Geological Quarterly, 2020, **64** (3): 754–765
DOI: http://dx.doi.org/10.7306/gq.1549

A reappraisal of K-Ar and new U-Pb age data for felsic rocks in the vicinity of the Kraków-Lubliniec Fault Zone (southern Poland)

Katarzyna JARMOŁOWICZ-SZULC[1, *]

[1] Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warszawa, Poland

Jarmołowicz-Szulc, K., 2020. A reappraisal of K-Ar and new U-Pb age data for felsic rocks in the vicinity of the Kraków-Lubliniec Fault Zone (southern Poland). Geological Quarterly, **64** (3): 754–765, doi: 10.7306/gq.1549

Associate Editor: Leszek Marks

New U-Pb zircon SHRIMP determinations from magmatic silicic rocks adjacent to the NE part of the Upper Silesia Coal Basin (USB) are provided and compared with earlier data obtained by K-Ar dating. The zircon samples studied came from the same boreholes and depth intervals previously sampled for K-Ar datings. Recalculations of the earlier K-Ar values for biotites yielded isochron ages in the range of 297–309 Ma. The zircon U-Pb SHRIMP values gave more precise ages between 300.1 ±1.2 Ma and 292.6 ±1.3 Ma (1σ) consistent with U-Pb and Re-Os determinations. In two cases, the recalculated results of K-Ar dates were nearly identical with those obtained from the SHRIMP isotopic analyses. In this context, the granitoids and porphyries of the USB area, once assigned to the Carboniferous-Permian based on the older K-Ar studies, actually are of the same age as other felsic igneous rocks from the vicinity of the Kraków-Lubliniec Fault Zone, with a higher dating precision, however. The new data underline the importance of Late Carboniferous- Early Permian felsic magmatism at the SW margin of the Trans-European Suture Zone in southern Poland. In the zircon populations dated, besides the dominant Late Paleozoic ages, there are some inherited zircon cores, likely remnant detrital grains from a sediment component in the source rocks, that reveal much older ages which range from ~2051 to 569 Ma.

Key words: magmatic rocks, zircons, geochronology, Kraków-Lubliniec Fault Zone.

INTRODUCTION

Magmatic rocks from the Upper Silesia Coal Basin (USB) and the adjacent areas have been for years studied by petrographic, genetic and geochronological means. The first geochronological analyses were made in the 1960s and 1970s, the results being archived and only partly published (e.g., Lis and Sylwestrzak, 1976, 1978). Progress in K-Ar age determinations at the Polish Geological Institute in the 1980s allowed new dates and some reinterpretations of earlier data (Jarmołowicz-Szulc, 1985). Recent interest in the igneous rocks of the USB brought new results obtained using the Ar-Ar, U-Pb and Re-Os methods (Żelaźniewicz et al., 2008; Mikulski et al., 2008; Nawrocki et al., 2010; Mikulski and Stein, 2012; Mikulski et al., 2019 and references therein). The present contribution provides more U-Pb analyses of zircons from magmatic rocks in the vicinity of the Kraków-Lubliniec Fault Zone (KLFZ) and compares the results with the older archived and published data obtained by means of the K-Ar volumetric method without isotopic control. For this, the borehole cores have been sampled from the approximately same or as close to as possible depth intervals that were earlier sampled for the K-Ar analyses. The present paper thus acts as a bridge between the older and newer geochronological methods which have been developed in the Polish Geological Institute – National Research Institute.

* E-mail: katarzyna.jarmolowicz-szulc@pgi.gov.pl

Received: February 19, 2020; accepted: June 1, 2020; first published online: August 18, 2020

GEOLOGICAL SETTING

The study area is located on the Małopolska Block (Fig. 1), southern Poland, to the NE of the KLFZ that separates this block from the Upper Silesia Block, both being extensively covered by Mesozoic-Cenozoic deposits and Carpathian nappes (Buła et al., 1997; Żaba, 1999). The KLFZ represents part of the Trans-European Suture Zone (TESZ) in which crustal blocks/terranes of Gondwana affinity came into contact with the East European Craton/Baltica (e.g., Buła et al., 1997; Narkiewicz et al., 2015; Żelaźniewicz et al., 2016). In both walls of the KLFZ, igneous rocks are present. K-rich rhyolites to dacites intruded in the form of laccoliths, being more abundant in the Małopolska Block than in the Upper Silesian Block (Żelaźniewicz et al., 2008). In boreholes located along the SW margin of the Małopolska Block, granites, porphyritic dacites and rhyolites and minor mafic rocks were encountered at a dis-

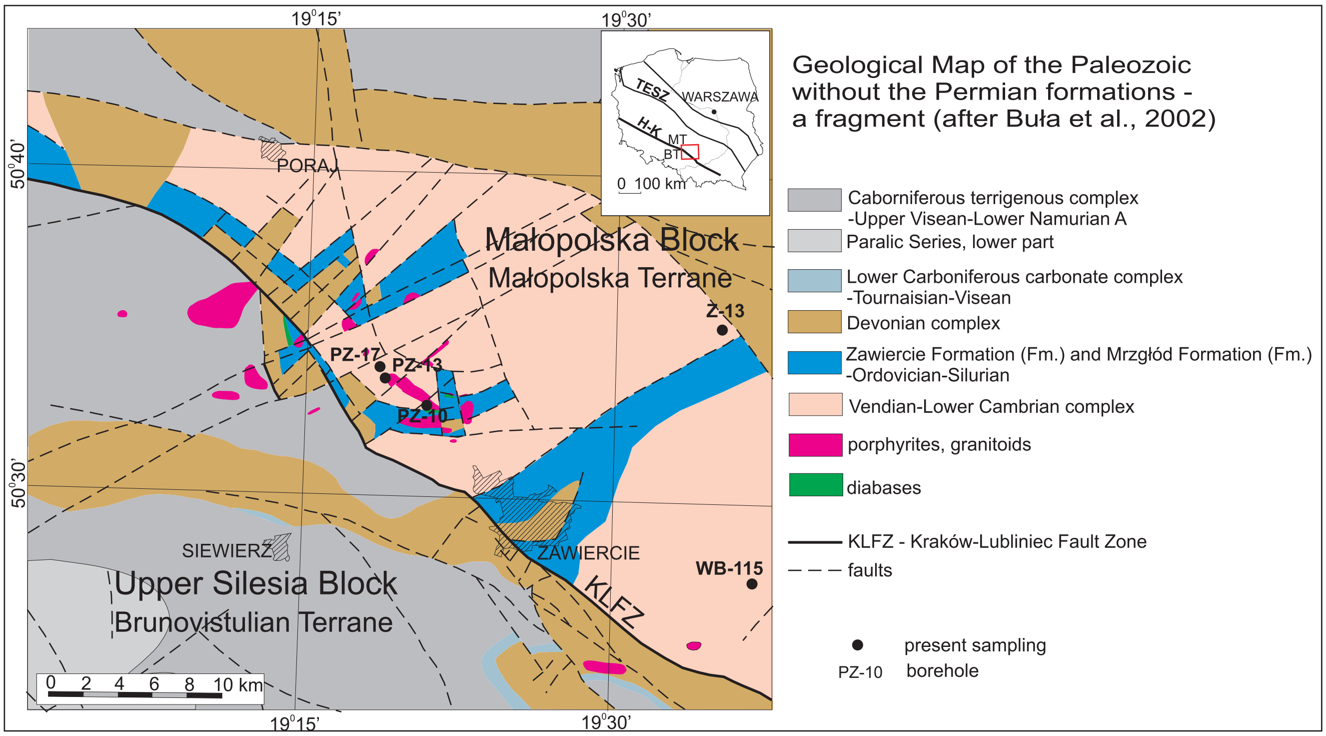


Fig. 1. Geology and boreholes sampled; part of a geological map of the area (Buła et al., 2002) with sampling points shown

BT – Brunovistulian Terrane; MT – Małopolska Terrane; H-K – Hamburg-Kraków Tectonic Zone; TESZ – Trans-European Suture Zone (Teisseyre-Tornquist Zone)

tance of up to 10 km from the KLFZ during extensive surveying for ore mineralisation (Fig. 1).

Borehole cores from four boreholes were selected for this study: PZ-10, PZ-13, Z-13 and WB-115. Their lithological logs can be found in Nawrocki et al. (2010) and Mikulski et al. (2019). In these boreholes, magmatic rocks occur as complex bodies some hundreds to >1000 metres thick.

Magmatic rocks in the Upper Silesia Coal Basin and in the area adjacent on the NE are known only from deep boreholes. These are: granitoids, porphyries, diabases and lamprophyres inferred to be Carboniferous/Permian in age (Bukowy and Cebulak, 1964, 1971; Górecka et al., 1971; Lis and Sylwestrzak, 1976, 1978; Martinec et al., 1994 and references therein). Based on the chemical and mineral compositions of those rocks, Homola (1960) and Papalová and Tomšik (1970) distinguished further petrographic varieties, namely: granodiorite porphyry, quartz-diorite, and diorite porphyry, syenite porphyry, melaphyre and olivine melaphyre. Nawrocki et al. (2010) supported the interpretation of three magmatic events in the vicinity of the KLFZ, in the border area of the Brunovistulia and Małopolska terranes. The oldest episode occurred in the Late Emsian, a younger one in the Visean and the youngest in the Early Permian.

PREVIOUS AGE DETERMINATIONS

Previous age determinations of magmatic rocks of the USB margin were by the K-Ar volumetric method at the Polish Geological Institute – National Research Institute. The earliest results were reported by Depciuch (1974). Some data (PZ-10) were described in detail by Jarmołowicz-Szulc (1985) together with an attempt to interpret the wide spread of the values obtained. They were interpreted using the isochore method (Jarmołowicz-Szulc, 1985) to give the first isotope age approximation in the Polish area, quoted later by different authors. On the Czech side of the USCB, K-Ar ages of 240 and 260 Ma were obtained for dyke rocks in the USCB by Papalová and Tomšik (1970), though no exact data sources or detailed explanations were given. These published age determinations were followed by results for the Dolina Będkowska, PZ-17 and PZ-32 boreholes (Jarmołowicz-Szulc, archive materials 1989, unpublished). Later, some Ar-Ar data from rocks such as diabases of the Kraków-Lubliniec Fault Zone were published (Nawrocki et al., 2008, 2010). Some results of SHRIMP U-Pb dating of the granodiorite from the WB-102A borehole were also then reported (Żelaźniewicz et al., 2008), and from the Zalas porphyry. More recently, the age determination summaries and SHRIMP U-Pb values were published (Mikulski et al., 2019).

These earlier results came from a variety of boreholes, rocks and depths from both the Brunovistulian and the Małopolska terranes. The age data for the Małopolska Block with sources are shown in Table 1 as reference material for the present study.

MATERIAL AND METHODS

Petrographically, the porphyries and granitoids (Fig. 2) are coarse, medium to fine-grained rocks of either equigranular or porphyritic textures (see: WB-115 in Fig. 2B, or PZ-10 in Fig. 3A–F). Occasionally they are altered (Fig. 2A) and show direc-

Table 1

Summary of previously obtained ages

Borehole/ sample number	Depth [m]	Rock/mineral dated	Method	Age [Ma]	Error [Ma]	References
Myszków- Mrzygłód region PZ-10	610–1173	granitoids	K-Ar	312	17	Jarmołowicz-Szulc (1985); isochore
Myszków- Mrzygłód region	459–955	porphyries	K-Ar	301	29	Jarmołowicz-Szulc (1985); isochore
Myszków Mo-Cu-W deposit	diversified	molybdenite	Re-Os	303 294.7	2.2 2.3.	Stein et al. (2005)
Zalas region	quarry	rhyodacites	U-Pb zircon	295.1	2.6	Nawrocki et al. (2007)
WB-102A	1091.5	granodiorite	U-Pb zircon	300.3	3.2	Żelaźniewicz et al. (2008)
Upper Silesia Basin	diversified	rhyolites to dacites	U-Pb zircon	295.0	3.0	Nawrocki et al. (2008) from Żelaźniewicz et al. (2008)
PZ-10 PZ-10-287	284	dacites/amphibole	Ar-Ar	298.7	0.9 1σ	Nawrocki et al. (2008)
PZ-10 PZ-10-287	287	dacites/amphibole	Ar-Ar	292.6	1.3	Nawrocki et al. (2008)
PZ-10 PZ-10-287	289	dacites/amphibole	Ar-Ar	295.1	1.5 1σ	Nawrocki et al. (2008)
DB5 DB5/4	1239	granodiorites	U-Pb SHRIMP	294.8	2.6	Mikulski et al. (2019)
PZ-10 /PZ10/36	1163	granodiorites	U-Pb SHRIMP	295.9	3.0	Mikulski et al. (2019)

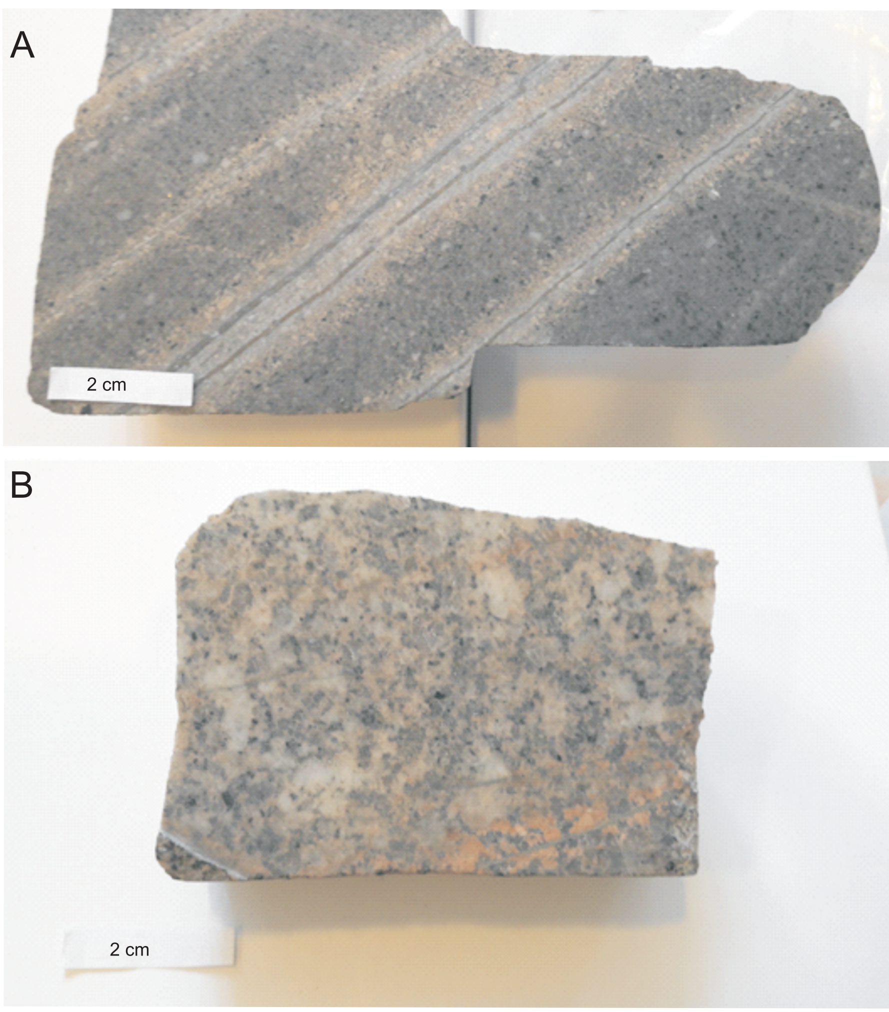


Fig. 2. Rocks from boreholes on the NE margin of the Upper Silesian Coal Basin

Macroscopic images of dated rock samples: **A** – quartz porphyry cut by quartz veinlets; analyses were conducted on the non-altered parts; sample Z-13 (depth 231–231.3 m); **B** – granodiorite (WB-115, depth 570–580 m)

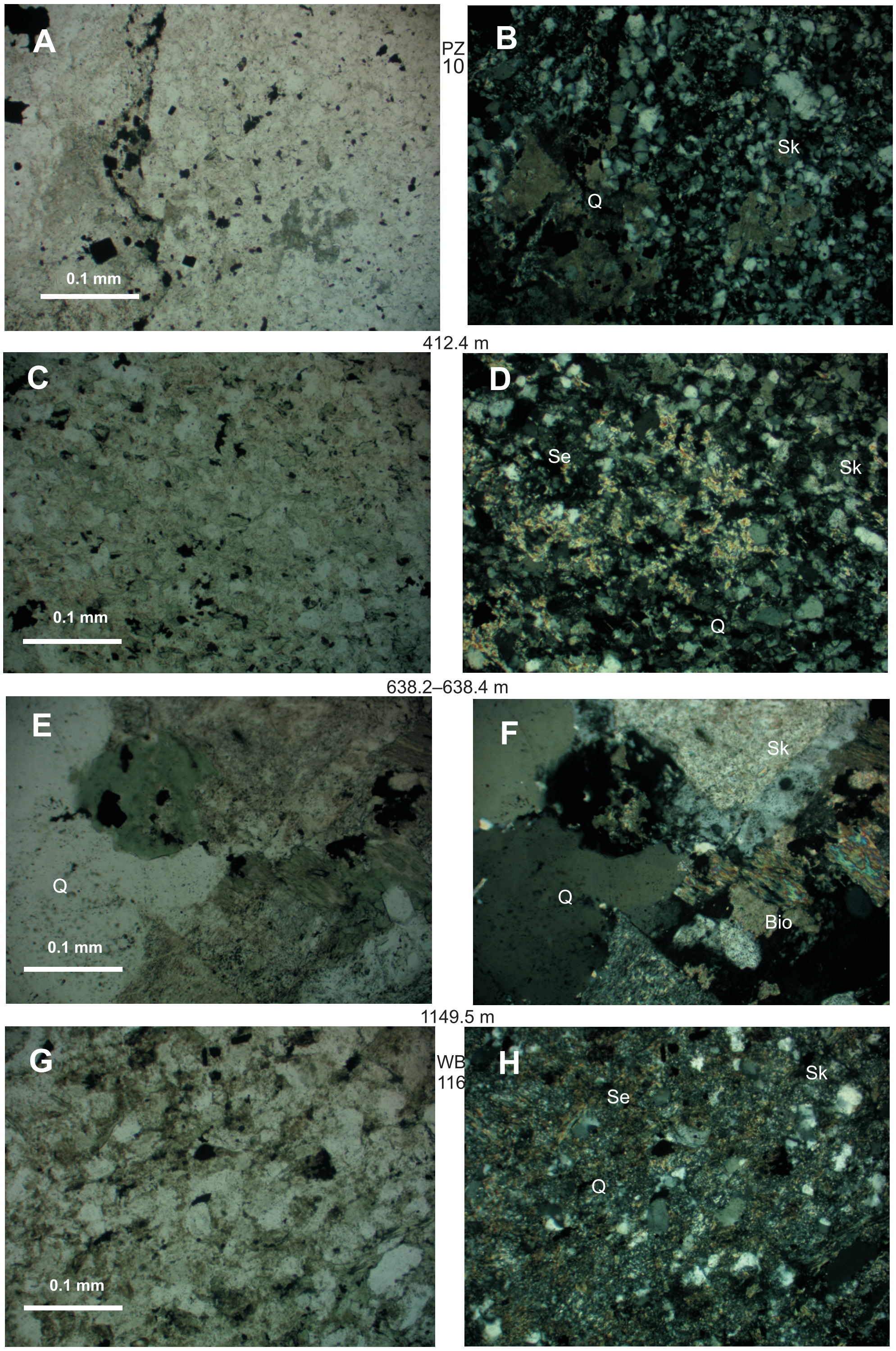


Fig. 3. Photomicrographs of rocks from the PZ-10 and WB-116 boreholes in transmitted light (parallel and crossed polars)

A–F – petrographic profile of granitoids in the PZ-10 borehole (depth from 412.4 to 1149.5 m); **G, H** – WB-116 sample; Q – quartz, Sk – feldspar, Bio – biotite, Se – sericite

tional textures both at macro- and micro-scales (Fig. 3G, H). Their composition is dacitic and granodioritic. The rocks comprise quartz, K-feldspar, plagioclase, biotite and hornblende in various proportions. Zircon, apatite and epidote are accessory minerals. The detailed petrographic characteristics of these rocks in the Upper Silesia Basin and adjacent regions in Poland and Czech have been widely described [e.g., Homola, 1960; Papalová and Tomšík, 1970; Martinec et al., 1994 and references therein; Markiewicz and Markowiak, 1998; Truszel and Karwowski, 2003; Markowiak, 2005; Truszel et al., 2006; Nawrocki et al., 2008 (diabases) and Żelaźniewicz et al., 2008 (granitoids)]. The most recent petrographic geochemical description is by Mikulski et al. (2019).

The present study concerns dating by two methods: K-Ar on biotite (archival determinations; re-appraised) and U-Pb SHRIMP on zircon.

Biotite and zircons were separated using conventional heavy liquid and magnetic techniques. Zircon grains were imaged in cathodoluminescence and photographed both in transmitted and reflected light to identify cores and overgrowths prior to the analysis. The zircon samples were dated by means of the SHRIMP method together with comparative standards.

K-Ar AGE DETERMINATIONS

K-Ar age determinations (volumetric method) used to be performed at the Polish Geological Institute in Warsaw in the last century. The earliest results in the USB area were reported by Depciuch (1974), with later dating and interpretation by Jarmołowicz-Szulc (1985). Those published results were followed by other measurements, reported here. Determinations were conducted on biotite and/or whole rock samples. The purity of the biotite fraction selected was controlled by handpicking. K-Ar dating was performed on biotite taking into account its more compact structure and possible lesser alteration by contrast with the feldspar. The closure of the ^{40}K-^{40}Ar system in geological time is the condition of the dating. Argon gas can be released from weak compact structures such as of feldspars that may result in much lower apparent ages. The biotite has also a relatively high potassium content that has a positive influence on the analytical error of final measurements and results obtained.

Potassium content was determined separately by flame photometry. Values for the biotite/ whole rock aliquots come from the chemical laboratory of the Polish Geological Institute.

Details of the Ar releasing instrument, the method used and results of calibration of measurements have been described elsewhere (e.g., Depciuch, 1974; Lis and Sylwestrzak, 1976; Jarmołowicz-Szulc, 1985, 2017). Atomic constants suggested by Steiger and Jäger (1977) were used for calculating and re-calculating the ages.

U-Pb SIMS DATING

The U-Pb age measurements were conducted using single zircon crystals *in situ* by the *Secondary Ion Mass Spectrometry SIMS* on *Sensitive High Resolution Ion Microscope SHRIMP II* instrument at the Polish Geological Institute – National Research Institute, Warsaw. The zircon separates mounted in epoxy discs along with relevant zircon standards Temora 2 (^{206}Pb/^{238}U = 0.06683) and 91500. Details related to SHRIMP analytical procedures, including the calibration routine, were described by Williams and Claesson (1987) and/or Williams (1998). In general, for each analysis, an $^{16}O_2$-primary ion beam was rastered across every zircon grain for 2 minutes, to remove the gold coat and surface contamination. Positive secondary ions were collected by excavating an ~3 μm deep elliptical (regular dimension ~21 to 25 μm) spot.

SQUID 1.0 software was used for data processing. Individual corrected ratios and ages were reported with 1σ analytical errors. U-Pb concordia ages and the weighted mean age diagram were calculated using the *Isoplot/Ex 3.0* program of Ludwig (2009). Age calculations were based on IUGS recommended values for U decay constants (Steiger and Jäger, 1977).

RESULTS

RESULTS OF K-Ar DATING

Hitherto unpublished results of K-Ar dating of the samples from different boreholes by the present author are shown in Table 2. They concern potassium and argon measurements for granitoid and porphyry samples from the PZ-10, PZ-17, DB-5, Z-13 and WB-115 boreholes extracted from archive materials (Jarmołowicz-Szulc, 1989, unpublished). They were carefully selected and analyzed taking into account the character of material dated. In most cases, biotite was analysed, where the potassium content appeared to be relatively high and the crystal size large. A high potassium content is the first suggestion of no

Table 2

^{40}K-^{39}Ar dating results – a reappraisal of archival measurements

Analytical number	Borehole	Depth [m]	Material	K [%]	Sample weight [g]	Age * [Ma]	Age ** [Ma]
891/Ar	DB-5	1099.7–1100	biotite 0.5–1.0 mm	7.32	6.2407	309	297
922/Ar	PZ-10	534	biotite	6.48	5.9063	304	
935/Ar	PZ-17	1105.5	biotite + chlorite	4.99	5.5933	297	
932/Ar	PZ-17	1116.3–1116.5	biotite	4.53	5.0865	299	
936/Ar	PZ-17	1137.5	biotite	4.92	5.0245		305
937/Ar	PZ-32	252.5	biotite + chlorite	3.15	7.0375	297	
945/Ar	WB-115	570–580	biotite 0.4–0.6 mm	5.90	5.0139	297	
947/Ar	Z-13	235.4–235.5	whole rock	2.3	12.0415	305	

Remarks: * – calculation laboratory coefficient 1.59 ; ** – calculation laboratory coefficient 1.51

alteration in the mineral. Locally, however, the biotite is chloritized, as marked in the table. Only one sample (Z-13, depth 235.4–235.5 m) was analysed as a whole-rock-sample (Table 2).

RESULTS OF U-Pb SHRIMP DATING AND ZIRCON CHARACTERISTICS

DETAILED DESCRIPTION OF ZIRCON SAMPLES

As it is seen in Figure 4, zircons in all 4 samples presently dated differ in their size, transparency and structure. They also differ from the standards used.

Sample PZ-10, depth 666.2 m. Long prismatic, transparent crystals; occasional larger darker crystals. In general, crystal size (up to ~200 μm) is smaller than that those of the TEMORA 2 sample (Fig. 4A, B).

Sample PZ-13, depth 629.4 m. Small zircons, not abundant, prismatic, mostly transparent. In most cases, one point measurement was done per crystal, in larger grains two points were selected for analysis (Fig. 4C, D).

Sample WB-115. Transparent medium-size zircon crystals, with some zonation, and of size similar in size to those of Temora.

Sample Z-13, depth 241–241.3 m. About 120 crystals from the metasomatically unaltered parts of the rock. Abundant large zircons show prismatic character. Two types of zircons are seen: large prismatic crystals with a large core (two points analysed); elongated thin dark bi-pyramidal prisms and small bi-pyramidal prisms – shorter, with narrow zonation. Some grains are broken (Fig. 4E, F) .

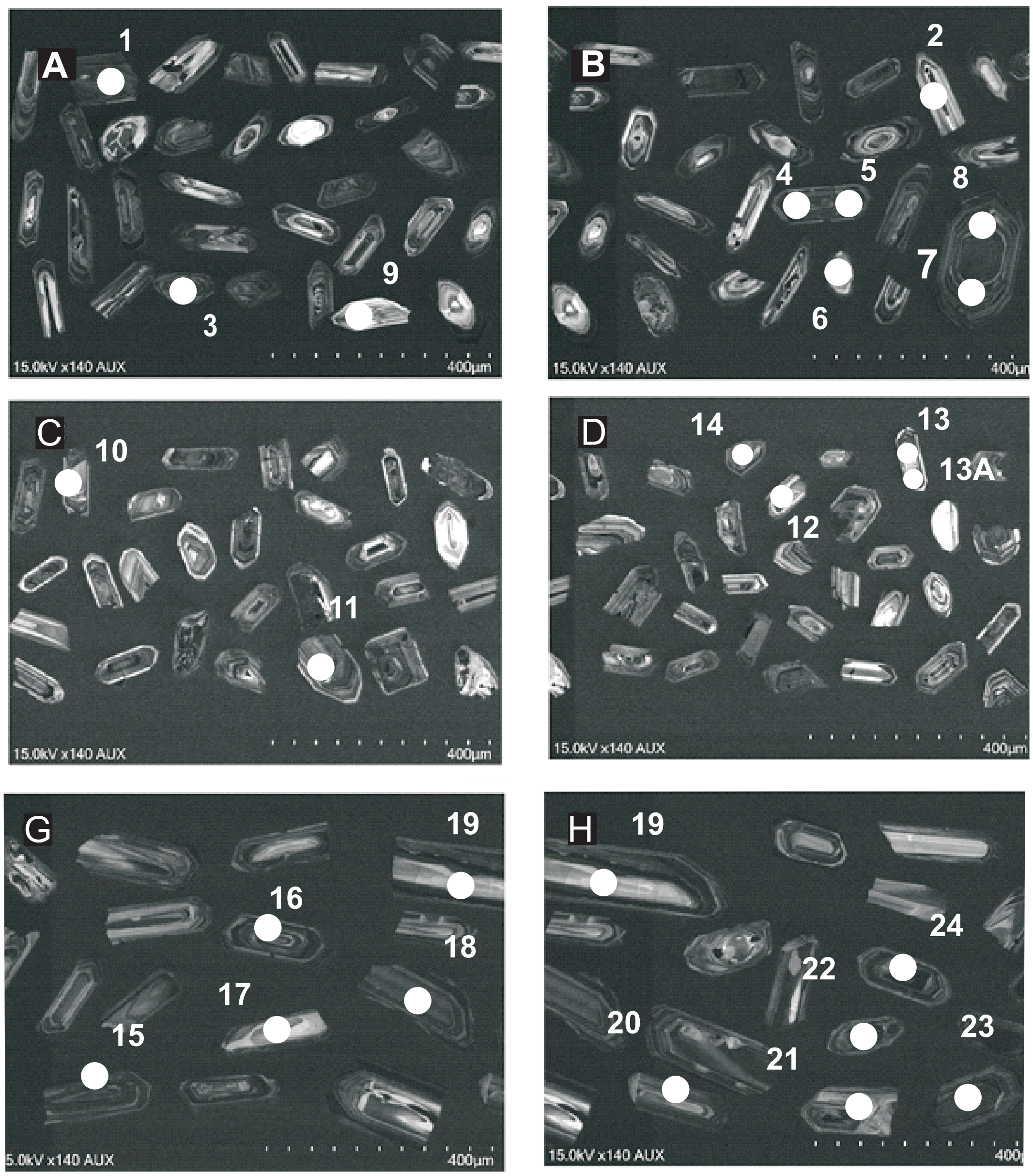


Fig. 4. CL images of zircons dated by the SHRIMP method – examples

A, B – sample PZ-10; **C, D** – sample PZ-13; **E, F** – sample Z 13; for age values see Table 3

Table 3

Zircon U-Pb SHRIMP dating results

Borehole/ Spot	Depth [m]	Individual crystal no*	U [ppm]	Th [ppm]	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	Age [Ma]**	Remarks
PZ-10	666.2	**Granodiorite**					300.2 ±1.2	
PZ-10/42.1		1	193	149	0.04734	0.265	298 ±3–304 ±4	Fig. 4A, B
PZ-10/39		2	343	268	0.04667	0.303	290 ±2–291 ±4	
PZ-10/43		3	1243	571	0.04587	0.344	288 ±3–289 ±3	
PZ-10/40.1		4	1256	524	0.04595	0.336	288 ±3–289 ±3	
PZ-10/40.2		5	860	269	0.04734	0.343	298 ±12–298 ±13	
PZ-10/38.2		6	1048	371	0.04518	0.324	299 ±4–300 ±3	
PZ-10/41.1		7	241	191	0.04812	0.380	302 ±4–302 ±4	
PZ-10/41.2		8	925	728	0.04611	0.347	290 ±42–291 ±2	
PZ-10/45		9	60	49	0.04846	0.442	296 ±4–305 ±5	
PZ-13	629.4	**Granodiorite**					295.7 ±1.3	
PZ-13/23		10	778	272	0.04581	0.342	288 ±3–289 ±3	Fig. 4C, D
PZ-13/25		11	1969	798	0.04661	0.339	289 ±3–300 ±3	
PZ-13/35		12	146	114	0.04583	0.342	290 ±2–291 ±4	
PZ-13/34.1		13	744	360	0.04616	0.337	290 ±2–291 ±3	
PZ-13/34.2		13A	433	212	0.04658	0.354	292 ±8–294 ±8	
PZ-13/32		14	906	213	0.04784	0.343	301 ±7–302 ±23	
Z-13	**231–231.3**	**Rhyolite** altered rock					292.6 ±1.3	
Z-13/29		15	714	358	0.0503	0.316	287 ±3–288 ±3	Fig. 4E, F
Z-13/30		16	366	272	0.0518	0.330	291 ±5	
Z-13/31		17	97	101	0.0605	0.391	293 ±5–296 ±5	
Z-13/32		18	479	116	0.0433	0.294	273 ±15–274 ±16	
Z-13/33.1		19	65	40	0.0468	0.355	295 ±2–295±3	
Z-13/34		20	343	199	0.0467	0.351	294 ±2–295 ±3	
Z-13/35		21	767	246	0.0477	0.360	300 ±3–301 ±3	
Z-13/36		22	874	245	0.0466	0.318	294 ±4	
Z-13/37		23	1667	131	0.1441	2.070	831 ±51–871 ±52	
Z-13/38		24	764	460	0.0453	0.338	285 ±4–286 ±4	
WB-115	570–580	**Granodiorite**					297.1 ±1.6	

* – numbers correspond to crystals shown in Figure 4, ** – full set of data – in Appendix 1*

In sum, the zircons extracted from the granitoids (PZ-10, PZ-13, WB-115) are mostly clear, colourless, fine to medium in size (40–200 μm). Only zircons from the porphyry (Z-13) are significantly larger (120–300 μm). They display a euhedral prismatic character and a fine zonation. Crystal phases of zircons are well developed. Some crystals in these populations are dark, and some are broken.

ANALYTICAL U-Pb RESULTS

In Figure 4 some examples of individual zircon crystals are illustrated together with numbers corresponding to age values shown in the table (Table 3).

The concordia results of U-Pb dating of the zircon samples from the PZ-10, PZ-13, WB-115, Z-13 boreholes are as follows:

- sample PZ-10, depth 666.2 m – 300.1 ±1.2 Ma with U and Th contents of 169–1924 ppm and 96-2942 ppm, respectively;
- sample PZ-13, depth 629.4 m – 295 ±1.3 Ma with U and Th contents of 155–3643 ppm and 65–2048 ppm, respectively;
- sample WB-115 – 297.1 ±1.6 Ma with U and Th contents of 139–429 ppm and 189–578 ppm, respectively;
- sample Z-13, depth 231–231.3 m – 292.6 ±1.3 Ma with U and Th contents of 76–3774 ppm and 114–826 ppm, respectively.

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1549

The age values discussed in the text are given with 1σ confidence limits (Table 3 and Appendix 1). Concordia diagrams in the plot of $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ have been constructed for recently dated samples and are shown in Figures 5 and 6.

When treated statistically, the age values obtained mostly lie within the age interval between 298–300 Ma, indicating zircon crystallization age in that interval in the rocks studied. Some values for inherited zircon cores were obtained in the populations studied (e.g., in PZ-10 sample for 6 grains form 60 measured). They lie in the range from ~2051 to 569 Ma showing, however, no clear age pattern (Appendix 1). One such crystal dated at 831 ±51 – 871 ±52 Ma (limits of three times repeated point measurements) is seen in Figure 4 and in Table 3 (the Z-13 borehole, crystal No 23, crystal spot Z-13/38).

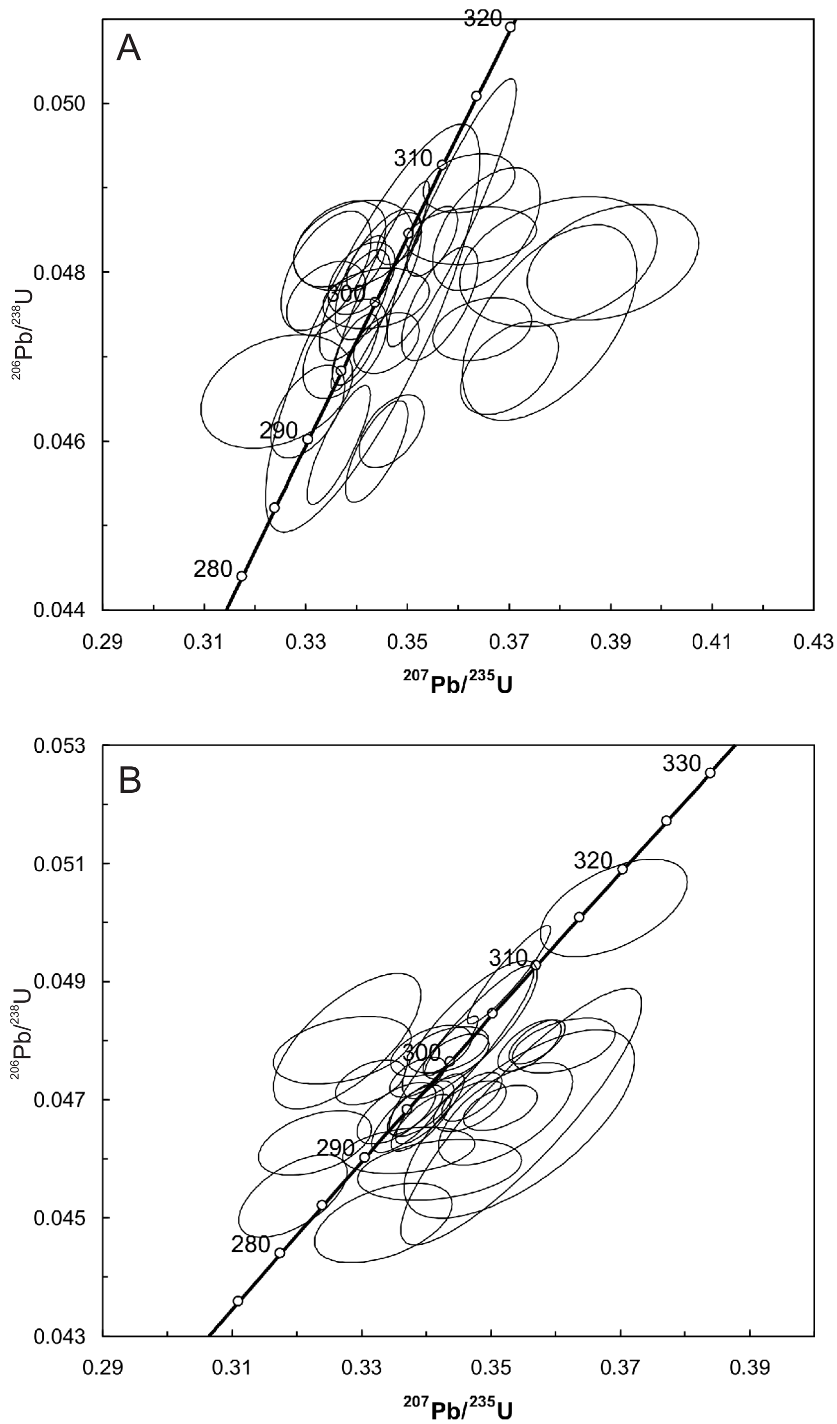
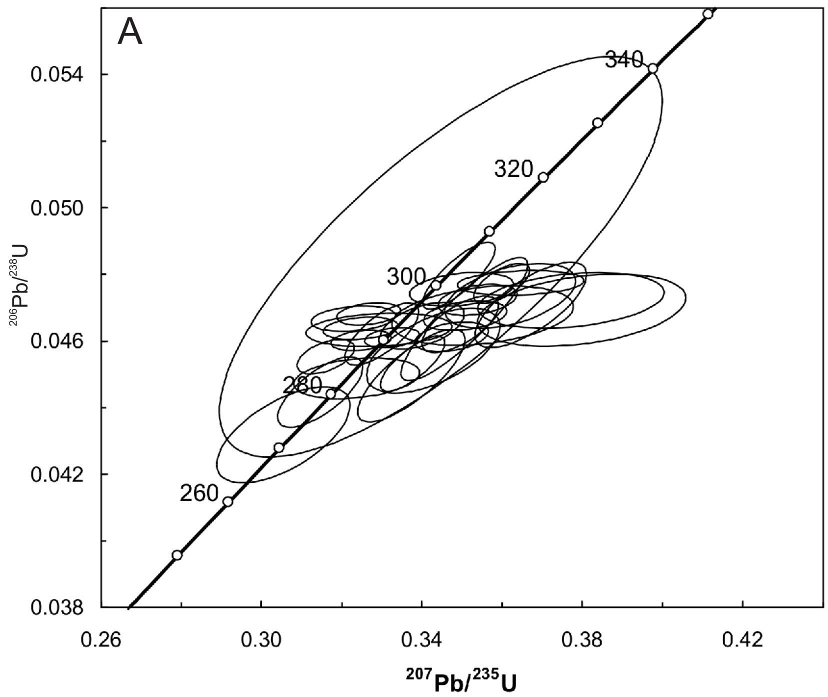


Fig. 5. Results of dating in a $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ plot (A – PZ-10, B – PZ-13 boreholes)

The Myszków-Mrzygłód area; ages on the regression line expressed in millions of years



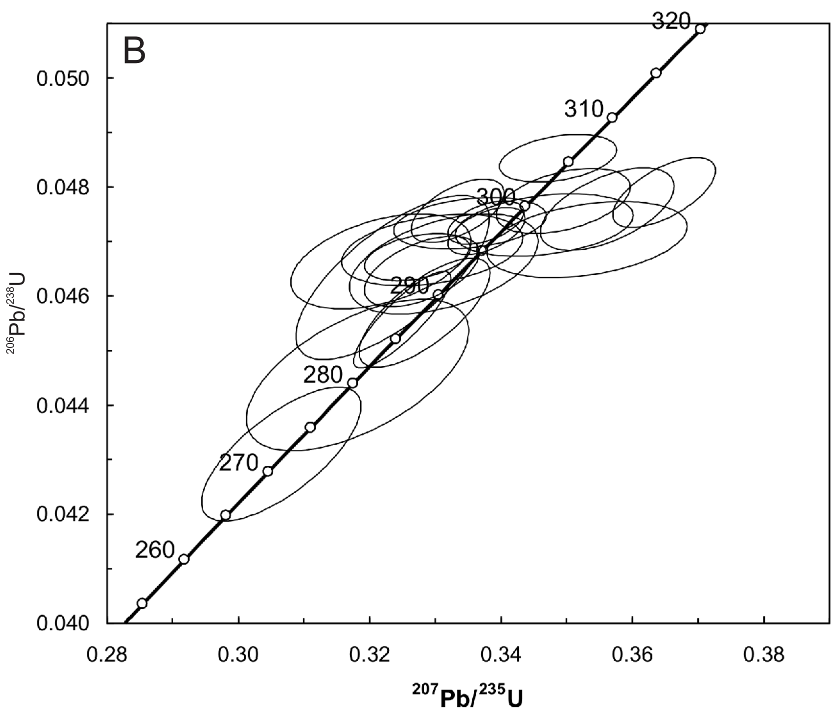


Fig. 6. Results of dating in $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ plot (A – Z-13, B – WB-115 boreholes)

The Zawiercie and Pilica regions; ages on the regression line expressed in millions of years

DISCUSSION

As seen in Figures 2–6, the rock samples dated contain biotite, pure or slightly altered, and unaltered zircon crystals which differ in their transparency, size and abundance. Biotite is rather large (0.4–1.0 mm in size). Zircon crystals are in general small, so in most cases only one isotopic "point maesurement" occurs per zircon grain (Fig. 4). After re-calculation to age values, the ^{238}U-^{206}Pb SHRIMP zircon results fall into the interval from 292.6 ±1.3 to 300.1 ±1.2 Ma (with a relatively low standard deviation). Occasionally, some inherited zircon cores, remnant detrital zircons from a sediment component in the source rocks, occur. They differ from the general population character in their colouring, commonly being much darker. Their ages range from ~2051 to 569 Ma. These inherited zircons are rare and there is no clear age pattern to explain reasonably their origin. Mikulski et al. (2019) tried to relate inherited age values from the Małopolska Block, i.e. those much "older" zircon results, to the development of Baltica. But, the inherited zircon material is too scarce and random to conduct a discussion of the origin of individual grains/cores.

The SHRIMP U-Pb zircon age values obtained point to a Carboniferous/Permian age. They support the K-Ar volumetric data from this part of the Małopolska Block and the NE marginal zone of the USB (Fig. 7).

The K-Ar individual data for granitoids display a wider age interval, ranging from 297 to 309 Ma. In detail, the age results range from 297 to 305 Ma for biotite from the PZ-17 borehole (average – 299.6 Ma) are 304 Ma for the PZ-10 borehole (depth 534 m), and 297 Ma for the granitoid from the Pilica area (WB-115). The porphyry (Z-13) yielded an age of 305 Ma.

In general, the present results, both K-Ar and U-Pb zircon, fall well into the Carboniferous/Permian age intervals. This is consistent with the results obtained in the region by other methods and other authors for magmatic felsic rocks from the Małopolska Block and the Kraków-Lubliniec Fault Zone (cf. Mikulski et al., 2019 and references therein; Fig. 7). Taking into account the presence of three magmatic events in the Brunovistulian and the Małopolska terranes, that are separated by the Kraków-Lubliniec Fault Zone (Nawrocki et al., 2010 and references therein), the emplacement of acid magmatic rocks as granodiorites and dacites marks the extensional stage of the tectonic evolution of the Kraków-Lubliniec Fault Zone (e.g., Żaba, 1999; Żelaźniewicz et al., 2008). The U-Pb SHRIMP zircon and other dating results (e.g., Mikulski et al., 2019), the age values obtained in the present paper for the granitoids (PZ-10, PZ-13, WB-115) and porphyries (Z-13) are within age limits that correspond to an Early Permian age. In other words, the rocks are the result of the third magmatic event characterizing the development of the KLFZ (Nawrocki et al., 2010; Mikulski et al., 2019). According to Narkiewicz et al. (2015) and Żeleźniewicz et al. (2016), the magmatism is coeval with post-collisional granite intrusions in the Central European Variscides.

CONCLUSIONS

The present results of geochronological studies – a re-appraisal of K-Ar age values and new U-Pb SHRIMP dating results – place the age limits for the formation of magmatic rocks from the Małopolska Block and the Kraków-Lubliniec Fault Zone within an interval of 290–310 Ma. Silicic magmatism in the area studied occurred between 292.6 ±1.3 to 300.1 ±1.2 Ma (U-Pb SHRIMP zircon) and 297-305 Ma (K-Ar, biotite). SHRIMP U-Pb dating of felsic rocks from the Myszków-Mrzygłód area (PZ-10, PZ-13 boreholes), the Zawiercie vicinity (Z-13) and the Pilica region (WB-115), points to short-term magmatism there and is consistent with the older K-Ar volumetric data from that NE margin of the USB. The rocks dated are the result of the third magmatic event characterizing the development of the KLFZ while the magmatism is coeval with post-collisional granite intrusions in the Central European Varisci-

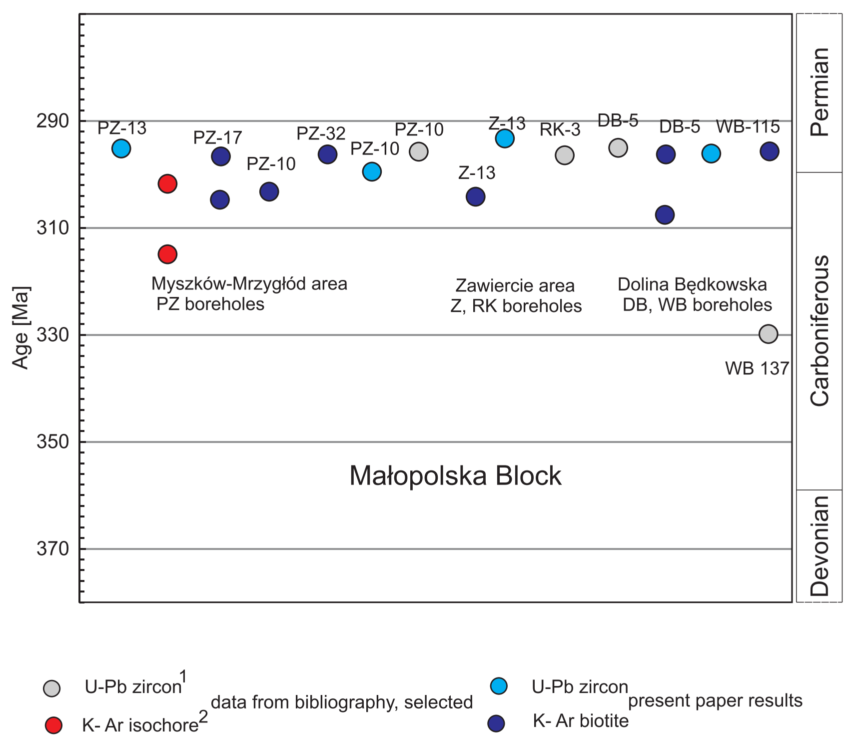


Fig. 7. U-Pb SHRIMP zircon and K-Ar age results on the background of earlier published data

1 – Mikulski et al. (2019); 2 – Jarmołowicz-Szulc (1985)

des (Narkiewicz et al., 2015; Żelaźniewicz et al., 2016). Geochronological data clearly fall into the age intervals obtained by other methods and other authors for the magmatic rocks, both in case of the primary and inherited zircon ages (e.g., Mikulski et al., 2019 and references therein).

Acknowledgements. The present paper and the analytical determinations were conducted within the project of the Ministry of Science and Higher Education during 2017–2019 (internal PGI-NRI project no. 61.2909.1701.00.0 entitled “Analysis, actualization and verification of the results of studies on magmatic rocks by use of newest research techniques”). Analytical assistance with the SHRIMP IIe/MC calibration was provided by Z. Czupyt. L. Skowroński is thanked for graphic elaboration of some figures. The detailed critical reviews of two anonymous reviewers have had a great impact on the manuscript. The reviewers are sincerely thanked for their helpful remarks and suggestions.

REFERENCES

Bukowy, S., Cebulak, S., 1964. New data on magmatism of the Silesia–Cracow anticlinorium (in Polish with English summary). Biuletyn Instytutu Geologicznego, **184**: 41–89.

Bukowy, S., Cebulak S., 1971. Magmatism occurrences in the Silesia-Cracow region (in Polish with English summary). Kwartalnik Geologiczny, **15** (3): 703–704.

Buła, Z., Jachowicz, M., Żaba, J., 1997. Principal characteristics of the Upper Silesian Block and Małopolska Block border zone (southern Poland). Geological Magazine, **134**: 669–677.

Buła, Z. (ed.), Habryn, R., Krieger, W., Kurek, S., Markowiak, M., Woźniak, P., 2002. The Geological Atlas of the Paleozoic (without Permian) Rocks Contacts Between the Upper Silesian and Małopolska Blocks. Państwowy Instytut Geologiczny, Warszawa.

Depciuch, T., 1974. Geochronological studies of magmatic rocks (in Polish with English summary). Prace Instytutu Geologicznego, **74**: 81–83.

Górecka, E., 1971. Ore mineralization in the Paleozoic deposits in NE part of the Cracow area (in Polish with English summary). Acta Geologica Polonica, **22**: 275–326.

Homola, V., 1960. Kyselá vyvřelina z východní části ostravsko-karvínského kamenouhelného revíru (in Czech). Věstník Ústředního ústavu geologického, **35**: 219–220.

Jarmołowicz-Szulc, K., 1985. K-Ar geochronological studies of magmatic rocks in NE margin of the Upper Silesian Coal basin (in Polish with English summary). Kwartalnik Geologiczny, **29** (2): 343–354.

Jarmołowicz-Szulc, K., 2017. Geochronological studies on the crystalline bedrock from NE Poland – an overview and summary (in Polish with English summary). Przegląd Geologiczny, **65**: 1536–1539.

Lis, J., Sylwestrzak, H., 1976. Opracowanie geochronologiczne K-Ar skał z obszaru Polski. Etap I – Badania wieku bezwzględnego wulkanitów sudeckich i z obszaru śląsko-krakowskiego (in Polish). Centralne Archiwum Geologiczne PIG-PIB, Warszawa, Nr 4422/490.

Lis, J., Sylwestrzak, H., 1978. Opracowanie geochronologiczne K-Ar skał z obszaru Polski (in Polish). Centralne Archiwum Geologiczne PIG-PIB, Warszawa, Nr. ObO/1773.

Ludwig, K., 2009. SQUID 2: A user’s manual, rev. 12 Apr., 2009. Berkeley Geochronology Center Special Publication, **5**: 1–110.

Markiewicz, J., Markowiak, M., 1998. Inwentaryzacja (kolekcje skał i baz danych) paleozoicznych skał krystalicznych i piroklastycznych regionu krakowsko-częstochowskiego (in Polish). Centralne Archiwum Geologiczne PIG-PIB, Warszawa, Nr 3248/98.

Markowiak, M., 2005. Description of ore mineralization against the background of thermal-metamorphic alterations of rocks in the Żarki-Kotowice area (in Polish with English summary) Prace Państwowego Instytutu Geologicznego, **203**: 74.

Martinec, P., Kožušniková, A., Konečný, P., 1994. Biotite dioritic porphyrites in the Če-1 (Čeladná) borehole (in Czech with English summary). In: Sborník referátů 2. Česko-Polské konference o sedimentologii karbonu hornoslezské pánve (eds. P. Martinec and P. Konečný): 147–159. Ústav Geoniky AVČR, Ostrava

Mikulski, S., Stein, H.J., 2012. The age of molybdenites in Poland in the light of Re-Os isotopic studies (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **452**: 199–216.

Mikulski, S.Z., Markowiak, M., Oszczepalski, S., 2008. Gold in quartz-sulfide veinlets from db-4 drillhole (Będkowska Valley, southern Poland) (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **429**: 99–112.

Mikulski, S.Z., Williams, I.S., Markowiak, M., 2019. Carboniferous-Permian magmatism and Mo-Cu (W) mineralization in the contact zone between the Małopolska and Upper Silesia Blocks (south Poland): an echo of the Baltica-Gondwana collision. International Journal of Earth Sciences, **108**: 1467–1492.

Nawrocki, J., Lewandowska, A., Fanning, M., 2007. Isotope and paleomagnetic ages of the Zalas rhyodacites (S Poland) (in Polish with English summary). Przegląd Geologiczny, **55**: 475–478.

Nawrocki, J., Fanning, M., Lewandowska, A., Polechońska, O., Werner, T., 2008. Palaeomagnetism and the age of the Cracow volcanic rocks (S Poland). International Geophysical Journal, **174**: 475–488.

Nawrocki, J., Krzemiński, L., Pańczyk, M., 2010. ^{40}Ar-^{39}Ar ages of selected rocks and minerals from the Kraków–Lubliniec Fault Zone, and their relation to the Paleozoic structural evolution of the Małopolska and Brunovistulian terranes (S Poland). Geological Quarterly, **54** (3): 289–300.

Narkiewicz, M., Maksym, A., Malinowski M., Grad, M., Guterch, A., Petecki, Z., Probulski, J., Janik, T., Majdański, M., Środa, P., Czuba, W., Gaczyński, E., Jankowski, L., 2015. Transcurrent nature of the Teisseyre-Tornquist Zone in Central Europe: results of the POLCRUST 01 deep reflection seismic profile. International Journal of Earth Sciences, **104**: 775–796.

Papalová, J., Tomšík, J., 1970. První zjištění vulkanismu v karbonu pod Beskydami (in Czech). Geologický Průzkum, **12**: 170–172.

Steiger, R.H., Jäger, E., 1977. Subcomission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters, **36**: 359–362.

Stein, H., Markowiak, M., 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 (eds. J. Mao and F.P. Bierlein): 833–836. Springer, Berlin.

Truszel, M., Karwowski, Ł., 2003. Skarns and skarn mineralization in the Cracow-Lubliniec region (Southern Poland). Mineralogical Society of Poland Special Papers, **23**: 175–178.

Truszel, M., Karwowski, Ł., Lasoń, K., Markiewicz, J., Żaba, J., 2006. Magmatism and metamorphism of the Kraków-Lubliniec tectonic zone as a clue to the occurrence of polymetallic deposits (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **418**: 55–103.

Williams, I.S., 1998. U-Th-Pb geochronology by ion microprobe. Reviews in Economic Geology, **7**: 1–35.

Williams, I.S., Claesson, S., 1987. Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragenesis from the Seve Nappes, Scandinavian Caledonides. II. Ion microprobe zircon U-Th-Pb. Contributions to Mineralogy and Petrology, **97**: 205–217.

Żaba, J., 1999. The structural evolution of Lower Palaeozoic succession in the Upper Silesian and Małopolska Block border zone (Southern Poland) (in Polish with English summary). Prace Państwowego Instytutu Geologicznego, **166**.

Żelaźniewicz, A., Pańczyk, M., Nawrocki, J., Fanning, M., 2008. A Carboniferous/Permian, calc-alkaline, I-type granodiorite from the Małopolska Block, Southern Poland: implications from geochemical and U-Pb zircon age data. Geological Quarterly, **52** (4): 301–308.

Żelaźniewicz, A., Oberc-Dziedzic, T., Fanning, C.M., Protas, A., Muszyński, A., 2016. Late Carboniferous – Early Permian events in the Trans–European Suture Zone: tectonic and acid magmatic evidence from Poland. Tectonophysics, **675**: 227–243.