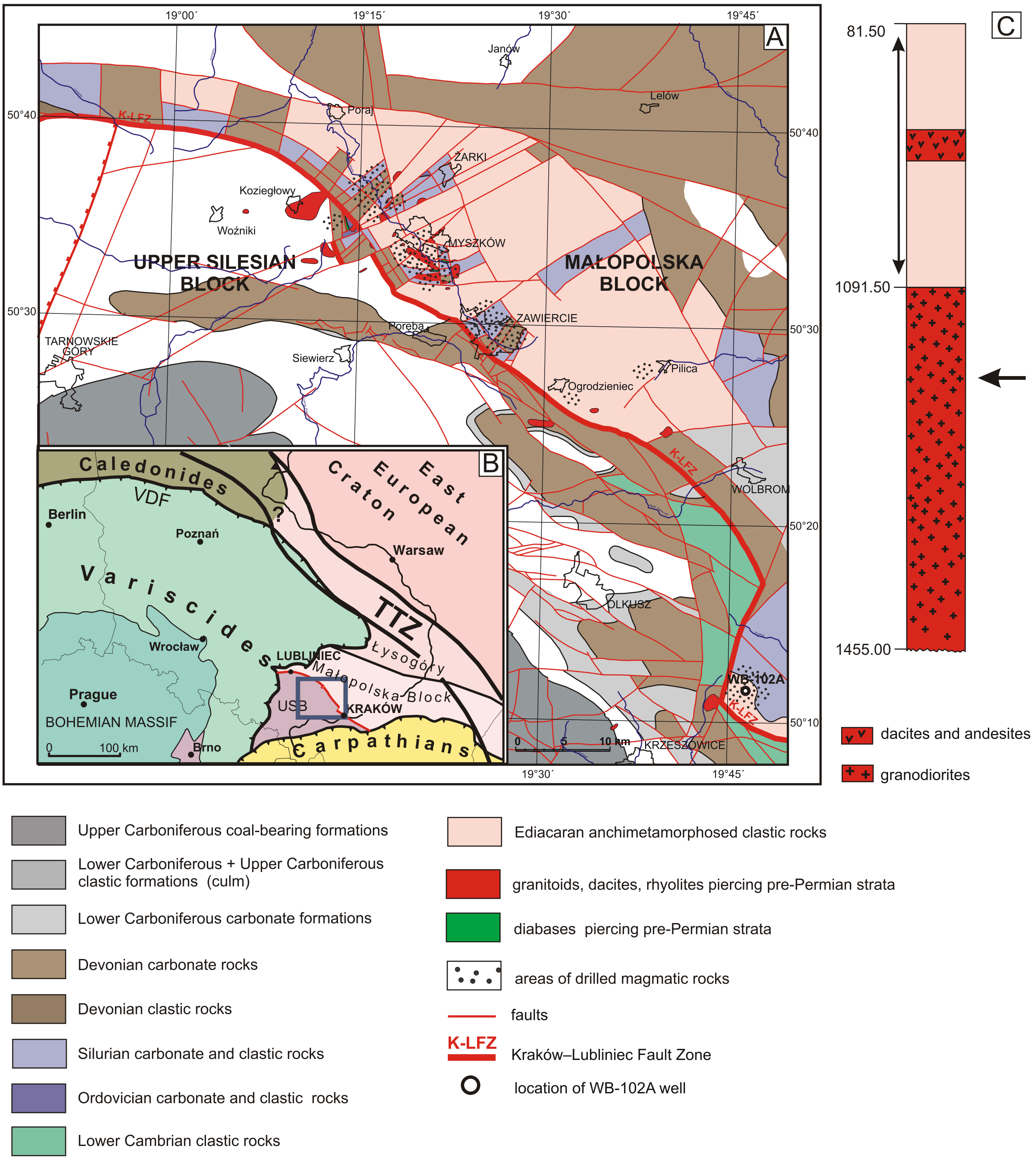

Fig. 1A — geological map of the Kraków–Lubliniec Fault Zone area (after Buła and Habryn, 2008, modified): TTZ — Teisseyre-Tornquist Zone, USB — Upper Silesia Block, VDF — Variscan deformation front (after Pożaryski and Karnkowski, 1992; B — location of the KLFZ area in Poland (after Mazur and Jarosiński, 2006, modified; Pożaryski *et al.*, 1992); C — simplified log of borehole WB-102A

laccolith into Carboniferous mudstones that locally crop out WNW of Kraków in the Upper Silesian Block (Fig. 1). These were dated at 295 ±3 Ma (U-Pb zircon, Nawrocki *et al.*, 2008).

In boreholes located along the SW margin of the Małopolska Block, granites, porphyritic dacites and rhyolites, and minor mafic rocks have been encountered for up to some 10 km from the Kraków–Lubliniec Fault Zone during extensive surveying aimed at prospecting firstly, Pb-Zn and then for Cu, Mo, and W ore mineralization (Dolina Będkowska, where the borehole WB-102A is located, Pilica, Zawiercie, Myszków and Żarki areas; Fig. 1A). The Kraków–Lubliniec Fault Zone coincides with a marked gravity gradient and magnetic anomalies owing to the mineralization of the igneous rock masses (Królikowski and Petecki, 1995; Podemski, 2001). There is an array of low gravity anomalies, stretched in a NW–SE direction between Lubliniec, Myszków and Kraków on the Małopolska Block, which reflects the extensive presence of felsic igneous rocks at upper crustal levels. As some of these rocks intruded

Devonian carbonates, their late Palaeozoic age has been long, if imprecisely, known. A few attempts of dating (K-Ar, Ar-Ar, Re-Os) yielded whole-rock or mineral ages between 312 Ma and 290 Ma (Jarmołowicz-Szulc, 1984, 1985; G. Oliver in Harańczyk, 1989; Chaffee *et al.*, 1997; Podemski, 2001; Stein *et al.*, 2005). This paper reports the first U-Pb SHRIMP II analyses of zircons from a granitic rock of the Dolina Będkowska area, some details of the geochemistry of this rock, and the implications of the new data.

PETROGRAPHY AND GEOCHEMISTRY

In the Dolina Będkowska area, some 30 km NNW of Kraków (Fig. 1), granodiorites were encountered in the boreholes DB-5 and WB-102A at a depth of 1198 and 1091.5 m respectively, beneath an uppermost Neoproterozoic (Ediacaran) succession of anchimetamorphosed clastic rocks (Fig. 1C). The two boreholes are 270 m apart which is the minimum size of the concealed granitic body. A core retrieved from borehole WB-102A from a depth of 1186–1188 m (Fig. 1C), is of an unfoliated, coarse-grained granitoid with virtually no fabric (Fig. 2). It is noteworthy that a lack of fabric is characteristic of all the Małopolska granitoids and related subvolcanic rocks.

The WB-102A granodiorites are greyish red to rarely greyish green, generally holocrystalline, massive, medium-grained rocks. They are characterized by porphyritic texture with medium- and even coarse-grained plagioclase and fine-grained crystals of quartz, alkali feldspar and mafic minerals represented by biotite and amphibole. Zircon, apatite and titanite are present as accessory minerals. In modal composition, rock-forming minerals occur in various proportions: plagioclase 42–55 modal per cent, quartz 24–38%, alkali feldspar 3–20%, biotite 3–9%, and amphibole (Mg-hornblende) 0.4–3.2% (Markiewicz, 2006). Subhedral or euhedral tabular crystals of plagioclase are dominant within the rock. Plagioclase with conspicuous recurrent zonation are commonly observed (Fig. 2). The cores were identified as andesine, whereas the outer rims are oligoclase and albite. Most plagioclase crystals are slightly altered (sericitisation, carbonatisation, albitisation and rarely epidotisation). Alkali feldspar forms anhedral crystals which are occasionally replaced by kaolinite. Biotites which form coarse- and medium-grained crystals (Fig. 2), very often with inclusions of zircon and apatite, are only rarely chloritised.

Based on geochemistry (Table 1), the WB-102A rock is a metaluminous, K-rich, calc-alkaline granodiorite. On the Ba-Rb-Sr plot (El Bouseily and El Sokkary, 1975), it also appears in the granodiorite field. The A/CNK index of 0.9 allows assignation to an I-type granite with a K/Rb ratio of 268 and high K_2O+Na_2O. Such characteristics resemble A-type granites, however the Ga/Al ratio of 2.1 as well as relatively high CaO, Ba, Sr but low Zr contents are not consistent with such an affinity (Whalen *et al.*, 1987). Although some A-type similarity is not surprising in view of the geological position of the granodiorite in the Małopolska Block, the negative Nb and Ti anomalies strongly indicate a suprasubduction affinity, which is in line with relatively low Th contents (<10 ppm). On the Pearce *et al.* (1984) diagrams, the granodiorite plots persistently in the field of VAG and on the modified Rb-(Y+Nb) plot (Pearce, 1996) it also lies in the field of post-collision granites. LREE contents are 10–60 times chondrite and the REE pattern is moderately fractionated (La/Yb ratio). A lack of Eu anomaly, relatively high contents of Sr (>200 ppm) and Ba (> 800 ppm), and undepleted Rb and Cs suggest that plagioclase was not left at the source and consequently the melt could only be moderately fractionated and evolved (SiO_2 <70%). The high Ba and relatively low Rb (<100 ppm) also indicate insignificant feldspar fractionation (Blevin and Chappell, 1992). Utilizing some A-type resemblance, the melt may be thought to have been of crustal derivation as suggested by Y-Nb-Ce and Y-Nb-3Ga plots (Eby, 1992). The ratio CaO/Na_2O of 0.8 seems to speak in favour of partial melting of metapsammitic or granodioritic to tonalitic precursor rather than pelitic rocks (Jung and Pfänder, 2007). In the R1–R2 diagram (Batchelor and Bowden, 1985), it plots close to the border between the fields of pre-plate collision and post-collisional uplift. The lack of fabric in this rock corresponds well with the post-collisional signature and does not contradict a post-tectonic or anorogenic event in the region. However, in Zr+Nb+Ce+Y *versus* FeO_t/MgO and (K_2O+Na_2O)/CaO discrimination diagrams (Whalen *et al.*, 1987), the WB-102A granodiorite plots in the field of unfractionated granites (OGT), far from the field of A-type granites.

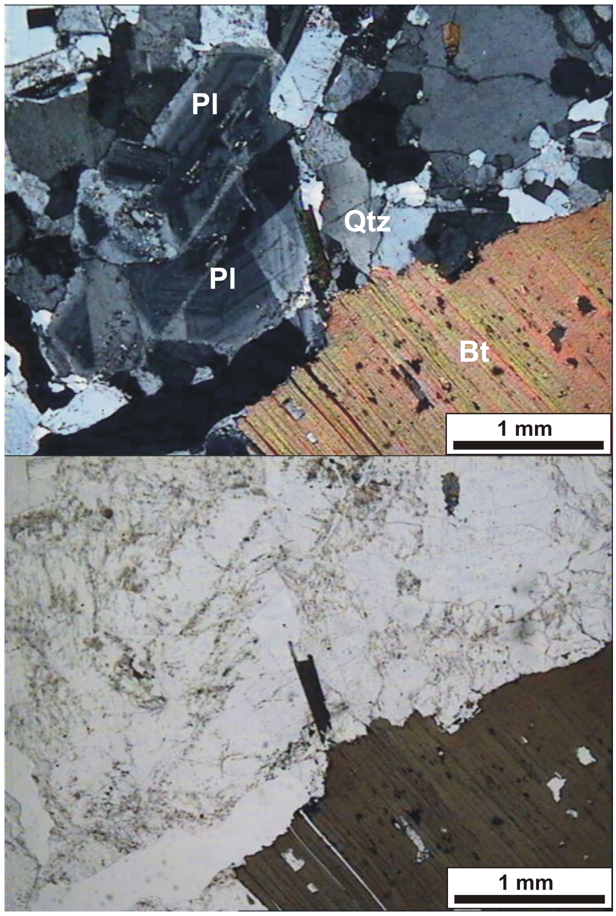

Fig. 2. Microphotograph of granodiorite WB-102A

Pl — plagioclase, Qtz — quartz, Bt — biotite

Table 1

Geochemistry of the granodiorite studied

Major elements oxides [wt.%]		Trace elements [ppm]					
SiO_2	68.19	Ba	843	Th	9.39	Eu	0.967
Al_2O_3	15.39	Co	85	Tl	0.60	Gd	3.29
Fe_2O_3	3.35	Cs	2.7	U	2.78	Tb	0.47
MnO	0.039	Ga	17	V	60	Dy	2.54
MgO	1.28	Ge	1.5	W	509	Ho	0.51
CaO	3.23	Hf	3.2	Y	15.6	Er	1.47
Na_2O	4.07	Nb	9.3	Zr	119	Tm	0.221
K_2O	3.20	Pb	9	La	21.8	Yb	1.40
TiO_2	0.585	Rb	99	Ce	45.9	Lu	0.225
P_2O_5	0.14	Sn	1	Pr	4.54		
LOI	0.65	Sr	373	Nd	16.8		
Total	100.12	Ta	0.93	Sm	3.21		

More detailed study of the geochemistry of the felsic rocks from the Małopolska Block is beyond the scope of this paper. Geochemical correlations with felsic rocks from other occurrences in the Małopolska Block are limited, as most published analyses from this region only show limits of contents of elements except for the paper by Markiewicz (2002) which refers to major and some trace elements. Comparisons based on available data reveal that the chemistry of three granitoids from the Myszków area resembles that of the studied sample WB-102A.

GEOCHRONOLOGY

ANALYTICAL METHODS

Zircons were separated using conventional heavy liquid and magnetic techniques. The sample was analyzed by the SHRIMP II at the Research School of Earth Sciences, Australian National University, Canberra. Zircon standard FC1 (zircon from the Duluth Gabbro) was used to correct Pb/U ratios for instrumental fractionation. All grains were imaged in cathodoluminescence (Fig. 3) and photographed in both trans-

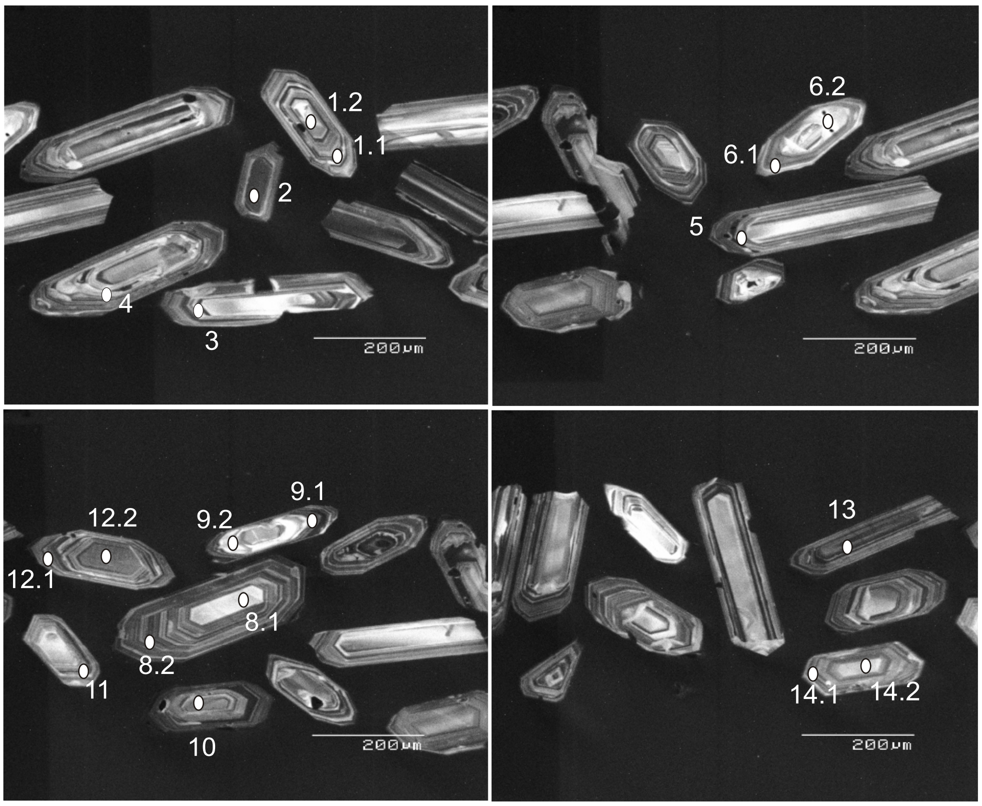

Fig. 3. Zircons in cathodoluminescence with locations of the analyzed spots marked

Table 2

Results of SHRIMP U-Pb analyses of zircons for the Dolina Będkowska granodiorite, sample WB-102A

Grain spot	U [ppm]	Th [ppm]	Th/U	$^{206}Pb^*$ [ppm]	$^{204}Pb/^{206}Pb$	f_{206} [%]	Total				Radiogenic		Age [Ma]	
							$^{238}U/^{206}Pb$	±	$^{207}Pb/^{206}Pb$	±	$^{206}Pb/^{238}U$	±	$^{206}Pb/^{238}U$	±
1.1	264	124	0.47	10.6	–	0.05	21.33	0.25	0.0526	0.0011	0.0469	0.0006	295.2	3.5
1.2	280	80	0.28	12.0	0.000629	0.23	20.14	0.27	0.0544	0.0010	0.0495	0.0007	311.7	4.1
2.1	637	338	0.53	24.2	0.000070	<0.01	22.60	0.29	0.0513	0.0008	0.0443	0.0006	279.3	3.5
3.1	297	139	0.47	12.3	0.000193	<0.01	20.76	0.27	0.0520	0.0009	0.0482	0.0006	303.5	3.8
4.1	467	200	0.43	19.2	0.000073	0.09	20.84	0.26	0.0531	0.0007	0.0479	0.0006	301.8	3.7
5.1	203	95	0.46	8.5	0.000369	0.14	20.54	0.37	0.0536	0.0011	0.0486	0.0009	306.1	5.4
6.1	307	109	0.36	13.0	0.000835	<0.01	20.33	0.24	0.0525	0.0010	0.0492	0.0006	309.6	3.6
6.2	187	96	0.51	7.6	0.000391	0.37	21.17	0.27	0.0553	0.0020	0.0471	0.0006	296.5	3.7
7.1	231	145	0.63	9.8	0.000305	0.22	20.29	0.25	0.0543	0.0010	0.0492	0.0006	309.5	3.8
8.1	203	121	0.60	8.5	0.000078	0.01	20.44	0.25	0.0526	0.0011	0.0489	0.0006	307.9	3.8
8.2	462	185	0.40	19.1	0.000140	0.11	20.80	0.23	0.0533	0.0007	0.0480	0.0005	302.4	3.3
9.1	481	249	0.52	19.5	0.000090	<0.01	21.22	0.24	0.0520	0.0007	0.0471	0.0005	296.9	3.3
9.2	195	194	1.00	7.8	0.000050	0.12	21.49	0.27	0.0532	0.0012	0.0465	0.0006	292.8	3.6
10.1	248	124	0.50	10.1	0.000116	<0.01	20.99	0.25	0.0508	0.0010	0.0477	0.0006	300.6	3.6
11.1	344	149	0.43	13.1	0.000281	0.24	22.61	0.27	0.0537	0.0009	0.0441	0.0005	278.3	3.2
12.1	528	232	0.44	21.0	0.000063	0.16	21.63	0.24	0.0534	0.0007	0.0461	0.0005	290.8	3.2
12.2	422	190	0.45	16.9	0.000197	0.18	21.45	0.55	0.0536	0.0008	0.0465	0.0012	293.3	7.4
13.1	812	533	0.66	32.5	0.000081	0.11	21.49	0.23	0.0531	0.0006	0.0465	0.0005	292.9	3.1
14.1	357	122	0.34	14.7	0.000125	<0.01	20.91	0.24	0.0524	0.0008	0.0478	0.0006	301.2	3.4
14.2	216	104	0.48	8.9	0.000434	0.38	20.76	0.31	0.0555	0.0011	0.0480	0.0007	302.1	4.5

Notes:

- uncertainties given at the ones level;
- error in FC1 Reference zircon calibration was 0.55% for the analytical session (not included in above errors but required when comparing data from different mounts);
- f_{206} [%] denotes the percentage of ^{206}Pb that is common Pb;
- correction for common Pb made using the measured $^{238}U/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios following Tera and Wasserburg (1972) as outlined in Williams (1998)

mitted and reflected light prior to SHRIMP analysis to identify cores and overgrowths and crack- and inclusion-free areas. Analytical procedures followed the methods described in Compston *et al.* (1984) and Williams and Claesson (1987). The data were reduced in a manner similar to that described by Williams (1998, and references therein), using the *SQUID Excel Macro* of Ludwig (2000). All ages in this study are calculated using the weighted average of the $^{206}Pb/^{238}U$ ages as normally preferred for Phanerozoic samples because the $^{207}Pb/^{206}Pb$ ages are sensitive to the common Pb correction. The plots of SHRIMP results, using *ISOPLOT/EX* (Ludwig, 2003) include: (1) a Tera-Wasserburg plot $^{238}U/^{206}Pb$ *versus* $^{207}Pb/^{206}Pb$ using data corrected for common Pb; Tera and Wasserburg (1972) as outlined in Williams (1998) which allows a visual assessment of the data to determine which data points should be used for the age calculation, (2) a stacked histogram, and (3) a weighted averages plot of $^{206}Pb/^{238}U$ ages (using the ^{207}Pb-common Pb correction method: Compston *et al.*, 1984). Individual analyses (Table 2) are presented as 1 sigma error ellipses on concordia plots and uncertainties in mean ages are quoted at the 95% confidence level (2 sigma).

DESCRIPTION OF SAMPLE

Zircons from the sample analyzed are generally transparent, pale-coloured and euhedral with short-prismatic to normal-prismatic and less frequent long-prismatic morphology (typical elongation from 2:1 to 4:1 and 7:1). Internally, most grains have a simple structure of characteristically magmatic oscillatory zoning and a few grains have planar-banded zoning (Fig. 3). Around one third of grains have a weakly zoned or slightly differently structured euhedral to somewhat subhedral core in crystallographic continuity with a euhedral overgrowth which displays more intense zoning.

RESULTS

The grains analysed have moderate U and Th contents with a Th/U ratio of 0.28–1.00 which is typical of zircons grown under magmatic conditions. 14 grains were analyzed in 20 spots (Table 2, Figs. 3 and 4). All 20 analyses form a single cluster around 300 Ma and a spread of ages between 311 Ma and 278 Ma, with no record of inherited old components. 10 analyses might apparently represent "older" zircons with a mean age of 304 ±2 Ma (MSWD = 0.89) and 7 analyses would represent "younger" grains with a mean age of 294 ±3 Ma (MSWD = 0.44). This would be in accord with the presence of euhedral to subhedral cores in some grains that might suggest two stages of zircon growth. However, there is no correlation between the core or outgrowth positions and the measured $^{206}Pb/^{238}U$ ages. The cores show a range of ages (Nos. 1, 6, 8, 9, 12, 14) between 311 to 293 Ma and do not define any distinct

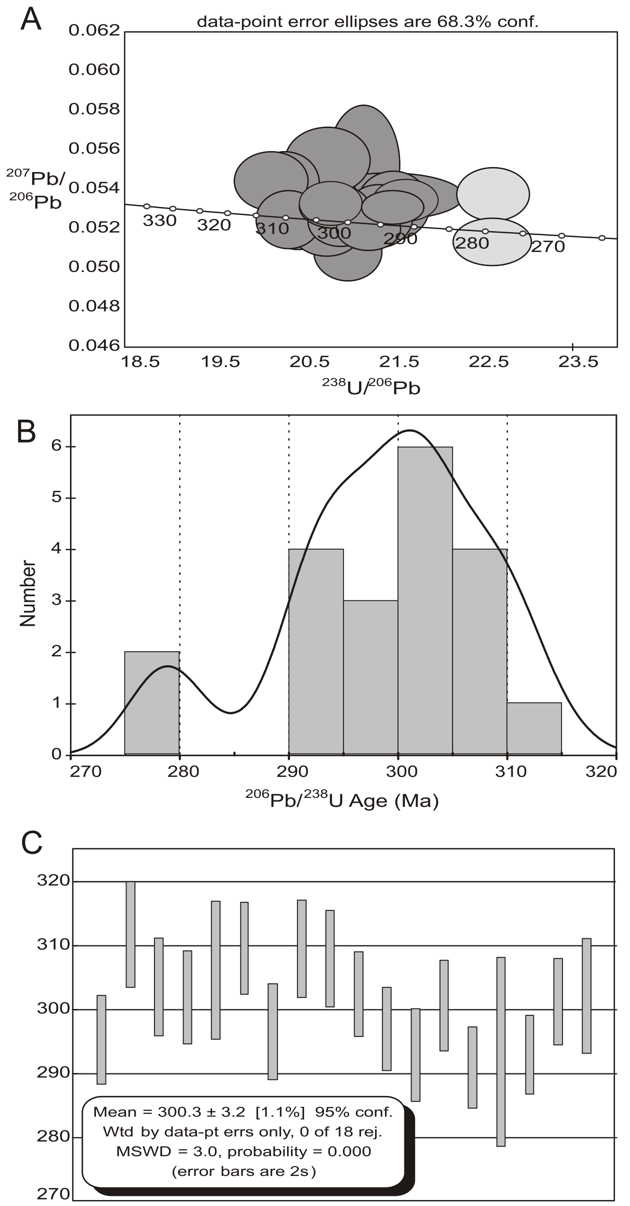

Fig. 4. U-Pb SHRIMP analyses of zircons from granodiorite WB-102A

A — Tera-Wasserburg concordia diagram; **B** — probability density distribution plot; **C** — frequency plot

independent event of zircon crystallization. Moreover, in two grains (Nos. 6 and 9), the cores appear younger than the rims (Fig. 3). Therefore, any apparent distinction within the entire group has no real significance, as confirmed by the Tera-Wasserburg concordia diagram (Fig. 4). Two analyses plot to the right of the group and are thought to possibly reflect Pb loss. Discarding these two youngest ages, 18 analyses yielded ages ranging from 311 to 293 Ma, with a mean age of 300 ±3 Ma (Table 2, Fig. 4) which records the main zircon crystallization event in the granodioritic magma. This is taken to date magma emplacement at the Carboniferous/Permian boundary (Gradstein *et al.*, 2004).

DISCUSSION

The time interval, 311–293 Ma, is very similar to that obtained by other methods for the Małopolska felsic rocks to the north of the Dolina Będkowska area, which is nearest to the rhyolitic laccolith area of the Upper Silesian Block (Fig. 1). The mean age of 300 ±3 Ma of the WB-102A granodiorite overlaps within error with a mean age of 295 ±3 Ma for the Zalas rhyolite (Nawrocki *et al.*, 2008). It follows that the igneous intrusions in the Małopolska Block and the Upper Silesian Block of Brunovistulia were contemporaneous, straddling the Carboniferous/Permian boundary. In view of the similar timing and their present-day proximity, their derivation from the same source is likely though not certain. More isotopic studies are required to resolve this question. A striking difference lies in the absence of mineralization in the Upper Silesian rocks, which is in marked contrast to those on the Małopolska side of the Kraków–Lubliniec Fault Zone. Borehole log profiles show that the outer portions of the granodiorite body(ies) and the enveloping country rocks are mineralized (Cu-Mo-W) and include calc-alkaline porphyry copper-type deposits (Podemski, 2001). In the case of the WB-102A and DB-5 boreholes, such mineralization likely developed towards the end of the magmatic activity in the area, and the bulk of the granodiorite body having remained barren.

Localization of the igneous intrusions mainly in the NE wall of the Kraków–Lubliniec Fault Zone and a lack of any fabric in the granitoids and related subvolcanic rocks suggest some control of the crustal-scale fault zone on the distribution of the high-level magmatic bodies in the regime with nearly zero deviatoric stress. Alternatively, the felsic magmas may have intruded as a mush with a low percentage of crystals, that might have prevented them from acquiring any directionally preferred arrangement at the time of emplacement. This is in line with the nearly 15 m.y. long time interval when zircons crystallized in the granodiorite magma that must have been in a protracted molten state, allowing for dissolution of all older zircons as no inherited component survived in the new zircon population. The high temperature of the intruding magmas, although still requiring quantification, is clearly shown by wide thermal halos around the igneous bodies, and corroborated by contact metamorphism up to migmatitic stage (Heflik and Piekarski, 1992; Moryc and Heflik, 1998).

At the Carboniferous/Permian boundary, the Małopolska wall of the Kraków–Lubliniec Fault Zone was subject either to an overall extension or to wrenching that might have given room for an array of igneous intrusions, possibly emplaced in pull-apart conditions. Indeed, a complex strike-slip regime comprising dextral transtension, followed by dextral transpression and then normal faulting with a sinistral slip component is suggested to have controlled the KLFZ evolution in latest Carboniferous through Permian times (Żaba, 1999). Such conditions are very likely to have facilitated the felsic intrusions, especially the dextral transtensional event that was thought by Żaba (1999) to be the one that favoured magma rise and final emplacement of the granodiorite bodies in the Małopolska Block in late Westphalian times. Our new SHRIMP data on zircons shows the event (300 ±3 Ma) actually straddled the Carboniferous/Permian boundary, by reference to the GTS2004 scale (Gradstein *et al*., 2004).

Late- to post-collisional felsic magmatism of similar age occurred in the Variscan orogenic belt in Central Europe at *ca*. 310–290 Ma (Bonin, 1998; Finger and Steyrer, 1990; Finger *et al*., 1997; Franke, 2000). However, the Małopolska intrusions occur outside the orogenic belt (Fig. 1) and granitoids are unlikely to generate in foreland settings. Therefore, we propose a hypothesis that the parent melt for the Małopolska and Upper Silesian silicic rocks was derived from the thickened lower crust of the Variscan orogenic belt owing to extensional decompressional melting near the crust/mantle boundary. The supra-subduction signatures inherited from the original setting were written in the chemical memory of the granitic melts which were derived from below the orogen that was undergoing thermal relaxation. They were likely driven by the hydraulic gradient and transported from their place of origin, in the westerly located orogenic root with remnant subduction zone, towards the not-too-distant pull-apart openings developed along the wrenched Kraków–Lubliniec Fault Zone in the relatively low velocity crust of the Małopolska Block (see Malinowski *et al.*, 2005). The high temperature granitic magma probably traveled as a crystal mush which kept it from forming a fabric alignment or, alternatively, the magmatic flow was turbulent. Advective heating in the crustal zone of the Kraków–Lubliniec Fault Zone is consitent with extensive contact metamorphism in the area (including skarns developed in overlying Devonian carbonates) and subsequent extensive hydrothermal processes around the Carboniferous/Permian boundary. Further geochemical and geochronological studies are necessary to test this hypothesis.

CONCLUSIONS

1. Silicic calc-alkaline magmatism occurred in the Variscan foreland parallel to the Kraków–Lubliniec Fault Zone between 310 Ma and 290 Ma, which was coeval with post-collisional granite intrusions in the Central European Variscides.

2. The magmatism was genetically connected with the Variscan orogen from which the felsic magma was likely driven by the hydraulic gradient and migrated towards the foreland.

3. Intrusions of felsic rocks were facilitated by the complex strike-slip and normal regime active along the crustal-scale Kraków–Lubliniec Fault Zone.

4. Although broadly coeval, granodiorites apparently intruded earlier than associated hypabyssal rocks in both the Małopolska Block and the Upper Silesian Block.

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REFERENCES

BATCHELOR R. A. and BOWDEN P. (1985) — Petrogenetic interpretation of granitoid rock series using multicationic parameters. Chem. Geol., **48**: 43–55.

BLEVIN L. B. and CHAPPELL B. W. (1992) — The role of magma sources, oxidation states and fractionation in determining the granite metallogeny of eastern Australia. Trans. Royal Soc. Edinburgh: Earth Sc., **83**: 305–316.

BONIN B. (1998) — Orogenic to non-orogenic magmatic events: overview of the Late Variscan magmatic evolution of the Alpine Belt. Tr. J. Earth Sc., **7**: 133–143.

BROCHWICZ-LEWIŃSKI W., VIDAL G., POŻARYSKI W., TOMCZYK H. and ZAJĄC R. (1986) — Pre-Permian tectonic position of the Upper Silesian Massif (S Poland) in the light of studies on the Cambrian. C. R. Acad. Sc., Ser., II, **303**, (16): 1493–1496.

BUŁA Z. (2000) — Dolny paleozoik Górnego Śląska i zachodniej Małopolski. Pr. Państw. Inst. Geol., **171**.

BUŁA Z. and HABRYN R. eds. (2008) — Atlas geologiczno-strukturalny podłoża paleozoicznego Karpat Zewnętrznych i zapadliska przedkarpackiego. Państw. Inst. Geol. Warszawa.

BUŁA Z., JACHOWICZ M. and ŻABA J. (1997) — Principal characteristics of the Upper Silesian Block and Małopolska Block border zone (southern Poland). Geol. Mag., **134** (5): 669–677.

CHAFFEE M. A., EPPINGER R. G., LASOŃ K., ŚLÓSARZ J. and PODEMSKI M. (1997) — A geological, alteration, and geochemical model of the Myszków porphyry Cu-Mo deposit, southern Poland. In: Mineral Deposits (ed. H. Papunen): 851–854. Balkema, Rotterdam.

COMPSTON W., WILLIAMS I. S. and MEYER C. (1984) — U-Pb geochronology of zircons from lunar breccia 73217 using a sensitive high mass-resolution ion microprobe. J. Geoph. Res., **89**: B252–B534.

DADLEZ R. (1995) — Debates about the pre-Variscan tectonics of Poland. Stud. Geoph. Geodaet., **39**: 227–234.

DUDEK A (1980) — The crystalline basement block of the Outer Carpathians in Moravia: Bruno-Vistulicum. Roz. Čes. Akad. Věd, Ř. mat-prirod. Věd, **90**: 1–85.

EBY G. N. (1992) — Chemical subdivision of the A-type granitoids: petrogenetic and tectonic implications. Geology, **20**: 641–644.

EL BOUSEILY A. M. and EL SOKKARY A. A. (1975) — The relation between Rb, Ba, and Sr in granitic rocks. Chem. Geol., **16**: 207– 219.

FINGER F., ROBERTS M. P., HAUNSCHMID B., SCHERMAIER A. and STEYRER H. P. (1997) — Variscan granitoids of central Europe: their typology, potential sources and tectonothermal relations. Miner. Petrol., **61**: 67–96.

FINGER F. and STEYRER H. P. (1990) — I-type granitoids as indicators of a late Paleozoic convergent ocean-continent margin along the southern flank of the central European Variscan orogen. Geology, **18**: 1207–1210.

FRANKE W. (2000) — The mid-European segment of the Variscides: tectono-stratigraphic units, terrane boundaries and plate evolution. J. Geol. Soc., London, Spec. Publ., **179**: 35–61.

GRADSTEIN F., OGG J. and SMITH A. (2004) — A Geologic Time Scale 2004. Cambridge Univ. Press.

HARAŃCZYK C. (1989) — Wulkanizm rejonu Krzeszowic (in Polish). Przewodnik 60 Zjazdu Pol. Tow. Geol. Kraków, 14–16 września 1989: 51–71. Warszawa.

HARAŃCZYK C. (1994) — Znaczenie sutury terranowej Zawiercie-Rzeszotary dla poznania kaledońskiego transpresyjnego górotworu krakowidów (in Polish). Przewodnik 65 Zjazdu Pol. Tow. Geol. w Sosnowcu. Pr. Nauk. UŚl., **1431**: 69–80.

HEFLIK W. and PIEKARSKI K. (1992) — Contact metamorphic rocks from the vicinity of Myszków (Upper Silesia). Bull. Pol. Acad. Sc., Earth Sc., **40** (1): 31–42.

JACHOWICZ M. (1994) — O występowaniu mikroskamieniałości grupy Acritarcha w utworach starszego paleozoiku północno-wschodniego obrzeżenia GZW. Prz. Geol., **42** (8): 631--637.

JACHOWICZ M., BOBIŃSKI W., BUŁA Z., CWOJDZIŃSKI S., ŻABA J. and ŻELAŹNIEWICZ A. (2002) — Geneza i pozycja stratygraficzna podkambryjskich i podorodowickich anchimetamorficznych skał w południowej Polsce — przedpole orogenu neoproterozoicznego? Final report: grant KBN 9T12B03217 (in Polish). Centr. Arch. Geol. Państw. Inst. Geol.

JARMOŁOWICZ-SZULC K. (1984) — Datowania metodą K-Ar skał NE obrzeżenia Górnośląskiego Zagłębia Węglowego (in Polish). Spraw. Pos. Nauk. Inst. Geol., Kwart. Geol., **28** (3/4): 749–750.

JARMOŁOWICZ-SZULC K. (1985) — K-Ar datings of igneous rocks from NE margin of the Upper Silesian Coal Basin. Kwart. Geol., **29** (2): 343–354.

JUNG S. and PFÄNDER J. A. (2007) — Source composition and melting temperatures of orogenic granitoids: constraints from CaO/Na_2O, Al_2O_3/TiO_2 and accessory mineral saturation thermometry. Eur. J. Miner., **9**: 859–870.

KRÓLIKOWSKI and PETECKI Z. (1995) — Gravimetric atlas of Poland. Państ. Inst. Geol. Warszawa.

LUDWIG K. R. (2000) — SQUID 1.00, A User's Manual. Berkeley Geochronol. Center Spec. Publ., **2**.

LUDWIG K. R. (2003) — Isoplot/Ex version 3.0. A geochronological toolkit for Microsoft Excel. Berkeley Geochronol. Center Spec. Publ., **1a**.

MALINOWSKI M., ŻELAŹNIEWICZ A., GRAD M., GUTERCH A. and JANIK T. (2005) — Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland — CELEBRATION 2000 experiment, profile CEL02. Tectonophysics, **401** (1–2): 55–77.

MARKIEWICZ J. (2002) — Przejawy kontaktowo-metasomatycznego oddziaływania granitoidowej intruzji mrzygłodzkiej. Biul. Państw. Inst. Geol., **402**: 101–132.

MARKIEWICZ J. (2006) — Granitoidowy magmatyzm Doliny Będkowskiej (strefa krawędziowa bloku małopolskiego) jako przesłanka występowania złóż porfirowych Mo-Cu-W. Centr. Arch. Geol. Państw. Inst. Geol.

MAZUR S. and JAROSIŃSKI M. (2006) — Budowa geologiczna głębokiego podłoża platformy paleozoicznej południowo-zachodniej Polski w świetle wyników eksperymentu sejsmicznego POLONAISE'97. Pr. Państw. Inst. Geol, **188**: 203–222.

MORYC W. and HEFLIK W. (1998) — Metamorphic rocks in the basement of the Carpathians between Bielsko-Biała and Cracow. Geol. Quart., **42** (1): 1–14.

NAWROCKI J., ŻYLIŃSKA A., BUŁA Z., GRABOWSKI J., KRZYWIEC P. and POPRAWA P. (2004) — Early Cambrian location and affinities of the Brunovistulian terrane (Central Europe) in the light of paleomagnetic data. J. Geol. Soc., London, **161**: 513–522.

NAWROCKI J. FANNING M., LEWANDOWSKA A., POLECHOŃSKA O. and WERNER T. (2008) — Palaeomagnetism and the age of the Cracow volcanic rocks (S Poland). Geoph. J. Int., **174**: 475–488.

PEARCE J. (1996) — Sources and settings of granitic rocks. Episodes, **19**: 120–125.

PEARCE J. A., HARRIS N. B. W. and TINDLE A. G. (1984) — Trace element discrimination for the tectonic interpretation of granitic rocks. J. Petrol., **25**: 956–983.

PODEMSKI M. ed. (2001) — Palaeozoic porphyry molybdenum-tungsten deposit in the Myszków area, southern Poland. Pol. Geol. Inst. Spec. Pap., **6**: 1–88.

POŻARYSKI W. and KARNKOWSKI P. (1992) — Tectonic map of Poland during the Variscan time, 1:1 000 000. Wyd. Geol. Warszawa.

POŻARYSKI W., GROCHOLSKI A., TOMCZYK H., KARNKOWSKI P. and MORYC W. (1992) — The tectonic map of Poland in the Variscan epoch. Prz. Geol., **40** (11): 643–651.

STEIN H. J., MARKOWIAK M. and MIKULSKI S. Z. (2005) — Metamorphic to magmatic transition captured at the Myszków Mo-W deposit, southern Poland. In: Mineral Deposit Research: Meeting the Global Challenge: 833–836. Springer.

TERA F. and WASSERBURG G. J. (1972) — U-Th-Pb systematics in three Apollo 14 basalts and the problem of initial Pb in lunar rocks. Earth Planet. Sc. Lett., **14**: 281–304.

WHALEN J. B., CURRIE K. L. and CHAPPELL B. W. (1987) — A-type granites: geochemical characteristics, discrimination and petrogenesis. Contrib. Miner. Petrol., **95**: 407–419.

WILLIAMS I. S. (1998) — U-Th-Pb Geochronology by Ion Microprobe. In: Applications of microanalytical techniques to understanding mineralizing processes (eds. M. A. McKibben, W. C. Shanks III and W. I. Ridley). Rev. Econ. Geol., **7**: 1–35.

WILLIAMS I. S. and CLAESSON S. (1987) — Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragneisses from the Seve Nappes, Scandinavian Caledonides, II. Ion microprobe zircon U-Th-Pb. Contrib. Mineral. Petrol., **97**: 205–217.

ŻABA J. (1999) — Ewolucja strukturalna utworów dolnopaleozoicznych w strefie granicznej bloków górnośląskiego i małopolskiego. Pr. Państw. Inst. Geol., **166**.

ŻELAŹNIEWICZ A. (1998) — Rodinian-Baltican link of the Neoproterozoic orogen in southern Poland. Acta Univ. Carolinae, Geol., **42** (3–4): 509–515.