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Early Carboniferous (~337 Ma) granite intrusion in Devonian (~400 Ma) ophiolite of the Central-European Variscides

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The Central-Sudetic ophiolites comprise mafic-ultramafic complexes around the E and S edges of the Góry Sowie Massif in SW Poland and are recognized as fragments of Devonian (~400 Ma old) oceanic crust. They contain small rodingite bodies and tectonized granite dykes that potentially can highlight the igneous, metamorphic and structural development of the ophiolitic suites. The granite dykes have been tentatively correlated with the Variscan granitoids of the Strzegom–Sobótka Massif to the north. However, new U-Pb SHRIMP zircon data for granites from the serpentinite quarry at Jordanów show a concordia age of 337 ±4 Ma for the main zircon population, and of 386 ±10 Ma for minor inheritance. Thus, the age of the granite is considerably older than the ages of the Strzegom–Sobótka granitoids, dated at ~310–294 Ma. The granite dyke has a similar age as some other granitoids found near the ophiolitic fragments, e.g., the Niemcza granitoids to the south, dated at 338 +2/–3 Ma; these older granitoids all represents a relatively early stage of granitoid magmatism recorded in that part of the Variscan Orogen. The age of the granitoid dyke within serpentinites confirms that the Paleozoic ophiolites were incorporated into the continental crust already in early Visean times.

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INTRODUCTION

The Central-Sudetic ophiolites (CSO) comprising several outcrops of mafic-ultramafic complexes around the E and S edges of the Góry Sowie Massif in the Central Sudetes and Fore-Sudetic Block (SW Poland) have been recognized as broadly complete and well-preserved fragments of Paleozoic oceanic crust (Majerowicz, 1979; Pin *et al*., 1988) incorporated into the structural mosaic of the NE part of the Bohemian Massif. These ophiolites have been used as key arguments for constructing palaeotectonic models for the evolution of the eastern part of the Variscan belt of Europe (e.g., Jamrozik, 1981; Matte *et al*., 1990; Pin, 1990; Narębski, 1993; Finger and Steyer, 1995; Cymerman *et al*., 1997; Höck *et al*., 1997; Franke, 2000; Franke and Żelaźniewicz, 2000; Aleksandrowski and Mazur, 2002; Kryza *et al*., 2004; Mazur *et al*., 2006; Kryza and Pin, 2010; Nance *et al*., 2010).

The petrology of the ophiolites is well-studied, and in particular the predominant MORB characteristics of the mafic rocks, as well as the mantle affinity of the ultramafic rocks, are well-documented (e.g., Majerowicz, 1979, 1994; Pin *et al*., 1988; Gunia, 1992, 2000; Dubińska, 1997; Dubińska and Gunia, 1997; Abdel Wahed, 1999; Kryza and Abdel Wahed, 2000; Floyd *et al*., 2002; Kryza and Pin, 2010). Detailed geochemical studies of rodingites from these ophiolites (Dubińska, 1997) suggest that the rodingite protoliths could have originated in a supra-subduction setting, possibly in a fore-arc environment, during obduction of the oceanic crust.

The age of the magmatic emplacement of the mafic rocks, after two decades of controversies (see Pin *et al*., 1988; Oliver *et al*., 1993; Dubińska *et al*., 2004), is now fairly well constrained at *ca*. 400 Ma (Kryza, 2010; Kryza and Pin, 2010). More vague remains the metamorphic and structural evolution of the ophiolitic suite. The mafic rocks are usually selectively (non-penetratively) deformed, but in one outcrop (the Braszowice Massif, south of the Ślęża ophiolite), the gabbros are exceptionally highly deformed. Dziedzic (1989) interpreted this strong deformation as a result of "dynamic crystallisation" after the emplacement of the gabbros.

The model of metamorphic evolution proposed by Dubińska (1995) refers to petrological constraints from ultramafic rocks and associated rodingites. In this model, the initial serpentinisation and rodingitisation occurred in an oceanic setting, whereas subsequent alteration took place in a continental environment (which is typical of many ophiolitic suites). The early low-temperature serpentinisation (and rodingitisation) was extensive, promoted by intense fracturing and deep sea-water penetration (Jędrysek *et al*., 1989). The subsequent continental stage involved "tectonic granulation" (intense brecciation) and formation of late metamorphic minerals, and was broadly contemporaneous with intrusion of Variscan granitoids. The main points of this model are broadly in line with the sequence of metamorphic events inferred by Kryza (in Majerowicz *et al*., 2000) for the gabbros of Ślęża: (1) magmatic emplacement of gabbro; (2) early low-T metamorphism (probably ocean-floor metamorphism); (3) peak-T regional metamorphism associated with localized, non-penetrative shearing of the gabbro; (4) waning (late) metamorphism, under decreasing T, and partly replacing the earlier parageneses, and associated with localized deformation in semi-brittle to brittle conditions.

According to Mierzejewski and Abdel Wahed (2000), the serpentinites show two deformational episodes: earlier top-to-WNW thrusting along listric thrust faults, and later top-to-ESE normal faulting due to relaxation of the thrust blocks. The contact between the serpentinites and the gabbroic member higher in the ophiolitic pseudostratigraphy is strongly tectonized.

As mentioned above, important petrological issues of the CSO concern the rodingites found in serpentinites of the structurally lowermost member of the ophiolite (Majerowicz, 1979, 1984; Heflik, 1982; Dubińska and Szafranek, 1990; Dubińska, 1995), which bear evidence of important episodes in the geological, and particularly the metamorphic, evolution of the ophiolitic suite. The rodingites are locally associated with leucocratic rocks of granitic (or less frequently plagiogranitic) character (called "weiβstein" in older literature), displaying very complex mineralogy and structural relationships. The most famous locality of such "leucocratic zones" is the quarry at Jordanów, in the central part of the Fore-Sudetic Block. The quarry has been known in the mineralogical literature for over 120 years (Traube, 1888), mainly for the famous occurrence of nephrite. Many papers describing the mineralogy and petrology of this locality, published within the past few decades, provided a range of interesting mineralogical data, and contributed much to our understanding of the metamorphic evolution of the Ślęża ophiolie (for a review of the extensive literature, see Heflik, 1982; Majerowicz, 1984; Dubińska and Szafranek, 1990; Dubińska, 1995, 1997).

One of the key problems in the leucocratic zone at Jordanów are granite bodies which form a very complex contact zone against serpentinites and associated calc-silicate rocks. The granites have been tentatively correlated with the Variscan granitoids of the Strzegom–Sobótka Massif (Dubińska and Szafranek, 1990; Dubińska, 1995); however, their true age has been unconstrained.

This study provides a U-Pb SHRIMP zircon age for the granite from the leucocratic zone at Jordanów. Based on this new geochronological data, some regional age correlations of granitoid rocks are made. The new results give further important constraints for the model of the incorporation of the Paleozoic ophiolites into continental crust during the Variscan collision.

GEOLOGICAL FRAMEWORK AND PREVIOUS STUDIES

Small leucocratic bodies and veins have been reported from a number of localities in the Gogołów–Jordanów serpentinite massif, which is the outcrop of the lowermost, ultramafic member of the Ślęża ophiolite (Fig. 1; Majerowicz, 1979, 1984, 1994; Dubińska and Wiewióra, 1988; Pin *et al*., 1988; Majerowicz and Pin, 1989; Dubińska and Szafranek, 1990; Dubińska, 1995, 1997). Typically, they are strongly tectonized and weathered, but show distinct contact zones, taken as evidence that they represent apophyses of the Variscan Strzegom–Sobótka granitoids (Dubińska and Szafranek, 1990, and references therein).

Majerowicz (1984) and Majerowicz and Pin (1989) clearly distinguished between typical rodingitic rocks and aplitic rocks, the later apparently related to the Variscan granitoids. The rodingites are composed of grossular, diallage, sheridanite and vesuvianite and are interpreted as boudinaged and metasomatically rodingitised (strongly inriched in calcium) fragments of gabbroic dykes of the ophiolite. These rocks have been considered as common components of ophiolitic complexes, being transformation products of surrounding rocks at various stages of serpentinisation. On the other hand, the aplitic rocks, which are light-coloured, fine-grained vein rocks locally found within serpentinites, correspond mostly to granite-granodiorite in composition, and have been interpreted as related to the granitoids.

The best studied "leucocratic zone" in the serpentinites is exposed in the famous nephrite quarry at Jordanów. Heflik (1967, 1982) described the mineralogy of this leucocratic zone and interpreted the altered rocks as rodingites or rodingite-like rocks developed at the expense of gabbroic dykes. Lis and Sylwestrzak (1981) reported "small inclusions of granitic pegmatite", with beryl, garnet, tourmaline, columbite, gahnite *etc*., within a quartz-zoisite vein in the Jordanów quarry, and they considered these pegmatites as genetically related to the Strzegom–Sobótka granitoids.

Dubińska and Wiewióra (1988) described in detail layer-silicates in the contact zone between granite and serpentinite at Jordanów and tentatively concluded that the contact zone can be regarded as a rodingite backwall, formed during serpentinisation of ultramafic rocks. In a subsequent paper, Dubińska and Szafranek (1990) correlated the formation of layer silicates: chlorite, vermiculite, talc and so on, with textural changes of the rocks of the contact zone between an apophyse of Variscan granite and older serpentinite.

A systematic description of the rodingites of the E part of the Gogołów–Jordanów Massif is given by Dubińska (1995),

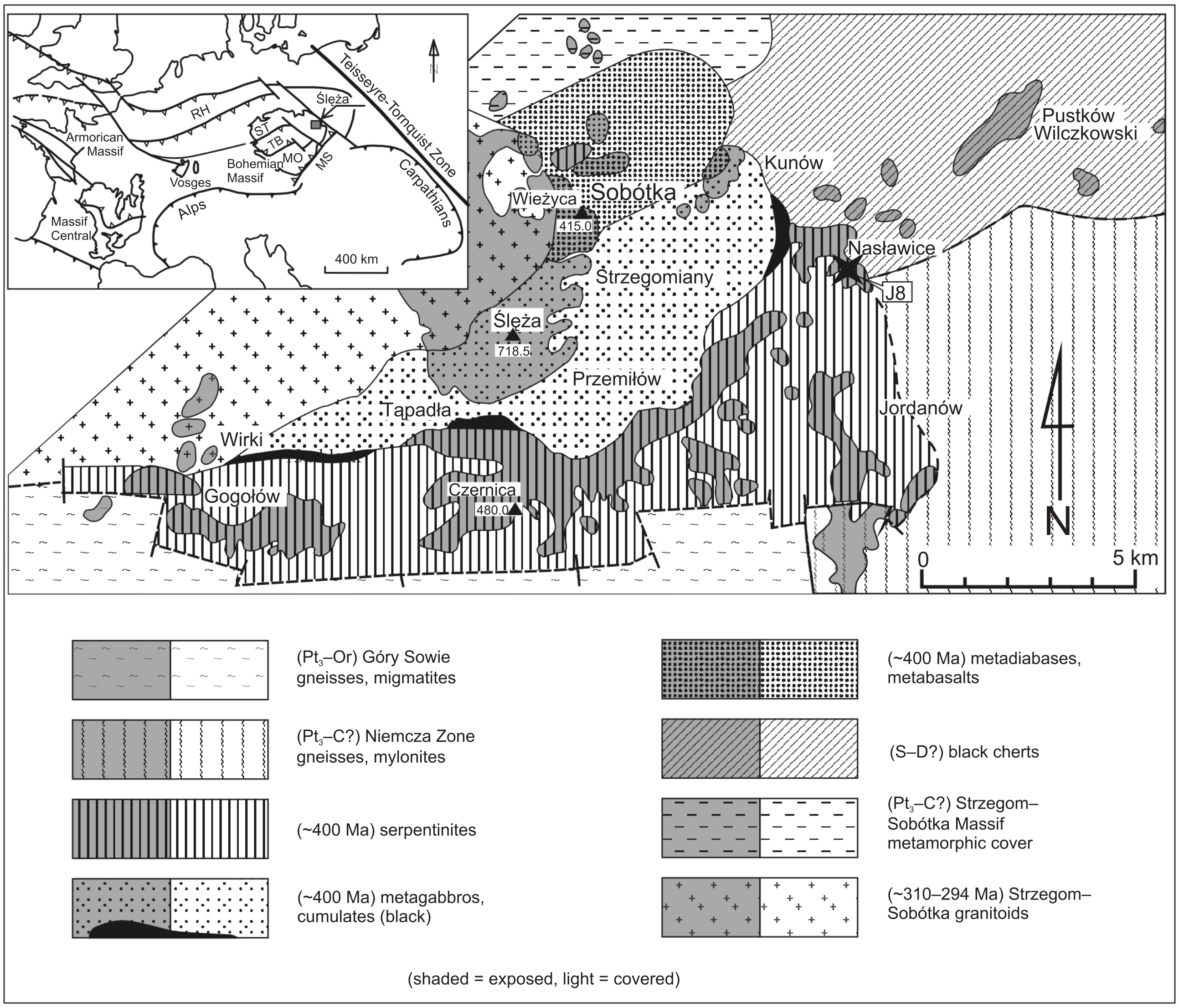

Fig. 1. Geological sketch of the Ślęża ophiolite (based on Majerowicz, 1979, computerized by A. Wójcik and M. Kryza)

Tectonic units (zones) of the Central-European Variscides: MO – Moldanubian, MS – Moravosilesian, RH – Rhenohercynian, ST – Saxothuringian, TB – Tepla-Barrandian; location of sample J8 from Jordanów Quarry is indicated

who states that the rodingites are derived from two types of protoliths: mafic rocks, and albitites or plagiogranites. Rodingites, and the enclosing serpentinites, form the highly tectonized and mineralogically very complex contact zone against younger granites in the Jordanów Quarry.

FIELD RELATIONSHIPS AND PETROLOGICAL NOTES

Field relationships between various rocks in the Jordanów Quarry and their mineralogy, petrology and geochemistry were described by Dubińska and Szafranek (1990). The serpentinites dominant in the quarry are represented by an antigoritic variety, with no relict mafic minerals nor pseudomorphic textures. However, opaque minerals indicate bastite pseudomorphs, and the texture is locally obliterated by fine-grained talc and colourless monoclinic amphibole (*op. cit.*).

According to Dubińska (1995), the various felsic rocks (i.e., rodingites and metagranites – R. Kryza) in the Jordanów Quarry occur in two adjacent zones, 20–25 m and ~5 metres wide, both at the contact between granite and serpentinite. In a schematic sketch of the contact zone (Dubińska, 1995, fig. 4), the country rocks, antigorite serpentinites are associated with several varieties of rodingites (zoisite ± garnet, zoisite ± garnet and diopside), ridingite breccias and plagiogranite, as well as tectonized leucocratic granite. Along the main contact, vermiculite–chlorite–tremolite ± talc contact schists are developed, with local concentrations of nephrite and tremolite rocks.

Within the leucocratic zone, fragments of brecciated leucogranite are common. According to Dubińska (1995), the light-coloured and fine-grained granite is composed of quartz, plagioclase ($An_{18–22}$), microcline and minor biotite, fine-grained white mica and accessory zircon. No overprinting of the granite by Ca-silicates of the "rodingitic" assemblage has been found, except for "...small sheafs of actinolite formed after <granulation> of the granite...” (Dubińska, 1995). However, the petrographic observations on the samples studied (see below) indicate that the leucocratic rocks derived from a K-rich granite (containing K-feldspar, albite, quartz and accessory zircon and apatite) are strongly overprinted by secondary parageneses, with abundant grossular and subordinate actinolite-type mineral.

According to Dubińska and Szafranek (1990), the leucocratic rocks of the Gogołów–Jordanów Massif are relatively rich in potassium (up to 9.90 wt.%) and thus their compositions correspond to the field of “continental granophyre” of Coleman (1977, *vide* Dubińska and Szafranek, 1990). Their two granite samples analysed from the Jordanów Quarry have the main components within the following ranges (in wt.%): SiO_2 68.58–75.22, Al_2O_3 13.10–16.39, Fe_2O_3 0.02–0.38, FeO 0.35–0.85, MgO 0.31–0.35, CaO 0.38–0.46, K_2O 5.12–9.90, Na_2O 2.94–4.12. Two other analysed samples of “feldspar-rich rocks” contain less SiO_2 and K_2O, and more Al_2O_3, CaO and Na_2O; their composition corresponds to oligoclasite and they are suggested to be possible parental material for the calc-silicate rocks (Dubińska and Szafranek, 1990).

A model for the development of the calc-silicate rocks from the leucocratic zone at Jordanów is complex and comprises several stages (Dubińska and Szafranek, 1990). The early rodingites developed at the expense of albitite and/or plagiogranite bodies. The subsequent episodes of the evolution of this zone were strongly influenced by the emplacement of granitic veins, producing a contact zone between serpentinite (containing a rodingite body) and granite. A sort of mélange of calc-silicate rocks was formed in the small leucocratic zone as a result of tectonic disruption and displacement (Dubińska, 1995).

METHODS

The sample selected for SHRIMP analysis was thin-sectioned for petrographic investigation, using routine polarizing microscopy, X-ray diffraction and electron microprobe (*Cambridge Microscan M9* at the Department of Mineralogy and Petrology, Institute of Geological Sciences, University of Wrocław, donated by the Free University of Amsterdam).

The sample for zircon separation, *ca*. 3 kg in weight, was crushed and the heavy mineral fraction (0.06–0.25 mm) separated using a standard procedure with heavy liquids and magnetic separation. Zircons were hand-picked under a microscope, mounted in epoxy and polished. Transmitted and reflected light photomicrographs were made together with CL images in order to select grains and choose sites for analysis. The Sensitive High Resolution Ion Microprobe (SHRIMP II) at the Centre of Isotopic Research (CIR) at the All-Russian Geological Research Institute (VSEGEI) in St. Petersburg was used to determine zircon ages in the sample selected. Details of the SHRIMP procedures and analytical details are given in the Appendix. Uncertainties for individual analyses (ratios and ages) are at the one level; however, the uncertainties in calculated concordia ages are reported at the 2 level.

SAMPLE DESCRIPTION

The sample for SHRIMP zircon dating was collected from the main leucocratic body, at the base of the northern wall of the Jordanów quarry (Fig. 2). The rock is leucocratic, whitish-cream in colour, with practically no mafic minerals discernable. The texture is fine-grained and massive, dominated by a creamy mass, intergrown with greyish patches of mineral aggregates difficult to recognize with the naked eye. Locally, joints are covered by colourless “droplets” of opal.

Under the microscope, the rock appears to be dominated by garnet of grossular composition (Table 1). The garnet is colourless, commonly cloudy, displaying weak birefringence in places. The mass of grainy garnet is intergrown with stripes and nests of microaggreagtes composed of quartz and feldspars. The latter are represented by nearly pure albite and K-feldspar;

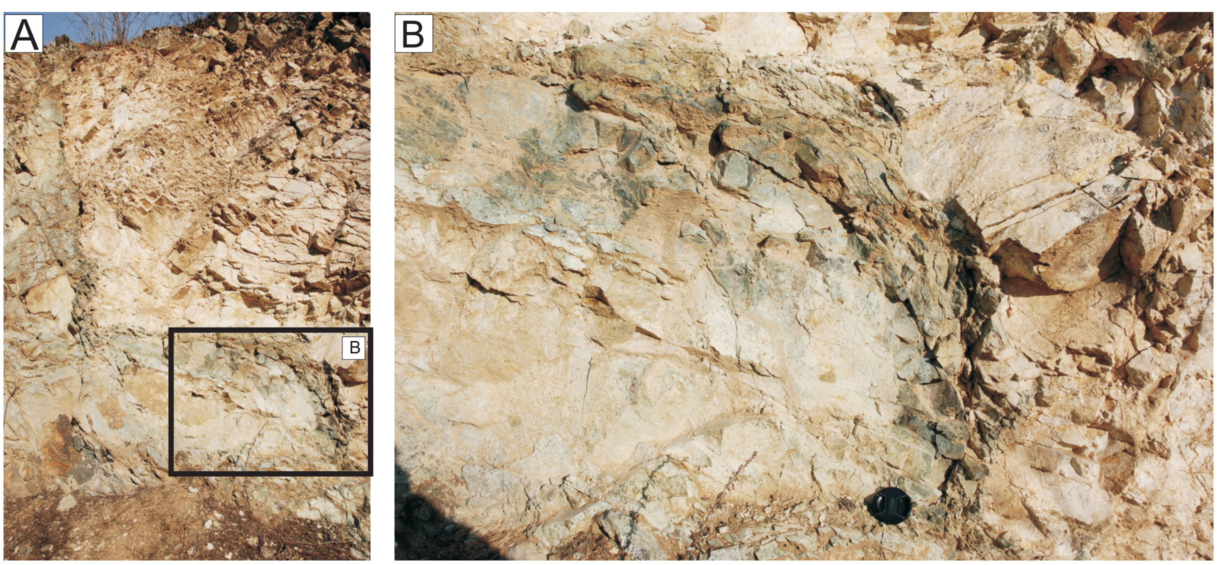

Fig. 2. Leucocratic rocks within serpentinites on the northern wall of the Jordanów Quarry (A)

Sample 8 was collected on the right-hand edge of photo B

Table 1

Microprobe analyses and formulae of grossular garnet from sample S-8

Analysis	Gr1	Gr2	Gr6	Mean
SiO_2	38.666	40.314	39.143	39.374
TiO_2	0.009	0.081	0.058	0.049
Al_2O_3	22.460	21.962	22.612	22.345
FeO	0.513	0.785	0.234	0.511
MnO	0.000	0.000	0.000	0.000
MgO	0.071	0.057	0.064	0.064
CaO	36.549	34.832	36.106	35.829
Total	98.268	98.031	98.217	98.172
Si IV	2.960	3.069	2.986	3.005
Al IV	0.040	0.000	0.014	0.000
T site	3.000	3.069	3.000	3.005
Al VI	1.987	1.970	2.018	2.010
Ti VI	0.001	0.005	0.003	0.003
O site	1.987	1.975	2.022	2.013
Fe^{+2}	0.033	0.050	0.015	0.033
Mn^{+2}	0.000	0.000	0.000	0.000
Mg^{+2}	0.008	0.006	0.007	0.007
Ca^{+2}	2.998	2.841	2.951	2.930

Table 2

Microprobe analyses and formulae of feldspars from sample S-8

Analysis	NaFs7	NaFs5	NaKFs3	KFs4
SiO_2	68.575	68.060	66.810	64.704
TiO_2	0.000	0.000	0.000	0.019
Al_2O_3	19.166	18.933	18.476	18.197
Fe_2O_3	0.064	0.051	0.091	0.108
MnO	0.000	0.000	0.061	0.026
MgO	0.026	0.030	0.000	0.000
CaO	0.178	0.056	0.024	0.019
Na_2O	11.543	9.948	4.611	0.197
K_2O	0.087	2.281	9.677	15.739
Total	99.639	99.359	99.750	99.009
Si^{+4}	3.005	3.011	3.018	3.009
Ti^{+4}	0.000	0.000	0.000	0.001
Al^{+3}	0.990	0.987	0.984	0.998
Fe^{+3}	0.002	0.002	0.003	0.004
Mn^{+2}	0.000	0.000	0.002	0.001
Mg^{+2}	0.002	0.002	0.000	0.000
Ca^{+2}	0.008	0.003	0.001	0.001
Na^{+1}	0.981	0.853	0.404	0.018
K^{+1}	0.005	0.129	0.558	0.934
Total	4.992	4.986	4.970	4.965
K+Na+Ca	0.994	0.985	0.963	0.953
or	0.005	0.131	0.579	0.980
ab	0.987	0.867	0.420	0.019
an	0.008	0.003	0.001	0.001

a few analyses show significant proportions of both albite and orthoclase end-members (Table 2). The rock also contains patchy segregations of microaggregates composed of a cloudy mineral mass, yellowish to brownish-red in colour, often with a fibrous texture. These are highly inhomogeneous in BSE images, containing an acicular or fibrous mineral intergrown with Fe-rich secondary phases. In spite of usually poor polishing, the chemical composition of these aggregates, tested with EDS, is fairly constant and correspond to actinolite-type amphibole (Fig. 3). Accessories are represented by apatite and zircon. The main components: grossular, quartz, albite, and K-feldspar, have been confirmed by X-ray diffraction analysis, whereas minor and accessory components have not been detected.

Summing up, the sample contains, apart from evidently metamorphic calc-silicate minerals such as grossular and actinolite, components typical of granite composition: quartz, albite, K-feldspar, and accessory zircon (fairly abundant) and apatite, which together with field evidence, suggest that we are dealing with a strongly altered granitoid dyke intruding serpentinites.

SHRIMP RESULTS

ZIRCON CHARACTERISTICS

The main zircon population is rather homogeneous: the euhedral and subhedral crystals are short-prismatic, transparent, with a characteristic pink-brownish tint (Fig. 4). In transmitted light, they show delicate, magmatic zonation, rather poorly visible in CL and BSE images. No distinct cores are discernable.

SHRIMP DATA AND AGES

Nine points in 9 zircon crystals analysed yielded a generally clear picture of age distribution (Table 3, Figs. 4 and 5).

Two fairly concordant points (1.1 – discordance D + 6, and 3.1 – D + 1) are distinctly older and give an average concordia age of 386 ±10 Ma. These two older zircons have different morphology: subhedral, short-prismatic, with poorly developed prisms. Also, in contrast with zircons of the main population, they are nearly colourless and clear. Furthermore, they contain relatively low amounts of U and Th, compared with the zircons of the main population.

Seven points in seven grains all seem to belong to the main population of zircons and they display similar chemical isotopic signatures: high U (2877–6433 ppm) and Th (160–920 ppm), low $^{232}Th/^{238}U$ ratios (0.06–0.17), and low common lead, $^{206}Pb_c$ contents, between 0 and 0.45%. All are concordant to slightly discordant (Table 3). The average concordia age for six points, excluding one significantly older, is 336.5 ±4.5 Ma (Fig. 5).

Two grains, 2.1 and 8.1, of similar physical features (prismatic habit and characteristic pinkish tint) and chemical signatures, have significantly older ages (Table 3). If these two

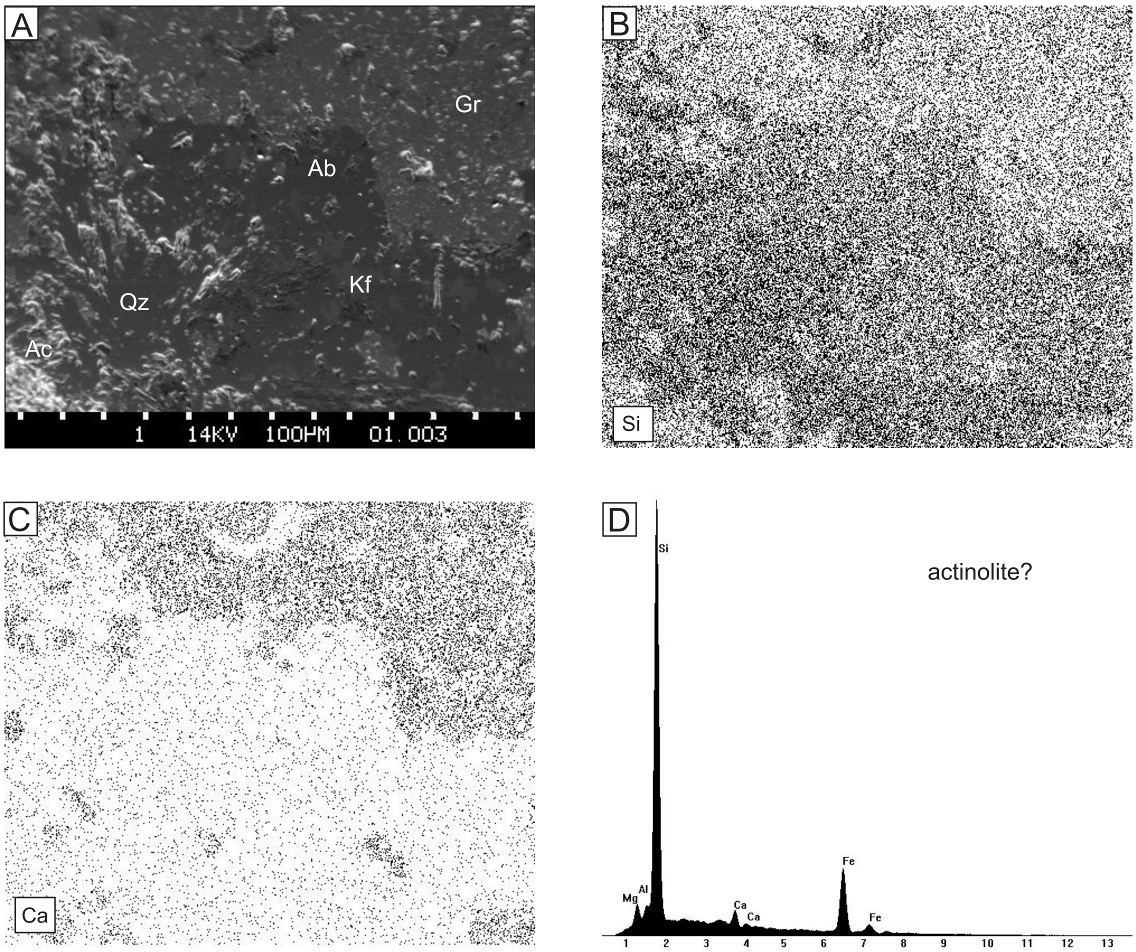

Fig. 3. Electron-microprobe data from sample S-8

A – BSE image showing the main mineral components of the leucocratic rock: Ab – albite, Ac – actinolite?, Gr – grossular, Kf – K-feldspar, Qz – quartz; **B** and **C** – distribution of Si and Ca in the field shown in A; **D** – EDS spectrum of actinolite-type

points were included, the average concordia age would increase to 339 ±4 Ma, and if both were excluded, the mean concordia age would be by *ca*. 3 My years younger: 334 ±5 Ma. Theoretically, the two older dates, around 350 Ma, could be interpreted as mixed ages, between the inherited zircons of *ca*. 386 Ma and the main population zircons of *ca*. 337 Ma. However, there are no indications of such "mixing" in the crystals. An alternative is that they belong to the main population and the true magmatic age is around 339 ±4 Ma.

DISCUSSION AND CONCLUSION

The new SHRIMP results from the granite dyke in serpentinites at Jordanów indicate that the magmatic cristallization age of the granite was 337 ±4 Ma. The rock contains a few considerably older inherited zircons, *ca*. 386 ±10 Ma in age. These have different morphology, with subhedral, short-prismatic habit, and poorly developed prisms. Also, in contrast with zircons of the main population, the inherited grains are nearly colourless and clear. Furthermore, they contain relatively low amounts of U and Th compared with the zircons of the main population.

Interestingly, the age of the inherited zircons is similar to the age of the Ślęża gabbro (Kryza, 2010). How did these older zircons get into this granite sample? One possibility is contamination of granitic magma with the country rocks (gabbro).

Some of the granite dykes found within the ophiolite suite have been tentatively correlated with the local Variscan granitoids, such as those in the Strzegom–Sobótka Massif to the north. Dubińska and Szafranek (1990) convincingly argue that "...the granitic rock from Jordanów, which is extremely rich in potassium, should not be included into the ophiolite sequence, since granitoids genetically related to ophiolites are mostly K-poor. Moreover, the texture of slightly tectonized granite fragments is similar to that of one of the varieties of Variscan Strzegom–Sobótka granites." Also, Nb-Ta minerals discovered in the contact schists have been taken as another possible argument for this correlation, since similar phases were reported by Lis and Sylwestrzak (1981) from pegmatite bodies at Jordanów, that were considered as related to the Strzegom–Sobótka granitoids.

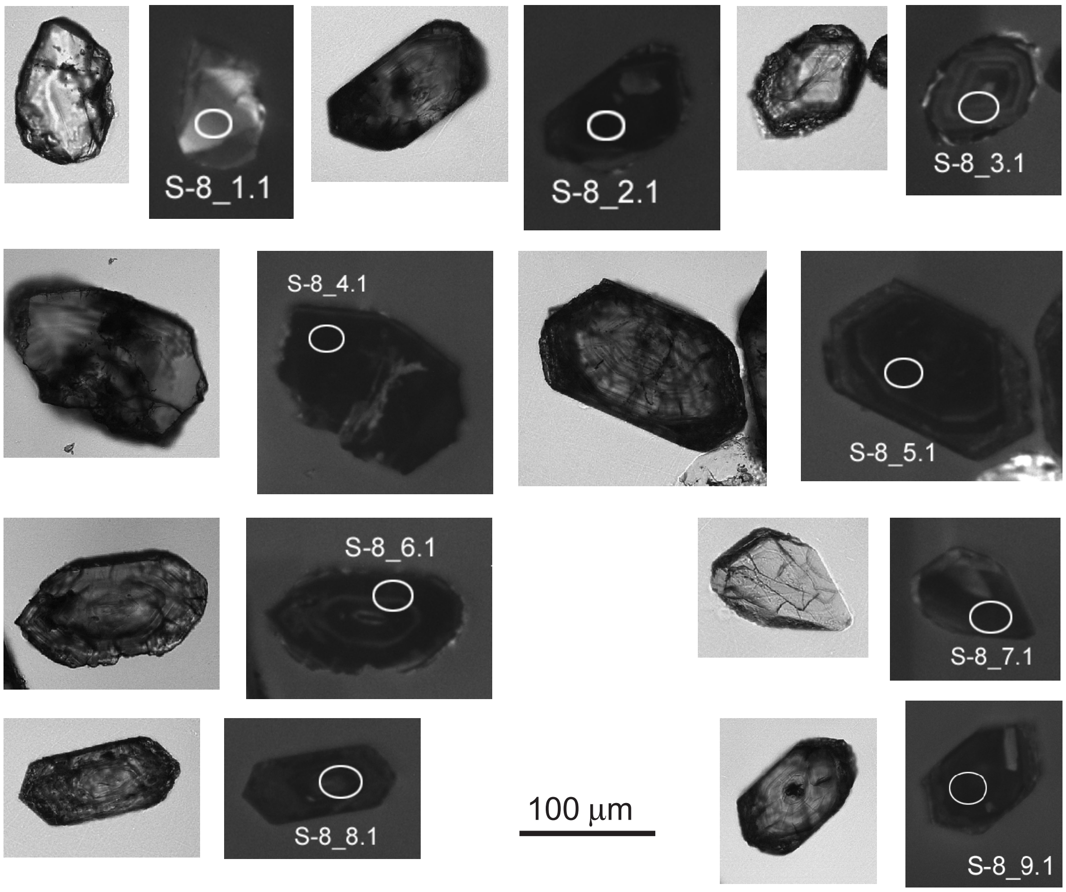

Fig. 4. Transmitted light and CL images of the zircons from dated sample S-8 from the Jordanów Quarry

SHRIMP analytical spots are indicated by ellipses; symbols of spots correspond to those in Table 3

Table 3

SHRIMP data for zircons from granite, sample S-8 from Jordanów

Spot	$^{206}Pb_c$ [%]	U [ppm]	Th [ppm]	$^{232}Th/^{238}U$	$^{206}Pb^*$ [ppm]	(1) $^{206}Pb/^{238}U$ age		(1) $^{207}Pb/^{206}Pb$ age		Dis-cor-dant [%]	(1) $^{238}U/^{206}Pb^*$	± [%]	(1) $^{207}Pb^*/^{206}Pb^*$	± [%]	(1) $^{207}Pb^*/^{235}U$	± [%]	Error corr
1.1	0.42	486	162	0.34	25.9	386.8	±7.5	411	±120	6	16.17	2.0	0.05500	5.2	0.4690	5.6	0.359
2.1	0.07	6232	705	0.12	297	347.9	±5.8	346	±26	0	18.03	1.7	0.05341	1.1	0.4084	2.1	0.829
3.1	0.45	1524	250	0.17	80.9	384.9	±6.7	396	±82	3	16.25	1.8	0.05460	3.6	0.4630	4.1	0.444
4.1	0.10	5045	507	0.10	228	330.8	±5.6	343	±33	4	18.99	1.7	0.05334	1.5	0.3873	2.3	0.765
5.1	0.18	5285	552	0.11	239	329.5	±5.5	329	±36	0	19.07	1.7	0.05301	1.6	0.3833	2.3	0.729
6.1	0.00	4059	650	0.17	188	338.3	±5.7	343	±28	1	18.56	1.7	0.05333	1.3	0.3961	2.1	0.810
7.1	0.01	4437	491	0.11	203	333.9	±5.6	332	±28	–1	18.81	1.7	0.05307	1.2	0.3890	2.1	0.818
8.1	0.43	2877	160	0.06	140	353.2	±6.0	326	±91	–8	17.75	1.8	0.05290	4.0	0.4110	4.4	0.399
9.1	0.03	6433	920	0.15	297	337.6	±5.6	327	±24	–3	18.60	1.7	0.05296	1.1	0.3926	2.0	0.851

Errors are 1-sigma; Pb_c and Pb* – the common and radiogenic portions, respectively; error in standard calibration was 0.68% not included in above errors but required when comparing data from different mounts; (1) – common Pb corrected using measured ^{204}Pb

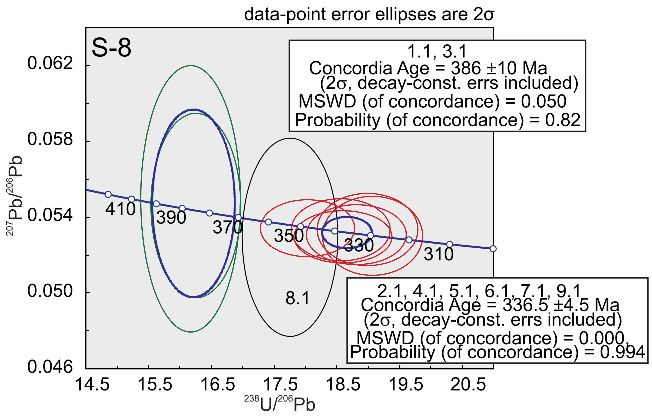

Fig. 5. Terra-Wasserburg plot for zircons of sample S-8

The new U-Pb SHRIMP zircon data for the granite from the well-known serpentinite quarry at Jordanów put in doubt the correlation of such granites with the Strzegom–Sobótka granitoids. The magmatic age of 337 ±4 Ma of the granite is much older than the recently verified ages of the Strzegom–Sobótka granitoids, most of which fall within the range of 310–294 Ma (Turniak *et al*., 2005). However, the granite dyke from Jordanów has a similar age to some other granitoid bodies that occur close to ophiolitic fragments in that area, e.g., the Niemcza granitoids to the south, dated at 338+2/–3 Ma (Oliver *et al*., 1993). All these older granitoids represent a relatively early stage of granitoid magmatism recorded in that part of the Variscan Orogen. Within the wider context of the Bohemian Massif, the most widespread magmas of that time (around 338 Ma) are of durbachitic affinity (Finger *et al*., 2009). These granitoids are defined by very high-K contents but, nevertheless, are commonly interpreted as mantle magmas (melts from enriched mantle), likely related to postcollisional slab break-off (Janoušek and Holub, 2007; Finger *et al*., 2007). Many durbachite plutons of the Bohemian Massif are intermediate magmatites. They are syenitic, melagranodioritic or quartzmonzonitic, in terms of the Streckeisen classification, but felsic end-members with high-K granitic composition are locally also associated (e.g., in the Rastenberg pluton in Austria; Finger *et al*., 2009).

The timing of particular petrogenetic events in the evolution of the Central-Sudetic ophiolites remains, at least in part, problematic. Dubinska *et al*. (2004) argued that their SHRIMP zircon age of 400+4/–3 Ma from rodingite corresponds to the rodingitization and serpentinization processes, rather than to the magmatic emplacement age of the gabbros. However, new SHRIMP zircon ages from gabbros from several different localities fall within this range of 395–405 Ma and they are assumed as the magmatic ages of the gabbros (Kryza, 2010). If both the interpretations are correct, the rodingitisation and serpentinisation processes must have occurred fairly soon after the magmatic emplacement of the mafic rocks of the ophiolites. On the other hand, the strong alteration of the 337 Ma old metagranite at Jordanów indicates that metasomatic processes may have been active, at least locally, much later than the magmatic processes in the ophiolite. This would be in line with the model of a multi-stage PT path for the Ślęża gabbros proposed by Kryza (in Majerowicz *et al*., 2000; see above).

The regional framework and structural position of the CSO remain controversial (e.g., Żelaźniewicz, 1995; Mazur *et al*., 2006; Kryza and Pin, 2010). However, the granitoids of the early plutonic phase of the Variscan orogeny in this part of the Bohemian Massif, ~340 Ma in age, are interpreted as synorogenic intrusions (Mazur *et al*., 2007, and references therein), thus the emplacement of these magmatites into the ophiolite complex must have taken place still within a tectonothermally active setting. The clear spatial coincidence of granitoid sills with zones of strong penetrative deformation in the Niemcza Shear Zone has recently been emphasized by Lorenc and Kennan (2007). The small granitoids in that area were emplaced syntectonically during the regional shearing that affected the rocks of the Niemcza Zone, where the lineations and foliations in some of the intrusives, as well as the elongations of their enclaves, are subparallel to the penetrative fabrics in the country rocks (Dziedzic, 1963). Parts of the ophiolite complex, such as that exposed at Jordanów, could have been located outside zones of intense shearing, though the original spatial relationships have been obscured by tectonic displacements.

Despite controversial structural interpretations, the *ca*. 337 ±4 Ma age of the granitoid dykes of continental-crustal affinity (e.g., the high-K granitic composition of these rocks) within serpentinites shows that the ophiolites were incorporated into the continental crust already in early Visean times. This geochronological-palaeotectonic constraint should be kept in mind when models of the Variscan orogenic collision are refined.

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REFERENCES

ABDEL WAHED M. (1999) – The Ślęża ophiolite (SW Poland): petrological and structural evolution. PhD Thesis, Institute of Geological Sciences, University of Wrocław, Poland.

ALEKSANDROWSKI P. and MAZUR S. (2002) – Collage tectonics in the northeasternmost part of the Variscan Belt: the Sudetes, Bohemian Massif. In: Palaeozoic Amalgamation of Central Europe (eds. J.

Winchester, T. Pharaoh and J. Verniers). Geol. Soc. London Spec. Publ., **201**: 237–277.

BLACK L. P., KAMO S. L., ALLEN C. M., ALEINIKOFF J. N., DAVIS D. W., KORSCH R. J. and FOUDOULIS C. (2003) – TEMORA 1: a new zircon standard for Phanerozoic U-Pb geochronology. Chem. Geol., **200**: 155–170.

COLEMAN R. G. (1977) – Ophiolites. Springer, Berlin.

CYMERMAN Z., PIASECKI M. A. J. and SESTON R. (1997) – Terranes and terrane boundaries in the Sudetes, northeast Bohemian Massif. Geol. Mag., **134** (5): 717–725.

DUBIŃSKA E. (1995) – Rodingites of the eastern part of the Jordanów-Gogołów serpentinite massif, Lower Silesia, Poland. Canadian Miner., **33**: 585–608.

DUBIŃSKA E. (1997) – Rodingites and amphibolites from the serpentinites surrounding Góry Sowie block (Lower Silesia, Poland): record of supra-subduction zone magmatism and serpentinization. Neues Jahrb. Miner., Abh., **171** (3): 239–279.

DUBIŃSKA E., BYLINA P., KOZŁOWSKI A., DŐRR W. NEJBERT K., SCHASTOK J. and KULICKI C. (2004) – U-Pb dating of serpentinization: hydrothermal zircon from a metasomatic rodingite shell (Sudetic ophiolite, SW Poland). Chem. Geol., **203** (3–4): 183–203.

DUBIŃSKA E. and GUNIA P. (1997) – The Sudetic ophiolite: current view on its geodynamic model. Geol. Quart., **41** (1): 1–20.

DUBIŃSKA E. and SZAFRANEK D. (1990) – On the origin of layer silicates from Jordanów (Lower Silesia, Poland). Arch. Miner., **46** (1–2): 19–36.

DUBIŃSKA E. and WIEWIÓRA A. (1988) – Layer-silicates in the contact zone between granite and serpentinite, Jordanów, Lower Silesia, Poland. Clay Miner., **23**: 459–470.

DZIEDZIC H. (1963) – So-called syenites of the Niemcza zone (Lower Silesia) (in Polish with English summary). Arch. Miner., **24** (2).

DZIEDZIC H. (1989) – Tectonics and petrogenesis of the Braszowice gabbro. Multilateral Cooperation of Academies of Sciences of Socialist Countries, Guidebook of Excursion in Poland, University of Wrocław, Poland: 124–156.

FINGER F., GERDES A., JANOUŠEK V., RENÉ M. and RIEGLER G. (2007) – Resolving the Variscan evolution of the Moldanubian sector of the Bohemian Massif: the significance of the Bavarian and the Moravo-Moldanubian tectonometamorphic phases. J. Geosc., **52**: 9–28.

FINGER F., GERDES A., JANOUŠEK V., RENÉ M. and RIEGLER G. (2009) – The Saxo-Danubian Granite Belt: magmatic response to postcollisional delamination of mantle lithosphere below the south-western sector of the Bohemian Massif (Variscan orogen). Geol. Carpath., **60** (3): 205—212, doi: 10.2478/v10096-009-0014–3

FINGER F. and STEYRER H. P. (1995) – A tectonic model for the Eastern Variscides: indicators from the chemical study of amphibolites in the south-eastern Bohemian Massif. Geol. Carpath., **46**: 137–150.

FLOYD P. A., KRYZA R., CROWLEY Q. G., WINCHESTER J. A. and ABDEL WAHED M. (2002) – Ślęża ophiolite: geochemical features and relationship to Lower Palaeozoic rift magmatism in the Bohemian Massif. In: Palaeozoic Amalgamation of Central Europe (eds. J. Winchester, T. Pharaoh and J. Verniers). Geol. Soc. London Spec. Publ., **201**: 197–215.

FRANKE W. (2000) – The mid-European segment of the Variscides: tectonostratigraphic units, terrane boundaries and plate tectonic evolution. In: Orogenic Processes: Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London Spec. Publ., **179**: 35–61.

FRANKE W. and ŻELAŹNIEWICZ A. (2000) – The eastern termination of the Variscides: terrane correlation and kinematic evolution. In: Orogenic Processes: Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London Spec. Publ., **179**: 63–86.

GUNIA P. (1992) – Petrology of the ultrabasic rocks from the Braszowice-Brzeźnica Massif (Fore-Sudetic Block). Geol. Sudet., **26** (1–2): 119–170.

GUNIA P. (2000) – The petrology and geochemistry of mantle-derived basic and ultrabasic rocks from the Szklary massif in the Fore-Sudetic Block (SW Poland). Geol. Sudet., **33** (2): 71–83.

HEFLIK W. (1967) – Mineralogical and petrographic investigation of the leucocratic altered zone of Jordanów (Lower Silesia) (in Polish with English summary). Pr. Miner. Komis. Nauk Miner. Pol. Acad. Sc., **10**.

HEFLIK W. (1982) – Pozycja petrologiczna rodingitów z Jordanowa (Dolny Śląsk) (in Polish with English summary). Prz. Geol., **30** (6): 277–280.

HÖCK V., MONTAG O. and LEICHMAN J. (1997) – Ophiolite remnants at the eastern margin of the Bohemian Massif and their bearing on the tectonic evolution. Miner. and Petrol., **60**: 267–287.

JAMROZIK L. (1981) – Tectonic position of ultrabasite-basite massifs surrounding the Góry Sowie block. In: Ophiolites and Initialites of Northern Border of the Bohemian Massif (ed. W. Narębski): 86–95. Conference Proceedings, Potsdam-Freiberg.

JANOUŠEK V. and HOLUB F. V. (2007) – The causal link between HP-HT metamorphism and ultrapotassic magmatism in collisional orogens: case study from the Moldanubian Zone of the Bohemian Massif. Proc. Geol. Ass., **118**: 1–12.

JĘDRYSEK M.-O, MAJEROWICZ A., JASIŃSKA B. and HAŁAS S. (1989) – The migration of oceanic water into the upper mantle. Evidence from δD and δ^{18}O values of minerals of rodingitic rocks of the ophiolitic complex of Ślęża, SW Poland. Miner. Pol., **20** (1): 107–117.

KRYZA R. (2010) – The Central-Sudetic ophiolites: SHRIMP zircon geochronology (preliminary results). Miner., Spec. Pap., **37**: 89–90.

KRYZA R. and ABDEL WAHED M. (2000) – The Ślęża mafic complex: contrasting geochemistry of plutonic and subvolcanic/volcanic rocks. Miner. Soc. Poland Spec. Pap., **17**: 195–197.

KRYZA R., MAZUR S. and OBERC-DZIEDZIC T. (2004) – The Sudetic geological mosaic: insights into the root of the Variscan orogen (in Polish with English summary). Prz. Geol., **52** (8/2): 761–773.

KRYZA R. and PIN C. (2010) – The Central-Sudetic ophiolites (SW Poland): petrogenetic issues, geochronology and palaeotectonic implications. Gondwana Res., **17** (2–3): 292–305.

LARIONOV A. N., ANDREICHEV V. A. and GEE D. G. (2004) – The Vendian alkaline igneous suite of northern Timan: ion microprobe U-Pb zircon ages of gabbros and syenite. In: The Neoproterozoic Timanide Orogen of Eastern Baltica (eds. D. G. Gee and V. L. Pease). Geol. Soc. London Mem., **30**: 69–74.

LIS J. and SYLESTRZAK H. (1981) – Nowy zespół minerałów w leukokratycznej strefie Jordanowa k. Sobótki i jego znaczenie genetyczne (in Polish with English summary). Prz. Geol., **29** (2): 67–72.

LORENC M. and KENNAN P. (2007) – Intrusive rocks from the Niemcza zone (Lower Silesia, Poland) in the light of petrologic and Rb-Sr isotope studies. Granitoids in Poland (eds. A. Kozłowski and J. Wiszniewska). Arch. Miner. Monograph, **1**: 253–259.

LUDWIG K. R. (2005*a*) – SQUID 1.12 A User's Manual. A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Center Special Publication, http://www.bgc.org/klprogrammenu.html

LUDWIG K. R. (2005*b*) – User's Manual for ISOPLOT/Ex 3.22. A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Center Special Publication, http://www.bgc.org/klprogrammenu.html

MAJEROWICZ A. (1979) – The Ślęża Mt group and ophiolite problems (in Polish with English summary). In: Wybrane zagadnienia stratygrafii, petrografii i tektoniki wschodniego obrzeżenia gnejsów sowiogórskich i metamorfiku kłodzkiego (ed. T. Gunia): 9–34. Field Conference, September 8–9, 1979, Nowa Ruda, Wrocław.

MAJEROWICZ A. (1984) – Petrography and origin of rodingitic rocks from serpentinites of Ślęża ophiolitic sequence (in Polish with English summary). Geol. Sudet., **18** (2): 109–132.

MAJEROWICZ A. (1994) – Textural features and symptoms of ocean-floor metamorphism in the top part of the Ślęża ophiolite (SW Poland). Arch. Miner., **50** (2): 97–139.

MAJEROWICZ A., KRYZA R. and WRÓBLEWSKA G. (2000) – Diallagite pegmatitoids from Mt. Ślęża gabbro. In: Tectonics of the Ślęża Mt. Ophiolite and its Influence on the Distribution of Some Mineral Ores and Groundwater (ed. M. Mierzejewski): 49–54. Institute of Geological Sciences, University of Wrocław, Wrocław.

MAJEROWICZ A. and PIN C. (1989) – Recent progress in petrologic study of the Ślęża Mt. ophiolite complex, Lower and Upper Paleozoic metabasites and ophiolites of the Polish Sudetes. Multilateral Cooperation of Academies of Sciences of Socialist Countries, Guidebook of Excursion in Poland, University of Wrocław, Poland: 34–72.

MAJEROWICZ A. and PIN C. (1994) – The main petrological problems of the Mt. Ślęża ophiolite complex, Sudetes, Poland. Zentralblatt Geologie und Palaeontologie, Teil I, **9/10**: 989–1018.

MATTE P., MALUSKI H., RAJLICH P. and FRANKE W. (1990) – Terrane boundaries in the Bohemian Massif: results of large-scale Variscan shearing. Tectonophysics, **177**: 151–170.

MAZUR S., ALEKSANDROWSKI P., KRYZA R. and OBERC-DZIEDZIC T. (2006) – The Variscan Orogen in Poland. Geol. Quart., **50** (1): 89–118.

MAZUR S., ALEKSANDROWSKI P., TURNIAK K. and AWDANKIEWICZ M. (2007) – Geology, tectonic evolution and Late Palaeozoic magmatism of Sudetes – an overview. In: Granitoids in Poland (eds. A. Kozłowski and J. Wiszniewska). Arch. Miner. Monograph, **1**: 59–87.

MIERZEJEWSKI M. P. and ABDEL WAHED M. (2000) – Overlapping thrust faults within the Gogołów-Jordanów serpentinite massif (SW Poland): evidence for the obduction of Ślęża ophiolite complex. In: Tectonics of the Ślęża Mt. Ophiolite and its Influence on the Distribution of Some Mineral Ores and Groundwater (ed. M. Mierzejewski): 29–41. Institute of Geological Sciences, University of Wrocław, Wrocław.

NANCE R. D., GUTIÉRREZ-ALONSO G., KEPPIE J. D., LINNEMANN U., MURPHY J. B., QUESADA C., STRACHAN R. A. and WOODCOCK N. (2010) – Evolution of the Rheic Ocean. Gondwana Res., **17** (2–3): 194–222.

NARĘBSKI W. (1993) – On the model of evolution of the NE part of the Bohemian Massif – petrologist's remarks (in Polish with English summary). Prz. Geol., **41** (11): 751–756.

OLIVER G. J. H., CORFU F. and KROUGH T. E. (1993) – U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. J. Geol. Soc. London, **150**: 355–369.

PIN C. (1990) – Variscan oceans: ages, origins and geodynamic implications inferred from geochemical and radiometric data. Tectonophysics, **177**: 215–227.

PIN C., MAJEROWICZ A. and WOJCIECHOWSKA I. (1988) – Upper Paleozoic oceanic crust in the Polish Sudetes: Nd–Sr isotope and trace element evidence. Lithos, **21**: 195–209.

STACEY J. S. and KRAMERS J. D. (1975) – Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sc. Lett., **26**: 207–221.

STEIGER R. H. and JÄGER E. (1977) – Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. Earth Planet. Sc. Lett., **36**: 359–362.

TRAUBE H. (1888) – Die Minerale Schlesiens. Breslau.

TURNIAK K., TICHOMIROWA M. and BOMBACH K. (2005) – Zircon Pb-evaporation ages of granitoids from the Strzegom-Sobótka Massif (SW Poland). Miner. Soc. Poland Spec. Pap., **25**: 241–245.

WIEDENBECK M., ALLÉ P., CORFU F., GRIFFIN W. L., MEIER M., OBERLI F., von QUADT A., RODDICK J. C. and SPIEGEL W. (1995) – Three natural zircon standards for U–Th–Pb, Lu–Hf, trace element and REE analyses. Geostandards Newslett., **19**:1–23.

WILLIAMS I. S. (1998) – U–Th–Pb Geochronology by ion microprobe. In: Applications in Microanalytical Techniques to Understanding Mineralizing Processes. Rev. Economic Geol., **7**: 1–35.

ŻELAŹNIEWICZ A. (1995) – Fore-Sudetic part of the Góry Sowie Block (in Polish with English summary). Ann. Soc. Geol. Pol., Spec. Issue, Guide to Excursions, 66 Annual Meeting of Polish Geological Society: 85–109.

APPENDIX

SHRIMP analytical procedure

The Sensitive High Resolution Ion Microprobe (SHRIMP II) at the Centre of Isotopic Research (CIR) at the All-Russian Geological Research Institute, VSEGEI, in St. Petersburg was used to determine zircon ages in the samples selected. *In situ* U-Pb analyses were performed applying a secondary electron multiplier in peak-jumping mode following the procedure described in Williams (1998) or Larionov *et al.* (2004). A primary beam of molecular oxygen was employed to bombard zircon in order to sputter secondary ions. The elliptical analytical spots had a size of *ca*. 27×20 μm, and the corresponding ion current was *ca*. 4 nA. The sputtered secondary ions were extracted at 10 kV. The 80 μm wide slit of the secondary ion source, in combination with a 100 μm multiplier slit, allowed mass-resolution of $M/\Delta M \geq 5000$ (1% valley) so that all the possible isobaric interferences were resolved. One-minute rastering over a rectangular area of *ca*. 60×50 m was employed before each analysis in order to remove the gold coating and possible surface common Pb contamination.

The following ion species were measured in sequence: $^{196}(Zr_2O)$–^{204}Pb–background (*ca*. 204 AMU)–^{206}Pb–^{207}Pb–^{208}Pb–^{238}U–^{248}ThO–^{254}UO with integration time ranging from 2 to 20 seconds. Four cycles for each spot analysed were acquired. Each fifth measurement was carried out on the zircon Pb/U standard TEMORA 1 (Black *et al*., 2003) with an accepted $^{206}Pb/^{238}U$ age of 416.75 ±0.24 Ma. The 91 500 zircon with a U concentration of 81.2 ppm and a $^{206}Pb/^{238}U$ age of 1062.4 ±0.4 Ma (Wiedenbeck *et al*., 1995) was applied as a "U-concentration" standard.

The collected results were then processed with the *SQUID v1.12* (Ludwig, 2005*a*) and *ISOPLOT/Ex 3.22* (Ludwig, 2005*b*) software, using the decay constants of Steiger and Jäger (1977). The common lead correction was done using measured ^{204}Pb according to the model of Stacey and Kramers (1975).