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GEOCHRONOLOGY OF TESCHENITIC INTRUSIONS IN THE OUTER WESTERN CARPATHIANS OF POLAND — CONSTRAINTS FROM ^{40}K /^{40}Ar AGES AND BIOSTRATIGRAPHY

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Abstract: New ^{40}K/^{40}Ar datings for teschenitic rocks in the Silesian Unit of the Outer Western Carpathians in Poland are presented. Several petrological varieties of intrusions were studied in 5 localities. Dating was performed on monomineral separates of biotites and amphiboles as well as on whole rock samples. The biotite ages (137.9–133.1 Ma — Valanginian) are significantly older than those of amphiboles (112.5–89.9 Ma — Albian–Turonian). Whole rock ages are considerably spread between those two clusters, being concordant either with "biotite" or "amphibole" dates or much younger. Interpretation of data poses some problems because evidence exists for hydrothermal alterations, which might influence Ar content in both minerals. Older, biotite ages are interpreted as more reliable crystallization ages, since they are close to the age of surrounding sediments and are concordant with field observations that intrusions in some cases are almost surficial. Amphibole ages are probably affected by Ar loss due to hydrothermal activity. Comparison with recently published ^{40}Ar/^{39}Ar datings implies that the duration of the teschenitic and related magmatism in the Silesian Basin was probably from Valanginian up to Barremian–Aptian (ca. 15 Ma).

Key words: Cretaceous, Outer Western Carpathians, Silesian Unit, teschenitic rocks, ^{40}K/^{40}Ar geochronology.

Introduction

The Outer Western Carpathians constitute a thin-skinned fold and thrust belt. They consist of several nappes (Fig. 1) which comprise uppermost Jurassic–Lower Miocene sediments which were thrust onto the European platform in the early Neogene (for review see e.g. Oszczypko & Ślączka 1985; Roca et al. 1995). Magmatic rocks are extremely rare in the Outer Western Carpathians. Among them "teschenitic rocks" or teschenite association rocks comprise variegated basic alkaline rocks of lamprophyre, limburgite, diabase, syenite and teschenite type (Smulikowski 1930, 1980; Mahmood 1973; Kudělásková 1987). They occur exclusively within the western part of the Silesian Unit of the Polish and Moravian segments of the Outer Western Carpathians (Fig. 1). Numerous geochemical data indicate affinity to within plate basalts or ocean island basalts (Narębski 1990; Hovorka & Spišiak 1993; Dostal & Owen 1998; Lucińska-Anczkiewicz 2000).

The age of the teschenitic rocks, discussed since their first description by Hohenegger (1861), was interpreted between Cretaceous and Miocene (Wieser 1971; Konior 1977). The opinion on their Early Cretaceous age (e.g. Hovorka & Spišiak 1993) has been finally established because: (i) they mostly form sills in the Tithonian–Neocomian strata (Smulikowski 1930) (ii) hypabyssal and sub-volcanic bodies are associated with surface volcanism in the Lower Cretaceous sediments (Matejka & Roth 1953; Šmid 1962; Roth 1967; Gucwa et al. 1971) (iii) redeposited fragments of teschenitic rocks were reported, in a single locality, from the Albian sediments (Geroch et al. 1978). However, until recently no radiometric data were available to constrain the time of the intrusions. The first ^{40}Ar/^{39}Ar data on amphiboles by Lucińska-Anczkiewicz et al. (2002) gave plateau ages of 122–120 Ma (Barremian). In this paper new ^{40}K/^{40}Ar results from typical varieties of teschenitic rocks are presented, together with updated biostratigraphical ages of contact rocks.

Geological setting and sampling

Teschenitic rocks outcrop between Nový Jičín and Bielsko-Biała (Fig. 1) in a single tectonic element called the Cieszyn Nappe. The nappe comprises sedimentary rocks of Upper Jurassic–Lower Cretaceous age. The oldest member is the Lower Cieszyn Shales, which constitute the detachment horizon of the Cieszyn Nappe in the studied area (Fig. 2). Their age was determined as Kimmeridgian(?)/Tithonian (Nowak 1968, 1976; Szydło & Jugowiec 1999) and they attain a thickness of ca. 300 m. They are overlain by the turbiditic complex of Cieszyn Limestones. Their age is well constrained as Late Tithonian–Berriasian and their maximum thickness attains 250 m (Książkiewicz 1964; Nowak 1976). They pass upwards into the Upper Cieszyn Shales of Valanginian–Hauterivian age and reach 300 m in thickness (Koszarski & Ślączka 1976;

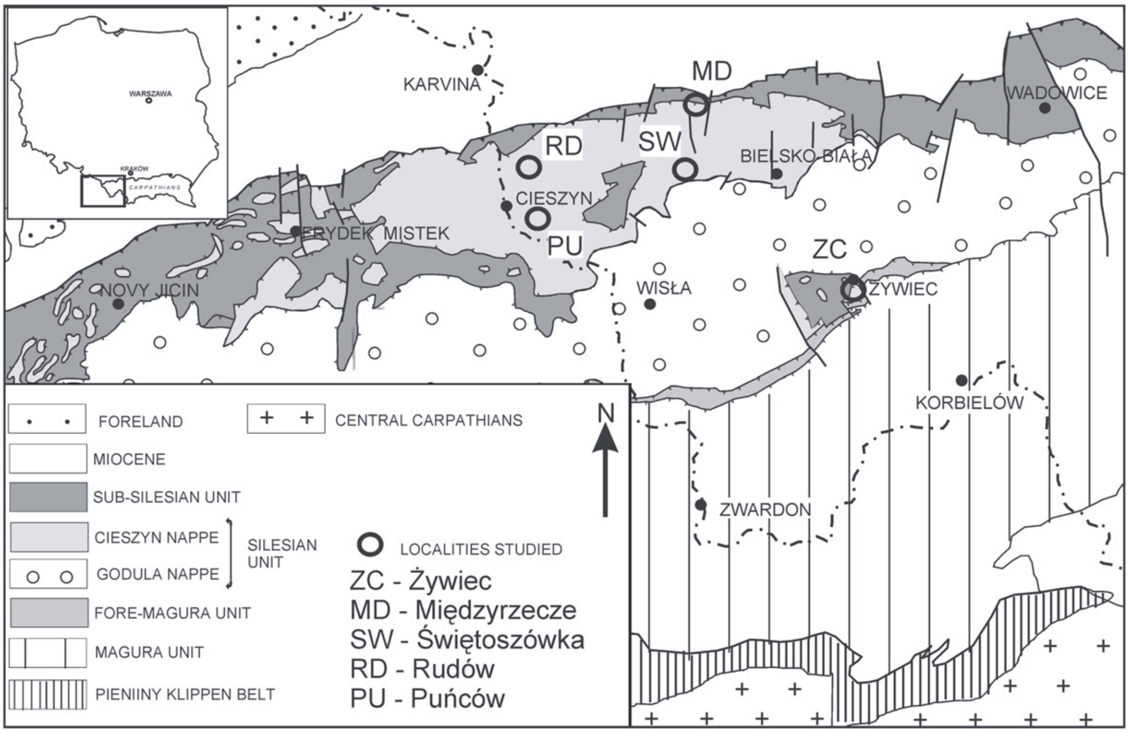

Fig. 1. Tectonic sketch map of the Outer Western Carpathians with sampling localities indicated (after Żytko et al. 1989).

Słomka 1986). Overthrust zone between the Godula Nappe and the Cieszyn Nappe is noted in the Grodziszcze-Verovice Beds (Hauterivian–Lower Aptian, 60–80 m), (Fig. 2).

Hand and drill samples were taken from several varieties of teschenitic rocks from Międzyrzecze, Rudów, Świętoszówka, Puńców, and Żywiec (Fig. 1). The outcrop in Międzyrzecze is their northernmost occurrence. It was mentioned by Smulikowski (1930) as the richest in olivine in the Cieszyn area. Samples were collected from the abandoned quarry, from hard blocks of apparently fresh rock surrounded by completely altered ones. Samples in Rudów (Nowak & Wieser 1978) were taken from the series of outcrops in the Piotrówka stream, from the same intrusion as sample C-200 of Lucińska-Anczkiewicz et al. (2000). Teschenitic rocks in Puńców (Nowak & Wieser 1978; Lemberger 1971) occur in a small outcrop in a Puńcówka creek, north of the church. Samples were taken from the "older" teschenite, which hosts the syenite vein sampled (sample C-53) by Lucińska-Anczkiewicz et al. (op.cit.). Samples in Świętoszówka were collected from the southern part of the Łański creek, south of the Bielsko–Skoczów motorway (see Wieser 1985, fig. 7). In Żywiec, two intrusions of teschenitic rocks were sampled along the famous, well exposed section along the Soła river (Ślączka & Kamiński 1998). The entire sequence, intensely folded, crops out at the eastern margin of the Żywiec tectonic window, where the Sub-Silesian Unit is exposed from beneath the Silesian Unit, at the contact with the Fore-Magura and Magura units (Fig. 1).

Methods

K-Ar dating was carried out using whole rock (WR) samples and monomineral concentrates of biotite and amphiboles. The samples were crushed and sieved. The 0.2–0.3 mm fraction was divided for analysis of its potassium content by the XRF method and for the radiogenic argon content by means of the static-vacuum mass spectrometry. Mineral separates of the 350–120 μm fraction were prepared according to standard procedures (e.g. Geyh & Schleicher 1990) including magnetic and hydrodynamic separation. Handpicking was applied at the final stages to eliminate grains with intergrowths of other minerals (e.g. pyroxene). The determination of the potassium content was made in the Central Chemical Laboratory, Polish Geological Institute, on the Philips PW 2400 spectrometer. The determination of the radiogenic argon content was made in the Mass Spectrometry Laboratory, Institute of Physics, Lublin University, using the internal spike method on the modified MS-10 mass spectrometer. One sample (PU6 — see Table 1) was processed at the Institute of Nuclear Research in Debrecen. Aliquots from about 60 mg for the major part of samples up to about 180 mg for samples, which contain only about 0.1 % K has been made. Large samples were necessary, because a relatively low radiogenic argon content was expected. Each sample was melted in the double-vacuum crucible of the argon extraction-purification line in temperature of 1300 °C. Pure argon-38 (produced by the Institute for Inorganic and Physical Chemistry, University of Bern) was used as the spike. The content of the atmospheric argon was determined by measurement of the argon-36 peak in the mass spectrum. After every measurement cycle the blank cycle was performed (at temperature of about 1350 °C) to check if all argon was extracted from the sample.

Amphibole analyses were carried out using a Jeol JSM-35 electron microprobe equipped with a Link energy-dispersive spectrometer at the Polish Geological Institute. Accelerating voltage was 20 kV with a beam current 2 nA and 50 s count

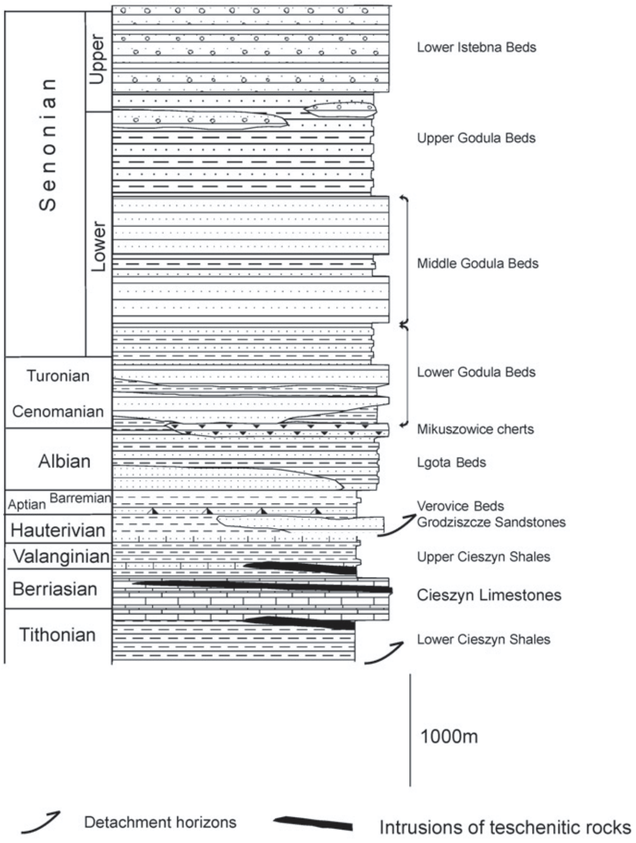

Fig. 2. Stratigraphic scheme of the Silesian Unit.

time. Natural and synthetic mineral standards were used and the raw data were reduced with a ZAF correction procedure.

Foraminifers were separated from the samples which were taken in the vicinity to teschenitic intrusions, in order to check the stratigraphic age of the host rock (i.e. maximum possible age of intrusions). Samples localized nearest to these magmatic bodies were always barren. The lack of microfauna was associated with thermal and metasomatic processes accompanying the intrusions. These processes resulted in dilution and destruction of foraminiferal shells. Foraminifers were found in more distant samples (maximum 5 meters from an intrusion). Biostratigraphical position of the studied samples was based on specific foraminiferal assemblages, which were partly described from the Cieszyn Beds by Geroch (1966), Bielecka & Geroch (1977), Olszewska (1997), Szydło & Jugowiec (1999) and Szydło (2003). Correlation of radiometric dates to stage boundaries has been performed using the timescales of Gradstein et al. (1994) and Channell et al. (1995), which differ significantly in placing the Jurassic/Cretaceous boundary.

Petrographic description of samples

Międzyrzecze. The rock from this locality was classified as alkali biotite-pyroxene picrite. It displays strongly porphyritic texture with large, well-rounded phenocrysts of olivine (up to 7 mm in diameter), totally pseudomorphed by green bowlingite, and smaller phenocrysts of augite (Fig. 3), set in a fine- to medium-grained, occasionally glassy groundmass. Biotite typically forms large poikilitic grains with abundant inclusions of augite, olivine (bowlingite), Ti-magnetite, apatite, and altered glass. It occurs rarely in aggregates of randomly oriented and somewhat lighter fine blades. This assemblage is accompanied by anhedral grains of melanite garnet. Titanomagnetite is a relatively common phase in this rock, while apatite is significantly less abundant. Additionally, brown chrome spinel (up to 1.7 mm) occurs in an accessory amount. It is mantled by rims of chrome-bearing Ti-magnetite (see Włodyka et al. 1999). Secondary phases include chlorite and carbonate. Pseudomorphs of bowlingite after olivine with numerous inclusions of Ti-magnetite, as well as fine-grained fragments composed of bowlingite + clinopyroxene + Ti-magnetite assemblage, are most probably derived from the fragmentation of mantle xenoliths.

Rudów. Teschenites of analcite monzonite composition occur in this locality. These are coarse- to medium-grained rocks composed of titanium augite (prisms up to 5.5 mm long), alkali feldspars, plagioclase and analcite as the major constituents. Amphibole is a relatively common phase, which frequently occurs as overgrowths on clinopyroxene (Fig. 4). It contains inclusions of augite and apatite, and is accompanied by scarce greenish olive sheet silicates, mainly as small aggregates of smectite-group mineral, as well as trace amounts of biotite. The probed amphiboles are high titanium kaersutite or ferrokaersutite (0.508–0.706 Ti pfu; Table 1), according to Leake et al.'s (1997) classification scheme. Kaersutite rims are usually slightly enriched in Fe relative to the cores. Moreover, some grains have narrow rims of magnesio-hastingsite composition. The potassium content in the analysed kaersutites is typical for this group of amphiboles and comparable with that of amphibole concentrate (Table 2). The slightly lower value in the latter is due to impurities (clinopyroxene, apatite). Small amounts of the greenish aegirine-augite locally mantles earlier titanium augite. Plagioclase mostly forms large tabular crystals, whereas anhedral grains of alkali feldspar and analcite are localized in the interstitial spaces. Feldspars are partially altered to phyllosilicates, which are also found as an interstitial phase. Analcite has a partially primary nature, but may be formed also at the expense of feldspars. These light minerals are usually crowded with fine opaque material and fluid inclusions. Accessory minerals are represented by apatite, sphene and Ti-magnetite (most often 1–2.5 mm in diameter). Titanomagnetite is partially replaced by goethite. Abundant secondary minerals also include chlorite, carbonate, as well products of the autometasomatic replacement of feldspars: prehnite and fibrous aggregates of thomsonite.

Puńców. This locality has porphyritic camptonite-type alkaline lamprophyres representing two varieties: mesocratic and melanocratic. The lighter variety is mainly composed of euhedral prisms of titanium augite (up to 3 mm long) and large subhedral grains of brown amphibole (Fig. 5). Clinopyroxene also forms small grains and microlites in the groundmass. Amphibole is represented by kaersutite or ferrokaersutite, the chemical composition and zonation of which are very similar to that of Rudów amphibole (Table 1). Their potassium content is comparable with that of P2, P4 and P5 amphibole concentrates (Table 2). Kaersutite grains appear in general fairly fresh but frequently contain abundant inclusions or intergrowths of clinopyroxene, apatite, Ti-magnetite and occasion-

Table 1: Representative electron microprobe analyses of amphibole.

	Sample P4								Sample RD2					
	2 c1 core Krs	**2 r1 rim Krs**	**1 c1a core Krs**	**1 r1a rim Krs**	**1 c1 core Krs**	**1 c2 core Krs**	**1 r2 rim Krs**	**1 r1 rim Fe-Krs**	**2 c1 core Krs**	**2 c2 core Krs**	**2 r1 rim Fe-Krs**	**2 r2 rim Krs**	**1 c1 core Krs**	**1 r1 rim Mg-Hs**
SiO_2	37.22	38.24	37.44	37.41	37.62	37.85	39.03	38.18	37.11	37.74	37.56	37.48	37.08	37.62
TiO_2	4.95	5.08	5.38	4.65	5.37	5.68	5.47	4.52	5.97	6.25	4.39	5.69	6.10	4.07
Al_2O_3	13.28	11.87	13.25	11.86	13.23	12.81	12.28	11.91	12.99	13.34	12.41	13.21	13.17	11.74
FeO^a	12.39	14.72	12.80	16.44	11.74	12.20	11.70	17.86	13.60	13.55	19.09	13.88	12.69	18.20
MnO	0.00	0.21	0.06	0.25	0.19	0.11	0.17	0.31	0.05	0.00	0.07	0.28	0.05	0.39
MgO	12.24	11.36	11.98	10.07	12.19	12.02	12.43	9.56	11.33	10.85	8.38	11.02	11.81	9.43
CaO	13.61	13.76	13.12	13.57	13.58	13.41	13.37	12.53	13.42	13.01	12.94	13.46	13.01	12.50
Na_2O	2.97	2.82	2.73	2.80	2.61	2.96	2.65	2.79	2.76	2.58	2.55	1.78	2.96	2.86
K_2O	1.17	1.28	1.29	1.33	1.42	1.31	1.35	1.19	1.06	1.15	1.42	1.09	1.15	1.38
Total	97.83	99.34	98.05	98.38	97.95	98.35	98.45	98.85	98.29	98.47	98.81	97.89	98.02	98.19
	Structural formula based on 23 oxygens													
Si	5.625	5.755	5.645	5.742	5.661	5.683	5.821	5.833	5.608	5.668	5.782	5.672	5.595	5.814
Ti	0.563	0.575	0.610	0.537	0.608	0.641	0.614	0.519	0.679	0.706	0.508	0.648	0.692	0.473
Al	2.365	2.105	2.355	2.145	2.346	2.267	2.158	2.144	2.313	2.361	2.251	2.356	2.342	2.138
Fe^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021
Fe^{2+}	1.566	1.853	1.614	2.110	1.477	1.532	1.459	2.282	1.719	1.702	2.457	1.756	1.601	2.331
Mn	0.000	0.027	0.008	0.032	0.024	0.014	0.021	0.040	0.006	0.000	0.009	0.036	0.006	0.051
Mg	2.758	2.549	2.693	2.304	2.735	2.691	2.764	2.177	2.553	2.429	1.923	2.486	2.657	2.172
Ca	2.204	2.219	2.119	2.231	2.189	2.157	2.136	2.051	2.173	2.093	2.134	2.182	2.103	2.069
Na	0.870	0.823	0.798	0.833	0.761	0.862	0.766	0.826	0.809	0.751	0.761	0.522	0.866	0.857
K	0.226	0.246	0.248	0.260	0.273	0.251	0.257	0.232	0.204	0.220	0.279	0.210	0.221	0.272
Total	16.177	16.151	16.090	16.195	16.075	16.098	15.997	16.105	16.063	15.931	16.104	15.869	16.085	16.198
***mg*-no.**	0.64	0.58	0.63	0.52	0.65	0.64	0.65	0.49	0.60	0.59	0.44	0.59	0.62	0.48

[a] Total iron as FeO. Oxide results in wt. %. Fe partition calculated on the basis of stoichiometry after Droop (1987). Krs — kaersutite; Fe-Krs — ferro-kaersutite; Mg-Hs — magnesiohastingsite. *mg*-no. = Mg/(Mg + Fe^{2+}) at.

ally rounded aggregates of greenish smectite-group mineral (probably after olivine). In the sample P2, amphibole overgrowths on clinopyroxene are frequently observed. The amphibole from this sample is rather poor in inclusions (mainly relics of clinopyroxene). Reddish brown biotite is considerably less abundant than amphibole. It is optically nearly unaltered and contains only a few inclusions of clinopyroxene, Ti-magnetite (Fig. 6), and traces of secondary smectite-group mineral. Associated interstitial phases include small amounts of feldspars, colourless glass commonly altered to chlorite, analcite or zeolites, and secondary prehnite and carbonate. Among accessory minerals apatite and Ti-magnetite predominate, whereas sphene occurs occasionally. Amphibole clearly prevails with titanium augite and biotite in the melanocratic lamprophyre, and light minerals (alkali feldspars, analcite) still less abundant than in the mesocratic type. Irregular, lighter segregations occur within melanocratic variety. These segregations are largely contaminated by mafic fragments to various extents.

Żywiec. The Żywiec samples are metasomatized rocks with preserved original igneous texture. The large degree of alteration makes it difficult to ascertain their protolith: presumably it belongs to a monchiquite group (see Smulikowski 1930). They are characterized by extensive replacement of primary ferromagnesian minerals by chlorite, pale green cryptocrystalline aggregates of smectite-group mineral, and carbonate. Chlorite-carbonate-titanium oxides (anatase, brookite) pseudomorphs after clinopyroxene are particularly common. Apatite, which largely takes the form of long prisms, is very abundant. Similarly, iron and titanium oxides are common constituents. Pale brown biotite and secondary quartz are also found. The biotite is very scarce in the majority of samples (e.g. sample Ż11), but is locally present in greater amounts (sample Ż9). Both samples were dated and differ significantly in potassium content (see Table 2). In Ż9, biotite is accompanied by relic clinopyroxene (Fig. 7). Chloritization and carbonatization of the primary igneous rock took place probably at the stage of hydrothermal metasomatism in the presence of the Ca-bearing fluids from the surrounding sediments (Smulikowski 1930).

Świętoszówka. The rock defined as altered dolerite is aphyric with relic intergranular or subophitic texture. It is mainly composed of plagioclase and secondary chlorite, accompanied by relic augite and minor biotite (Fig. 8). Titanium oxides are common accessory constituent, while iron oxides, usually in association with chlorite and carbonate, are distinctly rarer. Chlorite also occurs fairly commonly as a radial or fan-shaped aggregates in amygdales, where is frequently associated with carbonates (Fig. 9) and sometimes with pyrite. Analcite occurs occasionally in the interstitial areas in some samples (e.g. in the dated sample SWy).

Results and discussion

As can be seen from the Table 2, the Cretaceous age of the teschenitic rocks is generally supported by the new K-Ar data and no Neogene data were obtained. The dates comprise, however, an unexpectedly broad time interval — 148.6–63.6 Ma which requires some comments. It is clear that the biotite ages are significantly older than those of the amphiboles (Table 2). Mean biotite ages vary between 137.9 and 126.4 Ma (Neocomian) while amphibole ages span between 112.5 and 89.9 (Albian–Turonian/Coniacian). Whole rock ages are considerably

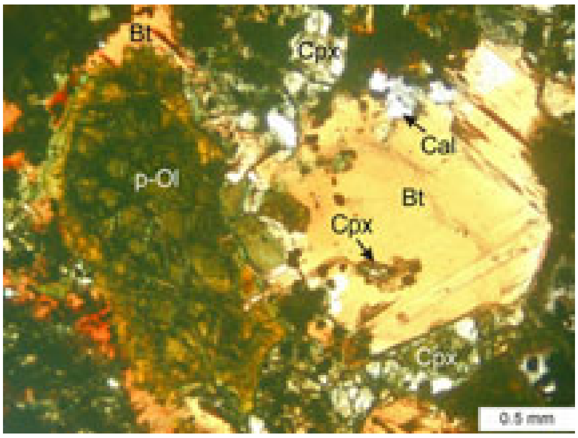

Fig. 3. Photomicrograph of alkali biotite-pyroxene picrite from Międzyrzecze (sample MD1). Rounded olivine phenocryst is completely replaced by bowlingite (**p-Ol**) and rimmed by biotite (**Bt**); a large biotite grain contains inclusions of clinopyroxene (**Cpx**) and Fe-Ti oxides and is weakly replaced by carbonate (**Cal**). Plane-polarized light.

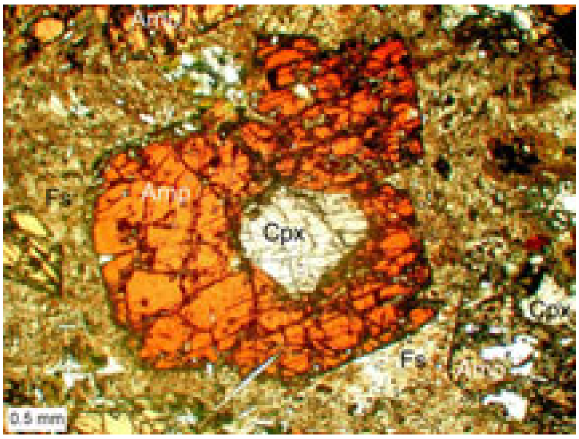

Fig. 4. Photomicrograph of teschenite from Rudów (sample RD2). Brown amphibole (**Amp**) mantles clinopyroxene (**Cpx**); interstitial alkali feldspars (**Fs**) are strongly altered. Plane-polarized light.

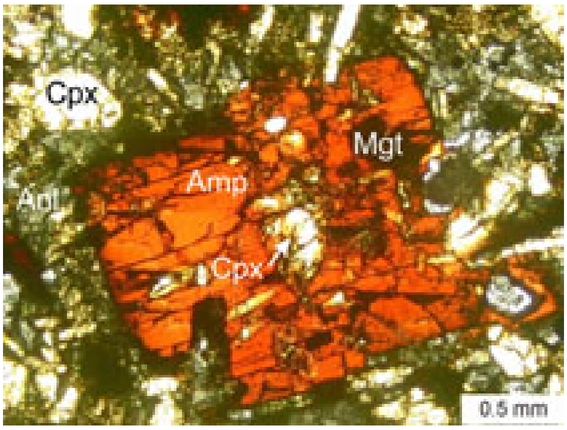

Fig. 5. Photomicrograph of alkaline lamprophyre from Puńców (sample P4). A large grain of amphibole (**Amp**) containing inclusions of clinopyroxene (**Cpx**) and Ti-magnetite (**Mgt**); fine-grained groundmass composed of clinopyroxene, analcite (**Anl**) and Fe-Ti oxides. Plane-polarized light.

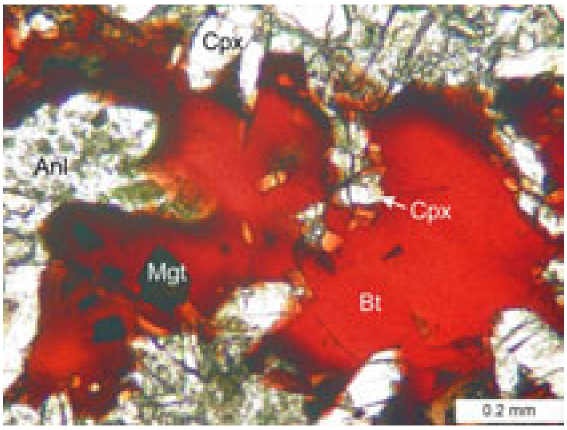

Fig. 6. Photomicrograph of an unaltered biotite grain (**Bt**) with inclusions of clinopyroxene (**Cpx**) and Ti-magnetite (**Mgt**); analcite grain is visible near to biotite. Alkaline lamprophyre from Puńców (sample P5). Plane-polarized light.

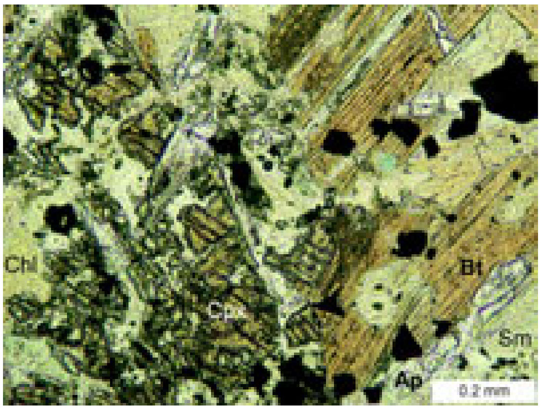

Fig. 7. Photomicrograph of metasomatized rock from Żywiec (sample Ż9c). Numerous biotite grains (**Bt**) and relics of clinopyroxene (**Cpx**) in a matrix of smectite-group mineral (**Sm**), chlorite (**Chl**) and Fe-Ti oxides, with accessory apatite (**Ap**). Plane-polarized light.

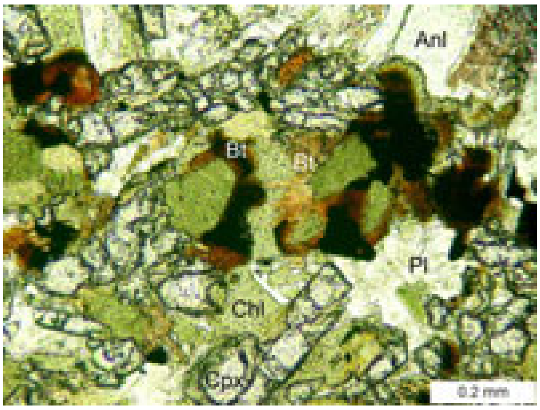

Fig. 8. Photomicrograph of altered dolerite from Świętoszówka (sample SWy) composed of abundant secondary chlorite (**Chl**) with minor biotite (**Bt**), relict clinopyroxene (**Cpx**), plagioclase (Pl) and analcite (**Anl**). Plane-polarized light.

Table 2: K-Ar ages of studied localities (errors at 2σ level).

Locality	Sample	Fraction dated	K [%]	$^{40}Ar_{rad}$ [pmol/g]	$^{40}Ar_{rad}$ [%]	Age (Ma)
Międzyrzecze	MD1	biotite	4.894	1110.6	93.4	126.4 (±1.8)
		WR	1.506	370.3	81	136.5 (±2.0)
	MD2	biotite	4.132	992.2	91.7	133.4 (±1.8)
		WR	1.329	318.2	83	133.1 (±1.8)
Rudów	RD2	amphibole	0.762	153.3	68.4	112.5 (±1.6)
	H9	WR	1.191	153.8	53	73.0 (±1.2)*
	H15	WR	0.858	96.4	60	63.6 (±1.6)*
Puńców	P2	amphibole	1.000	199.7	32.0	111.7 (±1.8)*
	P4	biotite	3.733	927.6	90.8	137.9 (±2.0)
		amphibole	0.937	161.9	68.5	97.0 (±1.8)*
		WR	1.133	180.8	78	89.7 (±1.6)*
	P5	biotite	4.157	1009.6	71.6	134.9 (±3.0)
		amphibole	0.916	162.4	73.3	99.4 (±1.6)*
		WR	1.229	194.5	67	89.0 (±1.4)*
	PU6**	amphibole	1.648	263.3	65.9	89.9 (±3.5)*
Żywiec	Z9	WR	1.498	388.1	82	143.5 (±2.0)*?
	Z11	WR	0.110	29.5	38	148.6 (±3.6)*?
Świętoszówka	SW1	WR	0.592	98.7	53	93.7 (±2.4)*
	SW2	WR	0.111	19.8	22	100.3 (±4.0)*

*age interpreted as overprinted (see text). **This sample was dated at the Institute of Nuclear Research, Hungarian Academy of Sciences. WR — whole rock.

spread between those two clusters, being concordant either with "biotite" (e.g. Międzyrzecze, Żywiec) or "amphibole" dates (Puńców, Świętoszówka) or much younger (Rudów). It is impossible that these differences reflect a real time interval between the crystallization of biotite and amphibole. Both minerals crystallized from the same melt (Smulikowski 1930, 1980; Mahmood 1973). It is also unlikely that the K-Ar age differences between biotite and amhibole originated due to argon loss during a reheating event (which might be shown by hydrothermal alterations). K-Ar closure temperatures are lower for biotite (350–400 °C) than for hornblende (500–700 °C) (Geyh & Schleicher 1990) and in the case of a regional thermal event rather hornblende would preserve the primary K/Ar ratio.

A kind of test for reliability of the K-Ar datings would be the comparison of the radiometric ages of different fractions and biostratigraphic ages of host sedimentary rocks giving the oldest possible age of intrusions (Table 3). All the taxons listed in the Table 3 are new findings and were described by Szydło (2003) from the Cieszyn Beds, close to the contact with the teschenitic intrusions.

Table 3: Comparison of K-Ar ages of teschenitic rocks with biostratigraphic ages of surrounding sedimentary rocks.

Locality	Lithostratigraphic units	Selected foraminifers (stratigraphical ranges*) Age of foraminiferal assemblages	Maximum age of intrusion (Ma)	Radiometric ages (Ma)
Międzyrzecze	Cieszyn Limestones	*Neotrocholina molesta* Gorbachik (Late Tithonian–Hauterivian) *"Trocholina" solecensis* Bielecka (Tithonian) **age: Late Tithonian**	144.7–141.6[1] 146–144.2[2]	133.4–126.4 (biotite) 136.5–133.1 (WR)
Rudów	Upper Cieszyn Shales	*Ammobaculoides carpathicus* Geroch (Late Valanginian–Barremian) *Bigenerina jurassica* (Haeusler) (Late Tithonian–Late Valanginian) *Pseudoreophax cisovnicensis* Geroch (Late Tithonian–Barremian) *Trochammina quinqueloba* Geroch (Late Valanginian–Cenomanian) *Buccicrenata condensa* Dulub (Berriasian–Early Hauterivian) **age: Late Valanginian**	134–131[1] 136–132[2]	112.5 (amphibole) 73–63.6 (WR)
Puńców	contact zone between Cieszyn Limestones and Upper Cieszyn Shales	*?Planispirilna flava* Sztejn (Late Valanginian–Early Hauterivian) *Ishnusella burlini* (Gorbachik) (Latest Tithonian–Hauterivian) *Spirilina minima* Schacko (Latest Tithonian–Lower Cretaceous) **age: Latest Tithonian–Hauterivian (?Late Valanginian)**	141.6–126[1] (?134–131)[1] 144.2–127[2] (?136–132)[2]	111.7–89.6 (amphibole) 137.9–134.9 (biotite) 89.7–89 (WR)
Żywiec	Cieszyn Limestones	lack of foraminifers (Berriasian calpionellids)	141.6–135.8[1] 144.2–137[2]	148.6–143.5 (WR)
Świętoszówka	Upper Cieszyn Shales	*Gaudryina oblonga* Zaspelova (Hauterivian–Albian) *Pseudoreophax cisovnicensis* Geroch (Late Tithonian–Barremian) *Buccicrenata condensa* Dulub (Berriasian–Early Hauterivian) *Verneuilinoides neocomiensis* (Mjatliuk) (Valanginian–Aptian) **age: [Hauterivian]**	131–126[1] 132–127[2]	100.3–93.7 (WR)

*Stratigraphical ranges according to Geroch (1966), Dulub (1972), Geroch & Nowak (1984), Sztejn et al. (1984), Kuznecova & Gorbachik (1985), Olszewska (1997), Szydło & Jugowiec (1999), Szydło 2003 (in print). [1] Ages of stratigraphical divisions after Channell et al. (1995) time scale. [2] Ages of stratigraphical divisions after Gradstein et al. (1994) time scale.

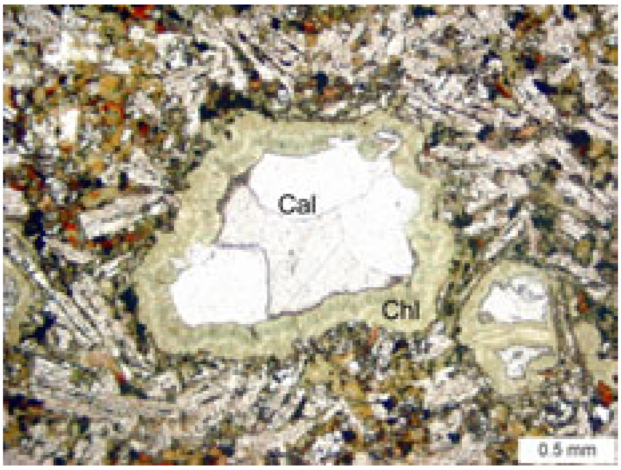

Fig. 9. Photomicrograph of altered dolerite from Świętoszówka (sample SW11). Vesicles filled with carbonates (**Cal**) and radial aggregates of chlorite (**Chl**). Plane-polarized light.

In Międzyrzecze and Żywiec, the teschenitic rocks intrude the Cieszyn Limestones, which are of the Late Tithonian–Berriasian age (Nowak 1976). In Międzyrzecze, marly shales interbedding limestones, yielded *"Trocholina" solecensis* Bielecka and *Neotrocholina molesta* Gorbachik, which suggest Late Tithonian age (Table 3). Three of the obtained K-Ar data indicate a Valanginian age of intrusion, the fourth — earliest Barremian. The Valanginian age is therefore accepted for the intrusion. The crystalline structure of the dated rock indicates that it must have cooled under some overburden. The younger age for biotite from the sample MD1 must be considered as an effect of a low temperature alteration (see Fig. 3). Foraminifers have not been found in Żywiec but calpionellids indicate that teschenitic intrusions occur within the Berriasian part of the Cieszyn Limestone (Nowak 1970). The K-Ar ages obtained in this locality are slightly older than expected. The age of sample Ż9 falls within the Early Berriasian, but only in the framework of Gradstein et al. 1994 time scale (Table 2). Sample Ż11 yielded definitely Tithonian ages. Since the potassium content in the sample Ż11 is very low (Table 2) we consider the age of sample Ż11 (143.5 Ma) as more reliable. However, both Ż9 and Ż11 ages overlap within a 2σ error.

Teschenitic intrusions in Puńców were noted in the contact zones between the Cieszyn Limestones and Upper Cieszyn Shales. Samples from the Upper Cieszyn Shales contain microfauna from which stratigraphically the most important is (?)*Planispirillina flava* Sztejn suggesting Late Valanginian–Early Hauterivian age (Table 3). However, since the determination of this taxon is problematic, an Early Valanginian or Late Hauterivian age for the samples cannot be excluded. In this locality three different fractions have been dated, even in the same hand sample. The difference between biotite and amphibole ages amounts to 27–42 Ma. The age of the host rock is close to the biotite age: in the sample P4 — Late Berriasian–Earliest Valanginian, in the sample P5 — Valanginian. Lapillas, benthontized tuffs and lava breccias occurring in the locality were mentioned (Gucwa et al. 1971). These support the view that the cooling ages must be coeval rather with the surrounding sediments. For this reason the "amphibole" (Albian–Late Cretaceous) age is considered unlikely.

The Upper Cieszyn Shales are host rocks for the teschenitic intrusions in Świętoszówka and Rudów. Variegated foraminiferal assemblages indicate Hauterivian age for the former and Late Valanginian age for the latter locality (Table 3). Pyroclastic rocks were described from Świętoszówka (Gucwa et al. 1971) and the intrusion itself is regarded as almost surficial (Wieser 1971), which is also supported by thin section observation in this study. Therefore its apparent K-Ar Albian–Cenomanian age (100.3–93.7) must be rejected too. Lava intruded into the sediments of Hauterivian age (Table 3) and the age of subvolcanic rock cannot be much younger. The whole rock and amphibole ages of the Rudów teschenite are significantly younger than the host sediments which is concordant with the coarse crystalline structure of the teschenite, indicating rather slow cooling. The large difference between the whole rock and amphibole age suggests that significant Ar loss affected the whole rock system. However, as the amphibole ages from Puńców gave a unrealistically young age (Table 2), the amphibole age from Rudów must also be treated with some caution.

Taking into account all the constraints mentioned above, the K-Ar ages which might be interpreted as crystallization ages are derived from biotites and whole rock of Międzyrzecze picrite and biotites of Puńców lamprophyre (Table 2). The whole rock age of teschenitic sill from Żywiec is close to the age of surrounding sediments. However, bearing in mind strong alterations (chloritization, zeolitization) of the teschenites in this locality, it might have been affected by hydrothermal metasomatism. The K-Ar age is evidently related to apparently fresh biotite, which is abundant in the sample Ż9 with high potassium content (Table 2; Fig. 7).

A question remains why the ages of amphiboles are systematically younger than those of biotites? Two explanations must be considered:

(1) Amphiboles might contain unrecognized inclusions of other high K minerals (e.g. K-feldspar, reported by Lucińska-Anczkiewicz et al. 2002). This must be rejected since the potassium content in the amphiboles from Puńców and Rudów determined by EDS study is comparable with that of the amphibole concentrates dated (Tables 1, 2).

(2) Secondary alterations (chloritization, zeolitization), which affected in variegated degree all studied localities, caused significant Ar loss in hornblende. This option is a likely explanation. Low temperature hydrothermal changes in the teschenitic rocks are common (Smulikowski 1930) and were noted also by Lucińska-Anczkiewicz et al. (2002). Their first degassing steps indicate apparent ages between 62 and 125 Ma (which embrace the amphibole ages obtained in our study) and were attributed to disturbance of the K-Ar system related to secondary alterations.

It is remarkable that the alterations, which most probably affected the K/Ar ratios in the amphiboles, have not influenced biotite in the same way. Geyh & Schleicher (1990, p. 60) mention that, for example, chloritization of biotite causes loss of potassium and argon in the same proportions, due to the layered structure of this mineral and, therefore, do not change its apparent age determined by the K-Ar method. Thus, as already indicated, biotite ages might be interpreted as crystallization ages. However alternatively, an "excess Ar" in biotite must be seriously considered, as an explanation for the apparently older biotite ages. Solubility of Ar in biotite is relatively high (see Kelley 2002 for review). An "excess Ar" might appear in metamorphic biotites or in fluid-rich environments in thrust belts, where fluids are derived from basement rocks. We cannot totally reject that our biotite ages were affected by additional ^{40}Ar influx. Hydrothermal alterations of teschenitic rocks are well known (e.g. Wieser 1971). The most affected teschenitic rock in Żywiec yielded ages indeed, slightly older than "expected" (i.e. than surrounding sediments), which might show that extra Ar was introduced.

The results obtained in this study might be compared with the recently published ^{40}Ar/^{39}Ar datings of Lucińska-Anczkiewicz et al. (2002). They dated four amphibole concentrates from the Rudów, Puńców and Boguszowice intrusions (Fig. 1). All samples yielded similar (Upper Barremian–Lower Aptian) ages: teschenites from Rudów and Boguszowice — ca. 122 Ma, syenite dyke from Puńców — 120 Ma. Age of amphibole from Rudów obtained here (112.5 Ma) is younger than that of Lucińska-Anczkiewicz et al. (op.cit.). In our opinion the Ar-Ar age might be more accurate because this method eliminates errors resulting from inhomogeneity of the studied grains (Geyh & Schleicher 1990). The K-Ar ages of biotites obtained in Puńców are ca. 15–18 Ma older than those calculated by Lucińska-Anczkiewicz et al. (op. cit.). However, as in the area of Puńców up to four varieties of teschenitic rocks were described (Smulikowski 1930), Ar-Ar and our K-Ar results are not comparable because they come from different kinds of rocks. The syenite dyke dated by Lucińska-Anczkiewicz et al. (op. cit.) is definitely younger than the mesocratic teschenitic intrusions. Our data concern a small, shallowly intruding lamprophyre body, which was coeval with the pyroclastic rocks described from this locality by Gucwa et al. (1971). The age 137.9–134.9 Ma in Puńców probably reflects an older phase of alkaline magmatism, almost synchronous with deposition of Cieszyn Beds. Although we cannot discard the "excess Ar" hypothesis, the relatively late (Barremian–Early Aptian) and very short (less than 5 Ma) time of emplacement of the entire teschenite association rocks, as postulated by Lucińska-Anczkiewicz et al. (2002) does not explain the presence of extrusive rocks in Valanginian–Hauterivian sediments. This early phase of magmatism seems to be supported by the biotite (133.4–126.4 Ma) and whole rock (136.5–133.1 Ma) ages of Międzyrzecze picrite. More data is certainly required to reconstruct the evolution of teschenitic magmatism. Methods other than K-Ar should be applied, especially to solve uncertainties concerning Ar mobility and retentivity.

Conclusions

1. New K-Ar dating of teschenitic rocks in the Silesian Nappe of the Polish Outer Western Carpathians, performed on amphiboles, biotites and whole rock, confirmed their Cretaceous age. The considerable scatter of results (148.6–63.6 Ma) is caused by hydrothermal alterations of the rocks. Biotite and whole rock ages of the olivine picrite from Międzyrzecze (133.4±1.8, 136.5±2.0, 133.1±1.8 Ma), and biotite ages of the alcalic lamprophyres in Puńców (137.9±2.0, 134.9±3.0 Ma) are interpreted as most reliable, indicating Valanginian age. The Early Berriasian (143.5±2.0 Ma) age of teschenitic rocks in Żywiec must be treated with some caution, as the rock is strongly altered and tectonized and the presence of some "extra Ar" in biotite is not unlikely.

2. Radiometric data obtained here indicate that teschenitic magmatism within the Silesian Unit of the Outer Western Carpathians might have started earlier than 122 Ma (Barremian) (Lucińska-Anczkiewicz et al. 2002). Independent evidence is supplied by the presence of extrusive rocks in the Valanginian–Hauterivian sediments.

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