

RADIOMETRIC DATING OF THE TERTIARY VOLCANICS IN LOWER SILESIA, POLAND. IV. FURTHER K-Ar AND PALAEO-MAGNETIC DATA FROM LATE OLIGOCENE TO EARLY MIOCENE BASALTIC ROCKS OF THE FORE-SUDETIC BLOCK

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Abstract: The Tertiary volcanic rocks of the Fore-Sudetic Block (FSB), Lower Silesia (Poland), exposed between Strzelin in the east and Legnica in the west, typically represent within-plate basalts. Petrologically, they consist mainly of alkali basalts, basanites, tephrites and ankaratrites. 16 new K-Ar dates are recorded, spanning the Oligocene (31 Ma) through Early Miocene (Burdigalian c. 18 Ma) time. The majority of these K-Ar dates plot around two significantly different ages: 27 ± 1.5 Ma, and 20 ± 1.5 Ma. They indicate the presence in the FSB of two distinct separate phases of Tertiary vulcanicity: (i) the *first phase*, mainly Late Oligocene (Chattian), with a peak at c. 27; (ii) the *second phase*, Early Miocene (Aquitani–Burdigalian), with a peak at about 20 Ma. These phases seem to be separated by a gap in vulcanicity about 3 Ma long at the Oligocene/Miocene boundary.

Correlation of K-Ar-dated volcanic activity in the FSB with specific radiometrically-dated polarity intervals, poses some problems, and cannot be regarded definite at this stage of investigations. Considering the whole set of K-Ar and palaeomagnetic data from 40 sites, between the Opole area in the east and the Legnica area in the west, we suggest that volcanism of the *first phase* (Oligocene), although significantly spread out in time across multiple reversals, took place mostly during two well-defined, previously recognized events: (i) an older, reversed *Odra event* (within the C9r chron: 28.1 ± 1.2 Ma); and (ii) a younger, normal *Gracze event* (within the C8n chron: 26.5 ± 1.1 Ma). The *second phase* (Early Miocene) volcanism includes mainly a continuous set of reversely magnetized sites (mostly a single reversed C6r chron: 20.5 ± 0.87 Ma).

Key words: K-Ar dating, basaltic rocks, palaeomagnetism, Late Oligocene, Early Miocene, Lower Silesia, Poland.

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INTRODUCTION

The present paper is the fourth contribution to a geo-chronological study of the Tertiary basaltic rocks in Lower Silesia, Poland. These volcanics belong to the eastern branch of the Bohemo-Silesian volcanic belt, part of the Central European Tertiary volcanic province (Fig. 1). Together with the Early Miocene basaltic sites near Jawor and

Złotoryja elaborated previously (Birkenmajer *et al.*, 2000b), they are located in the Fore-Sudetic Block which was down-thrown along the Marginal Sudetic Fault with respect to the Sudetic Mts Block (Fig. 2). Sixteen K-Ar dates have been obtained from 12 volcanic sites situated between Strzelin in the east, and Legnica in the west.

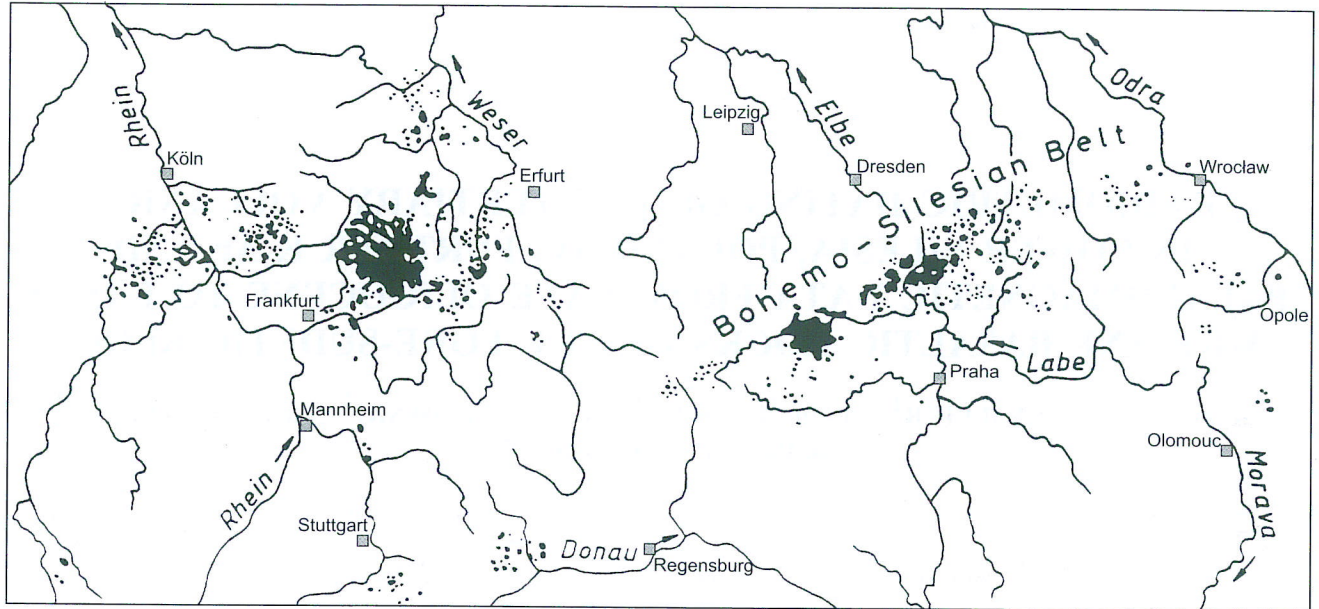


Fig. 1. Basaltic volcanics of the Bohemo-Silesian Belt in Central European Tertiary volcanic province (simplified from Kopecký, 1966)

The geochronological study reported here is a result of bilateral co-operation between the Polish Academy of Sciences (Institute of Geological Sciences, Cracow Research Centre) and the Hungarian Academy of Sciences (Institute of Nuclear Research, Debrecen), which began in 1998 aiming at K-Ar dating of the Polish Tertiary volcanics (Birkenmajer & Pécskay, 1999, 2000). Since 2000, it has been extended towards a systematic K-Ar age determination of the Tertiary basaltic rocks in Lower Silesia. The following occurrences of basaltic rocks have so far been elaborated: (I)

The Late Oligocene basaltic plugs and lavas of the Opole area, Sudetic Foreland (Birkenmajer & Pécskay, 2002); (II) The Neogene basanite plug (Messinian/Zanclean) and lava flows (Zanclean) of the Łądek Zdrój area, Sudetes Mountains (Birkenmajer *et al.*, 2002a); (III) The Early Miocene basaltic plugs and lavas in the vicinity of Jawor and Złotoryja, Fore-Sudetic Block (Birkenmajer *et al.*, 2002b).

Since 2001, a palaeomagnetic sampling programme supplements geochronological study of the Lower Silesian Tertiary basaltic rocks, involving the Polish Geological In-

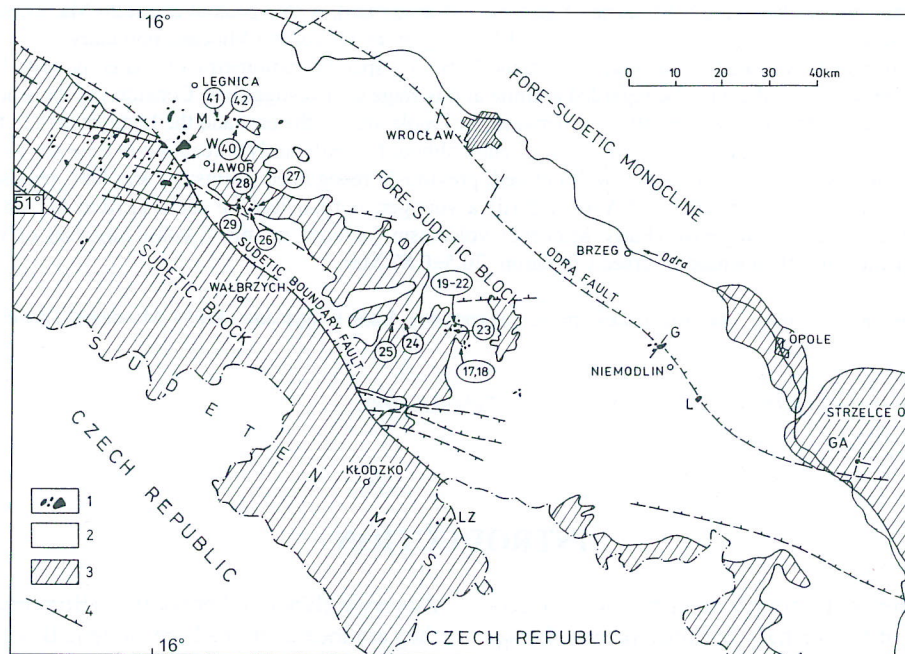


Fig. 2. Location of basaltic sampling sites in simplified geological map of Lower Silesia, Poland. 1 – Tertiary basaltic rocks; 2 – Cenozoic sedimentary cover; 3 – pre-Cenozoic rocks; 4 – major Tertiary faults; G – Gracze; GA – Góra św. Anny; L – Ligota Tułowicka; LZ – Łądek Zdrój; M – Męcinka; W – Winna Góra (= Winnica); circled – numbers of sites (BP) discussed in the present paper

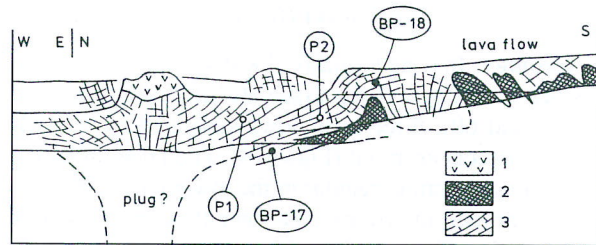


Fig. 3. Targowica quarry (sites BP-17, 18). 1 – top lava (not investigated); 2 – inter-flow volcanic breccia and red scoria; 3 – basanite lava flow passing northwards into ?plug. Height of the outcrop, c. 25 m (left side)

stitute in Warsaw (see Birkenmajer *et al.*, 2002a, b). It aims at refining and revising palaeomagnetic data from these rocks published earlier (e.g., Birkenmajer & Nairn, 1969; Birkenmajer *et al.*, 1970, 1977; Kruczyk *et al.*, 1977, and references therein).

GEOLOGICAL SETTING

In the area of the Fore-Sudetic Block (FSB), there are numerous exposures of the Tertiary basaltic rocks, mainly plugs and lava flows (see Berg, 1930; Wojno *et al.*, 1951; Jerzmański, 1956, 1961, 1965; Jerzmański & Maciejewski, 1968; Birkenmajer, 1967; Śliwa, 1967; Birkenmajer & Nairn, 1969; Birkenmajer *et al.*, 1970; Wójcik, 1973; August *et al.*, 1995). The volcanic rocks dealt with in the present paper are usually well exposed in working and/or abandoned quarries, some also in natural exposures.

SAMPLING DATA

STRZELIN AREA

Targowica (BP-17, 18)

Geology. Two lava flows are exposed in a large working quarry. They dip gently (10–20°) due north, and are separated from one another by volcanic breccia and red scoria (Fig. 3). In northern part of the quarry, arrangement of thermal columnar jointing in the basalt is suggestive of a volcanic plug.

Sampling. Samples for K-Ar dating BP-17 and BP-18 were collected in southern part of the quarry, from the lower (BP-17), and the upper (BP-18) flows, respectively (Fig. 3). Samples for palaeomagnetic investigations were collected from the upper lava flow and from associated plug-like basaltic structure (see Fig. 3).

Petrology and geochemistry. These rocks have previously been described as: plagioclase basalt or trachybasalt (Wojno *et al.*, 1951; Birkenmajer *et al.*, 1970: site 58), or nephelinite-normative basalts (Kozłowska-Koch, 1987), or olivine basalts (August *et al.*, 1995). Our petrological study indicates that the lower and upper lava flows differ in their mineral and chemical composition.

Table 1

Chemical composition of Tertiary basaltoid rocks from the Strzelin area (sites BP-17–23), Lower Silesia. Analysed at the Chemistry Laboratory of the Polish Geological Institute, Warsaw (Project No 6.20.1719.00.0)

	BP-17	BP-18	BP-19	BP-20	BP-21	BP-22	BP-23
%							
SiO ₂	44.18	42.83	38.73	38.96	38.90	38.25	38.03
TiO ₂	2.63	3.10	2.68	2.64	2.67	2.68	2.71
Al ₂ O ₃	14.69	14.69	12.29	12.08	12.19	12.10	11.86
Fe ₂ O ₃	12.24	12.79	13.14	12.91	13.08	13.15	13.12
MnO	0.18	0.17	0.21	0.20	0.21	0.21	0.21
MgO	9.73	9.40	12.95	12.97	13.10	13.06	13.02
CaO	10.08	10.15	12.91	12.88	12.89	13.35	13.50
Na ₂ O	3.29	3.36	3.32	3.07	3.04	2.91	2.79
K ₂ O	1.01	1.27	0.81	0.72	0.89	0.85	0.86
P ₂ O ₅	0.55	0.73	0.97	0.96	0.97	0.96	1.02
SO ₃	0.01	0.02	0.04	0.04	0.05	0.02	0.03
Cl	0.08	0.08	0.03	0.03	0.03	0.03	0.04
F	0.06	0.03	0.06	0.10	0.03	0.06	0.08
LOI	1.02	1.09	1.44	2.03	1.59	1.94	2.30
SUM	99.74	99.70	99.57	99.60	99.55	99.57	99.58
ppm							
As	<3	<3	4	4	4	<3	<3
Ba	490	656	614	588	726	675	605
Bi	<3	4	<3	<3	<3	<3	<3
Ce	57	83	116	120	130	124	121
Co	53	65	56	56	64	67	55
Cr	273	226	403	412	469	440	373
Cu	40	44	73	74	77	74	72
Ga	20	23	18	18	18	18	18
Hf	4	6	8	8	8	6	5
La	34	49	59	63	67	74	66
Mo	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Nb	54	66	89	88	87	88	93
Ni	138	131	276	275	281	276	174
Pb	<3	3	45	11	<3	<3	19
Rb	32	46	34	25	22	29	38
Sr	594	748	1020	1100	1196	1241	1110
Ta	4	3	7	5	5	4	5
Th	7	8	8	10	9	8	9
U	3.0	4.2	3.3	4.0	3.8	4.4	4.2
V	219	238	225	223	242	230	209
W	<5	<5	142	<5	<5	<5	<5
Y	31	32	32	32	31	31	34
Zn	115	127	121	120	117	114	117
Zr	232	291	309	309	312	315	324
Ti/Y	508.6	580.8	502.1	494.6	516.4	518.3	477.8
Zr/Y	7.48	9.09	9.66	9.66	10.06	10.16	9.53
R1	1165	964	814	946	908	918	944
R2	1849	1841	2265	2259	2269	2314	2323

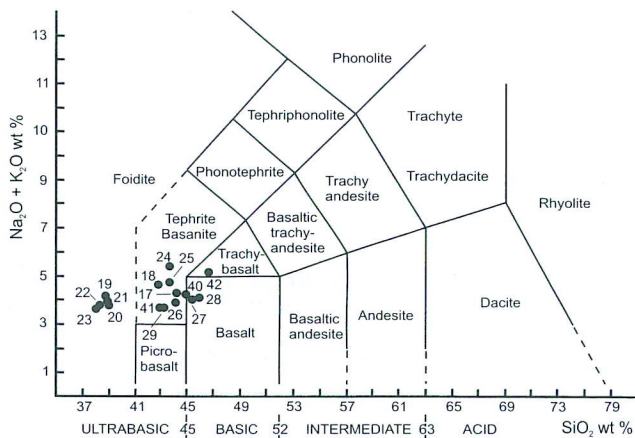


Fig. 4. Plot of Tertiary basaltoid rock samples from the Fore-Sudetic Block dealt with in the present paper, in the TAS classification diagram

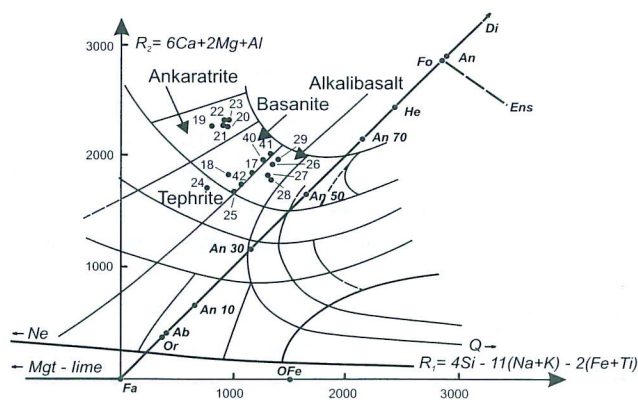


Fig. 5. Plot of Tertiary basaltoid rock samples from the Fore-Sudetic Block dealt with in the present paper, in the R1-R2 classification diagram of de la Roche *et al.* (1980)

The *lower lava flow* (BP-17) is nearly black in colour. It is very fine-grained, porphyritic, its phenocrysts usually do not exceed 0.5 mm (sometimes 1.5 mm) in size. Flow structure is well accentuated by arrangement of plagioclase plates. The groundmass is composed of very fine fresh plagioclase (labradorite An₅₀₋₅₅) showing distinct albitic twins, and of fine pyroxene. Opaque minerals (iron-oxides) are dispersed in the groundmass. Olivine phenocrysts display irregular cracks filled with secondary minerals of serpentine group. Pyroxene (augite) phenocrysts, sometimes twinned, are common.

The *upper lava flow* (BP-18) is a dark-grey fine-grained basaltic rock without flow structure. Its groundmass composition does not differ from that of the lower lava flow. Olivine is a dominant phenocryst, its microcracks being filled with minerals of serpentine group. Pyroxene phenocrysts are rare.

The mineral and chemical composition of these rocks (Tab. 1), interpreted according to the IUGS standard of igneous rocks systematics (Le Bas & Streckeisen, 1991) permit to classify them as basanites; in the case of sample BP-17, the rock is closer to alkali basalt (Figs 4, 5).

Janowiczki (BP-19-22)

Geology. In a new quarry, located east of the Kowalskie-Żelowice I and II sites (see Birkenmajer *et al.*, 1970, sites 59 and 60), three lava flows separated by inter-flow volcanic breccia crop out (Figs 6–8). The lavas show vertical columnar jointing, regular in the lower part of the flows, less regular near their tops. The inter-flow breccias consist of yellowish tuff-like rock and lava fragments. In southern and western parts of the quarry, the first lava flow comes in direct contact with metamorphic basement (Fig. 8B) which consists of weathered white to yellowish quartzite and red-and-yellowish sericite schist – probably the Devonian Jęglowa quartzite.

Sampling. Samples BP-21 and 22 have been collected from the first lava flow, sample BP-19 from the second lava



Fig. 6. Janowiczki quarry, northern part: second (BP-19) and third ankartrite lava flows (cf. Fig. 7)

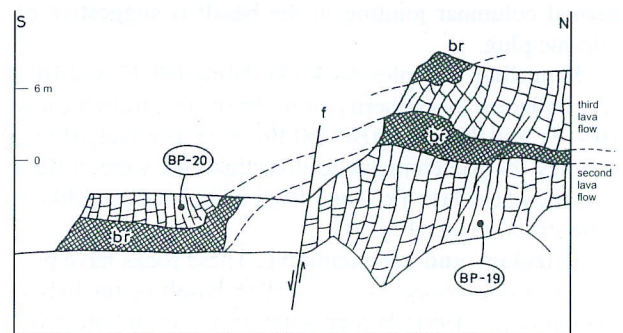


Fig. 7. Janowiczki quarry, second (BP-19) and third ankartrite lava flows (cf. Fig. 7, right side). br – inter-flow volcanic breccia; f – fault downthrowing to the south

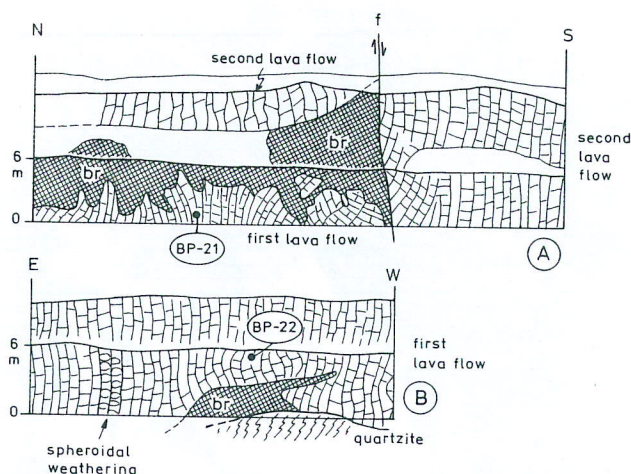


Fig. 8. Janowiczki quarry, first (BP-21, 22) and second ankara-trite lava flows. br – inter-flow volcanic breccia

flow, sample BP-19 – from the third lava flow (see Figs 7, 8). Six samples for palaeomagnetic dating were collected: JAN 1 and JAN 2 were taken at site BP-19; JAN 3 and JAN 4 – at site BP-20; JAN 5 – at site BP-21; JAN 6 – at site BP-22.

Petrology and geochemistry. These lava flows are devoid of flow structure. The rocks are dark-grey to almost black, very fine-grained, with groundmass consisting of nepheline and partly chloritized glass, moreover of numerous opaque minerals, mainly iron-oxides. Among phenocrysts, olivine (<1.00 mm in size) is a dominant one. Its crystals are somewhat altered, with secondary minerals of serpentine group filling micro-cracks; other alterations consist in carbonatization and crystallization of secondary talc. Small nepheline and pyroxene phenocrysts are subordinate. The pyroxene (Ti-augite, $z/\gamma = 38^\circ$) is commonly twinned, showing typical zonal and hourglass structures.

Previously, the rocks exposed at Janowiczki had been described as nepheline basalt (Wójcik, 1973). Our investigations show that the lava flows represent ankara-trite, i.e. olivine mela-nephelinite – a variety of foidite (see Tab. 1; Figs 4, 5).

Kowalskie-Żelowice (BP-23)

Geology. This is a volcanic plug showing thick vertical columns (Birkenmajer *et al.*, 1970: site 60, Kowalskie-Żelowice II), presently poorly exposed in an abandoned quarry strongly overgrown with vegetation. (N.B.: Site 59, Kowalskie-Żelowice I, of Birkenmajer *et al.*, 1970, is not exposed any more.) The country rocks are represented by metamorphic rocks belonging to thermal aureole of the Variscan Strzegom granite.

Sampling. Sample BP-23 for K-Ar dating and two samples for palaeomagnetic investigations (KŻ 1, 2, taken at a 30 cm distance) were collected in southern part of the abandoned quarry.

Petrology and geochemistry. The rock was previously determined as nephelinite (Wojno *et al.*, 1951; see also

Birkenmajer *et al.*, 1970: site 60). The results of new petrological and chemical studies are, however, not consistent. The rock is black, very fine-grained, with porphyritic structure visible only under microscope. Very fine groundmass consist of plagioclase plates too small to be identifiable using optical methods, moreover of glass and isotropic opaque minerals. Phenocrysts are rare, small (<1.0 mm in size): fresh Ti-augite ($z/\gamma = 38^\circ$) showing typical twins and hourglass structure; olivine exhibits irregular network of cracks filled with secondary minerals of serpentine group (sometimes, the olivine is totally replaced by secondary serpentine); nepheline is rare.

Following the results of microscopic observation, our rock could be classified as basalt or nepheline basalt. However, graphic interpretation of its chemical composition (see Tab. 1), places it within the foidite (see Fig. 4), resp. ankara-trite (see Fig. 5) fields.

NIEMCZA AREA

Gilów I (BP-24)

Geology. This is a basaltic rock, probably lava flow (previously considered to be a volcanic plug – Birkenmajer, 1967; Śliwa, 1967), very poorly exposed in an abandoned quarry on a hill (Butterberg on German maps) overgrown with vegetation (Gilów I, site 61 in Birkenmajer *et al.*, 1970). Country rocks are represented by gneisses of the Sowie Góry Mts.

Sampling. Due to the lack of suitable *in situ* rock exposures, sample BP-24 for K-Ar dating was taken from a large loose basaltic block.

Petrology and geochemistry. The rock was previously determined as plagioclase basalt (Wojno *et al.*, 1951; see also Birkenmajer *et al.*, 1970, site 61). The rock is nearly black, very fine-grained, showing porphyritic texture, with flow structure marked in arrangement of platy minerals. Its groundmass consists of very fine plagioclase (andesine An₅₀) plates, with small amount of glass between them. Isotropic grains of iron oxides are dispersed in the groundmass. Phenocrysts are very small (0.3–0.5 mm in size): they are mainly represented by pyroxene (Ti-augite) showing distinct twinning and zonal structure, sometimes with hourglass structure (Fig. 9); less common olivine is surrounded by red iddingsite rims and cut by irregular cracks filled with some isotropic minerals.

Mineral and chemical composition (Tab. 2) of the rock are not consistent with its graphic representation (see Figs 4, 5): the rock thus seems to be tephrite, rather than basanite.

Gilów II (BP-25)

Geology. This is a volcanic vent or a shallow part of a plug, previously well exposed in an abandoned quarry (see Birkenmajer, 1967, figs 32, 33; Gilów II, site 62 in Birkenmajer *et al.*, 1970). Presently, there is only a very poor exposure of basaltic rock in bottom part of the old quarry covered with vegetation. Country rocks are represented by gneisses of the Sowie Góry Mts.

Table 2

Chemical composition of Tertiary basaltoid rocks from the Niemcza area (sites BP-24, 25), Lower Silesia. Analysed at the Chemistry Laboratory of the Polish Geological Institute, Warsaw (Project No 6.20.1719.00.0)

	BP-24	BP-25
%		
SiO ₂	43.65	43.66
TiO ₂	3.11	3.12
Al ₂ O ₃	15.09	15.04
Fe ₂ O ₃	12.55	12.48
MnO	0.17	0.18
MgO	8.81	8.14
CaO	9.22	9.21
Na ₂ O	3.97	3.34
K ₂ O	1.43	1.38
P ₂ O ₅	0.68	0.67
SO ₃	0.02	0.02
Cl	0.14	0.11
F	0.03	0.09
LOI	0.84	2.26
SUM	99.72	99.71
ppm		
As	3	4
Ba	590	485
Bi	<3	<3
Ce	74	72
Co	57	41
Cr	191	162
Cu	46	47
Ga	24	25
Hf	10	9
La	48	36
Mo	<2.0	<2.0
Nb	60	61
Ni	142	150
Pb	<3	<3
Rb	43	43
Sr	746	773
Ta	4	<3
Th	7	7
U	3.8	2.5
V	214	178
W	<5	<5
Y	37	38
Zn	139	144
Zr	369	374
Ti/Y	503.9	492.2
Zr/Y	9.97	9.84
R1	770	1008
R2	1720	1684



Fig. 9. Gilów I (BP-24), tephrite plug. Hourglass pyroxene, crossed polarizers

Sampling. Sample BP-25 for K-Ar dating, and one palaeomagnetic sample (G 1), were collected in the lowest part of the abandoned quarry (Fig. 10).

Petrology and geochemistry. Previously, the rock was determined as plagioclase basalt (Wojno *et al.*, 1951; Birkenmajer *et al.*, 1970, site 62). This is an almost black fine-grained rock similar to that of site BP-24. Its groundmass is composed of fine plagioclase (labradorite An₅₀₋₅₅) plates showing very distinct albitic twins. Fresh olivine (0.4–0.7 mm in size) is a dominant phenocryst. Fresh pyroxene (Ti-augite) phenocrysts are smaller and less common than the olivine ones.

Mineral and chemical (see Tab. 2) composition of the rock in graphic presentation correlates with basanite field (see Figs 4, 5).

STRZEGOM AREA

Strzegom III (BP-26)

Geology. Exposures of basaltic rock showing columnar (columns 0.5–1.5 m in diameter) and platy jointing are in a large abandoned quarry, its lower level being filled with water (Figs 11, 12). Originally, the site was considered to represent a volcanic plug (Birkenmajer, 1967, fig. 14). How-

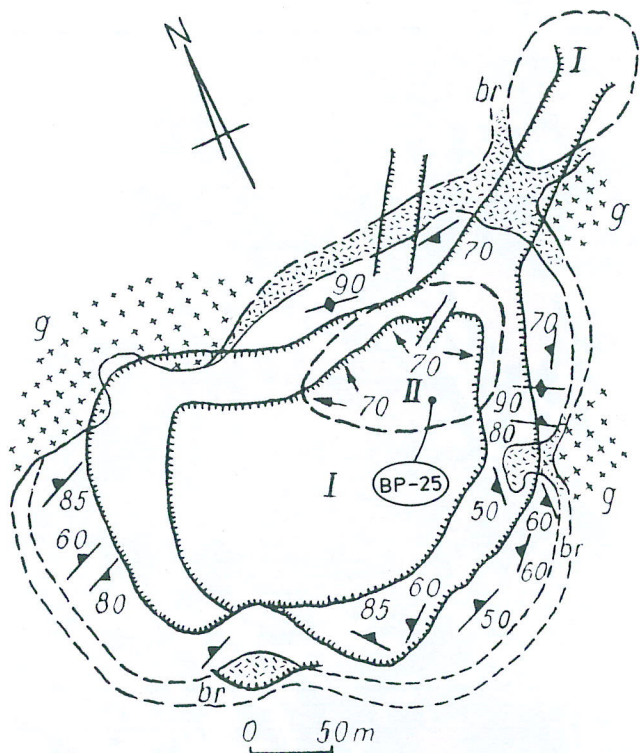


Fig. 10. Gilów II (BP-25), basanite plug (after Birkenmajer, 1967). I, II – two telescoping parts of plug; br – contact breccia; g – Precambrian gneiss; strike/dip signs refer to jointing pattern in the plug

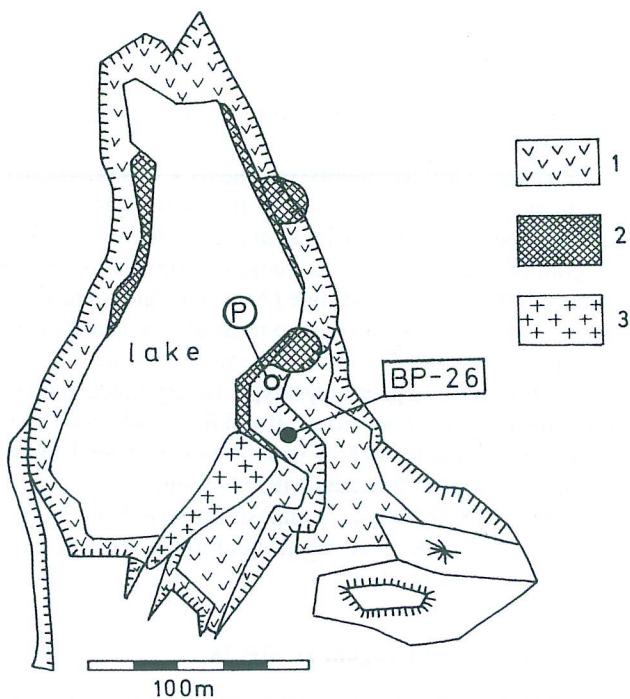


Fig. 11. Strzegom III (Żółkiewka, BP-26), sketch of abandoned quarry (modified from Zagożdżon, 2001). 1 – alkali basalt lava flow; 2 – tuff and volcanic breccia; 3 – granite; location of samples for K-Ar dating (BP-26) and palaeomagnetic study (P) is shown

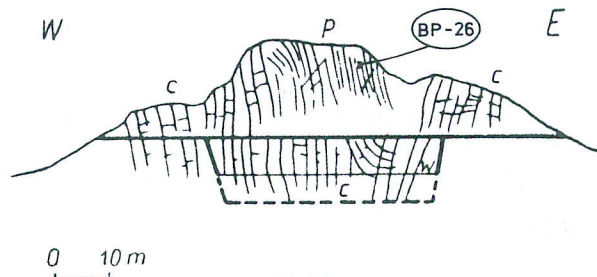


Fig. 12. Strzegom III (Żółkiewka, BP-26), alkali basalt flow. Schematic cross-section of the exposure showing location of sample for K-Ar dating (BP-26); c – columnar jointing; p – platy jointing; w – water table

ever, fluidal structures recognizable in some parts of the exposure are suggestive of lava flow (see also Kural, 1982). Red volcanic breccias exposed in northern part of the quarry (at upper exploitation level), probably represent vertical explosion pipes which cut through the lava flow. Country rocks are represented by the Variscan Strzegom granite.

Sampling. Sample BP-26 (for K-Ar dating), and a sample for palaeomagnetic study (STR 1), were collected in north-eastern part of the abandoned quarry (Figs 11, 12).

Petrology and geochemistry. The rock was previously determined as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951; see also Strzegom III, site 11 in Birkenmajer *et al.*, 1970). It is black in colour, very fine-grained, showing fluidal structure expressed by arrangement of elongated groundmass minerals and by rare, very small phenocrysts. The groundmass consists of fresh fine plagioclase plates (labradorite, An₅₅₋₆₀) and equally fine fresh pyroxene (augite) grains. Opaque minerals, mainly iron-oxides, are dispersed in relatively large amount within the groundmass. Small, fresh olivine grains (0.3–0.8 mm in size) dominate among phenocrysts; even smaller, also fresh pyroxene (augite) phenocrysts show very clear zonal structure.

Chemical composition of this rock (Tab. 3) when plotted on classification diagrammes (see Figs 4, 5) indicates that sample BP-26 is an alkali basalt with some characteristics of basanite.

Strzegom I (BP-27)

Geology. The site – Krzyżowa Góra hill (Kreuzberg in German maps; site 9 – Strzegom I, in Birkenmajer *et al.*, 1970), is located at western outskirts of Strzegom town. Our observations made in an abandoned quarry nearby, and at the hill, indicate that we deal here with a vertical basaltic dyke several hundred metres long and 10–20 m thick. The dyke extends in a W–E direction and shows two systems of thermal jointing: a curvilinear/platy one (every 3–50 cm) is transverse to dyke elongation, a platy jointing (every 1–5 cm), is parallel with the dyke margin. The dyke cuts the Variscan Strzegom granite (its weathered exposures are visible some 20 m to the north of the dyke, and in the abandoned quarry).

Sampling. Sample BP-27 for K-Ar dating (west of the cross), and samples for palaeomagnetic study (KG 1 – c. 18 m west of the cross; KG 2 – 12 m west of the cross), have

Table 3

Chemical composition of Tertiary basaltoid rocks from the Strzegom area (sites BP-26–29), Lower Silesia. Analysed at the Chemistry Laboratory of the Polish Geological Institute, Warsaw (Project No 6.20.1719.00.0)

	BP-26	BP-27	BP-28	BP-29
%				
SiO ₂	44.14	45.88	45.35	43.20
TiO ₂	2.26	2.10	2.38	2.45
Al ₂ O ₃	15.89	15.43	15.89	13.62
Fe ₂ O ₃	11.20	11.46	11.52	11.28
MnO	0.18	0.17	0.16	0.18
MgO	10.44	9.90	8.07	11.50
CaO	10.22	9.74	10.13	10.63
Na ₂ O	2.87	3.23	3.16	2.24
K ₂ O	1.01	0.88	0.83	1.44
P ₂ O ₅	0.41	0.35	0.42	0.62
SO ₃	<0.01	<0.01	<0.01	0.02
Cl	0.08	0.06	0.05	0.08
F	<0.01	0.07	0.05	0.03
LOI	1.02	0.50	1.76	2.36
SUM	99.74	99.77	99.74	99.63
ppm				
As	<3	<3	<3	4
Ba	123	254	191	367
Bi	<3	<3	<3	3
Ce	44	38	37	75
Co	23	46	25	37
Cr	308	486	356	374
Cu	40	27	40	46
Ga	21	20	19	18
Hf	5	6	3	7
La	22	19	23	41
Mo	<2.0	<2.0	<2.0	<2.0
Nb	33	33	32	72
Ni	151	109	157	219
Pb	<3	6	<3	4
Rb	33	28	26	55
Sr	516	480	493	924
Ta	3	<3	<3	6
Th	7	7	5	8
U	3.9	3.5	3.3	3.7
V	142	182	152	175
W	<5	<5	<5	7
Y	29	27	28	32
Zn	104	106	104	101
Zr	222	191	200	286
Ti/Y	467.2	466.3	509.6	459.0
Zr/Y	7.66	7.07	7.14	8.94
R1	1347	1316	1343	1400
R2	1923	1836	1796	1975

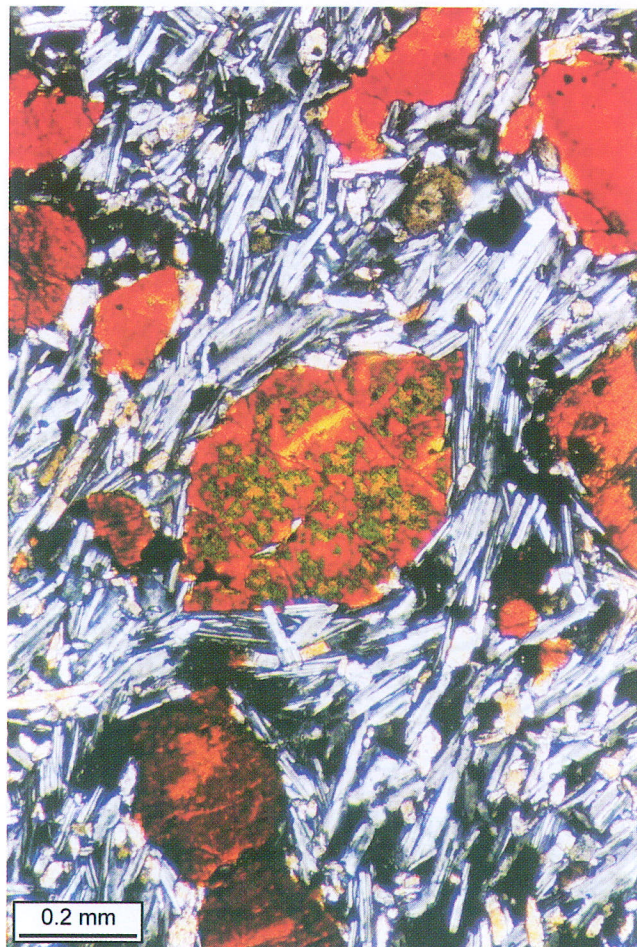


Fig. 13. Strzegom II (BP-28), alkali basalt lava flow. Iddingsite pseudomorphs after olivine

been collected from a good exposure of the rock at Krzyżowa Góra.

Petrology and geochemistry. The rock was previously determined as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951; see also Birkenmajer *et al.*, 1970, site 9). This is a fine-grained, porous porphyric rock, its groundmass being composed of fresh fine andesine (An₄₂₋₄₅) plates, and fresh augite ($z/\gamma = 42^\circ$) grains. Opaque minerals are nearly lacking, what results in grey colour of the rock. Olivine (0.3–0.5 mm in size), the only phenocryst type, is very much altered: red iddingsite forms rims around it and fills cracks within its crystals. Small aggregates of opaque minerals tend to locally appear close to the iddingsitized olivine.

Based on its chemical composition (see Tab. 3), the rock plots within the alkali basalt field in the classification diagrammes (see Figs 4, 5).

Strzegom II (BP-28)

Geology. The basaltic rock is poorly exposed in an abandoned quarry on the top of a hill (Georgen Berg in German maps) overgrown with forest, west of site Strzegom I. The rock shows columnar (columns 0.5–1.5 m in diameter), irregular or platy jointing. Previously, the site was consid-



Fig. 14. Mikołajowice (BP-40), basanite plug showing well developed vertical columnar jointing. Height of the outcrop ca. 20 m

ered to represent a plug (Birkenmajer *et al.*, 1970, site 10), the present observations suggest rather a lava flow. Country rocks are represented by the Variscan Strzegom granite.

Sampling. Sample for K-Ar dating (BP-28), and two samples for palaeomagnetic study (KG 3 and KG 4), were collected from an old quarry on top of the hill.

Petrology and geochemistry. The rock was previously determined as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951: see also Birkenmajer *et al.*, 1970, site 10), or as a nephelinite-normative basalt (Kozłowska-Koch, 1987). This is a grey rock showing porphyric texture and fluidal structure. Its groundmass is similar to that of BP-27, but its phenocrysts are different: red iddingsite pseudomorphs after olivine (0.4–0.8 mm in size) are dominant (Fig. 13); fresh plagioclase (labradorite, An₆₂; 0.5–1.0 mm in size) shows distinct albitic and periclinic twins and zonal internal structure; pyroxene (augite) phenocrysts are of similar size, showing distinct zonal structure displaying Fe-richer rims and Fe-poorer cores. As follows from its chemical composition (see Tab. 3), the rock should be classified as alkali basalt (see Figs 4, 5).

Żelazowa (BP-29)

Geology. Poor exposures of a basaltic rock showing columnar jointing (columns 10–50 cm in diameter), vertical or steeply dipping due north, are in abandoned quarries on the top of a forested hill to the north of the road leading from Strzegom to Rogoźnica (site of the infamous Grossrosen Nazi concentration camp). Its geological form is unknown: probably a plug (see also Kural, 1982). Country rocks are represented by the Variscan Strzegom granite.

Sampling. Sample for K-Ar dating (BP-29), and one sample for palaeomagnetic study (ZL 1), were collected from an abandoned quarry on top of the hill.

Petrology and geochemistry. The rock (determined as olivine basalt by Drozdowski and Mizerski, 1969 – *vide* Zagózdźon, 2001) is almost black in colour, very fine-grained, with porphyric texture and with very fine pores. Its groundmass consists of very fine plagioclase (unidentifiable with optical methods), pyroxene (augite) grains, and partly chloritized glass. Strongly altered olivine phenocrysts (<2.0 mm in size) are often surrounded by red iddingsite rims, sometimes by very fine pyroxene rims. Small (<1 mm in size) fresh Ti-augite ($z/\gamma = 44\text{--}48^\circ$) phenocrysts display distinct zonal structure. Single quartz grains with fine-grained pyroxene rims are present.

Based on its chemical characteristics (see Tab. 3), the rock should be classified as alkali basalt or basanite (see Figs 4, 5).

LEGNICA AREA

Mikołajowice (BP-40)

Geology. This is a basaltic plug (= site No 31 Mikołajowice I of Birkenmajer *et al.*, 1970) showing well developed vertical columns, exposed in working quarry (Fig. 14).

Sampling. Sample BP-40 for K-Ar dating was collected in eastern part of the quarry.

Petrology and geochemistry. This rock was previously described as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951), basalt (Birkenmajer *et al.*, 1970) or basanite (Kozłowska-Koch, 1987). It is black in colour, very fine-

Table 4

Chemical composition of Tertiary basaltoid rocks from the Legnica area (sites BP-40–42), Lower Silesia. Analysed at the Chemistry Laboratory of the Polish Geological Institute, Warsaw (Project No 6.20.1719.00.0)

	BP-40	BP-41	BP-42
%			
SiO ₂	44.91	42.95	46.71
TiO ₂	2.31	2.31	2.43
Al ₂ O ₃	12.30	12.34	14.79
Fe ₂ O ₃	12.23	12.17	11.75
MnO	0.18	0.17	0.18
MgO	11.52	12.58	8.63
CaO	10.87	10.85	9.59
Na ₂ O	3.06	2.54	3.93
K ₂ O	1.15	1.13	1.22
P ₂ O ₅	0.94	0.88	0.60
LOI	0.19	0.63	1.32
SUM	99.60	98.39	100.99
ppm			
As	3	4	4
Ba	522	554	575
Bi	<3	<3	<3
Ce	84	85	62
Co	48	51	43
Cr	453	454	378
Cu	69	72	29
Ga	18	18	20
Hf	5	6	6
La	36	43	36
Mo	<2.0	<2.0	<2.0
Nb	58	59	40
Ni	238	300	121
Pb	<3	<3	<3
Rb	38	38	40
Sr	744	809	614
Ta	<3	<3	<3
Th	7	9	9
U	3.8	3.5	4.5
V	179	187	162
W	<5	<5	<5
Y	25	27	31
Zn	94	91	95
Zr	264	258	288
Ti/Y	553.9	512.9	469.9
Zr/Y	10.56	9.56	9.29
R1	1271	1331	1074
R2	1976	2027	1744

grained, displaying porphyric texture. Its groundmass consists of fresh fine plagioclase (andesine, An₄₅₋₅₀) plates showing distinct albitic twins, fine fresh pyroxene (augite), small amount of glass, and numerous grains of opaque minerals (mainly iron-oxides). Phenocrysts consist of: dominant pyroxene (Ti-augite, $z/\gamma = 44-48^\circ$), its grains (1.0–1.5 mm in size) showing very distinct zonal internal structure; fresh olivine (<1.0 mm in size); sporadically also quartz surrounded by very fine-grained pyroxene rims.

Chemical analysis (Tab. 4) indicates that the rock corresponds to basanite (see Figs 4, 5).

Pawlowice (BP-41)

Geology. This is a basaltic plug with well developed vertical columns, strongly weathered in upper part (Birkenmajer, 1967, fig. 23; see also Birkenmajer *et al.*, 1970, site 30), exposed in an abandoned quarry. Country rocks are represented by terrestrial Tertiary deposits (without closer age determination).

Sampling. Sample BP-41 for K-Ar dating was collected in northern part of the quarry.

Petrology and geochemistry. The rocks was originally determined as plagioclase basalt with glass (Wojno *et al.*, 1951). Petrologically, it is very similar to that of site BP-40. Its chemical composition (see Tab. 4) indicates a basanite (see Figs 4, 5).

Lubień (BP-42)

Geology. This is a basaltic lava flow (site 29a, Lubień II of Birkenmajer *et al.*, 1970), exposed in abandoned quarry.

Sampling. Sample BP-42 for K-Ar dating was collected in southern part of the outcrop, from a loose block.

Petrology and geochemistry. Previously, the rock was determined as plagioclase basalt or trachybasalt (Wojno *et al.*, 1951; Birkenmajer *et al.*, 1970). The rock is dark-grey, fine-grained, displaying porphyric texture and fluidal structure. Its groundmass consists of fresh, very fine plagioclase (andesine, An₄₅) plates showing distinct albitic and pericline twins, very fine pyroxene (augite, $z/\gamma = 43^\circ$), pseudomorphs after olivine totally replaced by iddingsite, and grains of isotropic opaque minerals. Phenocrysts, maximum 1.5 mm in size, consist of olivine (presently: red iddingsite pseudomorphs) and pyroxene (Ti-augite, $z/\gamma = 45^\circ$). The latter shows distinct zonal structure with pleochroic (green) Fe-enriched outer zones, and contains numerous inclusions of minerals from the groundmass (plagioclase, olivine, opaque minerals).

Chemical analysis of the rock (see Tab. 4) indicates its attribution to basanite or trachybasalt (see Figs 4, 5).

EXPERIMENTAL METHODS IN K-Ar DATING

Sixteen samples were analysed by conventional K-Ar dating techniques, of which 11 were from lava flows, 4 from plugs and 1 from dyke. Analytical work has been carried out on whole-rock samples, the potassium and argon determina-

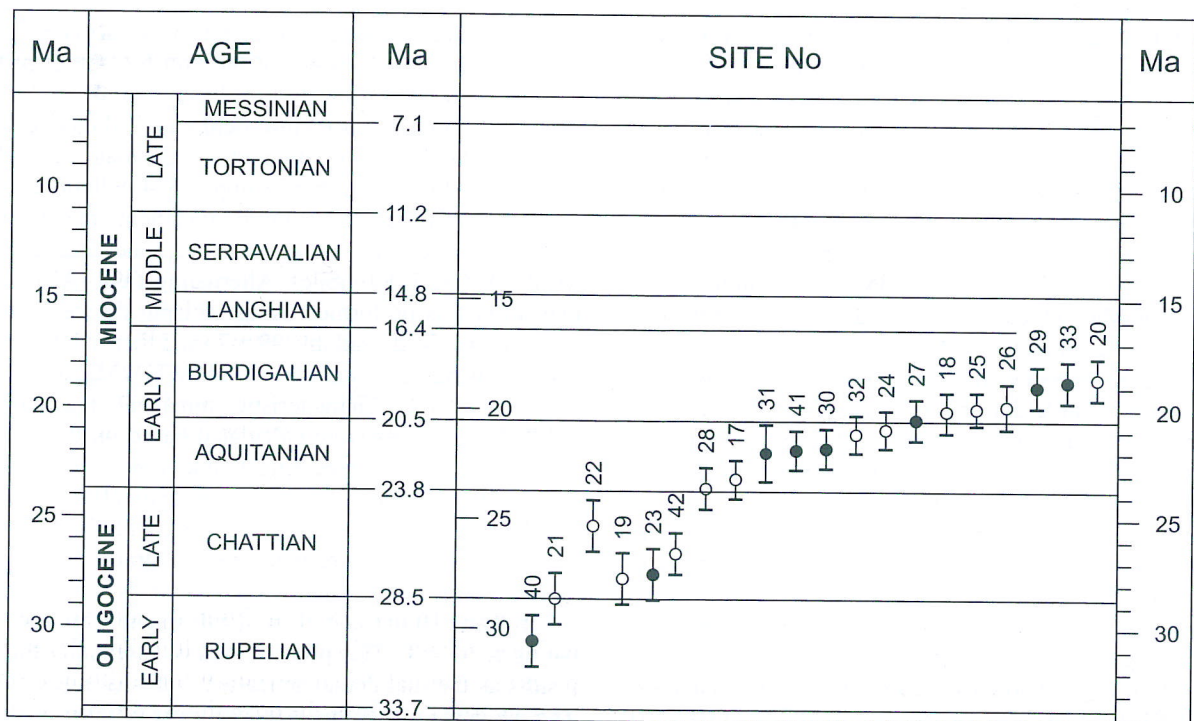
Table 5

Results of K-Ar dating of Tertiary basaltoid rocks from the Fore-Sudetic Block, Lower Silesia (performed at the Institute of Nuclear Research, Hungarian Academy of Sciences, Debrecen, ATOMKI). w.r – whole rock

K-Ar No	Sample No	Site	Geology	Dated fraction	K %	⁴⁰ Ar rad cc STP/g	⁴⁰ Ar rad %	K-Ar age Ma
5573	BP-17	Targowica	lower lava flow	w.r.	1.033	9.376×10^{-7}	75.30	23.20 ± 0.89
5574	BP-18		upper lava flow	w.r.	0.848	6.674×10^{-7}	47.5	20.13 ± 0.86
5575	BP-19	Janowiczki	second lava flow	w.r.	0.645	7.060×10^{-7}	53.30	27.94 ± 1.16
5576	BP-20		third lava flow	w.r.	0.597	4.325×10^{-7}	32.1	18.54 ± 0.96
5577	BP-21		first lava flow	w.r.	0.721	8.114×10^{-7}	66.6	28.72 ± 1.13
5578	BP-22		first lava flow	w.r.	0.656	6.501×10^{-7}	51.9	25.32 ± 1.06
5579	BP-23	Kowalskie-Żelowice	plug	w.r.	0.604	6.542×10^{-7}	37.3	27.65 ± 1.32
5580	BP-24	Gilów I	? lava flow	w.r.	1.250	1.022×10^{-6}	59.8	20.91 ± 0.84
5581	BP-25	Gilów II	plug	w.r.	1.199	9.369×10^{-7}	74.1	19.99 ± 0.77
5582	BP-26	Strzegom III	? lava flow	w.r.	0.821	6.367×10^{-7}	38.7	19.84 ± 0.93
5583	BP-27	Strzegom I	dyke	w.r.	0.594	4.737×10^{-7}	45.6	20.40 ± 0.89
5584	BP-28	Strzegom II	lava flow	w.r.	0.565	5.210×10^{-7}	70.1	23.56 ± 0.91
5585	BP-29	Żelazowa	? plug	w.r.	1.379	1.014×10^{-6}	63.2	18.82 ± 0.75
5665	BP-40	Mikołajowice	plug	w.r.	0.950	1.149×10^{-6}	58.5	30.85 ± 1.25
5667	BP-41	Pawłowice	plug	w.r.	0.909	7.784×10^{-7}	61.3	21.89 ± 0.87
5666	BP-42	Lubień	lava flow	w.r.	0.966	1.009×10^{-6}	72.2	26.67 ± 1.03

Table 6

K-Ar ages (with analytical error bars) of Tertiary basaltoid rocks from the Fore-Sudetic Block, Lower Silesia (see Tab. 5) set against chronostratigraphic scale (from Palmer & Gassman, 1999). Open circles – lava flow; full circles – plugs and vent/dyke intrusion



tions were performed at the Institute of Nuclear Research, Hungarian Academy of Sciences (ATOMKI, Debrecen).

The most suitable samples were crushed and sieved. A split of the crushed rock was selected and finely ground for potassium determination. The whole-rock samples, approximately 500 mg wt, were further used for Ar analysis. For details of the procedures – see Birkenmajer and Pécskay (2002), for calibration of the instruments and methods applied – see Balogh (1985).

Apparent ages were calculated using the decay constants as proposed by Steiger and Jäger (1977). All analytical errors represent one standard deviation (68% analytical confidence level). The results of K-Ar age determination of collected rock samples are given in Tab. 5. For stratigraphic evaluation of the results, the Geological Society of America 1999 Geologic Time Scale (Palmer & Geissman, 1999) has been used (Tab. 6).

In K-Ar dating, the assumption that the non-radiogenic argon has atmospheric isotope composition allows calculation of amount of radiogenic ^{40}Ar by subtracting the non-radiogenic ^{40}Ar (obtained from multiplying ^{36}Ar by the atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio = 295.5) from the total amount of ^{40}Ar . The fact that the majority of basaltic rocks investigated yielded geologically significant K-Ar ages, gives strong evidence that the non-radiogenic argon component in these samples has a $^{40}\text{Ar}/^{36}\text{Ar}$ ratio close to atmospheric value. In some cases, petrological investigations suggest a probability of some Ar loss by later reheating (i.e. apparent rejuvenation of sample's geological age).

RESULTS OF K-Ar DATING

(1) Two unaltered basanite samples from Targowica, Strzelin area (BP-17, lower lava flow; BP-18, upper lava flow) yielded whole-rock K-Ar dates of 23.20 ± 0.89 Ma, and 20.13 ± 0.86 Ma, respectively. Difference in the K-Ar dates, of the order of 3 Ma, between these two lava flows, is consistent with their respective geological ages.

(2) Four K-Ar whole-rock dates from Janowiczki, Strzelin area (PB-19 to BP-22), were obtained from three successive ankaratrite lava flows. With the exception of sample BP-22, the K-Ar whole-rock dates are consistent with the lava flow succession: first flow (BP-21) – 28.72 ± 1.13 Ma; second flow (BP-19) – 27.94 ± 1.16 Ma; third flow (BP-20) – 18.54 ± 0.96 Ma. The K-Ar date from sample BP-22 (25.32 ± 1.06 Ma), which was collected at the base of the first flow just above contact with the basement rocks, is younger than could be expected from geological observation (see Fig. 8). It is possible that this is an apparent date resulting from argon loss caused by reheating by higher lava flows, or by thermal solutions which penetrated contact of the first lava with its basement (quartzite/sericite schist).

(3) A K-Ar whole rock date, 27.65 ± 1.32 Ma, from ankaratrite plug of Kowalskie-Żelowice, Strzelin area (BP-23), is very close to two dates from the Janowiczki ankaratrite lava flows, Nos BP-21 and BP-19 (see above, and Tab. 5). This plug could be a feeder vein for the latter lavas.

(4) Two K-Ar whole-rock dates from Gilów, Niemcza area, 20.91 ± 0.84 Ma (BP-24) and 19.99 ± 0.77 Ma (BP-25),

taken from a (?) lava flow (tephrite) and from a plug (basanite), respectively, indicate an Early Miocene volcanic event not earlier than 21 Ma.

(5) In the Strzegom area, three K-Ar dates: 20.40 ± 0.89 Ma (BP-27: Strzegom I – alkali basalt dyke); 19.84 ± 0.93 Ma (BP-26: Strzegom III – alkali basalt/basanite lava flow); and 18.82 ± 0.75 Ma (BP-29: Żelazowa – alkali basalt/basanite, probably plug) resemble the K-Ar dates from Gilów. They also indicate an Early Miocene phase of volcanic activity.

(6) The fourth K-Ar date from the Strzegom area, 23.56 ± 0.91 Ma (BP-28: Strzegom II – alkali basalt lava flow), is older than the other ones (i.e., BP-26, 27, 29), but still Early Miocene in age. It may represent initiation of the alkali basalt volcanism in the Strzegom area (see also remarks in: Discussion and conclusions – 9).

(7) Three K-Ar dates from the Legnica area seem to correspond to three stages of volcanic activity: (i) the Mikołajowice basanite plug (BP-40: 30.85 ± 1.25 Ma) is the oldest; (ii) the Lubień basanite/trachybasalt lava flow is younger (BP-42: 26.67 ± 1.03 Ma); and (iii) the Pawłowice basanite plug (BP-41: 21.89 ± 0.87 Ma) is the youngest. In this area, the period of vulcanicity spanned the Early Oligocene (Rupelian) through the Late Oligocene (Chattian) to the Early Miocene (Aquitanian) time. The two older dates (from sites BP-40 and BP-42) correspond to those of the Opole area in eastern part of Lower Silesia (see Birkenmajer & Pécskay, 2002). The youngest one (from site BP-41) corresponds to the Early Miocene phase of volcanic activity, already documented in the Fore-Sudetic Block near Jawor (Birkenmajer *et al.*, 2002b).

PALAEOMAGNETISM

PROCEDURES

All palaeomagnetic experiments were carried out in the Palaeomagnetic Laboratory of the Polish Geological Institute, Warsaw (PGI Project No 6.20.1719.00.0), 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 obtained. Natural remanent 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 remanent magnetization (ChRM) directions were calculated based on the principal component analysis (see Kirschvink, 1980), and using the PALMAG package of Lewandowski *et al.* (1997).

The specimens were treated mostly with the AF demagnetization. Typical demagnetization diagrams are presented in Fig. 15. A weak viscous component was removed between 0 and 10 mT and, then, the demagnetization was stable up to 95 mT. This procedure gave essentially the same results as thermal demagnetization, but was much quicker. The AF demagnetization was also more efficient in separa-

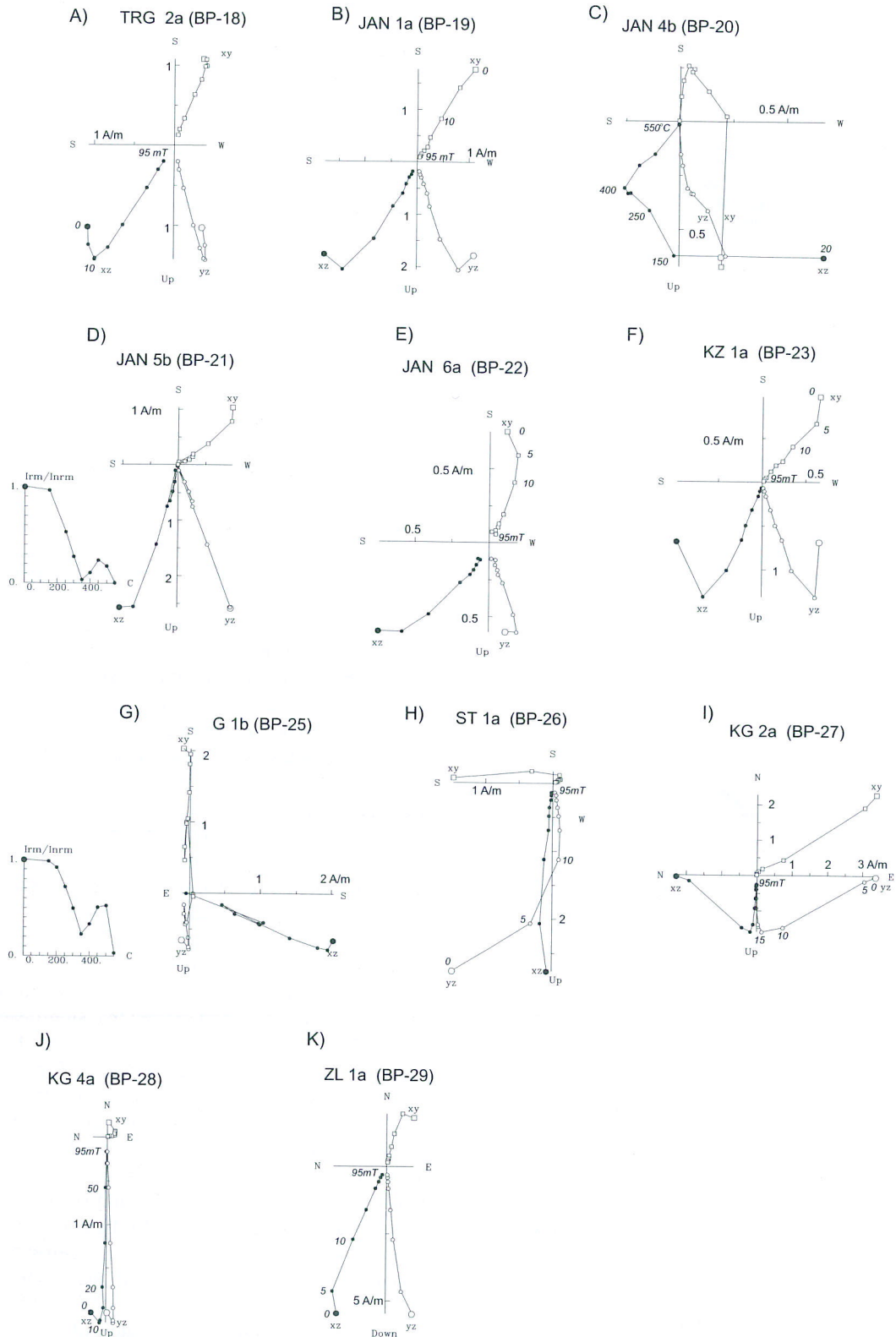


Fig. 15. Orthogonal projection of typical AF and thermal demagnetization paths in Tertiary basaltoid rocks, Fore-Sudetic Block. In two cases (D and G), where an antipodal component occurred during demagnetization (self-reversal?), NRM intensity decay curves were attached

tion of the two components of magnetization which differed in coercivity (see Fig. 15I).

Thermal demagnetization was applied only occasionally when, after treatment up to 95 mT, still more than 20%

of the initial NRM remained (e.g., Fig. 15C). In some cases, thermal demagnetization revealed the presence of a second antipodal component, which was demagnetized between 350 and 450° (Fig. 15D, G). This might be related to the

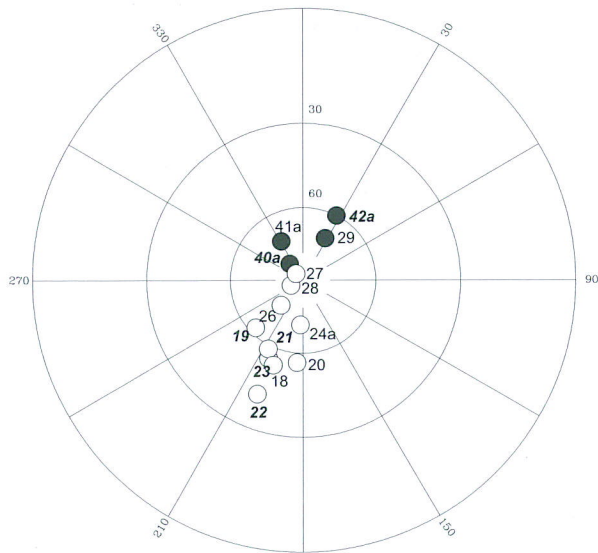


Fig. 16. Stereographic projection of the site-mean directions in Tertiary basaltoid rocks, Fore-Sudetic Block. Open circles – upper hemisphere projection; full circles – lower hemisphere projection. Sites attributed to the *first phase* of volcanicity are indicated by italics. “a” – refers to site-mean directions taken from Birkenmajer & Nairn (1969). For source of data – see Tab. 8

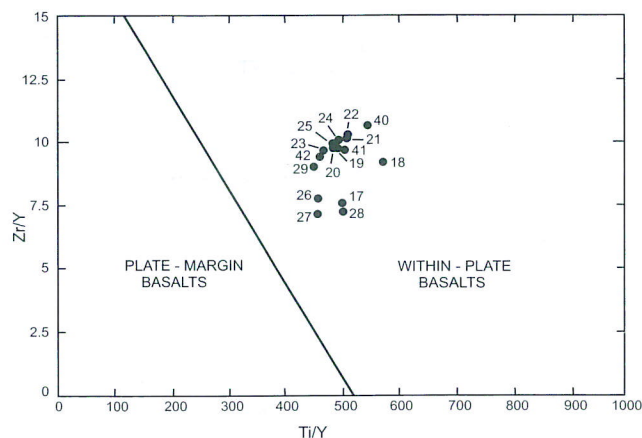


Fig. 17. Plot of Tertiary basaltoid rocks from the Fore-Sudetic Block, in the classification diagram of Pearce and Galle (1977). Numbers refer to the BP sites

self-reversal processes, as already noted in the Lower Silesian basalts by Kądziałko-Hofnokl and Kruczyk (1976).

RESULTS

(1) In most sites investigated, reversed polarity directions were observed, and only one sample (BP-29) revealed normal polarity. However, as implied by previous studies (Birkenmajer & Nairn, 1969), also sites BP-40 to BP-42 (presently palaeomagnetically not investigated) should be of normal polarity. The extrapolation seems justified, since in all sites of Birkenmajer and Nairn (*op. cit.*), re-studied here and in previous papers (Birkenmajer *et al.*, 2002a, b), the results were the same.

(2) Stereographic projection (Fig. 16) indicates that characteristic directions are slightly stretched along a SW–NE direction.

(3) Reversed direction from sites near Strzegom (BP-26 to 28) show abnormally steep inclination, as already observed by Birkenmajer and Nairn (1969) – see also Tab. 8. Inconsistence is noted at site BP-25 which, in this study, yielded abnormally shallow inclination of -25° , while in the previous investigations (*op. cit.*) the measured inclination was much steeper (-72° – see Tab. 8). However, the Gilów quarry was in much better state in the 60-ies when sampled by Birkenmajer and Nairn (*op. cit.*), while only single outcrops are available at present. Therefore, since there is no sufficient control whether the rocks have not been disturbed by surficial processes, the previous results have been taken as more reliable.

(4) The normal polarity directions give bimodal distribution of declinations: 30° (BP-29 and BP-42) and 330° (BP-40 and BP-41) – see Fig. 16.

DISCUSSION AND CONCLUSIONS

(1) New petrologic and geochemical investigations show that the Tertiary basaltic rocks of the Fore-Sudetic Block typically represent within-plate basalts (Fig. 17). Petrologically, they consist mainly of alkali basalts, basanites, tephrites and ankaratrites (Figs 4, 5).

(2) The oldest K-Ar date, close to 31 Ma (BP-40), was recorded from a basanite plug at Mikołajowice, Legnica area. This date may indicate an Early Oligocene age of initiation of volcanic activity in the area.

(3) Another K-Ar date, about 27 Ma (BP-42, Lubień), from a basanite/trachybasalt lava flow in the Legnica area, correlates well with a peak of Late Oligocene volcanism of the Opole area (eastern part of Lower Silesia) determined at 26.5 Ma (Birkenmajer & Pécskay, 2002).

(4) The majority of the whole-rock K-Ar dates (13 out of 16 measurements) plot around two significantly different ages: 27 ± 1.5 Ma, and 20 ± 1.5 Ma (Fig. 18). This phenomenon has already been recognized in the Fore-Sudetic Block volcanics in the area of Jawor (Birkenmajer *et al.*, 2002b). It might indicate the presence of two distinct separate phases of Tertiary volcanicity in the Fore-Sudetic Block (Fig. 16; Tab. 7): (i) the *first phase*, mainly Late Oligocene (Chatian), with a peak at c. 27 Ma; and (ii) the *second phase*, Early Miocene (Aquitaniian–Burdigalian), with a peak at about 20 Ma. These phases seem to be separated by a gap in volcanicity about 3 Ma long at the Oligocene/Miocene boundary.

(5) The problem of correlation of K-Ar dates of volcanic events available now from the Fore-Sudetic Block (Opole area – Birkenmajer & Pécskay, 2002; Jawor area – Birkenmajer *et al.*, 2002a; area between Strzelin and Legnica – this paper) with specific radiometrically-dated polarity intervals is difficult, because: (i) frequency of reversals during Oligocene and Miocene was high (geomagnetic polarity sometimes changed every 250–300 Ky); (ii) analytical errors of the K-Ar analysis applied are usually of the order of 1 Ma.

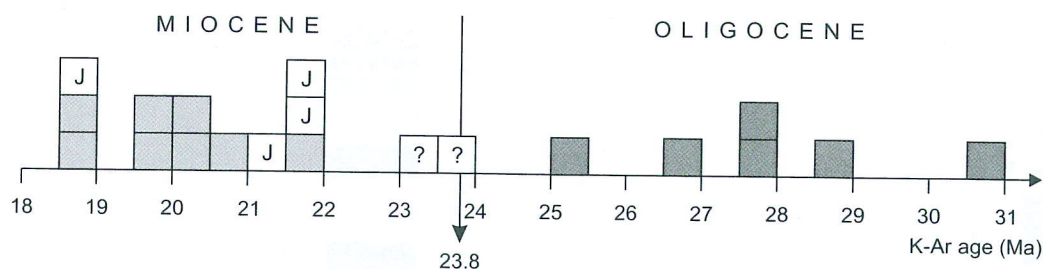


Fig. 18. Age distribution of the K-Ar dated Tertiary volcanics from the Fore-Sudetic Block. J – Jawor area (see Birkenmajer *et al.*, 2002b). Grey – K-Ar dates presented in this paper (Tabs 5, 6). Boxes correspond to single dates; question marks – samples with uncertain geological age

(6) It can be seen from Fig. 19 that volcanism of the *first phase* (Oligocene), although significantly spread out in time across multiple reversals, took place mostly in two well-defined events: (i) an older, reversed *Odra event*; and (ii) a younger, normal *Gracze event* (cf. Kruczyk *et al.*, 1977; Birkenmajer & Pécskay, 2002). The problem is why the older volcanic activity occurred mainly during reversed chrons (with exception of the oldest one: BP-40), and the younger volcanic activity – exclusively during normal chrons. It may be supposed that the Gracze event (normal) corresponds to the C8n chron (between 26.554 and 25.823 Ma), although the K-Ar age of the BP-2 lavas (at Gracze) points rather to the chron C7An (Fig. 19). The mean age

(26.5±1.1 Ma) calculated from four normal entries fits a lower part of the C8n chron.

(7) It might be speculated whether or not the reversed polarity sites of the Odra event represent one or several reversed chrons. The mean age for those reversely magnetized sites (see Fig. 19) is 28.10±1.2 Ma, thus falling within the C9r magnetozone. If this interpretation is correct, the Odra and the Gracze events would represent two separate episodes of the Late Oligocene vulcanicity. A still earlier episode of this activity (close to Early/Late Oligocene boundary) might take place during the C12n magnetozone (site BP-40).

(8) A similar approach may be applied to volcanism of

Table 7

Synopsis of the K-Ar-dated Tertiary basaltoid rocks from the Fore-Sudetic Block, Lower Silesia
(source of dates: Tab. 5, this paper, and Birkenmajer *et al.*, 2002b)

No (BP)	K-Ar (Ma)	Rock/volcanic form	Supposed geological age
20	18.54 ± 0.96	ankaratrite lava	Burdigalian
33	18.66 ± 0.82	olivine basalt dyke	Burdigalian
29	18.82 ± 0.75	alk. basalt/basanite ?plug	Aquitanian/Burdigalian
26	19.84 ± 0.93	alk. basalt/basanite lava	Aquitanian/Burdigalian
25	19.99 ± 0.77	alk. basalt/basanite lava	Aquitanian/Burdigalian
18	20.13 ± 0.86	basanite lava	Aquitanian/Burdigalian
27	20.40 ± 0.85	alkali basalt dyke	Aquitanian/Burdigalian
24	20.91 ± 0.84	tephrite lava	Aquitanian/Burdigalian
32	21.05 ± 0.85	basanite lava	Aquitanian/Burdigalian
30	21.62 ± 0.93	basanite plug	Aquitanian/Burdigalian
41	21.89 ± 0.83	basanite plug	Aquitanian
31	21.96 ± 1.36	basanite plug	Aquitanian
17	23.20 ± 0.89	alk. basalt/basanite lava	Aquitanian
28	23.56 ± 0.91	alkali basalt lava	Chattian/Aquitanian
42	26.67 ± 1.03	basanite/trachybasalt lava	Chattian
23	27.65 ± 1.32	ankaratrite plug	Chattian
19	27.94 ± 1.16	ankaratrite lava	Rupelian/Chattian
22	[25.32 ± 1.06]	ankaratrite lava (bottom)	Rupelian/Chattian
21	28.72 ± 1.13	ankaratrite lava	Rupelian/Chattian
40	30.85 ± 1.25	basanite plug	Rupelian

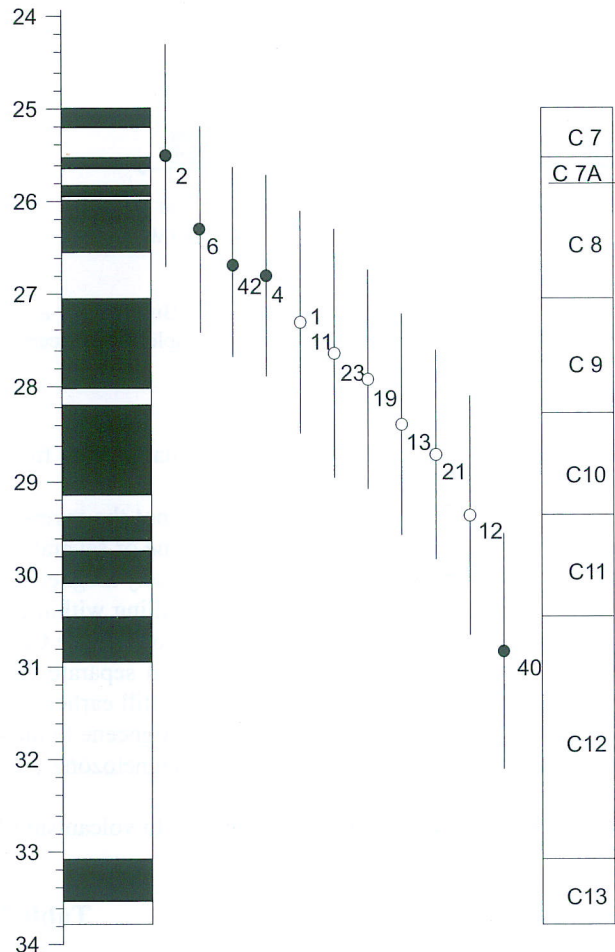


Fig. 19. Oligocene basaltoids of the Fore-Sudetic Block: K-Ar dated samples (BP numbers) plotted against geomagnetic polarity scale of Cande and Kent (1995). Left side – radiometric scale in Ma, and polarity column; right side – magnetozones; full circles – normal polarity; open circles – reversed polarity

the *second phase* (Early Miocene). Except for two sites (BP-29 and BP-41), the polarity is predominantly reversed (Fig. 20). A continuous set of reversely magnetized sites comprises 6 dates with a mean age value of 20.50 ± 0.87 Ma, that falls within the C6r magnetozones. This might indicate a maximum of volcanic activity during the second phase. Ankaratrite lava (BP-20) and olivine basalt vent/dyke (BP-33), both showing reverse magnetization, and normally magnetized alkaline basalt/basanite plug (BP-29) might represent the youngest volcanic episodes corresponding to the magnetozones C5Er or C5Dr (BP-20 and BP-33), and C6n or C5En (BP-29), respectively. Consequently, basanite plugs from sites BP-41 and BP-31 (Fig. 20) might be interpreted as an older episode, characterized by a mixed polarity magnetization.

(9) Alkali basalt lava from site BP-28 yielded a quite old K-Ar age. This poses a problem, because it is magnetized exactly in the same direction as an alkali basalt dyke from site BP-27 which has revealed a very characteristic “transitional” magnetization with very steep negative inclination (see Fig. 16 and Tab. 8) but was younger by almost 3

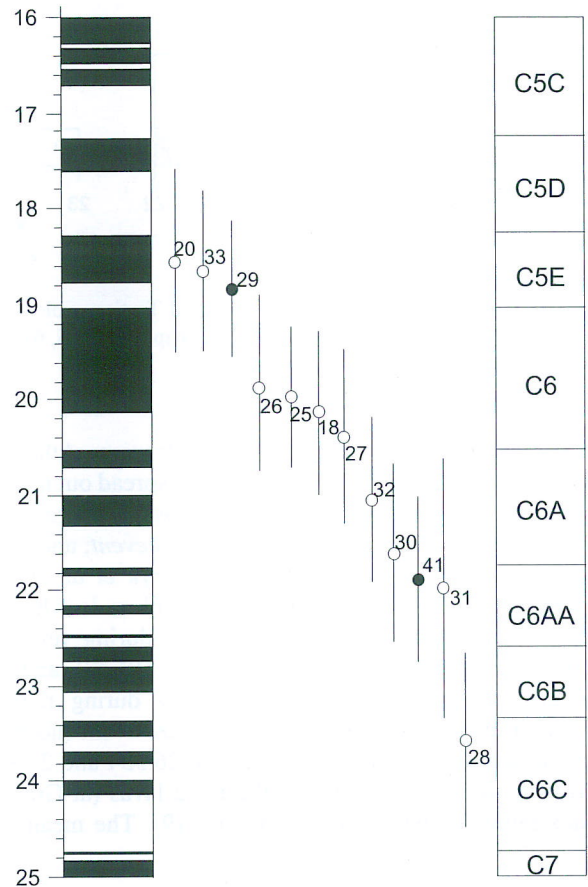


Fig. 20. Early Miocene basaltoids of the Fore-Sudetic Block: K-Ar dated samples (BP numbers) plotted against geomagnetic polarity scale of Cande and Kent (1995). Left side – radiometric scale in Ma, and polarity column; right side – magnetozones; full circles – normal polarity; open circles – reversed polarity

Ma. It is difficult to accept that both sites were magnetized in different magnetozones. An “excess argon” problem may have been involved.

(10) Summing up the above discussion (5–9), the palaeomagnetic data favour the interpretation that volcanic activity in the Fore-Sudetic Block took part during two phases:

(i) The Late Oligocene phase with two distinct episodes: the older reversed *Odra event* (C9r); and the younger normal *Gracze event* (C8n);

(ii) The Early Miocene phase: mostly one reversed event (C6r).

If the volcanism was continuous, the normally and reversely magnetized sites would occur in more or less equal proportions, what is not the case (i.e. the reverse magnetization predominates).

(11) The mean palaeomagnetic directions calculated for particular *events* are hardly distinguishable from each other, i.e. they give no strong evidence for a significant latitudinal drift or rotation about vertical axis of the area studied. A higher inclination for the Early Miocene event (see Tab. 9)

Table 8

Mean palaeomagnetic directions of the Tertiary basaltoid rocks from the Fore-Sudetic Block, Lower Silesia. Source of data: this paper, and Birkenmajer & Nairn (1969; abbreviated B&N)

Locality	Site	Sample	Dec/Inc	α_{95}	k	n_0/n
Targowica	BP-17	No palaeomagnetic samples taken				
	BP-18	TRG 2	200/-54	14.9	69.3	3/3
		<i>B & N 1969 Site 58</i>	<i>196/-60</i>	8.2	-	6/6
Janowiczki	BP-19	JAN 1	211/-56	8.7	201.3	3/3
		JAN 2	252/-78	10.8	131.8	3/3
		Mean	225/-68	12.6	29.2	6/6
	BP-20	JAN 3	182/-62	6.1	407.5	3/3
		JAN 4	187/-51	3.6	1190	3/3
		Mean	185/-56	5.9	129.5	6/6
	BP-21	JAN 5	207/-59	20	38.6	3/3
	BP-22	JAN 6	202/-42	8.9	75	5/5
Kowalskie-Żelowice	BP-23	KZ 1	198/-55	24.5	14.8	4/4
		KZ 2	217/-57	12.7	95.3	3/3
		Mean	206/-56	12.7	23.5	7/7
		<i>B & N 1969 Site 60</i>	<i>218/-54</i>	7	-	6/6
Gilów I	BP-24	No palaeomagnetic samples taken				
Gilów II	BP-25	G 1	185/-24	8.7	111.6	4/4
		<i>B & N 1969 Site 62</i>	<i>185/-72</i>	11		6/6
Strzegom III	BP-26	STR 1	222/-76	6.1	228.4	4/4
		<i>B & N 1969 Site 11</i>	<i>142/-82</i>	8.2	-	6/6
Strzegom I	BP-27	KG 1	301/-84	5.1	584.9	3/3
		KG 2	21/-87	7.5	271.3	3/3
		Mean	324/-86	4.2	253.4	6/6
		<i>B & N 1969 Site 9</i>	<i>286/-84</i>	4.3	-	6/6
Strzegom II	BP-28	KG 3	231/-83	14.9	68.8	3/3
		KG 4	284/-87	21.6	33.2	3/3
		Mean	249/-85	9.3	52.3	6/6
		<i>B & N 1969 Site 10</i>	<i>286/-86</i>	5.2	-	6/6
Żelazowa	BP-29	ZL 1	26/70	5.3	304.9	4/4
Mikołajowice	BP-40	No palaeomagnetic samples taken				
		<i>B & N 1969 Site 31</i>	<i>322/81</i>	6.1	-	5/6
Pawłowice	BP-41	No palaeomagnetic samples taken				
		<i>B & N 1969 Site 30</i>	<i>333/72</i>	16.7	-	6/6
Lubień	BP-42	No palaeomagnetic samples taken				
		<i>B & N 1969 Site 29</i>	<i>26/60</i>	3.1	-	8/8

Dec – declination; Inc – inclination; α_{95} , k – Fisher statistics parameters; n_0 – number of specimens demagnetized, n – number of specimens used for calculation of the site (sample) mean direction

Table 9

Mean palaeomagnetic directions of the Tertiary basaltoid rocks from the Fore-Sudetic Block, Lower Silesia.

Event	Polarity	D/I	A95	k	N
Odra **	R	195/–56	8.9	39.6	8
Gracze **	N	29/57	4.4	771.5	3
Early Miocene	R	189/–68	12.8	19.7	8
Early Miocene *	R	183/–57	11	49.4	5

* without sites BP26–28

** calculated after data of Kruczyk *et al.* (1977), Birkenmajer *et al.* (1972)

results from some high-inclination intermediate direction, especially of the Strzegom area (sites BP-26 to BP-28). There are some subtle trends recognized in the European apparent polar wander path (APWP) during Cenozoic: a c. 10–15° clockwise rotation between 20 and 0 Ma (Besse & Courtillot, 2002). They are possibly related to a change in the movement direction of Eurasia at 20 Ma (Torsvik *et al.*, 2001). In the case of the FSB, too few independently oriented samples were collected to draw any definite tectonic conclusion at this stage of investigations.

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REFERENCES

- August, Cz., Awdankiewicz, M. & Wojewoda, J., 1995. Tertiary basaltoids, volcanoclastics and sedimentary rocks in the eastern part of the Fore-Sudetic Block (in Polish). In: *Geology and environmental protection of the Fore-Sudetic Block. Guide, LXVI Field Meeting of the Geological Society of Poland*. Wrocław.
- Balogh, K., 1986. K-Ar dating of Neogene volcanic activity in Hungary: Experimental technique, experiences, and methods of chronological studies. *ATOMKI Report*, D/1: 277–288.
- Berg, G., 1930. Die niederschlesischen Basaltvorkommen. *Sonder Band, Preussische Geologische Landesanstalt*, 5: 65–74.
- Besse, J. & Courtillot, V., 2002. Apparent and true polar wander and the geometry of the geomagnetic field over last 200 Myr. *Journal of Geophysical Research*, 107 (B11), EPM 6: 1–31.
- Birkenmajer, K., 1967. Lower Silesian basalts as monuments of inanimate nature (in Polish, English summary). *Rocznik Ochrony Przyrody (Kraków)*, 32: 225–276.
- Birkenmajer, K. & Nairn, A. E. M., 1969. Palaeomagnetic investigations of the Tertiary and Quaternary igneous rocks. V. The basic Tertiary basalts of Lower Silesia, Poland. *Geologische Rundschau*, 58: 697–712.
- Birkenmajer, K. & Pécskay, Z., 1999. K-Ar dating of the Miocene andesite intrusions, Pieniny Mts, West Carpathians. *Bulletin of the Polish Academy of Sciences: Earth Sciences*, 47: 155–169.
- Birkenmajer, K. & Pécskay, Z., 2000. K-Ar dating of the Miocene andesite intrusions, Pieniny Mts, West Carpathians, Poland: a supplement. *Studia Geologica Polonica*, 117: 7–25.
- Birkenmajer, K. & Pécskay, Z., 2002. Radiometric dating of the Tertiary volcanics in Lower Silesia, Poland. I. Alkali basaltic rocks of the Opole region. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 50 (1) 21–40.
- Birkenmajer, K., Jerzmański, J. & Nairn, A. E. M., 1970. Palaeomagnetic studies of Polish rocks. IV. Cenozoic basalts of Lower Silesia. *Annales de la Société Géologique de Pologne*, 40: 31–61.
- Birkenmajer, K., Jeleńska, M., Kądziałko-Hofmokl, M. & Kruczyk, J., 1972. Magnetic properties of Polish Tertiary basaltic rocks from the Opole region. *Publications, Institute of Geophysics, Polish Academy of Sciences*, 57: 59–68.
- Birkenmajer, K., Jeleńska, M., Kądziałko-Hofmokl, M. & Kruczyk, J., 1977. Age of deep-seated fracture zones in Lower Silesia (Poland), based on K-Ar and palaeomagnetic dating of Tertiary basalts. *Annales de la Société Géologique de Pologne*, 47: 545–552.
- Birkenmajer, K., Pécskay, Z., Grabowski, J., Lorenc, M. W. & Zagożdżon, P. P., 2002a. Radiometric dating of the Tertiary volcanics in Lower Silesia, Poland. II. K-Ar ages and palaeomagnetic data from Neogene basanites near Łądek Zdrój, Sudetes Mts. *Annales Societatis Geologorum Poloniae*, 72 (2): 119–129.
- Birkenmajer, K., Pécskay, Z., Grabowski, J., Lorenc, M. W. & Zagożdżon, P. P., 2002b. Radiometric dating of the Tertiary volcanics in Lower Silesia, Poland. III. K-Ar ages and palaeomagnetic data from Early Miocene basaltic rocks near Jawor, Fore-Sudetic Block. *Annales Societatis Geologorum Poloniae*, 72 (3): 241–253.
- Cande, S. C. & Kent, D. V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, 100: 6093–6095.
- De la Roche, H., Letterier, J., Grandclaude, P. & Marchal, M., 1980. A classification of volcanic and plutonic rocks using R1R2-diagram and major element analysis – its relationship with current nomenclature. *Chemical Geology*, 29: 183–210.
- Jerzmański, J., 1956. The basalts in the vicinity of Jawor in Lower Silesia (in Polish, English summary). *Biuletyn Instytutu Geologicznego (Warszawa)*, 106: 119–132.
- Jerzmański, J., 1961. Comment on the geological structure of the Jawor region in Lower Silesia. *Uniwersytet Wrocławski, Zeszyty Naukowe, Ser. B*: 8: 113–121.
- Jerzmański, J., 1965. Geology of the north-western part of the Kaczawa Mountains and of their eastern extent (in Polish, English summary). *Biuletyn Instytutu Geologicznego (Warszawa)*, 185: 109–193.
- Jerzmański, J. & Maciejewski, S., 1968. Tertiary basalts in Lower

Silesia. *Biuletyn Instytutu Geologicznego (Warszawa)*, 227: 247–260.

- Kirschvink, J. L., 1980. The least square line and plane and the analysis of palaeomagnetic data. *Journal of the Royal Astronomical Society*, 62: 699–718.
- Kopecký, L., 1966. Tertiary volcanics, in Svoboda, J. (ed.), *Regional Geology of Czechoslovakia. I. The Bohemian Massif*. Czechoslovak Academy of Sciences (Praha): 554–581.
- Kądziałko-Hofmokl, M. & Kruczyk, J., 1976. Complete and partial self-reversal of natural remanent magnetization of basaltic rocks from Lower Silesia. *PAGEOPH*, 114: 207–213.
- Kozłowska-Koch, M., 1987. Classification and nomenclature of the Tertiary volcanic rocks of the Lower and Opole Silesia (in Polish, English summary). *Archiwum Mineralogiczne*, 42: 43–95.
- Kruczyk, J., Kądziałko-Hofmokl, M., Jeleńska, M. & Birkenmajer, K., 1977a. Paleomagnetism and magnetic properties of Tertiary basaltic rocks from Góra św. Anny and Ligota Tułowicka, Lower Silesia. *Publications, Institute of Geophysics, Polish Academy of Sciences*, C3 (111): 1–17.
- Kruczyk, J., Kądziałko-Hofmokl, M., Jeleńska, M., Birkenmajer, K. & Arakelyants, M. M., 1977b. Tertiary polarity events in Lower Silesian basalts and their K-Ar age. *Acta Geophysica Polonica*, 25: 183–191.
- Kural, S., 1982. Explanations to the geological map, 1:25,000 scale, sheet Strzegom (in Polish). *Polish Geological Institute (Warsaw)*.
- Le Bas, M. J. & Streckeisen, A. L., 1991. The IUGS systematics of igneous rocks. *Journal of the Geological Society (London)*, 148: 825–833.
- Lewandowski, M., Nowożyński, K. & Werner, T., 1997. PDA – a package of FORTRAN programs for paleomagnetic data analysis. *Mscr., Institute of Geophysics, Polish Academy of Sciences (Warsaw)*.
- Palmer, A. R. & Geissman, J., 1999. Geologic Time Scale. *Geological Society of America*. Product code CTS004.
- Pearce, J. A. & Gale, G. H., 1977. Identification of ore deposition environment from trace element geochemistry of associated igneous rocks. *Geological Society (London), Special Publication*, 7: 14–24.
- Śliwa, Z., 1967. Structures in Silesian basalts (in Polish, English summary). *Annales de la Société Géologique de Pologne*, 37 (3): 435–454.
- Steiger, R. H. & Jäger, E., 1977. Subcommittee on the use of decay constants in Geo- and Cosmochronology. *Earth and Planetary Science Letters*, 36: 359–362.
- Torsvik, T. H., Mosar, J. & Eide, E. A., 2001. Cretaceous–Tertiary dynamics: a North Atlantic exercise. *Geophysical Journal International*, 146: 850–866.
- Wójcik, L., 1973. Explanations to geological map of the Sudeten Mts, 1:25,000 scale, Ciepłowody sheet. *Geological Institute (Warsaw)*.
- Wojno, T., Pentlakowa, Z. & Szarras, S., 1951. Investigations of Lower Silesian basalts in the years 1950–1951 (in Polish, unpublished). *Państwowy Instytut Geologiczny, Archiwum (Warszawa)*.
- Zagożdżon, P. P., 2001. “Sunburn” (“Sonnenbrand”) in Tertiary basalts of Lower Silesia and possibilities of utilizing them (in Polish). *Ph.D. Thesis*.

Streszczenie

DATOWANIE RADIOMETRYCZNE TRZECIORZĘDOWYCH WULKANITÓW DOLNEGO ŚLĄSKA. IV. DATY K-Ar I WYNIKI BADAŃ PALEOMAGNETYCZNYCH PÓŻNOOLIGOCENSKICH I WCZESNOMIOCEŃSKICH SKAŁ BAZALTOWYCH BLOKU PRZEDSUDECKIEGO

Krzysztof Birkenmajer, Zoltán Pécskay, Jacek Grabowski, Marek W. Lorenc & Paweł P. Zagożdżon

Czwarta część datowań K-Ar i badań paleomagnetycznych trzeciorzędowych wulkanitów Dolnego Śląska obejmuje odsłonięcia tych skał w bloku przedsudeckim pomiędzy Strzeliną na wschodzie a Legnicą na zachodzie. Pod względem petrologicznym skały te są reprezentowane przez bazalty alkaliczne, bazanity, tefryty i ankaratryty. 16 nowych dat radiometrycznych (K-Ar) wskazuje na wiek wulkanitów w granicach od 31 Ma (oligocen) do ok. 18 Ma (niższy miocen). Większość z tych dat grupuje się wokół dwóch znacznie różniących się wiekiem wartości: $27 \pm 1,5$ Ma i $20 \pm 1,5$ Ma, co wskazuje na dwie fazy trzeciorzędowego wulkanizmu w bloku przedsudeckim: (1) *pierwsza faza* (głównie późny oligocen = szat) z kulminacją na ok. 27 Ma; (ii) *druga faza* (wczesny miocen = akwitan–burdygał) z kulminacją na ok. 20 Ma. Fazy te wydają się być rozdzielone przerwą w działalności wulkanicznej na granicy oligocenu i miocenu, która trwała ok. 3 mln lat.

Korelacja radiometrycznie datowanych trzeciorzędowych zdarzeń wulkanicznych Dolnego Śląska z wyróżnionymi, datowanymi radiometrycznie, zdarzeniami paleomagnetycznymi świata stwarza jeszcze pewne trudności i nie może być uznana za definitywną. Biorąc pod uwagę komplet dotychczasowych datowań K-Ar z 40 stanowisk na terenie bloku przedsudeckiego (między rejonem Opola na wschodzie a rejonem Legnicy na zachodzie), sugerujemy, że wulkanizm *pierwszej fazy* (oligocen), pomimo że jego daty są rozrzucone w czasie obejmując szereg odwróceń namagnesowania ziemskiego, zachodził głównie w ciągu dwóch wydarzeń dobrze już zdefiniowanych na terenie Dolnego Śląska: (i) starszego *wydarzenia Odry* (polarność odwrotna, chron C9r: $28,1 \pm 1,2$ mln lat), oraz (ii) młodszego *wydarzenia Graczy* o polarności normalnej (chron C8: $26,5 \pm 1,1$ mln lat). Do *drugiej fazy* wulkanizmu (wczesny miocen) zaliczono ciągłą serię radiometrycznie datowanych wulkanitów o polarności odwrotnej (głównie chron C6r: $20,5 \pm 0,87$ mln lat).

The first part of the book is devoted to a general history of the United States from its discovery to the present time.

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