Tectonophysics, 157 (1989) 149–178
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

K–Ar geochronology of different tectonic units at the northwestern margin of the Bohemian Massif

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(Received August 31, 1987; accepted October 14, 1987)

Abstract

Kreuzer, H., Seidel, E., Schüssler, U., Okrusch, M., Lenz, K.-L. and Raschka, H., 1989. K–Ar geochronology of different tectonic units at the northwestern margin of the Bohemian Massif. In: R. Meissner and D. Gebauer (Editors), The Evolution of the European Continental Crust: Deep Drilling, Geophysics, Geology and Geochemistry. *Tectonophysics*, 157: 149–178.

The polymetamorphic Moldanubian (MO) of the northeasthern margin of the Bohemian Massif has been thrust to the north onto the mainly Paleozoic sedimentary Saxothuringian of the Fichtelgebirge (FG). These two units have undergone polyphase deformation and the last regional event to affect both units was a low-pressure metamorphism in which temperatures decreased towards the north.

In contrast, the nappe units of the Erbendorf–Vohenstrauss Zone (ZEV) and the Erbendorf Greenschist Zone (EGZ), which partly cover the border of the Moldanubian and the Saxothuringian, and the Münchberg nappe pile (MM), which lies on the Saxothuringian, were in parts subjected to a late medium-pressure metamorphic event.

The ZEV, the EGZ, the MO and the FG are intruded by Late Carboniferous granites.

Conventional K–Ar analyses, mainly of hornblendes and muscovites from the autochthonous FG and MO, the units beneath the nappes, have yielded exclusively Carboniferous dates. The oldest dates point to a regional cooling of the rocks which outcrop at the present-day surface at about 330–320 Ma, i.e., at the Early–Late Carboniferous boundary. The Late Carboniferous cooling history was largely governed by the thermal influence of the post-kinematic granites (320–295 Ma), especially in the FG and the northern MO.

The high-grade metamorphic rocks in the western part of the ZEV and in the upper three nappes of the MM mostly yield dates around 380 Ma, i.e., Early Devonian. The results show a relatively wide scatter. Moreover, biotites frequently appear to be older than the coexisting muscovites. Both observations indicate that the rocks underwent a later thermal influence. Whether some groups of older dates (e.g., 400 Ma) are due to excess argon or to inherited argon is still open to discussion.

Slightly scattered muscovite dates around 366 Ma were obtained for the prasinite–phyllite series, one of the lower nappes of the MM. A single hornblende from the EGZ gave the same age. These two nappes have, therefore, probably been affected by a Late Devonian thermal and/or tectonic event.

The muscovite dates obtained from the Paleozoic Bavarian lithofacies, the lowermost nappe of the MM *, and the hornblende dates from the eastern part of the ZEV are indistinguishable from those of the autochthonous units FG and MO.

* Ahrendt et al. (1986).

Introduction

Recent geological and geophysical investigations carried out during the site-selection studies for the German Continental Deep-Drilling Program (KTB) led to a reinterpretation of the well-established tectonic units in the northwestern part of the Bohemian Massif (Weber and Vollbrecht, 1986). The dominant aspects of this new picture are as follows:

(1) An important suture zone along which the Moldanubian (MO) is thrust upon the Saxothuringian is indicated by prominent SE-dipping reflectors in the German Continental Reflection Seismic Program (DEKORP) seismic profiles. In spite of this and the fact that imbrication is widespread within the Saxothuringian of the Fichtelgebirge (FG) these two units are referred to as "autochthonous" in the present paper.

(2) The following units are regarded as remnants of a huge nappe complex: The Münchberg Gneiss "Massif" (MM) with the underlying Bavarian lithofacies of Paleozoic age, the Erbendorf–Vohenstrauss Zone (ZEV) together with the Erbendorf Greenschist Zone (EGZ), and the Tepla–Taus (Teplá–Domažlice) Zone. The MM in particular exhibits a well-defined dish-like shape in the line-drawings of the DEKORP profile 4 (Schmoll, in Weber and Vollbrecht (1986), fig. 45) and in magnetotelluric sections (Haak and Blümecke, in Weber and Vollbrecht (1986), fig. 14).

The present geotectonic configuration is interpreted as a result of continental collision during the Variscan orogeny.

The rock sequences in the different tectonic units underwent different metamorphic evolutionary phases. Although the P–T time paths are so far not well understood, there is little doubt that the last phase of regional metamorphism in much of the Münchberg Gneiss Massif and the ZEV took place under medium-pressure conditions, whereas the autochthonous units of the Saxothuringian Fichtelgebirge and the east Bavarian Moldanubian were later subjected to a low-pressure metamorphism.

Our research group has carried out extensive K–Ar dating in order to obtain information on the ages of these latest metamorphic events in the different tectonic units. The initial results of this work were published in a preliminary paper (Schüssler et al., 1986). We now present the data in full and discuss our results.

Geology

Saxothuringian

On the northwestern border of the Bohemian Massif (northeastern Bavaria) the Saxothuringian comprises the rocks of the Frankenwald and the FG (Fig. 1).

The Frankenwald is predominantly built up of thick sedimentary sequences of Ordovician to Early Carboniferous age which belong to the Thuringian lithofacies (Wurm, 1961). They contain extensive intercalations of tholeiites and alkaline basalts (Wirth, 1978) and the corresponding pyroclastites, mainly of Late Devonian age. These Paleozoic sequences are locally weakly metamorphosed (Ludwig, 1973; Brand, 1980).

The FG crystalline complex (Figs. 1 and 2) forms an anticline. It is highly dissected by imbrication and faulting, causing tectonic juxtaposition of all the members of the assumed stratigraphic successions. In its core the FG anticline consists of a metamorphosed sequence of variable lithological character: the "Bunte Gruppe" (the "variegated group" in the sense of the diverse lithology; Stettner, 1980), metapelites and metagraywackes with intercalations of marbles (Wunsiedler Marmor), calc-silicate rocks, and minor metabasites of alkaline basaltic affinity (Schüssler et al., this issue). In the lower part there are transitions to the "Monotone Gruppe" ("monotonous group") with a predominance of pelitic to psammitic metasediments. Stettner (1980) regards the core sequence as Late Proterozoic on the basis of a comparison of the "Bunte Gruppe" with the Spilite Group of Inner Bohemia (Vejnar, 1965). The marginal areas of the FG anticline are made up of pelitic and psammitic metasediments with intercalated acidic metavolcanics ("epigneisses"), resembling the Cambro-Ordovician rocks of the Thuringian lithofacies (Stettner, 1975, 1980; Emmert et al., 1981). The FG sequences underwent a

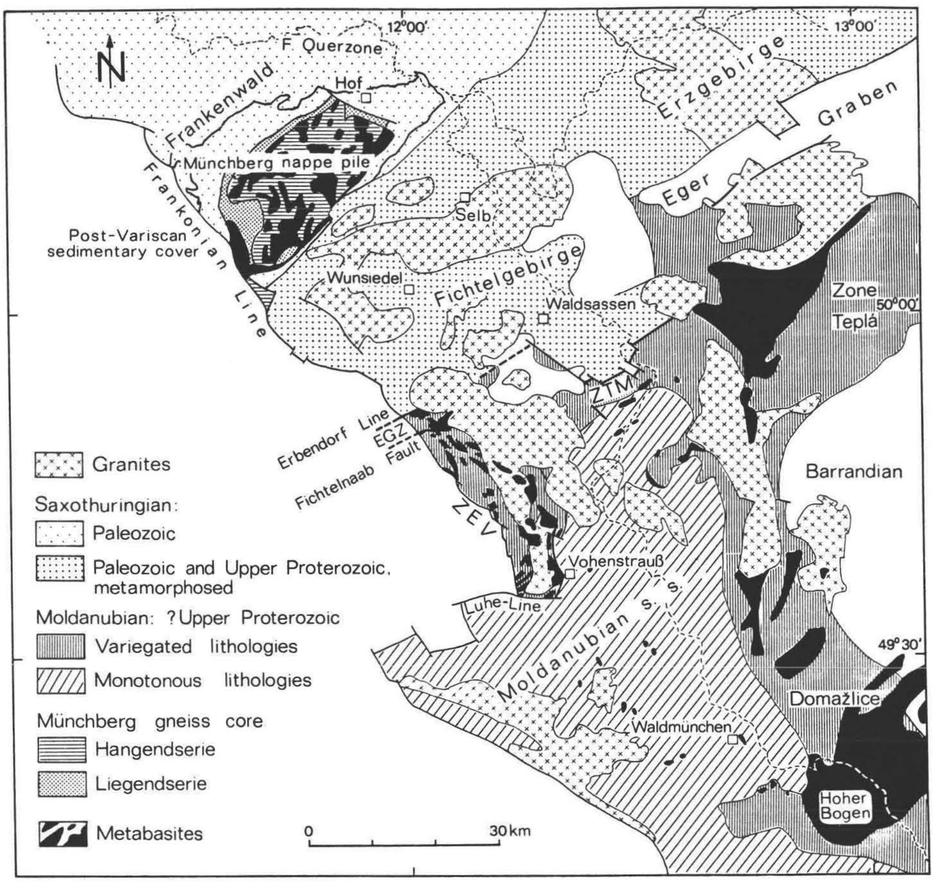

Fig. 1. Schematic geological map of the northeastern Bavarian basement (based on the 1 : 500,000 geological map of Bavaria (1981, 3rd ed.)).

low-pressure metamorphism ranging from greenschist to amphibolite facies. At the highest metamorphic grade reached the following assemblages were stable (Mielke and Schreyer, 1969; Mielke et al., 1979: staurolite + andalusite, and almandine + biotite + muscovite + quartz.

Relict minerals from an older medium-pressure event were recently recognized by Lenz et al. (in prep.) in the northern FG, northwest of Selb.

Moldanubian (MO)

Within the classical Moldanubian Zone of Kossmat (1927), the ZEV and the Tepla–Taus (Teplá–Domažlice) Zone are now regarded as parts of a nappe complex (Weber and Vollbrecht, 1986). They are discussed in the next section.

The Moldanubian sensu stricto (MO) (Stettner, 1981) consists of polymetamorphic gneisses and migmatites with a predominantly monotonous lithology. Intercalations of metabasites and metamorphosed ultramafics are extremely rare. Among the metabasites, eclogitic relics provide evidence of an older high-pressure metamorphic event (Busch, 1970); the conditions of formation were determined as > 10 kbar and 680 °C (O'Brien, 1987). Relics of a subsequent phase of medium-pressure metamorphism are described by Blümel (in Weber and Vollbrecht (1986), fig. 9). The latest regional metamorphic event in the MO is a low-pressure metamorphism which reached the stability field of cordierite + sillimanite + K feldspar combined with regional anatexis over wide areas.

The Tirschenreuth–Mähring Zone (ZTM) (Fig. 3) represents a special situation. Here, a transition in metamorphic grade between the MO and the Saxothuringian was recognized by Schreyer (1966)

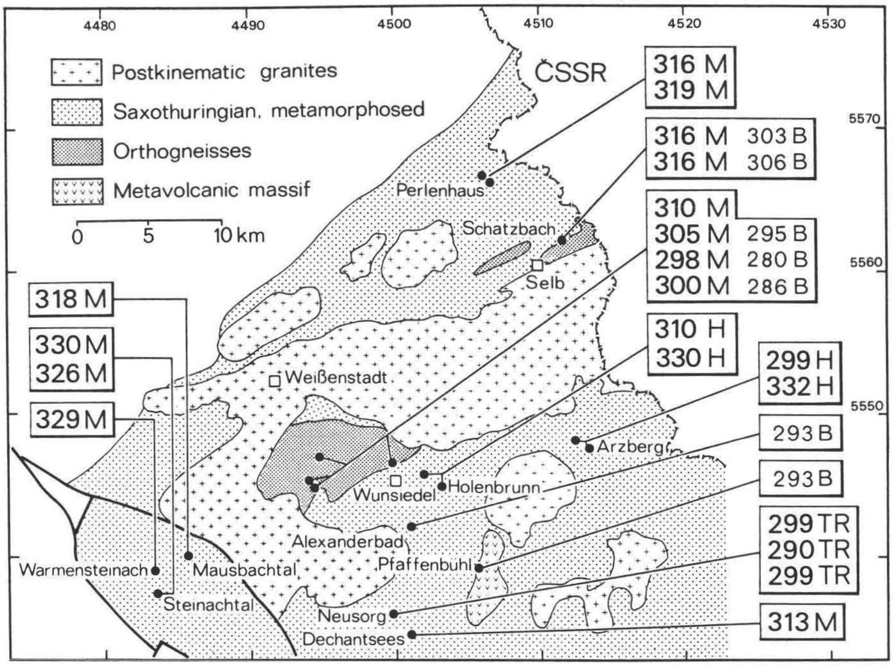

Fig. 2. Schematic geological map of the Fichtelgebirge crystalline complex (based on the 1 : 200,000 1981 geological map of Bavaria) showing sample localities and K–Ar dates. *H*—hornblende; *M*—Muscovite; *B*—biotite; *TR*—phyllite as the sieve fraction of rough-ground whole rock.

and has been investigated in more detail by Wagener-Lohse and Blümel (1984) and Wagener-Lohse (in prep). The grade of the low-pressure metamorphism decreases from the cordierite–K feldspar zone in the southeast to the chlorite zone in the Waldsassen area (southeastern Fichtelge-

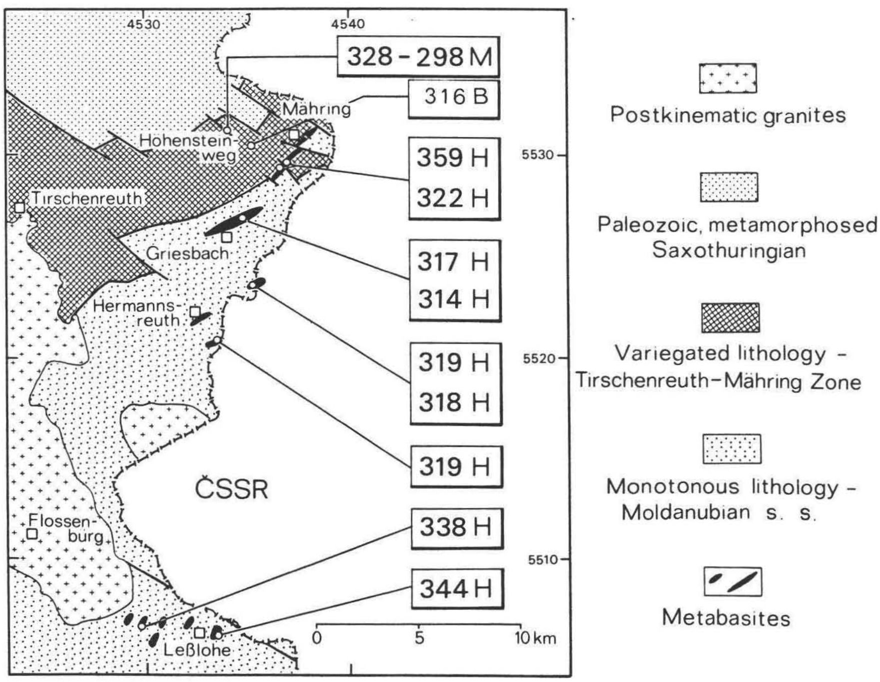

Fig. 3. Schematic geological map of the Tirschenreuth–Mähring Zone and the adjacent Moldanubian sensu stricto (based on the 1981 1 : 200,000 geological map of Bavaria) showing sample localities and K–Ar dates. *H*—hornblende; *M*—muscovite; *B*—biotite. The single apparent age of 359 Ma is recognized as being caused by excess argon.

birge), and increases again towards the northwest in the FG crystalline complex. The ZTM exhibits a transitional lithology which is less diverse than the Bunte Gruppe but more variable than the MO gneisses (Richter and Stettner, 1983). The rare amphibolites are of N-MORB tholeiitic character (Schüssler et al., this issue). Despite the transitional character of the ZTM, the border between the MO and the Saxothuringian in this area is defined by a steep shear zone, now regarded as the outcrop of the prominent suture zone along which the Moldanubian was thrust onto the Saxothuringian (Weber and Vollbrecht, 1986). The sillimanite–K feldspar gneisses in the shear zone have undergone two stages of retrograde metamorphism (Schreyer, 1966; Kleemann, 1986).

The nappe units

The Münchberg nappe pile (MM)

The Paleozoic rocks of Thuringian lithofacies in the southeastern Frankenwald are overlain by a nappe pile showing inverse metamorphic zonation and designated as the Münchberg nappe pile (MM) (Fig. 4) (Franke, 1984).

The lowermost nappe unit consists of anchimetamorphic sediments with intercalated tholeiitic to alkaline basalts (Wirth, 1978) and minor keratophyres. These sequences, like the Thuringian sequences, comprise Paleozoic rocks, but are of different lithological character–the Bavarian lithofacies (Wurm, 1961). Stratigraphically this unit is inverted: The Lower Carboniferous turbiditic Grauwacken–Tonschiefer (graywacke-slate) group at the base is overlain by the Devonian Kieselschiefer (chert) group which in turn is overlain by the Ordovician Randschiefer (marginal slate) group.

The next, higher, tectonic unit, the Prasinit–Phyllit-Serie (prasinite–phyllite series) (Kraus, 1954) consists predominantly of prasinites and quartz phyllites in variable proportions. Intercalations of serpentinite, partly altered to blackwall assemblages, are concentrated near the top of the unit. Geochemically, the prasinites are calc-alkaline in character (Oppermann, 1985).

Higher up in the nappe pile there is a unit of considerably higher metamorphic grade, the Randamphibolit-Serie (marginal amphibolites). It consists almost exclusively of garnet- and epidote-bearing amphibolites with minor intercalations of calc-silicate rocks and marbles. The amphibolites have a chemical composition similar to tholeiites (Oppermann, 1985).

The next higher crystalline nappe unit is conventionally designated as the Liegendserie (lower series) of the MM. It consists predominantly of metasediments and acidic orthogneisses. Locally, the orthogneisses display well-preserved relict igneous minerals and textures and occasionally they are bordered by metahornfelses (Schüller, 1949; Stettner, 1960). Among the subordinate metabasite intercalations, the most prominent is the Steinhügel metagabbronorite near Höflas (Matthes and Seidel, 1977).

The topmost unit of the MM is the Hangendserie (top series), a diverse sequence of amphibolites, banded hornblende gneisses, paragneisses with minor intercalations of marble and calc-silicate rock. According to Pommerenke (1985), the chemical composition of the amphibolites and hornblende gneisses is similar to that of calc-alkaline basalts.

Eclogites (dark and light kyanite-bearing varieties, and eclogite–amphibolites are concentrated in the boundary zone between the Hangendserie and the Liegendserie. They can be interpreted either as constituents of the Hangendserie (Matthes et al., 1974) or as dislocated slices, tectonically intercalated between the two units (Stettner, 1960). The dark eclogites have a N-MORB-like composition, whereas the light eclogites are high-Al basaltic in character (Matthes et al., 1975; Puchelt et al., 1978) and may be derived from plagioclase-rich gabbroic cumulates (Stosch and Lugmair, 1987).

The eclogites provide evidence for a high-pressure stage of metamorphism with pressures of 13–17 kbar and temperatures of about 620°C (Franz et al., 1986). It is still an open question whether this high-pressure event affected only part of, or all the metamorphic sequences of the Hangendserie and the Liegendserie. The main metamorphic event in the Hangendserie and in the Liegendserie of the MM is a medium-pressure metamorphism which partially transformed the

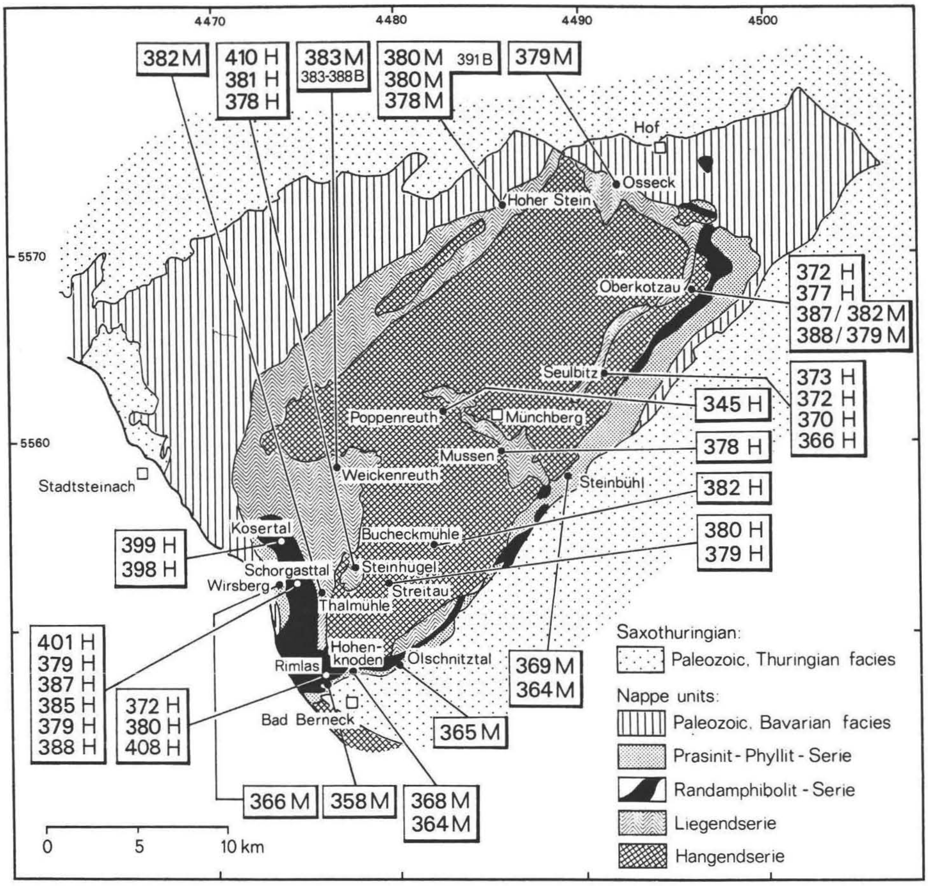

Fig. 4. Schematic geological map of the Münchberg nappe pile (based on the 1981 geological map of Bavaria) showing sample localities and K–Ar dates. *H*—hornblende; *M*—muscovite; *B*—biotite.

eclogites into eclogite–amphibolites. The metamorphic grade conforms to the amphibolite facies, and reached the stability field of the assemblage kyanite + garnet ± staurolite in metapelites (Matthes et al., 1974; Blümel, in Weber and Vollbrecht (1986), fig. 15).

The Erbendorf Greenschist Zone (EGZ)

The EGZ, between the Fichtelnaab Fault in the south and the Erbendorf Line in the north, is a tectonic unit overlain by the ZEV (Fig. 5). The EGZ seems to be in a tectonic position similar to that of the Prasinit–Phyllit-Serie in the MM (Weber and Vollbrecht, 1986). Similar also is the chemical composition of the metabasites which is transitional between tholeiitic and calc-alkaline in both units, with a clear island-arc affinity (Oppermann et al., 1986; Schüssler, in Weber and Vollbrecht (1986), fig. 16).

The EGZ consists mainly of various metabasites, including metagabbros, and of serpentinites, but contains only minor metasediments. The main phase of regional metamorphism took place under the conditions of the lower amphibolite facies. Owing to a later retrograde event, the mineral assemblages of the first metamorphism are partly replaced by greenschist facies minerals, giving rise to the somewhat misleading designation "greenschist zone". The metamorphic sequences of the EGZ underwent strong thermal metamorphism in the contact aureoles of the Steinwald and Falkenberg granites (Matthes, 1951; Matthes and Olesch, 1986).

The Erbendorf–Vohenstrauss Zone (ZEV)

The ZEV comprises the area between the Fichtelnaab Fault in the north and the Luhe Line in the south (Figs. 1 and 5). The Leuchtenberg granite divides it into a larger western part and a smaller eastern part. In the south, southeast and east the border between the ZEV and the MO sensu stricto is marked by a 2.0–2.5 km wide zone of diaphthorites, formed by retrograde metamorphism of the MO gneisses (Voll, 1960). Blümel (1985) was the first to propose, based on petrological and structural geological arguments, an allochthonous position for the ZEV, an assumption which has been supported by the recent DEKORP seismic profiles (Weber and Vollbrecht, 1986).

The ZEV is characterized by a variety of lithologies. Within predominantly pelitic metasediments, there are intercalations of various metabasites, ultramafics, calc-silicate rocks, graphite quartzites, graphite schists, metacherts and orthogneisses. Among these intercalations, the metabasites are the most important. They can be divided into three major types, each of different geochemical character (Schüssler et al., this issue.): Chemically, the flaser amphibolites are similar to an E-MORB composition, the schistose and striped

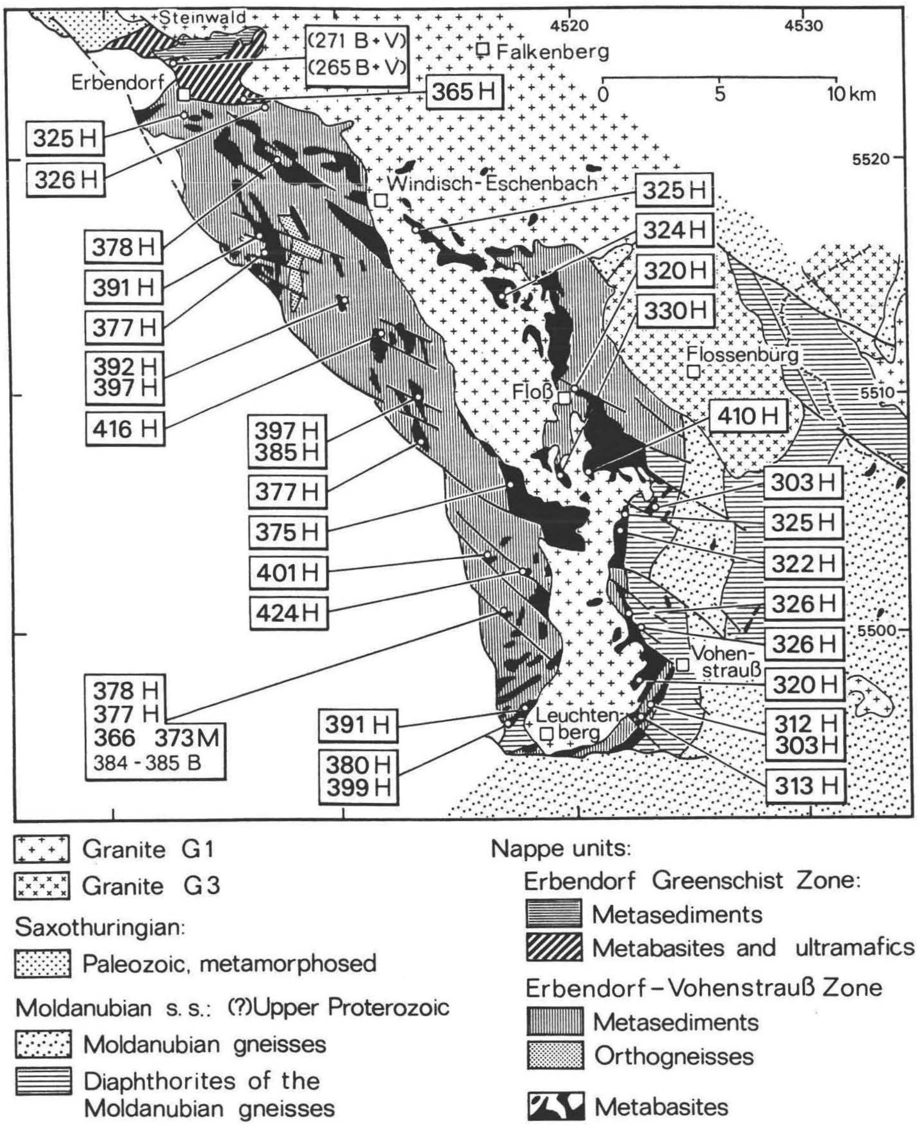

Fig. 5. Schematic geological map of the Erbendorf–Vohenstrauss Zone and the Erbendorf Greenschist Zone (based on the 1981 1 : 200,000 geological map of Bavaria) with sample localities and K–Ar dates. *H*—hornblende; *M*—muscovite; *B*—biotite; *V*—vermiculite.

amphibolites to a N-MORB composition and the metagabbros to a slightly enriched N-MORB composition.

The diverse sequence of the ZEV underwent medium-pressure metamorphism under amphibolite facies conditions. The absence of anatectic features in areas with the highest-grade assemblages of sillimanite/kyanite + K feldspar suggests that the P_{H_2O}–P_{tot}–T conditions approached those of the granulite facies (Voll, 1960; Frank,

TABLE 1

K–Ar mineral data from the Fichtelgebirge and the bordering Moldanubian.

Sample No.	1:25000 Map No.	Grid r value h value	Rock type locality	Mineral fraction (μm)	K-Ar date (Ma)	K (wt.%)	Argon rad. (nl/g)STP	Argon atm.
Western Fichtelgebirge								
FG 752	Weidenberg 6036	44 8622 55 3952	chloritoid schist, Mausbach valley, at the fork	mu	318 ± 2.5	7.08 4	95.6 5	0.9 4
FG 756	Weidenberg 6036	44 8346 55 3864	phyllite, S exit of Warmensteinach, small road cut at the W valley slope	mu	328.5 ± 2.5	7.39 4	103.6 6	0.8 8
FG 749	Weidenberg 6036	44 8382 55 3705	phyllite, Eselsweg, E slope of the Steinach valley, above Brunnenhaus	mu	325.5 ± 2.5	5.42 4	75.2 4	0.42 10
FG 750	Weidenberg 6036	44 8382 55 3705	phyllite, Eselsweg, E slope of the Steinach valley, above Brunnenhaus	mu	330 ± 2.5	7.12 4	100.2 5	0.31 11
Eastern and Central Fichtelgebirge								
FG 748	Rehau 5738	45 0565 55 6590	phyllite, road cut E of Schönwald - Rehau road, 500 m NW of Perlenhaus	mu 125- 63	316 ± 4	7.02 6	94.3 1.1	0.73 9
FG 747	Rehau 5738	45 0630 55 6535	phyllite, road cut E of Schönwald - Rehau road, 300 m SSE of Perlenhaus	mu 250-125	320 ± 3	7.49 6	101.9 8	0.8 3
				mu 125- 63	318 ± 3	7.58 6	102.7 8	1.3 3
FG 85/4	Selb 5838	45 1150 55 6145	mu-bi gneiss, SE exit of Schatzbach, cut at Prell farmhouse	mu 250-125	316 ± 3	8.74 7	117.2 1.0	4.3 4
				bi 250-125	303 ± 3	7.70 6	98.9 8	0.70 16
				bi 125- 63	302 ± 3	7.66 6	97.7 8	0.87 16
FG 85/5	Selb 5838	45 1150 55 6145	mu-bi-schist, SE exit of Schatzbach, cut at Prell farmhouse	mu 250-125	316 ± 3	8.56 6	114.8 9	3.88 18
				bi 250-125	306 ± 3	7.82 6	101.3 8	1.02 18
FG 704	Marktredwitz 5938	45 0004 55 4604	Wunsiedler augen gneiss, slope E of Wunsiedel-Nord - Bibersbach road	mu 125- 63	310 ± 3	8.42 6	110.5 9	1.6 2
FG 739	Fichtelberg 5937	44 9474 55 4645	Wunsiedler flaser gneiss, 500 m NNE of Vordorf, crag SE of fish-pond	mu 250-125	306 ± 3	8.84 7	114.4 9	1.97 14
				mu 125- 63	304 ± 3	8.89 7	114.3 9	1.7 12
				bi 250-125	294 ± 3	7.44 6	92.2 7	0.16 14
				bi 125- 63	295 ± 3	7.15 6	89.0 7	0.49 12
FG 510	Fichtelberg 5937	44 9433 55 4480	fine-grained Wunsiedler Gneis, 250 m NW of Waffenhammer	mu 250-125	298 ± 2	8.79 4	110.5 9	1.0 5
				bi 250-125	280 ± 2	5.71 3	67.1 5	0.43 13
FG 507	Fichtelberg 5937	44 9470 55 4432	Wunsiedler augen and flaser gneiss, 400 m SSE of Waffenhammer	mu 250-125	299.5 ± 2.5	8.81 5	111.5 9	0.9 5
				bi 250-125	286.5 ± 2	7.43 4	89.6 5	0.42 8

Y 4	Marktredwitz 5938	45 0206 55 4512	amphibolite (metam. basalt dike in Wunsiedler Marmor), Holenbrunn qu.	**amph** 63-36	**310** **± 5**		0.343 5	4.512 25	0.254 6
Y 2	Marktredwitz 5938	45 0325 55 4427	amphibolite with green bi, qu. on the Holenbrunn - Juliushammer road	**amph**	**330** **± 4**		0.323 4	4.553 25	0.229 6
Y 3a	Marktredwitz 5938	45 0110 55 4160	bi-gneiss, core from Lehmgrube bore hole near Alexanderbad	**green bi**		**293** **± 3**	6.73 5	83.2 5	0.9 8
662	Waldsassen 5939	45 1240 55 4775	amphibolite, Flitterbach valley, between Sand- and Flittermmühle	**hbl**	**299** **± 5**		0.229 4	2.892 23	0.300 14
WS 1a	Waldsassen 5939	45 1345 55 4707	amphibolite, at the church of Arzberg	**hbl**	**332** **± 6**		0.158 3	2.232 16	0.262 6
Höll 10	Ebnath 6037	44 9980 55 3560	phyllite, core 94 m, Neusorg bore hole	**TR** 400-250	**299** **± 3**		6.20 5	77.8 6	0.45 25
Höll 13	Ebnath 6037	44 9980 55 3560	phyllite, core 180 m, Neusorg bore hole	**TR** 400-250	**290** **± 3**		6.63 5	81.2 4	0.5 6
				TR 125- 63	**289** **± 3**		6.18 5	75.2 6	0.5 3
Höll 14	Ebnath 6037	44 9980 55 3560	phyllite, core 189 m, Neusorg bore hole	**TR** 400-250	**299** **± 3**		5.15 4	65.1 5	0.5 3
FG 514	Waldershof 6038	45 0585 55 3890	cataclastic metadacite, metavolcanic massif at Waldershof, Pfaffenbühl	**bi** 250-125		**292.5** **± 2.5**	7.59 4	93.6 7	2.24 16
FG 720	Waldershof 6038	45 0096 55 3388	mu-qtz marble, qu. in Wunsiedler Mar- mor, N-wall, 1. level. E of Dechantsees	**mu**	**312.5** **± 2.5**		8.73 5	115.8 6	0.68 16
Zone of Tirschenreuth - Mähring									
MD 1042	Neualbenreuth 6040	45 3580 55 3000	monzogranite of Mähring, block, qu. Poppenreuther Berg, radar station	**bi** 630-500		**315.5** **± 2.5**	7.60 6	101.9 6	0.54 12
				bi 500-250		**315** **± 3**	7.65 6	102.4 8	0.40 14
				bi 250-125		**316.5** **± 3**	7.83 5	105.3 9	2.9 9
			mean biotite date **315.5 ± 1.5**	**bi** 125- 63		**314** **± 4**	7.62 7	101.8 1.0	0.73 13
OP-85- 244	Mähring 6041	45 3732 55 2940	amphibolite with relics of garnet ca. 1200 m SW of Mähring	**hbl**	**359** **± 6**		0.229 4	3.536 19	0.244 6
OP-85- 242	Treppenstein 6141	45 3722 55 2910	amphibolite, ca. 1500 m SW of Mähring	**hbl**	**322** **± 4**		0.687 9	9..42 7	0.26 3
Moldanubian sensu stricto									
675	Tirschenreuth 6140	45 3520 55 2660	amphibolite, NE of Griesbach	**hbl**	**314** **± 7**		0.1453 35	1.938 16	0.442 10
OP-85- 239	Tirschenreuth 6140	45 3490 55 2645	amphibolite, ca. 600 m NNE of Griesbach	**hbl**	**317** **± 11**		0.0738 27	0.993 9	0.272 9
OP-85- 245	Tirschenreuth 6140	45 3580 55 2335	amphibolite, Weiße Marter ca. 2000 m NE of Hermannsreut	**hbl**	**319** **± 6**		0.1653 33	2.242 18	0.269 9
676	Tirschenreuth 6140	45 3565 55 2330	amphibolite, Weiße Marter ca. 2000 m NE of Hermannsreuth	**hbl**	**318** **± 5**		0.391 6	5.29 4	0.259 9
OP-85- 247	Tirschenreuth 6140	45 3406 55 2055	amphibolite, Großes Dürrmaul, ca. 1300 m S of Hermannsreuth	**hbl**	**319** **± 5**		0.422 6	5.72 4	0.199 9
OP-84- 123	Vohenstrauß 6340	45 3142 55 0650	amphibolite, Brünst, ca. 1750 m WNW of Leßlohe	**hbl**	**338** **± 4**		0.439 5	6.33 4	0.295 12
OP-84- 120	Vohenstrauß 6340	45 3408 55 0610	amphibolite, Breitenschlag ca. 900 m E of Leßlohe	**hbl**	**344** **± 4**		0.355 5	5.24 3	0.181 8

The samples are grouped according to maps of the area and from north to south. Abbreviations: amph = amphibole; ab = albite; bi = biotite; chl = chlorite; ep = epidote; ga = garnet; hbl = hornblende; mu = muscovite; pl = plagioclase; qtz = quartz; TR = sieve fraction of rough-ground rock; qu = quarry. If not mentioned otherwise, the 125–63 μm fraction was analyzed. Argon as nannoliters per gram at standard conditions ((nl/g)STP). All analytical data are corrected for short-period mean values of blank analyses. The IUGS-recommended constants (Steiger and Jäger, 1977) were used. The K–Ar dates of hornblende or muscovite and those of biotite are given in separate columns. Error estimates refer to the 95% confidence level of intralaboratory precision. They are based on the larger value of the individual and the average relative standard deviations. Our K–Ar date for the standard glaucony GL-O is 1% younger than the mean value given in the compilation of Odin (1982).

TABLE 2

K–Ar mineral data from the Bavarian Moldanubian

Sample No.	1:25000 Map No.	Grid r value h value	Rock type locality	Mineral fraction (µm)	K-Ar date (Ma)	K (wt.%)	Argon rad. (nl/g)STP	Argon atm.
Oberpfälzer Wald (OPW, High Palatinate Forest)								
MD 1005	Waldmünchen	45 5828	leptite (few garnets), 100 m N of	**bi**	**314**	7.41	98.6	1.5
	6642	54 6612	Gaisriegel, near castle Voithenberg		**± 3**	4	7	4
MD 1006	Waldmünchen	45 5760	light leptite, crag in forest, 125 m	**bi**	**318**	7.53	101.9	1.05
	6642	54 6608	NW of Gaisriegel, near castle Voithenberg		**± 3**	4	8	14
MD 1008	Waldmünchen	45 5760	dark inclusions and schlieren in	**bi**	**320**	7.83	106.4	1.3
	6642	54 6608	sample MD 1006		**± 3**	4	8	4
MD 1002	Waldmünchen	45 5704	massive amphibolite, block, Dachs-	**hbl**	**328**	0.243	3.396	0.16
	6642	54 6474	riegel, 1.5 km SW of castle Voithenberg		**± 5**	4	29	4
MD 1003	Waldmünchen	45 5704	banded amphibolite (hbl-bi-pl para-	**hbl**	**309**	0.266	3.495	0.17
	6642	54 6474	gneiss), block, Dachsriegel		**± 5**	4	29	3
Analyses from Harre et al., 1967, recalculated								rad/tot (%)
AL 129	Neunburg v.W.	45 3270	Neunburger Granit, qu. NE of Eixen-	**mu**	**319**	7.70	104.4	90
	6640	54 6825	dorf, E slope of Schwarzach valley	600-400	**± 6**	9	1.8	
				mu	**324**	7.99	110.2	95
				400-200	**± 6**	14	1.2	
				bi	**320**	6.92	94.2	91
				600-400	**± 5**	9	8	
				bi	**323**	7.16	98.5	96
				400-200	**± 5**	7	1.5	
Regensburger Wald (RW, the western end of the Vorderer Bayerischer Wald, i.e. the western end of the southwestern mountain chain of the Bavarian Forest); for Rb-Sr dates see Köhler and Müller-Sohnius (1985, Tab. 2)								
AL 136	Schwandorf	45 1097	anatectic gneiss, 3rd qu. on	**mu**	**320**	6.48	88.0	94
	6638	54 7259	Schwarzenfeld - Willhof road	400-200	**± 6**	8	1.5	
AL 131	Reichenbach	45 2580	Kristallgranit I, qu. between	**mu**	**320**	8.08	109.8	91
	6840	54 5010	Waldersbach and Reichenbach	400-200	**± 4**	10	1.0	
				bi	**326**	5.72	79.4	89
				400-200	**± 5**	7	7	
AL 130	Reichenbach	45 3450	diorite, Niklas qu.	**bi**	**325**	5.06	70.1	94
	6840	54 4800	near Trasching	400-200	**± 6**	8	9	
				bi	**327**	4.98	69.5	95
				200-100	**± 6**	9	8	
AL 135	Nittenau	45 2134	Körnelgneis (granite-like bi-gneiss),	**bi**	**326**	7.48	104.0	94
	6839	54 4207	Refberg, qu., 250 m NNE of Refthal	600-400	**± 5**	9	1.1	
				bi	**331**	7.48	105.6	96
				400-200	**± 5**	9	1.3	
AL 137	Donaustauf	45 1894	Kristallgranit I, qu. 300 m	**bi**	**325**	6.23	86.2	95
	6939	54 3510	NNW of Unterlichtenwald	600-400	**± 5**	8	8	
AL 138	Donaustauf	45 1894	metatectic banded gneiss, qu.	**bi**	**331**	6.74	95.2	95
	6939	54 3510	300 m NNW of Unterlichtenwald	600-400	**± 5**	8	1.0	
				bi	**322**	6.66	91.3	96
				400-200	**± 5**	8	1.0	

Vorderer Bayerischer Wald (VBW)

AL 44	Deggendorf 7143	45 6754 54 1540	Mettener Granit, medium-grained facies, Aalter qu., N of Laufmühle	**mu** >600h	**310** **± 5**	8.68 11	114.2 1.2	93
				bi 600-300	**303** **± 5**	7.80 10	100.0 1.3	95
				bi 300-200g	**302** **± 7**	7.18 9	91.9 1.8	94
AL 145	Lalling 7144	45 7819 54 1602	Perlgneis with cordierite, qu. at Ruselabsatz	**mu** 600-400	**321** **± 9**	4.65 7	63.6 1.7	94
				bi 600-400	**321** **± 5**	7.16 9	97.8 1.1	93
				bi 400-200	**317** **± 6**	7.26 12	97.8 1.1	95
AL 149	Schöllnach 7245	45 9515 53 9825	Saldenburger Granit, qu. near the Einzendoblmühle, E of Eging	**mu** 600-400	**312** **± 5**	8.62 11	114.3 1.2	94
				mu 400-200	**302** **± 5**	8.25 10	105.3 1.2	92
				bi 600-400	**291** **± 4**	7.36 9	90.2 8	89
				bi 400-200	**297** **± 5**	7.07 9	88.6 1.4	97
AL 150	Schöllnach 7245	45 9770 53 9750	diorite, Merckenschlager qu., on the Fürstenstein - Nammering road	**bi** 400-200	**300** **± 5**	7.13 9	90.4 1.0	95
AL 151	Tittling 7246	46 0050 54 0180	Saldenburger Granit, qu. on the Hohenberg	**bi** 400-200	**315** **± 5**	7.04 9	94.1 1.0	93
AL 34	Waldkirchen 7247	53 9886 53 9793	Hauzenberger Granit, Albrechtsbruch No. 1, N slope of the Lindberg	**bi** 600-300	**300** **± 6**	6.98 12	88.5 1.4	93
				bi 300-200g	**290** **± 7**	7.64 11	93.5 1.9	93
AL 148	Hauzenberg 7347	53 9734 53 9610	Hauzenberger Granit I, qu. on the Neidlingerberg	**mu** 600-400	**289** **± 5**	6.59 8	80.3 1.0	89
				mu 400-200	**318** **± 5**	8.26 10	111.7 1.2	94
				bi 600-400	**297** **± 4**	7.10 9	89.0 8	89
				bi 400-200	**303** **± 6**	5.90 11	75.7 7	94
AL 146	Unter- grießbach 7448	54 0555 53 8300	banded biotite gneiss, waste-heap of the abandoned Ficht graphite mine, 3.5 km E of Untergrießbach, S of the road	**bi** 400-200	**318** **± 7**	7.12 16	96.2 1.1	93
				bi 200-100	**318** **± 5**	6.96 9	94.0 1.0	96

South of Donau-Randbruch (DRB, Danube marginal fault)

AL 139	Osterhofen 7244	45 8424 53 9900	Perlgneis, qu. on the Iggensbach - Vilshofen road	**bi** 600-400	**309** **± 5**	6.50 8	85.2 9	89
				bi 400-200	**315** **± 5**	6.29 8	84.0 9	95
AL 141	Vilshofen 7345	45 8595 53 9114	migmatite gneiss (partly relic Perlgneis), qu. 1 km NW of Wimhof, road on the N bank of Danube river	**bi** 600-400	**321** **± 5**	7.06 9	96.4 1.1	95
				bi 400-200	**320** **± 5**	6.88 9	93.7 1.0	95
AL 140	Vilshofen 7345	45 9170 53 8705	migmatite gneiss, qu. 150 m SE Gerharding, road on N bank of Danube river	**bi** 600-400	**320** **± 5**	7.19 9	98.0 1.1	95
				bi 400-200	**322** **± 5**	7.20 9	98.6 1.1	93

TABLE 2 (continued)

Bayerischer Wald (BW, Bavarian Forest)									
AL 134	Neukirchen b. Heil. Blut 6743	45 7198 54 5553	micaschist, S road cut, 300 m S of Mais	mu 600-300	326 ± 5		6.48 9	90.1 1.0	93
				mu 300-200	321 ± 5		6.90 9	94.1 1.1	97
AL 132	Bodenmais 6944	45 8192 54 3662	metatectic ga-bi gneiss, stock, 150 m NW of the entrance of the Barbarastollen	bi 600-400		315 ± 4	7.32 9	97.9 9	91
				bi 400-200		323 ± 6	7.00 12	96.2 1.1	94
AL 133	Lam 6844	45 8480 54 4093	Arbergneis, block, car park E of road, 100 m NE of the Arberhaus	mu+qtz 600-400	317 ± 25		4.17 5	56.2 4.7	88
				mu 400-200	314 ± 6		5.90 7	78.8 1.2	96
				bi 600-400		315 ± 5	7.16 9	95.9 9	91
				bi 400-200		322 ± 7	7.40 9	101.4 1.9	94
AL 144	Zwiesel 6945	45 8882 54 2995	? Kristallgranit I, road cut near Zwieselberg	bi 600-400		306 ± 4	7.51 9	97.4 9	89
				bi 400-200		316 ± 5	7.36 9	98.6 1.1	95
AL 142	Zwiesel 6945	45 9486 54 3665	banded biotite gneiss, qu. near Schwarze Brücke	bi 600-400		320 ± 5	7.38 9	100.5 1.2	95
				bi 400-200		318 ± 6	7.28 12	98.6 1.1	95
AL 143	Zwiesel 6945	45 9670 54 3502	biotite-cordierite gneiss, qu. in Eselngespreng forest	mu 400-200	321 ± 7		7.35 10	100.4 1.9	93
				bi 600-400		325 ± 5	7.15 10	98.9 9	94
				bi 400-200		322 5	7.26 9	99.6 1.1	95
AL 147	Jandelsbrunn 7248/49	54 1194 54 0438	Dreisesselgranit (Eisgarn type), car park on the road to the summit of the Dreisessel	mu 600-400	311 ± 4		8.72 11	115.1 1.0	90
				mu 400-200	318 ± 6		7.96 10	107.6 1.8	94
				bi 600-400		312 ± 4	7.43 9	98.2 9	89
				bi 400-200		309 ± 7	7.38 15	96.8 1.5	92

h = handpicked; g = mica books split up by rubbing under alcohol. For further comments and abbreviations see Table 1.

1986). Older eclogitic relics, more-or-less transformed into amphibolites, are scarce (Voll, 1960; Busch, 1970). The intrusion of the Falkenberg and Leuchtenberg granites caused a thermal overprint, especially in the Steinach aureole (Voll, 1960; Okrusch, 1969) and near Windisch-Eschenbach (Schüssler, 1987; Schüssler et al., this issue).

Analytical methods

Potassium and argon were analyzed in separate, representative aliquots, the former by flame photometry, and the latter by mass-spectrometric isotope-dilution analysis (e.g., Seidel et al., 1982). Duplicate or replicate analyses were made of most of the mineral concentrates. The averages of recent determinations are given in Tables 1, 3 and 4. Table 2 contains mainly recalculated analyses from Harre et al. (1967). For uncertainties in the latter analyses, see Carl et al. (1985, p. 501). On average, recent analyses have a relative standard deviation (i.e., the standard deviation divided by the respective quantity) of 0.3% for micas and 0.5% for amphiboles. The higher value of the average and

TABLE 3

K–Ar mineral data from the Münchberg nappe pile

Sample No.	1:25000 Map No.	Grid r value h value	Rock type locality	Mineral fraction (µm)	K-Ar date (Ma)	K (wt.%)	Argon rad. (nl/g)STP	Argon atm. (nl/g)STP
Hangendserie								
MM 85/10	Schwarzen- bach/S. 5737	44 9438 55 7115	mu-rich part in eclogite, Oberkotzau clay pit	3T mu 500-250	388 ± 3	8.48 7	142.8 1.1	4.2 6
				3T mu 125- 63	379 ± 3	8.26 6	135.2 7	2.16 18
MM 85/12	Schwarzen- bach/S. 5737	44 9438 55 7115	mu-rich part in eclogite, Oberkotzau clay pit	3T mu 500-400	388 ± 4	8.36 7	140.4 1.1	3.8 7
				3T mu 500-250	386 ± 3	8.27 6	138.5 7	1.93 17
				3T mu 125- 63	382 ± 2.5	8.19 5	135.4 7	9.65 20
O 2	Schwarzen- bach/S. 5737	44 9577 55 6845	banded ga-hbl gneiss, Schwarzen- bach - Hof road cut, S of Oberkotzau	hbl	372 ± 4	0.385 4	6.19 4	0.226 9
O 5	Schwarzen- bach/S. 5737	44 9576 55 6828	amphibolite, block, road, 100 m S of Oberkotzau	hbl	377 ± 4	0.384 4	6.26 3	0.336 17
S 16	Schwarzen- bach/S. 5737	44 9105 55 6453	banded hbl gneiss, abandoned qu. 400 m N of Seulbitz	hbl	373 ± 5	0.338 4	5.45 5	0.204 7
S 50	Schwarzen- bach/S. 5737	44 9039 55 6408	garnet amphibolite, abandoned qu. 200 m W of Seulbitz	hbl	370 ± 6	0.250 3	3.99 5	0.161 20
S 52	Schwarzen- bach/S. 5737	44 9039 55 6408	amphibolite, abandoned qu. 200 m W of Seulbitz	hbl	366 ± 14	0.177 7	2.79 3	0.26 5
S 53	Schwarzen- bach/S. 5737	44 9039 55 6408	banded amphibolite with hbl-ep-qtz-pl layers, same loc.	hbl	372 ± 8	0.224 5	3.60 4	0.217 6
S72/109	Münchberg 5836	44 8190 55 6175	amphibolite, quarry W of Poppenreuth	hbl	345 ± 4	0.409 5	6.04 3	0.30 4
S72/102	Münchberg 5836	44 8450 55 5986	hornblendite, Eisenbühl, 400 m N of Mussen	hbl	378 ± 6	0.204 3	3.34 3	0.175 7
S72/100	Münchberg 5836	44 8140 55 5460	amphibolite, Autobahn cut W of Bucheckmühle	hbl	382 ± 5	0.293 3	4.85 4	0.253 9
S72/95	Münchberg 5836	44 7908 55 5314	eclogite amphibolite, block, Wallberg, N of Streitau	hbl	380 ± 6	0.432 6	7.10 6	0.304 17
S72/94	Münchberg 5836	44 7894 55 5236	amphibolite, block, S of Streitau	hbl	379 ± 6	0.413 6	6.78 5	0.19 3
Liegendserie								
MM 1	Hof 5637	44 9214 55 7416	flaser gneiss, 750 m SE of Osseck	mu	379 ± 2.5	8.84 5	145.0 8	2.5 4
MM 9	Helmbrechts 5736	44 8553 55 7314	gneiss, light, Hoher Stein, W of Leupoldsgrün	mu	378 ± 2.5	8.82 4	144.2 9	1.42 21
MM 7	Helmbrechts 5736	44 8544 55 7310	augen gneiss, Hoher Stein, W of Leupoldsgrün	mu	380 ± 2.5	8.70 4	143.1 6	0.84 21
				bi	391 ± 3	7.32 5	124.3 6	0.64 26
MM 5	Helmbrechts 5736	44 8546 55 7305	augen gneiss, Hoher Stein, W of Leupoldsgrün	mu	379.5 ± 2.5	8.83 4	145.1 6	0.71 15
S72/89	Münchberg 5836	44 7696 55 5338	metagabbro, Steinhügel near Höflas	hbl	381 ± 3	0.506 4	8.35 3	0.260 7
S72/91	Münchberg 5836	44 7696 55 5338	metagabbro, Steinhügel near Höflas	hbl	378 ± 3	0.576 5	9.42 5	0.202 11
H 4	Münchberg 5836	44 7696 55 5338	metagabbro, Steinhügel near Höflas	hbl	410 ± 5	0.427 5	7.64 5	0.244 11

TABLE 3 (continued)

W 8	Stadtsteinach 5835	44 7563 55 5889	metagranodiorite, Gareisen, W of Weickenreuth	bi 1000-500	385 ± 3	7.52 6	125.4 6	0.56 10
				bi 500-250	388 ± 3	7.48 6	126.0 6	0.58 19
				bi 250-125	383 ± 2.5	7.32 3	121.5 6	0.79 19
W 1	Stadtsteinach 5835	44 7550 55 5880	mu-flaser gneiss (metagranodiorite), Gareisen, W of Weickenreuth	mu 500-250	382 ± 3	8.78 5	145.0 9	0.9 6
				mu 250-125	383 ± 3	8.84 5	146.7 9	1.4 7
P28/6	Stadtsteinach 5835	44 7525 55 5163	mu-(bi) gneiss, abandoned qu. at Thalmühle, near Marktschorgast	mu 125- 63	382 2.5	8.86 5	146.5 8	2.4 1.8
R a n d a m p h i b o l i t - S e r i e								
RA 16	Stadtsteinach 5835	44 7265 55 5475	amphibolite, Koser valley 370 m ESE of Schlackenmühle	hbl	399 ± 7	0.160 3	2.784 18	0.72 3
RA 49	Stadtsteinach 5835	44 7275 55 5440	garnet amphibolite, Koser valley, 700 m SE of Schlackenmühle	hbl	398 ± 10	0.1004 25	1.738 19	0.403 20
RA 44	Stadtsteinach 5835	44 7350 55 5275	amphibolite, abandoned qu. in Schorgast valley	hbl	379 ± 6	0.186 3	3.06 3	0.487 20
RA 47	Stadtsteinach 5835	44 7350 55 5275	amphibolite, abandoned qu. in Schorgast valley	hbl	401 ± 6	0.213 3	3.708 24	0.484 20
RA 31	Stadtsteinach 5835	44 7390 55 5245	garnet amphibolite, Rabenstein	hbl	387 ± 6	0.222 4	3.72 3	0.264 10
RA 39	Stadtsteinach 5835	44 7315 55 5235	amphibolite, forest track, 750 m NNW of Sessenreuth	hbl	385 ± 9	0.1014 25	1.690 11	0.370 20
RA 40	Stadtsteinach 5835	44 7325 55 5235	garnet amphibolite, forest track, 850 m NNW of Sessenreuth	hbl	379 ± 10	0.0936 26	1.536 10	0.409 5
RA 34	Stadtsteinach 5835	44 7385 55 5150	amphibolite, country lane, 500 m N of Mittelpölitz	hbl	388 ± 4	0.376 4	6.33 4	0.45 11
RA 69	Marktschor- gast 5935	44 7555 55 4775	garnet amphibolite, road cut 500 m NNW of Rimlas	hbl	372 ± 6	0.1930 35	3.099 17	0.318 20
RA 70	Marktschor- gast 5935	44 7555 55 4775	garnet amphibolite, road cut 500m NNW of Rimlas	hbl	380 ± 6	0.2180 35	3.583 21	0.34 3
RA 83	Marktschor- gast 5935	44 7585 55 4743	amphibolite, N of Rimlas	hbl	408 ± 13	0.090 3	1.596 12	0.492 10
P r a s i n i t - P h y l l i t - S e r i e								
PH 16	Weißenstadt 5837	44 8880 55 5800	phyllite Steinbühl, SW of Sparneck	mu	369 ± 4	6.67 7	106.2 6	2.6 8
PH 14	Weißenstadt 5837	44 8883 55 5790	phyllite, Steinbühl, SW of Sparneck, at Waldhotel Heimatliebe	mu	364 ± 4	6.34 8	99.3 5	0.9 7
S86/15	Stadtsteinach 5835	44 7278 55 5260	phyllite, S slope Schorgast valley, 200 m W of Wirsberg swimming-bath	mu	366 ± 4	7.22 7	113.8 6	0.81 17
PH 19	Bad Berneck 5936	44 7953 55 4818	phyllite, Ölschnitz valley, between Entenmühle and Stein	mu	365 ± 3	7.41 6	116.4 6	0.80 18
PH 4	Bad Berneck 5936	44 7678 55 4750	phyllite, Hohenknoden, Wirth sawmill	mu 250-125	368 ± 5	7.17 10	113.7 9	1.28 13
				mu 125- 63	367 ± 5	6.24 8	98.9 8	0.91 13
PH 10	Bad Berneck 5936	44 7678 55 4750	phyllite, Hohenknoden, Wirth sawmill	mu	364 ± 4	7.15 7	112.2 6	0.51 8
PH 11	Marktschor- gast 5935	44 7583 55 4710	phyllite, road cut at fork S of Rimlas	mu	358 ± 3	6.25 5	96.2 6	0.44 10

For comments and abbreviations see Table 1.

TABLE 4

K–Ar mineral data from the Erbendorf–Vohenstrauss area

Sample No.	1:25000 Map No.	Grid r value h value	Rock type locality	Mineral fraction (µm)	K-Ar date (Ma)	K (wt.%)	Argon rad. (nl/g)STP	Argon atm. (nl/g)STP
Erbendorfer Grünschieferzone								
ZEV 85/1	Erbendorf	45 0240	blackwall, steatite mine,	(bi+vermiculite	271)	5.83	66.2	1.55
	6138	55 2446	1.5 km E of Grötschenreuth		± 2.5	3	5	18
ZEV 85/2	Erbendorf	45 0240	blackwall, steatite mine,	(bi+vermiculite	265)	4.65	51.5	1.21
	6138	55 2446	1.5 km E of Grötschenreuth		± 3	4	4	18
RBU-78-50	Erbendorf	45 0585	metagabbro	hbl	365	0.1634	2.568	0.26
	6138	55 2210	250 m E of Plärn		± 7	32	14	5
Western part of the Erbendorf-Vohenstrauß Zone								
84-152	Erbendorf	45 0710	amphibolite, contact aureole	hbl	326	0.2444	3.395	0.24
	6138	55 2225	of the Falkenberger Granit,		± 6	44	26	1
			Grillenbühl, 700 m N of Krummennaab					
84-8	Erbendorf	45 0325	amphibolite, Galgenbach valley,	hbl	325	0.472	6.530	0.36
	6138	55 2150	600 m NW of Hauxdorf		± 4	7	24	16
84-9	Erbendorf	45 0725	flaser amphibolite, Mittelberg,	hbl	378	1.032	16.86	0.26
	6138	55 2000	1 km SSE of Burggrub		± 4	12	8	9
2-5	Parkstein	45 0660	garnet flaser amphibolite,	hbl	391	0.298	5.050	0.260
	6238	55 1650	400 m W of Steinreuth		± 6	5	29	7
1-7	Parkstein	45 0690	flaser amphibolite, 100 m E of	hbl	377	0.266	4.337	0.24
	6238	55 1560	Kirchendemenreuth churchyard		± 7	5	33	1
84-126	Parkstein	45 1012	schistose, striped amphibolite,	hbl	392	0.1301	2.212	0.203
	6238	55 1362	Klobenreuth, excavation		± 9	33	17	4
84-127	Parkstein	45 1012	schistose, striped amphibolite,	hbl	397	0.1309	2.258	0.205
	6238	55 1362	Klobenreuth, excavation		± 9	33	18	5
84-131	Parkstein	45 1190	flaser amphibolite, exit of Mühlberg	hbl	416	0.841	15.29	0.28
	6238	55 1195	towards Denkenreuth		± 5	10	12	2
84-137	Neustadt	45 1362	garnet flaser amphibolite,	hbl	397	0.1909	3.292	0.26
	6239	55 0988	900 m NNW of Roschau		± 6	32	19	3
84-140	Neustadt	45 1362	garnet flaser amphibolite,	hbl	385	0.2046	3.409	0.186
	6239	55 0988	spot height 485, 900 m NNW of Roschau		± 6	32	23	18
84-135	Neustadt	45 1398	garnet flaser amphibolite,	hbl	377	0.3212	5.234	0.122
	6239	55 0780	spot height 525, 400 m NW of Görnitz		± 5	39	30	18
84-36	Waldthurn	45 1738	schistose, banded amphibolite,	hbl	375	0.1205	1.953	0.196
	6339	55 0582	Steinbühl, 1 km SE of Theisseil		± 13	45	11	9
84-65	Waldthurn	45 1638	amphibolite, Mitterhöll,	hbl	401	0.2090	3.647	0.246
	6339	55 0282	above shooting stand		± 8	41	28	6
84-60	Waldthurn	45 1808	amphibolite, Wolfswinkel,	hbl	424	0.2758	5.119	0.222
	6339	55 0230	900 m E of Matzlesrieth		± 6	40	30	10
85-260	Waldthurn	45 1700	ga-mu-bi-pl gneiss,	mu	373.5	7.89	127.2	0.74
	6339	55 0075	Oedenthal quarry	250-125	± 2.5	4	7	20
				mu	369.5	7.74	123.3	0.9
				125- 63	± 2.5	4	7	3
				bi	385	7.71	128.6	0.38
				250-125	± 4	6	1.0	28
				bi	384	7.76	128.9	0.41
				125- 63	± 4	6	1.0	31
85-261	Waldthurn	45 1700	ga-mu-bi-pl gneiss,	mu	373	8.21	132.2	1.09
	6339	55 0075	Oedenthal quarry	250-125	± 3	7	7	18
				mu	371	8.32	133.2	1.43
				125- 63	± 3	7	1.0	22
				bi	385	7.57	126.2	0.41
				250-125	± 4	6	1.0	27
				bi	384	7.66	127.2	0.61
				125- 63	± 4	6	1.0	31

TABLE 4 (continued)

85-263	Waldthurn 6339	45 1700 55 0075	leucogneiss, Oedenthal qu.,	mu (rg) 500-250	**371** ± 3	8.83 5	141.1 1.1	0.8 3
				mu (dm) 500-250	**369.5** ± 2.5	8.85 5	141.6 8	1.57 16
				mu (rg) 250-125	**366** ± 2.5	8.83 5	139.4 8	0.78 15
				mu (dm) 250-125	**369** ± 3	8.88 5	141.6 1.1	1.5 3
				mu (rg) 125- 63	**368** ± 4	8.66 7	137.6 1.1	0.35 30
				mu (dm) 125- 63	**369** ± 4	8.82 7	140.4 1.1	2.4 3

(rg) = from rough-ground sample
(dm) = additional short grinding with disc mill

Additional grinding increases purity, as can be seen from increasing K concentrations of the remaining mica flakes, but it increases the concentration of atmospheric argon, too. The muscovite dates are slightly discordant. The mean date of the coarsest fractions of all three samples is a minimum age of the main event recorded: 372 ± 2.5 Ma

84-38	Waldthurn 6339	45 1700 55 0075	amphibolite, Oedenthal quarry	hbl	**378** ± 5	0.316 4	5.161 29	0.18 8
84-150	Waldthurn 6339	45 1700 55 0075	amphibolite, Oedenthal quarry	hbl	**377** ± 4	0.445 5	7.26 4	0.18 12
84-76	Waldthurn 6339	45 1780 54 9656	schistose epidote amphibolite, Luhe valley, between Michldorf and Burgmühle	hbl	**391** ± 5	0.2300 33	3.904 22	0.362 13
84-89	Waldthurn 6339	45 1748 54 9605	schistose epidote amphibolite, new Michldorf quarry	hbl	**380** ± 5	0.3121 38	5.133 29	0.255 15
84-90	Waldthurn 6339	45 1748 54 9605	schistose epidote amphibolite, new Michldorf quarry	hbl	**399** ± 7	0.2255 40	3.916 22	0.337 16
Eastern part of the Erbendorf-Vohenstrauß Zone								
84-237	Neustadt/W. 6239	45 1338 55 1672	flaser amphibolite, Hohlerstein, 250 m E of Pfaffenreuth	hbl	**325** ± 4	0.785 10	10.88 8	0.22 3
84-233	Neustadt/W. 6239	45 1710 55 1430	flaser amphibolite, Asper, 750 m NE of Ilsenbach	hbl	**324** ± 4	0.666 9	9.20 7	0.27 3
3-8	Neustadt/W. 6239	45 2025 55 1030	flaser amphibolite, St. Nikolaus, near Floß	hbl	**320** ± 4	0.807 10	10.98 6	0.206 8
84-47	Waldthurn 6339	45 1960 55 0660	schistose amphibolite, 700 m NW of Diebersreuth	hbl	**330** ± 9	0.0866 25	1.220 9	0.258 9
84-49	Waldthurn 6339	45 2060 55 0660	massive amphibolite, 500 m NW of Grafenreuth	hbl	**410** ± 10	0.1024 26	1.830 10	0.260 6
84-44	Waldthurn 6339	45 2365 55 0506	amphibolite, 1.1 km SSW of Goldbrunn	hbl	**303** ± 12	0.0602 26	0.773 7	0.247 6
84-50	Waldthurn 6339	45 2238 55 0500	massive amphibolite, Brunnenhof, SW of Ottenrieth	hbl	**325** ± 7	0.1862 45	2.579 12	0.287 11
84-55	Waldthurn 6339	45 2200 55 0414	amphibolite, Maienberg, between Lennesrieth and Albersrieth	hbl	**322** ± 6	0.2272 43	3.108 24	0.266 7
84-164	Waldthurn 6339	45 2250 55 0058	schistose amphibolite, 400 m N of Waldau, near spot height 523	hbl	**326** ± 7	0.1065 25	1.478 8	0.224 10
84-168b	Waldthurn 6339	45 2288 55 0004	schistose amphibolite, 400 m E of Waldau	hbl	**326** ± 8	0.1201 32	1.670 13	0.194 6
84-183	Waldthurn 6339	45 2290 54 9760	massive amphibolite, 750 m NNE of Unterlind	hbl	**320** ± 5	0.1965 31	2.675 15	0.152 9
84-190	Waldthurn 6339	45 2344 54 9718	amphibolite, Kalvarienkapelle, 650 m NE of Oberlind	hbl	**312** ± 5	0.272 5	3.592 18	0.119 14
84-192	Waldthurn 6339	45 2344 54 9718	amphibolite, Kalvarienkapelle, 650 m NE of Oberlind	hbl	**303** ± 8	0.1216 32	1.561 12	0.156 8
84-186	Waldthurn 6339	45 2287 54 9687	amphibolite, between Oberlind and Unterlind	hbl	**313** ± 10	0.0848 28	1.128 7	0.065 30

For sample Nos. beginning with 84 and 85 read OP-84 and OP-85, respectively. For other comments, see Table 1.

the individual relative standard deviations was used to calculate the analytical error. However, some potassium determinations on hornblendes and on muscovite concentrates from phyllites with relative standard deviations > 1% were excluded from the calculation of the average standard deviations. The errors for the potassium determinations are arbitrarily enlarged by 0.002 wt.% to allow for possible systematic error. All K–Ar dates, including those cited from the literature, were calculated using the IUGS-recommended constants (Steiger and Jäger, 1977). The given errors represent the 95% confidence intervals of the intra-laboratory precision. Our K–Ar date for the standard glaucony GL-O is 1% younger than the average value of the compilation of Odin (1982).

Analytical results

Radiometric dating of the autochthonous units

Published K–Ar and Rb–Sr mineral dates for the autochthonous FG and MO sensu stricto units exclusively pointed to Carboniferous ages, in most cases indistinguishable from those of the post-kinematic granites (e.g., Carl et al., 1985) (for a Carboniferous time scale see Hess and Lippolt, 1986). Nevertheless, Stettner (1980) (and in Mielke and Stettner (1984), p. 9) invokes a pre-Late Devonian deformation and metamorphism. In order to check this idea, hornblendes from the rare amphibolites and muscovites from phyllites and gneisses well away from the contact aureoles of the young granites were analyzed. The most promising area for detecting a pre-Late Carboniferous metamorphic event seemed to be the downthrown block of the western Fichtelgebirge (Figs. 1 and 2). In the presentations of the results (Table 1 and Fig. 8), the dates for the block of the western Fichtelgebirge are at the top of the roughly N–S profile which trends across the eastern FG crystalline complex and from the ZTM to the MO sensu stricto. For comparison, published Rb–Sr isochron dates and K–Ar mica dates for post-kinematic granites are also given in Fig. 8.

The Fichtelgebirge (FG) crystalline complex

In the FG anticline metapelites and metapsammites predominate. The common assemblage in the phyllites of the western and northeastern areas is muscovite + chlorite + quartz ± albite. Chloritoid schists with the following paragenesis occur in a restricted area of the western Fichtelgebirge: Chloritoid ($Fe_{85}Mg_{12}Mn_3$) + chlorite + muscovite + quartz + plagioclase (An_{14}) (compositions from microprobe data of sample FG 752).

As expected, the three phyllites from the Steinach Valley (part of the western Fichtelgebirge downthrown block) yielded the oldest muscovite dates (330–325 Ma) which, however, are still Carboniferous dates. The chloritoid schist from the western Fichtelgebirge (Mausbach Valley), and the two phyllites from the northeastern Fichtelgebirge (Perlenhaus) gave muscovite dates of between 320 and 316 Ma, which are indistinguishable from the oldest dates for the first post-kinematic granite, G1 (Fig. 8).

Two metamorphics from Schatzbach, northeast of Selb, gave the same dates. The fine- to medium-grained rocks of Schatzbach contain phenocrysts of microcline, orthoclase and quartz. Albitized microcline also occurs. Muscovites from a muscovite–biotite gneiss (a) and a muscovite–biotite schist (b) both yielded ages of 316 Ma. The mineral parageneses are: (a) muscovite + biotite + quartz + K feldspar + plagioclase, and (b) muscovite + biotite + quartz + plagioclase. However, the biotites of these two rock samples (306–302 Ma) reveal younger influences, probably those involving reheating by the younger granites.

The four analyzed samples of the Wunsiedler Gneis are augen and flaser gneisses composed of quartz + orthoclase, microcline + plagioclase + muscovite + biotite. They often have phenocrysts of orthoclase, plagioclase and quartz. Locally, remnants of garnet are found, and in the northern part of the massif sillimanite occurs in some places. Sillimanite probably reflects the influence of contact metamorphism by the Weissenstadt–Marktleuthen granite (G1) in the north but was not detected in the two dated samples FG 704 and 739 from this area. Tourmaline, schorl with a dravite component, occurs in massive aggregates (up to 10 cm in diameter) mainly in the eastern and western rims of the gneiss (e.g., sample FG 704), but also in smaller aggregates and single crystals in the center of the gneiss.

The muscovite dates of the four Wunsiedler Gneis samples, which range from 310 to 298 Ma in age, can be related to the influence of the younger granites (G2–G4). The biotite dates range from 295 to 287 Ma; they approach the biotite ages of cooling and late hydrothermal activity of the young granites (Figs. 2 and 8).

These various later influences are a prominent feature of nearly all other samples from the Fichtelgebirge area. In some of them late modification is recorded by the growth of a biotite, usually green. It should be noted, however, that green biotite is also present in one of the amphibolites with a relatively old K–Ar date (Y 2, 330 Ma).

The other samples comprise two amphibolites from the Holenbrunn area. They both represent former basaltic dikes within the northern strip of Wunsiedler Marmor, and display the following mineral assemblage: light yellowish to bluish green amphibole + plagioclase + quartz ± chlorite ± olive-green biotite. The hornblende yielded dates of 330 and 310 Ma.

Two further hornblendes from schistose amphibolites from localities at and near Arzberg gave dates of 332 and 299 Ma. The amphibolites both consist of pale green hornblende + plagioclase + opaques.

Six other dates are as follows:

(1) Biotite (293 Ma) from Alexanderbad in a biotite gneiss with the paragenesis olive green biotite (+muscovite) + quartz + plagioclase.

(2) Muscovite (313 Ma) from the southern strip of Wunsiedler Marmor near Dechantsees in a muscovite–quartz marble with the assemblage muscovite + quartz + calcite.

(3) Biotite (293 Ma) from the Waldershof Metavolcanic Massif in a cataclastic metadacite with phenocrysts and the paragenesis quartz + orthoclase + microcline + muscovite, sericite + biotite + plagioclase.

Three total-rock dates of 299, 297 and 290 Ma from the borehole at Neusorg (Höll) were obtained in phyllites with the assemblage muscovite + albite + quartz ± biotite. Sample Höll 10 contains a Ti- and Fe-rich, partly chloritized biotite, predominantly within muscovite, whereas the biotite of sample Höll 13 is yellow–green and highly chloritized.

The only mineral dates of the central and eastern Fichtelgebirge which appear to be older than those of the post-kinematic granites are the hornblende dates of 330 ± 4 and 332 ± 6 Ma from two samples from Holenbrunn and Arzberg, respectively.

The other amphibolite from Holenbrunn yielded a hornblende date of 310 ± 5 Ma which is intermediate between the intrusion and cooling ages of the G1 and G2–G4 granites of the Fichtelgebirge. The second amphibolite sample from near Arzberg (Flitterbach Valley) is from an occurrence close to a small granite apophysis. Its K–Ar hornblende date of 299 ± 5 Ma matches the intrusion age of the young granites.

Tirschenreuth–Mähring Zone (ZTM)

The two investigated schistose and striped amphibolites from the southern rim of the ZTM (Fig. 3), southwest of Mähring, contain the assemblage brown edenitic to magnesiohornblende + plagioclase (An_{35}–An_{45}) + diopsidic clinopyroxene + opaques + sphene ± garnet. The date of 359 ± 6 Ma for one of these samples is caused by excess argon, as is demonstrated by a roughly U-shaped pattern of $^{39}Ar/^{40}Ar$ step dates with a youngest one of 324 ± 5 Ma. The other sample from nearby gave a date of 322 ± 4 Ma, which is consistent with the fairly concordant dates from five hornblendes from the immediately adjacent MO (mean, 318 ± 3 Ma). Carl et al. (1985, Tables, 1a and 8) report a wide range of muscovite dates from 330 to 298 Ma for samples from the Höhensteinweg mine (see also Fig. 3). The inconsistency is found over a few meters and even within different size fractions of the same sample, depending on the rock type. The single granitic sample analyzed in the present study gave a mean biotite date of 315 ± 1.5 Ma.

Moldanubian (MO) sensu stricto

The dated rocks were two schistose and striped amphibolites from near Griesbach with the same mineral assemblage as those from the ZTM, and three schistose amphibolites from two different outcrops near Hermannsreuth. The two amphibolite samples from the Weisse Marter, northeast of Hermannsreuth, are composed of brown hornblende with olive green cores + plagioclase + sphene + opaques. One sample also contains clinopyroxene. The hornblende dates range from

319 to 314 Ma. As mentioned above, they are fairly concordant within the occasionally large errors.

Considerably older, but still Carboniferous hornblende dates of 338 and 344 Ma were obtained from two amphibolites collected 15 km to the south at Lesslohe, northeast of Pleystein. The assemblage of these samples is brown to olive green hornblende + plagioclase + sphene + opaques ± biotite ± secondary chlorite.

Additional K–Ar mineral dates on two hornblendes, eight muscovites and 25 biotites from the Bavarian MO further to the south are given in Table 2. The range is similar to that of the northern border zone of the MO and the adjacent Saxothuringian. Three dates are around 330 Ma. The majority scatter unevenly around 320 Ma, and there is a faint tail towards 290 Ma, in mainly granitic samples.

Radiometric dating of the nappe units

The Tepl–Taus Zone (ZTT) (Teplá-Domažlice Zone)

In contrast to the MO sensu stricto the ZTT, which is regarded as a nappe unit (Weber and Vollbrecht, 1986) yielded Devonian and pre-Devonian K–Ar mineral dates (Vejnar, 1962; Šmejkal and Melková, 1969; Gottstein, 1970). In its southern extension in Bavaria (Hoher Bogen in Fig. 1) Fischer et al. (1968) determined an Early Devonian hornblende date of 392 ± 12 Ma for the gabbro–amphibolite massif at Neukirchen a.h. Blut.

The crystalline nappes of the Münchberg nappe pile (MM)

The Hangendserie Amphibolites and banded hornblende gneisses predominate in the Hangendserie of the MM. There is a gradual transition between these two rock types which both consist of olive green to bluish green (tschermakitic to magmesio-) hornblende + plagioclase (An_{18}–An_{35}) + quartz + rutile (partly replaced by sphene) ± almandine-rich garnet ± zoisite.

Hornblende concentrates from eleven samples (eight amphibolites, one banded hornblende gneiss, one hornblendite and one eclogite–amphibolite) from nine localities were analyzed. The five oldest dates cluster around a weighted mean age of 379 ± 2.5 Ma. There are five slightly younger dates which, together with samples from the older group, may represent a tail of partially rejuvenated samples or possibly form a distinct, slightly younger group with a weighted mean date of 372 ± 2.5 Ma. The possible younger group comprises all four samples from Seulbitz but also one from Oberkotzau. The single remaining hornblende date of 345 ± 4 Ma is significantly younger than all the others which we determined from the Hangendserie, as well as from all the other units of the MM (Table 3).

In addition to the hornblendes, two muscovites (3T polytype) were analyzed from muscovite-rich schlieren in the eclogite (light variety) exposed in a clay pit north of Oberkotzau. Sieve fractions prepared from each sample yielded significantly differing dates of 388 ± 2 Ma for the coarse fractions and of 382–379 ± 3 Ma for the fine ones (Table 3). (Another observation—so far not explained—is that the concentrations of atmospheric argon are relatively high and different for different sieve fractions of the same sample.) The younger muscovite dates are consistent with those of the older group fo hornblendes from the Hangendserie.

The Liegendserie This series mainly consists of gneisses with the assemblage quartz + albite + K feldspar + muscovite ± biotite. Metamorphic minerals in the embedded bodies with well-preserved relict igneous minerals and textures are palegreen hornblende, sodium-rich plagioclase, zoisite, garnet and rutile in metagabbros, and muscovite and garnet in metagranites.

K–Ar dating was performed on several muscovites and one biotite from five gneiss samples from three localities, on hornblendes from three samples of the Steinhügel metagabbronorite from near Höflas and on muscovites and biotites from two samples of the Gareisen metagranodiorite from west of Weickenreuth. All but one of the hornblendes and all the muscovites gave concordant ages of between 383 and 378 Ma with a weighted mean age of 381 ± 1 Ma, whereas the apparent dates of the biotites (positively magmatic relics in the case of the granodiorite) are generally slightly older (Table 3).

The Randamphibolit-Serie This series comprises massive, striped and schistose amphibolites with the assemblage lightbrown to olivegreen (tschermakitic, magnesio-, ferro-) hornblende + plagioclase (An_{33}–An_{40}) + sphene ± grossular-rich almandine ± augite (in one sample). Actinolitic hornblende, albite, chlorite, and at least some of the epidote are retrograde. Strong cataclastic deformation is a typical feature of these amphibolites.

Six amphibolites and five garnet amphibolites from seven localities were prepared for K–Ar analysis. The hornblende dates (Table 3) cover a wide interval from 408 to 372 Ma. Figure 6 shows that they tend to fall into two clusters, one of four samples having a weighted mean date of 401 ± 4 Ma, the other of six samples with ages of 384 ± 3 Ma, and a single sample of 372 ± 6 Ma. However, since the analytical uncertainties amount to half of the differences between the three mean values, a more-or-less continuous reset and/or excess pattern cannot be ruled out.

The Prasinit–Phyllit-Serie Metavolcanics occur in this series, with the greenschist facies assemblage actinolite + epidote + chlorite + albite + quartz. Also present are intercalated quartz-rich metapelites with the assemblage quartz + albite + muscovite + chlorite ± garnet + graphite.

Muscovite-enriched fractions from seven phyllites from five localities were dated. Six of these samples yielded fairly concordant K–Ar dates between 369 and 364 Ma with a mean value of 366 ± 2 Ma. One date is slightly younger (358 ± 3 Ma). These dates rectify data in a previous abstract by Kreuzer et al. (1986) in which we plotted two significantly older but spurious dates based on an erroneous series of potassium determinations.

The Erbendorf–Vohenstrauss Zone

The ZEV (Fig. 5) contains two main types of amphibolites. The flaser amphibolites are con-

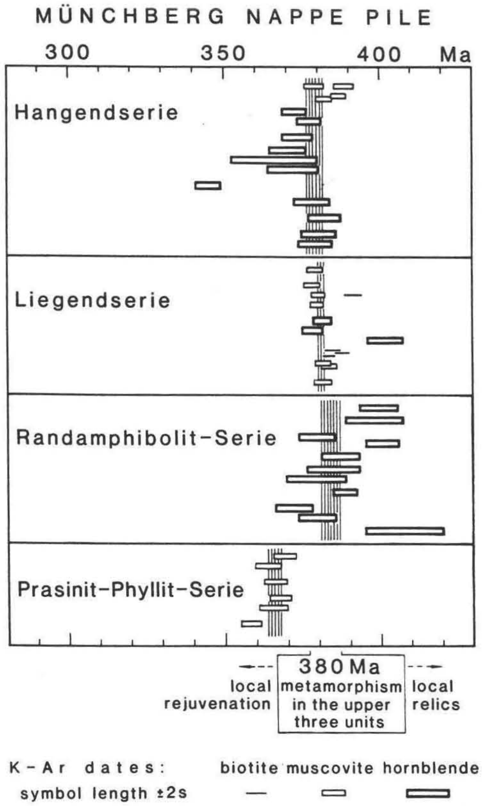

Fig. 6. K–Ar dates from the Münchberg nappe pile. The samples from each subunit are arranged from north to south (from top to bottom), as in Table 3. The length of a symbol represents the analytical precision at the 95% intra-laboratory confidence level. The ruled background marks the precision of the weighted mean of a cluster of dates.

centrated in the northern and central parts of the ZEV. They consist of olive green to olive brown (ferroan pargasitic to edenitic and tschermakitic to magnesio-) hornblende + plagioclase (An_{25}–An_{35}) ± garnet + sphene + apatite + ilmenite + sulfides.

The dominant types in the southern ZEV are schistose and striped amphibolites with the assemblage yellow (edenitic to magnesio-) hornblende + plagioclase (An_{35}–An_{65}) + ilmenite + sulfides + sphene + apatite.

Another, more massive type of amphibolite, is transitional between the schistose and striped amphibolites, and the flaser amphibolites.

For radiometric dating, 33 amphibolite samples, collected from 28 different localities, were selected. The results, listed in Table 4 and Fig. 7, show that no systematic differences exist between the individual amphibolite types. On the other

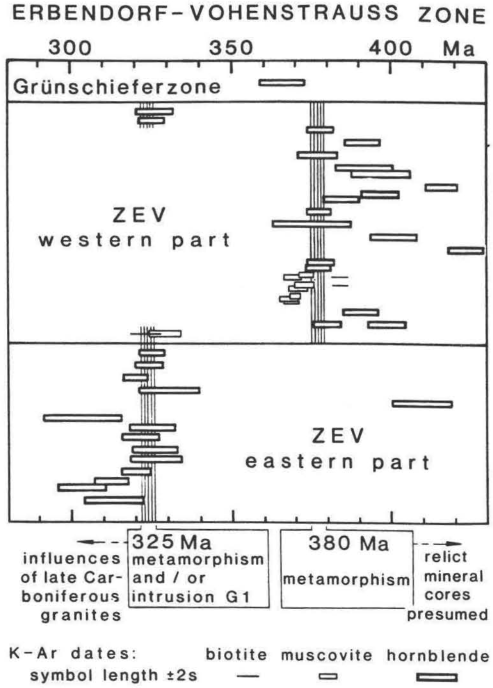

Fig. 7. K–Ar dates from the Erbendorf–Vohenstrauss Zone. The samples from each subunit are arranged from north to south (from top to bottom), as in Table 4. The length of a symbol represents the analytical precision at the 95% intra-laboratory confidence level. The ruled background marks the precision of the weighted mean of a cluster of dates.

hand, two different groups of hornblende dates can be distinguished, pre-Carboniferous and mid- to late Carboniferous. These exhibit a clear regional distribution:

(1) In the western part of the ZEV, fifteen hornblende dates range between 401 and 375 Ma. As with the Randamphibolit-Serie of the MM, two significantly different clusters of dates are recognized; eight dates range from 384 to 375 Ma with a weighted mean age of 378 ± 2 Ma, and the remaining seven dates range from 401 to 391 Ma. Two samples yielded distinctly older dates of 416 and 424 Ma.

The interpretation of the younger group of hornblende dates around 378 Ma as a realistic geological age is supported by only slightly younger muscovite dates. Two hornblendes from the Oedenthal quarry yielded dates of 377 Ma. Ten different concentrates of muscovites extracted from two garnet–muscovite–biotite–plagioclase gneisses and from a leucogneiss gave slightly discordant values of 373–366 Ma. Remarkably, the slight discordance of the muscovite dates is supported by even older dates for the coexisting biotites, namely 385–384 Ma.

(2) The second, the late Carboniferous group of fifteen distinctly younger hornblende dates ranging between 330 and 303 Ma, is predominantly confined to the eastern part of the ZEV. Only two samples in this group were collected from the western ZEV. All amphibolites containing hornblendes of the younger group, except sample OP-84-8, are spatially related to the granite intrusions, although textural evidence that thermal metamorphism has affected these amphibolites is scarce. On the other hand, most of these younger amphibolites are also situated close to the border zone between the ZEV and the MO sensu stricto. One amphibolite sample (OP-84-49) collected close to the contact of the Leuchtenberg granite yielded 410 Ma and may contain excess argon.

The Erbendorf Greenschist Zone (EGZ)

So far, only one metagabbro consisting of bluish green hornblende, plagioclase and opaques has been dated. It gave a hornblende date of 365 ± 7 Ma, which is slightly younger than the youngest hornblende dates in the pre-Carboniferous age groups for the western ZEV. It is the same as the mean muscovite date for phyllites from the Prasinit–Phyllit-Serie of the MM which also resembles the EGZ in geochemistry and tectonic position.

In contrast, two concentrates of biotite intergrown with vermiculite from blackwall samples collected in the steatite quarry between Erbendorf and Grötschenreuth yielded dates of 271 and 265 Ma, which are distinctly younger than the biotite dates for the Steinwald granite (304–296 Ma) (Wendt et al., 1988) in the north and the Falkenberg granite (mainly 300 Ma) (Wendt et al., 1986) in the east. The geological significance of the biotite–vermiculite dates is uncertain.

Discussion

The majority of our mineral dates fall into two distinct groups, one around 380 Ma, i.e. Early Devonian, and the other one around 320 Ma, i.e.,

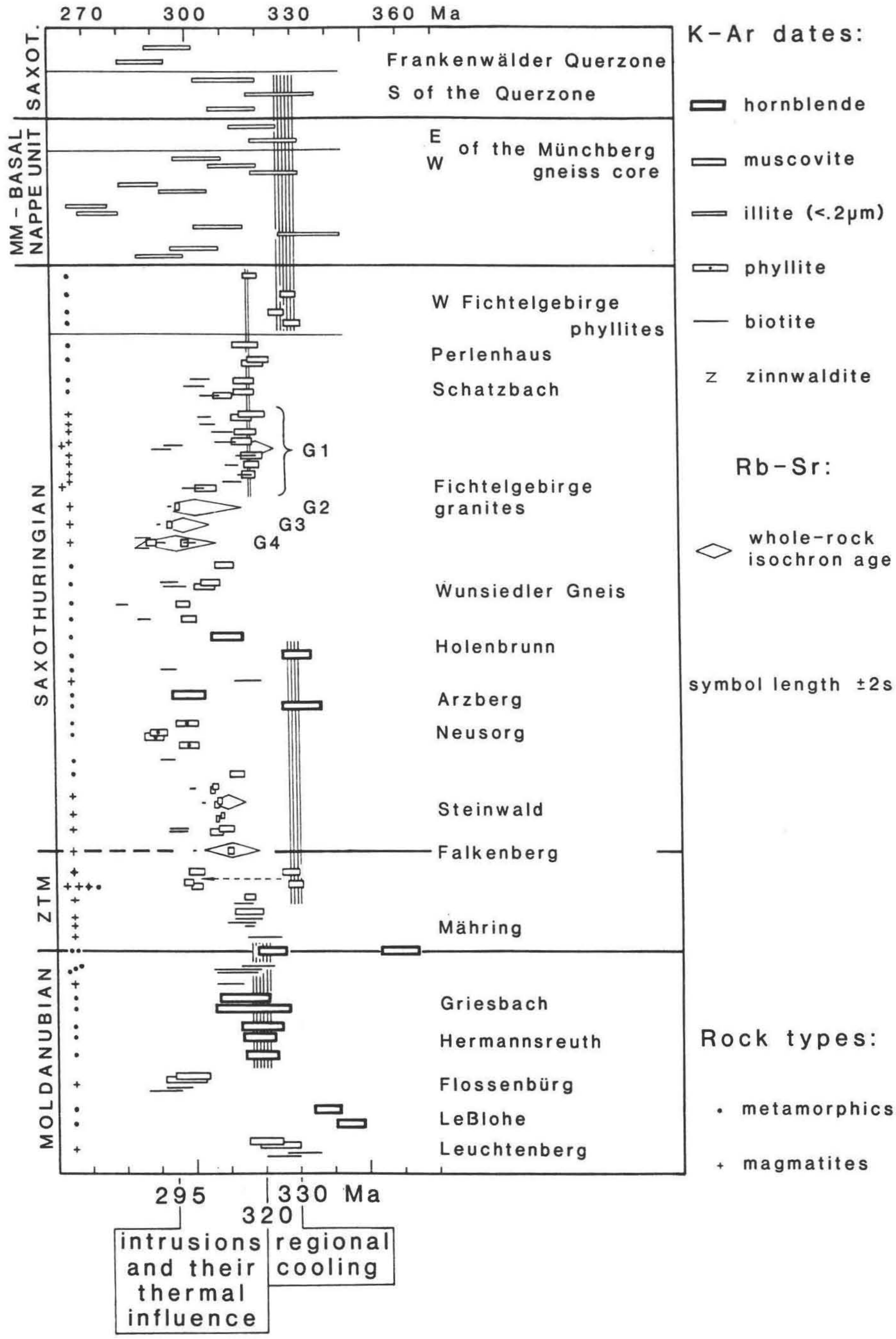

Fig. 8. K–Ar dates from the autochthonous Fichtelgebirge and the adjacent Moldanubian. The samples are arranged roughly from north to south (from top to bottom), as in Table 5, with the western downthrown block of the Fichtelgebirge at the top of the Fichtelgebirge section. Additional dates: fine fractions of illites (Ahrendt et al., 1986), micas (Carl et al., 1985), Rb–Sr whole-rock and mean values for micas in granites (Besang et al., 1976: Wendt et al., 1986, 1988). The length of a symbol represents the analytical precision at the 95% intra-laboratory confidence level. The ruled background marks the precision of the weighted mean of a cluster of dates. The single apparent age of about 360 Ma is recognized as being caused by excess argon.

mid-Carboniferous. The older dates are exclusively found in the nappe units, namely in the MM and in the western part of the Erbendorf–Vohenstrauss Zone. The younger dates occur in the autochthonous units (the Fichtelgebirge, the ZTM, and the MO sensu stricto), as well as in the lowermost thrust sheet of the MM (Ahrendt et al., 1986) and in the eastern part of the ZEV. Each group covers a wide range of dates. When one considers that considerable areas have been affected by imbrication, large-scale folding, contact metamorphism and late block faulting, only a rough interpretation of the age patterns can be given. In particular, the mean values for clusters of dates for a tectonic unit and the corresponding error estimates (the ruled areas in Figs. 6, 7 and 8) characterize the center of the cluster rather than being a precise age estimate for all parts of the respective unit.

Nappe units

The Münchberg nappe pile (MM)

Despite the relatively wide scatter of mineral dates, a geological event around 380 Ma seems to be established by clusters of similar dates obtained from hornblende and muscovite in the upper two crystalline nappes, and from just hornblende in the next lower one (Fig. 6) (see also Müller-Sohnius et al., 1987).

In the Hangendserie, half of the analyzed hornblendes and the fine fractions of two of the 3T muscovites from eclogites substantiate the 380 Ma event; the other hornblendes, which include a lowest date of 345 ± 4 Ma, seem to be partly reset.

In the Liegendserie, almost all hornblende and muscovite dates group around 380 Ma within the limits of analytical uncertainty. The biotite dates tend to be somewhat older, suggesting that they contain excess argon picked up during a moderate later thermal event.

Six of the eleven hornblende dates from the Randamphibolit-Serie are consistent with a weighted mean value of 384 ± 3 Ma. However, there are four older dates which form a distinct group at 401 ± 4 Ma, as well as a single younger date of 372 ± 6 Ma. The fact that the mean ages of the two clusters of dates show almost the same grouping as those from the western ZEV helps to demonstrate that they are geologically significant; this is supported by U–Pb dating on monazites and zircons (Teufel, 1988). Additional support is expected from ^{39}Ar–^{40}Ar analyses on the hornblendes.

At present, we interpret the Early Devonian dates as a minimum age for the medium-pressure amphibolite facies metamorphism which clearly post-dates the older high-pressure metamorphism recorded in the eclogites. It should be noted, however, that Müller-Sohnius et al. (1987) arrive at a different interpretation.

Sm–Nd and Rb–Sr whole-rock–mineral isochrons for both types of eclogites yielded 395 Ma with uncertainties of ± 4 and ± 5 Ma. This age is interpreted as the time of the earlier high-pressure event (Stosch and Lugmair, 1986, 1987). The date of 388 Ma obtained for the coarse fractions of 3T muscovites from the Oberkotzau eclogite lies between the two events at 395 and 380 Ma. Detailed insight into this problem is expected to be gained from the results of the current ^{39}Ar–^{40}Ar investigations.

Six of seven muscovite dates on the Prasinit–Phyllit-Serie range from 368 to 364 Ma. The samples were taken from five widely separated localities. The same date was also determined for the single hornblende analyzed from the EGZ which in its tectonic position and in geochemical affinities resembles the Prasinit–Phyllit-Serie. Therefore, these nappe units appear to have suffered a Late Devonian thermal or tectonic overprint. The slight discordance in the cluster of muscovite dates and the single younger date of 358 Ma might be explained by partial resetting during nappe thrusting which perhaps also may find its expression in the slightly increased biotite dates (excess argon) of the Liegendserie and in the reset hornblende dates of the Hangendserie. The youngest of these hornblende dates is 345 ± 4 Ma, which is compatible with the fact that Lower Carboniferous sediments, ranging up to the Late Visean in age, form part of the nappe pile since they occur in the lowermost tectonic unit of the MM.

This lowermost nappe, like the autochthonous units of the Saxothuringian and MO, reveals mid-Carboniferous to Early Permian phases of formation, cooling and/or rejuvenation. Fine fractions of metapelites and metatuffites from the Bavarian lithofacies east and west of the Münchberg Gneiss Massif and of the adjacent Saxothuringian to the north yielded, at maximum, dates around 325 Ma. Rejuvenation is observed in the form of youngest dates of 280–270 Ma as one approaches the Frankonian Line fault zone to the west and the slightly higher grade metamorphic Frankenwälder Querzone to the north (Ahrendt et al., 1986).

The Erbendorf–Vohenstrauss Zone (ZEV)

In the *western part* of the ZEV slightly discordant muscovite dates (maximum values around 373 Ma) from a single outcrop indicate the end of a regional metamorphic event at this time (Fig. 7). Nearly half of the hornblendes yield slightly older concordant dates around 380 Ma. The existence of an Early Devonian regional metamorphic event in the ZEV is corroborated by concordant U–Pb dates of 378 Ma on monazites from garnet–kyanite gneisses (Teufel et al., 1985; Teufel, 1988). However, there is a considerable scatter of hornblende dates to higher values: 401–391 Ma, and two dates of 416 and 424 Ma. These groups of older dates can be explained in two ways:

(1) Excess argon was picked up by some of the amphiboles during a later low-temperature metamorphic event. The slightly inconsistent muscovite dates from the Oedenthal quarry and the existence of biotites with apparent ages which make them seem older than coexisting muscovites support this explanation.

(2) Inherited argon is present in some of the amphiboles, owing to the fact that the medium-pressure metamorphism in the ZEV was a protracted event or was polyphase, possibly beginning with granulite facies conditions. This explanation is supported by a lower intercept age of 391 Ma for zircons from garnet–kyanite gneisses (Teufel et al., 1985; Teufel, 1988), as well as by textural evidence: Garnet in the flaser amphibolites is partly replaced by fine-grained aggregates of plagioclase and hornblende which are younger than the surrounding amphibolitic matrix (Schüssler, 1987).

It may be easier to choose between these two alternatives when ^{39}Ar–^{40}Ar dating has been carried out.

In the *eastern part* of the ZEV the majority of hornblende dates lie around 324 Ma, distinctly younger than in the west. These younger dates can be explained either by a regional metamorphic overprint contemporaneous with the low-pressure metamorphism in the neighboring MO sensu stricto or by thermal influence due to the Leuchtenberg granite, which was intruded about 324 m.y. ago (Köhler et al., 1974; Köhler and Müller-Sohnius, 1976a; Harre et al., 1968, in Carl et al., 1985), and later granites. Since this granite complex forms a sheet dipping to the east (Bücker and Soffel, 1986), the thermal effects would not have extended to the country rocks on the western contact. The strongest influence of the Leuchtenberg granite is seen in the Steinach aureole on the southern and southeastern border of the intrusion (Voll, 1960; Okrusch, 1969). On the other hand, replacement of regional metamorphic garnet by younger biotite in a micaschist (Moldanubian diaphthorite) near the *western* contact at Schmelzmühle, Luhe Valley, is attributed to the thermal influence of the Leuchtenberg granite (Okrusch (1969), fig. 3). This conforms with the fact that a muscovite–biotite pair from the garnet–kyanite gneiss in the old Michldorf quarry near the southwestern contact of the Leuchtenberg granite yielded young ages (Harre et al., 1968, in Carl et al., 1985).

One of the two young hornblende dates from the western part of the ZEV almost certainly reflects contact metamorphism by the 310 Ma old (Wendt et al., 1986) Falkenberg granite, whereas the other young hornblende is from an outcrop far away from this granite.

The autochthonous units

The Fichtelgebirge

Our attempts to date the regional metamorphism in the Fichtelgebirge area revealed only a few dates which exceed the age of the intrusion of the oldest post-kinematic granite in this area (G1, 319 ± 6 Ma (Lenz, 1986) and even these few are no older than the mid-Carboniferous (Fig. 8): Two hornblendes from amphibolites of the central and eastern Fichtelgebirge gave 330 ± 5 and 332 ± 6 Ma and three phyllites from the western downthrown block yielded a slightly discordant set of muscovite dates, i.e., 330, 329 and 325 ± 2.5 Ma. All other dates are indistinguishable from those of the G1 and the younger G2–G4 granite intrusions. This holds true even for samples collected far away from the exposed granite contacts, which show no traces of contact metamorphism. However, although the K–Ar method has so far failed to detect the main pre-Carboniferous regional metamorphism of the FG crystalline complex, deduced by Stettner (1980) from structural considerations, its existence is not completely ruled out:

Firstly, Ludwig (1968) described deformed and partly low-grade metamorphic clasts within a presumably Lower Carboniferous flysch from a small sedimentary wedge on the southern margin of the Fichtelgebirge. The lower parts of the wedge are fossiliferous Late Devonian sediments, and the deformed, partly metamorphic clasts of the flysch are considered to have been derived from Paleozoic Saxothuringian rocks a short distance away.

Secondly, the recent discovery of kyanite in a metapelitic schist from the northern Fichtelgebirge suggests that these low-pressure metamorphic rocks were previously metamorphosed under medium-pressure conditions (Lenz et al., in prep.).

Stettner (1964) deduced two distinct phases of post-kinematic granite intrusion in the Fichtelgebirge:

The G1 granite was intruded at a relatively deep level during the post-kinematic (post-Sudetian) uplift and unroofing. The associated aplitic and pegmatitic dikes were already emplaced at much shallower depths.

The fine-grained matrix of the porphyritic G2 granite indicates an intrusion into cool country rocks and hence implies a later period of emplacement. The subsequent G3 and G4 granites are medium grained and were therefore intruded into a warm environment.

The mineral dates fully confirm this (Carl et al. (1985), table 1):

Uplift of the Fichtelgebirge late in the early Carboniferous is indicated by occasional cooling ages, between 332 and 320 Ma, of hornblendes and muscovites from the metamorphic rocks. This range of 12 Ma may be partly due to different erosion levels caused by later block faulting, and partly due to thermal influence of the granites.

Rapid uplift and unroofing of the 319 ± 6 m.y. old G1 granite is radiometrically confirmed by a few biotite dates of 317–316 Ma, nearly concordant with muscovites and close to the intrusion age. A gap of about 20 Ma between the G1 granite on the one hand and the G2–G4 granites on the other has been established by Rb–Sr whole-rock dating (Besang et al., 1976) (Fig. 8). The frequent occurrence of reset or mixed mineral ages of less than 316 Ma in older country rocks demonstrates the widespread thermal influence of the younger granites. This conforms with the inference that G3 and G4 granites were intruded into reheated country rocks.

In the southern Fichtelgebirge and at the border with the Moldanubian, the succession of granite intrusions is more complex. Granites which reveal a similar geochemical evolution to the G1–G4 granites (Richter and Stettner, 1987) were intruded within a shorter time interval between 311 ± 8 Ma (Falkenberger Granit) (Wendt et al., 1986) and 310 ± 5 Ma (transitional type Friedenfels-Steinwald Granit) (Wendt et al., 1988, Fig. 8).

The Tirschenreuth–Mähring Zone (ZTM) and the Moldanubian (MO) sensu stricto

Six of nine amphibole dates from the ZTM and the adjacent MO sensu stricto cluster around 320 Ma, an age which has already been established by concordant U–Pb ages (325–320 Ma) of monazites (Teufel et al., 1985; Teufel, 1988). These authors relate the concordant monazite ages, consistently recognized over large areas of the MO realm (e.g., Grauert et al., 1974), to the waning stage of the low-pressure metamorphism during which the rocks cooled to temperatures of about 530 ° C; (in contrast, a concordant monazite age of 320 Ma from the muscovite–sillimanite zone of the Saxothuringian is assumed to be close to the culmination of the metamorphism of the lower grade metamorphic Saxothuringian rocks of the Fichtelgebirge). Single muscovite and biotite ages around 310 Ma are interpreted as the age of cooling of the low-pressure metamorphic rocks to the blocking temperatures of micas. The latter interpretation, favored also by Ahrendt et al. (1986), ignores the fact that there are several mica dates older than 310 Ma, even some concordant muscovite–biotite pairs, and single white mica dates close to 330 Ma (Carl et al., 1985) (Fig. 8, Table 2). Admittedly, biotite dates in the northern

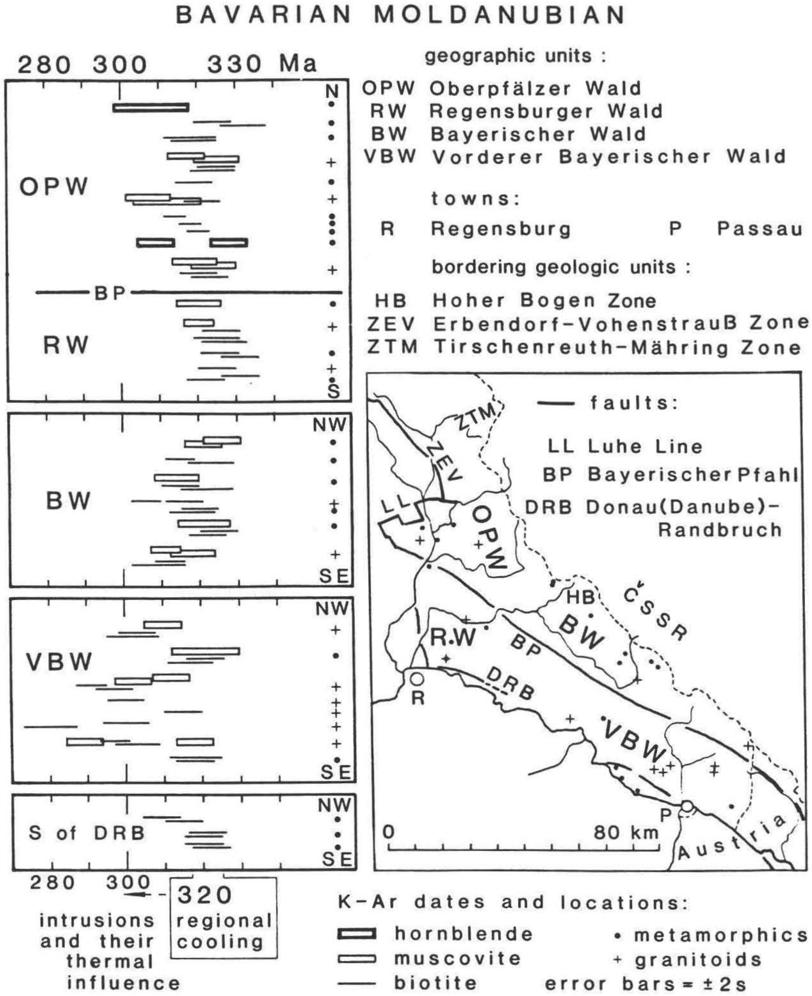

Fig. 9. K–Ar dates along schematic profiles across geographic units in the Bavarian Moldanubian. From top to bottom: hornblende sample H1 (Fischer et al., 1968) and the dates of Harre et al. (1967), given by Carl et al. (1985, table 8, Nos. 128, 123, 124, 122 and 27) and in this paper (Table 2). In the sketch map, the northern margin of the Moldanubian is marked by the *ZEV* and the *ZTM*.

Moldanubian frequently appear to be older than those of coexisting muscovites and thus point to the presence of excess argon in many of these "older" biotites. However, the relatively consistent groups of muscovites dates, partly around 330 Ma, partly around 320 Ma, show that regional uplift and cooling to about 400°–300°C took place in all parts of the autochthonous units of the northwestern, the western and the southwestern margins of the Bohemian Massif during the late early Carboniferous (Figs. 8 and 9).

Meanwhile, the single apparent date of about 360 Ma for a hornblende from Mähring is recognized as being caused by excess argon. The two condordant dates of 340 Ma from the MO near Lesslohe cannot be interpreted unless we can distinguish between inherited and excess argon.

Conclusions

In the allochthonous units of the northwestern margin of the Bohemian Massif, the metamorphic rocks of the Münchberg Massif and of the western part of the Erbendorf–Vohenstrauss Zone document an Early Devonian event: K–Ar dates around 380 Ma probably indicate the end of the regional metamorphism under medium-pressure amphibolite facies conditions.

In contrast, the lowermost nappe unit of the Münchberg nappe pile and the eastern part of the Erbendorf–Vohenstrauss Zone reveal the same late thermal history as the autochthonous Saxothuringian and the adjacent Moldanubian low-pressure metamorphic units, which yielded almost exclusively mid- to late Carboniferous dates. The oldest of these dates (330–320 Ma) marks a regional metamorphic event in the early Carboniferous, immediately followed by the intrusion of the first post-kinematic Variscan granites. Numerous radiometric dates from the Moldanubian sensu stricto also indicate that the latest regional event, a low-pressure metamorphism, ceased around 330–320 m.y. ago (Davis and Schreyer, 1962; Harre et al., 1967 (also see this paper, Table 2); Fischer et al., 1968; Gebauer and Grünenfelder, 1973; Grauert et al., 1974; Köhler and Müller-Sohnius, 1976b; Schulz-Schmalschläger et al., 1984; Carl et al., 1985; Teufel et al., 1985; Teufel, 1988).

In the Fichtelgebirge and in the northern part of the Moldanubian, the first post-tectonic granites were intruded around 320 Ma during rapid uplift and unroofing. Scattered dates down to 300 and 295 Ma are frequent. They reflect the thermal influence of later granite pulses during the late Carboniferous and earliest Permian.

The youngest dates of 280–270 Ma can partly be related to fault zones (the Frankonian Line) or post-magmatic hydrothermal activity (e.g., in the Zinngranit (tin granite), granite G4 of the Fichtelgebirge).

Our radiometric results clearly support the model of the allochthony of the Münchberg nappe pile and the Erbendorf–Vohenstrauss Zone: These units comprise medium-pressure metamorphic rocks of Early Devonian age surrounded by geological units which experienced a markedly younger, low-pressure metamorphism and related plutonism at the early–late Carboniferous boundary.

In spite of the similarities in their late metamorphic history, it is not possible to make a straightforward correlation of the Münchberg nappe pile to the Erbendorf–Vohenstrauss Zone. The geochemistry of the metabasites in the individual nappes of the Münchberg nappe pile demonstrates that the original basalts were emplaced in distinctly different geotectonic environments, for which no equivalents are found in the Erbendorf–Vohenstrauss Zone (Okrusch et al., in press). Similarities exist only between the Prasinit–Phyllit-Serie of the Münchberg pile and the Erbendorf Greenschist Zone. The arguments for correlating these two nappes units are the close geochemical resemblance between th metabasites, the similar lithological associations of the two units, and their analogous tectonic positions.

The relative pre-thrusting positions of the tectonic units and subunits in space and time are so far unknown due to the lack of relevant age criteria. Only the time of final emplacement of the nappes can be given with reasonable precision—as Late Visean: This was a little later than the age of the youngest sediments present within the Münchberg nappe pile (also Late Visean) (Gandl et al., 1986), but earlier than the overprint by the low-pressure metamorphism and/or by the subsequent granite intrusions in the eastern Erbendorf–Vohenstrauss Zone dated at 330–320 Ma, i.e., earlier than the early–late Carboniferous boundary.

Acknowledgements

We are indebted to U. Oppermann and K. Pommerenke for providing some of the samples and for mineral separation, to H. Mielke and G. Stettner for some samples from the autochthonous units, to H. Klappert, Mrs. M. Metz, L. Thiesswald and D. Uebersohn for carrying out the K–Ar analyses, to J. Lodziak and D. Requard for the XRF analyses, and to K.-P. Kelber for preparing the schematic geological maps. We are grateful to W. Schreyer and G. Stettner for helpful discussions, to U. Vetter and an unknown referee for carefully reading the manuscript, and to H. Toms for correcting the English. The considerable financial support provided by the Deutsche Forschungsgemeinschaft, Bonn (grant Ok2/25-1), is gratefully acknowledged.

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