Geologia Sudetica, 1999, 32: 49–53.

A review of Rb-Sr isotope patterns in the Carboniferous granitoids of the Sudetes in SW Poland

Pádhraig S. Kennan[1], Helena Dziedzic[2], Marek W. Lorenc[2] & Michał P. Mierzejewski[3]

[1] *University College Dublin, Geology Department, Belfield, Dublin-4, Ireland*
[2] *Polska Akademia Nauk, Instytut Nauk Geologicznych, Zakład Geologii Sudetów, 50-449 Wrocław, ul. Podwale 75*
[3] *Uniwersytet Wrocławski, Instytut Nauk Geologicznych, 50-205 Wrocław, ul. Cybulskiego 30*

Key words: Sudetes, Variscan granites, Rb-Sr ages, Sr-isotope systems, magma source

Abstract Carboniferous granite intrusions are a relatively uncontroversial element in the geological history of the Sudetes in SW Poland. The Sr-isotope systems in these granites show geological scatter indicative of contamination by crustal rock, failure to homogenise during intrusion/crystallisation and inheritance from source. Rb-Sr ages are thus somewhat compromised and imprecise. The granites originated from a relatively primitive source that underlay much of the region in Carboniferous times.

Manuscript received 17 October 1998, accepted 23 April 1999

INTRODUCTION

The Western Sudetes appear, geologically, to be a collage of discrete terranes that were drawn together during the complex and problematic history of a Palaeozoic orogen in central Europe (Żelaźniewicz, 1997). Though many aspects of the geological history of the region remain problematical, there is no question but that in Carboniferous and early Permian times, a major post-orogenic episode of granite plutonism and coeval volcanism occurred in the Western Sudetes.

Isotopic ages suggest that igneous activity continued for a relatively long period, i.e., during the interval 350–260 Ma. Important intrusions now exposed, and which are the subject of this paper, are those of the Niemcza Zone, Strzelin, Strzegom–Sobótka and Karkonosze. No Rb-Sr data is available for the related Kłodzko–Złoty Stok Massif (Fig. 1). In the discussion below, the generic term granite is widely used.

Whereas the ages of these granites in the broader scheme of things is not in doubt, precise Rb-Sr ages for the individual intrusions have proved somewhat elusive. The purpose of this short paper is to review the Rb-Sr data that are available for these granites as a group with a view to initiating further discussion on (a) comparisons between the individual granites, (b) any differences between the various intrusions and between these post-orogenic intrusions and older pre 450 Ma granitoids and (c) the possibility that whole-rock Sr-isotope data might reveal source variations at depth which in turn might help to locate major junctions in this area of great structural complexity on the NE margin of the Bohemian Massif.

Rb-Sr WHOLE-ROCK SYSTEMS IN GRANITE: INTERPRETATION

Whole-rock Rb-Sr data from many places including the Sudetes have provided poorly constrained ages or have quite simply proven difficult to interpret. Where confirmation of an age by means of, *e.g.*, single zircon U-Pb data, is available, the Rb-Sr data may be simply ignored or, at best, accorded a lesser status. Little attention is usually given to the possible reasons for the failure to obtain precise ages. The problem may lie not so much in the behaviour of Rb and Sr as in the field; perhaps it may be overcome by good sampling strategies.

Rb-Sr whole-rock isochron ages for granites rely on the assumption that at the time of intrusion/crystallisation, Sr-isotope homogenisation occurred, *i.e.*, that all the samples analysed were characterised by a common $^{87}Sr/^{86}Sr$ value at that time. It is frequent occurrence that data from individual samples fail to plot on an isochron defined

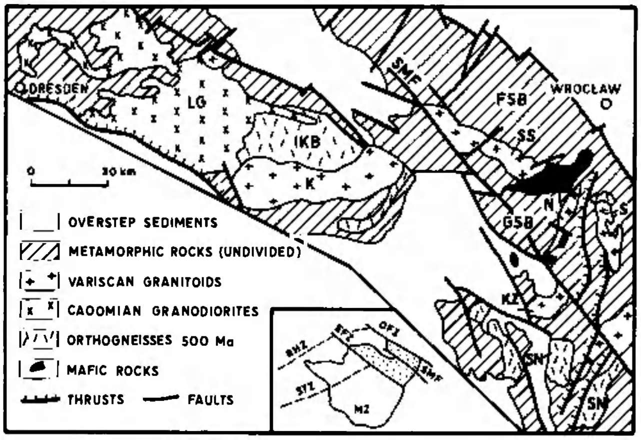

Fig. 1. Outline geology of the Variscan granites in the Western Sudetes (after Żelaźniewicz 1997, modified).
EFZ - Elbe Fault Zone; FSB - Fore-Sudetic Block; GSB - Góry Sowie Block; IKB - Izera-Karkonosze Block; K - Karkonosze; KZ - Kłodzko-Złoty Stok Massif; LG - Lausitz Granodiorite; MZ - Moldanubian Zone; N - Niemcza Shear Zone; OFZ - Odra Fault Zone; RHZ - Rhenohercynian Zone; S - Strzelin Massif; SMF - Sudetic Marginal Fault; SN - Śnieznik gneisses; SS - Strzegom-Sobótka Massif; STZ - Saxothuringian Zone.

by the majority of samples from a single granite intrusion or that a family of samples may fail to supply an isochron at all. This is simply a reflection of the fact that, in many granites, the essential condition was, for one reason or another, not attained. To reject the odd sample may compromise any age calculated. To consider the data set as useless may be to lose valuable information bearing on granite source.

Many reasons have been proposed to explain why granite whole-rock Rb-Sr data might fail to provide isochrons and thus fail to support reliable ages. These include weathering and alteration, magma mixing, inheritance for an inhomogeneous source, the resetting of isochrons by later events, assimilation of wall rocks during emplacement and fluid exchange (see, *e.g.*, Zheng, 1989). In addition, spurious ages may result if the scale of possible homogenisation is ignored (*e.g.*, Roddick & Compston, 1977); this draws attention to sampling strategy and the question of whether samples chosen (or forced to be chosen by, *e.g.*, available outcrop) are likely to produce a useful result. In single composite intrusions, it is clear that rock composition may influence apparent ages (*e.g.*, Stephens & Halliday, 1980). Sample size may play a crucial role. In a Caledonian granite in western Ireland, for example, Kennan *et al.*, (1987) using small samples obtained a very different result from that obtained by Leggo *et al.* (1966) though the very same locations were sampled. Finally, in even a single granite variety supposedly part of a fractionated sequence, a cryptic initial $^{87}Sr/^{86}Sr$ variation with depth in an intrusion may be preserved (Mohr, 1991).

It may seem that good Rb-Sr whole-rock ages might be the exception rather than the rule. However, a good sampling strategy can overcome most of the problems briefly noted above. Though ages may be often difficult to define precisely, the fact that Rb-Sr whole-rock data from granites is robust, and not as susceptible as might be though to late post-crystallisation disturbance, is supported by the fact that data from suites of individual granites reveal major and systematic regional differences. In Ireland, Rb-Sr whole-rock data for Caledonian granites precisely identify regional domains (Murphy *et al.*, 1991) and reflect (and locate) major structural boundaries, *e.g.*, the Iapetus Suture (Todd *et al.*, 1991).

The Sr-isotope chemistry of many granites not only reflects isotopic homogenisation but may clearly, at one and the same time, be an image their variable sources. Any attempt to date granites using whole-rock Rb-Sr methods must take account of that duality.

THE CARBONIFEROUS GRANITES OF THE WESTERN SUDETES

The Karkonosze Granite is the largest of the Carboniferous intrusions as exposed (Fig. 1). Rb-Sr data from samples collected in two separate quarries (Huta and Michałowice) define two parallel isochrons supporting ages of about 328 Ma for this intrusion (Duthou *et al.*, 1991). Clearly this granite did not have a uniform $^{87}Sr/^{86}Sr$ ratio at that time; intrusion and crystallisation did not result in large-scale Sr-isotope homogenisation. Data from borehole (Jakuszyce) samples, collected between 200–1000 metres depth, certainly do not define an isochron; a uniform $^{87}Sr/^{86}Sr$ was not achieved over that depth range. Data from samples representing a short 250 metre interval of the core confirm the age of Duthou *et al.*, 1991 (unpublished University College Dublin data).

These observations prompt comparison with the Leinster Granite in SE Ireland in which Mohr (1991) demonstrated significant Sr-isotope variation with depth in a granite intrusion not unlike the Karkonosze in overall structure and petrography. As the sampling was confined to individual quarries, the age of *c.* 328 Ma is probably accurate.

The Strzelin Granitoid Massif (Fig.1) is composed of small intrusions of granite, granodiorite and diorite corresponding to the deeper root zone of a pluton and which are hosted by Palaeozoic and Proterozoic rocks metamorphosed and deformed during the Variscan Orogeny (Lorenc, 1994; Oberc-Dziedzic *et al.*, 1994, 1996).

Rb-Sr data from biotite granites give an age of about 347 Ma and, data from biotite-muscovite granites, an age of about 330 Ma (Oberc-Dziedzic *et al.*, 1994, 1996). Data from more basic granites failed to give an age. Homogenisation of these various granitoids clearly did not occur on a large scale.

The granite data plot on or very close to the Variscan array drawn on Figure 2 where, curiously, the data for the different Strzelin rocks appear to bracket the data for the Karkonosze granite. A similar source is indicated by the similar initial ratios.

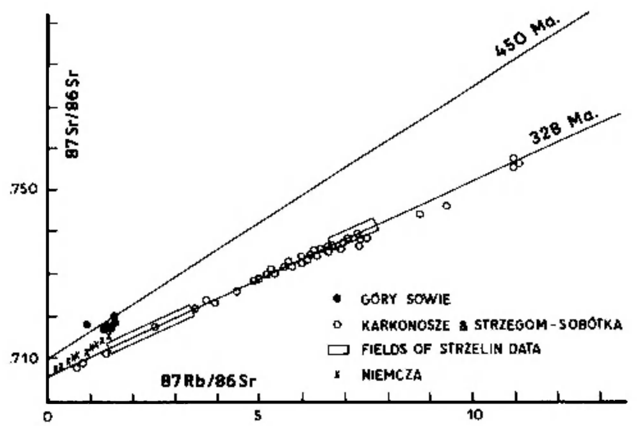

Fig. 2. Pattern of Sr-isotope data from the Variscan granites (mostly from text references but including some unpublished data from Karkonosze). Niemcza granitoids show trend towards Góry Sowie gneiss values. Data from Karkonosze and Strzegom–Sobótka are undifferentiated but much of the latter plots below the 328 Ma references line. Rectangular boxes enclose Strzelin granite values (see text). The 450 Ma reference line is as on Fig. 5.

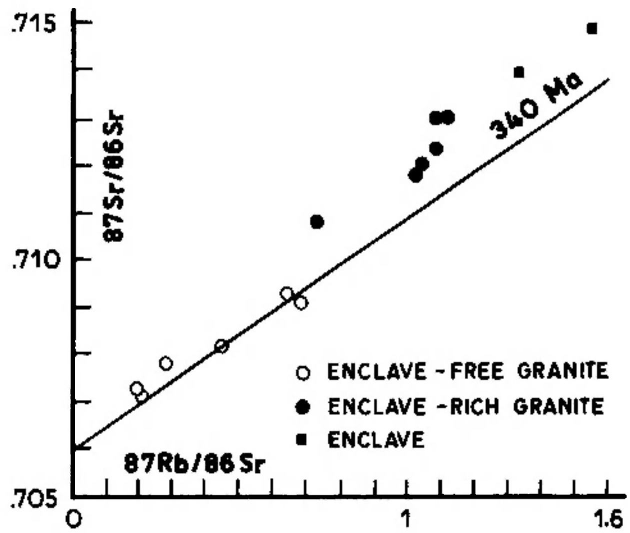

Fig. 3. Pattern of Sr-isotope data for the Niemcza granites. Enclave-rich granites form a transition between values from granites lacking enclaves and enclave values. The 340 Ma reference line corresponds to a U-Pb zircon age for these granites (see text).

The granitoids of the Niemcza Zone (Fig.1) were emplaced syntectonically into what was a major zone of regional shearing in Variscan times. The intrusions comprise numerous small bodies which are, perhaps, connected at depth. In the field, medium-grained porphyritic granites and granodiorites characterised by an abundance of enclaves are typical of the granites in the zone. These contrast with finer-grained, more dioritic varieties lacking enclaves. Their present outcrop is more or less confined to a number of discrete quarries in some of which, sharp contacts between the two varieties can be seen. Oliver *et al.* (1993) obtained a U-Pb zircon age of about 338 Ma for a hornblende syenite from this suite. A complete description of these granites and their chemistry is in preparation by Kennan, Lorenc and Dziedzic.

Rb-Sr data for these granites do not provide any reasonable age (Lorenc, 1998). They do, however, show (a) some degree of coherence within each quarry when the data are considered in the light of the U-Pb zircon age. On an isochron diagram, the data reveal an overall pattern rising from low ^{87}Rb/^{86}Sr and ^{87}Sr/^{86}Sr values to the relatively high values of both parameters (Fig. 3). The higher values apply to granites from the large quarry at Kośmin where the granite is relatively rich in enclaves. Outcrop observation suggests progressive digestion of the enclaves. Rb-Sr isotope data for two enclaves (Fig. 3) seem to indicate contamination by crustal material.

The Niemcza Shear Zone forms the eastern margin of the outcrop of the gneisses of the Góry Sowie (Fig. 1). A limited amount of Rb-Sr data for the gneisses given by Van Breemen *et al.* (1982) does not rule out contamination of the Niemcza granites by material from these gneisses.

The Niemcza data plot at the low ^{87}Rb/^{86}Sr end of the Variscan array on Figure 2. The granites lacking enclaves plot closest to the array suggesting that they and the other major granites come from comparable sources if not one source. The enclave-rich varieties curve upwards from the Variscan array towards that of the older gneisses. Some of the scatter in the data from, e.g., the Karkonosze intrusion which does contain scattered enclaves, may reflect the same incorporation of enclave material.

Some granitoids (monzogranites) from the Strzegom–Sobótka Granitic Massif (Fig. 1) give Rb-Sr ages of about 280 Ma (Pin *et al.*, 1989). Once again, parallel isochrons suggest batches of magma with distinct ^{87}Sr/^{86}Sr ratios that did not mutually homogenise. Somewhat surprisingly, a two-mica granite from this massif gives an older age of about 326 Ma. Pin *et al.* (1989) concluded that totally unrelated geodynamic causes had operated for different magmatic episodes contributing to this composite intrusion.

However, Pin *et al.* (1989) also revealed a clear spatial relationship between ^{87}Sr/^{86}Sr and geographic position which is independent of petrographic type. Clearly, this is not an isotopically homogeneous body; model initial ratios at about 328 Ma clearly show this as they do the contrast between this intrusion and, for instance, the Karkonosze Granite (Fig. 4). The granites of both intrusions have similar Rb/Sr values. Lower Sr-isotope initial ratios characterise the Strzegom–Sobótka Massif, a reflection, very likely, of a genetic relationship with nearby mafic (ophiolitc) rocks (Fig. 1).

In the light of the geographic ^{87}Sr/^{86}Sr variation, the demonstrable failure to homogenise at about 328 Ma displayed by the other Variscan granites and the relatively small number of samples used in the age determinations, it would seem that the apparent age difference between the two-mica granite and the monzogranites should be treated with caution and confirmed. What is certain is that this intrusion contains some granites with the lowest ^{87}Sr/^{86}Sr (at 328 Ma) of all the Variscan intrusions for which data are available, lower even than the low Rb/Sr granitoids of Niemcza.

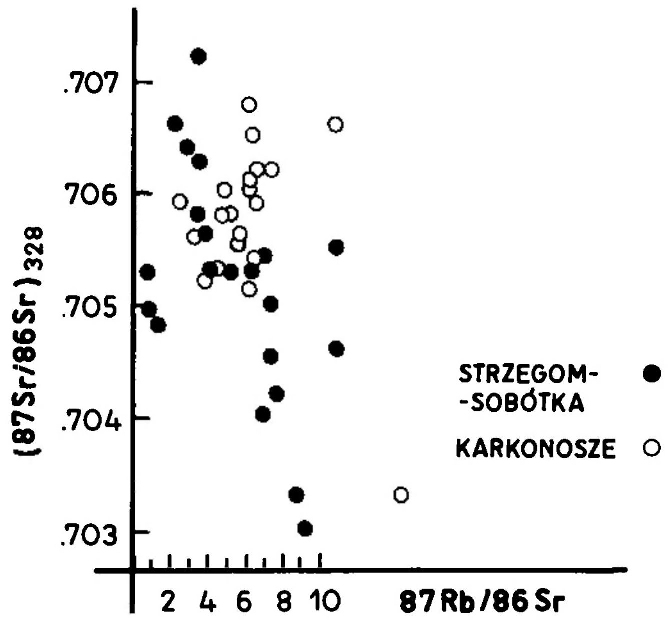

Fig. 4. Model initial ratios at 328 Ma for the Strzegom–Sobótka and Karkonosze intrusions.

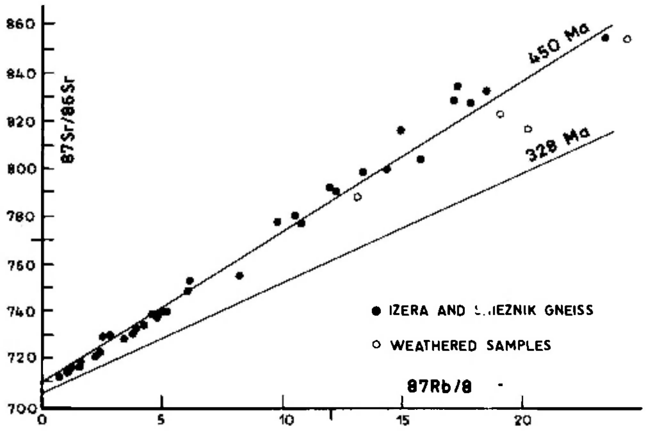

Fig. 5. Pattern of Sr-isotope data from the Izera and Śnieżnik gneisses. Variscan granite 328 Ma reference is shown. High Rb/Sr data and some low Rb/Sr samples are omitted for drafting purposes only. Weathered samples are included.

OLDER GRANITOIDS

The Variscan Karkonosze Granite is intruded into the older Izera gneisses (Fig. 1) of the Izera–KArkonosze Block. Borkowska et al. (1980) determined Rb-Sr whole-rock ages in the interval 450–500 Ma for these gneisses and for the chemically indistinguishable Rumburk granites into which the gneisses gradationally pass. The scatter on the data is appreciable. The data for samples with $^{87}Rb/^{86}Sr13$ are plotted on Figure 5 with similar additional data from the Snieznik gneisses by Borkowska *et al.* (1990) who note that their data are not in agreement with that of van Breemen *et al.* (1982). Data from samples with higher $^{87}Rb/^{86}Sr$ ratios than those shown exhibit considerable scatter – as do similar data from the Variscan granites; in these high Rb/Sr cases, open system behaviour may be responsible.

It is clear that the later Variscan granites, though they intruded the gneisses, did not originate from the reworking of these gneisses. On the ground (Fig. 1), the Izera gneisses occur to the west and beyond, the Śnieżnik gneisses outcrop to the south of the Kłodzko–Złoty Stok granitoid, similar gneisses occur to the north of the Strzegom–Sobótka intrusion (at Wądroże Wielkie) and the undeformed Strzelin granites intrude an older crystalline massif.

Pin *et al.* (1989) inferred, on the basis of the geographic control on the Sr-isotope initial ratios, that the Strzegom–Sobótka Massif straddles a major boundary between contrasting crustal blocks. This intrusion provides the only Sr-isotope hint of such. The questions raised by the regional occurrence of these late post-tectonic granites with relatively low Sr-initial ratios, when compared with those of the gneisses they intrude, concern the nature, origin and extent of their source and how it came to be below in Carboniferous times. Rb-Sr data will not answer these questions.

CONCLUSIONS

(1) It is more likely than not that all of the post-tectonic Carboniferous granites in the Western Sudetes derived from a source with a similar initial $^{87}Sr/^{86}Sr$ and were emplaced over a short time interval about 330 Ma ago.

(2) None of them resulted from the reworking and melting of any of the gneisses exposed in the region and for which data are available. In contrast, their source was more primitive with more juvenile mantle material in it.

(3) At least some of the granites, most obviously those of Niemcza, are contaminated by older crustal material (the older gneisses?) with a relatively high $^{87}Sr/^{86}Sr$.

(4) In Carboniferous times, the relatively primitive post-tectonic granites intruded.

REFERENCES

BORKOWSKA, M., HAMEURT, J. & VIDAL, P. 1980. Origin and age of Izera gneisses and Rumburk granites in the Western Sudetes. *Acta Geologica Polonica*, 30: 121–146.

BORKOWSKA, M., CHOUKROUNE, P., HAMEURT, J. & MARTINEAU, F. 1990. A geochemical investigation of the age, significance and structural evolution of the Caledonian-Variscan granite-gneisses of the Śnieżnik metamorphic area (Central Sudetes, Poland). *Geologia Sudetica*, 25: 1–27.

BREEMEN, O. VAN, AFTALION, M., BOWES, D. R., DUDEK, A., MISAR, Z., POVONDRA, P. & VRANA. 1982. Geochronological studies of the Bohemian Massif, Czechoslovakia, and their significance in the evolution of Central Europe. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, 73: 89–108.

BREEMEN, O. VAN, BOWES, D. R., AFTALION, M. & ZELAZNIEWICZ, A. 1988. Devonian tectonothermal activity in the Sowie Góry Gneissic Block, Sudetes, SW Poland: evidence from Rb-Sr and U-Pb isotope studies. *Annales Societatis Geologorum Poloniae*, 58: 3–19.

DUTHOU, J. L., COUTERIE, J. P., MIERZEJEWSKI, M. P. & PIN, C. 1991. Oznaczenia wieku granitu Karkonoszy metoda izochronową rubidowo-strontową, na podstawie całych próbek skalnych. [Next dating of granite sample from the Karkonosze Mountains using Rb-Sr total rock isochrone method]. *Przegląd Geologiczny*, 2: 75–79.

KENNAN, P. S., FEELY, M. & MOHR, P. 1987. The age of the Oughterard Granite, Connemara, Ireland. *Geological Journal*, 22: 273–280.

LEGGO, P. J., COMPSTON, W. & LEAKE, B. E. 1966. The geochronology of the Connemara granites and its bearing on the antiquity of the Dalradian series. *Quarterly Journal of the Geological Society, London*, 122: 91–118.

LORENC, M. W., 1994. Rola magm zasadowych w ewolucji intruzji granitoidowych (studium porównawcze wybranych masywów hercyńskich). [Role of basic magmas in the granitoid evolution (a comparative study of some Hercynian massifs)]. *Geologia Sudetica*, 28: 3–130.

LORENC, M. W., 1998. Badania izotopowe metodą Rb-Sr skał intruzyjnych strefy Niemczy (Dolny Śląsk). [Rb-Sr isotopic study of the intrusive rocks from the Niemcza Zone (Lower Silesia, Poland)]. *Archiwum Mineralogiczne*, 51: 153–164.

MOHR, P. J., 1991. Cryptic Sr and Nd isotopic variation across the Leinster Granite, southeast Ireland. *Geological Magazine*, 128: 251–256.

MURPHY, F. C., ANDERSON, T. B., DALY, J. S., GALLAGHER, V., GRAHAM, J. R., HARPER, D. A. T., JOHNSTON, J. D., KENNAN, P. S., KENNEDY, M. J., LONG, C. B., MORRIS, J. H., O'KEEFE, W. G., PARKES, M., RYAN, P. D., SLOAN, R. J., STILLMAN, C. J., TIETZCH-TYLER, D., TODD, S. P. & WRAFTER, J. P., 1991. Appraisal of Caledonian suspect terrains in Ireland. *Irish Journal of Earth Sciences, Irish J. Earth Sci.*, 11: 11–41.

OBERC-DZIEDZIC, T., PIN, C., DUTHOU, J. L. & COUTERIE, J. P. 1994. Age and origin of the Strzelin granitoids (Fore-Sudetic Block, Poland) studied by the ^{87}Rb/^{86}Sr system. In Kryza, R. (Ed.) Abstracts to meeting "*Igneous activity and metamorphic evolution of the Sudetes area*". Wrocław, p. 83–86.

OBERC-DZIEDZIC, T., PIN, C., DUTHOU, J. L. & COUTERIE, J. P. 1996. Age and origin of the Strzelin granitoids (Fore-Sudetic Block, Poland): ^{87}Rb/^{86}Sr data. *Neues Jahrbuch Miner. Abh.*, 171: 187–198.

OLIVER, G. J. H., CORFU, F. & KROGH, T. E. 1991. U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. *Journal of the Geological Society of London*, 150: 355–369.

PIN, C., PUZIEWICZ, J. & DUTHOU, J. L. 1989. Ages and origins of a composite granitic massif in the Variscan belt: a Rb-Sr study of the Strzegom–Sobótka Massif, W. Sudetes (Poland). *Neues Jahrbuch Miner. Abh.*, 160: 71–82.

RODDICK, J. C. & COMPSTON, W. 1977. Strontium isotope equilibration: a solution to a paradox. *Earth and Planetary Science Letters*, 34: 238–246.

STEPHENS, W. E. & HALLIDAY, A. N. 1980. Discontinuities in the composition surface of a zoned pluton, Criffel, Scotland. *Geological Society of America Bulletin*, 91: 165–170.

TODD, S. P., MURPHY, F. C. & KENNAN, P. S. 1991. On the trace of the Iapetus Suture in Ireland and Britain. *Journal of the Geological Society of London*, 148: 869–880.

ZHENG, Y. F. 1989. Influences on the nature of the inherited Rb-Sr system on isochron validity. *Chemical Geology (Isotope Geoscience)*, 80: 1–16.

ŻELAŹNIEWICZ, A. 1997. The Sudetes as a Palaeozoic orogen in Central Europe. *Geological Magazine*, 134: 691–702.