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# DEVONIAN TECTONOTHERMAL ACTIVITY IN THE SOWIE GÓRY GNEISSIC BLOCK, SUDETES, SOUTHWESTERN POLAND: EVIDENCE FROM Rb-Sr AND U-Pb ISOTOPIC STUDIES

**O. van Breemen**[1], **D. R. Bowes**[2], **M. Aftalion**[3] **& A. Żelaźniewicz**[4]

[1] *Geological Survey of Canada, 601 Booth Street, Ottawa, K1A 0E8, Canada*
[2] *Department of Geology, University of Glasgow, Glasgow G12 8QQ, Scotland*
[3] *Isotope Geology Unit, Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow G75 OQU, Scotland*
[4] *Polish Academy of Sciences, Institute of Geological Sciences, ul. Podwale 75, 50-449 Wrocław, Poland*

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Abstract: In widely developed biotite-oligoclase-quartz paragneiss a U-Pb upper intercept age of 1750±270 is interpreted as a (possibly mixed) sedimentary provenance age. U-Pb monazite and Rb-Sr biotite ages of 381±2 Ma and *ca.* 370–360 Ma, respectively, indicate rapid Devonian cooling from upper amphibolite to greenschist facies temperatures. The isotopic data are consistent with stratigraphic evidence for rapid Devonian uplift. U-Pb zircon isotopic data support, but do not prove conclusively, that the metamorphism associated with $D_2$ in the Sowie Góry block was Devonian in age. The $D_4$ event has been dated at 370±4 Ma using Rb-Sr in large muscovite books from a pegmatite in an $F_4$ hinge zone. Low-mid-amphibolite facies $D_5$ activity cannot be much younger in view of the biotite cooling ages.

The $D_{2-5}$ tectonothermal activity, rapid cooling and uplift in the Sowie Góry block of the Middle Sudetes pre-date the early Carboniferous granulite facies metamorphism and granitic plutonism further S in the Moldanubian zone of the Hercynides in Czechoslovakia.

Key words: biotite, cooling age, Devonian, gneiss, Hercynides, isotopic disturbance, monazite, muscovite, Rb-Sr mineral ages, Rb-Sr whole-rock isochron, stratigraphy, U-Pb concordia, uplift, zircon.

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## INTRODUCTION

The Sudetes border region between southwestern Poland and Czechoslovakia constitutes one of the horsts of Hercynian Europe and is bounded to the NE and SW by Cenozoic and Mesozoic cover (Figs. 1 and 2). Geologically this is an extremely complex region. Its western and central parts contain large masses of Hercynian granite but otherwise it consists of a number of

* Sowie Góry block = Góry Sowie block.

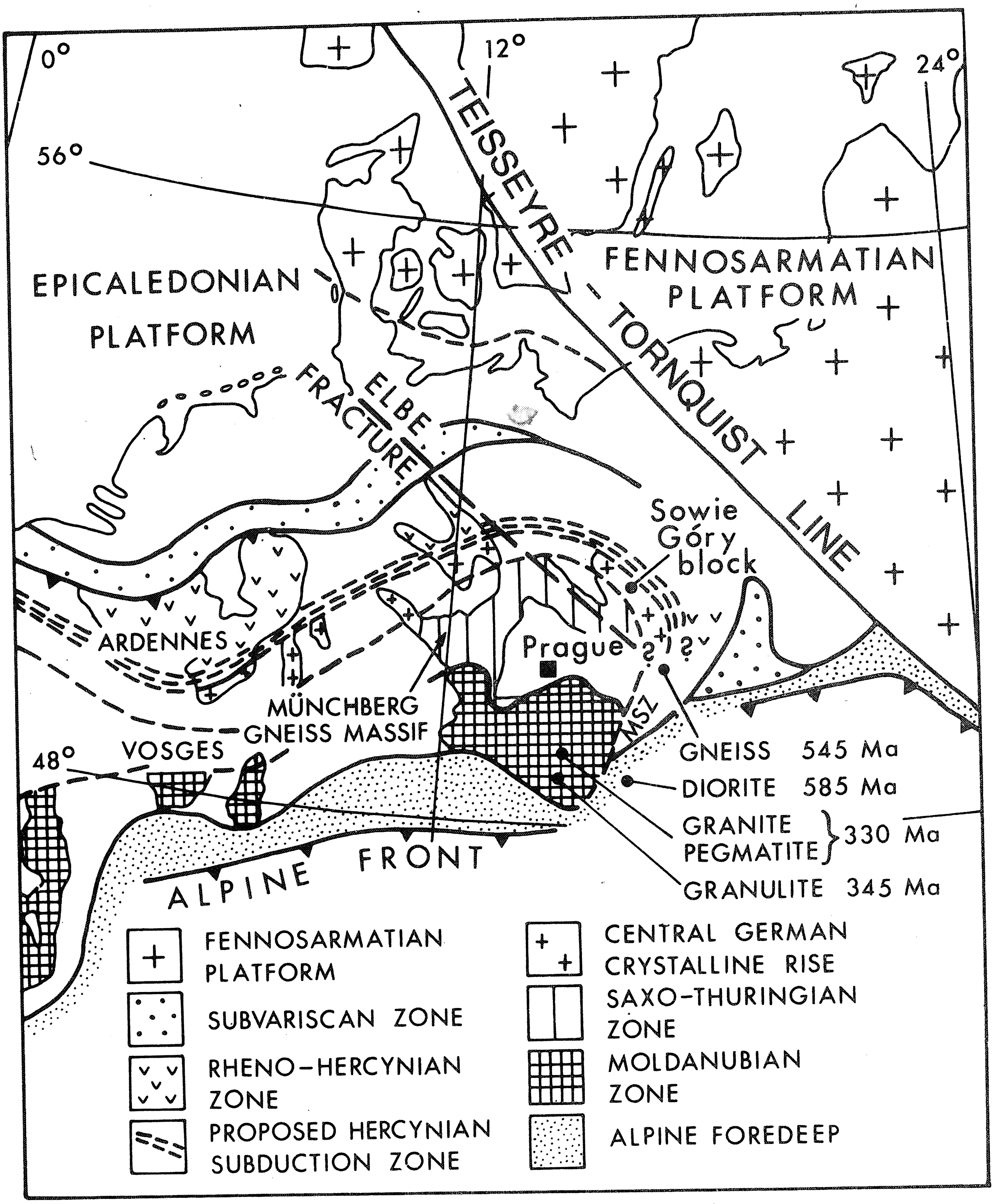


Fig. 1. Outline geological map showing relics of the Hercynian mountain chain in central and western Europe with delineation of main structural zones; continuation of these zones from Central Europe into southern Poland and northern Czechoslovakia is after Ellenberger and Tamain (1980); the Elbe fracture beyond which other workers do not extend these zones is also shown (*cf.* Matte, 1986) as are ages (Ma) of products of Cadomian and Hercynian episodes in Czechoslovakia (from van Breemen *et al.*, 1982); MSZ – Moravo-Silesian zone

structural-stratigraphic domains or blocks, generally bounded by tectonic breaks.

Its crustal position within the Hercynides is not clear. The interpretation of Ellenberger and Tamain (1980), who extend eastwards into the Sudetes the zones of contrasting stratigraphy and tectonic history in Central Europe (*cf.* Stille, 1951; Behr *et al.*, 1980), places it between the crystalline rocks of the Moldanubian zone and the foredeep of the Rheno-Hercynian zone (Fig. 1). This intermediate region, consisting of the Saxo-Thuringian zone and the Central German Crystalline Rise, is a complex domain with a strong vertical component of movement (Schwab & Mathe, 1981). Some authors (*cf.* Windley, 1984, fig. 14.2; Matte, 1986, fig. 1) do not continue the Hercynian zones eastwards into the Sudetes, but terminate them in the region of the Elbe fracture which is generally parallel to the Teisseyre-Tornquist line (Arthaud & Matte, 1977). According to Lorenz (1976) the Sudetes-Silesian region represents the lateral collision and shear zone between a NW-moving South European continent and the western margin of Fennosarmatia. Whatever may be the crustal setting of the Sudetes, its internal tectonic pattern is complex and it is unlikely that its geological evolution can be explained in terms of the simple application to it of knowledge from adjacent regions.

Stratigraphical and palaeontological studies indicate that some of the units in the Sudetes Mountains represent a folded and metamorphosed geosynclinal pile containing late Silurian fossils and having an unconformable relationship with Upper Devonian epicontinental sediments (e.g. Gunia & Wojciechowska, 1971). Interpretation of subsurface data in northwestern Poland indicates corresponding stratigraphical relationships (e.g. Czermiński, 1967; Dadlez, 1974; Znosko, 1974). Further to the NW, isotopic age determinations on metamorphic and igneous rocks encountered beneath the Mesozoic and Cenozoic cover indicate that a branch of the Caledonides extends eastwards under the North Sea into northern Germany and Poland (Znosko, 1974; Ziegler, 1978). However a radiometric study of the Bohemian massif of Czechoslovakia to the S (van Breemen *et al.*, 1982) revealed no clear evidence for Caledonian activity there (see also Zwart & Dornsiepen, 1978): the isotopic data indicate basement formation during the Cadomian episode, which straddles the Precambrian-Cambrian boundary, and intense metamorphism, tectonism and plutonism bracketed in the interval 345–330 Ma, i.e. in early Carboniferous times during the Hercynian episode. Geological evidence in Czechoslovakia indicates that rocks of the Moldanubian zone have been thrust onto the western margin of the Moravo-Silesian zone (Fig. 1; Jaroš & Mísař, 1976; Vrána, 1979) which in the S consists mainly of Cadomian granitoid basement but includes Devonian and lower Carboniferous sediments and volcanic rocks further N. Here the intensity of deformation and metamorphism in the Devonian assemblage increases from E to W while the folds verge to the ESE and are associated with SSW-striking thrusts. Exposures of pre-Devonian crystalline rocks occur in a number of domal structures near the northern extension of the Moravo-Silesian lineament.

The Sudetes region immediately W of the Moravo-Silesian lineament (the tectonic boundary with the Moravo-Silesian zone) is built by the Śnieżnik metamorphic complex (Fig. 2) which consists largely of (1) the Stronie schists,

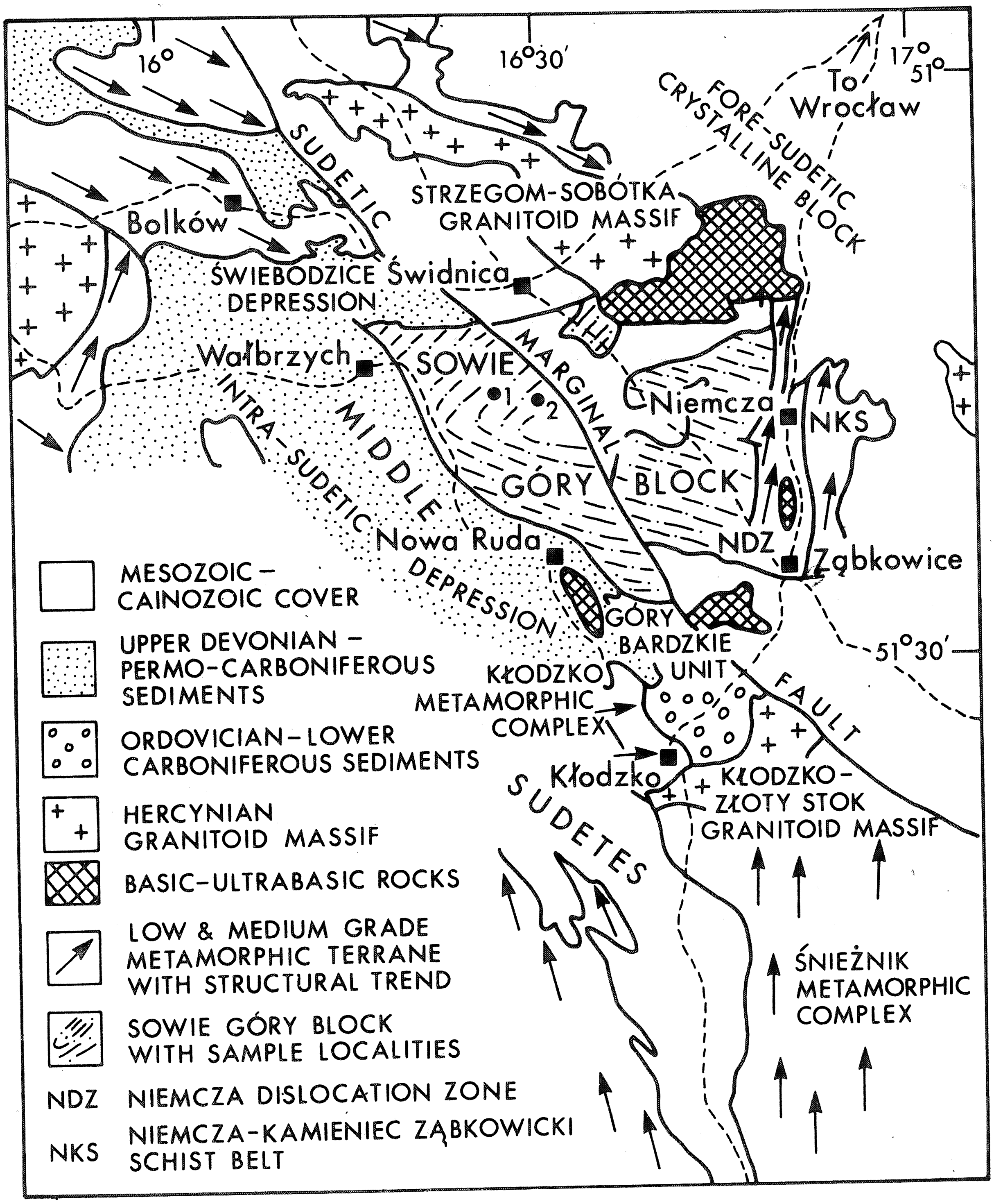


Fig. 2. Simplified geological map of the Middle Sudetes (after Sawicki, 1967) with locations of dated samples

(2) the Śnieżnik gneisses, which are coarse-grained, microcline-rich augen gneisses and (3) the Gierałtów gneisses which correspond compositionally with the Śnieżnik gneisses but are much finer grained. Rb-Sr whole-rock isotope data from the Śnieżnik gneisses in northwestern Czechoslovakia yield a regression age of $487 \pm 11$ Ma and a maximum possible age of 600 Ma (van Breemen *et al.*, 1982). These rocks contain evidence of extreme shearing (Teisseyre, 1964, fig. 3) and, by analogy with the ubiquitously sheared rocks in the Moldanubian zone bordering the Moravo-Silesian lineament, and on the basis of the southeasterly vergence of Devonian rocks in the northern part of the Moravo-Silesian zone, it is likely that much of the structural fabric of the Śnieżnik metamorphic complex was formed by SE-directed Hercynian thrusting (see also Bederke, 1929, 1934; Pauk, 1953, 1977). However K-Ar biotite and phengite ages of *ca.* 380 Ma for gneisses and eclogites in the Śnieżnik metamorphic complex (Bakun-Czubarow, 1968) suggest earth movements, probably uplift, in mid-Devonian times.

The rocks selected for this age and isotope study are those of the Sowie Góry block, an inlier of high grade rocks to the NW of the Śnieżnik metamorphic complex. They were selected because of the control available on their structural, metamorphic and igneous history resulting from the work of Żelaźniewicz (1979, 1984, 1985, 1987). The Sowie Góry block is separated from the Śnieżnik metamorphic complex by a Hercynian granitoid pluton, the Permo-Carboniferous Intra-Sudetic depression and the Góry Bardzkie unit embracing Ordovician-lower Carboniferous sediments (Fig. 2).

The aims of the study are (1) to place temporal controls on the formation of the high grade rocks of the Sowie Góry block which, until recently, have been widely interpreted as being Precambrian in age (e.g. Grocholski, 1967; Morawski, 1973), (2) to place constraints on their provenance and (3) to compare the structural and metamorphic development of this block with that of the Bohemian massif to the S.

## GEOLOGY OF SOWIE GÓRY BLOCK

### Regional setting

The Sowie Góry block occurs in the middle of the Sudetes region. It is a triangular tectonic block of about 650 km$^2$ composed of polyphase deformed gneisses and migmatites accompanied by minor amounts of other crystalline rocks. The elevated (Sowie Góry Mts) and foreland parts are divided by the Sudetic marginal fault and it is surrounded by various units of a late Proterozoic-Palaeozoic succession (Fig. 2). E of the block occur medium-grade metamorphic rocks of the Niemcza dislocation zone (related to eastward thrusting of rocks of the Moldanubian zone over rocks of the Moravo-Silesian zone) and Niemcza – Kamieniec Ząbkowicki schist belt, and late Carboniferous granitoids of the N—S-disposed Strzelin-Žulova massif. To the N the Sowie Góry block is bordered by the upper Devonian-lower Carboniferous clastic sedimentary assemblage of the Świebodzice depression, basic and ultrabasic rocks of an ophiolite assemblage, and the metamorphic envelope of the late Carboniferous Strzegom-Sobótka granitoid massif, largely hidden beneath Cenzoic deposits. To the SW and S the gneisses abut against the Permo-Carboniferous rocks of the Intra-Sudetic depression and the Ordovician-lower Carboniferous sedimentary assemblage of the Góry Bardzkie unit, both the basins being flanked by the post-Silurian—pre-late Devonian Kłodzko metamorphic unit (Fig. 2).

## Rock types, structure and metamorphism

Over 90% of the Sowie Góry block consists of gneisses and migmatites in which biotite, plagioclase ($An_{15-35}$), quartz and muscovite are essential constituents, microcline, sillimanite, cordierite and almandine are generally minor constituents and apatite, kyanite, monazite, zircon and Fe oxides are

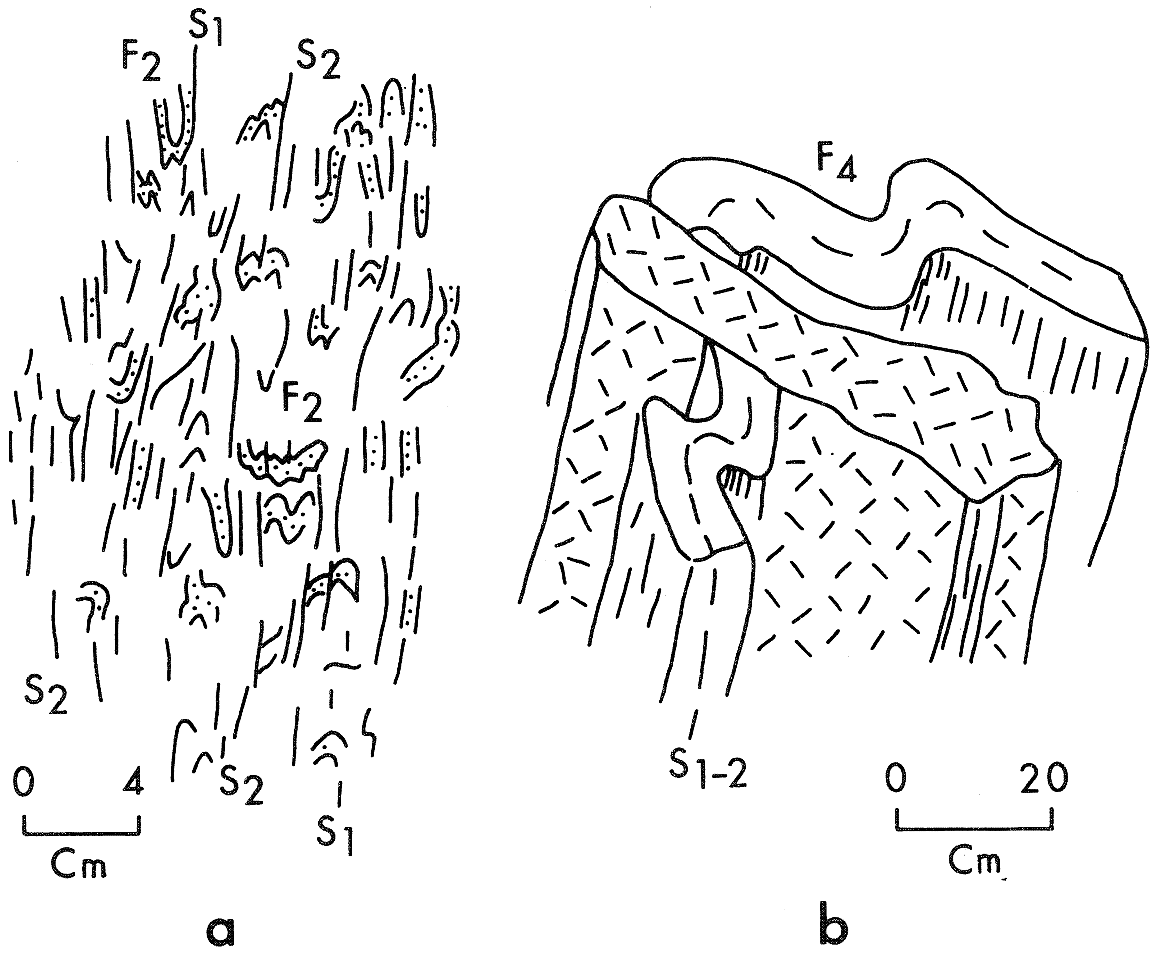


Fig. 3. Fabric elements and relationships of rock types in the Sowie Góry block (after Żelaźniewicz, 1979, figs 3, 7); (*a*) biotite-oligoclase-quartz gneiss with quartzofeldspathic patches (*dotted*) in an $S_2$-dominated biotite-oligoclase assemblage; (*b*) muscovite-bearing pegmatite (*dashes*) in hinge zone of $F_4$ fold cutting biotite-oligoclase-quartz gneiss

accessory constituents. Local abundance of sillimanite (fibrolite), cordierite or microcline gives variants to the biotite-oligoclase-quartz gneiss (Fig. 3a) that constitutes over two thirds of the block and the two mica-oligoclase-microcline-quartz variety that occurs in the southwestern part of the block.

The gneisses are associated with minor proportions of granulite (in pre-$D_2$ tectonic slices – Żelaźniewicz (1985)), amphibolite, marble, calc-silicate rock, serpentinite and hyperite. The medium-grained often thinly banded granulites consist of quartz, plagioclase ($An_{25}$), alkali feldspar, garnet and kyanite, with apatite, rutile, zircon and opaque minerals as accessory minerals. Some of the amphibolites are associated with the marbles and are of sedimentary (or pyroclastic) derivation. Others containing relics of primary igneous texture are orthoamphibolites.

The gneisses and associated rocks are cross-cut by many pegmatite dykes some of which occur in the hinge zones of $F_4$ folds (Fig. 3b). These are from several tens of centimetres to 2 – 3 m thick and consist of quartz, plagioclase, microcline, biotite and muscovite, with scarce tourmaline, garnet, apatite, beryl and kyanite. Numerous lensoid or irregularly-shaped bodies of granite-granodiorite, up to 1 m thick, occur within the gneisses in the central part of the block. Locally there are also masses of homophanous plagioclase-quartz-biotite rock (the "homophanous granitoid-looking gneisses" of Żelaźniewicz (1979, pp. 197 – 199)) whose development may have been the result of static recrystallization at low-mid-amphibolite facies (Żelaźniewicz, 1987).

The polyphase deformational and polymetamorphic history of the rocks of the Sowie Góry block are summarised in Table 1.

Table 1

Outline of tectonometamorphic history of Sowie Góry gneisses

| | Structure | Metamorphism |
|---|---|---|
| $D_1$ | Upright and recumbent tight to isoclinal, ESE- to E-trending folds ($F_1$) | Penetrative axial planar foliation ($S_1$), commonly the dominant planar fabric; mid-amphibolite facies (almandine ± kyanite zone) |
| | Upthrusting of felsic granulites | |
| $D_2$ | Upright to inclined, tight to open, NE-trending folds ($F_2$); prominent in NW part | Axial planar schistosity ($S_2$), locally penetrative; mineral and $S_1 - S_2$ intersection lineation ($L_2$); upper amphibolite facies (sillimanite I zone) |
| $D_3$ | Asymmetrical, disharmonic, tight to open SE-trending folds ($F_3$); prominent in SE part | Axial planar schistosity ($S_3$); locally prominent; local leucosome; mineral lineation ($L_3$); upper amphibolite facies (sillimanite I zone) |
| $D_4$ | Open, asymmetrical folds ($F_4$), subvertical axes, subvertical N-trending axial planes | Very weak mineral growth ($S_4$); low-mid-amphibolite facies; pegmatites |
| $D_5$ | Open, recumbent ESE- to E-trending folds ($F_5$), subhorizontal axial planes | Very weak, sporadic axial planar cleavage ($S_5$); patchy textural homophanisation; low-mid-amphibolite facies |

### Isotopically analysed rocks

The biotite-oligoclase-quartz gneiss displaying the rock fabric and mineralogy characteristic of the $D_2$-$M_2$ tectonothermal event was collected for U-Pb zircon and monazite and Rb-Sr whole-rock and biotite isotopic analysis. Because of the polymetamorphic history evidenced in the Sowie Góry block, the samples for Rb-Sr whole-rock analysis were large, generally 6–8 kg, with the smallest 4 kg. For Rb-Sr mineral analysis biotite was separated from samples la and b. For the U-Pb mineral analysis sample *ca.* 10 kg was crushed. Books of muscovite up to $5 \times 5 \times 1$ cm in size occurring in an $F_4$-controlled pegmatite were also collected for Rb-Sr mineral analysis (sample 2).

*Biotite-oligoclase-quartz gneiss.* The locality is an abandoned quarry on the southern side of the Jezioro Bystrzyckie dam-lake at Zagórze Śląskie, 750 m W of the "Fregata" hostel; specimens were collected over an area of 160 $m^2$. The rock has ubiquitous $F_2$ folds and $S_2$ is a very strongly expressed penetrative foliation (Fig. 3a). Melanocratic layers (2–6 mm) are composed of quartz, plagioclase ($An_{23-30}$), biotite and sillimanite with occasional accessory garnet, apatite, zircon and monazite. Leucocratic layers (2–10 mm) are dominantly quartz and plagioclase ($An_{23-30}$) with scarce representatives of the other minerals in the darker layers. The thickness ratio of these layers is 1:1–1:5.

*Muscovite-bearing pegmatite.* The locality is a small inactive quarry at Lutomia Górna, 800 m E of the forester's house and 200 m SSE of the main road. The pegmatite occurs as a 0.5 m thick dyke cross-cutting biotite-oligoclase-quartz gneiss. It is composed of plagioclase, potassium feldspar, quartz, biotite, muscovite and tourmaline.

## RESULTS OF AGE AND ISOTOPIC STUDY

### Data

Analytical techniques are identical to those described in van Breemen *et al.* (1982). All ages have been calculated or recalculated with the decay constants as recommended by Steiger and Jäger (1977). Regression analyses are according to York (1969).

The spread of Rb/Sr ratios in the biotite-oligoclase-quartz gneiss at Zagórze Śląskie (Table 2, sample 1) is limited and data points show much scatter on the isotope ratio plot (Fig. 4). A regression analysis yields an age of $350 \pm 150$ Ma and an initial $^{87}Sr/^{86}Sr$ of $0.712 \pm 0.003$.

Rb-Sr isotopic data for biotite separated from two samples of the gneiss and for muscovite books from the pegmatite are also given in Table 2. All Rb-Sr mica ages have been calculated with an initial $^{87}Sr/^{86}Sr$ of $0.710 \pm 0.007$. The

Table 2

Rb-Sr whole-rock and mineral data and model ages

| Sample | Rb (p.p.m.) | Sr (p.p.m.) | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr$ | Model age (Ma) |
|---|---|---|---|---|---|
| | 1 Biotite-oligoclase-quartz gneiss, Zagórze Śląskie | | | | |
| 1a wr | 83.8 | 174 | 1.398 | 0.71783 | |
| a bt | 366 | 10.6 | 105.4 | 1.2500 | 360±7 |
| b wr | 88.1 | 175 | 1.460 | 0.71880 | |
| b bt | 346 | 9.81 | 107.4 | 1.2785 | 372±7 |
| c wr | 60.1 | 119 | 1.466 | 0.71946 | |
| d wr | 54.5 | 171 | 0.9260 | 0.71645 | |
| dupl | 54.2 | 171 | 0.9181 | 0.71621 | |
| e wr | 88.5 | 186 | 1.380 | 0.71866 | |
| f wr | 89.6 | 203 | 1.280 | 0.71786 | |
| | 2 Muscovite-bearing pegmatite, Lutomia Górna | | | | |
| 2a ms | 768 | 1.60 | 4697 | 25.006 | 363±4 |
| b ms | 2176 | 3.84 | 10164 | 53.936 | 368±4 |
| c ms | 1372 | 2.36 | 13366 | 71.643 | 373±4 |
| d ms | 1397 | 2.46 | 10923 | 58.564 | 372±4 |
| e ms | 1883 | 3.09 | 18996 | 100.500 | 369±4 |
| f ms | 3148 | 6.15 | 6483 | 35.233 | 374±4 |

Explanation: Samples la-f are samples RC 1743, 1748, 1749, 1751, 1752, 1754 and samples 2a-f are samples 1768 A-F in the rock catalogue of Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow G75 OQU, Scotland; locations of samples given in text; wr — whole rock, dupl — duplicate, bt — biotite, ms — muscovite.

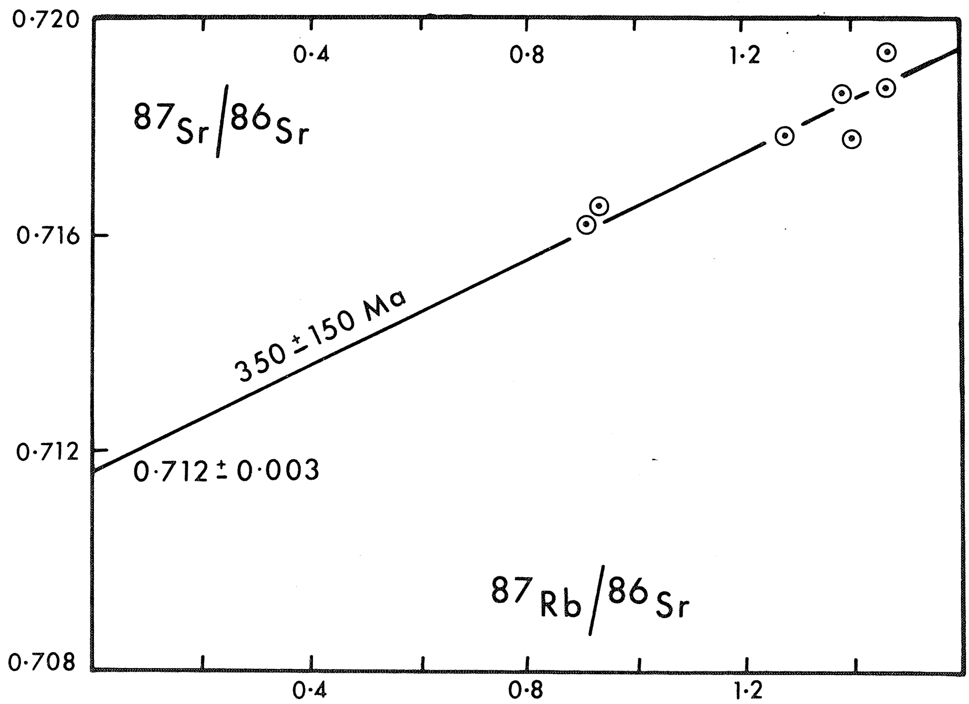


Fig. 4. Rb-Sr isochron plot for whole-rock samples of biotite-oligoclase-quartz gneiss (see Table 2)

Table 3

U-Pb isotopic data and model ages for biotite-oligoclase-quartz gneiss, Zagórze Śląskie

| | Sample | | | | |
|---|---|---|---|---|---|
| | zircon | zircon | zircon | monazite | monazite |
| Size fractions [in microns] | −106+ +85NM1° | −85+ +70NM1° | −53NM1° | all fractions | duplicate |
| Pb [ppm] | 36.0 | 40.3 | 48.4 | 1008 | 993 |
| U [ppm] | 558 | 645 | 695 | 7478 | 7354 |
| $^{206}Pb/^{204}Pb$ | 9147 | 5884 | 22633 | 19408 | 17102 |
| Atom % radiogenic Pb | | | | | |
| $^{206}Pb$ | 87.619 | 87.486 | 87.850 | 39.198 | 39.173 |
| $^{207}Pb$ | 5.2889 | 5.1822 | 5.7395 | 2.1258 | 2.1198 |
| $^{208}Pb$ | 7.0923 | 7.3319 | 6.4106 | 58.6758 | 58.7071 |
| Atomic ratios | | | | | |
| $^{207}Pb/^{206}Pb$ | 0.060363 | 0.059235 | 0.065333 | 0.054233 | 0.054113 |
| $^{207}Pb/^{235}U$ | 0.54732 | 0.51937 | 0.63991 | 0.45718 | 0.45655 |
| $^{206}Pb/^{238}U$ | 0.065757 | 0.063588 | 0.071033 | 0.061360 | 0.061187 |
| Model ages [Ma] | | | | | |
| $^{207}Pb/^{206}Pb$ | 616 | 576 | 785 | 382 | 376 |
| $^{207}Pb/^{235}U$ | 444 | 425 | 502 | 382 | 382 |
| $^{206}Pb/^{238}U$ | 411 | 400 | 442 | 383 | 383 |

Explanation: The sample is RC 1755 in the rock catalogue of the Scottish Universities Research and Reactor Centre, East Kilbride, Glasgow G75 OQU, Scotland; location is given in the text.

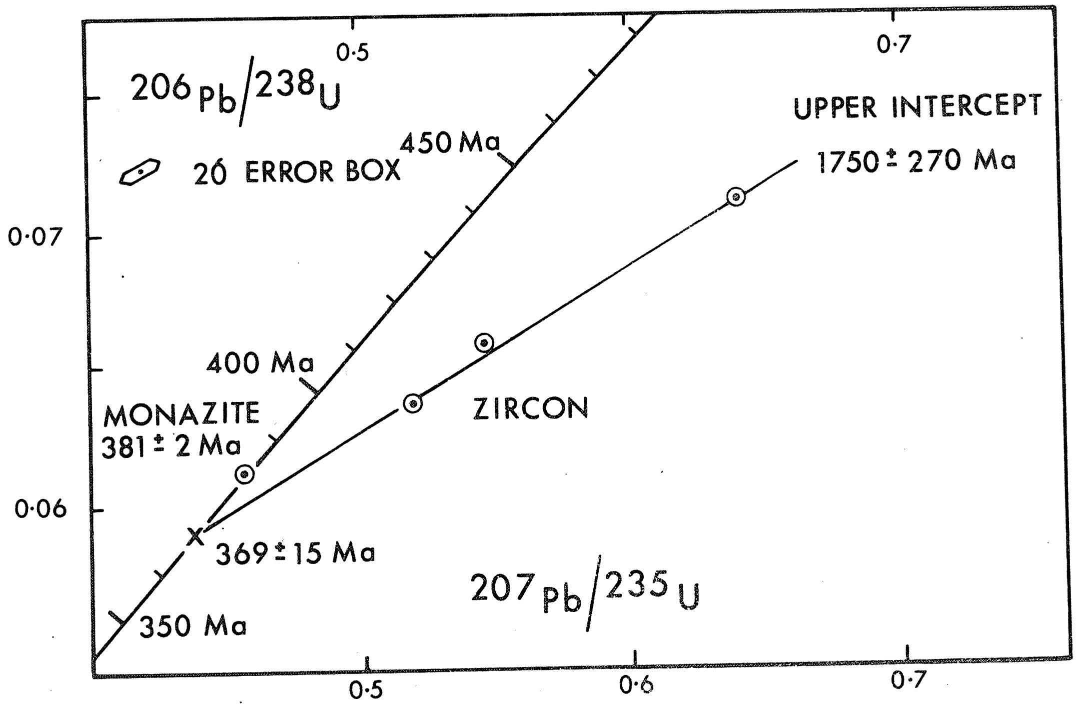


Fig. 5. U-Pb concordia plot for zircon and monazite from biotite-oligoclase-quartz gneiss (see Table 3)

biotites yield ages of 360±7 Ma and 372±7 Ma. Muscovite ages range from 363±4 Ma to 374±4 Ma and the average of all six ages is 370±4 Ma.

U-Pb isotopic data are presented in Table 3 and have been plotted on a concordia diagram (Fig. 5). From the gneiss (sample 1) three zircon size fractions were analysed. These are aligned but do not show a regular progression of discordance with increasing U content and decreasing grain size. A regression line with a mean square of weighted deviates (MSWD) of 19 corresponds to an upper intercept age of 1750±270 Ma and a lower intercept age of 369±15 Ma. Duplicate U-Pb monazite data points are concordant and correspond to an age of 381±2 Ma.

## Interpretation

A mixed derivation for the gneiss with a mid-Proterozoic U-Pb zircon upper intercept is indicated, both on the basis of the isotopic data and also as acritarch, cyanophyte and other microfloristic assemblages discovered recently in the Sowie Góry paragneisses by Gunia (1981) show a late Riphean maximum age. As the Sowie Góry block appears to consist generally of paragneisses (Teisseyre, 1964), the zircons are likely to be detrital in origin and may have had an ultimate origin in the Baltic Shield to the N or the Ukrainian Shield to the E.

The 460–420 Ma K-Ar ages from gneisses of the Sowie Góry block (Depciuch *et al.*, 1980) which suggest cooling and uplift as early as Ordovician times, have not been confirmed for the samples dated in this study. Nor can they be explained readily on the basis of the stratigraphic evidence.

The blocking temperature of the U-Pb system in the monazite appears to correspond to upper amphibolite facies conditions (Cliff, 1985) and recent work by R. R. Parrish (pers. comm.) has shown that this isotope system can, to a considerable extent, survive ductile shearing accompanied by sillimanite–K--feldspar grade metamorphism. As (1) the $D_2-M_2$ fabric is pervasive in the dated sample while $S_3$ and related $M_3$ mineral growth are not evident and (2) the effects of $D_3$ are prominent in the southeastern part of the Sowie Góry block rather than in the northwestern part where the dated sample was collected, the 381±2 Ma monazite age is likely to date the waning stage of $D_2-M_2$. However correspondence with the waning stage of $D_3-M_3$ cannot be ruled out.

This interpretation is consistent with the 370±4 Ma muscovite age and the mineralogical evidence that subsequent conditions were below the blocking temperature in the Rb-Sr system in large muscovite books (*ca.* 600°C – van Breemen & Piasecki, 1983). The U-Pb zircon data are also consistent with a Devonian age for sillimanite grade metamorphic conditions. On its own the lower intercept of a chord with an MSWD of 19 would not be considered to represent a reliable age. However with the concordant monazite age available, the U-Pb zircon data can be interpreted in terms of Pb loss and, or, new zircon growth shortly before 381±2 Ma, followed by minor Pb loss in recent times. In addition, while they cannot be used to establish a Devonian age, the Rb-Sr whole-rock data are not inconsistent with such an age.

The $D_1$ event has not been dated and further data are required to establish whether it represents an early stage of the dated Devonian tectonothermal activity or a significantly older event.

In view of the $M_5$ metamorphic activity being at low-mid-amphibolite facies, and the blocking temperature of the Rb-Sr system in biotite being *ca.* 300°C (Purdy & Jäger, 1976), i.e., greenschist facies, the $D_5$ phase must have been close to 370 Ma in age.

The most significant result of this isotopic study is considered to be the evidence for rapid cooling during Devonian times, with temperature dropping from that for upper amphibolite facies mineral growth to that for greenschist facies mineral growth over a period of 10–20 Ma. This cooling, which stratigraphic evidence relates to rapid uplift, and the preceding tectonothermal event, pre-date the tectonothermal and igneous activity including granite emplacement, demonstrated to have taken place in early Carboniferous times (345–330 Ma) in the Bohemian massif of Czechoslovakia (van Breemen *et al.*, 1982, table 6).

## NATURE OF THE DEVONIAN EVENT

Independent stratigraphic evidence for a Devonian event in the Sudetes region comes from the Kłodzko metamorphic complex to the S of the Sowie Góry block (Fig. 2). At the top of the so-called lower metapelitic formation there is a 40 m thick bed of crystalline limestone which contains abundant coral fauna (*Stromatoporoides, Tabulata, Tetracoralla*) of the Lower Ludlovian (Gunia & Wojciechowska, 1971). The folded crystalline assemblage of the Kłodzko metamorphic complex is discordantly overlain by clastic and carbonate sedimentary rocks of the Upper Devonian as evidenced by the presence of conodonts, brachiopods, crinoids, cephalopods, *etc.* (Chorowska, 1979).

The Sowie Góry block must have been rapidly uplifted as the Świebodzice depression, with which it is in faulted contact to N, is filled up with coarse, clastic and palaeontologically dated Upper Devonian–lowermost Carboniferous deposits. These include the Late Fammenian–Early Tournaisian Książ Formation which is composed chiefly of conglomerates consisting almost entirely of fragments of gneisses, granites and pegmatites whose source is considered to be the Sowie Góry block (Porębski, 1981). By the late Visean the present erosional level must have been brought to the surface as the Sowie Góry block was covered by small clastic Culm deposits of that age (Żakowa, 1963).

According to the record of Fammenian–Tournaisian clastic sedimentation in the Świebodzice depression, the Sowie Góry block was brought into tectonic contact with an assemblage of basic-ultrabasic rocks that is considered to represent oceanic crust (Fig. 1b). Stratigraphical evidence shows that part of this crust formed sea-floor in late Frasnian times: it was covered with upper Devonian – lower Carboniferous carbonate and clastic sediments (*cf.* Chorowska, 1979). Thus it is very likely that the upward movement of the Sowie Góry block commenced as early as late Frasnian times.

The new radiometric data are also compatible with the model of Matte (1986; see also Bard *et al.*, 1980) according to which oceans, of limited extent, both N and S of the European Hercynides closed in Devonian time. In the northern ocean the switch from extension to plate convergence appears to have occurred *ca.* 450 Ma ago (Gebauer, 1983; Behr *et al.*, 1984). Thus the possibility of Caledonian activity elsewhere in the Sudetes region must be borne in mind (*cf.* Borkowska *et al.*, 1980).

Recent geophysical results confirm N-verging thrust tectonics W of the Sudetes region (DEKORP, 1985; *cf.* Behr *et al.*, 1984; Matte, 1986). In Central Europe SE-directed thrusting during the Visean-Namurian marks a late phase of Hercynian activity (van Breemen *et al.*, 1982, table 6). This thrusting also affected the rocks of the Śnieżnik metamorphic complex, although some caution must be exercised in view of the *ca.* 380 Ma K-Ar biotite ages from this complex reported by Bakun-Czubarow (1968), which also appear to record the Devonian uplift. Accepting the evidence that the late shearing which affected the Śnieżnik metamorphic complex coincided with the SE-verging folds and thrusts involving basement and Devonian sediments of the Moravo-Silesian zone, it appears that the WNW structural trend of the western part of Sudetes region predates the NNE trend of the Moravo-Silesian zone and the Moldanubian zone further S. However the tectonic significance of the Devonian event in the isolated Sowie Góry block remains to be resolved.

## CONCLUSIONS

The following are the main conclusions reached from this study in the Sowie Góry gneissic block in the Sudetes of southwestern Poland.

1. A declining stage of tectonothermal activity, igneous activity and uplift are dated at $381 \pm 2$ Ma, $370 \pm 4$ Ma and *ca.* 370 – 360 Ma respectively, i.e. during the Devonian period.

2. There is independent stratigraphic evidence for a Devonian event.

3. Cooling from upper amphibolite to greenschist facies conditions took only 10 – 20 Ma.

4. The dated activity preceded tectonothermal and igneous activity (early Carboniferous) in the Bohemian massif of Czechoslovakia.

5. A mixed derivation for the gneiss is indicated, including a mid-Proterozoic component, presumably from a shield region.

6. Further data are required to establish whether the gneiss contains a pre-Devonian component of metamorphism-migmatization.

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## Streszczenie

# DEWOŃSKA AKTYWNOŚĆ TEKTONOMETAMORFICZNA W GNEJSACH BLOKU GÓR SOWICH W ŚWIETLE BADAŃ IZOTOPOWYCH Rb-Sr I U-Pb

**O. van Breemen, D. R. Bowes, M. Aftalion & A. Żelaźniewicz**

Abstrakt: Schyłek progresywnego metamorfizmu, aktywność magmową (pegmatyty) i podniesienie kompleksu gnejsów sowiogórskich datowano odpowiednio na 381±2 Ma, 370±4 Ma i 370–360 Ma. Szybkie stygnięcie kompleksu, wiążące się z inwersją tektoniczną przy końcu dewonu, trwało około 10–20 mln lat.

Podobnie jak ciągle niezbyt jest jasna pozycja Sudetów wśród europejskich Waryscydów (Fig. 1), tak nadal niezbyt jest jasna pozycja bloku Gór Sowich w obrębie samych Sudetów (Fig. 2). Jakiekolwiek korelacje odnoszące się do kompleksu gnejsów sowiogórskich muszą brać pod uwagę zarówno przebieg jego tektonometamorficznej ewolucji (Tab. 1), jak i mało dotąd poznaną historię izotopową, do której nowych danych dostarcza niniejsza praca.

Do badań radiometrycznych pobrano próbki biotytowo-oligoklazowego gnejsu warstewkowego znad Jeziora Bystrzyckiego oraz próbki wieloblaszkowych agregatów muskowitu pochodzące z pegmatytu odsłoniętego w Lutomii Górnej. Próbki gnejsu poddano analizie izotopowej metodą U-Pb dla cyrkonu i monacytu, a metodą Rb-Sr dla całej skały oraz dla biotytu. Muskowit z pegmatytu zbadano metodą Rb-Sr.

Analizowany gnejs posiada więźbę mineralną ukształtowaną w czasie wydarzenia tektonometamorficznego $D_2-M_2$ i tworzy go zespół minerałów charakterystycznych dla I strefy syllimanitowej, bez śladów późniejszej rekrystalizacji lub przebudowy więźby (Fig. 3a). Pegmatyt z Lutomii Górnej należy do zespołu subwertykalnych żył, biegnących N–S, związanych strukturalnie z fałdami epizodu $D_4$ (Fig. 3b).

Stwierdzone stosunki izotopowe Rb/Sr w badanych łyszczykach oraz w całej skale w przypadku gnejsu przedstawia Tabela 2, a stosunki izotopowe U/Pb w cyrkonach i monacytach z tegoż gnejsu – Tabela 3. Uzyskane dane naniesiono na diagram izochronowy (Fig. 4) i diagram konkordia (Fig. 5).

Wieki Rb-Sr dla łyszczyków policzono przyjmując stosunek pierwotny $^{87}Sr/^{86}Sr = 0{,}710 \pm 0{,}007$. Dla biotytów z gnejsu otrzymane wyniki wahają się od 360±7 Ma do 372±7 Ma. Dla muskowitów z pegmatytu średnia z 6 oznaczeń wynosi 370±4 Ma.

U-Pb wiek 1750 ± 270 Ma cyrkonu (Fig. 5) jest zapewne wiekiem mieszanym, nawiązującym do wieku skał z tarczy bałtyckiej lub ukraińskiej, z których przypuszczalnie pochodziły ziarna detrytycznego cyrkonu złożone w osadzie wyjściowym dla gnejsów kompleksu sowiogórskiego. U-Pb wiek 381 ± 2 Ma monacytu z badanego gnejsu najprawdopodobniej datuje epizod tektonometamorficzny $D_2-M_2$, choć nie można wykluczyć, iż odnosi się on do epizodu $D_3-M_3$, zachodzącego również w warunkach termicznych I strefy syllimanitowej. Porównanie wieku monacytu z 370–360 Ma wiekiem biotytów z tego gnejsu wskazuje na szybkie dewońskie stygnięcie skał sowiogórskich od temperatur właściwych górnej facji amfibolitowej do temperatur facji zieleńcowej. Dane izotopowe zgodne są tu zatem z dowodami stratygraficzno-sedymentologicznymi na szybkie podnoszenie kompleksu gnejsowego Gór Sowich, zapisanymi w późnodewońskiej-wczesnokarbońskiej sekwencji osadów depresji Świebodzic.

U-Pb wiek 369 ± 15 Ma cyrkonów z badanego gnejsu, w połączeniu z innymi danymi (zwłaszcza dla monacytu), również przemawia za dewońskim wiekiem metamorfizmu zachodzącego w warunkach strefy syllimanitowej ($D_2-M_2$ – $D_3-M_3$).

Przyjęto, że Rb-Sr wiek muskowitu wynoszący 370 ± 4 Ma określa czasowo epizod $D_4$. Ponieważ epizod $D_5$ odbywał się w temperaturze właściwej niskiej-średniej facji amfibolitowej, a temperatura zamknięcia układu Rb-Sr w biotycie wynosi około 300°C, to epizod ów nie mógł być dużo młodszy od epizodu $D_4$ wieku 370 mln lat.

Przedstawione dane izotopowe w nawiązaniu do danych strukturalnych sugerują, że szybkie ochłodzenie kompleksu gnejsów sowiogórskich od temperatur facji amfibolitowej do temperatur facji zieleńcowej odbyło się w okresie trwającym 10–20 mln lat, u schyłku dewonu.

Epizod $D_1$ pozostał wiekowo nie określony. Potrzebne są dalsze badania izotopowe dla stwierdzenia, czy reprezentuje on najwcześniejsze stadium datowanego obecnie cyklu dewońskiej aktywności tektonometamorficznej i magmowej oraz inwersji tektonicznej ($D_2-D_5$), czy też jest wydarzeniem znacznie starszym. Problemem otwartym pozostaje również geodynamiczny kontekst owego cyklu, rozpoznanego w izolowanym bloku Gór Sowich.