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Krzysztof BIRKENMAJER[1], Maria JELEŃSKA[2]
Magdalena KĄDZIAŁKO-HOFMOKL[2], Jadwiga KRUCZYK[2]

AGE OF DEEP-SEATED FRACTURE ZONES IN LOWER SILESIA (POLAND), BASED ON K-Ar AND PALAEOMAGNETIC DATING OF TERTIARY BASALTS

(1 Fig., 1 Tab.)

Wiek głębokich stref uskokowych na Dolnym Śląsku na podstawie datowania radiometrycznego i paleomagnetycznego bazaltów trzeciorzędowych

(1 fig., 1 tab.)

Abstract: K-Ar and palaeomagnetic dating of Tertiary basaltic rocks related to deep fracture zones in the area between the Fore-Sudetic Monocline and the Sudetic Block, Lower Silesia (Poland), allowed to distinguish three major phases of Tertiary tectonic deformation: (1) the Odra phase of tension (late Oligocene) which produced the Sudetic Boundary Fault (NW-SE) and the Odra Fault zone (NW-SE on the west, changing to WNW-ESE on the east); (2) the Opole phase of compression (late Oligocene/early Miocene), corresponding to the Savian phase of folding in the Carpathians, which produced strike-slip faults (SW-NE) transversal to the Odra Fault, and possibly also resulted in some compressional rotation along the Sudetic Boundary Fault plane; (3) the Jawor phase of tension (Middle Miocene, mainly Badenian), corresponding to the Styrian phase, which produced faults (WNW-ESE) in the Kaczawa Mountains (Sudetic Block).

PALAEOMAGNETIC EVENTS AND AGE OF LOWER SILESIAN BASALTIC ROCKS

Palaeomagnetic investigation of Lower Silesian Tertiary rocks (Birkenmajer, Nairn, 1969; Birkenmajer et al., 1970, 1972, 1973; Kruczyk *et al.*, 1977a) and radiometric (K-Ar) determination of their age (Kruczyk *et al.*, 1977b) allowed to recognise six polarity events in the area

[1] *Institute of Geology, Polish Academy of Sciences, ul. Senacka 3, 31-002 Kraków*

[2] *Institute of Geophysics, Polish Academy of Sciences, ul. Pasteura 3, 02-093 Warszawa*

of the Sudetic Block (Kaczawa Mountains), Sudetic Boundary Fault and Odra Fault.

(1) The Sichów Event (N) is represented by melabasanite[3] plug at Sichów. Its K-Ar date 28 ± 3 Ma corresponds to the late Oligocene. The magma intruded exactly along the line of the NW-SE-running Sudetic Boundary Fault, as shown by Jerzmański (1965 — Fig. 1). Thus, it is assumed, that the K-Ar age of the melabasanite equally represents the age of the fault. The palaeomagnetic directions are, however, different from roughly coeval basaltic rocks of Ligota Tułowicka (L I—III: reversed polarity), Góra Św. Anny (A II: reversed polarity) and Gracze (G III: normal polarity) — see Kruczyk *et al.* (1977b). A better fit of palaeomagnetic coordinates with those for European Tertiary palaeomagnetic directions (normally magnetised rocks) was obtained by rotating the Sichów palaeopole with respect to a horizontal axis lying in the plane of the Sudetic Boundary Fault (NW-SE) by about 60° northeast. This suggests a post-emplacement rotation of the Sichów melabasanite plug as a result of younger movements which caused oversteepening of the Sudetic Boundary Fault plane (*op. cit.*).

(2) The Odra Event (R) is represented by two close dates from Ligota Tułowicka melabasanite lavas (L II: 27 ± 3 Ma) and from older melanephelinite lava fill of crater resp. caldera of Góra Św. Anny (A II: 26·5 ± 3 Ma). The age of the event corresponds with the late Oligocene (Chattian resp. Egerian). The palaeomagnetic pole position obtained for A II is, however, different from that for L I—III. A better agreement between the palaeopole positions may be obtained by rotating the A II palaeopole with respect to a horizontal axis parallel to the Odra Fault (roughly W—E) by about 25° south. This could suggest a post-emplacement rotation of the A II melabasanite lava as a result of tilting related to the formation of faults transversal to the Odra Line. With such transversal system of faults is probably associated the melanephelinite lava of A I (Birkenmajer, Siemiątkowski, 1977). The date for L I—III corresponds to the lavas extruded either directly from the Odra Fault or from the faults transversal to the Odra Fault (Birkenmajer, 1974a), the date for A II — to the lava fill of a central volcano, possibly also related to the Odra Fault line. Both dates seem to indicate the age of faulting.

(3) The Gracze Event (N) is represented by melabasanite lava flow (lower NW flow) at Gracze (G III: 25 ± 3 Ma) which was extruded from SW—NE-trending faults transversal to the Odra Fault (Birken-

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[3] Petrographic attribution of basaltic rocks dealt with here is after A. Nowakowski and J. Siemiątkowski (see Birkenmajer *et al.*, 1973; Birkenmajer, Siemiątkowski, 1977; Kruczyk *et al.*, 1977b). Other names have often been used by Wojno *et al.* (1951), Smulikowski (1960), Birkenmajer and Nairn (1969), Birkenmajer *et al.* (1970), Jerzmański (1956), Jerzmański and Maciejewski (1968) and others.

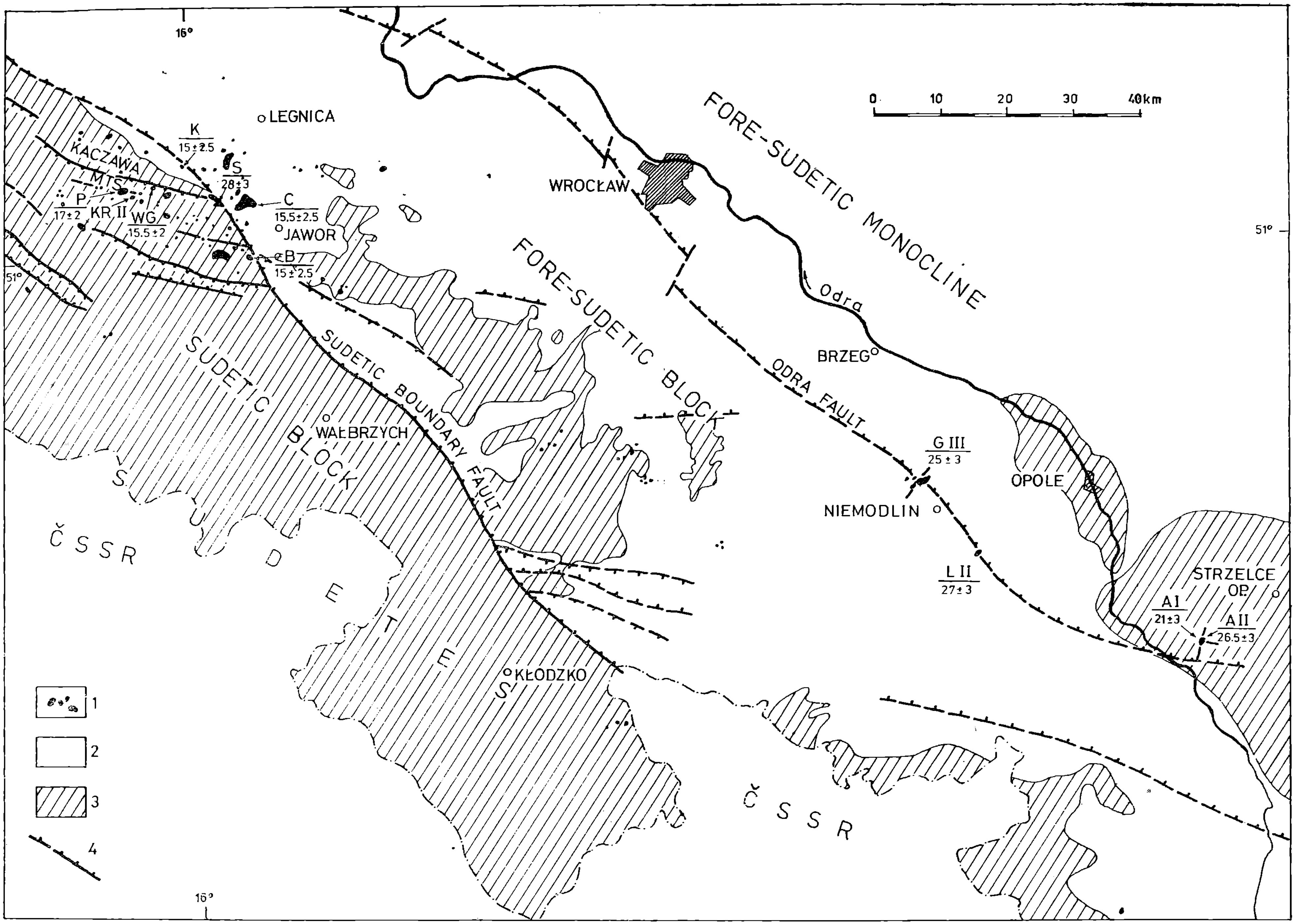
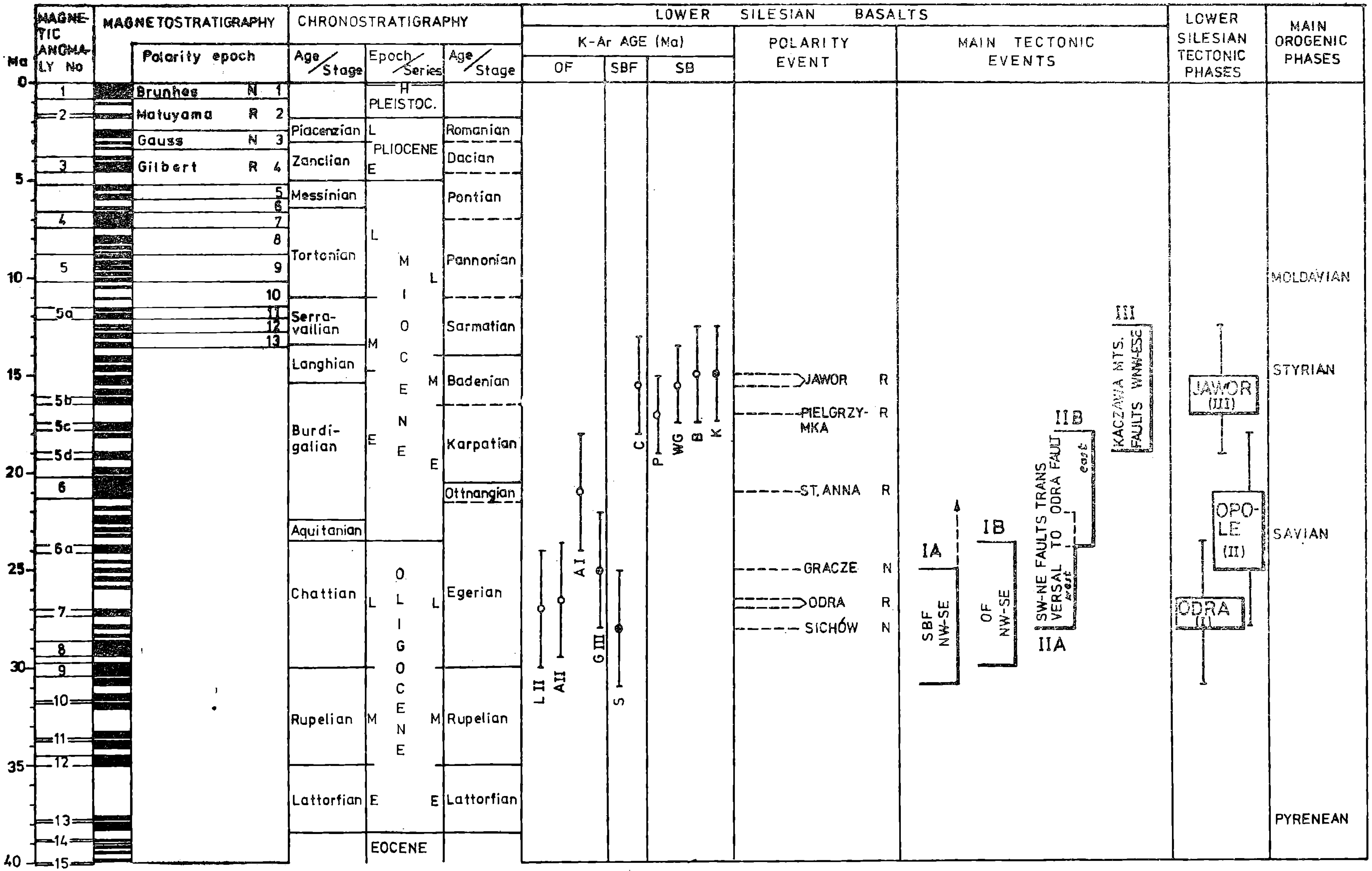


Fig. 1. Location of investigated basaltic sites in Lower Silesia against simplified geological structure of the area. 1 — Cenozoic (mainly Tertiary) basaltic rocks; 2 — Cenozoic sedimentary cover; 3 — Pre-Cenozoic rocks; 4 — Major Tertiary faults (data from Birkenmajer *et al.*, 1970; Oberc, Dyjor, 1968, 1969; Oberc, 1972). A I, II — Góra Św. Anny; B — Bazaltowa; C — Męcinka; G — Gracze; K — Kozów; KR II — Krzeniów; L — Ligota Tułowicka; P — Pielgrzymka; S — Sichów; WG — Wilcza Góra. Numbers denote K-Ar ages

Fig. 1. Lokalizacja badanych skał bazaltowych na tle uproszczonej mapy geologicznej Dolnego Śląska. 1 — skały bazaltowe kenozoiczne (głównie trzeciorzędowe); 2 — pokrywa osadowa kenozoiczna; 3 — skały przedtrzeciorzędowe; 4 — główne uskoki trzeciorzędowe (dane według Birkenmajera *et al.*, 1970; Oberca i Dyjora, 1968, 1969 i Oberca, 1972). A I, II — Góra Św. Anny; B — Bazaltowa; C — Męcinka; G — Gracze; K — Kozów; KR II — Krzeniów; L — Ligota Tułowicka; P — Pielgrzymka; S — Sichów; WG — Wilcza Góra. Liczby oznaczają wiek radiometryczny (K-Ar)

Table (Tabela) 1



Correlation of polarity events, radiometric ages and tectonic event of Lower Silesian basaltic rocks related to deep-seated fractures, with chronostratigraphic and magnetostratigraphic scales. Magnetostratigraphic scale after Watkins (1976). OF — Odra Fault; SBF — Sudetic Boundary Fault; SB — Sudetic Block. The remaining symbols — as in Fig. 1

Korelacja zdarzeń polaryzacji wieku radiometrycznego i zdarzeń tektonicznych bazaltów dolnośląskich w strefach głębokich uskoków, ze skalą chronostratygraficzną i magnetostratygraficzną. Skala magnetostratygraficzna według Watkinsa (1976). OF — uskok Odry; SBF — uskok sudecki brzeżny; SB — blok sudecki. Pozostałe symbole jak na fig. 1

majer, 1974a, b). The lavas were succeded by plugs, both showing a very similar palaeomagnetic characteristics (Birkenmajer *et al.*, 1973). This suggests a short time interval for the volcanic activity of Gracze, most probably within the same polarity event. The event corresponds to the late Oligocene, resp. the Oligocene/Miocene boundary (Egerian-Eggenburgian resp. Chattian-Aquitanian).

(4) The St. Anna Mt. Event (R) is represented by the younger melanephelinite lava fill of crater resp. caldera at Góra Św. Anny (A I), dated as 21 ± 3 Ma, which thus corresponds to the early Miocene. The emplacement of the lava occurred along a SW—NE-trending fault transversal to the Odra Line, of the same system as that recognised at Gracze.

(5) The Pielgrzymka Event (R) is represented by basalt plug which used a WNW—ESE fault cutting through the Kaczawa Mountains. The age of the event (17 ± 2 Ma) corresponds to the boundary of the Karpatian and Badenian stages of the Miocene.

(6) The Jawor Event (R) is represented by lava flow of Męcinka (C: melabasanite, 15·5 ± 2·5 Ma) and by plugs of Bazaltowa (B: melabasanite, 15 ± 2·5 Ma) and Wilcza Góra (WG: basanite, 15·5 ± 2 Ma). The age of the event corresponds with the Badenian, resp. late Karpatian to early Sarmatian stages of the Miocene.

The Męcinka melabasanite lava occurs in the downthrown Fore-Sudetic Block, immediately northeast of the Sudetic Boundary Fault. It could have been extruded from fractures or plugs younger than the latter fault, concealed under Cenozoic cover.

The dates for Bazaltowa and Wilcza Góra correspond to plugs emplaced along WNW—ESE-running faults which cut through the Kaczawa Mountains (Sudetic Block) and seem to terminate at the Sudetic Boundary Fault. These dates are believed to represent the age of faulting.

The Kozów melanephelinite lava flow (K: 15 ± 2·5 Ma) corresponds in age with the Jawor Event, but is normally magnetized in the direction of the present geomagnetic field. The lava occurs within the Sudetic Block, immediately southwest of the western prolongation of the Sudetic Boundary Fault. The lava could have been connected either with a fissure parallel to the WNW—ESE faults of the Kaczawa Mountains or with a plug in the vicinity of the Sudetic Boundary Fault.

It should be noted that much older date, 36 ± 2 Ma, was obtained for the Bazaltowa plug, and 34 ± 2 and 29 ± 2 Ma for the Męcinka lava, on He-dating (Urry, 1936; see also Jerzmański, 1956). The K-Ar dating shows that the He radiometric ages do not represent the age of the rocks (Kruczyk *et al.*, 1977b).

Jerzmański (1965) described a weathered basaltic lava flow about 100 m thick from a borehole situated between the Męcinka lava cover and the Sudetic Boundary Fault. The flow was underlain by Upper Eocene and overlain by Upper Oligocene-Lower Miocene sediments as indicated by their pollen content. A Middle or Lower Oligocene age of the basalt flow was thus suggested. Jerzmański (*op. cit.*, Fig. 5: cross--section 3) thought that the basalt from the borehole and the lava flow of Męcinka are of similar age and belong to the same lava cover. His conclusions were apparently based on He-dating by Urry (1936) which dates are, however, too high and do not represent the age of the rock as proved by K-Ar dating (Kruczyk *et al.*, 1977b). The present conclusion is that we deal here with two separate lava flows, an older one (Oligocene) represented by the basaltic lava in the borehole, and a younger one (Middle Miocene, as indicated by K-Ar dating) represented by the lavas quarried at Męcinka and its vicinity. The lava flow in the borehole would possibly correlate in age and origin with the Sichów melabasanite plug (28 $\pm$ 3 Ma: late Oligocene).

AGE OF TERTIARY FAULTING IN LOWER SILESIA

Three well pronounced phases of Tertiary faulting may be distinguished in the area between the Sudetic Block and the Fore-Sudetic Monocline, their age based on K-Ar dating of basaltic rocks related to these faults. It is assumed that the main basaltic activity was genetically bound to the formation of those deep-seated fractures, which often reach down to and displace the Moho discontinuity, and that there was no significant geological age difference between the formation of fractures and intrusion resp. extrusion of basaltic magma from these fractures. The apparent overlapping of the ages of faulting (Tab. 1) results from comparatively broad error limits (2 to 3 Ma) for particular radiometric dates.

I. The late Oligocene (Chattian resp. Egerian) phase is characterized by:

(IA) The formation of NW—SE-trending Sudetic Boundary Fault and related melabasanite plug of Sichów (28 $\pm$ 3 Ma). This seems to be a deep-seated fault as indicated by the depth of magmatic chamber for the Sichów plug — about 50 km (calculated on magnetic fraction minerals of the rock). There seems to be a palaeomagnetic evidence (see the Sichów Event) that the plug had been rotated at a later stage, due to an oversteepening of the fault plane;

(IB) The formation of NW—SE-trending Odra Fault (changing to WNW—ESE at its eastern termination) and related basaltic lava effusions from chambers situated at the depths of about 45 km (Góra Św. Anny, A II: melanephelinite) and ca 50 km (Ligota Tułowicka, L I—III: melabasanite) — see Kruczyk *et al.* (1977a), i.e. well below the Moho discontinuity which in the area of the Odra Fault lies at about 30—32 km. The Odra Fault is a deep-seated fracture separating the Fore-Sudetic Block from the Fore-Sudetic Monocline, which displaces the Moho by 2—3 km (Guterch *et al.*, 1973a, b, 1975a, b). The age of the faulting, based on related basaltic effusions, 26·5 ± to 27 ± 3 Ma (L II and A II sites respectively), seems to be slightly younger than that of the Sudetic Boundary Fault.

II. The late Oligocene/early Miocene phase is characterized by:

(IIA) The formation of SW—NE-trending faults transversal to the Odra Fault in the vicinity of Niemodlin, and the formation of melabasanite stratovolcanoes, with lava effusions from the depth of about 45 km (Gracze — see Kruczyk *et al.*, 1977a). The faulting is dated by the oldest lavas as 25 ± 3 Ma;

(IIB) The formation of SW—NE (SSW—NNE)-trending faults transversal to the Odra Fault (roughly W—E) in the vicinity of Strzelce Opolskie, and related melabasanite lava effusion from the depth of about 50 km (Góra Św. Anny A I: see Kruczyk *et al.*, 1977a). The faulting is dated by subsequent lava fill of crater resp. caldera of a central volcano as 21 ± 3 Ma.

III. The Middle Miocene phase (mainly Badenian) is characterized by the formation of normal, WNW—ESE-trending faults which cut through the upthrown Sudetic Block (Kaczawa Mountains). The age of the phase based on radiometric (K-Ar) ages of the related basaltic lavas and plugs is between 17 ± 2 and 15 ± 2·5 Ma, i.e. it corresponds with the Badenian stage. The Pielgrzymka basalt plug (P: 17 ± 2 Ma) delimits the lower age of faulting, the Męcinka melabasanite lava flow (C: 15·5 ± ± 2·5 Ma) and the Wilcza Góra basanite plug (WG: 15·5 ± 2 Ma) correspond to successively younger faults, the Bazaltowa melabasanite plug (B: 15 ± 2 Ma) and the Kozów melanephelinite lava flow (K: 15 ± 2·5 Ma) delimit the upper age of faulting.

The faults discussed seem to be deep-seated fractures as is shown by the depth of magmatic chambers calculated on magnetic mineral fraction of the rocks for particular sites: Pielgrzymka (P) — about 65 km; Męcinka (C) — about 50 km; Bazaltowa (B) — about 40—45 km; Wilcza Góra (WG) — about 60 km; Krzeniów (KR II) — about 60 km.

STAGES OF TERTIARY DEFORMATION IN LOWER SILESIA

The interrelation of faulting and basaltic volcanism in Lower Silesia allows to formulate some more general conclusions as to the stages of Tertiary deformation of that area, the ages of which being based on radiometric (K-Ar) age determination of volcanics. Three major phases of deformation may be distinguished, each given a local name after the best dated event: (I) the Odra phase (late Oligocene); (II) the Opole phase (boundary of Oligocene and Miocene), and (III) the Jawor phase (Middle Miocene: Badenian).

I. The *Odra phase* is subsequent to the Pyrenean phase but older than the Savian phase. During this phase of crustal tension, major deep-seated faults running NW—SE were formed in Lower Silesia: the Odra Fault (OF) and the Sudetic Boundary Fault (SBF). The age of faulting is 28 ± 3 Ma (for SBF) and 27 to 26·5 ± 3 Ma (for OF).

According to Oberc (1972) the Odra Fault is a normal (gravity) fault some 200—300 km long or, rather, a zone of deep-seated fractures some 10—12 km wide (Guterch *et al.*, 1975a). Its surface trace is concealed under thick Cenozoic cover and there is no morphological step corresponding to the fault. The Laramian age of the fault, as assumed by Oberc (1972) finds, however, no confirmation by the present study.

The Sudetic Boundary Fault is a normal (gravity) fault about 150 km long. For the most part, it is well expressed in the morphology of the area as a step between the foothills of the Fore-Sudetic Block (downthrown) and the hills and low mountain ranges of the Sudetic Block (upthrown). The development of the Neogene to Quaternary sediments north of the fault and analysis of the relief formation indicate that the fault was active from late Miocene through Quaternary times (Oberc, Dyjor, 1968, 1969; Oberc, 1972). The present study indicates that the fault was formed already during the late Oligocene but was probably renewed later, as suggested by the Sichów palaeomanetic data.

II. The *Opole phase* corresponds well with the Savian compression in the Carpathians. Predominantly sinistral strike-slip movement displaced the Odra Fault along short faults running SW—NE (Birkenmajer, 1974a, b). The decreasing age of faulting in an eastward (SE) direction seems to indicate the general sense of migration of deformation with time toward the east (i.e. toward the Carpathians). The age of faulting lies within the limits of 25 ± 3 Ma (Niemodlin area: Gracze) and 21 ± 3 Ma (Strzelce Opolskie area: Góra Św. Anny I).

The rotation of the Sichów melabasanite plug due to the oversteepening of the Sudetic Boundary Fault plane, as suggested by palaeomagnetic data, could correspond with the Opole (Savian) phase of compression.

III. The *Jawor phase* corresponds with the Styrian folding and faulting in the Carpathians. During this phase of tension in the Sudetes, WNW—ESE-directed normal fault were formed in the Sudetic Block (Kaczawa Mountains). The age of faulting lies within the limits of 17 ± 2 and 15 ± 2 Ma.

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STRESZCZENIE

Datowanie radiometryczne (K-Ar) i paleomagnetyczne trzeciorzędowych skał bazaltowych związanych ze strefami głębokich uskoków między monokliną przedsudecką a blokiem sudeckim na Dolnym Śląsku pozwoliło na wyróżnienie trzech głównych faz trzeciorzędowych deformacji tektonicznych w tym obszarze: 1) fazy odrzańskiej — tensyjnej (późny oligocen), w której wyniku zaczął się tworzyć uskok sudecki brzeżny (o kierunku NW—SE) i system uskokowy Odry (o kierunku NW—SE w części zachodniej i WNW—ESE w części wschodniej); 2) fazy opolskiej — kompresyjnej (późny oligocen/wczesny miocen), odpowiadającej sawskiej fazie fałdowań w Karpatach, w której wyniku powstały uskoki przesuwcze (o kierunku SW—NE), poprzeczne do uskoku Odry, a prawdopodobnie także zachodziła rotacja kompresyjna w strefie uskoku sudeckiego brzeżnego; 3) fazy jaworskiej — tensyjnej (środkowy miocen, głównie baden), odpowiadającej fazie styryjskiej, która spowodowała powstanie uskoków (o kierunku WNW—ESE) w Górach Kaczawskich.