NEW AGE AND PETROLOGICAL CONSTRAINTS ON LOWER SILESIAN BASALTOIDS, SW POLAND

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ABSTRACT
Fifteen samples of basaltoid rocks were analysed from Lower Silesia, SW Poland, all of them situated close to the Sudetic Marginal Fault. K-Ar datings were made on whole rock samples, using the methodology applied by the Institute of Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary. Most of the samples gave dates ranging between 21-38 Ma, whereas that derived from a borehole in the Mokrzeszów graben was dated to 44 Ma. Another borehole sample (Jeżów Sudecki B-5) is of 59 Ma age. On the other hand, the supposedly "Quaternary" basalts from the Dębowiec area fall into the interval of 29-30 Ma.The southeasternmost occurrences of the Lower Silesian basalts at Nowa Cerekiew display two generations of effusive activity: the older lava flows (26 Ma) are cut by plugs dated to 22 Ma. The Oligocene-Lower Miocene (26-33 Ma, 20-24 Ma) rocks represent alkali basalts and basanites. Most of the samples studied show properties typical of the two phases of volcanic activity, hitherto recorded in the Opole area by other authors.

KEYWORDS: basalts, K-Ar dating, petrology, Cenozoic, Lower Silesia, SW Poland

1. INTRODUCTION

Cenozoic volcanic rocks, generally called "basalts", are ubiquitous in the area of Lower Silesia. Most of the known occurrences are situated on the Fore-Sudetic Block, and in the western part of the Sudetes Mts. In the Fore-Sudetic Block, basaltoid exposures have been described from the Jawor, Legnica and Złotoryja, as well as Niemcza and Kowalskie-Żelowice, Targowica, and Ziębice areas. As far as the first region is concerned, basaltoid rocks occur on either side of the morphotectonic boundary of the Middle Sudetes. Basaltoid occurrences in the second region are scattered over a larger area. In the western part of the Sudetes, numerous exposures are associated with the northern part of the NE-orientated Ohře volcano-tectonic graben that cuts the Bohemian Massif. The other basaltoid occurrences are located in a depression occupied by the so-called "Opole" Cretaceous strata and in its eastern surroundings, whereas isolated exposures are known from the Karkonosze and Złote Góry Mts. Basaltoid volcanic rocks have also been drilled by numerous boreholes and their vast subsurface spread has also been confirmed by geophysical soundings (Cwojdziński and Jodłowski, 1982; Badura and Przybylski, 2000).

The aim of our paper is to present preliminary results of new K-Ar datings and petrological studies of basaltoid rocks exposed between Złotoryja in the NW and Nowa Cerekiew in the SE of Lower Silesia.

2. GEOLOGICAL SETTING

The Lower Silesian Cenozoic volcanic rocks, mostly basaltoids and their pyroclastics, occur between the western frontier of the country up to the St. Anna Mt. in the east (Fig. 1). These volcanics constitute the eastern part of the *Central European Volcanic Province* (CEVP), nearly 700 km long, and situated in front of the European Alpides (Cwojdziński and Jodłowski, 1982; Blusztajn and Hart, 1989); or, following Kopecký (1966, 1978) and Ulrych et al. (1999, 2002a,b), in the marginal part of a vast rift system that extends between the Rhine River valley through Germany, Czech Republic, up to Poland. A few occurrences of volcanic rocks in Lower Silesia can be distinguished. In the Czech Republic, the volcanic Ohře rift does occur, and its north-eastern continuation in Poland and Germany is the Zittau-Bogatynia rift (Alibert et al., 1987; Ulrych et al., 1999), and - probably - basaltoid occurrences in the Western Sudetes and their foreland.

Volcanic lavas in Lower Silesia are typical of brittle, unfolded regions. Basaltoid rocks are represented here by predominant tephrites and basanites, rare foidites, and singular basalts and trachybasalts (Bolewski and Parachoniak, 1982; Kozłowska-Koch, 1987; Wierzchołowski, 1993; Lorenc et al., 2004). Apart from magmatic rocks, the Lower Silesian basaltoid formation includes as well pyroclastic rocks, such as: volcanic breccias, tuffs,

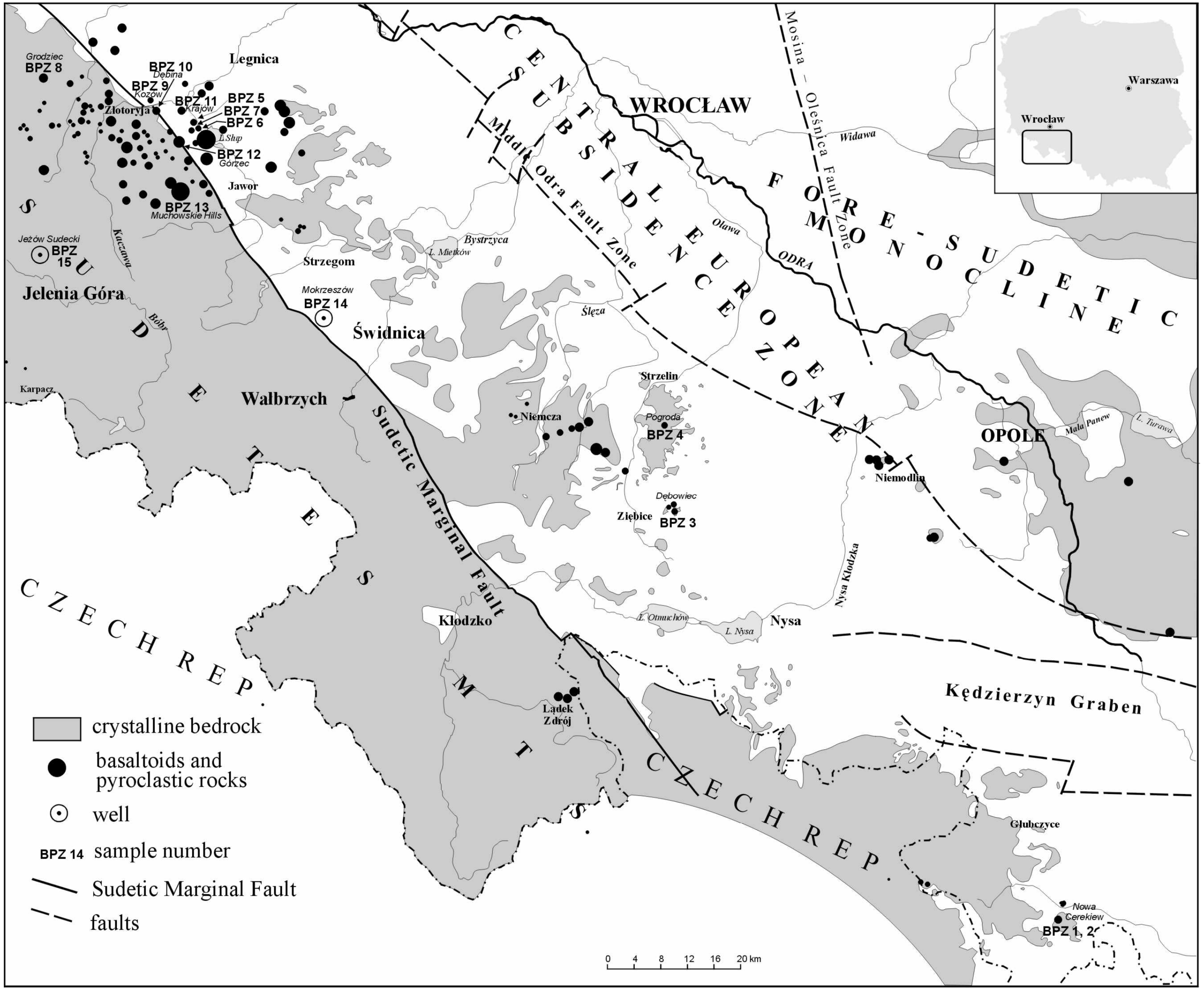


Fig. 1 Distribution of the studied basaltoid samples in Lower Silesia

and tuffites. The occurrences of volcanic rocks in SW Poland are associated with deep-seated faults, and form "spot-like" concentrations (Cwojdziński and Jodłowski, 1982; Dyjor and Kościówko, 1986). Cwojdziński and Jodłowski (1982) distinguished three regions of basaltic rock concentrations: Zittau-Zgorzelec-Lubań, Legnica-Jawor- Złotoryja, and Strzelin-Ziębice. Solitary occurrences of basaltoids are also known from other areas of SW Poland, like: the Lądek Zdrój area, Głubczyce Plateau, or Karkonosze Mts. Basaltoid rocks are hosted in differentiated bedrock, including: Cretaceous strata near Opole (melabasanites and melanephelinites), Palaeogene and Neogene strata in the Lubań-Bogatynia zone (basanites and foidites), metamorphic rocks of the Niemcza-Strzelin (foidites and basanites) and Lądek Zdrój areas (basanites), Hercynian granitoids and their metamorphic cover of the Jawor-Strzelin-Złotoryja (basanites, foidites, alkali basalts) and Karkonosze-Izera areas (basanites; cf. Birkenmajer et al., 2004a; Lorenc et al., 2004).

Altogether, 314 surface exposures of basalt-like rocks have been counted in Lower Silesia, including: 156 small veins (sills and dykes), 89 fragments of lava flows, 44 volcanic necks, 22 plugs and veins bearing fragments of lava flows, and 3 isolated tuff and conglomerate occurrences (Jerzmański and Śliwa, 1979). The magnetic and gravimetric data show that the Cenozoic basaltoid occurrences are associated with the so-called "basalt anomalies"which may point to a relatively shallow depth of volcanic rocks, whose subsurface extent is much more greater than the surfacicial one (Cwojdziński and Jodłowski, 1982; Badura and Przybylski, 2000). The basaltoid veins attain diametres ranging from a few metres to a few tens of metres. An example of the exposed basalt vein is the so-called "Perkun fan" structure (Kozłowski and Parachoniak, 1960). The diameter of volcanic plugs changes from a few tens to a few hundred metres. The accompanying tuffs and volcanic breccias have only been preserved fragmentarily, undergoing weathering, erosion, and denudation. Typical examples of volcanic necks, showing a few effusive phases, can be found near Złotoryja, and also in other parts of Lower Silesia, like close to Gracze and Niemodlin. The basaltoid lava flows are particularly frequent in the SW part of Lower Silesia (Jerzmański and Maciejewski, 1968). The thickness of lava flows changes from a few to a few tens of metres. Their basement is usually represented by older crystalline rocks, rarely sedimentary rocks of the Upper Cretaceous or the Palaeogene and Neogene.

The pyroclastic rocks have been much eroded; they are usually strongly weathered and turned into clayey beds showing traces of tuffs, lapillae, and volcanic bombs (Dyjor and Kościówko, 1986). The primary, much more widespread, extent of pyroclastic rocks can be inferred basing on the Mokrzeszów graben borehole log, wherein tuffs and tuffites occurring at a depth of 418-660 m have not been drilled through (Grocholski, 1977). In the upper part of the tuffite series, a 6-m-thick basalt layer was drilled. The preservation of such a thick volcanogenic series has only been possible due to its location in a tectonic graben, showing a tendency to tectonic subsidence. Minor admixture of granitoid blocks and other crystalline rocks found in tuffites, as well as plant remains indicate that these sediments have largely been redeposited in an aquatic environment. The sporomorph studies conducted on clays overlying the tuffite series point to a Late Oligocene age of the latter (Jaworska, 1975). Cwojdziński and Jodłowski (1982) infer that a similar tuff/tuffite series could also occur in a deeper part of the Paczków Graben fill.

The results of geochemical studies indicate that the majority of Lower Silesian basaltoid rocks originated in the upper mantle at depths ranging between 75 and 90 km (Wierzchołowski, 1993), whereas more alkaline varieties were formed due to magma differentiation at depths of 30-45 km. Most of the Lower Silesian basaltoids are, hence, a result of rapid processes of magma upheaval that made its differentiation impossible. The basalts contain enclaves of rocks derived from the mantle, such as: peridotites (harzburgites, lherzolites), dunites, and clinopyroxenites (Cwojdziński and Jodłowski, 1982; Białowolska, 1993; Wierzchołowski, 1993). The mantle origin of Lower Silesian volcanic rocks is also testified to by proportions of Sr, Hf and Nd (Alibert et al., 1987; Blusztajn and Hart, 1989; Ladenberger et al., 2004).

3. MATERIAL

We sampled 13 surficial exposures of basaltoids and cores of two boreholes drilled at Mokrzeszów (no. 14) and Jeżów Sudecki (B-5; no. 15; Fig. 1; Table 1). Most of the studied localities cluster close to the Sudetic Marginal Fault. The surficial exposures represent both lava flows (6 localities) and plugs (6); and one sample (no. 11) comes from a loose block, probably derived from a plug. The Nowa Cerekiew localities (nos. 1 and 2) are situated in the southeasternmost portion of Lower Silesia, in the Głubczyce Plateau. The Fore-Sudetic Block is represented by samples collected in the Strzelin (no. 3 - Pogroda, no. 4 - Dębowiec) and Strzegom-Złotoryja areas (no. 5 - Chroślice, no. 6 - Kościelna Góra, no. 7 - Winnik, and no. 11 - Krajów). The last area, although situated already in the Sudetic Block (SW of the Sudetic Marginal Fault), was sampled at Grodziec (no. 8), Kozów (no. 9), Dębina (no. 10), Górzec (no. 12), and Muchowskie Wzgórza Hills (no. 13). The Jeżów Sudecki (B-5) borehole (no. 15) is also situated in the Sudetic Block, on the NE margin of the Karkonosze Massif, in the Intra-Sudetic fault zone. The second borehole (Mokrzeszów), in turn, is located shortly NE of the Sudetic Marginal Fault, within a tectonic trough filled with Palaeogene and Neogene sediments.

Table 1 K-Ar datings of alkaline basaltic rocks of Lower Silesia

Lab. No.	Sample No.	Locality	Dated fraction	K (%)	^{40}Ar rad (ccSTP/g) *10^{-7}	^{40}Ar rad (%)	K-Ar age (Ma)
6312	BPZ 1	Nowa Cerekiew plug	w.r.	0.97	8.491	68.9	22.31±0.87
6311	BPZ 2	Nowa Cerkiew lava flow	w.r.	0.77	7.955	69.1	26.41±1.03
6310	BPZ 3	Pogroda plug	w.r.	0.72	8.503	66.1	30.33±1.09
6314	BPZ 4	Dębowiec lava flow	w.r.	0.69	7.867	64.7	29.09±1.07
6315	BPZ 5	Chroślice lava flow (?)	w.r.	0.61	6.643	57.6	27.88±1.13
6309	BPZ 6	Kościelna Góra plug (?)	w.r.	0.66	5.434	63.6	20.99±0.83
6313	BPZ 7	Winnik lava flow	w.r.	0.76	9.273	58.5	31.28±1.26
6343	BPZ 8	Castle Grodziec plug	w.r.	0.61	7.746	48.7	32.16±37
6344	BPZ 9	Kozów plug	w.r.	0.63	5.191	47.7	21.14±0.91
6345	BPZ 10	Dębina lava flow	w.r.	0.79	7.592	57.4	24.46±0.99
6346	BPZ 11	Krajów block of plug (?)	w.r.	0.41	6.225	58.1	38.27±1.55
6347	BPZ 12	Górzec lava flow	w.r.	0.76	1.004 10^{-6}	45.4	33.67±1.48
6348	BPZ 13	Muchowskie Wzgórza plug	w.r.	0.82	1.018 10^{-6}	69.6	31.62±1.23
6349	BPZ 14	Mokrzeszów borehole	w.r.	1.27	2.208 10^{-6}	8.0	44.1±7.7
6350	BPZ 15	Jeżów Sudecki B-5 borehole	w.r.	0.46	1.072 10^{-6}	14.2	58.7±5.9

4. METHODS AND DATING RESULTS

K-Ar datings were made by one of us (Z. Pécskay) on whole rock samples, using the methodology applied by the Institute of Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary (cf. Balogh, 1985; Birkenmajer and Pécskay, 2002; Birkenmajer et al., 2002, 2004b).

Approximately, 0.05 g of finely ground sample was digested in acids and finally dissolved in 0.2M HCl. Potassium was determined by flame photometry with a Na buffer, and Li international standard. The inter-laboratory standards Asia 1/65, LP-6, HD-B1, and GL-O were used for checking the measurements. Argon was extracted from the samples by RF fusion in Mo crucibles, in a previously backed stainless steel vacuum system. The ^{38}Ar spike was added from gas pipette system and the evolved gases were cleaned using Ti and SAES getters and liquid nitrogen traps, respectively. The purified Ar was then transported directly into the mass spectrometer, and Ar isotope ratio was measured in the static mode, using a 15 cm radius magnetic sector-type mass spectrometer, built in Debrecen. Atomic constants suggested by Steiger and Jäger (1977) were used for calculating the ages. All analytical errors represent one standard deviation, i.e., 68% of analytical confidence level. Since we base our analytical errors on the long-time stability of instruments, and on the deviation of our results obtained on standard samples from the inter-laboratory mean, the analytical errors are likely to be overestimated.

Petrological and mineralogical studies were made by two of us (E. Koszowska, A. Wolska) at the Department of Mineralogy, Petrology, and Geochemistry, Institute of Geological Sciences, Jagiellonian University in Kraków. Microscopic study of thin sections was performed using AMPLIVAL petrographic microscope. The morphology of minerals and their chemical composition were examined using scanning electron microscopy (JEOL 5410), equipped with an energy dispersive spectrometer Voyager 3100 (NORAN). Geochemical analyses were performed at the Activation Laboratories, Ltd., Canada.

Samples no. 5-13 gave dates ranging between 21-38 Ma, whereas sample derived from Mokrzeszów borehole (no.14) was dated to 44 Ma. Another borehole sample (Jeżów Sudecki B-5; no. 15) is of 59 Ma age. On the other hand, the supposedly "Quaternary" basalts from the Dębowiec area (no. 4; Fore-Sudetic Block) fall into the interval of 29-30 Ma. The southeasternmost occurrences of the Lower Silesian basalts at Nowa Cerekiew (nos. 1, 2) display two generations of effusive activity: the older lava flows (26 Ma) are cut here by plugs dated to 22 Ma (Tables 1, 2).

5. PETROLOGICAL AND MINERALOGICAL ASPECTS

The basaltoid rocks studied have dark-grey, nearly black colour, and are massive and very fine-grained. The amygdaloidal structures are very rare (sample no. 15). Microscopic observations indicate that the structure of these rocks is fine-grained, porphyric, whilst the texture is chaotic. Only in sample no. 12, medium-grained structure, and intergranular and rare fluidal texture, marked by the arrangement of platy minerals (plagioclases), were observed. The enclaves of host rocks (xenoliths) are very rare (samples no. 1, 3). The presence of fragments of the oldest basaltoid rocks is observed in sample no. 2.

The oldest, K-Ar age-dated, basaltoids are represented by samples no. 14 (ca. 44 Ma) and 15 (ca. 58 Ma). These rocks are strongly altered when compared to the other samples studied. In sample no. 14, bowlingite (a mixture of secondary minerals from the serpentinite, chlorite, and saponite group) occurs as pseudomorphs after olivine phenocrysts. Pyroxene phenocrysts are very rare in these samples. In sample no. 15, bowlingitic pseudomorphs after olivine phenocrysts, and pseudomorphs after pyroxenes filled by secondary minerals (carbonates, silica) and relic crystals of pyroxene were observed. Crystals of Ca-rich clinopyroxenes (bearing ca. 4 wt. % of TiO_2) and opaque minerals (mainly titanomagnetite) occur in the groundmass.

The K-Ar age of samples no. 2, 3, 4, 5, 7, 8, 12, 13 was found to be 26-33 Ma.

In samples no. 3, 5, 7, 8, 12, olivine and pyroxene phenocrysts do occur. Their size ranges from 0.8 – 1.7 mm to 0.4 – 0.6 mm, respectively. In samples no. 2, 4, and 13, olivine phenocrysts are predominant; pyroxene phenocrysts are very rare and smallest in size (0.1 – 0.4 mm). These rocks are alkali basalts and basanites (Fig. 2).

Olivine phenocrysts in both types of basaltoid rocks are represented mainly by Mg-rich (core Fo_{88-80}, rim Fo_{78-71}) chrysolite. Nickel and chromium are commonly present in olivine phenocrysts. These phenocrysts are altered to a different degree. In samples no. 2, 3, and 13, bowlingite occurs both in central parts and micro-cracks within olivine phenocrysts. The latter minerals are surrounded by red iddingsite rims (samples no. 5, 7, 12), and their margins are corroded in all the studied samples.

Pyroxene phenocrysts vary in size from 0.2 – 0.4 mm, through 0.5 – 0.7 mm, to 0.8 – 1.2 mm). They are represented by Ca-rich clinopyroxenes (En_{41-34} Fs_{14-9} Wo_{53-48} – salite; where: En – enstatite, Fs – ferrosilite, Wo - wollastonite) showing a distinct zonal structure and displaying Fe-richer rims and Fe-poorer cores. Very rare sieve texture (alkali glass in a fine, mesh-like arrangement) was observed in central parts of pyroxene phenocrysts (samples no. 2, 5).

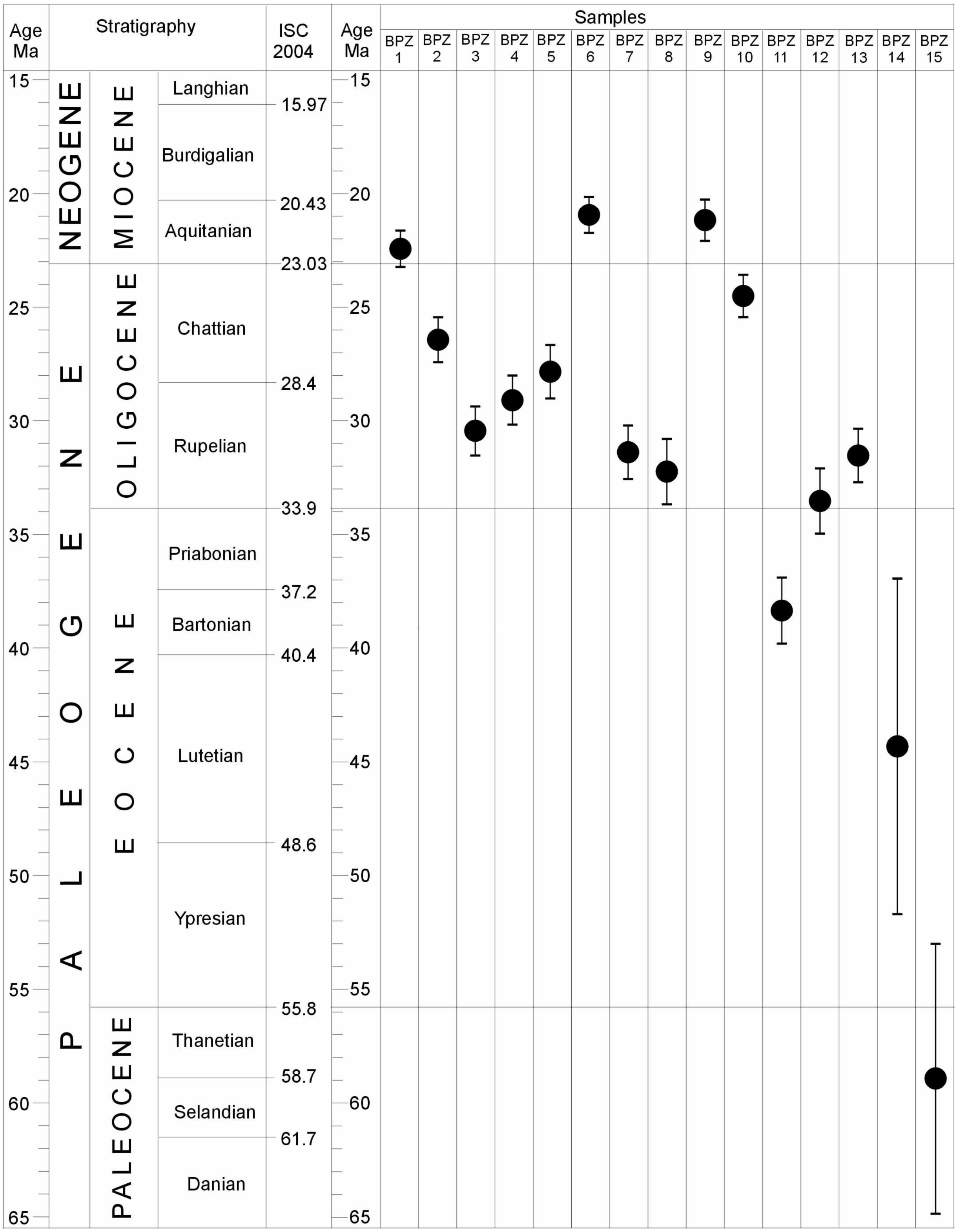
In the groundmass of the basaltoid rock samples, clinopyroxenes and opaque minerals (iron oxides, ilmenite) were mainly observed. The Ca-rich clinopyroxene crystals (En_{37-29} Fs_{17-12} Wo_{53-48} - salite; according to Poldervaart and Hess' (1951) nomenclature) display variable content of TiO_2 (2-3 wt. % - sample no. 7, and 4-5 wt. % samples no. 1, 3, 8). In the groundmass, there also occur very small plates of plagioclases: labradorite (An_{68-56} Ab_{41-32} Or_{5-1}), rare bytownite (An_{74-72} Ab_{28-26}), and andesine (samples no. 1, 2, 5, 7). Samples no. 3 and 8 are characterised by the presence of nepheline, analcite, and sodalite. Small olivine crystals are observed in the groundmass. They are represented by hyalosiderite (Fo_{66-57}), iddingsitized to a variable degree. Brown alkali glass occurs in the interstices among mineral crystals.

K-Ar ages of samples no. 1, 6, 9, and 10 were determined to 20-24 Ma. The rocks represent alkali basalts and basanites (Fig. 2).

In samples no. 9 and 10, olivine phenocrysts are common (being 0.3 – 0.6 mm, 0.7 – 1.2 mm, and 1.6 – 2,5 mm in size), whereas small (0.4 – 0.6 mm in size) pyroxene phenocrysts are very rare. In sample no. 6, only olivine phenocrysts do occur, whereas in sample no. 1 olivine phenocrysts are strongly altered into a mixture of secondary minerals of the bowlingite type.

Olivine phenocrysts of the basaltoid rocks studied are represented mainly by Mg-rich (core Fo_{83-79}, rim Fo_{77-71}) chrysolite. These phenocrysts are commonly altered to a variable degree. In samples no. 9 and 10, bowlingite-like alteration processes in

Table 2 Age distribution of alkaline basaltic rocks in Lower Silesia



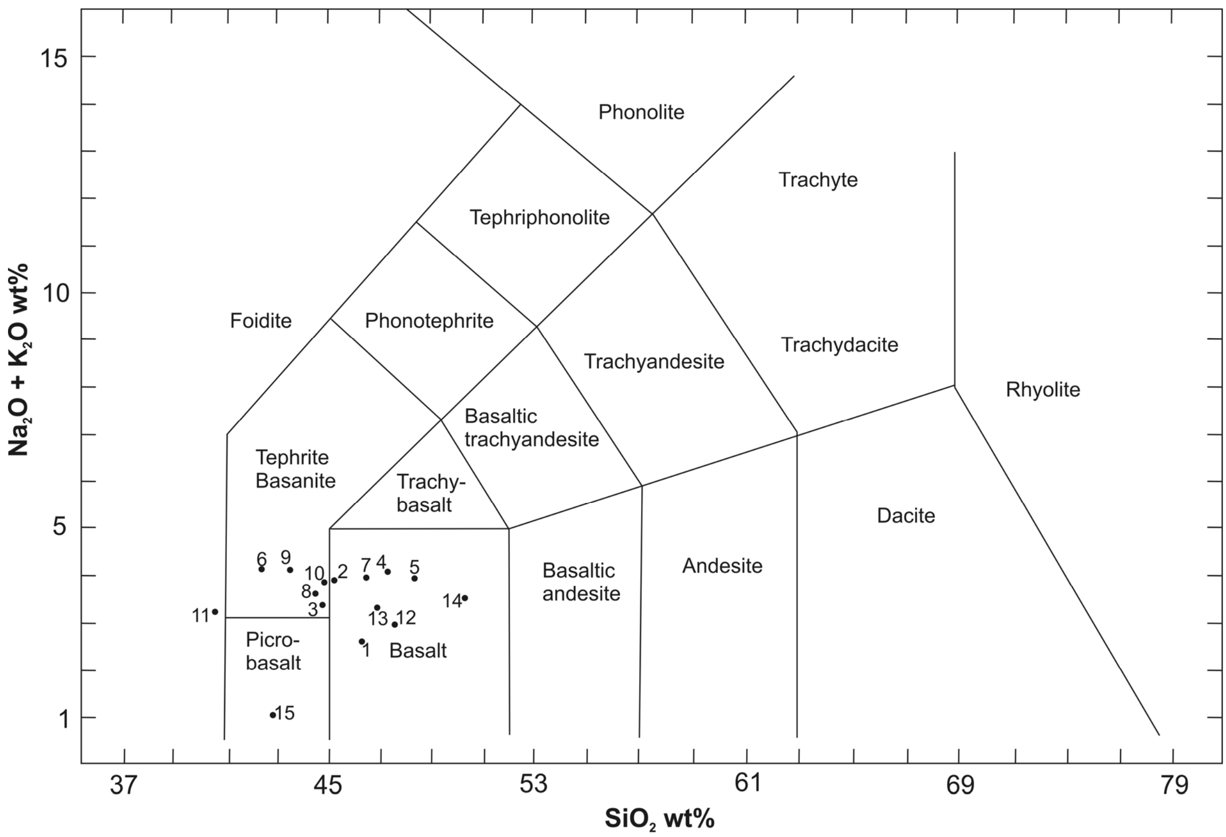


Fig. 2 Plots of the studied basaltoids on the TAS diagram (Le Maitre et al., 1989)

central parts, and cracks in olivine phenocrysts were observed. In sample no. 9 olivine phenocrysts are overgrown by red iddingsite rims. The margins of olivine phenocrysts are corroded in all the samples.

Pyroxene phenocrysts are represented by clinopyroxenes and have salitic composition (En_{38-27} Fs_{17-10} Wo_{53-52}), showing as well a distinct zonal structure and often displaying sector (hour-glass) structures.

In the groundmass of the basaltoids, clinopyroxenes and opaque minerals (iron oxides, ilmenite) were mainly observed. The Ca-rich clinopyroxene crystals (En_{36-29} Fs_{16-12} Wo_{53-51}) contain variable amount of TiO_2 (2-3 wt. % - sample no. 10, and 4-5 wt. % - samples no. 1, 6, 9). In the groundmass of samples no. 1, 9, and 10, there occur very small plates of plagioclases (bytownite – An_{74-73} Ab_{26-24} Or_{3-2} and andesine – An_{43-38} Ab_{54-49} Or_{9-7}). Light minerals are represented by nepheline and, probably, sodalite in sample no. 6. Small olivine crystals are present in the groundmass (samples no. 6 and 9). These are hyalosideritic (Fo_{68-65}) in composition, and commonly iddingsitized. Brown alkali glass occurs in interstices among the groundmass minerals.

According to TAS discrimination diagram (LeMaitre et al., 1989; Fig. 2), the analysed samples represent both tephrites/basanites (nos. 3, 8, 6, 9, 10) and basalts (nos. 1, 2, 4, 5, 7, 12, 13, 14). Sample no. 15 (B-5 borehole) is altered to such a degree that its classification is not possible.

6. AGE CONSTRAINTS

Samples no. 5, 6, 7, 8, 9, 10, 11, 12, and 13 are generally low-potassium basaltic rocks (<0.9%).This is a typical feature of all Palaeogene-Neogene alkaline basaltic rocks of the Opole region (Table 2). According to radiometric ages, two main volcanic phases can be distinguished: 21-24.5 Ma, and 31.3-33.7 Ma (Birkenmajer and Pécskay, 2002; Birkenmajer et al., 2002, 2004b). Only one older age was determined on sample no. 11 (38.27±1.55 Ma), probably due to the presence of excess argon. Therefore, this radiometric age can only be concerned as an analytical age. Basing on geological inferences, sample no. 15 can be correlated with sample no. SK-10 coming from Śnieżne Kotły, Karkonosze Mts. However, analytical data contradict geological observations. The K-Ar age (26.01±1.27 Ma) obtained on SK-10 is much more reliable than the radiometric age obtained on sample no. 15 (58.7±5.9 Ma) which can be related to strong alteration of the core sample. Highly consistent ages (30.33±1.09 Ma and 29.09±1.07 Ma, resp.) were obtained on samples nos. 3 and 4. Basing on analytical data, it can be ruled out completely that this volcanic activity took place in the

Quaternary, as it has been supposed in some earlier papers (Wroński, 1970). Two samples (nos. 1, 2) were collected at Nowa Cerekiew quarry. Following the field observations, the radiometric age of the lava flow (26.41±1.03 Ma) is older than that of the plug (22.31±0.87 Ma). These apparent ages are similar to those obtained on basaltic rocks occurring in the Opole region (Birkenmajer and Pécskay, 2002).

The oldest K-Ar age is an Eocene one. However, this age estimation can be older than the real geological age. The dominant phase of volcanic activity appears to have taken place in Oligocene times. This also holds true for the Pogroda area, wherefrom much more younger ages have been expected. The second peak of volcanic activity took place in the Early Miocene. Nevertheless, more detailed analytical and geological work should be made for the sake of a correct explanation of the basalt eruptive sequences in the Lower Silesian volcanic field.

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