The $^{40}Ar/^{39}Ar$ ages from the West Sudetes (NE Bohemian Massif): constraints on the Variscan polyphase tectonothermal development

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Abstract: The West Sudetes (NE margin of the Bohemian Massif) consist of a complex mosaic of several tectonometamorphic units juxtaposed during the Variscan orogeny. The polyphase Variscan tectonothermal development of the West Sudetes was determined by $^{40}Ar/^{39}Ar$ ages of single grains and mineral concentrates. Late Famennian (359 Ma) mica ages from the high-grade Góry Sowie Block suggest continuous uplift after a Late Devonian high temperature–low pressure (HT–LP) event contemporaneous with the end of subduction-related high pressure–low temperature (HP–LT) metamorphism in the East Krkonoše Complex.

Mid-Late Devonian high pressure events in the Krkonoše-Jizera Terrane and Orlica-Śnieżnik Dome are followed by coeval high temperature events between 345 and 335 Ma (Visćan). The latter are interpreted as consequence of uplift, and decompression during overthrusting of both complexes on their forelands. Subsequent small- to large-scale shear movements dated at around 325–320 Ma (early Namurian) affected the Orlica-Śnieżnik Dome, Krkonoše-Jizera Terrane, including the Intra-Sudetic Fault, and also the eastern Lusatian Granitoid Complex. They were accompanied by contemporaneous emplacement of the Krkonoše-Jizera pluton. The upper limit of the tectonometamorphic and magmatic activity is dated at 314–312 Ma (Namurian/Westphalian boundary). The final juxtaposition of the diversified tectonometamorphic units, which constitute the West Sudetes, took place in early Namurian times.

The Bohemian Massif occupies a key position as the largest exposed part of the Variscan orogen in Central Europe (e.g. Matte *et al.* 1990). Recently it has been presented as a complex mosaic of terranes, with each one showing independent protolith and tectonometamorphic development. The terrane amalgamation of Central Europe was a result of the Variscan multiple interactions during the Variscan orogeny between the Gondwana-derived Armorican Terrane Assemblage with Baltica and East Avalonia which were already attached to extraneous (also peri-Gondwanan?) fragments accreted in pre-Variscan cycles. The subsequent late Variscan large-scale thrust and horizontal shear movements created the dominant architecture of the Bohemian Massif. Numerous attempts have been made to identify individual terranes in the Bohemian Massif, define them regionally and describe their evolution (e.g. Franke 1989; Matte *et al.* 1990; Oczlon 1992; Cymerman *et al.* 1997; Tait *et al.* 1997; Pharaoh 1999).

The West Sudetes are the easternmost part of the Saxothuringian Zone of the European Variscan orogen (e.g. Franke *et al.* 1993; Narębski 1994; Franke & Żelaźniewicz 2000), and form the northern and northeastern margins of the Bohemian Massif (Fig. 1). There they have a unique position facing the NW–SE oriented Trans-European Suture Zone (TESZ) separating Palaeozoic Europe from the Precambrian East European Craton (e.g. Pharaoh 1999). The succession of Palaeozoic tectonothermal events is recorded in the Cambrian to Upper Carboniferous meta-igneous and meta-sedimentary rocks of the West Sudetes.

This paper presents new information on the West Sudetic metamorphic and igneous rocks as

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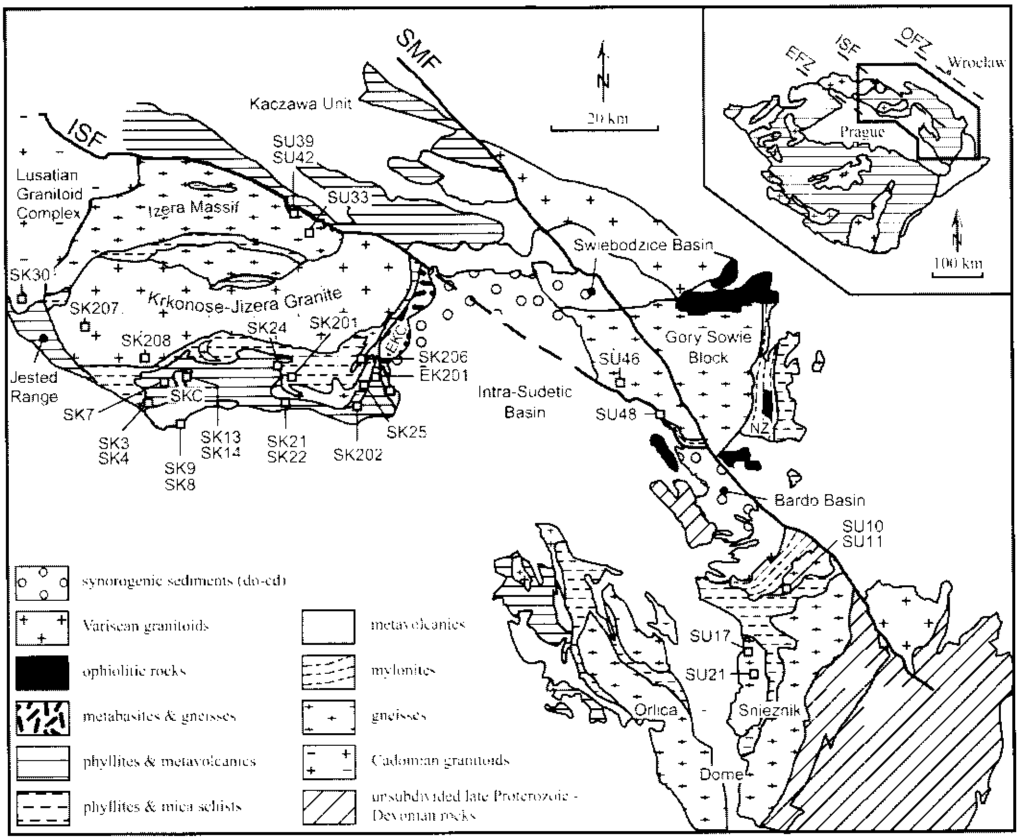

Fig. 1. Simplified geological map of the West Sudetes (modified after Aleksandrowski *et al.* 1997) with sample localities. EKC, East Krkonoše Complex; ISF, Intra-Sudetic-Fault; NZ, Niemcza Shear Zone; SKC, South Krkonoše Complex; SMF, Sudetic Marginal Fault. Black squares, sample localities. Inset: schematic map of the Bohemian Massif. EFZ, Elbe Fault Zone; OFZ, Odra Fault Zone.

well as shear zones and mylonites developed within them. It is based on the interpretation of dating using the $^{40}Ar/^{39}Ar$ step-wise heating technique. The resulting ages were evaluated in order to determine the sequence of prominent events, i.e. timing of terrane collisions, amalgamations and strike-slip movements in the West Sudetes and their significance for the Palaeozoic evolution of the Central European part of the Variscan orogen.

Geological setting

The West Sudetes are composed of Upper Proterozoic to Lower Carboniferous low- to medium-grade metamorphosed sedimentary and volcanosedimentary sequences, with local tectonic insertions of high pressure rocks, that were intruded by latest Proterozoic as well as early and late Palaeozoic granitoids (Svoboda & Chaloupský 1966; Teisseyre 1973; Żelaźniewicz 1997). The West Sudetes are a collage of the differentiated lithotectonic units which are interpreted as terranes, defined according to autonomous stratigraphic, igneous and tectonometamorphic records (Narębski 1994; Cymerman *et al.* 1997; Franke & Żelaźniewicz 2000). The assembly of the West Sudetic terrane mosaic is interpreted as a result of (early?) Variscan (Maluski & Patočka 1997) collision of Gondwana-derived terranes with Baltica (± East Avalonia) (e.g. Franke 2000) and late Variscan large-scale shear movements along prominent strike-slip faults parallel to the TESZ (e.g. Aleksandrowski *et al.* 1997).

The Krkonoše-Jizera Terrane

An important role in the terrane evolution of the West Sudetes is attributed to the

Krkonoše-Jizera Terrane (KJT, after Narębski 1994). Three lithotectonic units are currently distinguished in the Krkonoše-Jizera Terrane sequence and are described in structurally upwards succession (e.g. Kachlík & Patočka 1998).

(1) The basal autochthonous unit includes the Cadomian Lusatian granitoids, which intrude the late Proterozoic flysch sequence (Chaloupský *et al.* 1989). The unit is exposed along the NW margin of the Ještěd Range (the westernmost part of the KJT at the boundary with the Lusatian Granitoid Complex, Fig. 1) as a foreland of overlying lithotectonic units. It experienced greenschist facies metamorphism of Cadomian age (between *c.* 560 and 545 Ma) and has a non-penetrative Variscan overprint (e.g. Kröner *et al.* 1994*a*).

(2) The overlying parautochthonous to allochthonous unit contains a very low-grade metamorphosed early to late Palaeozoic volcanosedimentary sequence with features typical of the Saxothuringian Zone (e.g. Chlupáč 1993). This unit, which experienced only late Variscan lower greenschist facies metamorphism forms several imbricated slices in the central and possibly also the eastern parts of the Ještěd Range (Kachlík & Patočka 2001).

(3) The uppermost allochthonous composite unit comprises a large antiform of the Izera and Krkonoše (Kowary) gneisses, which include metamorphosed Cambrian to Ordovician granitoids (e.g. Borkowska *et al.* 1980; Kryza & Pin 1997; Białek 1998). The core is intruded by the late Variscan Krkonoše-Jizera granite pluton. Its southern and eastern rims consist of the Lower Palaeozoic metamorphosed volcanosedimentary sequences of the South and East Krkonoše Complexes (e.g. Fajst *et al.* 1998; Kachlík & Patočka 1998; Patočka *et al.* 2000; Dostal *et al.* 2001). The East Krkonoše Complex (EKC), exposed on the east of the KJT, was defined by Berg (1912), Oberc (1960) and Teisseyre (1968). It comprises the Rýchory Mountains (Czech Republic), the Lasocki Range and Rudawy Janowickie Mountains (Poland) (Patočka & Smulikowski 1998). The South Krkonoše Complex (SKC) is situated on the SW margin of the KJT (Fajst *et al.* 1998). The complexes show considerable diversity both in metamorphic grade and protolith composition, and are mostly tectonically bounded. They underwent early Variscan blueschist facies metamorphism, followed by a widespread greenschist facies overprint (Patočka *et al.* 1996) which is related to the Early Carboniferous tectonic uplift of the previously subducted crustal slices.

Interpretations of the tectonometamorphic development of the KJT vary widely, but encompass the effects of the Cadomian, Caledonian (?) and Variscan orogenies (see review by Chlupáč 1993). Lithostratigraphic studies on the South Krkonoše Complex (Chaloupský 1963, 1966; Kachlík 1997; Chlupáč 1997, 1998), and the ^{40}Ar/^{39}Ar dating from the East Krkonoše Complex (Maluski & Patočka 1997) show that the KJT structure is a result of Variscan tectonometamorphic processes. The KJT volcanosedimentary successions were deposited during a protracted period of intracontinental rifting of the Cadomian basement, and (as suggested by some of the EKC metabasites) the formation of an oceanic basin of limited extent (Kryza *et al.* 1995; Winchester *et al.* 1995; Patočka *et al.* 2000; Dostal *et al.* 2000, 2001).

Collision of peri-Gondwanan microplates with Baltica (± East Avalonia) in Middle to Late Devonian closed the above-mentioned basin, and produced progressive stacking of the basin fill. The early Variscan subduction-related blueschist facies metamorphism of estimated peak conditions $T = 400–450$ °C and $P = 10–12$ kbar (Patočka *et al.* 1996) affected the rocks of the subducted plate. Its ending is dated at 365–360 Ma (Maluski & Patočka 1997). The subsequent greenschist facies retrogression (345–340 Ma; Maluski & Patočka 1997) was followed by the late tectonic Krkonoše–Jizera pluton intrusions (Pin *et al.* 1987; Mierzejewski *et al.* 1994) and major late Variscan shearing and thrusting which produced the NW–SE directed linear fabric of the KJT.

Góry Sowie Block

The Góry Sowie Block (GSB) is a tectonostratigraphic unit composed of the gneiss–migmatite Góry Sowie Complex (GSC) with minor occurrences of felsic granulite and basite–ultrabasite rocks (Żelaźniewicz 1990, 1995). The triangular block is bounded by steep fault zones with records of polyphase ductile and then brittle deformation. Magnetic and gravimetric data suggest that its eastern part is underlain by the Sudetic ophiolite (Fig. 1) dated by the U–Pb zircon method at *c.* 420–400 Ma (Oliver *et al.* 1993; Żelaźniewicz *et al.* 1998). During the Late Devonian the GSB together with the ophiolite were rapidly exhumed and both delivered clasts to adjacent sedimentary Late Devonian–Early Carboniferous Bardo and Świebodzice basins (e.g. Żelaźniewicz 1997; Hladil *et al.* 1999; Kryza *et al.* 1999).

Based on relationships between deformational structures and successive stages of migmatite formation, five phases (deformation phases D_1–D_5) of evolution of the gneiss–migmatite portion of the GSC have been discerned, with peak metamorphic conditions during migmatization at 3–6 kbar and 700–730 °C (Żelaźniewicz 1990, 1995). Several isotopic dates on migmatites formed in different phases show that the peak conditions were attained at Mid–Late Devonian boundary (van Breemen *et al.* 1988; Bröcker *et al.* 1998; Timmermann *et al.* 2000). Age constraints on post-peak metamorphism are documented by Rb–Sr ages between 375 ± 4 and 360 ± 7 Ma (van Breemen *et al.* 1988; Bröcker *et al.* 1998) for D_2–D_5 migmatite phases. They suggest a rapid uplift, which was contemporaneous with blueschist-facies metamorphism in Palaeozoic rocks of the East Krkonoše Complex (Maluski & Patočka 1997).

Minor occurrences of felsic granulites and mantle-derived garnet peridotite, yielding Early Devonian isotopic ages (O'Brien *et al.* 1997; Brueckner *et al.* 1996) were tectonically inserted into migmatites (Żelaźniewicz 1995) and were retrogressively metamorphosed contemporaneously with the progressive migmatization under upper amphibolite facies conditions which obliterated the boundary shear zones.

Orlica-Śnieżnik Dome

The Orlica-Śnieżnik Dome (OSD) is the southeasternmost tectonostratigraphic unit of the West Sudetes (Fig. 1) and the Saxothuringian Zone, and it has a complicated fault zone contact with the Moravo-Silesian zone further east. The OSD generally consists of a mainly orthogneissic core, locally embracing (ultra) high pressure eclogites and granulites, enveloped by a variegated middle–lower amphibolite facies series of mica schists and paragneisses with marbles and amphibolites, which is surrounded in turn by greenschist-facies metapelites and metabasites. Metabasites are geochemically linked with an intraplate rift setting (Floyd *et al.* 1996). Palaeontological data, although controversial, for metasediments (Gunia 1996 and references therein) point to the late Proterozoic–Early Cambrian age. Pb/Pb dating of zircon from a leptynite yielded an age of *c.* 520 Ma (Kröner *et al.* 1997).

The orthogneiss core of the OSD consists of (1) porphyritic coarse- to medium-grained metagranites (Śnieżnik augen gneisses) of calc-alkaline affinity and (2) laminated, variably grained, two-mica migmatitic alkaline gneisses (Gierałtów gneisses), with lensoid bodies of augen gneisses, amphibolites, eclogites and felsic granulites (Borkowska *et al.* 1990). A structural inventory of the migmatitic gneisses differs profoundly from that of the augen metagranites, whereas both the gneiss variants are zonally sheared and deformed to mylonites and ultramylonites.

Eclogite bodies have amphibolitized margins and occur in narrow discontinuous belts (Dumicz 1993). Their protoliths range from MORB, through calc-alkaline to bimodal volcanic rocks (Bakun-Czubarow 1998), which excludes single source of the original mafic rocks and obscures their relationships to the gneissic hosts. Most of the eclogites show signs of UHP metamorphism under conditions of 660–800 °C and above 27 kbar, followed by marked decompression under amphibolite facies conditions (Bakun-Czubarow 1992, 1998; Bröcker & Klemd 1996), with isothermal decompression in the pressure range 9–5 kbar at ≤ 600 °C (Kozłowski & Bakun-Czubarow 1997), or 11–4 kbar at 650–600 °C (Bröcker & Klemd 1996). Strong metamorphic contrasts between neighbouring eclogites, granulites and some gneisses and amphibolites on one hand and other gneisses and amphibolites, mica schists and phyllites on the other hand, point to large tectonic displacements between and within these rock units.

Review of geochronology

Lusatian Granitoid Complex (LGC)

Constraints on the sedimentation age of the Lusatian greywackes, representing the oldest rocks of the LGC, are given by magmatic zircons of synsedimentary pyroclastic intercalations dated at 562 ± 4 Ma using the Pb/Pb evaporation method (Gehmlich *et al.* 1997). These late Proterozoic greywackes were later intruded by the voluminous Lusatian pluton granitoids.

The time of zircon crystallization in the western Lusatian granodiorites is given by Pb/Pb zircon ages between 550 and 535 Ma (mean age 542 Ma) for the biotite-granodiorite near Kindisch reported by Tichomirova *et al.* (1997) and for the muscovite-bearing biotite-granodiorite (near Kubschütz) with 542 ± 9 Ma (Kröner *et al.* 1994*a*).

Further east, on the northwestern flank of the Krkonoše-Jizera region, the Lusatian granodiorites, referred to as the Zawidów granodiorite and the Leśna gneisses (foliated variant of granodiorite) which also yielded Early Cambrian intrusion ages (U–Pb zircon lower intercept) of 540 +6/–7 Ma and 540 +19/–21 Ma, respectively (Korytowski *et al.* 1993). Different older emplacement Pb/Pb single zircon evaporation ages for the various granitoids of the LGC between 587 and 560 Ma were reported by Kröner *et al.* (1994*a*) which coincides with

K-feldspar Pb/Pb model ages between 589 and 563 Ma obtained by Bielicki *et al.* (1989).

The so-called Rumburk granite of East Lusatia is considered as a member of the most differentiated and youngest granitoid generation which intruded the LGC. For the undeformed Rumburk granite a late Middle Cambrian Rb–Sr whole rock age of 501 ± 32 Ma was reported by Borkowska *et al.* (1980). More recently, it yielded latest Cambrian to Early Ordovician Pb/Pb zircon emplacement ages between 494 ± 12 Ma and 480 ± 12 Ma (Hammer *et al.* 1997). An older emplacement age of 571 ± 16 Ma is given by Kröner *et al.* (1994*a*).

Small bodies of hornblende monzogranite (Wiesa) and amphibole-bearing granodiorite (Kleinschweidnitz) were dated by the Pb/Pb single zircon evaporation method at 304 ± 14 Ma and 312 ± 10 Ma (Late Carboniferous), respectively (Kröner *et al.* 1994*a*; Hammer *et al.* 1997).

A compilation of published and unpublished Rb–Sr and K–Ar age data (up to 1992) of the pre-Variscan Lusatian granitoids is given by Kröner *et al.* (1994*a*).

Krkonoše-Jizera Terrane (KJT)

From the KJT (situated to the east of the LGC), the oldest available ages were provided by the Izera Gneisses derived from the Cambrian Izera granites. In the western part of the KJT, the gneissic samples from Frýdlant yielded Pb/Pb single zircons ages of 515 ± 8 Ma and 504 ± 10 Ma (Kröner *et al.* 1994*b*). Likewise in the eastern part of the KJT, the weakly foliated granitic samples from Perła Zachodu yielded the U–Pb zircon lower intercept ages of 515 +5/–7 Ma (Korytowski *et al.* 1993) and 514 +5/–6 Ma (Philippe *et al.* 1995). A further U–Pb lower intercept age of 493 ± 2 Ma for a Rumburk-type metagranite was regarded as the minimum emplacement age due to moderate U-content in the investigated zircons (Oliver *et al.* 1993).

The Rb–Sr whole rock ages of weakly deformed Izera Gneiss (462 ± 15 Ma) and a leucogneiss variety (473 ± 16 Ma) dated by Borkowska *et al.* (1980) were possibly affected by (partial) homogenization during the Variscan metamorphic overprint. The Late Carboniferous Rb–Sr ages of 320–310 Ma (using one muscovite and two biotite grains) were interpreted as the products of isotopic resetting due to the Krkonoše-Jizera pluton intrusion (see below) (Borkowska *et al.* 1980).

The Kowary gneiss (Poland), petrographically equivalent of the Izera Gneiss from the northern part of the KJT yielded compatible U–Pb zircon lower intercept ages between 492 and 481 Ma (Oliver *et al.* 1993). Published Pb/Pb single zircon ages on the Krkonoše gneiss (on the Czech territory corresponding to the Kowary gneiss) date its magmatic origin between 509 and 490 Ma (Kröner *et al.* 1994*b*, 1997).

East and South Krkonoše Complexes (EKC; SKC) In the EKC the geochronological data were reported from the Rýchory Mountains (Czech Republic), and their northern continuation, the Rudawy Janowickie Mountains (Poland). The porphyroids from the Rýchory Mountains provided the Rb–Sr whole rock age of 495 ± 9 Ma and in combination with associated greenschists, an age of 501 ± 8 Ma. Both of the ages were interpreted to date the Cambro-Ordovician rift-related magmatism (Bendl & Patočka 1995). Recent U–Pb data on zircons from the Rýchory Mountains mafic blueschists yielded a protolith age of 485 ± 4 Ma (Timmermann *et al.* 1999). In the Rudawy Janowickie Mountains, Oliver *et al.* (1993) obtained by U–Pb method (on zircons) an age of 505 ± 5 Ma from a felsic volcanic rock boudin as well as an age of 494 ± 2 Ma from a rock described as 'hornblende gabbro', that in fact corresponds to a Paczyn gneiss variety (Patočka & Smulikowski 1998).

The Bítouchov metagranite from the South Krkonoše Complex (SKC) was dated at *c.* 540 Ma (U–Pb zircon; Dörr unpublished). This metagranite yields a homogeneous age pattern recording neither inherited components nor younger zircons (Dörr pers. comm.), and thus may indicate the presence of a Cadomian basement.

The early Variscan high pressure–low temperature metamorphism of the EKC in the eastern Rýchory Mountains was dated by the single grain Ar/Ar technique on phengites in the mafic blueschists yielding Late Devonian plateau ages of 364 ± 2 Ma and 359 ± 2 Ma, respectively and were interpreted as the end of subduction-related blueschist metamorphism. Other phengites were resetted by the subsequent retrogressive greenschist facies overprint and provided plateau ages between 345 and 340 Ma (Maluski & Patočka 1997).

Krkonoše-Jizera pluton The late-tectonic Krkonoše-Jizera pluton intruded central sectors of the KJT. It consists essentially of several different granite types representing at least two distinct (major) magmatic events: The medium grained aphyric Tanvald two-mica granite, cropping out only on the SW and west margin of the Krkonoše-Jizera pluton, is assumed to be the oldest type (Klomínský 1969). The medium to coarse grained porphyritic granite (the 'Liberec-type' granite), and a younger fine to medium grained facies, the 'Krkonoše ridge-type granite' (e.g. Mierzejewski *et al.* 1994) constitute the main part of the pluton. The emplacement of the porphyritic Liberec-type granite was dated by Rb–Sr whole rock isochrons at around 330–325 Ma (Pin *et al.* 1987; Duthou *et al.* 1991) whereas the finer grained Krkonoše ridge-type granite yielded Rb–Sr whole rock isochron ages about 310 ± 5 Ma (Mierzejewski *et al.* 1994). However, the coarse grained porphyritic monzogranite near Liberec provided a Pb/Pb zircon evaporation age of 304 ± 14 Ma (Kröner *et al.* 1994*a*).

Góry Sowie Block (GSB)

Pb/Pb single zircon ages between 487 ± 2 and 482 ± 2 Ma of gneisses in the GSB have been interpreted as crystallization ages of Ordovician granitoids (Kröner & Hegner 1998). The layered migmatitic gneiss from Zagórze and the diatexitic migmatite from Potoczek yielded the U–Pb monazite ages of 381 ± 2 Ma (lower intercept; van Breemen *et al.* 1988) and of 383–379 Ma (nearly concordant; Bröcker *et al.* 1998), respectively. They are identical with concordant xenotime ages of 384–380 Ma obtained for the augen gneiss from Sokolec (Bröcker *et al.* 1998) and correspond well with recent U–Pb monazite and xenotime ages of 378 ± 2 Ma and 383–370 Ma, for the anatectic granite and the pegmatite, respectively (Timmermann *et al.* 2000). These highly consistent results of rocks deformed during the D_2 to D_5 stages contrast with the Pb/Pb single zircon evaporation data published by Kröner & Hegner (1998), which range from 473 to 440 Ma, and the U–Pb zircon lower intercept age of 461 +50/–2 Ma of the diatexite (Oliver *et al.* 1993). After studying the internal morphology of zircons from these rocks the apparent Ordovician ages were re-interpreted as inherited or mixed ages dominated by an older core component (Timmermann *et al.* 2000). This interpretation is supported by several well-documented Rb–Sr thin-slab and mineral isochron ages of the Góry Sowie migmatites varying from 375 ± 4 Ma to 362 ± 8 Ma (Bröcker *et al.* 1998) and 372 ± 7 Ma to 360 ± 7 Ma (van Breemen *et al.* 1988). These results together point to Late Devonian high temperature metamorphism (cf. Tucker *et al.* 1998).

Somewhat older Early Devonian U–Pb and Pb/Pb metamorphic zircon ages of 401 ± 10 Ma and 402 ± 1 Ma, respectively were reported for felsic high pressure granulites (O'Brien *et al.* 1997). For a mantle-derived garnet–peridotite associated with the granulites, Brueckner *et al.* (1996) obtained an identical age of 402 ± 3 Ma using the Sm–Nd method (Cpx–Opx–Grt–whole rock isochron). These ages were interpreted as mineral growth ages during high pressure-granulite facies pressure and temperature conditions.

A single post-tectonic granitoid body in the eastern part of the GSB (Piława), dated at 334 ± 2 Ma (Pb/Pb zircon; Kröner & Hegner 1998), is identical to an adjacent syn-tectonic granodiorite of the Niemcza Zone to the east (Fig. 1), which yielded a Pb/Pb single zircon age of 334 ± 2 Ma (Kröner & Hegner 1998) and a U–Pb lower intercept zircon age of 338 +2/–3 Ma (Oliver *et al.* 1993) from the same quarry at Koźmice.

Late Variscan activity in the GSB is documented by the Ar/Ar total fusion ages of two to three grains of muscovite and biotite (Oliver & Kelley 1993) which show a range of ages of mylonitized gneisses between 337 ± 13 Ma to 319 ± 17 Ma. These are thought to provide a very rough time estimate for movements on mylonite zones bordering the GSB.

Orlica-Śnieżnik Dome (OSD)

The protolith ages of orthogneisses in the OSD have been determined on many zircons by the U–Pb and Pb/Pb methods. Cambrian Pb/Pb single zircon ages of *c.* 520 Ma were obtained for felsic metavolcanic rocks in the Stronie formation and for the Gierałtów and Śnieżnik orthogneisses (Kröner *et al.* 1997), which intruded the Stronie Formation. However, Pb/Pb zircon ages of 507 ± 10 Ma, 503 ± 4 Ma and 499 ± 15 Ma were also reported as apparent emplacement ages for their granitic protolith (Kröner *et al.* 1994*b*). The differences are possibly caused by an influence of inherited components, as revealed by U–Pb dating of abraded zircons from the Śnieżnik gneiss dated between 540 and 500 Ma (Borkowska & Dörr 1998). These results were confirmed by SHRIMP U–Pb and Pb/Pb analyses on zircons yielding ages of *c.* 500 Ma reflecting the age of magmatic crystallization of the protolith and 540–530 Ma in a few inherited zircon cores for both Śnieżnik and Gierałtów gneisses (Turniak *et al.* 2000). U–Pb zircon lower intercept ages between 504 ± 3 Ma and 488 +4/–7 Ma of mylonitized Śnieżnik gneiss support a Cambro-Ordovician emplacement of the gneiss protolith (Oliver *et al.* 1993; Kröner *et al.* 1994*b*). The Rb–Sr whole rock analyses of the Gierałtów gneiss yielded ages of 487 ± 11 Ma (van Breemen *et al.* 1982) as well as 465 ± 35 Ma and 464 ± 18 Ma (Borkowska *et al.* 1990), both interpreted as protolith emplacement ages. Some data record a Devonian metamorphic event in the OSD; for example the Rb–Sr whole rock age of 395 ± 35 Ma on the Śnieżnik augengneiss (Borkowska *et al.* 1990), the Rb–Sr thin slab whole rock isochron age of 396 ± 17 Ma and the U–Pb zircon lower intercept age of 372 ± 7 Ma both on Gierałtów gneisses associated with eclogites, and nearly concordant U–Pb zircon ages between 369 and 360 Ma on an omphacite granulite assumed as the date of high pressure–high temperature metamorphism (Bröcker *et al.* 1997).

Carboniferous ages of metamorphism were documented in all the above-mentioned lithologies or varieties respectively. Eclogite lenses yielded Sm–Nd garnet–whole rock–(clinopyroxene) isochron ages, grouped between 352 and 326 Ma (Brueckner *et al.* 1991; Bröcker *et al.* 1997) and the U–Pb zircon lower intercept age of 337 ± 3 Ma was considered by Bröcker *et al.* (1997) to date the late stage of high pressure-metamorphism. However, the SHRIMP analyses on rims of the Gierałtów gneiss zircons yielded concordant age of 342 ± 6 Ma (Turniak *et al.* 2000) which is considered to record the high temperature–low pressure metamorphism peak. The Rb–Sr biotite–muscovite–whole rock (Śnieżnik gneiss) and phengite–whole rock (eclogite; Gierałtów gneiss) isochron ages of 335 ± 5 Ma (Borkowska *et al.* 1990) and 333–329 Ma (Bröcker *et al.* 1997), respectively, fit into this range.

The late Variscan history of the OSD was dated by the ^{40}Ar/^{39}Ar method. The ^{40}Ar/^{39}Ar plateau ages of 329 ± 2 Ma (muscovite) and 328 ± 2 Ma (biotite) were reported for the migmatitic Gierałtów gneiss; a muscovite age of 328 ± 2 Ma for the mylonite Śnieżnik augengneiss and a hornblende age of 327 ± 2 Ma for the Lewin Kłodzki amphibolites have also been recorded (Steltenpohl *et al.* 1993). An identical biotite plateau age of 328 ± 3 Ma for a migmatitic gneiss in the Śnieżnik unit is given by Maluski *et al.* (1995). All these late Viséan Ar/Ar ages were interpreted as uplift-related cooling ages.

The youngest age in the OSD (313 ± 3 Ma) was obtained by the ^{40}Ar/^{39}Ar method on undeformed primary muscovite. It reflects a cooling under static conditions after a late increase in temperature (Maluski *et al.* 1995).

Analytical techniques

^{40}Ar/^{39}Ar measurements

The mineral concentrates were prepared by crushing, sieving, Frantz magnetic separation and handpicking. Finally the minerals were cleaned using ultrasonic treatment successively in alcohol, acetone and distilled water.

According to the grain sizes, either mineral concentrates (≤ 250 µm) or single grains (> 250 µm) were analysed. In the case of the mineral concentrates, *c.* 100 mg of material encapsulated in evacuated quartz vials were irradiated for 58 hours in the Osiris reactor in Saclay (France). The single grain samples, wrapped in aluminium-foil packets were irradiated in the McMaster reactor in Ontario (Canada) for nearly 70 hours. The monitors were the MMhb-1 hornblende standard (Alexander *et al.* 1978) with a recommended age of 520.4 ± 1.7 Ma (Samson & Alexander 1987) and an internal hornblende standard with an intralaboratory age of 344.5 ± 3 Ma.

The ^{40}Ar/^{39}Ar analyses were completed at the ^{40}Ar/^{39}Ar Laboratoire de Géochronologie of the Université Montpellier II. The mineral concentrates were incrementally heated at first with a resistance furnace followed by a Mo crucible coupled with a high-frequency inductor for the high-temperature steps. The isotopic measurements were carried out on a highly modified THN 205E noble-gas mass spectrometer. Details of the analytical procedure are given in Maluski *et al.* (1993) and Monié *et al.* (1994).

The single grain analyses were performed using a LEXEL 3500 continuous 6W argon-ion laser for step-wise heating and a MAP 215-50 noble gas mass spectrometer equipped with a Nier source and a Johnston MM1 electron multiplier for the mass analyses. A detailed description is given by Monie *et al.* (1994, 1997).

The measured isotope ratios were corrected for total system blanks, atmospheric contamination, effects of mass discrimination, irradiation induced mass interference due to Ca and Cl and radioactive decay of ^{37}Ar and ^{39}Ar isotopes. The age calculation is based on the constants recommended by the 'IUGS subcommission on geochronology' quoted in Steiger & Jäger (1977) and cited by McDougall & Harrison (1999). The reported 1σ-errors for plateau and total ages include the uncertainties of the monitors and their ^{40}Ar/^{39}Ar ratios. The detailed results can be obtained from the Society Library or the British Library Document Supply Centre, Boston Spa, Wetherby, West Yorkshire LS23 7BQ, UK as Supplementary Publication No. SUP 18179 (14 pages).

Electron microprobe analyses

Polished thin-sections was used for electron microprobe studies. Analyses of mineral chemistry were prepared on the Cameca SX100 electron microprobe at the University of Montpellier II. The operating conditions were a 20 kV acceleration voltage, a 10 nA beam current and a counting time of 30 s per element (peak and background).

Results

$^{40}Ar/^{39}Ar$ dating

Twenty-eight samples of crystalline rocks from the West Sudetes were dated by the $^{40}Ar/^{39}Ar$ incremental step-wise heating technique (Figs 2, 3, 4). Depending of the mineral grain sizes, either mineral concentrates (conventional technique) or single grains (laser technique) were analysed.

From the East Lusatia (west of Bílý Kostel) a cataclastic granodiorite (the Zawidów-type) was analysed (sample SK30). It contains sericite flakes (pseudomorphs after muscovites) and relicts of chloritized biotite. A small (~ 300 μm) sericite–muscovite single grain (SK30 #1) displayed an irregular complex age spectrum whereas the second analysis of two sericite-muscovite grains heated together (SK30 #2) showed an age spectrum with low-temperature steps beginning at 152 ± 23 Ma and increasing regularly up to a plateau of 323 ± 6 Ma (87.3% of ^{39}Ar released).

From the Krkonoše-Jizera Terrane (KJT) 21 samples were analysed, including rocks of the Izera Gneiss, Intra-Sudetic Fault Zone, Krkonoše-Jizera pluton, South and East Krkonoše Complexes.

Two samples of biotite and muscovite rich Izera gneiss near Siedlecin (Perła Zachodu) were investigated: an undeformed metagranite (sample SU35) and a sheared gneiss (SU33). Single muscovite of the former sample displayed a completely disturbed age spectrum lacking any clear features. Muscovite from the sheared gneiss (SU33) revealed a disturbed spectrum as well, but, beside the scattering low-temperature steps and one exceptional step at intermediate temperatures of 366 Ma (representing the interval of 39 to 55% of the released ^{39}Ar) an age of *c.* 335–328 Ma is quite evident. Two distinct 'plateau ages' were calculated, excluding the step of 366 Ma, which yield ages of 335 ± 3 Ma and 328 ± 3 Ma corresponding to 27.5% and 44.9% of the released ^{39}Ar, respectively. A coexisting sheared biotite yielded an overall plateau age of 294 ± 3 Ma, but with two recognizable plateaus for the low- and high-temperature steps, which are 289 ± 3 Ma (54.8% released ^{39}Ar) and 301 ± 4 Ma (42.8% released ^{39}Ar), respectively.

Two mylonites (samples SU39 and SU42) from the Intra-Sudetic Fault (Pilchowice dam) belonging to the KJT were analysed. A single grain of muscovite from the sample SU39 yielded the plateau age of 324 ± 3 Ma (93% released ^{39}Ar) followed by two younger steps and a final high-temperature step of 326 ± 3 Ma. The muscovite in sample SU42 displayed an age spectrum beginning with seven scattered low-temperature steps (9.4% of the released ^{39}Ar) followed by an age plateau at 333 ± 3 Ma, corresponding to 68.6% of the ^{39}Ar release and ending with two high-temperature steps with an integrated age of 339 ± 3 Ma.

From the Krkonoše-Jizera pluton two granite varieties, the Liberec-type granite and Tanvald-type granite were dated. The former is a porphyritic biotite–monzogranite (sample SK207) which provided a single biotite for analysis. The obtained age spectrum displayed increasing low-temperature steps (representing 20% of the released ^{39}Ar) from 50 Ma up to 316 Ma. The following age plateau comprising 16 heating steps (70% of ^{39}Ar released) yielded age of 320 ± 2 Ma. Two last high-temperature steps reveal a slight decrease in ages to 315 Ma and 314 Ma. Single muscovite of the Tanvald-type two-mica granite (sample SK208) records a well-defined plateau age at 312 ± 2 Ma (94.8% of the released ^{39}Ar).

The following data were obtained on the set from the South Krkonoše Complex (SKC). From the phyllonitized metagranite (sample SK3) near Železný Brod eight very small grains (≤ 200 μm) of muscovite were analysed together displaying regular increment of ages until the total fusion age of 350 ± 4 Ma, representing 62.5% of released ^{39}Ar. Zoned phlogopite from an altered olivine–pyroxene minette (SK4) cross-cutting the SKC metasediments after young apparent ages in the first four low-temperatures steps revealed ages between 321 and 327 Ma followed by an age plateau at 314 ± 6 Ma corresponding to 71.5% released ^{39}Ar.

From a metagabbro (SK7) sample from Loužnice an amphibole (crossite overgrown by aggregates of fibrous pale actinolitic hornblende and actinolite) revealed a well-defined age plateau at 321 ± 6 Ma after the first scattered low-temperature steps corresponding to 10.9% of the released ^{39}Ar.

Muscovite from a mylonitized Bitouchov metagranite (SK8) showed a plateau age of 352 ± 6 Ma (93.4% released ^{39}Ar) whereas the muscovite concentrate of a nearby greenschist sample (SK9) from the Jizera River Valley yielded a concordant plateau age of 344 ± 3 Ma (94.7% released ^{39}Ar).

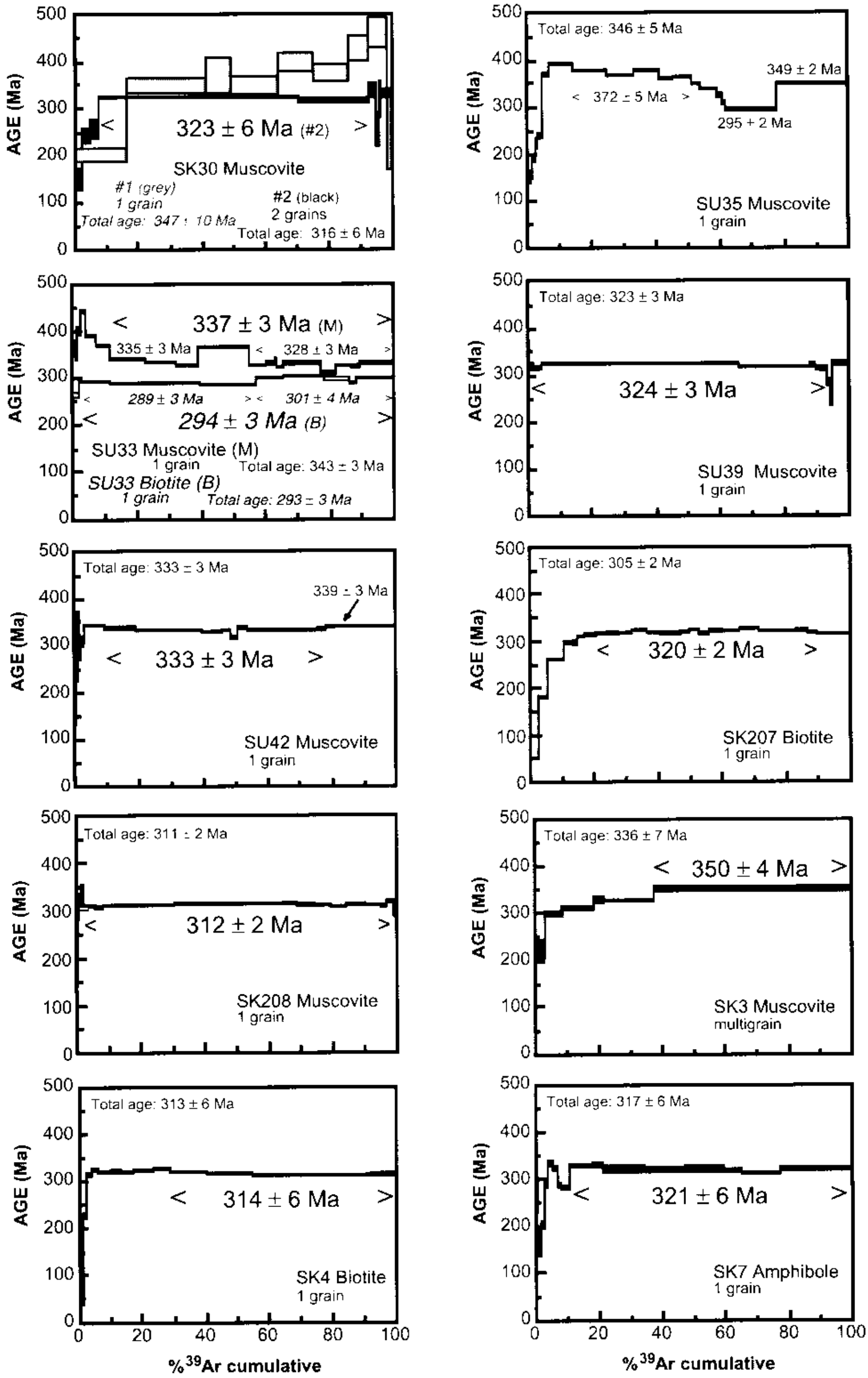

Fig. 2. ^{40}Ar/^{39}Ar age spectra from the Lusatian Granitoid Complex and the Krkonoše-Jizera Terrane.

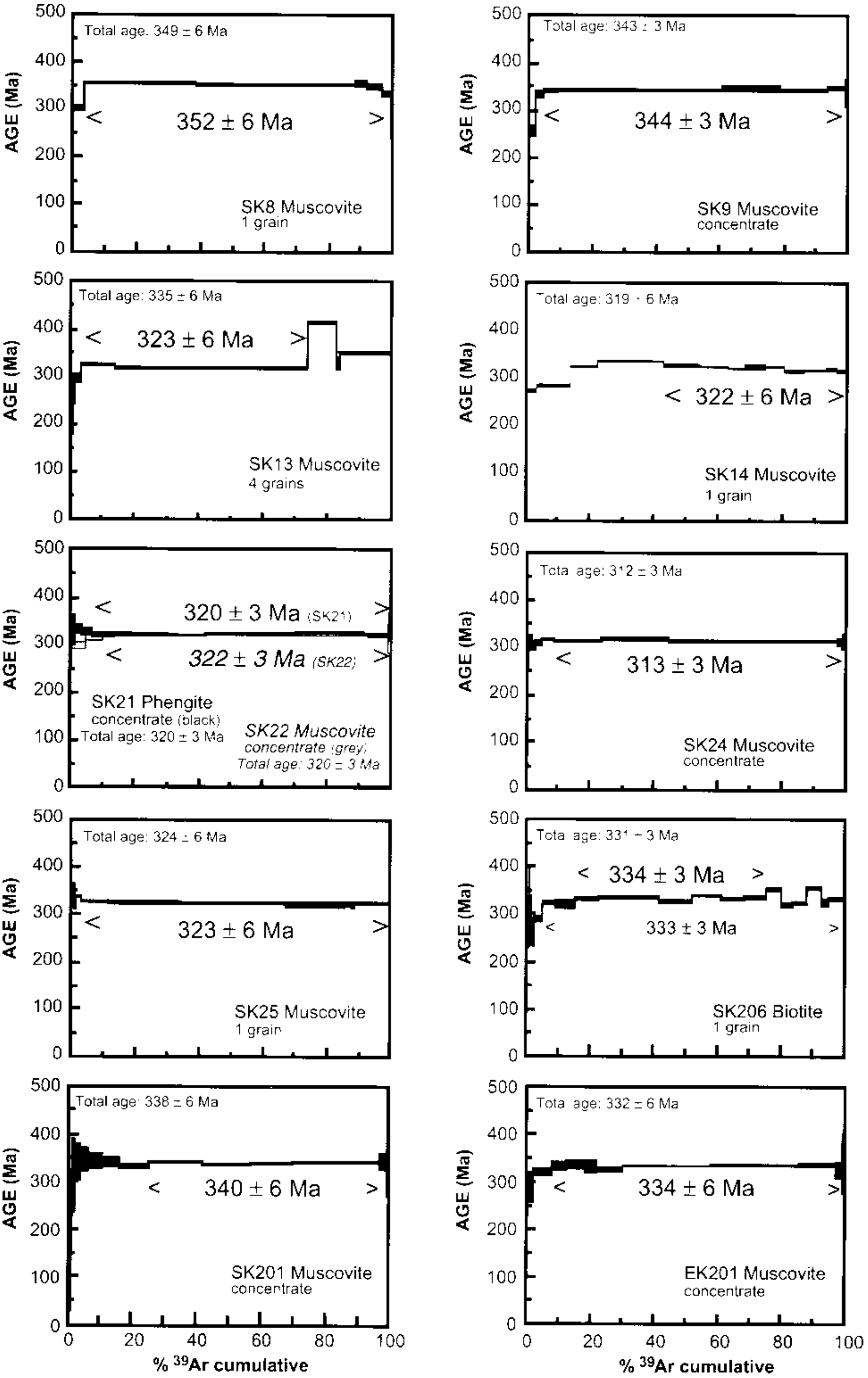

Fig. 3. ^{40}Ar/^{39}Ar age spectra from the Krkonoše-Jizera Terrane.

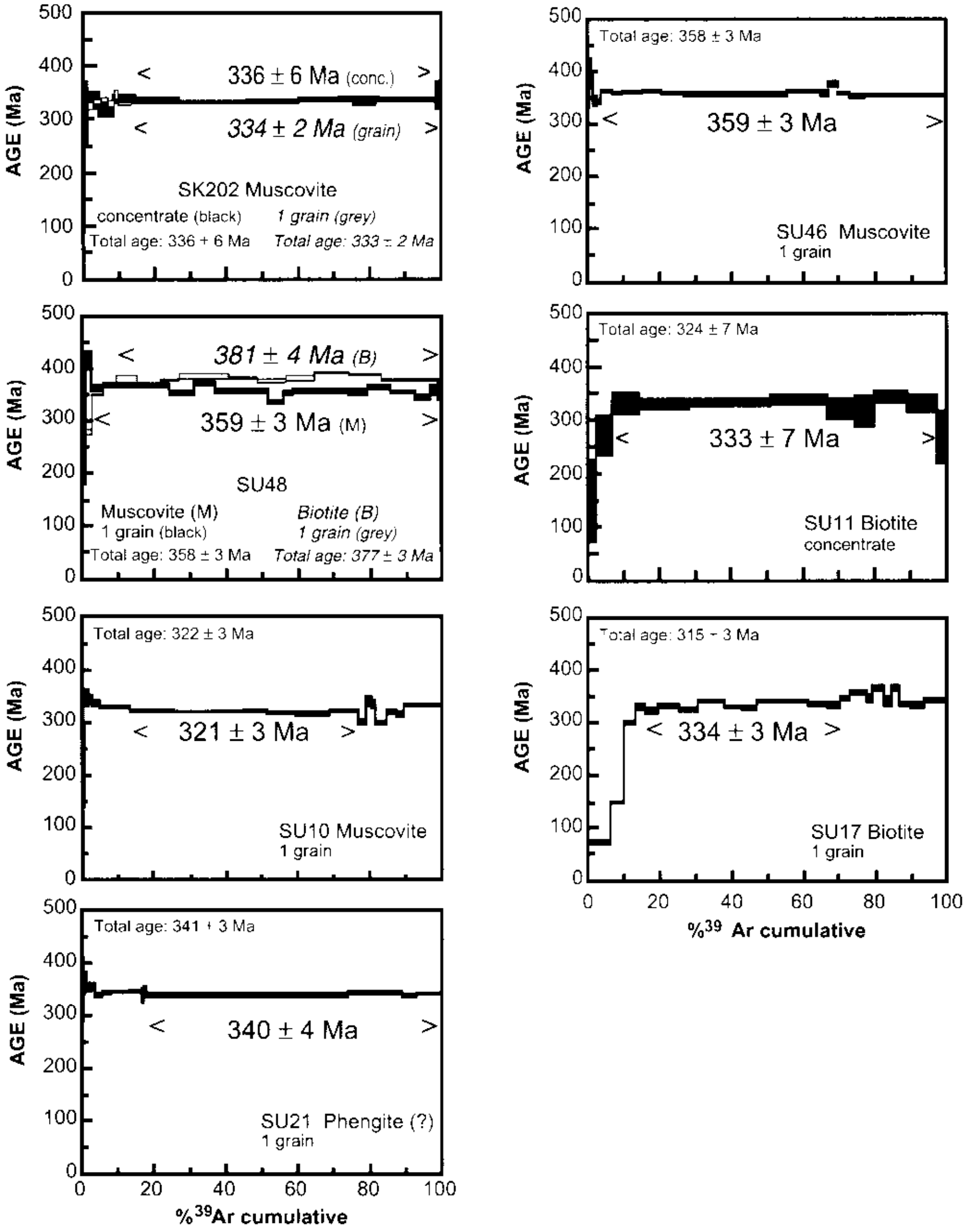

Fig. 4. ^{40}Ar/^{39}Ar age spectra from the Krkonoše-Jizera Terrane, Góry Sowie Block and the Orlica-Śnieżnik Dome.

From a banded metatuffite greenschist sampled near Návarov Castle (SK13) four small muscovite grains (160–250 μm) were dated together, and after the first low-temperature steps, displayed an age plateau at 323 ± 6 Ma, representing 70% of released ^{39}Ar. This is followed by an exceptionally high value of 418 Ma after which the ages decreased abruptly and ended in a total fusion age of 352 ± 1 Ma.

From the western part of the SKC (close to the sample site SK13) a large sericite flake provided by a Ordovician–Silurian sericite–quartz metarhyolite tuff (SK14) from the Kamenice River was analysed. The age spectrum showed increasing low- to intermediate-temperature steps up to 335 Ma continuing in the age plateau of 322 ± 6 Ma equal to 57.1% of the released ^{39}Ar. Mineral concentrates of phengite from the sheared blueschist and phengitic muscovite in sheared phyllite (SK21 and SK22, respectively) near Vrchlabí yielded well-defined plateau ages of 320 ± 3 Ma (92.4% ^{39}Ar release) and 322 ± 3 Ma (89% released ^{39}Ar), respectively.

From the sheared Krkonoše gneiss sampled at the Elbe Dam, the muscovite concentrate (SK24) was dated giving a plateau age of 313 ± 3 Ma, corresponding to 92.5% released ^{39}Ar. A single grain of muscovite from the sheared Krkonoše gneiss (SK25) sampled in the Úpa Valley near the Leszczyniec shear zone provided a plateau age of 323 ± 6 Ma calculated for 96.6% of the ^{39}Ar release. A single biotite separated from massive coarse-grained porphyritic metagranite (SK206) from the northeastern part of the Krkonoše gneiss body displayed considerable age discordance between the low- and high-temperature steps. The intermediate temperature gas fractions give an integrated plateau age of 334 ± 3 Ma representing 60.1% of the released ^{39}Ar.

From deformed Ordovician–Silurian conglomeratic quartzite (SK201) in the vicinity of the Krkonoše orthogneiss in the Malé Labe Valley, a muscovite concentrate was separated and analysed. The obtained age spectrum reveals a distinct age plateau at 340 ± 6 Ma calculated for 72.1% ^{39}Ar released.

Muscovite concentrate was analysed from the strongly sheared and mylonitized porphyroid (sample EK201) located in the Leszczyniec shear zone in the East Krkonoše Complex (EKC). The concentrate records the well-defined plateau age of 334 ± 6 Ma, corresponding to 89.2% of the ^{39}Ar release. Another Ordovician–Silurian quartzite (SK202) near Janské Lázně was dated on single muscovite grain (~1mm) and muscovite concentrate, respectively. The latter yielded an age spectrum with irregular low-temperature steps, terminated in a flat age plateau at 336 ± 6 Ma (83.9% of the released ^{39}Ar). The single grain records the age plateau at 334 ± 2 Ma, corresponding to 90.1% of the released ^{39}Ar.

From the SW, part of the Góry Sowie Block (GSB) muscovite from the D_3 anatectic granite (sample SU46, south of Walim) with sillimanite lineation (Żelaźniewicz 1990) yielded the plateau age of 359 ± 3 Ma representing 96.3% of released ^{39}Ar. The muscovite of sheared gneiss (SU48) from a sinistral fault zone of the SW margin of the GSB near Przygórze revealed similar spectrum with the identical plateau age of 359 ± 3 Ma (97.6% of ^{39}Ar release). However, the coexisting biotite displays the age spectrum with irregularly increasing low-temperature steps up to apparent ages slightly oscillating around 380 Ma. The integration of 90.5% released ^{39}Ar give the 'plateau age' of 381 ± 4 Ma.

From the eastern part of the Orlica-Śnieżnik Dome (OSD) four samples were dated: the migmatitic Gierałtów gneiss (SU11), mylonitic Gierałtów gneiss (SU10), mylonitic Śnieżnik gneiss (SU17) and orthogneiss (SU21) associated with eclogites from the transition between Gierałtów and Śnieżnik gneisses.

Biotite concentrate of migmatitic Gierałtów gneiss (SU11) NE of Radochów displays an age spectrum with considerable errors, due to very small amounts of Ar released during the analysis. The integrated plateau age of 333 ± 7 Ma was calculated for 90.5% of the released ^{39}Ar. The apparent younger ages in the initial low-temperature and final high-temperature steps matched higher Ca/K ratios, which suggest intra-sample inhomogeneity. The muscovite of the mylonitic Gierałtów gneiss from a sharply limited sinistral shear zone (SU10) in the migmatitic gneisses (SU11) displays an age plateau at 321 ± 3 Ma, representing 63.7% of the released ^{39}Ar, followed by scattered high-temperature steps finishing at 333 ± 1 Ma.

A large biotite flake (500 μm) of the mylonitized Śnieżnik gneiss at Idzikow (SU17) records an age spectrum with increasing low-temperature steps from 73 to 329 Ma, succeeded by the age plateau at 334 ± 3 Ma, corresponding to 54.6% released ^{39}Ar. The following high-temperature steps scatter between ages of 366 and 333 Ma terminating with a total fusion age of 343 ± 2 Ma. A single white mica (phengite) of the high pressure-orthogneiss at the SE end of Międzygórze (SU21) displays the age plateau of 340 ± 4 Ma, corresponding to 82.2% released ^{39}Ar.

Additional electron microprobe investigations

The blueschist white mica samples occurring on foliation planes or as inclusions in carbonates (from the vicinity of Vrchlabí, SK21) were analysed by electron microprobe (Table 1). The results are plotted in the Si v. Al diagram (see Fig. 5). The foliation plane white micas are phengites with high Si contents of 3.37 to 3.49 per formula unit (f.u.). In comparison, the white mica inclusions in carbonate yielded somewhat lower Si (f.u.) contents of 3.31 to 3.40; although, they are also regarded as phengites. Two white

Table 1. *Microprobe analyses of white micas from sample SK21*

Analysis No.	2	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23
Position*	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Fol.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
SiO_2	50.94	50.17	50.99	49.89	49.79	49.61	49.58	49.88	50.30	49.75	51.28	50.81	47.72	49.38	49.33	47.37	49.76	49.61	50.90	49.94
TiO_2	0.18	0.17	0.16	0.20	0.18	0.21	0.18	0.20	0.18	0.18	0.15	0.18	0.09	0.17	0.23	0.05	0.16	0.11	0.13	0.24
Al_2O_3	26.62	27.01	26.74	27.88	27.28	27.09	27.83	28.03	26.46	27.44	24.97	25.80	36.76	28.24	30.21	37.60	27.81	27.93	27.87	28.26
Cr_2O_3	0.02	0.01	0.01	0.03	0.07	0.02	0.00	0.08	0.02	0.04	0.04	0.00	0.04	0.01	0.12	0.04	0.15	0.01	0.06	0.14
FeO^T	2.83	2.74	2.81	3.20	2.81	3.62	2.73	2.92	2.80	2.92	3.05	3.10	1.18	2.80	2.01	0.60	2.76	2.81	2.60	2.73
MnO	0.06	0.03	0.00	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00
MgO	3.22	3.13	3.18	2.72	2.92	3.11	2.79	2.76	3.08	2.84	3.69	3.43	0.89	2.76	2.26	0.33	2.65	2.86	3.09	2.52
CaO	0.02	0.00	0.00	0.00	0.03	0.03	0.01	0.00	0.03	0.02	0.00	0.03	0.13	0.05	0.08	0.12	0.04	0.01	0.01	0.02
Na_2O	0.26	0.28	0.21	0.42	0.34	0.39	0.54	0.47	0.28	0.49	0.17	0.16	5.23	0.42	0.69	6.11	0.46	0.50	0.43	0.50
K_2O	9.41	9.66	9.74	9.28	9.02	9.81	9.11	9.00	8.95	8.80	10.16	9.20	2.85	8.93	8.99	1.44	9.13	9.05	9.22	9.04
H_2O	4.43	4.41	4.44	4.42	4.38	4.41	4.40	4.42	4.37	4.39	4.40	4.39	4.63	4.40	4.47	4.66	4.40	4.40	4.48	4.43
Sum	97.99	97.61	98.28	98.07	96.82	98.31	97.19	97.78	96.46	96.88	97.92	97.10	99.51	97.16	98.38	99.32	97.34	97.30	98.80	97.83
Atomic proportions on the basis of 11 oxygen atoms																				
Si	3.443	3.411	3.441	3.377	3.402	3.373	3.378	3.377	3.445	3.396	3.489	3.466	3.089	3.362	3.307	3.046	3.385	3.375	3.405	3.377
Ti	0.009	0.009	0.008	0.010	0.009	0.011	0.009	0.010	0.009	0.009	0.008	0.009	0.004	0.008	0.012	0.002	0.008	0.006	0.006	0.012
Al	2.121	2.165	2.127	2.225	2.197	2.171	2.235	2.237	2.136	2.208	2.002	2.075	2.805	2.266	2.387	2.925	2.230	2.240	2.197	2.252
Cr	0.001	0.001	0.001	0.002	0.004	0.001	0.000	0.004	0.001	0.002	0.002	0.000	0.002	0.001	0.006	0.002	0.008	0.001	0.003	0.008
Fe	0.160	0.156	0.158	0.181	0.160	0.206	0.156	0.165	0.160	0.167	0.173	0.177	0.064	0.160	0.113	0.032	0.157	0.160	0.146	0.154
Mn	0.003	0.002	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Mg	0.325	0.318	0.320	0.275	0.298	0.315	0.283	0.278	0.314	0.289	0.374	0.348	0.086	0.280	0.226	0.032	0.269	0.290	0.308	0.254
Ca	0.001	0.000	0.000	0.000	0.002	0.002	0.001	0.000	0.002	0.001	0.000	0.002	0.009	0.003	0.005	0.008	0.003	0.001	0.001	0.001
Na	0.034	0.037	0.027	0.055	0.045	0.051	0.071	0.062	0.037	0.065	0.022	0.022	0.657	0.056	0.090	0.762	0.060	0.067	0.055	0.065
K	0.812	0.838	0.838	0.802	0.786	0.851	0.792	0.778	0.782	0.766	0.882	0.800	0.235	0.775	0.769	0.118	0.792	0.786	0.787	0.780
OH	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Sum	8.909	8.935	8.920	8.928	8.904	8.982	8.926	8.912	8.887	8.905	8.953	8.899	8.950	8.912	8.915	8.928	8.914	8.925	8.910	8.904

* Fol. - on foliation plane; Incl. - as inclusion

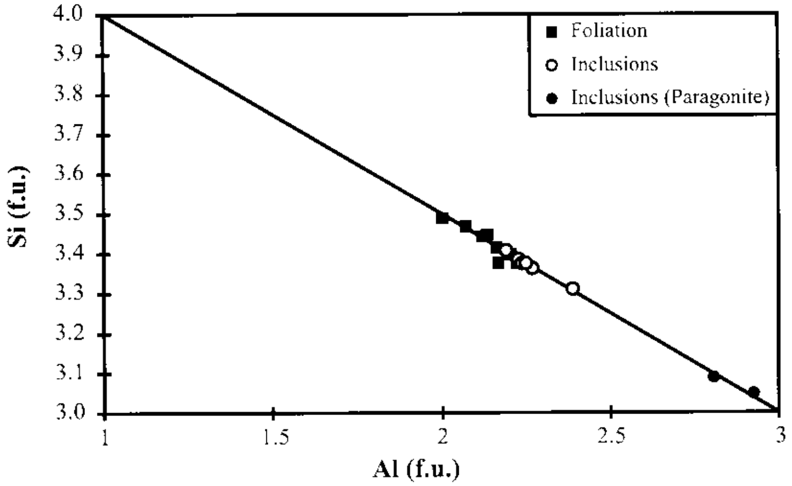

Fig. 5. Si/Al (f.u.) diagram for white micas of the blueschist sample SK21 showing the microprobe results of micas occurring in the foliation plane or as inclusions in carbonate, respectively.

mica inclusions show paragonitic composition that, as regards metabasites, indicate an earlier blueschist facies metamorphic episode (Guidotti 1984). Considering a temperature range of 300–500 °C for the blueschist facies in the South Krkonoše Complex (Patočka *et al.* 1996; Kryza 1998) the pressure-conditions are estimated at more than 10 kbar.

Discussion and interpretation of the $^{40}Ar/^{39}Ar$ ages

The mineral plateau ages are interpreted to date last cooling through appropriate temperatures necessary for intracrystalline retention of argon. Although these so-called closure temperatures are variable and hard to define (e.g. Villa 1997; McDougall & Harrison 1999), 'nominal' values of closure temperatures are used in most geochronological studies. The applied temperatures are typically *c.* 500 °C for hornblende (Harrison 1981), 350 °C for muscovite (e.g. Purdy & Jäger 1976) and 300 °C for biotite (e.g. Hodges 1991).

Lusatian Granitoid Complex (LGC)

The Early Cambrian cataclastic Zawidów-type granodiorite (540 Ma, U–Pb zircon; Korytowski *et al.* 1993) from the southeastern part of the LGC reveals highly disturbed $^{40}Ar/^{39}Ar$ age spectra on recrystallized muscovites (SK30#1) due to partial resetting of their K–Ar systems during sericitization related to the later cataclasis. However, the completely reset sericite flakes (SK30#2) date cataclastic deformation at 323 ± 6 Ma (Visćan/Namurian).

Krkonoše-Jizera Terrane (KJT)

The results from the KJT distinguish several prominent age intervals: 352–350 Ma, 344–340 Ma, 336–333 Ma, 324–320 Ma and 314–312 Ma (Fig. 6). The following discussion is subdivided into these age groups.

352–350 Ma and 344–340 Ma The oldest $^{40}Ar/^{39}Ar$ ages were obtained from strongly mylonitized metagranites of the South Krkonoše Complex (SKC). In the analysed metagranite samples (SK3 and SK8) the box shaped quartz ribbons and plastic recrystallization of quartz indicate elevated temperatures in the range of 400–450 °C during deformation corresponding to higher greenschist facies metamorphic conditions. The samples provided ages of about 352–350 Ma, interpreted as cooling after mylonitization during tectonic exhumation and thrusting after the high pressure event. While SK8 showed a concordant age plateau at 352 ± 6 Ma, SK3 yields younger apparent ages in low- to intermediate-temperature steps due to partial diffusion after the tectonothermal event at 350 ± 4 Ma. This partial diffusion probably took place during uplift-related greenschist facies metamorphism which ceased at *c.* 340 Ma as indicated by $^{40}Ar/^{39}Ar$ ages of 344 ± 3 Ma provided by the metavolcanic greenschist (SK9) of the SKC and 340 ± 6 Ma measured on the ductile deformed conglomeratic quartzite (SK201) overlying the Krkonoše gneiss. These ages are

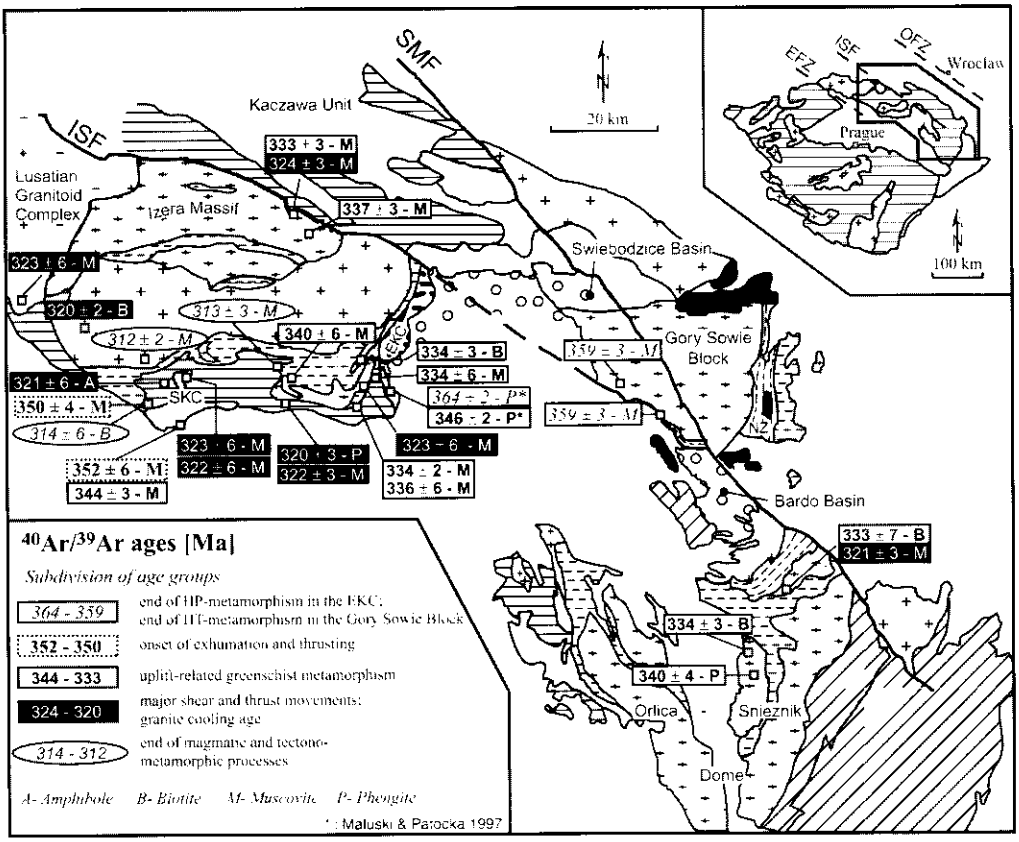

Fig. 6. ^{40}Ar/^{39}Ar plateau ages in the West Sudetes. For the legend and explanations see Figure 1.

consistent with the ^{40}Ar/^{39}Ar age span of 345–340 Ma from the EKC (Rýchory Mountains), which is interpreted as the age of the greenschist facies retrogression after the high pressure–low temperature event (Maluski & Patočka 1997).

336–333 Ma Ages between 336 and 334 Ma were obtained from the slightly deformed Krkonoše gneiss sample (SK206) with only poorly developed foliation as well as from rocks of the East Krkonoše Complexes involving the strongly sheared quartzite sample (SK202) with a prominent NW–SE oriented lineation dipping moderately to the SE, and the mylonitized porphyroid (EK201) of the Leszczyniec shear zone. The similar ages of biotite and muscovite indicate relatively rapid cooling through their appropriate closure temperatures. As both nearly undeformed and mylonitized samples yielded the same ages, some local shearing and deformation under greenschist facies conditions may be assumed as results of the same event. These ages are interpreted to date nappe thrusting in the South and East Krkonoše Complexes.

In the eastern part of the KJT, the Izera gneiss (sheared variety) provided the mica ages reflecting the Viséan tectonothermal overprint. However, the seriously disturbed age spectrum of the sheared gneiss sample (SU33), suggests that an excess of Ar may have been incorporated. Provided that the calculated ages of 335 ± 3 Ma and 328 ± 3 Ma represent the timing of a distinct tectonothermal event, it has to be decided whether they correspond to either post-deformational cooling throughout widespread greenschist facies metamorphism or subsequent local shearing in the Izera gneiss body. The interpretation of this age has to remain not unequivocal because both microfabric studies and the data on the coexisting sheared biotites failed to give any further information. The latter revealed a disturbed age spectrum indicating partial loss of Ar. The apparent ages of 301 ± 3 Ma and 289 ± 3 Ma are therefore regarded as minimum ages which probably post-date the latest granite intrusion of the Krkonoše-Jizera pluton (310 ± 5 Ma: Mierzejewski *et al.* 1994; 304 ± 14 Ma: Kröner *et al.* 1994*a*; 312 ± 2 Ma: this work).

In the northern part of the KJT two mylonites from the Intra-Sudetic Fault (ISF) (Pilchowice dam) provided muscovites yielding distinct plateau ages of 333 ± 3 Ma (SU42) and 324 ± 3 Ma (SU39). Taking into account more pronounced shear strain features of the sample SU39 in a comparison with SU42, the age difference may indicate that during the shearing SU39 experienced also higher temperatures sufficient for opening/resetting of the muscovite K–Ar system at 324 ± 3 Ma.

However, the above described ages may reflect several different stages of (re)activation of the ISF (e.g. Aleksandrowski *et al.* 1997). The latter interpretation is supported by the apparent age given by the last two high-temperature steps in the age spectrum of sample SU42 (339 ± 3 Ma) that is comparable to the age of the greenschist overprint in the EKC and SKC.

According to the Ar/Ar data from the SKC, EKC, Krkonoše and Izera gneisses, ubiquitous early Viséan (344–333 Ma) greenschist facies metamorphism associated with local shearing and thrusting dominated in the KJT during exhumation processes following the high pressure–low temperature event.

324–320 Ma Most of the ages are grouped between 324 Ma and 320 Ma. The example is the previously mentioned mylonite age from the internal part of the ISF at the eastern border of the Izera gneisses of 324 ± 3 Ma. In the SKC the sheared metatuffite greenschist (SK13) and weakly deformed metagabbro (SK7) reveal plateau ages of 323 ± 6 Ma and 321 ± 6 Ma, respectively. The metatuffite underwent a greenschist facies overprint with subsequent strong shearing. The plateau age of 323 ± 6 Ma dates the time of shearing whereas the last high-temperature-steps of the Ar-release spectrum reveal an age of 352 ± 1 Ma which may represent a record of the onset of exhumation and thrusting according to the ages from the metagranites of the SKC. The metagabbro contains indicators (Na-amphiboles) of a former high pressure event which was overprinted under greenschist facies conditions. By comparison with the age of the deformed metatuffite the plateau age of the slightly deformed metagabbro (SK7) is 320 ± 6 Ma and must date either shearing or some late deformation.

In the connecting belt between the South and East Krkonoše Complexes the samples of glaucophane blueschist (SK21) and encompassing graphite–sericite phyllite (SK22) were taken. Both samples retrogresed under greenschist facies conditions, and experienced later shearing, too. The blueschist and phyllite white micas are phengites and phengitic muscovites, respectively (see above). The ages of 320 ± 3 Ma and 322 ± 3 Ma provided by the micas are interpreted as records of late shearing. From the SKC also the sericite–quartz metarhyolite tuff sample (SK14) revealed an identical age of 322 ± 6 Ma. The strongly sheared metagranite sample (SK25) from the southeastern part of the Cambro-Ordovician Krkonoše gneiss (509–490 Ma; Kröner *et al.* 1994*b*, 1997) adjacent to the Leszczyniec shear zone yielded a well-defined age plateau of 323 ± 6 Ma, which is evidence of complete resetting during the shear and fault movements.

An identical ^{40}Ar/^{39}Ar age (320 ± 2 Ma) was obtained on the sample SK207 (biotite) from the Krkonoše-Jizera pluton (Liberec-type granite). The biotite age, representing the closure of the K–Ar system at a temperature of *c.* 300 ± 50 °C (e.g. Hodges 1991), constrains an emplacement and cooling of the granite throughout the late Variscan shearing mentioned above and corresponds to results on the magnetic fabric of the Krkonoše-Jizera pluton (Diot *et al.* 1995) as well as to the description of WNW–ESE trending feldspar lineation by Cloos (1925). These structural features indicate that both the granite and in its metamorphic envelope shared deformations. The biotite cooling age fits with the lack of contact metamorphism along the ISF (e.g. Mierzejewski & Oberc-Dziedzic 1990). The contact metamorphism with conditions of temperature above 600 °C and pressure below 2 kbar (Aleksandrowski *et al.* 1997) was older than the biotite cooling at *c.* 320 Ma whereas the semi-brittle and brittle left-lateral displacements along the ISF were the youngest process.

According to the above results, small- to large-scale shear and thrust movements took place in the KJT between 324–320 Ma close to the Viséan/Namurian boundary.

314–312 Ma The youngest ages were obtained on the Tanvald-type granite (Krkonoše-Jizera pluton), the minette dyke cross-cutting the SKC metasediments, and sheared metagranite from the northwestern part of the Krkonoše gneiss nearby the Krkonoše-Jizera pluton. The ideal age plateau of 312 ± 2 Ma of a large muscovite (>2mm) of the Tanvald-type granite (SK208) from the SW border of the Krkonoše-Jizera pluton dates the cooling after a later magmatic pulse than the Liberec-type granite intrusion.

This age matches with the Rb–Sr whole rock ages of 310 ± 5 Ma obtained for the fine-grained variety (ridge-type granite) of the Krkonoše-Jizera pluton (Mierzejewski *et al.* 1994). The muscovite of the Tanvald-type granite, which is considered to be the oldest granite generation of the Krkonoše-Jizera pluton (e.g. Klomínský 1969), may be reset as the result of the late magmatic pulse dated at 312 ± 2 Ma. The late or final magmatic pulse generated the dykes cross-cutting the SKC metasediments (Pták 1962). The postmetamorphic and postdeformational dykes are represented by the minette (SK4: phlogopite) dated at 314 ± 6 Ma. They correspond to the final stage of Variscan magmatic and tectonometamorphic processes.

The sample SK24 presents a complex history. Despite its belonging to sheared Krkonoše gneiss, the age of its muscovite is much younger (313 ± 3 Ma) than the defined age of shearing in the KJT (324–320 Ma). Its proximity to the youngest fine grained granite facies may explain a complete resetting of the small muscovites (160–250 μm) which occurred within temperature conditions high enough for such a process, but not sufficient to create contact metamorphic mineral growth.

Góry Sowie Block (GSB)

The syntectonic granite mobilisate (SU46) yielded a muscovite age of 359 ± 3 Ma. This cooling age supports the conclusion of a late Devonian high temperature–medium pressure metamorphism occurring in the GSB, as proposed by Bröcker *et al.* (1998) and Timmermann *et al.* (2000) who found the ages of 372 ± 3 Ma (Rb–Sr isochron) and 378 ± 2 Ma (U–Pb monazite), respectively. Our result, linked to these ages contradicts the interpretation of Kröner & Hegner (1998) based on a Pb/Pb zircon evaporation age of 473 ± 2 Ma.

The sheared gneiss (SU48) from an oblique sinistral shear zone on the SW margin of the GSB near Przygórze yielded the identical muscovite age of 359 ± 3 Ma identical to that of the syntectonic granite mobilisate. The shearing, which overprinted the earlier amphibolite facies dextral strike-slip event, took place under low-temperature greenschist conditions (biotite was substituted by chlorite and quartz behaved plastically) which were insufficient to reset the K–Ar system of the muscovite. Therefore this age is also interpreted as the date of an uplift related cooling postdating the peak metamorphism. The coexisting biotite yielded the 'older plateau age' of 381 ± 4 Ma. The calculation of the corresponding inverse isotope correlation age yielded 372 ± 4 Ma with an inverse ordinate intercept (^{40}Ar/^{36}Ar ratio) of 564 ± 224. This could suggest, although the isotope correlation is not well defined (MSWD = 8.8), an intracrystalline contamination with excess argon components. An alternative explanation of the apparent plateau age (which is even older than the U–Pb monazite ages) would be the K-loss during chloritization of the biotite leading to erroneous higher 'age' values.

Orlica-Śnieżnik Dome (OSD)

The ^{40}Ar/^{39}Ar age results from the Śnieżnik Massif, in the eastern part of the OSD, range between 340 and 321 Ma.

The early Viséan white mica (probably phengite) age (340 ± 4 Ma) obtained on a high pressure orthogneiss (SU21) (associated with eclogites) corresponds with a SHRIMP result on zircon rims of a migmatitic Gierałtów gneiss (342 ± 6 Ma) which is interpreted to be close to the high temperature–low pressure peak metamorphism (Turniak *et al.* 2000). These coincidental zircon and white mica ages imply fast cooling, and represent the time of uplift and decompression after older high pressure and high temperature events.

Biotites separated from the samples of the mylonitic Śnieżnik and migmatitic Gierałtów gneisses (SU17 and SU11) yielded ages of 334 ± 3 Ma and 333 ± 7 Ma, respectively. Both ages represent the continuation of uplift-related cooling since biotites are less Ar-retentive (i.e. lower closing temperatures) than the white micas dated at 340 Ma (SU21). Therefore the minimum age of the Śnieżnik gneiss mylonitization is 334 ± 3 Ma. The equivalent age shown by the migmatitic Gierałtów gneiss (SU11) confirms this mid-Viséan uplift-related cooling, and is consistent with previously published data from the OSD (see Review of geochronology).

The sample of mylonitic Gierałtów gneiss (SU10) from a sinistral shear zone (lineation 240/15) exposed about ten metres from the sample SU11 yielded a muscovite age of 321 ± 3 Ma. Regarding the older biotite age of the mylonite country rock, this age is considered as the time of movements in this discrete shear zone. Consequently it is evidence for the very limited extent of the early Namurian shearing.

Several samples show low-temperature extraction ages (samples: SK4, SK7, SK30, SK207, SU11, SU17, SU35) suggesting a post-Palaeozoic overprint in the northeastern Bohemian Massif. Comparable ^{40}Ar/^{39}Ar ages from this region have been interpreted as thermal pulse related to the Alpine–Carpathian orogeny (Maluski *et al.* 1995).

Conclusions: Variscan tectonothermal development in the West Sudetes

The West Sudetes are a complex mosaic of peri-Gondwanan crustal fragments or terranes that are considered to be members of the recently termed Armorican Terrane Assemblage (Tait *et al.* 1997). Its components were welded together by closing intervening narrow basins (seaways) and oceans due to series of mutual collisions as well as collisions with Baltica (± East Avalonia) culminating in the Variscan orogeny.

The closure of the intervening seaways by oceanic lithosphere subduction was associated with high pressure metamorphism. The oldest high pressure–high temperature event (15–20 kbar, 900–1000 °C) in the West Sudetes was dated at 402 Ma (Early Devonian) on felsic granulites and garnet peridotites of the Góry Sowie Block (Brueckner *et al.* 1996; O'Brien *et al.* 1997). Subsequently, an amphibolite-facies (i.e. high temperature–medium pressure) metamorphism associated with widespread migmatization at temperatures of about 700–730 °C and pressures of around 4–5 kbar affected the granulites and peridotites as well as the surrounding migmatite gneisses (Żelaźniewicz 1995). The peak of the later metamorphic event is dated around 380 Ma (van Breemen *et al.* 1988; Bröcker *et al.* 1998; Timmermann *et al.* 2000), i.e. to the earliest Late Devonian (Frasnian) (cf. Tucker *et al.* 1998). Rb–Sr ages between 374 and 360 Ma (van Breemen *et al.* 1988; Bröcker *et al.* 1998) and ^{40}Ar/^{39}Ar data of 359 Ma (SU46, SU48) indicate a post-peak metamorphic cooling down to temperatures of around 350 °C (nominal muscovite blocking temperature for Ar, e.g. Purdy & Jäger 1976), and evidence of a rapid Famennian uplift of the GSB after the preceding early Frasnian amphibolite facies event. This is the final stage of metamorphism in the GSB. Following the Late Devonian the GSB became the source area of conglomerate sequences in the adjacent sedimentary basins (Żelaźniewicz 1997; Kryza *et al.* 1999).

The Famennian uplift of the GSB was contemporaneous with the subduction-related blueschist facies metamorphism in the EKC terminating at about 365–360 Ma (Maluski & Patočka 1997). Eclogite facies metamorphism in the OSD where U–Pb zircon ages in the span between 372 and 360 Ma may define the time of high pressure–high temperature metamorphic episode (Bröcker *et al.* 1997).

The pressure and temperature conditions in the high pressure units of the EKC (Rýchory Mountains) and OSD (Międzygórze and Złote units) are quite different. In the Rýchory Mountains the blueschist facies metamorphism was estimated at T = 300–500 °C and P = 7–10 kbar (Patočka *et al.* 1996; Kryza 1998) whereas the eclogites in the OSD underwent UHP metamorphism in a continent–continent collisional regime at around 660–800 °C and above 27 kbar (Bakun-Czubarow 1989, 1992; Bröcker & Klemd 1996). The ultra high pressure event in the OSD was followed by isothermal decompression and cooling from eclogite to amphibolite facies conditions of T = 600–650 °C and P = 4–11 kbar (Bröcker & Klemd 1996; Kozlowski & Bakun-Czubarow 1997).

The U–Pb and Sm–Nd data that cluster around 340 Ma (early Viséan) are considered to be the final stage of high pressure and temperature metamorphism (Bröcker *et al.* 1997) or as close to the peak of a distinct high temperature–low pressure overprint (Turniak *et al.* 2000), respectively. In a combination with the identical ^{40}Ar/^{39}Ar result of 340 Ma on the sample SU21 these ages are interpreted to be a consequence of rapid uplift and decompression during thrusting in east to NE direction (e.g. Turniak *et al.* 2000). This deformation continued through middle Viséan times under greenschist facies conditions as documented by cooling ages of 334–333 Ma on the samples SU11, SU17 and the earlier published Rb–Sr and Ar/Ar data grouped between 335 and 328 Ma (Borkowska *et al.* 1990; Steltenpohl *et al.* 1993; Maluski *et al.* 1995; Bröcker *et al.* 1997).

In the KJT the blueschist facies metamorphism of the latest Devonian age was rapidly followed by tectonic exhumation and thrusting of once deeply buried crustal slices at around 350 Ma (early to middle Tournaisian) producing the uplift-related greenschist facies metamorphism dated at 345–340 Ma (Maluski & Patočka 1997; Marheine *et al.* 1999). Thrusting and deformation under greenschist facies metamorphism produced by propagation of the Variscan orogenic front generally from east to west direction in the KJT (e.g. Kachlík & Patočka 1998) was dated between *c.* 345 and 335 Ma. The propagation of the orogenic wedge is shown by the decrease of metamorphism from a garnet zone on the east to a chlorite zone on the NW and by diminishing ages of flysch sedimentation onsets (Kachlík & Patočka 1998, 2001). The younger ages (of *c.* 335 Ma) occurring in the eastern part of the KJT may be also interpreted as out-of-sequence-stacking at the back of a thrust belt (e.g. Plesch & Oncken 1999), where still deeply buried and therefore hot material was uplifted and thrust over an already cooled nappe-pile. During this stage the dextral strike-slip ISF zone was activated. In a more general interpretation the KJT, comprising the Izera gneiss, Krkonoše gneiss, EKC and SKC underwent a pervasive early to middle Viséan greenschist metamorphism with localized shearing and thrusting between 345 and 335 Ma.

The comparison of ^{40}Ar/^{39}Ar ages from the KJT and OSD reveal coeval uplift and decompression in both complexes. The KJT is interpreted as a pile of parautochthonous to allochthonous slices thrust to the NW on the Saxothuringian foreland in Early Carboniferous times, while the OSD is stacked in an east to NE direction on the Moravo-Silesian nappe-pile (e.g. Schulmann & Gayer 2000; Turniak *et al.* 2000). The overthrusting of both complexes on their forelands is related to microcontinent collisions in the West Sudetes (e.g. Maluski & Patočka 1997; Cymerman *et al.* 1997; Kachlík & Patočka 2001).

Subsequent early Namurian (325–320 Ma) small- to large-scale shear movements including thrusting, strike-slip and normal faulting, affected the OSD and KJT as well as the ISF zone and the eastern part of the LGC. These major late Variscan processes modified the dominant composed NW–SE directed linear fabric of the KJT, reactivated the ISF, and generated the contemporaneous emplacement of the late-tectonic Krkonoše-Jizera pluton (biotite ^{40}Ar/^{39}Ar cooling age: 320 ± 2 Ma).

The latest magmatic and tectonometamorphic processes in the KJT are dated at 314–312 Ma (Namurian/Westphalian boundary). This limit is set both by the intrusion of the latest Krkonoše-Jizera pluton related dyke (represented by the post-tectonic minette) and the age of the contact aureole of the pluton (within the adjacent contact metamorphosed gneiss). An identical ^{40}Ar/^{39}Ar age obtained on post-deformational muscovites from the OSD rocks reflects cooling under static conditions (Maluski *et al.* 1995).

In conclusion, the prominent early Namurian (325–320 Ma) localized shear and thrust movements accompanied (and followed) by NW–SE oriented extension (e.g. Mazur & Kryza 1996) resulted in juxtaposition of the distinct KJT tectonometamorphic units. The corresponding ages of the shear movements in the OSD give evidence for coeval tectonic processes over large parts of the West Sudetes. Thus the juxtaposition of the diversified West Sudetic terranes took place during early Namurian times and the termination of tectonometamorphic processes is constrained at the Namurian/Westphalian boundary.

The distribution of ^{40}Ar/^{39}Ar ages in the West Sudetes reflects the complexity of the Variscan polyphase deformation and metamorphism ranging from very low-grade to eclogite facies. The Famennian subduction-related eclogite/blueschist metamorphism may be interpreted as recording closure of narrow seaway(s) between fragments of the Armorican Terrane Assemblage (ATA). That would have required an amalgamation of members of the ATA prior to their final collision with East Avalonia and Baltica, respectively, which commenced in the Tournaisian (e.g. Stoppel & Zscheked 1971; Marheine 1997; Franke 2000). The interpretation is supported by the presence of widespread Famennian subduction-related high pressure–low temperature metamorphism along the Armorican Terranes from Malpica-Tuy in the northwestern Iberian Massif (e.g. Santos Zalduegui *et al.* 1995; Rodriguez Aller *et al.* 1997) through the Ile de Groix and Champtoceaux in the Armorican Massif (e.g. Ballèvre *et al.* 1999, 2000; Bosse *et al.* 2000, 2001) to the East Krkonoše Complex in the Bohemian Massif. All these parts of the ATA subsequently underwent broadly synchronous deformation and thrusting during Viséan exhumation processes provoked by joint accretion and the docking with East Avalonia and Baltica.

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References

Aleksandrowski, P., Kryza, R., Mazur, S. & Żaba, J. 1997. Kinematic data on major Variscan strike-slip faults and shear zones in the Polish Sudetes, northeast Bohemian Massif. *Geological Magazine*, **134**, 727–739.

Alexander, E. C. Jr., Mickelson, G. M. & Lanphere, M. A. 1978. MMhb-1: A new ^{40}Ar/^{39}Ar dating standard. *In:* Zartman, R. E. (eds) *Short Paper, 4th International Conference on Geochronology, Cosmochronology and Isotope Geology. U.S. Geological Survey Open File Report*, ***78–701***, 6–8.

Bakun-Czubarow, N. 1989. On the Sudetic eclogites, SW Poland. *Terra Cognita (Third Int. Eclogite Conf., Würzburg, Germany)* **1**, 2.

Bakun-Czubarow, N. 1992. Quartz pseudomorphs after coesite and quartz exsolutions in the eclogitic clinopyroxenes of the Złote Mountains in the Sudetes (SW Poland). *Archiwum Mineralogiczne*, **48**, 3–25.

Bakun-Czubarow, N. 1998. Ilmenite-bearing eclogites of the West Sudetes – their geochemistry and mineral chemistry. *Archiwum Mineralogiczne*, **51**, 29–110.

Ballevre, M., Bosse, V. & Capdevila, R. 1999. Large-scale correlations of the Variscan metamorphic terranes across the Ibero-Armorican

Arc (Western Europe). *Journal of Conference Abstracts*, **4**, 88.

Ballèvre, M., Bosse, V., Capdevila, R., de Jong, K., Féraud, G., Guerrot, C., Peucat, J. J. & Ruffet, G. 2000. Structure and thermochronology of the Champtoceaux Complex (France): a key for the Ibero-Armorican correlations. *In: Variscan-Appalachian dynamics: the building of the Upper Paleozoic basement*. Basement Tectonics 15. A Coruña, Spain. Program and Abstracts, 52–55.

Bendl, J. & Patočka, F. 1995. The ^{87}Rb-^{86}Sr isotope geochemistry of the metamorphosed bimodal volcanic association of the Rýchory Mts crystalline complex, West Sudetes, Bohemian Massif. *Geologia Sudetica*, **29**, 3–18.

Berg, G. 1912. Die Kristallinen Schiefer des Östlichen Riesengebirges. *Abhandlungen der Preussischen Landesanstanstalt*, **68**, 1–184.

Biaek, D. 1998. Aspects of geochemistry of the Zawidów Granodiorite and Izera Granite-arc to rift transition? *Geolines*, **6**, 11.

Bielicki, K. H., Haase, G., Eidam, J., Kemnitz, H., Schust, F., Gerstenberger, H., Hiller, H. & Habedank, M. 1989. Pb-Pb and Rb-Sr dating of granitoids from the Lusatian Block. *ZfI-Mitteilungen, 5th Working Meeting Isotopes in Nature Proceedings II, Leipzig*, 23–45.

Borkowska, M. & Dörr, W. 1998. Some remarks on the age and mineral chemistry of orthogneisses from the Lądek-Śnieżnik metamorphic massif – Sudetes, Poland. *Terra Nostra*, **98/2**, 27–30.

Borkowska, M., Hameurt, J. & Vidal, P. 1980. Origin and age of Izera gneisses and Rumburk granites in the West Sudetes. *Acta Geologica Polonica*, **30**, 121–145.

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.

Bosse, V., Ballèvre, M., Féraud, G. & Peucat, J. J. 2000. Petrological and gochronological constraints in the Ile de Groix blueschists (Armorican Massif, France). *In: Variscan-Appalachian dynamics: the building of the Upper Paleozoic basement*. Basement Tectonics 15, A Coruña, Spain. Program and Abstracts, 63–66.

Bosse, V., Féraud, G., Ruffet, G., Ballèvre, M., Peucat, J. J. & de Jong, K. 2001. Evidence for a late Devonian continental subduction in the Variscan belt: geochronology of eclogite-facies rocks from the Champtoceaux Complex (Armorican Massif, France). *Geological Journal*, **35**, 297–325.

Bröcker, M. & Klemd, R. 1996. Ultrahigh-Pressure metamorphism in the Śnieżnik Mountains (Sudetes, Poland): P-T constraints and geological implications. *Journal of Geology*, **104**, 417–433.

Bröcker, M., Cosca, M. & Klemd, R. 1997. Geochronologie von Eklogiten und assoziierten Nebengesteinen des Orlica-Śnieżnik Kristallins (Sudeten, Poland): Ergebnisse von U-Pb, Sm-Nd, Rb-Sr und Ar-Ar Untersuchungen. *Terra Nostra*, **97/5**, 29–30.

Bröcker, M., Żelaźniewicz, A. & Enders, M. 1998. Rb-Sr and U-Pb geochronology of migmatic gneisses from the Góry Sowie (West Sudetes, Poland): the importance of Mid-Late Devonian metamorphism. *Journal of the Geological Society, London*, **155**, 1025–1036.

Brueckner, H. K., Medaris, L. G. & Bakun-Czubarow, N. 1991. Nd and Sr age and isotope patterns from Variscan eclogites of the eastern Bohemian Massif. *Neues Jahrbuch für Mineralogie, Abhandlungen*, **163**, 169–196.

Brueckner, H. K., Blusztajn, J. & Bakun-Czubarow, N. 1996. Trace element and Sm-Nd 'age' zoning in garnets from peridotites of the Caledonian and Variscan Mountains and tectonic implications. *Journal of Metamorphic Geology*, **14**, 61–73.

Chaloupský, J. 1963. Conglomerates in the Krkonoše Crystalline Complex (in Czech, English abstract). *Sborník Ústředního ústavu geologického*, **28**, 143–190.

Chaloupský, J. 1966. Caledonian and Variscan orogenies in the Ještěd Crystalline Complex (in Czech, English abstract). *Sborník geologických věd, ř. Geologie*, **10**, 7–37.

Chaloupský, J., Červenka, J., Jetel, J., Králík, F., Líbalová, J., Píchová, E., Pokorný, J., Pošmourný, K., Sekyra, J., Shrbený, O., Šalanský, J., Šrámek, J. & Václ, J. 1989. *Geology of the Krkonoše and Jizerské hory Mts.* Geological Survey Czechoslovakia, Prague.

Chlupáč, I. 1993. Stratigraphic evaluation of some metamorphic units in the north part of the Bohemian Massif. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **188**, 363–388.

Chlupáč, I. 1997. Palaeozoic ichnofossils in phyllites near Železný Brod, northern Bohemia. *Journal of the Czech Geological Society*, **42**, 75–94.

Chlupáč, I. 1998. New paleontological finds in the western part of the Krkonoše-Jizerské hory Mts. metamorphics and their impact on stratigraphical and tectonical concepts. *Geolines*, **6**, 29–30.

Cloos, H. 1925. *Einführung in die tektonische Behandlung magmatischer Erscheinungen (Granittektonik). I Teil. Das Riesengebirge in Schlesien, Bau, Bildung und Oberflächengestaltung*. Berlin.

Cymerman, Z., Piasecki, M. A. J. & Seston, R. 1997. Terranes and terrane boundaries in the Sudetes, northeast Bohemian Massif. *Geological Magazine*, **134**, 717–725.

Diot, H., Mazur, S. & Pin, C. 1995. Karkonosze batholith (NE Bohemian Massif): The evidence for pluton emplacement during transtensional-extensional collapse. *Journal of the Czech Geological Society*, **40**, 62.

Dostal, J., Patočka, F. & Pin, C. 2000. Early Palaeozoic intracontinental rifting and early seafloor spreading in the Central West Sudetes (Bohemian Massif): Geochemical and Nd-Sr isotopic study on metavolcanic rocks of the East Krkonoše Complex. *Geolines*, **10**, 19–20.

Dostal, J., Patočka, F. & Pin, C. 2001. Middle/Late Cambrian intracontinental rifting in the central West Sudetes, NE Bohemian Massif (Czech

Republic): geochemistry and petrogenesis of the bimodal metavolcanic rocks. *Geological Journal*, **36**, 1–17.

Duthou, J. L., Couturie, J. P., Mierzejewski, M. P. & Pin, C. 1991. Rb/Sr age of the Karkonosze granite on the base of the whole rock method. *Przegląd geologiczny*, **2**, 75–79.

Dumicz, M. 1993. The history of eclogites in the geological evolution of the Śnieżnik crystalline complex based on mesostructural analysis. *Geologica Sudetica*, **27**, 21–64.

Fajst, M., Kachlík, V. & Patočka, F. 1998. Geochemistry and petrology of the Early Palaeozoic Železný Brod Volcanic Complex (W Sudetes, Bohemian Massif): geodynamic interpretations. *Geolines*, **6**, 14–15.

Floyd, P. A., Winchester, J. A., Ciesielczuk, J., Lewandowska, A., Szczepański, J. & Turniak, K. 1996. Geochemistry of early Palaeozoic amphibolites from the Orlica-Śnieżnik dome, Bohemian massif: petrogenesis and palaeotectonic aspects. *Geologische Rundschau*, **85**, 225–238.

Franke, W. 1989. Variscan plate tectonics in Central Europe – current ideas and open questions. *Tectonophysics*, **169**, 221–228.

Franke, W. 2000. The mid-European segment of the Variscides: tectono-stratigraphic units, terrane boundaries and plate tectonic evolution. *In:* Franke, W., Haak, V., Oncken, O. & Tanner, D. (eds) *Orogenic processes: Quantification and modelling in the Variscan Belt*. Geological Society, London, Special Publications, **179**, 35–62.

Franke, W. & Żelaźniewicz, A. 2000. The eastern termination of the Variscides terrane correlation and kinematic evolution. *In:* Franke, W., Haak, V., Oncken, O. & Tanner, D. (eds) *Orogenic processes: Quantification and modelling in the Variscan Belt*. Geological Society, London, Special Publications, **179**, 63–86.

Franke, W., Żelaźniewicz, A., A. Porebski, S. J. & Wajsprych, B. 1993. Saxothuringian Zone in Germany and Poland: differences and common features. *Geologische Rundschau*, **82**, 583–599.

Gehmlich, M., Linnemann, U., Tichomirova, M., Lützner, H. & Bombach, K. 1997. Die Bestimmung des Sedimentationsalters cadomischer Krustenfragmente im Saxothuringikum durch die Einzelzirkon-Evaporationsmethode. *Terra Nostra*, **97/5**, 46–49.

Guidotti, C. V. 1984. Micas in metamorphic rocks. *In:* Bailey, S. W. (eds) Micas. *Reviews in Mineralogy*, **13**, 357–456.

Gunia, T. 1996. Problem wieku marmurów okolicy Stronia Śląskiego na podstawie ikroskamieniałości (Sudety) *Acta Universitatis Wratislaviensis, Prace Geologiczno-Mineralogiczne*, **62**, 5–48.

Hammer, J., Bröcker, M. & Krauss, M. 1997. Alter und geologische Signifikanz von Deformationszonen im östlichen Teil des Lausitzer Granitoidkomplexes. *Terra Nostra*, **97/5**, 62–63.

Harrison, T. M. 1981. Diffusion of ^{40}Ar in hornblende. *Contributions to Mineralogy and Petrology*, **78**, 324–331.

Hladil, J., Melichar, R., Otava, J., Galle, A., Krs, M., Man, O., Pruner, P., Čejchan, P. & Orel, P. 1999. The Devonian in the easternmost Variscides, Moravia: a holistic analysis directed towards comprehension of the original context. *Abhandlungen der Geologischen Bundesanstalt*, **54**, 27–47.

Hodges, K. V. 1991. Pressure–temperature–time paths. *Annual Review of Earth Planetary Sciences*, **19**, 207–236.

Kachlík, V. 1997. Litostratigrafie a stavba železnobrodského krystalinika: výsledek variských tektodeformačních procesů. *Zprávy o geologických výzkumech v roce*. **1996**, 30–31.

Kachlík, V. & Patočka, F. 1998. Lithostratigraphy and tectonomagmatic evolution of the Železný Brod Crystalline Unit: Some constraints for the palaeotectonic development of the W Sudetes (NE Bohemian Massif). *Geolines*, **6**, 34–35.

Kachlík, V. & Patočka, F. 2001. Late Devonian to Early Carboniferous bimodal volcanic rocks of the Ještid Range Unit: constraints on the development of the Variscan orogenic wedge. *Geolines*, **13**, 74–75.

Klomínský, J. 1969. Krkonošsko-Jizerský granitoidní masív. *Sborník geologických věd, ř. Geologie*, **15**, 1–134.

Korytowski, A., Dörr, W. & Żelaźniewicz, A. 1993. U-Pb dating of (meta)granitoids in the NW Sudetes (Poland) and their bearing on tectonostratigraphic correlation. *Terra Nova*, **5**, 331–332.

Kozłowski, A. & Bakun-Czubarow, N. 1997. Fluidy w minerałach asocjacji eklogitowych z rejonu Śnieżnika. *Polskie Towarzystwo Mineralogiczne – Prace Specjalne*, **9**, 114–115.

Kröner, A. & Hegner, E. 1998. Geochemistry, single zircon ages and Sm-Nd systematics of granitoid rocks from the Góry Sowie (Owl Mts), Polish West Sudetes: evidence for early Palaeozoic arc-related plutonism. *Journal of the Geological Society, London*, **155**, 711–724.

Kröner, A., Hegner, E., Hammer, J., Haase, G., Bielicki, K.-H., Krauss, M. & Eidam, J. 1994*a*. Geochronology and Nd-Sr systematics of Lusatian granitoids: significance for the evolution of the Variscan orogen in east-central Europe. *Geologische Rundschau*, **83**, 357–376.

Kröner, A., Jaeckel, P. & Opletal, M. 1994*b*. Pb-Pb and U-Pb zircon ages for orthogneisses from eastern Bohemia: further evidence for a major Cambro-Ordovician magmatic event. *Journal of the Czech Geological Society*, **39**, 61.

Kröner, A., Jaeckel, P. & Jaeckel, P. 1997. Cambrian to Ordovician granitoid orthogneisses in the Polish and Czech West Sudetes Mts. and their geodynamic significance. *Terra Nostra*, **97/11**, 67–68.

Kryza, R. 1998. High pressure-low temperature metamorphism in the West Sudetes: Tectonic implications. *Geolines*, **6**, 38–39.

Kryza, R. & Pin, C. 1997. Cambrian/Ordovician magmatism in the Polish Sudetes: no evidence for subduction-related setting. *Terra Nova*, **7**, 144.

Kryza, R., Mazur, S. & Pin, C. 1995. The Leszczyniec meta-igneous complex in the eastern part of the

Karkonosze-Izera Block, Western Sudetes: trace element and Nd isotope study. *Neues Jahrbuch für Mineralogie, Abhandlungen*, **170**, 59–74.

Kryza, R., Mazur, S. & Aleksandrowski, P. 1999. Pre-Late Devonian unconformity in the Kłodzko area excavated: a record of Eo-Variscan metamorphism and exhumation in the Sudetes. *Geologica Sudetica*, **32**, 127–137.

Maluski, H. & Patočka, F. 1997. Geochemistry and ^{40}Ar/^{39}Ar geochronology of the mafic metavolcanics from the Rýchory Mts. complex (west Sudetes, Bohemian Massif): palaeotectonic significance. *Geological Magazine*, **134**, 703–716.

Maluski, H., Rajlich, P. & Matte, P. 1993. ^{40}Ar-^{39}Ar dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. *Tectonophysics*, **223**, 313–337.

Maluski, H., Rajlich, P. & Souček, J. 1995. Pre-variscan, Variscan and Early Alpine thermo-tectonic history of the north-eastern Bohemian Massif: An ^{40}Ar/^{39}Ar study. *Geologische Rundschau*, **84**, 345–358.

Marheine, D. 1997. Zeitmarken im variszischen Kollisionsbereich des Rhenoherzynikums-Saxothuringikums zwischen Harz und Sächsischem Granulitmassiv – Ergebnisse von K/Ar-Altersbestimmungen. *Göttinger Arbeiten zur Geologie und Paläontologie*, **75**, 1–97.

Marheine, D., Kachlík, V., Patočka, F. & Maluski, H. 1999. The Variscan polyphase tectonothermal development in the South Krkonoše Complex (W-Sudetes, Czech Republic). *Journal of Conference abstracts*, **4**, 95.

Matte, P., Maluski, H., Rajlich, P. & Franke, W. 1990. Terrane boundaries in the Bohemian Massif: Result of large-scale Variscan shearing. *Tectonophysics*, **177**, 151–170.

Mazur, S. & Kryza, R. 1996. Superimposed compressional and extensional tectonics in the Karkonosze-Izera Block, NE Bohemian Massif. *In:* Oncken, O., Janssen, C. (eds) *Basement tectonics 11*. Kluwer, Dordrecht, 51–66.

McDougall, I. & Harrison, T. M. 1999. *Geochronology and thermochronology by the ^{40}Ar/^{39}Ar method*. Second edition. Oxford Monographs on Geology and Geophysics, **9**, Oxford.

Mierzejewski, M. P. & Oberc-Dziedzic, T. 1990. The Izera-Karkonosze Block and its tectonic development (Sudetes, Poland). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **179**, 197–222.

Mierzejewski, M. P., Pin, C., Duthou, J. L. & Couturié, J. P. 1994. Sr-Nd isotopic study of the Karkonosze granite (Western Sudetes). *In:* Kryza, R. (ed.) *Igneous activity and metamorphic evolution of the Sudetes area. Abstracts*. Wroclaw University, 82.

Monié, P., Soliva, J., Brunel, M. & Maluski, H. 1994. Les cisaillements mylonitiques du granite de Millas (Pyrénées, France). Âge Crétacé ^{40}Ar/^{39}Ar et interprétation tectonique. *Bulletin de la Société Géologique de France*, **165**, 559–571.

Monié, P., Caby, R. & Arthaud, M.-H. 1997. The Neoproterozoic Brasiliano orogeny in Northeast Brazil: ^{40}Ar/^{39}Ar and petrostructural data from Ceara. *Precambrian Research*, **81**, 241–264.

Narębski, W. 1994. Lower to Upper Paleozoic tectonomagmatic evolution of NE part of the Bohemian Massif. *Zentralblatt für Geologie und Paläontologie*, **9/10**, 961–972.

Oberc, J. 1960. Tectonics of the eastern Karkonozsy and their relation to the structure of Sudetes (in Polish, English abstract). *Acta Geologica Polonica*, **10**, 1–48.

O'Brien, P. J., Kröner, A., Jaeckel, P., Hegner, E., Żelaźniewicz, A. & Kryza, R. 1997. Petrological and isotopic studies on Paleozoic high pressure granulites, Góry Sowie Mts, Polish Sudetes. *Journal of Petrology*, **38**, 433–456.

Oczlon, M. S. 1992. Gondwana and Laurussia before and during the Variscan orogeny in Europe and related areas. *Heidelberger Geowissenschaflichet Abhandlungen*, **53**, 1–56.

Oliver, G. J. H. & Kelley, S. 1993. ^{40}Ar-^{39}Ar fusion ages from the Polish Sudetes: Variscan tectonothermal reworking of Caledonian protoliths. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **1993**, 321–344.

Oliver, G. J. H., Corfu, F. & Krogh, T. E. 1993. U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. *Journal of the Geological Society, London*, **150**, 355–369.

Patočka, F. & Smulikowski, W. 1998. The geochemical correlation of the East Krkonoše Complex metabasites (West Sudetes, Czech Republic and Poland) – relation to the Cambrian-Ordovician northern Gondwana breakup: A review. *Acta Universitatis Carolinae, Geologica*, **42**, 485–488.

Patočka, F., Pivec, E. & Oliveriova, D. 1996. Mineralogy and petrology of mafic blueschists from the Rýchory Mts. crystalline complex (Western Sudetes, Bohemian Massif). *Neues Jahrbuch für Mineralogie, Abhandlungen*, **170**, 313–330.

Patočka, F., Fajst, M. & Kachlík, V. 2000. Mafic-felsic to mafic-ultramafic Early Palaeozoic magmatism of the West Sudetes (NE Bohemian Massif): the South Krkonoše Complex. *Zeitschrift für geologische Wissenschaften*, **28**, 177–210.

Pharaoh, T. C. 1999. Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review. *Tectonophysics*, **314**, 17–41.

Philippe, S., Haack, U., Żelaźniewicz, A., Dörr, W. & Franke, W. 1995. Preliminary geochemical and geochronological results on shear zones in the Izera-Karkonosze Block (Sudetes, Poland). *Terra Nostra*, **95/8**, 122.

Pin, C., Mierzejewski, M. P. & Duthou, J. L. 1987. Rb/Sr isochron age of the Karkonosze granite from quarry Szklarska Poręba Huta and determination of its ^{87}Sr/^{86}Sr initial ratio. *Przegląd geologiczny*, **35**, 512–517.

Plesch, A. & Oncken, O. 1999. Orogenic wedge growth during oblique convergence – constraints on the mechanics from its kinematic record (Rhenohercynian thrust belt, Central Germany). *Tectonophysics*, **309**, 117–139.

Pták, J. 1962. Lamprophyre dykes of the Jizera granite massif and their relation to the granite tectonics (in Czech). *Zprávy geologického výzkumu v roce*, **1962**, 71–75.

Purdy, J. W. & Jäger, E. 1976. K/Ar ages on rock-forming minerals from the Central Alps. *Memorie degli Instituti di Geologia e Mineralogia dell'università di Padova*, **30**, 1–31.

Rodriguez Aller, J., Cosca, M. & Gil Ibarguchi, J. I. 1997. ^{40}Ar/^{39}Ar dating of Hercynian metamorphism in the HP Malpica Tuy allochthon and LP parautochthon, Iberian Massif, NW Spain. *Terra Nova*, **9**, 497.

Samson, S. D. & Alexander, E. C. Jr. 1987. Calibration of the interlaboratory ^{40}Ar/^{39}Ar dating standard, MMhb-1. *Chemical Geology*, **66**, 27–34.

Santos Zalduegui, J. F., Scharer, U. & Gil Ibarguchi, J. I. 1995. Isotope constraints on the age and origin of magmatism and metamorphism in the Malpica-Tuy allochthon, Galicia, NW Spain. *Chemical Geology*, **121**, 91–103.

Schulmann, K. & Gayer, R. 2000. A model for a continental accretionary wedge developed by oblique collision: the NE Bohemian Massif. *Journal of the Geological Society, London*, **157**, 401–416.

Steiger, R. H. & Jäger, E. 1977. Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. *Earth Planet Science Letters*, **36**, 359–362.

Steltenpohl, M. J., Cymerman, Z., Krogh, E. & Kunk, M. J. 1993. Exhumation of eclogitized continental basement during Variscan lithospheric delamination and gravitational collapse, Sudety Mountains, Poland. *Geology*, **21**, 1111–1114.

Stoppel, D. & Zscheked, J. G. 1971. Zur Biostratigraphie und Fazies des höheren Mitteldevons und Oberdevons im Westharz mit Hilfe der Conodonten- und Ostracodenchonologie. *Beiheft zum Geologischen Jahrbuch*, **108**, 1–84.

Svoboda, J. & Chaloupský, J. 1966. The West Sudeten Crystalline. *In:* Svoboda, J., Dvořák, J., Havlena, V., Havlíček, V., Horný, R., Chlupáč, I., Klein, V., Kopecký, L., Malecha, A., Malkovský, M., Soukup, J., Tásler, R., Václ, J. & Žebera, K. (eds) *Regional geology of Czechoslovakia I.* Geological Survey, Prague, 215–278.

Tait, J. A., Bachtadse, V., Franke, W. & Soffel, H. C. 1997. Geodynamic evolution of the European Variscan fold belt: Palaeomagnetic and geological constraints. *Geologische Rundschau*, **86**, 585–598.

Teisseyre, J. H. 1968. On the Old-Palaeozoic initial volcanism in the West Sudetes. *Acta Geologica Polonica*, **18**, 239–256.

Teisseyre, J. H., 1973. Metamorphic complex of Rudawy Janowickie and Lasocki Grzbiet ridge. *Geologia Sudetica*, **8**, 7–129.

Tichomirova, M., Linnemann, U. & Gehmlich, M. 1997. Zircon ages as magmatic time marks – Comparison of the crustal evolution in different units of the Saxothuringian zone. *Terra Nostra*, **97/11**, 137–141.

Timmermann, H., Parrish, R. R., Noble, S. R., Kryza, R. & Patočka, F. 1999. Single cycle Variscan orogeny inferred from New U-(Th-)Pb data from the Sudetes Mountains in Poland and the Czech Republic. *In:* 4th PACE TMR meeting. Geological Institute, Copenhagen, World Wide Web Address: http://www.pangaea.esci.keele.ac.uk/pace/.

Timmermann, H., Parrish, R. R., Noble, S. R. & Kryza, R. 2000. New U-Pb monazite and zircon data from the Sudetes Mountains in SW Poland: evidence for a single-cycle Variscan orogeny. *Journal of the Geological Society, London*, **157**, 265–268.

Tucker, R. D., Bradley, D. C., Ver Straeten, C. A., Harris, A. G., Ebert, J. R. & McCutcheon, S. R. 1998. New U-Pb zircon ages and the duration and division of Devonian time. *Earth and Planetary Science Letters*, **158**, 175–186.

Turniak, K., Mazur, S. & Wysoczański, R. 2000. SHRIMP zircon geochronology and geochemistry of the Orlica-Śnieżnik gneisses (Variscan belt of Central Europe) and their tectonic implications. *Geodinamica Acta*, **13**, 293–312.

van Breemen, O., Aftalion, M., Bowes, D. R., Dudek, A., Mišař, Z., Povondra, P. & Vrána, S. 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 Science*, **73**, 89–108.

van Breemen, O., Bowes, D. R., Aftalion, M. & Żelaźniewicz, A. 1988. Devonian tectonothermal activity in the Góry Sowie gneissic block, Sudetes, southwestern Poland: evidence from Rb-Sr and U-Pb isotopic studies. *Annales Societatis Geologorum Poloniae*, **58**, 3–19.

Villa, I. M. 1997. Isotopic closure. *Terra Nostra*, **10**, 42–47.

Winchester, J. A., Floyd, P. A., Chocyk, M., Horbowy, K. & Kozdroj, W. 1995. Geochemistry and tectonic environment of Ordovician meta-igneous rocks in the Rudawy Janowickie Complex, SW Poland. *Journal of the Geological Society, London*, **152**, 105–115.

Żelaźniewicz, A. 1990. Deformation and metamorphism in the Góry Sowie gneiss complex, Sudetes, SW Poland. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **179**, 129–157.

Żelaźniewicz, A. 1995. Część przedsudecka bloku sowiogórskiego. *Przewodnik LXVI Zjazdu PTG, Wrocław*, 85–109.

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

Żelaźniewicz, A., Dörr, W. & Dubińska, E. 1998. Lower Devonian oceanic crust from U-Pb zircon evidence and Eo-Variscan event in the Sudetes. *Terra Nostra*, **98/2**, 174–176.