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RADIOMETRIC DATING OF THE TERTIARY VOLCANICS IN LOWER SILESIA, POLAND. VI. K-Ar AND PALAEOMAGNETIC DATA FROM BASALTIC ROCKS OF THE WEST SUDETY MOUNTAINS AND THEIR NORTHERN FORELAND

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Abstract: This article presents the sixth and final contribution in a series of papers focused mainly on the K-Ar dating of the Oligocene and Neogene (Miocene and Pliocene) intraplate basaltic volcanics of the Lower Silesia, SW Poland. The present paper includes 22 new K-Ar dates from the West Sudety Mountains and their northern foreland. The K-Ar dates range from 30.7 to 22.2 Ma. The data are supplied with geological description of the sampled outcrops, petrographic, geochemical and palaeomagnetic data of the analysed samples. Palaeomagnetic investigation confirmed the existence of two important volcanic episodes distinguished already in 1997: the reversed polarity Odra Event (mean age 28.2±1.2 Ma), and the normal polarity Gracze Event (mean age 26.28±1.8 Ma).

Key words: K-Ar dating, Oligocene, Miocene, intraplate basaltic volcanics, Lower Silesia, Poland.

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INTRODUCTION

The present paper is the sixth and final contribution to a geochronological study of the Oligocene, Miocene and Pliocene basaltic rocks from the Lower Silesia, Poland. This work focuses on the area of the West Sudety Mountains and their northern Foreland. Our previous studies included the areas of the Fore-Sudetic Block (Birkenmajer & Pécskay, 2002; Birkenmajer *et al.*, 2002b, 2004), eastern and central parts of the Sudety Mts. (Birkenmajer *et al.*, 2002a), and the North Sudetic Depression (Birkenmajer *et al.*, 2007). Additional K-Ar dating results of the Tertiary basaltic rocks in Lower Silesia have been presented by Badura *et al.* (2005).

The Tertiary basalts of Lower Silesia belong to the eastern branch of the Bohemo-Silesian volcanic belt, part of the Central European Tertiary intraplate volcanic province (Fig. 1). The volcanic activity started during Early Oligocene (Rupelian) and continued through Early Miocene (Aquitanian–Burdigalian) time in the platform area to the north of the Sudetic Marginal Fault, and in the North Sudetic Depression, with *ca.* 3 Ma break at the Oligocene/Miocene boundary. Another, much shorter cycle of basaltic volcanic activity, dated from the Miocene/Pliocene (Messinian/Zanclean) boundary through the Early Pliocene (Zanclean), was recognised in the eastern part of the Sudety Mountains.

The Tertiary volcanism in Lower Silesia includes a variety of forms and structures: stratocones (usually consider-

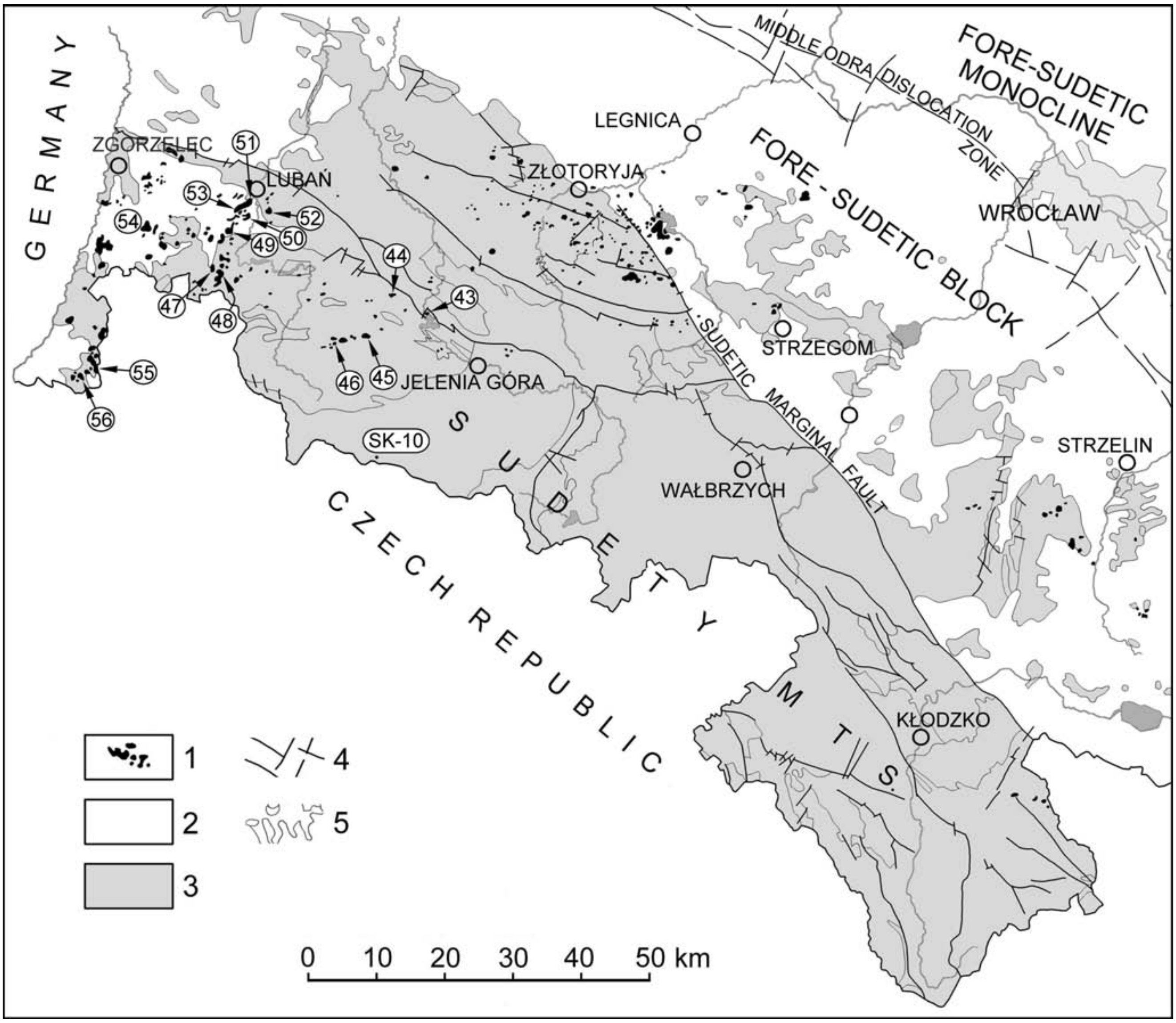

Fig. 1. Location of basaltic sampling sites: BP-43 to BP-46; SK-10 (circled numbers) in the West Sudety Mountains; and samples BP-47 to BP-56 between Lubań and Opolno Zdrój (northern foreland of the West Sudetes Mts.). *1* – Tertiary basaltic rocks; *2* – Cenozoic sedimentary cover; *3* – pre-Cenozoic rocks; *4* – major faults; 5 – main lithologic boundaries

ably damaged by erosion and denudation), lavas and tuffs, plugs, less frequently also dykes and sills (*e.g.*, Jerzmański, 1956, 1965; Kozłowski, 1960; Birkenmajer, 1967, 1974; Śliwa, 1971; Birkenmajer & Nairn, 1969; Birkenmajer *et al.*, 1970, 1972, 1977, 2002a, b, 2004, 2007; Birkenmajer & Pécskay, 2000; Zagożdżon, 2001; Zagożdżon & Zagożdżon, 2006).

GEOLOGICAL SETTING AND PETROLOGY

West Sudety Mountains

Pilchowice (BP-43)

Geology. The volcanic plug (Birkenmajer, 1967) is exposed in an old quarry *ca.* 300 m NE from dam of the Pilchowice artificial lake. It sits at the Intra-Sudetic Fault which separates Cambrian–Silurian mica schists from augen gneisses and a protolith (Szałamacha, 1974). The age of protolith to the gneiss was constrained to 515–480 Ma (Korytowski *et al.*, 1993; Żelaźniewicz *et al.*, 2003).

Petrography. The sample is a black fine-crystalline rock with a clear porphyric structure. Its groundmass is composed of glass (partly chloritized) with very fine pyroxene and nepheline crystals in equal amounts. Euhedral to subhedral, usually fresh olivine (sometimes with irregular network of microcracks) dominates among phenocrysts, which are 0.5–1.5 mm in size. Euhedral to subhedral nepheline phenocrysts are second in frequency. Rare pyroxene (Ti-augite, $z/\gamma = 36°$) phenocrysts, usually with hourglass structure, are partly chloritized.

The rock was previously classified as basanite (Kozłowska-Koch, 1987), however, based on its mineral composition and chemistry (*cf.* Le Bas & Streckeisen, 1991) it

Table 1

Chemical composition of Tertiary basaltic rocks from the West Sudety Mts (Sites BP-43-46, SK-10)

	BP-43	BP-44A	BP-45	BP-46A	SK-10
%	Karkonosze				
SiO_2	40.49	43.58	40.62	39.08	40.61
TiO_2	3.20	2.63	3.12	3.67	2.88
Al_2O_3	12.59	11.81	11.86	12.44	11.89
Fe_2O_3	12.33	11.87	12.82	13.29	12.45
MnO	0.18	0.17	0.19	0.21	0.20
MgO	12.86	11.92	12.91	10.77	11.04
CaO	11.20	10.59	12.21	13.52	11.94
Na_2O	3.40	3.51	3.63	3.76	1.55
K_2O	1.11	1.42	0.78	1.11	1.22
P_2O_5	0.77	0.83	1.02	1.02	0.74
LOI	1.51	1.37	0.46	0.69	5.08
SUM	99.49	99.52	99.47	99.49	99.41
ppm					
As	8	5	4	5	4
Ba	830	642	708	850	518
Bi	<3	<3	<3	<3	<3
Ce	117	118	145	161	119
Co	41	36	42	32	35
Cr	399	367	562	339	392
Cu	64	56	72	73	61
Ga	17	19	18	19	17
Hf	8	6	5	6	5
La	56	49	74	79	41
Mo	3.9	5.1	6.3	6.0	3.2
Nb	98	78	90	112	90
Ni	280	247	263	145	209
Pb	<3	<3	<3	<3	<3
Rb	78	46	63	46	79
Sr	967	825	1063	1195	1803
Ta	8	3	<3	8	4
Th	5	6	8	5	<3
U	4.4	3.5	4.3	3.5	2.6
V	257	207	268	317	213
W	<5	<5	<5	<5	<5
Y	27	30	30	32	30
Zn	90	103	102	98	101
Zr	288	292	336	390	376
Ti/Y	265.3	525.6	623.6	687.6	574.2
Zr/Y	10.67	9.73	11.20	12.19	12.53
R1	840	960	834	583	1484
R2	2083	1956	2180	2225	2059

Analysed at the Chemistry Laboratory, Polish Geological Institute, Warsaw (Project No 620.1719.00.0)

should be reclassified as ankaratrite (olivine melanephelinite) (Table 1, Figs 2, 3).

Palaeomagnetic sampling. Two representative hand samples (43-1; 43-2) were collected from the abandoned quarry, with location of *ca.* 2 m apart.

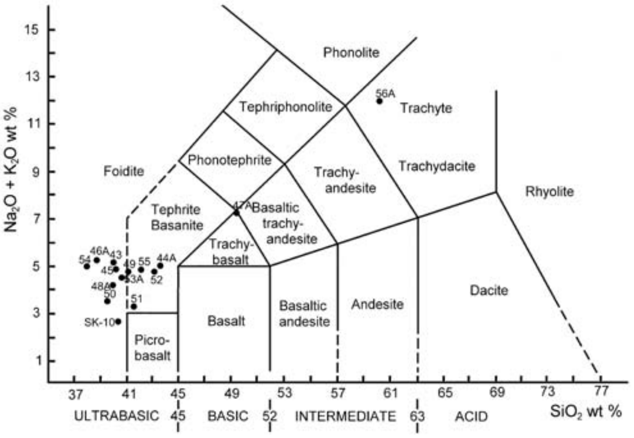

Fig. 2. Plot of Tertiary basaltic rock samples, West Sudety Mountains, TAS classification diagramme (Le Bas & Streckeisen, 1991). Numbers refer to the investigated sites (BP; SK)

Wojciechów (BP-44A)

Geology. The exposure is situated in a working quarry (Fig. 4), *ca.* 500 m E from Wojciechów (near Lubomierz). Well developed, radially arranged columnar jointing (columns 30–40 cm in diameter) is recognizable at the lower exploitation level. According to Szałamacha (1970), this is a central part of a volcanic vent.

Petrology. The sample is a very fine-crystalline, dark-grey to almost black rock showing porphyric structure. Its groundmass, very rich in glass (partly chloritized), includes very fine plagioclase laths (labradorite An_{52-55}) and pyroxene (augite). Olivine phenocrysts (1–2 mm in size) show an irregular network of fine microcracks. The pyroxene phenocrysts ($z/\gamma = 37–40°$) with similar size are often twinned, sometimes showing hourglass structure. The largest phenocrysts of pyroxene (*ca.* 3 mm in size) are thoroughly chloritized and surrounded by rims of not altered, very small augite ($z/\gamma = 35°$) crystals. Abundant opaque minerals, mainly iron-oxides, are dispersed within the groundmass. The rock was classified by Domański (1970) as basanite. Our data (Table 1; Figs 2, 3) confirm his classification.

Palaeomagnetic sampling. One hand sample (44-1 labelled as BP-44A radiometric sample), was taken from the northern wall. Additionally, two hand samples (44-2 and 44-3) were collected from the southern wall of the quarry.

Grudza (BP-45)

Geology. The rock is exposed in a working quarry, *ca.* 1 km S from Grudza, near Stara Kamienica. It probably represents a volcanic vent with remnants of lava flows and pyroclastic rocks.

Petrography. The sample is a black, fine-crystalline rock, devoid of fluidal structure. Its groundmass consists of brownish chloritized glass, with fine nepheline and pyroxene crystals. Isotropic, euhedral grains of opaque minerals abound. Euhedral to subhedral olivine, 0.5 mm (sometimes up to 1 mm) in size, predominates among phenocrysts. Pyroxene phenocrysts (Ti-augite, $z/\gamma = 38°$), usually subhedral, are second in frequency. The pyroxene is commonly twinned, sometimes showing very typical hourglass struc-

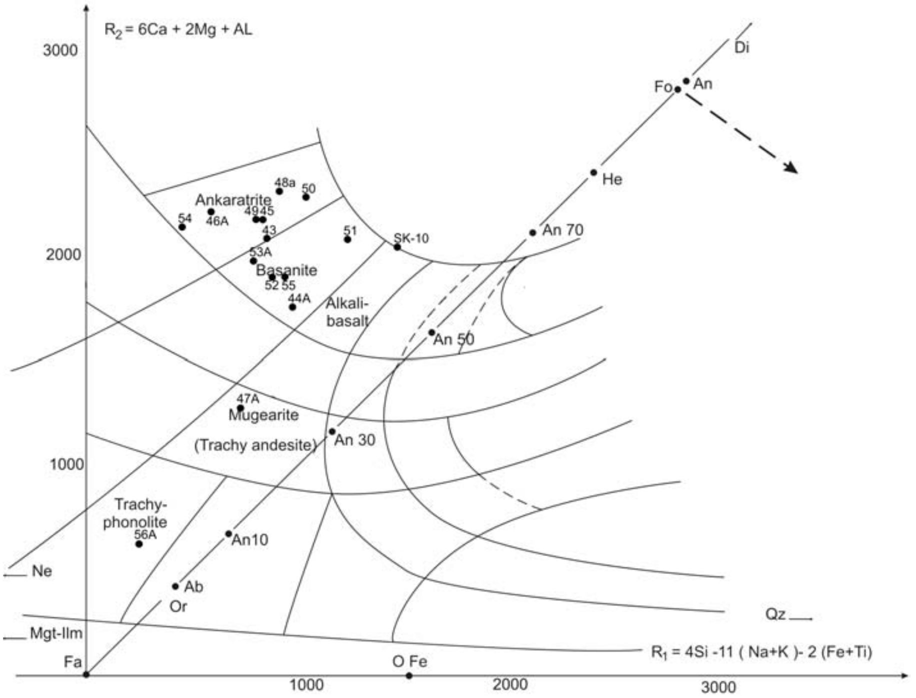

Fig. 3. Plot of Tertiary basaltic rock samples, northern foreland of the West Sudety Mts., R1-R2 classification diagram (De la Roche *et al.*, 1980). Numbers refer to the investigated sites (BP)

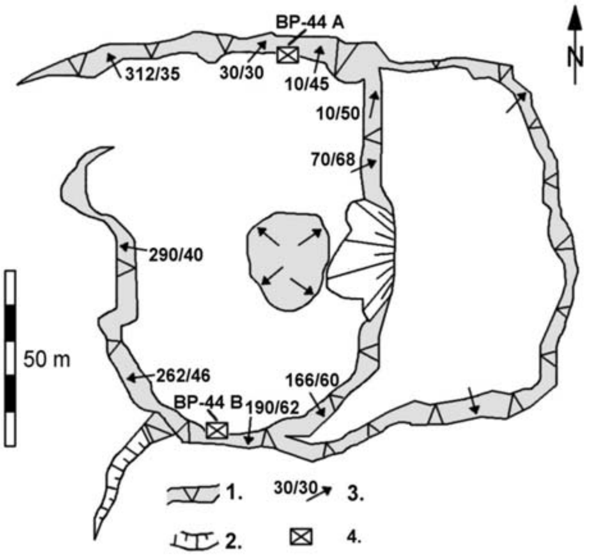

Fig. 4. Site BP-44 Wojciechów, basanite. *1* – exploitation scarps in the quarry and basanite exposures at quarry bottom; *2* – talus; *3* – dips of basanite columns; *4* – sampling sites

ture. Small aggregates of fine pyroxene and olivine crystals occur.

The bulk chemistry (Table 1, Figs 2, 3) indicates that the previous classification as the pyroxene basalt (Wojno *et al.*, 1951; Szałamacha, 1970) should be changed to the ankaratrite (olivine melanephelinite).

Palaeomagnetic sampling. Two hand samples (45-1; 45-2) were collected from the same wall of the quarry.

Rębiszów (BP-46A)

Geology. A working quarry, 1.5 km E from Przecznica village in the Łysa Góra area, exposes a volcanic vent with lava flows (Stachowiak, 1981). The vent is located at a tectonic contact of the Neoproterozoic Stara Kamienica mica schist unit (Maciejewski, 1957) with the gneisses and granitic gneisses of the Izera complex. The protolith age of the latter ones was constrained to 515–480 Ma (Korytowski *et al.*, 1993; Żelaźniewicz *et al.*, 2003).

Petrography. The sample is a black rock without fluidal structure. Its groundmass consists of fine nepheline, pyroxene and glass. Isotropic opaque minerals are commonly dispersed in the groundmass. Large phenocrysts (1–5 mm in size) include mainly olivine with an irregular network of microcracks filled with secondary minerals of serpentine group, or fine plagioclase and biotite. Pyroxene (Ti-augite, $z/\gamma = 37°$) phenocrysts are second in frequency, and smaller than the olivine. Some pyroxenes are relatively fresh, showing hourglass structure.

According to our data (Table 1; Figs 2, 3), the previously classified rock as nephelinite (Wojno *et al.*, 1951; Birkenmajer *et al.*, 1970) should be reclassified to the ankaratrite (olivine melanephelinite).

Palaeomagnetic sampling. Two hand samples (46-1; 46-2) were collected from the southern part of the quarry. The label is equal to the BP-46A radiometric sample.

Śnieżne Kotły (SK-10)

Geology. An exposure is located in the western wall of the Mały Kocioł Śnieżny glacial cirque (the so-called Bazaltowy Żleb gully). Samples were collected from an axial part of the basaltoid intrusion (Fig. 5), which cuts the

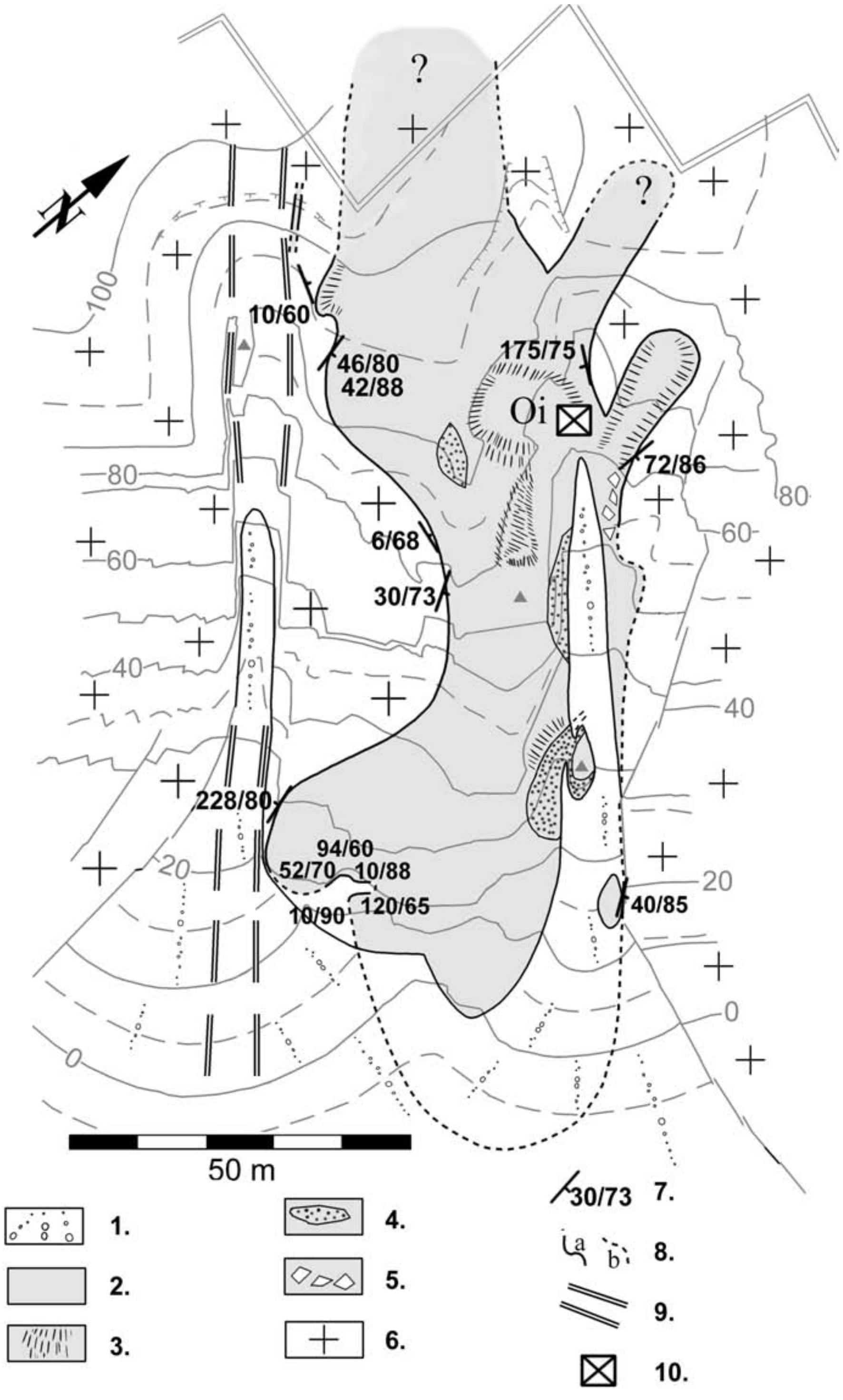

Fig. 5. Site SK-10 Śnieżne Kotły, basanite (after Zagożdżon & Zagożdżon, 2006). *1* – talus cones; *2* – basanite; *3* – columnar jointing; *4* – intrusive breccia; *5* – contact breccia; *6* – granite; *7* – strike and dip of contact surface; *8* – lithologic boundaries (*a* – certain; *b* – probable); *9* – dislocation zone; *10* – sampling site

Karkonosze granite pluton of Carboniferous age (see Zagożdżon & Zagożdżon, 2006).

Petrography. The rock is dark-grey, often vesicular, with porphyric structure, without fluidal structure. Its groundmass consists of strongly chloritized brownish glass, very fine crystals of augite, and altered plagioclase and nepheline. Numerous opaque minerals are dispersed in the groundmass. Pyroxene phenocrysts (1–2 mm in size), usually strongly altered (pseudomorphs filled with chlorite and iron-oxides), are most frequent. The phenocrysts of similar size plagioclase (labradorite An$_{56\text{-}58}$) with albite twinning are partly sericitized. Occasional vesicles are filled with quartz crystals enveloped by dark rims of very fine pyroxene that grows perpendicularly to surface of the vesicles.

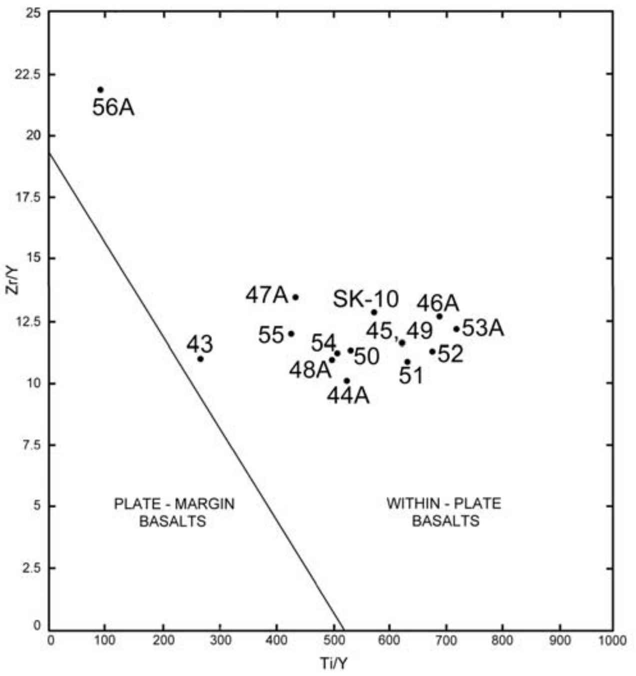

Fig. 6. Plot of Tertiary basaltic rock samples, northern foreland of the West Sudety Mts., Pearce and Gale's (1977) classification diagram. Numbers refer to the investigated sites (BP)

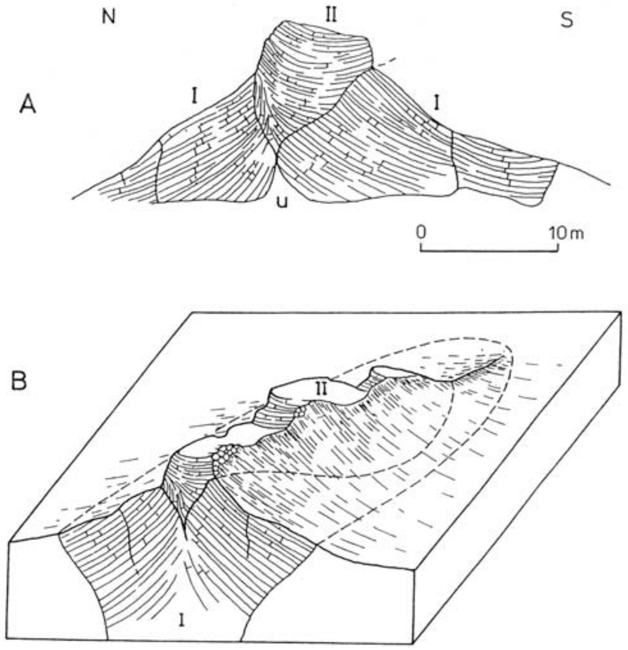

Fig. 7. Site 48 Stożek Perkuna, olivine melanephelinite plug, two generations (I – older; II – younger). **A** – exposure; **B** – blockdiagram; u – talus. After Birkenmajer (1967)

Fig. 8. Site BP-48 Stożek Perkuna, olivine-melanephelinite plug, with location of sampling sites (x – for K-Ar dating; I, II – two generations of the plug (see Fig. 7)

Our data (Table 1; Figs 2, 3) indicate that the studied sample is the basanite as was classified previously by Kozłowska-Koch (1987).

Area between Lubań and Opolno Zdrój

Leśna-Brzozy (BP-47A, B)

Geology. A massive lava flow (Śliwa, 1971) exposed in an abandoned quarry was sampled (note: a plug might occur SW of the quarry; Kochanowska, 1995).

Petrography. The sample is a very fine-crystalline dark-grey rock. Its groundmass consists of fresh, fluidally arranged laths of plagioclase (labradorite An_{50-55}) and Ti-augite (z/γ = 45–48°). Circular aggregates of green glass, <0.5 mm in size, are scattered within the groundmass and surrounded by plagioclase laths. Long, thin calcite veins run parallel to fluidal structure of the rock.

The rock was originally classified as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951), later reclassified as basanite, ankaratrite and, subordinately, basalt (Kochanowska, 1995). Our study (Table 2; Figs 2, 3, 6) indicates a within-plate trachybasalt affinity.

Palaeomagnetic sampling. Two hand samples (47-1; 47-2) were collected from two different lava columns located *ca.* 2 m apart, in the lower part of escarpment just above the lake. Two more hand samples (47-3; 47-4) were collected in a higher part of the escarpment, above the road.

Stożek Perkuna (BP-48A)

Geology. The natural exposure is situated at the top of the hill, while the old quarry is located in its western part. The elongated plug (Birkenmajer, 1967; volcanic vent of Śliwa, 1971) cuts augen gneisses (Berezowska & Berezowski, 1962a) attributed to the Upper Cambrian (Korytowski *et al.*, 1993; Żelaźniewicz *et al.*, 2003). Samples (BP-98A, B) were collected separately from two generations of basaltic rock (Figs 7, 8).

Petrography. The rock sample is dark-grey and exhibits porphyritic structure. Its groundmass consists of very fine pyroxene and plagioclase laths, green glass and abundant opaque minerals (mainly iron-oxides). Fresh olivine and nepheline phenocrysts are usually 1 mm in size, occasionally reaching size of 2–5 mm. Rare pyroxene (augite z/γ = 37°) phenocrysts sometimes show the presence of circular olivine inclusions.

Table 2

Chemical composition of Tertiary basaltic rocks from the northern foreland of the West Sudety Mts (Sites BP-47-56)

	BP-47A	BP-48A	BP-49	BP-50	BP-51	BP-52	BP-53A	BP-54	BP-55	BP-56A
%	Lubań									
SiO_2	49.37	39.80	41.07	39.45	41.67	42.87	40.76	38.15	42.06	60.60
TiO_2	2.35	2.61	2.83	2.61	2.66	3.29	3.57	3.30	2.59	0.56
Al_2O_3	17.65	10.72	11.71	10.33	12.02	14.08	13.79	12.76	12.69	18.85
Fe_2O_3	9.35	12.14	12.43	12.55	12.66	12.86	13.62	13.88	11.15	3.18
MnO	0.18	0.20	0.19	0.20	0.18	0.18	0.20	0.23	0.24	0.17
MgO	3.69	15.87	13.67	16.07	13.29	8.92	8.46	8.55	9.92	0.65
CaO	7.14	12.38	11.95	12.04	11.23	10.37	12.20	13.89	10.99	2.23
Na_2O	4.79	3.04	3.67	2.96	2.77	3.42	3.65	4.02	3.80	7.02
K_2O	2.43	1.14	1.01	0.62	0.72	1.32	0.82	0.96	0.96	5.09
P_2O_5	0.47	0.96	0.78	0.90	0.71	0.73	0.86	1.41	0.98	0.12
LOI	2.25	0.78	0.32	1.92	1.75	1.69	1.75	2.40	3.97	1.04
SUM	99.65	99.40	99.46	99.38	99.48	99.57	99.57	99.45	99.44	99.60
ppm										
As	5	9	6	4	<3	6	5	11	5	11
Ba	717	929	668	751	566	608	754	1019	1217	702
Bi	<3	<3	<3	<3	<3	3	<3	<3	<3	3
Ce	131	162	120	135	92	107	126	199	190	122
Co	16	42	41	48	44	35	32	29	30	<3
Cr	<3	907	596	709	611	165	243	180	332	<3
Cu	27	90	78	80	79	54	54	52	51	7
Ga	22	18	17	15	16	20	19	20	18	24
Hf	7	10	7	5	4	8	6	13	5	13
La	70	95	57	61	48	49	53	98	93	57
Mo	7.0	5.4	6.0	5.0	3.0	4.2	3.2	7.0	8.8	10.9
Nb	115	128	96	93	85	92	96	131	120	166
Ni	8	501	352	466	357	109	112	109	185	<3
Pb	6	<3	<3	<3	<3	<3	<3	<3	4	14
Rb	71	36	40	36	31	54	51	54	64	140
Sr	832	1103	914	847	828	901	962	1345	1361	653
Ta	9	3	3	<3	<3	7	9	6	9	13
Th	9	10	4	6	5	<3	<3	7	8	20
U	3.9	4.1	3.1	3.7	3.9	2.9	3.1	2.5	5.9	6.0
V	139	289	248	234	230	231	295	271	218	8
W	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Y	32	31	26	29	25	29	30	39	36	32
Zn	94	107	95	96	95	100	94	101	104	81
Zr	430	329	297	318	263	323	353	423	421	698
Ti/Y	440.3	504.7	630.7	539.6	637.9	680.1	712.4	506.7	431.3	104.9
Zr/Y	13.44	10.61	11.42	10.97	10.52	11.14	11.77	10.84	11.69	21.81
R1	726	935	813	1051	1239	927	796	458	883	260
R2	1293	2322	2187	2288	2097	1828	1996	2161	1917	641

Analysed at the Chemistry Laboratory, Polish Geological Institute, Warsaw (Project No 620.1719.00.0)

The rock in previous studies was classified as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951), basalt (Birkenmajer *et al.*, 1970; Grocholski & Jerzmański, 1975), and nephelinite (Kozłowska-Koch, 1987). Data from this study (Table 2; Figs 2, 3) indicate that the sample is an olivine melanephelinite (ankaratrite – a variety of foidite), which is interpreted as originated from an alkaline within-plate type magma (Fig. 6).

Palaeomagnetic sampling. The following three hand samples were collected from Stożek Perkuna: 48-1 – from the lower western part of the exposure (equal to the BP-48C radiometric sample); 48-2 – from the lower eastern part of

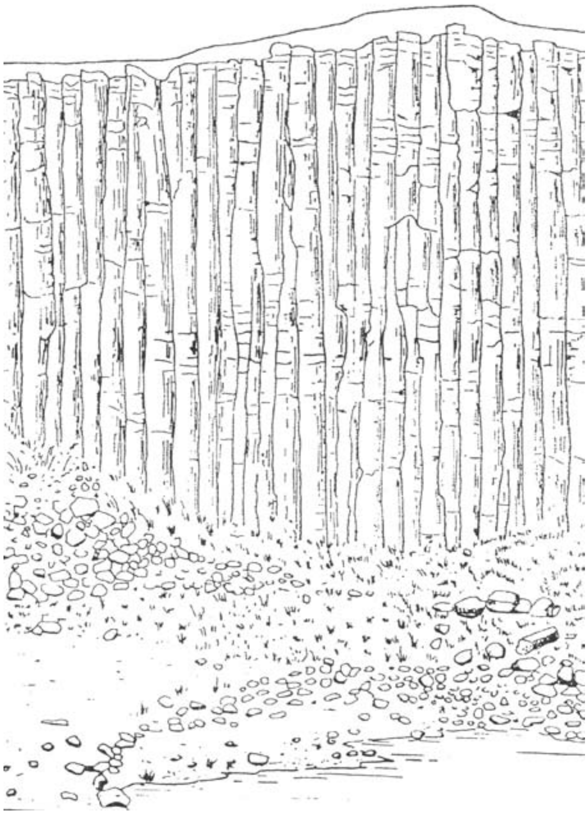

Fig. 9. Site BP-51 Lubań, columnar basanite lava flow (after Birkenmajer, 1967). Height of the exposure *ca* 10 m

the exposure (BP-48B radiometric sample); and 48-3 – from the upper part of the exposure (BP-48A radiometric sample).

Bukowa Góra (BP-49)

Geology. The exposure is located in a working quarry (Księginki II) in a *ca.* 5 km distance SW from Lubań. The lava flow (Birkenmajer, 1967; Śliwa, 1971) rests directly upon Cambro-Silurian phyllites (Berezowska & Berezowski, 1962a; Kural, 1967). The samples were collected in the eastern part of the lowest exploitation level.

Petrography. The rock sample is dark-grey, very fine-crystalline, with well developed fluidal structure. Its groundmass consists mainly of very fine nepheline crystals and green glass. Very fine plagioclase and pyroxene laths, both too small to be precisely determined, are less frequent. Abundant opaque minerals occur. Among phenocrysts, nepheline and olivine (<1 mm in size) predominate. The latter is partly altered, with red iddingsite rims, showing a microcrack network filled with secondary minerals of serpentine group. Smaller olivine phenocrysts are totally transformed into iddingsite. Pyroxene phenocrysts (Ti-augite z/γ = 38°) are less frequent.

The rock was originally named nephelinite (Birkenmajer *et al.*, 1970) and tephrite (Kozłowska-Koch, 1987). The new data (Table 2; Figs 2, 3) indicate that it should be reclassified as olivine melanephelinite (ankaratrite), while its primary magma belonged to an alkaline within-plate type (Fig. 6).

Palaeomagnetic sampling. Two hand samples (49-1; 49-2) were collected from the lower part of the quarry (equal to the BP-49 radiometric sample).

Lubań I (BP-50)

Geology. The exposure is located in a three-level working quarry, about 2.5 km south of the Lubań centre. The exposed extensive lava flow (Birkenmajer, 1967; Śliwa, 1971) is located partly upon the Ordovician phyllites, and partly upon the Miocene clays (Berezowski, 1956). The sample was collected at the lowest exploitation level.

Petrography. The sample is a dark-grey rock with porphyric structure. Its groundmass consists of very fine pyroxene and plagioclase, and a considerable amount of green glass. Abundant black opaque minerals are regularly dispersed in the glass. Pyroxene (augite z/γ = 37°) and olivine, up to 2 mm in size, are the only phenocrysts present. Pyroxene is commonly twinned or shows a typical hourglass structure. The olivine phenocrysts contain microcracks filled with serpentine group minerals, and are rimmed by a red iddingsite.

The rock was previously classified as a plagioclase-nepheline basalt or nepheline basanite (Wojno *et al.*, 1951), nephelinite (Birkenmajer *et al.*, 1970; Grocholski & Jerzmański, 1975; Białowolska, 1980), or basanite and tephrite (Kozłowska-Koch, 1987). The data from this study (Table 2; Figs 2, 3) indicate that the rock belongs to within-plate olivine melanephelinite (ankaratrite).

Palaeomagnetic sampling. Two hand samples (50-1; 50-2) were collected (labelled also as the BP-50 radiometric sample).

Lubań II (BP-51)

Geology. The samples were collected from the same extensive lava flow as at site BP-50 (Lubań I) located in an old quarry at the Kamienna Góra town-park at Lubań (see Birkenmajer *et al.*, 1970; Grocholski & Jerzmański, 1975) (Fig. 9).

Petrography. The sample is a dark-grey, very fine-crystalline rock with porphyric structure. Its groundmass consists of plagioclase and pyroxene (augite) laths. Glass and opaque minerals (mainly iron-oxides) abound in the groundmass. Pyroxene (Ti-augite, z/γ = 48°) dominates over fresh olivine, both being less than 1 mm in size. Thin iddingsite rims surround most of the olivine phenocrysts, and many of them are entirely transformed into iddingsite. Single quartz crystals rimmed by very fine pyroxene occur.

The rock was previously classified as plagioclase-nepheline basalt or nepheline basanite (Wojno *et al.*, 1951) and nephelinite (Birkenmajer *et al.*, 1970; Grocholski & Jerzmański, 1975). Our data (Table 2; Figs 2, 3, 6) indicate that we deal here with a typical within-plate basanite.

Palaeomagnetic sampling. Two hand samples (51-1; 51-2) were collected from different lava columns (the BP-51 radiometric sample).

Uniegoszcz (PB-52)

Geology. The samples were collected from a basaltic volcanic vent exposed in an old, two-level quarry at Ostróżek hill (see Birkenmajer, 1967, text figs 26, 27), SE from

Lubań. The vent is associated with lava flow (Birkenmajer *et al.*, 1970; Krzyśków, 1985) resting upon Ordovician phyllites (Berezowski, 1956).

Petrography. The sample is a dark-grey, very fine-crystalline rock with flow structure. The groundmass consists mainly of brownish glass, very fine plagioclase and pyroxene laths, and frequent opaque minerals. Olivine dominating among phenocrysts contains microcracks filled with serpentine group minerals. Augite (z/γ = 38°) is usually twinned and shows hourglass structure.

The rock was previously classified as a nepheline basalt (Wojno *et al.*, 1951), nephelinite (Birkenmajer *et al.*, 1970) and basanite (Krzyśków, 1985). Our data (Table 2; Figs 2, 3, 6) confirm that the rock is a within-plate basanite.

Palaeomagnetic sampling. Two hand samples (52-1; 52-2) were collected from a central part of the abandoned quarry (BP-52 radiometric sample).

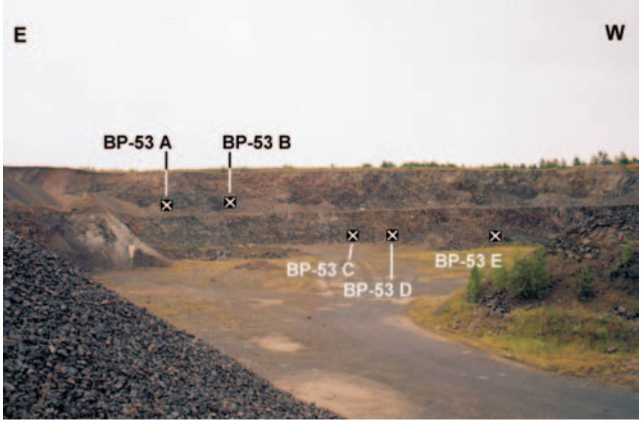

Fig. 10. Site Zaręba BP-53, basanite lava flow, x – location of sampling sites for K-Ar dating

Zaręba (BP-53A-E)

Geology. The samples were collected from a two-level working quarry at Zaręba (Księginki I), located about 3 km SW from Lubań centre. The site exposes a fragment of the same extensive lava cover as at sites BP-50 (Lubań I) and BP-51 (Lubań II), showing the presence of regular pyroclastic intercalations, often with lava breccias. Five samples (BP-53A-E) were collected from the lava (Fig. 10).

Petrography. The sample is a very dark, nearly black, very fine-crystalline rock. The groundmass contains high amount of glass, as well as fresh, very fine augite (z/γ = 38°) and plagioclase laths. Abundant black opaque minerals are dispersed within the groundmass. Relatively large (0.5–1 mm) olivine grains are entirely transformed into red iddingsite. Single nepheline phenocrysts of similar size occur.

The rock was previously classified as nephelinite (Birkenmajer *et al.*, 1970), however, the new data (Table 2; Figs 2, 3) indicate that the sample is a basanite. Relatively large amount of nepheline shifts its position in respective diagrams near to the olivine mela-nephelinite (ankaratrite) within-plate field (Fig. 6).

Palaeomagnetic sampling. The following six hand samples were collected: two samples (53-1; 53-2) from the upper part of the quarry (BP-53A, B radiometric samples); and four samples from the lower part of the quarry, *i.e.* 53-3 (BP-53C radiometric sample); 53-4 (BP-53D radiometric sample), 53-5, 6 (BP-53D and BP-53E radiometric samples, respectively).

Sulików (BP-54)

Geology. The site exposes a lava flow in a three-level working quarry located about 0.5 km NE from Sulików centre. A volcanic vent probably occurs N of the quarry (Birkenmajer, 1967; Jakubowska *et al.*, 1987). The site is located at the contact of the *ca.* 570 Ma Lausitian greywackes (Żelaźniewicz *et al.*, 2003), and the 540–530 Ma Zawidów granodiorite (Berezowska & Berezowski, 1962b; Korytowski *et al.*, 1993). A sample was collected from the lava flow exposed in the southern part of the lowest exploitation level.

Petrography. The sample is a dark-grey, very fine-crystalline rock with scattered phenocrysts of pyroxene and olivine which do not exceed 0.5 mm in size. Olivine is entirely replaced by red iddingsite.

The rocks from the Sulików quarry were previously classified as nepheline basalt, plagioclase basalt and nephelinite (Wojno *et al.*, 1951), and nephelinite (Birkenmajer *et al.*, 1970; Kozłowska-Koch, 1987). The sample in our study (Table 2; Figs 2, 3) is classified as belonging to olivine mela-nephelinite (ankaratrite).

Palaeomagnetic sampling. Two hand samples were collected at the same site (BP-54 radiometric sample).

Markocice (BP-55)

Geology. The old quarry (called "Wojtek") at Bogatynia exposes rocks representing the central part of an extensive lava flow which covers the 514–480 Ma Rumburk granite (Żelaźniewicz *et al.*, 2003).

Petrography. The sample is a dark-grey, very fine-crystalline rock with porphyric structure. Its groundmass consists of very fine fresh-preserved plagioclase (labradorite An_{58-60}) and pyroxene laths, with a small admixture of nepheline and opaque minerals, and brownish-green glass. Idiomorphic pyroxene (augite, z/γ = 48°) prisms predominate among phenocrysts; they are commonly twinned, with a typical hourglass structure. Olivine phenocrysts are second in frequency. They commonly show traces of magmatic corrosion in form of embayments filled with glass. Microcracks in olivine are filled with minerals of serpentine group. The rock was previously classifed as trachyandesite (Smulikowski, 1960) and basanite (Berezowski, 1973). Our study (Table 2; Figs 2, 3) confirms attribution of the rock to within-plate basanite.

Palaeomagnetic sampling. One hand sample has been collected (BP-55 radiometric sample).

Opolno Zdrój (BP-56A, B)

Geology. Samples (BP-56A, B) were collected in an old quarry which exposes a lava flow with centrally located vent (Birkenmajer, 1967, text fig. 31). The country rocks are represented by the 514–480 Ma Rumburk granite (Żelaźniewicz *et al.*, 2003) and augen gneisses of the Izera complex, with a protolith age constrained to 515–480 Ma (Korytowski *et al.*, 1993; Żelaźniewicz *et al.*, 2003).

Table 3

Results of K-Ar dating of basaltic rocks from the West Sudety Mts

No. of K/Ar	No. of sample	Location	Rock type	K (%)	40Ar$_{rad}$ (ccSTP/g)	40Ar$_{rad}$ (%)	K/Ar age (Ma)
6210	BP-43	Pilchowice	ankaratrite	0.82	$7.541\ 10^{-7}$	40.8	23.4±1.1
6211	BP-44A	Wojciechów quarry E	basanite	1.15	$1.249\ 10^{-6}$	52.3	27.8±1.2
6212	BP-45	Grudza quarry	ankaratrite	0.60	$6.128\ 10^{-7}$	55.9	26.0±1.0
6213	BP-46A	Rębiszów quarry S	ankaratrite	0.79	$7.867\ 10^{-7}$	57.3	25.3±1.0
6342	SK-10	Śnieżne Kotły	basanite	1.08	$1.100\ 10^{-6}$	35.5	26.0±1.3

The analyses were performed at the Institute of Nuclear Research, Hungarian Academy of Sciences (ATOMKI), Debrecen. The whole rock fraction was analysed

Petrography. The sample is a light-coloured (pale-green), fine-crystalline porphyric rock. Its groundmass is composed of elongated (<0.3 mm) plagioclase (oligoclase An$_{28-30}$) laths with albitic twins, and K-feldspar showing Carlsbad twinning. Needle-shaped pyroxene (augite z/γ = 48°) also occurs in the groundmass. K-feldspar (up to 2 mm in size), being the only phenocryst, is sub-idiomorphic and forms very fine granophyric intergrowths with quartz and polysynthetic feldspar twins. Zircon, the only accessory mineral, rarely occurs within the groundmass.

The rock was previously classified as plagioclase basalt or trachyphonolite (Smulikowski, 1960; Birkenmajer, 1967; Birkenmajer *et al.*, 1970), phonolite (Berezowski, 1971, 1973), and trachyte (Kozłowska-Koch, 1987). Our data (Table 2; Figs. 2, 3) confirms the latter attribution.

Palaeomagnetic sampling. One hand sample (56-1) was collected. Because the site is in a very bad condition and the phonolite occurs as isolated blocks, it is uncertain whether these blocks are *in situ.*

POTASSIUM-ARGON DATING

Dating methods and age calculations

The methods used to determine K-Ar ages of the basaltic rocks have been described in detail elsewhere (Birkenmajer & Pécskay, 2002). The K was analysed using the flame photometry, while the radiogenic Ar was measured by isotope dilution after extraction of the Ar in a high-vacuum line. The isotopic composition of the Ar was determined using a mass spectrometer (90° magnetic sector type of 150 mm radius – see Balogh, 1985) which was operated in the static regime. The precision of the K and Ar measurements was regularly checked by interlaboratory standards: LP-G, GL-O, HD-B1 and Asia 1/65 (see Odin *et al.*, 1982). Atomic constants suggested by Steiger and Jäger (1977) were used for calculating the ages. All of the analytical errors represent one standard deviation (68% confidence level). Details of the instruments have been described elsewhere (Balogh, 1985).

Jelenia Góra area

Five locations have been sampled in the Jelenia Góra area (Fig. 1). The basaltic rocks (basanite and ankaratrite) yielded K-Ar ages ranging from 27.8 Ma to 23.4 Ma (Table 3).

Except for the K-Ar age of 23.4±1.1 Ma obtained on sample BP-43, there is an agreement in ages between the remaining samples to within analytical errors. It is thought, therefore, that loss of radiogenic Ar was the reason for rejuvenated age of sample BP-43. Such an assumption is supported by the presence of glassy groundmass and secondary nepheline in this sample. Similar mineralogical-petrographic observations were also made in other samples, *e.g.* BP-44A, 45, 46A, and SK-10. It is well known (*e.g.*, McDougall, 1966) that lavas most suitable for K-Ar dating of the whole-rock samples should be holocrystalline and not altered. Unfortunately, many basaltic rocks from our study contain varying proportions of poorly crystallized groundmass or glass which contains potassium. Therefore, the constrained radiometric K-Ar ages should be generally regarded as the minimum ages.

On the other hand, the highly concordant ages determined in samples from four locations suggest that volcanism in this area was restricted to a relatively short period between 27.8 Ma and 25.3 Ma, *i.e.* to the Late Oligocene (Chattian). The 26.2 Ma value, a mean of four dates (27.8±1.2 Ma, 25.3±1.0 Ma, 26.0±1.0 Ma and 26.0±1.3 Ma), probably reflects the main volcanic episode, with ankaratrite being slightly younger than the basanite.

A general agreement between the K-Ar and palaeomagnetic data (Table 3 and Figs 11–13) suggest that the different K-Ar ages might represent different volcanic episodes.

Lubań area

The Lower Silesia Basaltic Province extends westwards from the Lubań area to Germany, and to the south to the Czech Republic. In the Lubań area, 17 representative basaltic samples were collected for K-Ar dating from nine exposures in working and abandoned quarries (Fig. 1). The dating results ranging from 30.7 to 22.2 Ma are shown in Table 4.

(1) The oldest dates of about 30 Ma were determined in two high-K basaltic rocks (BP-47A, B and BP-56A, B) classified as trachybasalt and trachyte, respectively. We consider these dates as representing real geological ages. The age difference between samples BP-47A and BP-47B might reflect some slight rejuvenation of the K-Ar age in sample BP-47B with a lower K content.

(2) The K-Ar dates obtained from the Stożek Perkuna quarry (BP-48A-C) do not agree with their relative geologi-

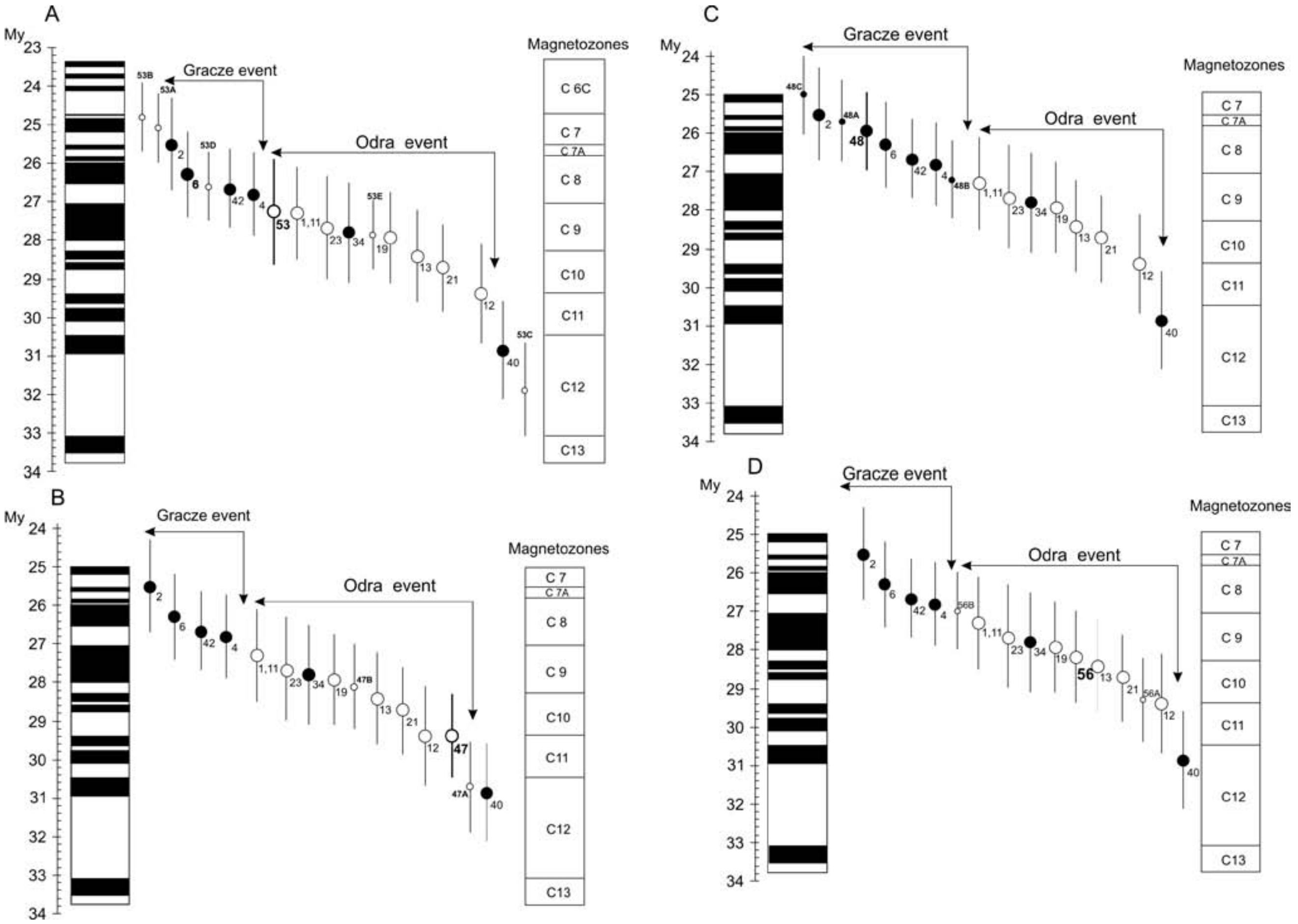

Fig. 11. K-Ar dating results from sites where more than one sample was radiometrically dated versus geomagnetic scale of Cande and Kent (1995), and results from the Oligocene basaltic rocks of the Lower Silesia (Birkenmajer & Pécskay, 2002; Birkenmajer *et al.*, 2002b, 2004, 2007, this paper). Left side – radiometric scale in Ma and polarity column; right side – magnetozones. Full circles – normal polarity; open circles – reversed polarity. Site mean ages are drawn in a bold line. (**A**) Site BP-53A-E; (**B**) Site B-57A, B; (**C**) Site 56A-C; (**D**) Site BP-56A, B

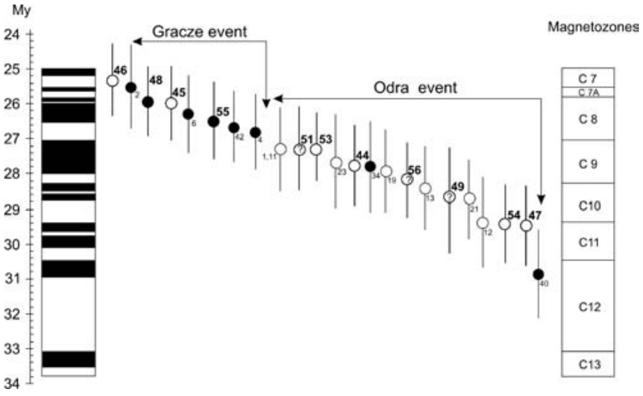

Fig. 12. K-Ar dating results from sites where more than one sample was radiometrically dated versus geomagnetic scale of Cande and Kent (1995), and results from the Oligocene basaltic rocks of the Lower Silesia (Birkenmajer & Pécskay, 2002; Birkenmajer *et al.*, 2002b, 2004, 2007, this paper). Left side – radiometric scale in Ma and polarity column; right side – magnetozones. Full circles – normal polarity; open circles – reversed polarity. Site mean ages are drawn in a bold line

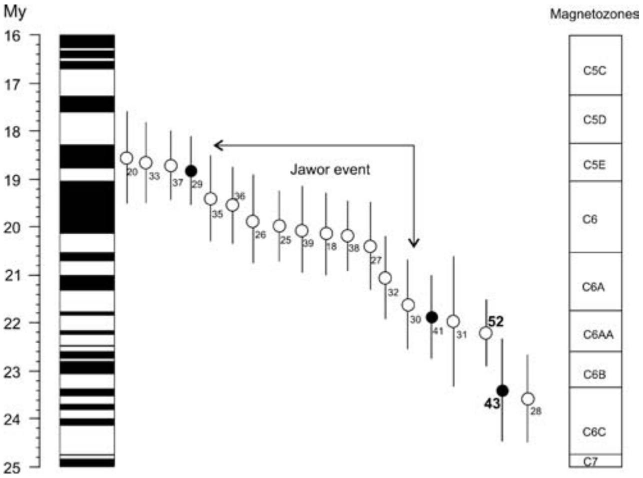

Fig. 13. Correlation of K-Ar dating results of the Miocene basaltic rocks from the Lower Silesia (data from Birkenmajer *et al.*, 2000b, 2004, 2007, this paper) versus geomagnetic scale of Cande and Kent (1995); full circles – normal polarity; open circles – reversed polarity; numbers of sites investigated in this paper are given in bold figures

Table 4

Results of K-Ar dating of basaltic rocks from the northern foreland of the Sudety Mts

No of K/Ar	No of sample	Location	Rock type	K (%)	$^{40}Ar_{rad}$ (ccSTP/g)	$^{40}Ar_{rad}$ (%)	K/Ar age (Ma)
6215	BP-47A	Leśna-Brzozy quarry S	trachybasalt	2.01	$2.418\ 10^{-6}$	78.6	30.7±1.2
6216	BP-47B	Leśna-Brzozy quarry N	trachybasalt	1.59	$1.751\ 10^{-6}$	73.8	28.1±1.1
6217	BP-48A	Stożek Perkuna quarry, upper	ankaratrite	0.81	$8.148\ 10^{-7}$	53.9	25.7±1.1
6218	BP-48B	Stożek Perkuna quarry, lower E	ankaratrite	0.58	$6.171\ 10^{-7}$	38.9	27.2±1.1
6219	BP-48C	Stożek Perkuna quarry, lower W	ankaratrite	0.65	$6.360\ 10^{-7}$	42.8	25.0±1.0
6220	BP-49	Bukowa Góra quarry	ankaratrite	0.75	$8.406\ 10^{-7}$	31.0	28.7±1.5
6221	BP-50	Księginki quarry	ankaratrite	0.46	$1.356\ 10^{-6}$	16.1 (!)	34.6±3.1 (?)
6222	BP-51	Lubań quarry	basanite	0.60	$6.406\ 10^{-7}$	45.6	27.3±1.2
6223	BP-52	Uniegoszcz	basanite	1.19	$1.031\ 10^{-7}$	60.7	22.2±0.7
6224	BP-53A	Zaręba, Josef quarry upper	ankaratrite	0.70	$6.883\ 10^{-7}$	56.1	25.1±0.9
6225	BP-53B		ankaratrite	0.60	$5.819\ 10^{-7}$	49.5	24.8±0.9
6226	BP-53C	Zaręba, Josef quarry lower	ankaratrite	0.58	$7.250\ 10^{-7}$	42.5	31.9±1.2
6227	BP-53D		ankaratrite	0.61	$6.349\ 10^{-7}$	52.7	26.6±0.9
6228	BP-53E		basanite	0.79	$8.630\ 10^{-7}$	74.2	27.9±0.9
6229	BP-54	Sulików quarry	ankaratrite	0.69	$7.971\ 10^{-7}$	70.6	29.4±1.1
6230	BP-55	Markocice quarry	basanite	0.67	$6.987\ 10^{-7}$	51.8	26.5±1.1
6231	BP-56A	Opolno Zdrój	trachyte	4.20	$4.821\ 10^{-7}$	88.1	29.3±1.1
6232	BP-56B		trachyte	4.20	$4.448\ 10^{-6}$	86.9	27.0±1.0

Dated at the Institute of Nuclear Research, Hungarian Academy of Sciences (ATOMKI), Debrecen. The whole rock fraction was analysed

cal ages. It seems likely that the geologically older rock (BP-48C) had lost some Ar, and that both lavas are at least 25.7 Ma old. However, the calculated mean age of 25.9 Ma for the three samples well corresponds to the normal polarity Gracze event.

(3) An older ankaratrite lava flow exposure south from Lubań (the Bukowa Góra quarry, BP-49, base of the section) yielded K-Ar date of 28.7±1.5 Ma. An extension of this lava flow might be at Księginki (BP-50). However, due to a very high atmospheric Ar contamination, its radiometric age was not considered as meaningful and, therefore, not included in Table 4.

(4) A basanite lava flow from the same area (Lubań II, BP-51) is slightly younger, *i.e.* 27.3±1.2 Ma.

(5) The youngest basaltic rock (alkalic basanite, BP-52) was collected from a volcanic vent in Uniegoszcz and yielded a date of 22.2±0.7 Ma. This is a clear evidence of the presence of the Early Miocene volcanism in the Lubań area, which, however, is areally more restricted than the Oligocene one in contrast to the northern (Jawor) and eastern parts of the Lower Silesia Basaltic Province (Birkenmajer *et al.*, 2002).

(6) The most detailed sampling was made in a melanephelinite (ankaratrite) lava flow at Józef quarry near Zaręba. The two samples (BP-53A, B) were taken from the upper part, and three (BP-53C-E) from the lower part of the quarry (Fig. 10). Palaeomagnetic study (see later) confirms that the samples represent a single lava flow. However, because the K-Ar geochronology provides a wide range of dates from 31.9 Ma to 24.8 Ma (Table 4), it appears that this ankaratrite lava flow cannot be considered as the isotopically "closed system". The scattered K-Ar data could be a result of Ar loss in sample BP-53C (lowest K content and, thus, the highest age) and the presence of some Ar excess. Nevertheless, other samples (BP-53A, B, and BP-53D-E) yielded concordant ages.

Moreover, assuming that the samples from the upper part of the quarry had lost some Ar, the age obtained on sample BP-53E (27.9±0.9 Ma) might be the best estimation. This would be in good agreement with the age determined for sample BP-51 (27.3±1.2 Ma). However, we cannot exclude a possibility that the different ages refer to two volcanic events.

(7) The constrained K-Ar date of sample BP-54 (29.4± 1.1 Ma) seems to be older than the geological age: therefore, it can be considered a maximum age.

(8) A basanite sample (BP-55) collected near the Polish–Czech state border yielded a date of 26.5±1.1 Ma. We interpret this date as the age of crystallization of the lava flow. This age is similar to that established for volcanics in the adjacent area of the Czech Republic (Cajz *et al.*, 1999).

PALAEOMAGNETISM

Palaeomagnetic studies of basaltic rocks from locations marked in here as BP-43, 47, 48, and 52–56 were initiated already half a century ago (Birkenmajer & Nairn, 1969; Birkenmajer *et al.*, 1970). Because previous results were presented in text-tables only, without details of demagnetization, we have decided to re-study these locations. For comparison, the previously published data are included in Table 5.

Table 5

Characteristic magnetizations of the basaltic rocks studied (Sites 43-56)

Locality	Sample	D/I	α_{95}	k	n/no
BP-43	43-1	302/66	3.7	618.5	4/4
	43-2	315/74	4.4	437.2	4/4
	Mean	307/70	–	–	2/2
	Site 57	*307/71*	*12.6*	–	*3/7*
BP-44	44-1 (44A)	8/-26	8.8	195.8	3/3
	44-2 (44B)	336/-10	13.4	85.4	3/3
	44-3 (44B)	339/-8	12.0	105.3	3/3
	Mean (44B)	337/-9	–	–	2/3
BP-45	45-1	190/-46	14.4	41.2	4/4
	45-2	189/-40	12.9	51.8	4/4
	Mean	189/-43	–	–	2/2
BP-46	46-1 (46A)	191/-74	2.2	1689.9	4/4
	46-2 (46A)	221/-75	9.5	95	4/4
	Mean	206/-75	–	–	2/2
BP-47	47-1 (47A)	269/-72	6.1	228.9	4/4
	47-2 (47A)	266/-66	14.5	72.8	3/4[1]
	47-3 (47B)	278/-67	–	–	1/2[1]
	47-4 (47B)	222/-56	8.1	230.9	3/4[2]
	Mean (47A)	267/-69	–	–	2/2
	Mean (47B)	238/-68	–	–	2/2
	Mean (47A-B)	252/-69	–	–	2/2
	Site 46	*161/-56*	*4.2*	–	*6/6*
BP-48	48-1 (48C)	342/62	4.2	473.5	4/4
	48-2 (48B)	25/60	6.5	198.9	4/4
	48-3 (48A)	47/55	13.1	49.8	4/4
	Mean (48A-C)	21/62	25.8	23.5	3/3
	Site 47	*352/52*	*9.4*	–	*5/6*
BP-49	49-1	176/23	3.8	573.5	4/4
	49-2	180/32	9.9	87.3	4/4
	Mean	178/28	–	–	2/2
BP-50	50-1	184/29	10.9	71.8	4/4
	50-2	180/32	2.5	1309	4/4
	Mean	182/31	–	–	2/2
BP-51	51-1	172/18	21.4	33.9	3/3
	51-2	180/32	19.2	41.7	3/3
	Mean	191/15	–	–	2/2
BP-52	52-1	256/-35	5.7	473.2	3/3
	52-2	257/-47	1.5	7200	3/4[2]
	Mean	256/-41	–	–	2/2
	Site 42	*164/27*	–	–	*6/6*
	Site 43	*169/-15*	–	–	*5/6*
	Site 44	*176/-74*	*9.1*	–	*6/6*
BP-53	53-1 (53A)	189/-42	13.3	48.1	4/4
	53-2 (53B)	184/-74	4.5	410.9	4/4
	53-3 (53C)	174/-65	8.4	121.3	4/4
	53-4 (53D)	176/-72	8.8	110.5	4/4
	53-5 (53E)	166/-71	7.7	144.2	4/4
	53-6 (53E)	167/-77	11.9	60.5	4/4
	Mean (53E)	166/-74	–	–	2/2
	Mean (53A-E)	180/-66	13.4	33.3	5/5
	Site 23	*176/-51*	*9.9*	–	*6/6*
	Site 24	*160/-46*	*17.7*	–	*6/6*
BP-54	54-1	197/-80	2.8	954	3/3
	54-2	191/-67	6.8	184.7	4/4
	Mean	193/-74	–	–	2/2
	Site 52	*168/-69*	*3*	–	*7/7*
BP-55	55-1	61/40	21.5	33.5	3/4[2]
	Site 49	*78/49*	–	–	*5/6*
BP-56	56-1 (56B)	341/-70	9.5	93.9	4/5[2]
	Site 51	*315/38*	–	–	*8/8*

D – declination, I – inclination, α_{95}, k -Fisher statistics parameters, no – number of specimens (samples) investigated, n – number of specimens (samples) used for calculation of the mean direction. *Italics:* Results of Birkenmajer & Nairn (1969). [1] – one specimen demagnetized with AF rejected; [2] – one specimen demagnetized thermally rejected

Palaeomagnetic methods

All palaeomagnetic experiments were carried out at the Palaeomagnetic Laboratory of the Polish Geological Institute in Warsaw, in the magnetically shielded space (low-field cage, Magnetic Measurements, UK) reducing the ambient geomagnetic field by about 95%. From each hand sample, 3–4 cylindrical specimens were prepared. Natural remnant magnetization (NRM) was measured using the JR-5 spinner magnetometer (AGICO, Czech Republic). Alternating field (AF) demagnetization was performed using Molspin device (max. demagnetizing field available 99 mT) and thermal demagnetization – using non-magnetic oven MMTD (Magnetic Measurements, UK). Characteristic remnant magnetization (ChRM) directions were calculated based on the principal component analysis (see Kirschvink, 1980), and using the PALMAG package (Lewandowski *et al.*, 1997). Most of the samples were treated with the AF. Thermal demagnetization was applied to pilot specimens, demagnetizing paths were, however, more noisy than in the case of the AF treatment, and sometimes it was not possible to isolate ChRM.

Palaeomagnetic results

After extraction of a small low coercivity component (following 5–10 mT demagnetization steps) a stable characteristic magnetization was revealed, which was interpreted as primary (Fig. 14). Characteristic magnetizations from all sites are quite dispersed (Fig. 15), *i.e.* only some of them are concordant with Neogene directions “expected” for the European Platform, with minor deviations which might be explained by secular variations. These are normal polarity results from sites BP-43 and BP-48 (Fig. 14A), and reverse

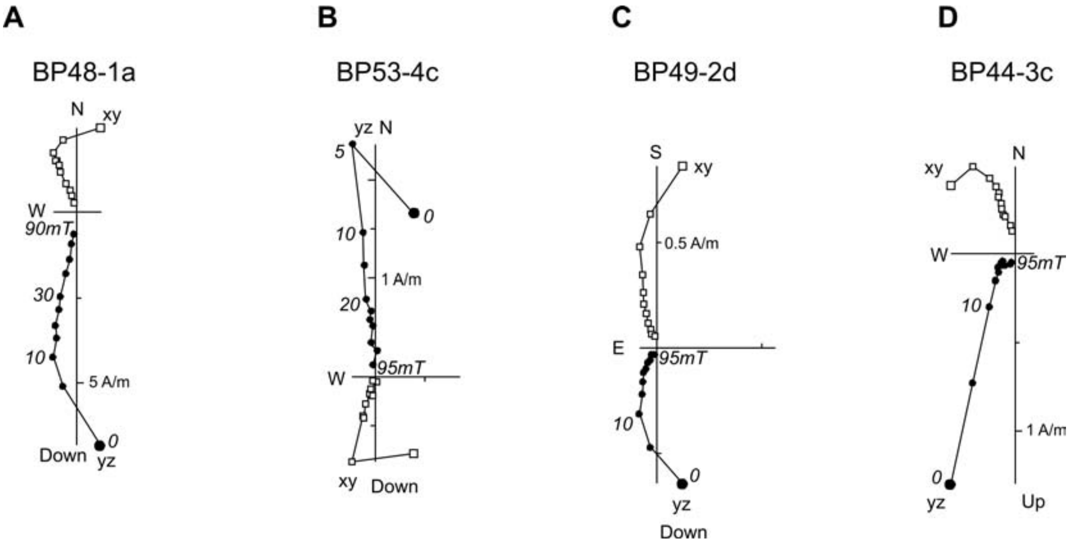

Fig. 14. Orthogonal projections of typical AF demagnetization paths. xy – horizontal plane projection; yz – vertical plane projection; (a) site BP-48C, normal polarity; (b) site BP-53D, reversed polarity; (c) – site BP-49, intermediate direction of undefined polarity; (d) site BP-44B, intermediate direction of undefined polarity

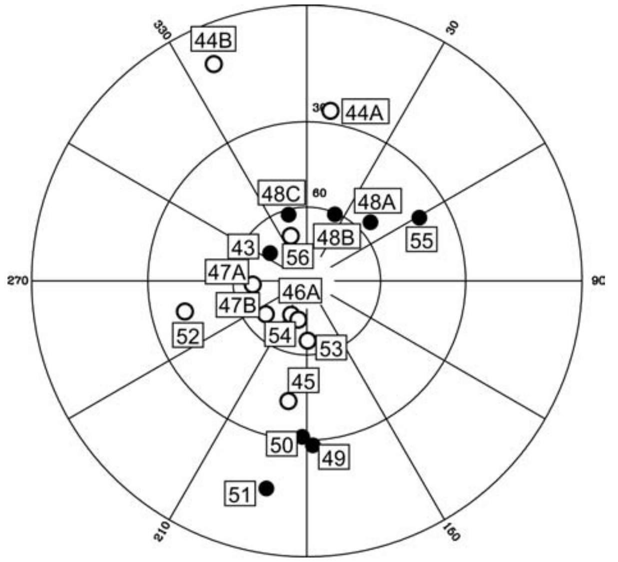

Fig. 15. Stereographic projection of site- and locality-mean directions. Open circles – upper hemisphere projection; full circles – lower hemisphere projection

polarity results from sites BP-45, BP-46, BP-53 (Fig.14B), and BP-54. Characteristic magnetizations at other sites were divergent from Neogene geomagnetic dipole field: these directions were interpreted as virtual magnetizations, *i.e.* acquired during an intermediate (anomalous) position of geomagnetic dipole during inversion or geomagnetic excursion. This concerns especially sites BP-44 (Fig. 14D) and BP-49–51 (Fig. 14C).

Magnetizations in basaltic flows of the same age correlate over long distances and might be used as stratigraphic markers (*e.g.*, Coe *et al.*, 2005). Based on this assumption, basalts from sites BP-49–51 might be interpreted as the same volcanic event. Indeed, K-Ar dates from sites BP-49 and BP-51 overlap within the error limit.

Discussion: magnetostratigraphy

Integration of magnetostratigraphy and K-Ar dating gives an unique opportunity to verify the reliability of both methods. In case of samples BP-53A-E, which were collected from the same lava flow, consistent reversed magnetization was revealed in all of them (Table 5). However, the K-Ar dates obtained from these samples were spread between 31.9 (±1.2) and 24.8 (±0.9) Ma (Table 5; Fig. 11A), *i.e.* over a time span that considerably exceeded the analytical errors of the radiometric method applied. The mean age from five measurements, 27.3±1 Ma, falls at the close of the reversed Odra Event (Fig. 11A).

It thus appears that analytical error for a single K-Ar dating is underestimated. As can be seen from results obtained at site BP-53, it amounts to 3.0–3.5 Ma. Therefore, for comparison with the global polarity time scale, mean ages were calculated for those sites where more than one K-Ar data was available (*i.e.*, BP-53, BP-57, BP-58, and BP-56 – see Fig. 11). This approach seems justified since all samples from these sites revealed the same polarity (BP-47 and 53 – reversed; BP-48 – normal).

Mean date from BP-47 (29.4±1.1 Ma) is concordant with the beginning of the Odra Event (Fig. 11B), while that from BP-48 falls in the middle part of the Gracze Event (25.9±1 Ma – see Fig. 11C). Additionally, mean age was calculated also for site BP-56, where only a single palaeomagnetic result was obtained (Fig. 11D): it agrees with the Odra Event.

Most of the intrusions studied are of Oligocene age (Fig. 12). The overall pattern of predominantly normal polarity of younger intrusions (Gracze Event), and reversed polarity of older intrusions (Odra Event), was confirmed. The most abundant were reversed polarity intrusions aged between 27.3±1.2 Ma (BP-51) and 29.4±1.1 Ma (BP-47 and 54). Together with dates obtained in our previous studies (Birkenmajer *et al.*, 2002b, 2004, 2007), they constitute an almost continuous data set divided by only one entry of normal polarity (BP-34). Within the error limit, they might represent a single volcanic phase – the Odra Event as defined by Birkenmajer *et al.* (1977). Its mean age would be 28.2± 1.2 Ma, which is close to the Early/Late Oligocene boundary (after Gradstein *et al.*, 2004). When compared to GPTS, it might be correlated with magnetozones C9r or C10r.

Two normal polarity intrusions, BP-48 and BP-55, might be assigned to the Gracze Event (as defined by Birkenmajer *et al.*, 1977). Its mean age amounts to 26.28±1.08 Ma, which might correspond to magnetozone C8n in the middle part of the Late Oligocene.

Two dates obtained at sites BP-43 and BP-52 fall within the latest Oligocene, close to the Oligocene/Miocene boundary (Fig. 13). They plot between the Gracze and Jawor events (as defined by Birkenmajer *et al.*, 1977), in the interval with relatively few datings, that might indicate decrease in volcanic activity (Pécskay *et al.*, 2004).

CONCLUSIONS

(1) Considering the geological age-ranges and spatial distribution of our K-Ar-dated Oligocene and Miocene basaltoid rocks in Lower Silesia, we could not discern signs of a preferential younging of volcanism in any particular geographic direction.

(2) There seems also to be no preferential pattern in changes of geochemical composition of these volcanics, both stratigraphically and/or areally.

(3) Palaeomagnetic investigations generally confirm the existence of a volcanic episode of reversed polarity close to the Early/Late Oligocene boundary. This episode was distinguished by Birkenmajer *et al.* (1977) as the **Odra Event** (see also Birkenmajer *et al.*, 2004, 2007). Its mean age might be estimated at 28.2±1.2 Ma.

(4) Another volcanic episode of normal polarity occurred during the Late Oligocene. It was distinguished by Birkenmajer *et al.* (1977) as the **Gracze Event** (see also Birkenmajer *et al.*, 2004, 2007). Its mean age might be estimated at 26.28±1.8 Ma.

(5) We do not imply that the Gracze and Odra events were two separate phases of volcanic activity. This activity might have been continuous throughout two or more polarity zones. However, as real error of K-Ar dating of our Oligocene volcanic samples might be as high as 3 Ma (see above), we decided to keep the divisions of Birkenmajer et al. (1977) until more precise radiometric data will be available.

(6) A multiple palaeomagnetic-radiometric sample investigations at site BP-53 (Zaręba) have revealed that a real error in K-Ar dating of the Neogene volcanics at this site might amount to 3–3.5 Ma. This suggests that more palaeomagnetic and radiometric investigations should be performed at this site to obtain a reliable dispersal of data.

(7) The basaltoid volcanics acquired their magnetization in the course of rapid cooling. Therefore, "intermediate" magnetizations from the time of magnetic reversals were usually preserved. In such cases, anomalous magnetizations might be treated as a stratigraphic tool to correlate the same lava flows over a considerable distance.

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