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Geochronology of the Spessart Crystalline Complex, Mid-German Crystalline Rise*

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With 6 Figures

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Summary

New Rb-Sr and K-Ar datings help to clarify the geologic history of the Spessart Crystalline Complex, Mid-German Crystalline Rise. The oldest dates, refined by new measurements, are recorded by whole-rock Rb-Sr analyses of the orthogneisses of the Rotgneiss Complex. These confirm a late Ordovician to Silurian age which is interpreted as the time of intrusion of the granitic precursors.

Hornblendes, muscovites. and biotites from different lithostratigraphic units and rock types of the Spessart Crystalline Complex yielded K-Ar dates mainly in the range 324 to 318 Ma, an interval which conforms to the analytical precision. Two hornblendes and one muscovite show slightly older dates up to 328 Ma. On the other hand, there is a tail of younger hornblende dates towards 311 Ma, and two hornblendes gave dates as low as 293 and 274 Ma for no immediately obvious reason.

The concordant dates around 324 Ma on the three different minerals may be interpreted as marking the time of a rapid uplift and cooling at about the boundary between Early and Late Carboniferous, presumably soon after culmination of the Variscan deformation and amphibolite facies metamorphism.

Zusammenfassung

Geochronologie des Spessart-Kristallins, mitteldeutsche Kristallinschwelle

Neue Rb-Sr- und K-Ar-Datierungen liefern einen Beitrag zum Verständnis der geologischen Geschichte des Spessart-Kristallins. Die älteste radiometrische Datierung, die

* Dedicated to Borwin Grauert on the occasion of his 60th birthday.

bislang im Spessart-Kristallin zur Verfügung steht, leitet sich aus Rb-Sr-Gesamtgesteinsanalysen von Orthogneisen des Rotgneis-Komplexes ab. Die bereits von früheren Bearbeitern gefundenen spät-ordovizischen bis silurischen Daten wurden durch neuere Messungen bestätigt. Sie werden als Intrusionsalter des granitischen Ausgangsmaterials der Rotgneise interpretiert.

Hornblenden, Muscovite und Biotite aus unterschiedlichen lithostratigraphischen Einheiten und Gesteinstypen des Spessartkristallins erbrachten K-Ar-Daten vorwiegend zwischen 324 und 318 Ma, d. h. einen Streubereich, der etwa der analytischen Genauigkeit entspricht. Zwei Hornblenden und ein Muscovit ergaben etwas ältere Daten bis 328 Ma. Auf der anderen Seite beobachtet man eine Reihe von jüngereren Hornblendedaten bis 311 Ma, und zwei Hornblenden von nur 293 und 274 Ma, die sich nicht ohne weiteres erklären lassen.

Die konkordanten Alterswerte um 320 Ma, die für die drei Mineralarten gewonnen wurden, können als die Zeit einer raschen Hebung und Abkühlung etwa an der Grenze Unter-/Oberkarbon interpretiert werden, die vermutlich bald nach dem Höhepunkt der variscischen Deformation und amphibolit-faziellen Metamorphose erfolgte.

Introduction

With the change from a fixistic to a mobilistic picture of the Variscan Orogen, the Mid-German Crystalline Rise—initially recognized by *Brandes* (1919) and later on defined by *Scholtz* (1930) and *Brinkmann* (1948)—has aroused renewed interest. This important structural element is now regarded as a suture zone where the Saxothuringian crystalline basement is thrusted upon the imbricated "Northern Phyllite Zone" and the anchimetamorphic Rhenohercynian (*Weber* and *Behr*, 1983; *Giese* et al., 1983; *Behr* et al., 1984; *Weber*, 1984, *Franke*, 1989), see Fig. 1. The new geological model received strong support by the fascinating results of deep-reflexion seismic recording along the profile DEKORP 2 south which exhibits a highly laminated upper crust with faulted and southeast dipping reflectors just below the Spessart Crystalline Complex (DEKORP Research Group, 1985; *Heinrichs*, 1986; *Behr* and *Heinrichs*, 1987).

One of the questions crucial to the geodynamic interpretation of the Mid-German Crystalline Rise is its metamorphic history. In this paper we present results of K-Ar dating on hornblendes, muscovites and biotites from various lithostratigraphic units of the Spessart Crystalline Complex which will give a minimum age of metamorphism. Another important event in the geological history of the Spessart is the intrusion of the granitic protolith of the Rotgneiss complex. The Rb-Sr whole-rock dates published by *Kreuzer* et al. (1973) and *Lippolt* (1986) are discussed in the light of new data.

Geological Setting

The Mid-German Crystalline Rise which extends in SW-NE direction from the Saar area to the Lusatia area is documented in several uplifted blocks, i.e. the crystalline complexes of Bergsträsser Odenwald, Böllstein Odenwald, Spessart, Ruhla and Kyffhäuser (Fig. 1). Major parts are hidden by a cover of Permian, Mesozoic and Cenozoic sediments.

Comprehensive reviews of the Spessart Crystalline Complex are given by *Matthes* and *Okrusch* (1977), *Okrusch* (1983) and *Hirschmann* and *Okrusch* (1988). The follow-

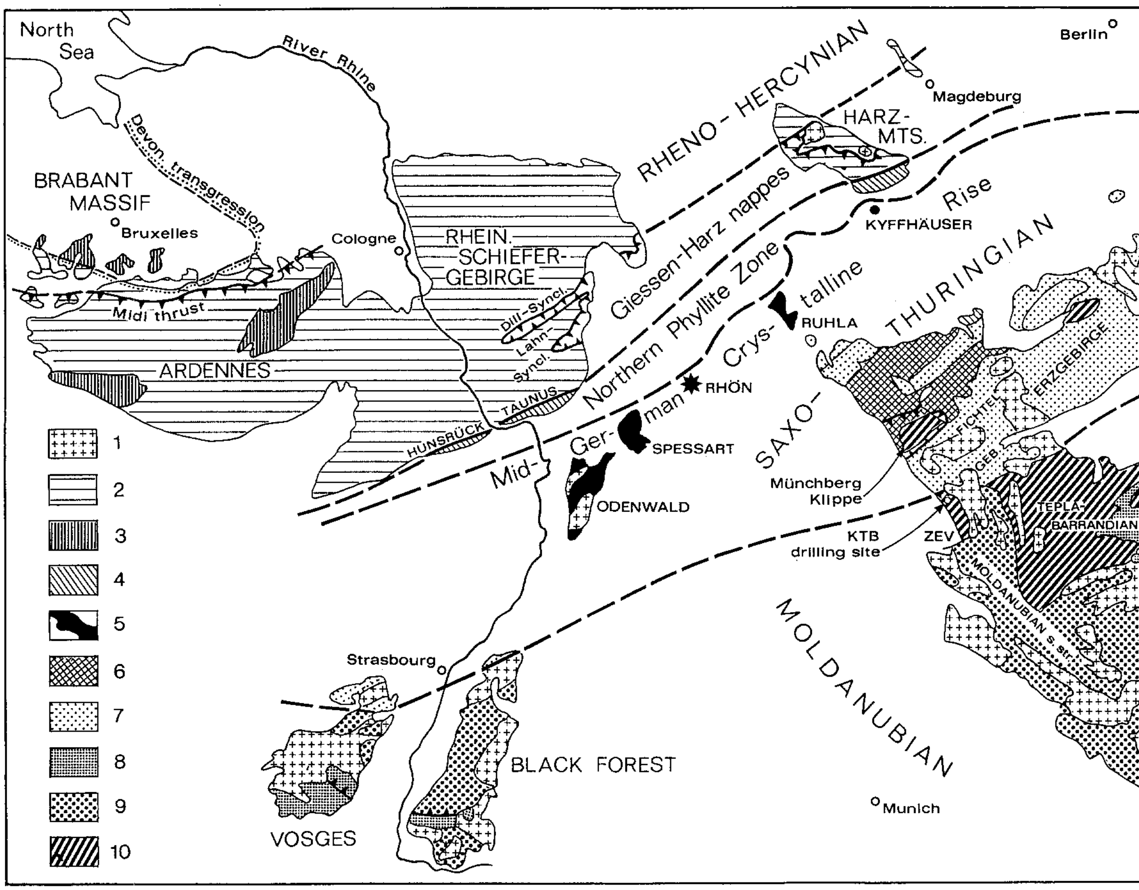

Fig. 1. Geological sketch map of the main tectonic units in the Central European Variscides (modified after *Franke*, 1989). Blank—Sedimentary cover of Permian, Mesozoic and Cenozoic age.

1 Variscan granites (largely post-tectonic).

Rhenohercynian Realm

2 Devonian and Carboniferous sedimentary and volcanic rocks with Variscan metamorphism of very low grade.

3 Pre-Devonian sedimentary, volcanic and plutonic rocks with Caledonian metamorphism of low grade.

Northern Phyllite Zone

4 Pre-Devonian sedimentary and volcanic rocks with Variscan metamorphism of low grade.

Mid-German Crystalline Rise

5 Precambrian to Silurian sedimentary, volcanic and plutonic rocks, with Variscan metamorphism of medium grade: Kyffhäuser, Ruhla, Rhön (metamorphic xenoliths in Tertiary volcanites), Spessart, Odenwald (Böllstein: NE part, Bergsträsser: main part).

Saxothuringian Realm

6 Devonian and Carboniferous sedimentary and volcanic rocks with Variscan metamorphism of very low grade.

7 Precambrian to Silurian sedimentary, volcanic and plutonic rocks with Variscan metamorphism of low, medium and high grade.

Moldanubian Realm

8 Paleozoic rocks, undifferentiated, in part slightly metamorphosed.

9 Moldanubian s. str., mostly polymetamorphic gneisses and migmatites, with rare eclogitic relics, last Variscan overprint under low-P/high-T conditions, about 325 Ma ago.

10 Münchberg crystalline nappes, Erbendorf-Vohenstrauss Zone, Teplá-Barrandian Zone; mostly polymetamorphic micaschists, gneisses and metabasites, in part with eclogitic relics, last metamorphic overprint under medium P/medium T conditions, about 380 Ma ago.

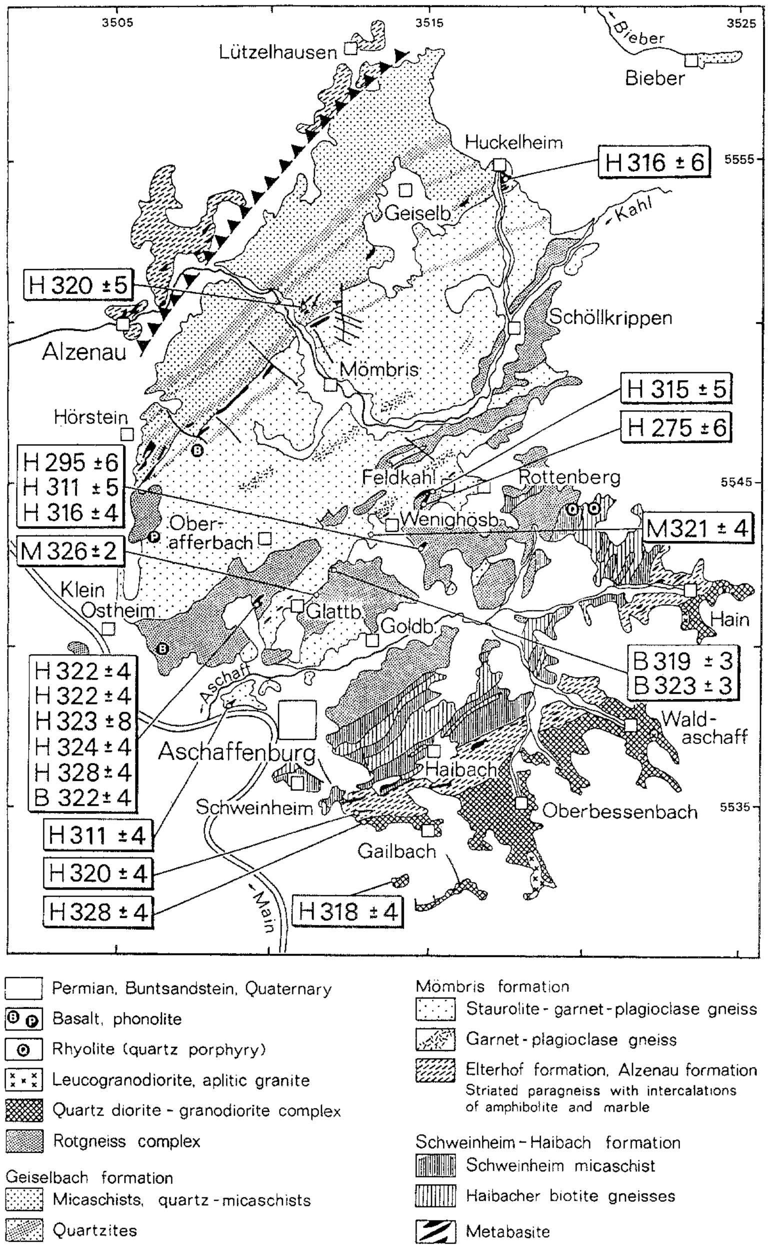

Fig. 2. Geological sketch-map of the Spessart crystalline complex. After *Bücking* (1891), *Gabert* (1957), *Weinelt* (1962), *Okrusch* and *Weinelt* (1965), *Okrusch* et al. (1967) and *Streit* and *Weinelt* (1971). Except for the metabasites, individual geological units are listed according to their respective, inferred or constrained ages. Sample localities and the new K-Ar dates are indicated; *B* biotite, *H* hornblende, *M* muscovite

ing, SW-NE striking units can be distinguished from NW to SE (Fig. 2):

1. The Alzenau formation: paragneisses, aplitic gneisses, amphibolites and subordinate marble.

2. The Geiselbach formation: micaschists and quartzites, with subordinate intercalations of paragneiss, epidote gneiss and amphibolite.

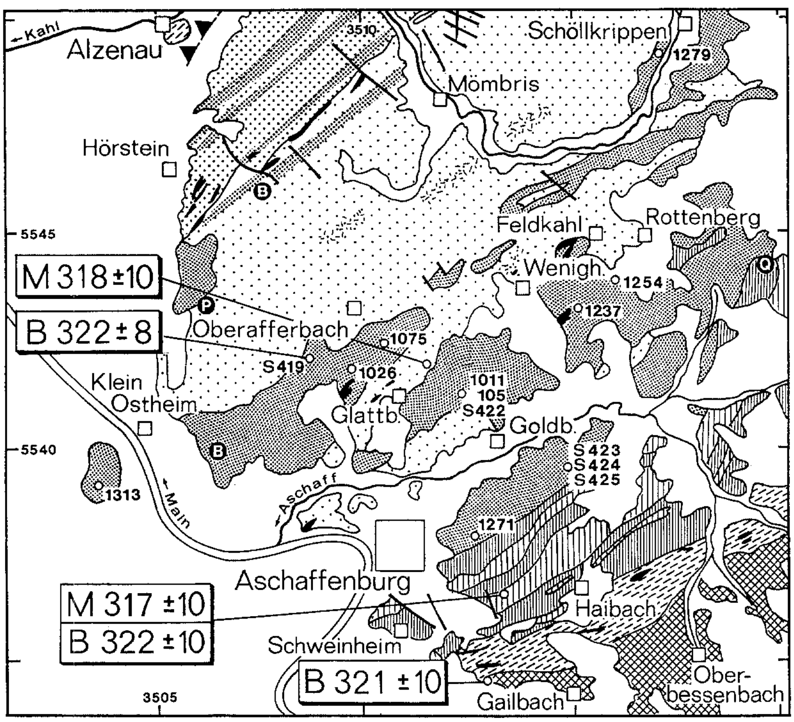

Fig. 3. Geological sketch map of the central part of the Spessart crystalline complex showing the sample localities for Rb-Sr whole-rock dating (circles with numbers) and the K-Ar dates of *Lippolt* (1986)

3. The Mömbris formation: predominantly staurolite-bearing paragneisses with minor intercalations of staurolite-free paragneiss, amphibolite, hornblende gneiss and chlorite-amphibole fels.

4. The Rotgneiss complex: orthogneisses with intercalations of meta-aplite, amphibolite, hornblende gneiss and chlorite-amphibole fels.

5. The Schweinheim-Haibach formation: intercalations of micaschists (Schweinheim member) and biotite gneisses (Haibach member).

6. The Elterhof formation: paragneisses with intercalations of marble, calcsilicate gneiss, graphite-bearing quartzite and amphibolite.

7. The quartz diorite-granodiorite complex with minor aplitic granites.

According to their respective tectonic positions, their lithologies and their inferred or constrained ages of deposition, the different units of the Spessart Crystalline Complex can be characterized as follows:

The Geiselbach and the Mömbris formations are assumed to represent a normal stratigraphic succession of Early Paleozoic age (*Matthes*, 1954; *Bederke*, 1957; *Weinelt* in *Okrusch* et al., 1967). Recently *Reitz* (1987) detected the first fossils in a garnet-bearing micaschist in the central part of the Geiselbach formation. The well preserved spores, derived from primitive land plants (Psilophytinae), point to a Silurian age (probably Ludlow) of the sedimentary protolith. This exciting paleontological evidence means that the Geiselbach formation may reach up to the Devonian/Silurian boundary while, judging from lithostratigraphic considerations, part of the Geiselbach and the whole Mömbris formation are assumed to be of Cambro-Ordovician age (*Hirschmann* and *Okrusch*, 1988). Both formations are of relatively monotonous lithological character. According to geochemical investigations of *Smoler* (1987) the staurolite-bearing metapelites and staurolite-free metagraywackes of the Mömbris formation were deposited in a continental-margin environment.

Part of the intercalated amphibolites, especially in the northwestern belt between Hörstein and Huckelheim, at the transition from the Mömbris to the Geiselbach formation, may represent a phase of volcanic activity during the Early Paleozoic sedimentation. The metabasites of the southeastern belt Aschaffenburg-Feldkahl-Rottenberg are intercalated within the metapelites of the Mömbris formation, but also within the orthogneisses of the Rotgneiss complex. Although the contact relationships are poorly exposed, we assume that at least part of these metabasites are derived from basaltic dikes which intruded the Rotgneiss granite (see below).

The Alzenau formation in the northwestern, and the Elterhof formation in the southeastern part of the Spessart crystalline complex are very similar in their variegated lithology, a fact already recognized by *Thürach* (1893). Both formations are now interpreted as remnants of one nappe (*Heinrichs*, 1986; *Behr* and *Heinrichs*, 1987). Based on lithostratigraphic correlations within the Variscan Orogen, this variegated group may be of Late Proterozoic (*Braitsch*, 1957b) or Early Cambrian age (*Bederke*, 1957; *Braitsch*, 1957b, *Hirschmann* and *Okrusch*, 1988).

Braitsch (1957b) showed that the metapelitic micaschists of the Schweinheim member underly the variegated Elterhof formation in a normal stratigraphie succesion and, consequently, might have a Late Proterozoic age (see also *Hirschmann* and *Okrusch*, 1988). The protolith of the intercalated biotite gneisses of the Haibach member—igneous vs. sedimentary—is still open to discussion. Our unpublished Rb-Sr whole-rock analyses of the Haibach gneiss did not yield an isochron.

The muscovite-biotite flaser-gneisses of the Rotgneiss complex are derived from a relatively shallow intrusion of granitic to granodioritic composition and S-type character (*Matthes* and *Okrusch*, 1965; *Okrusch* and *Richter*, 1986). Rb-Sr whole-rock analyses were interpreted towards a Silurian intrusion age of 414 ± 18 Ma (2s) (*Lippolt*, 1986, compatible with older, less precise data of *Kreuzer* et al., 1973) which would conform to the initial age estimate of *Bederke* (1957).

The quartz diorite-granodiorite complex in the southern part of the Spessart crystalline area does not exhibit a typical igneous texture, but reveals a crystalloblastic one as well as an indistinct foliation. Another crucial feature is the extremely inhomogeneous appearance on the scale of an outcrop: lensoid rafts of amphibolite and hornblende gneiss as well as acid veins and schlieren rich in K-feldspar are numerous. Therefore, *Okrusch* (1963) discarded an igneous origin of the complex (*Braitsch*, 1957a) and advocated a transformistic model. However, a recent petrofabric investigation speaks in favour of a magmatic origin (*O. Oncken*, pers. comm.).

Granite-pegmatites are widespread in the central and southeastern part of the Spessart Crystalline Complex, especially in the Haibach and in the Goldbach gneisses. They are syn- to post-tectonic.

Metamorphism in the Spessart Crystalline Complex took place under P-T conditions of the lower amphibolite facies. Mineral assemblages in the staurolite-bearing paragneisses of the Mömbris formation testify to temperatures of about 600 °C at pressures of about 6 kb (*Matthes* and *Okrusch*, 1977; *Okrusch*, 1983, 1990). The application of various mineral thermometers to the amphibolite intercalations point to somewhat lower temperatures in the northwestern part of the Mömbris formation and in the Geiselbach formation (*Nasir*, 1986).

Analytical Results

A short description of the investigated samples can be obtained from *M. Okrusch* on request. Conventional chemical analyses and optical properties of dated hornblendes are listed in Table 1; their designation according to the nomenclature of *Leake* (1978) is shown in Fig. 4. Except for Table 3, Fig. 3, and the bars in Fig. 6, all error estimates given refer to an interlaboratory analytical precision at a 95% confidence level. The IUGS-recommended constants (*Steiger and Jäger*, 1977) were used.

K-Ar Dating (Table 2)

In Fig. 5 the K-Ar dates of the analyzed hornblendes, muscovites, and biotites are depicted synoptically. Most of them group within the narrow range of 324 to 318 Ma which conforms to the analytical uncertainty. Two hornblendes and one muscovite yielded slightly older dates of 326 to 328 Ma. On the other hand, there is a tail of younger hornblende dates towards 311 Ma.

Two hornblendes from Münchhof (Sp83-W2) and nearby Sternberg (Sp83-W4) gave distinctly younger dates of 293 and 274 Ma, respectively. These two amphiboles as well as hornblende Sp83-W3 from Müchhof (which, too, gave a relatively young date of 311 Ma) are distinguished by cloudy cores of opaque dust. Otherwise, these three amphiboles have no special chemical composition (Table 1, Fig. 4), and do not show any sign of secondary alteration. In comparison, five hornblendes of variable composition from different rock types of the Rauenthal area revealed concordant dates of 322 ± 4 to 328 ± 4 Ma (weighted mean 324 ± 2 Ma). A biotite concentrate from one of these samples yielded the same date of 322 ± 4 Ma.

The K-Ar dates of *Lippolt* (1986, Table 6) fit well within the narrow range of the majority of our dates (Fig. 5). This holds true not only for biotites from an orthogneiss of the Rotgneiss complex (sample S 419-B, Steinbach quarry: 322 ± 16 Ma) and a quartz diorite (sample Sp76-B, Stengerts quarry: 321 ± 20 Ma), but also for a muscovite from the Grauenstein pegmatite (sample Peg2-76-M: 318 ± 20 Ma) as well as a muscovite and a biotite from the Wendelberg pegmatite (sample Peg1-76-M: 317 ± 20 Ma, sample Peg1-76-B: 322 ± 20 Ma).

Rb-Sr Whole-rock Dating

Kreuzer et al. (1973) analyzed six muscovite-biotite gneisses and one meta-aplite from the Rotgneiss complex. The data points define a regression line in the *Nicolaysen* (1961) diagram which was interpreted as an isochron yielding a date of 397 ± 22 Ma and an initial $^{87}Sr/^{86}Sr$ ratio (IR) of 0.712 ± 0.004. However, the authors were aware of the fact that five of the data points clustered within a narrow interval of $^{87}Rb/^{86}Sr$ around 10. Slope and precision of the regression line depend critically on the data points of the two remaining samples, one highly recrystallized orthogneiss (Sp63-1237) and the meta-aplite (Sp72-105) sampled from a dike 0.5 m in width.

Lippolt (1986) published high-precision Rb-Sr analyses on five whole-rock samples of muscovite-biotite gneiss (open circles in Fig. 6), three of which were taken from the same locality (S 423, S 424, S 425). The five data points, with a spread in the $^{87}Rb/^{86}Sr$ ratios of 3 to 55, defined a regression line corresponding to a date of 414 ± 18 Ma and an IR of 0.7068 ± 0.0022. However, the mean square of weighted deviates MSWD = 62 demonstrated that the basic requirements for an interpretation of the regression line as an isochron were violated.

Table 1. *Chemical analyses of dated hornblendes*

Sample	Sp83-M 13	Hc 4	A 3	Rh 3	Rh 1	Rh 4	Rh 5	W 1	W 2	W 3	W 4	F 6	Sp58-ADX	CAH
Wt.-%														
SiO_2	45.10	44.70	44.50	46.20	49.40	44.60	42.10	44.80	44.20	45.00	44.50	47.00	42.45	42.55
TiO_2	0.50	0.65	0.60	0.55	0.46	0.60	0.89	1.22	1.16	0.80	1.15	0.63	1.45	1.81
Al_2O_3	12.20	12.20	13.25	11.75	8.40	11.65	13.10	13.25	13.80	13.35	13.80	13.10	14.29	10.75
Fe_2O_3	3.93	4.43	3.91	3.65	1.52	3.62	5.81	4.01	3.50	3.66	2.66	4.40	0.50	3.79
FeO	10.37	9.46	11.59	9.80	9.98	12.88	14.31	12.10	10.00	9.74	11.34	12.16	12.53	12.02
MnO	0.26	0.22	0.29	0.24	0.21	0.20	0.39	0.24	0.20	0.22	0.20	0.24	0.26	0.28
MgO	12.12	12.68	10.62	13.43	15.32	11.01	7.98	10.04	11.54	11.63	11.49	9.96	12.46	12.06
CaO	11.25	10.96	10.90	10.15	11.10	10.90	11.25	11.08	10.85	11.15	10.45	10.84	12.21	11.27
Na_2O	1.42	1.58	1.56	1.40	0.95	1.25	1.49	1.25	1.63	1.25	1.38	1.65	1.53	1.68
K_2O	0.38	0.31	0.42	0.62	0.19	0.96	0.65	0.68	0.34	0.37	0.45	0.66	1.42	1.25
F	0.03	0.02	0.09	0.06	0.02	0.03	0.06	0.03	0.03	0.02	0.02	0.06	n.d.	n.d.
H_2O	2.12	1.93	1.87	1.76	2.15	2.08	1.88	1.82	2.01	1.98	2.04	1.84	2.08	1.98
Sum	99.68	99.14	99.60	99.61	99.70	99.78	99.91	100.52	99.26	99.17	99.48	99.54	100.23	99.38
Ions per 24 (O + OH + F)														
Si	6.561	6.548	6.527	6.709	7.070	6.578	6.316	6.539	6.444	6.556	6.482	6.506	6.252	6.363
Al(4)	1.439	1.452	1.473	1.291	0.930	1.422	1.684	1.461	1.556	1.444	1.518	1.494	1.748	1.637
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al(6)	0.668	0.653	0.826	0.725	0.492	0.613	0.645	0.824	0.826	0.854	0.864	0.795	0.733	0.258
Ti	0.055	0.071	0.066	0.060	0.050	0.067	0.101	0.134	0.127	0.088	0.126	0.070	0.161	0.204
Fe^{3+}	0.431	0.488	0.432	0.399	0.164	0.402	0.657	0.440	0.384	0.401	0.292	0.489	0.055	0.426
Mg	2.632	2.765	2.325	2.907	3.272	2.437	1.787	2.185	2.511	2.526	2.497	2.195	2.516	2.679
Fe^{2+}	1.214	1.023	1.351	0.909	1.022	1.481	1.798	1.417	1.152	1.131	1.221	1.451	1.535	1.433
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Fe^{2+}	0.049	0.136	0.072	0.281	0.174	0.074	0.000	0.061	0.068	0.056	0.161	0.052	0.008	0.070
Mn	0.032	0.026	0.036	0.030	0.025	0.025	0.038	0.030	0.025	0.027	0.025	0.030	0.032	0.035
Ca	1.756	1.718	1.715	1.579	1.704	1.726	1.810	1.733	1.697	1.740	1.632	1.718	1.927	1.806
Na	0.163	0.120	0.177	0.110	0.097	0.175	0.152	0.176	0.210	0.177	0.182	0.200	0.033	0.089
X	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
Na	0.238	0.327	0.267	0.284	0.167	0.183	0.270	0.178	0.251	0.176	0.208	0.272	0.404	0.398
K	0.071	0.058	0.079	0.115	0.035	0.181	0.125	0.127	0.063	0.069	0.084	0.125	0.267	0.238
A	0.309	0.383	0.346	0.399	0.202	0.364	0.395	0.305	0.314	0.245	0.292	0.397	0.671	0.636
F	0.014	0.010	0.042	0.028	0.009	0.014	0.029	0.014	0.014	0.010	0.010	0.028	-	-
OH	2.060	1.883	1.832	1.705	2.055	2.051	1.884	1.772	1.957	1.924	1.982	1.812	2.040	2.000
Optical data														
$2V_\alpha$			76°	81°				74°	78°	76°	78°		59°	68°
n_γ/c		18°	16°	17°	19°		16°	14°	17°	18°	16°		18°	15°
n_α													1.659	1.660
n_γ													1.680	1.682
$n_\gamma - n_\alpha$	0.021	0.024	0.022	0.021		0.023	0.021	0.023	0.024	0.021			0.021[c]	0.022[c]

[c] calculated

Analysts: Samples Sp 83-, *Nasir* (1986), samples Sp 58-, *Okrusch* (1961).

For a perfect regression the deviations of the determining analytical points should be in the range of the analytical uncertainties, i.e. the mean square of weighted deviates (MSWD) should be close to unity. For a number of samples $n > 6$, *Wendt* (1989) and *Wendt* and *Carl* (in press) estimate the standard deviation of the MSWD as

$$s(\mathrm{MSWD}) \approx \pm\sqrt{2/f},$$

whereby f is the number of freedoms ($f = n - 2$ in the case of a linear regression of n points). Hence, the MSWD of a five points' regression line should be in the range of $1 \pm 2\sqrt{2/3} \approx 1 \pm 2$ for a statistically safe isochron.

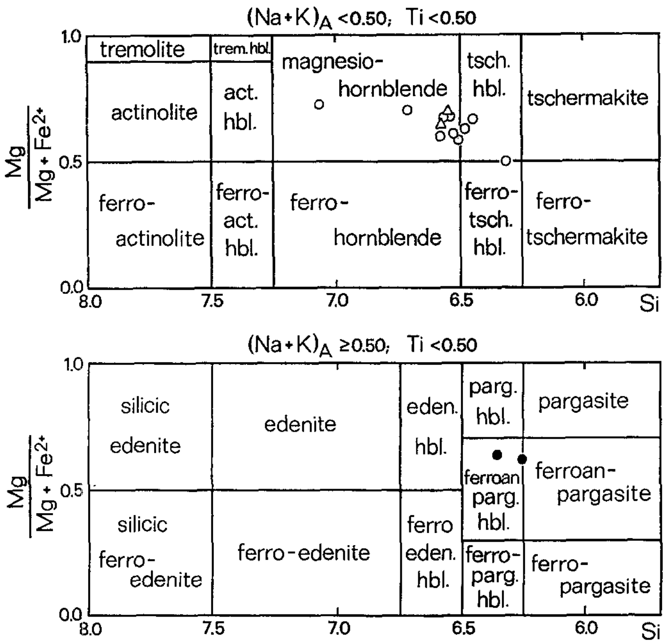

Fig. 4. Nomenclature (*Leake*, 1978) of analyzed hornblendes from the metabasite belts Hörstein—Huckelheim (open triangles) and Aschaffenburg-Feldkahl-Rottenberg (open circles) and from the quartz diorite-granodiorite complex (closed circles)

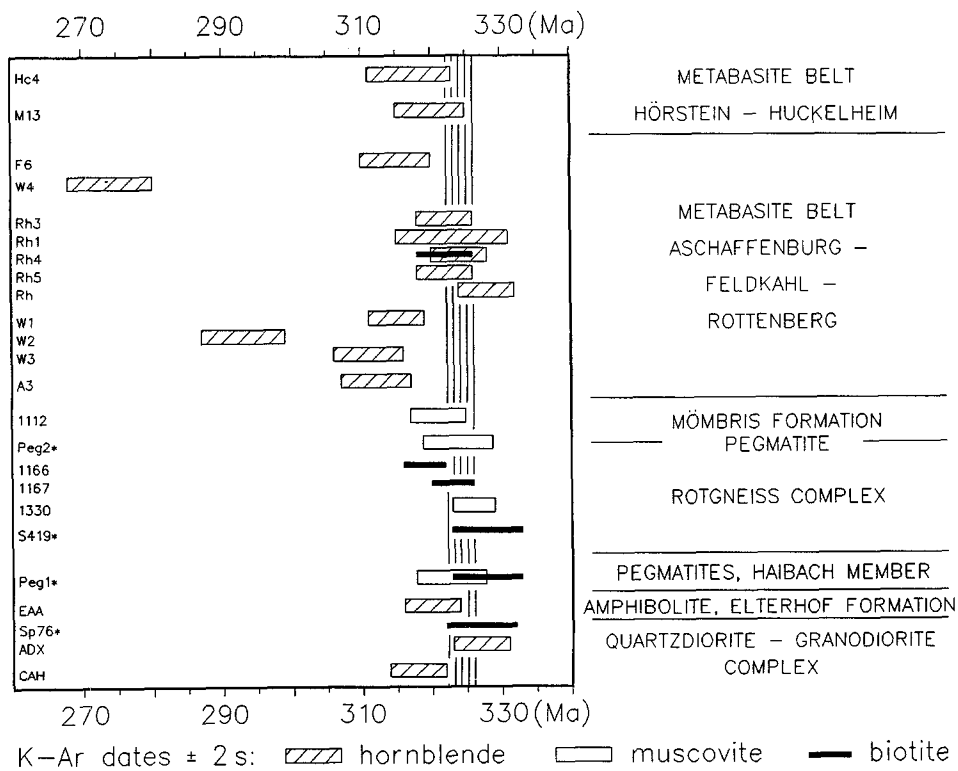

Fig. 5. K-Ar dates from the Spessart crystalline complex. The dates are arranged according to the lithostratigraphic succession as in Table 2, i.e. from NW (top) to SE (base). The dates for the mica samples of *Lippolt* (1986) are inserted and marked with an asterix. However, the original dates are increased by 1.8% which is the interlaboratory bias from Heidelberg to Hannover according to our analyses on the interlaboratory standard biotite HD-B1 (*Lippolt* and *Hess*, 1989, written commun.). The errors of these dates are given as twice the standard deviation of these 5 dates. All error bars are given at a level 95% intralaboratory confidence. The ruled background represents the interval ± twice of the standard error of the mean age of the 5 hornblendes from Rauenthal (samples Rh)

Table 2. *K-Ar mineral data of crystalline rocks from the Spessart, Mid-German Crystalline Rise*

Sample No.	Rock type	Locality	Mineral	K-Ar date (Ma)	K (wt.%)	Argon rad. (nl/g)STP	Argon atm. (nl/g)STP
		Metabasite belt Hörstein - Huckelheim					
Sp83-Hc4	hornblende gneiss	Ziegelhütte	**hbl**	**316** ± 6	0.199 ± 4	2.674 21	0.12 2
Sp83-M13	hornblende gneiss	north of Brücken	**hbl**	**320** ± 5	0.260 ± 4	3.54 3	0.24 2
		Metabasite belt Aschaffenburg - Feldkahl - Rottenberg					
Sp83-F6	quartz-bearing amphibolite	Feldkahl	**hbl**	**315** ± 5	0.326 ± 5	4.36 4	0.48 3
Sp83-W4	quartz-bearing amphibolite	Sternberg, between Feldkahl and Wenighösbach	**hbl**	**275** ± 6	0.293 ± 6	3.38 3	0.29 2
Sp83-Rh3	quartz-epidote amphibolite	Rosenberg, near Rauenthal	**hbl**	**322** ± 4	0.457 ± 5	6.26 5	0.49 5
Sp83-Rh1	hornblende fels	Rauenthal	**hbl**	**323** ± 8	0.114 ± 3	1.565 14	0.15 1
Sp83-Rh4	biotite-hornblende gneiss	Rauenthal	**hbl**	**324** ± 4	0.725 ± 7	10.00 8	0.35 1
			bi	**322** ± 4	6.44 ± 8	88.3 8	0.77 13
Sp83-Rh5	epidote-hornblende gneiss	Rauenthal	**hbl**	**322** ± 4	0.660 ± 7	9.03 7	0.34 6
Sp67-Rh	amphibolite	Rauenthal	**hbl**	**328** ± 4	0.711 ± 7	9.94 6	0.64 6
Sp83-W1	quartz-bearing amphibolite	Münchhof	**hbl**	**316** ± 4	0.443 ± 5	5.94 5	0.46 1
Sp83-W2	quartz-bearing amphibolite	Münchhof	**hbl**	**295** ± 5	0.253 ± 4	3.146 23	0.82 2
Sp83-W3	amphibolite	Münchhof	**hbl**	**311** ± 5	0.243 ± 4	3.21 3	0.84 26
Sp83-A3	epidote-bearing amphibolite	Strietwald, near Aschaffenburg	**hbl**	**311** ± 4	0.283 ± 4	3.732 21	0.57 2
		Mömbris formation					
Sp62-1112	quartz-plagioclase fels	Roter Grund, near Wenighösbach	**mus**	321 ± 4	8.01 ± 7	109.3 9	1.5 2
		Rotgneiss complex					
Sp62-1166	biotite gneiss, muscovite-bearing	Kufengrund, near Unterafferbach	**bi**	319 ± 3	7.35 ± 4	99.6 8	1.1 1
Sp62-1167	biotite gneiss, muscovite-bearing	Kufengrund, near Unterafferbach	**bi**	323 ± 3	7.47 ± 4	102.7 8	2.0 1
Sp64-1330	muscovite-biotite gneiss	Steinrücken, near Glattbach	**mus**	326 ± 2	7.58 ± 4	105.2 6	1.2 5
		Elterhof formation					
Sp58-EAA	chlorite-bearing amphibolite	Gniessen, near Schweinheim	**hbl**	320 ± 4	0.739 ± 8	10.06 8	0.48 2
		Quartz diorite - granodiorite complex					
Sp58-ADX	quartz diorite with feldspar blasts	Stengerts, near Schweinheim	**hbl**	328 ± 4	1.282 ± 12	17.93 14	1.42 17
Sp58-CAH	amphibolite raft in quartz diorite	Ameisenbrunnen, near Soden	**hbl**	318 ± 4	1.344 ± 12	18.19 15	0.35 6

Conventional K-Ar analyses (Seidel et al., 1982). Argon by total fusion isotope dilution static mass-spectrometrical analysis in nannoliter per gram at standard temperature and pressure, corrected for average blank analyses. K in duplicate by flame photometry with Li as internal standard. Error estimates refer to the intralaboratory analytical precision at a 95 % confidence level. For the K analyses they are arbitrarily enhanced by 0.002 wt.% to account for low level biasses. The IUGS-recommended constants (Steiger and Jäger, 1977) are used. Our date for the standard glauconite GL-0 is 1% less than the average value of the compilation of Odin (1982).
Abbreviations: bi = biotite, hbl = hornblende, mus = muscovite.

For comparison of precise data on samples from a more limited interval of Rb/Sr ratios, we decided to re-analyze six samples reported by Kreuzer et al. (1973), as well as three additional ones described, but not analyzed by these authors. Moreover, the two samples of *Lippolt* (1986) with high Rb/Sr ratios (S 423, S 425) were also re-analyzed.

Three samples re-analyzed for Rb and Sr reveal major discrepancies compared with the former results: The samples Sp63-1237 and Sp72-105 which mainly define the isochron of *Kreuzer* et al. (1973) revealed markedly higher $^{87}Sr/^{86}Sr$ ratios, the sample S 423 of *Lippolt* (1986) gave a 10% lower $^{87}Rb/^{86}Sr$ ratio.

Taking into account all 11 samples, our new results (Table 3) define a regression line conforming to an isochron date of 439 ± 15 Ma, with an IR of 0,7038 ± 0.0026 (Fig. 6). The scatter of the data points is significantly reduced. Yet the resulting MSWD = 4.9 is still far too large to assume a statistically sound isochron. Accord-

Table 3. *Rb-Sr whole-rock data of orthogneisses from the Rotgneiss Complex, Spessart*

Sample No.	^{87}Rb (ppm)	^{86}Sr (ppm)	$^{87}Rb/^{86}Sr$		$^{87}Sr/^{86}Sr$	
Charges of 600 mg						
Sp63-1279	47.78	5.403	8.74	(9)	0.75881	(23)
Sp61-1011	51.05	5.409	9.33	(9)	0.76283	(23)
Sp62-1026	52.73	5.158	10.11	(10)	0.76806	(23)
Sp63-1271	51.92	5.002	10.26	(10)	0.76919	(23)
Sp64-1313	58.89	5.256	11.08	(11)	0.77702	(23)
Sp62-1075	55.24	4.800	11.38	(11)	0.77395	(23)
Sp63-1254	57.53	4.728	12.03	(12)	0.77877	(23)
Sp72-105	63.78	3.178	19.84	(20)	0.82802	(25)
	63.37	3.177	19.72	(20)	0.82878	(25)
			19.78	(14)	0.82840	(38)
Sp63-1237	53.91	2.537	21.01	(21)	0.83891	(25)
	52.83	2.498	20.91	(21)	0.84034	(25)
			20.96	(15)	0.83962	(72)
S 425 at BGR	63.59	1.162	54.10	(54)	1.03641	(31)
ditto Lippolt	63.76	1.143	55.41	(19)	1.03810	(4)
			54.76	(66)	1.03726	(85)
S 423 at BGR	59.20	1.063	55.07	(55)	1.04865	(31)
ditto Lippolt	56.80	0.947	59.50	(30)	1.04760	(34)
					1.04812	(83)
Charges of 100 mg, for control of contamination und cross contamination - mean values of 10 determinations within about 2 years.						
NBS 607	148.16	6.046	24.21		1.20007	
standard dev.	49	24	13		80	

Rb and Sr determined by conventional isotopic dilution methods (Harre et al., 1968)., Sr on a MAT-261 mass spectrometer using a double collector, Rb on a VG=Micromass MM 30 spectometer. Replicates on the NBS 607 standard and on samples lead to intralaboratory standard deviations of 1% and 0.03% for the $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios, respectively. In parentheses errors at 68% confidence of intralaboratory precision. IUGS-recommended constants (Steiger and Jäger, 1977).

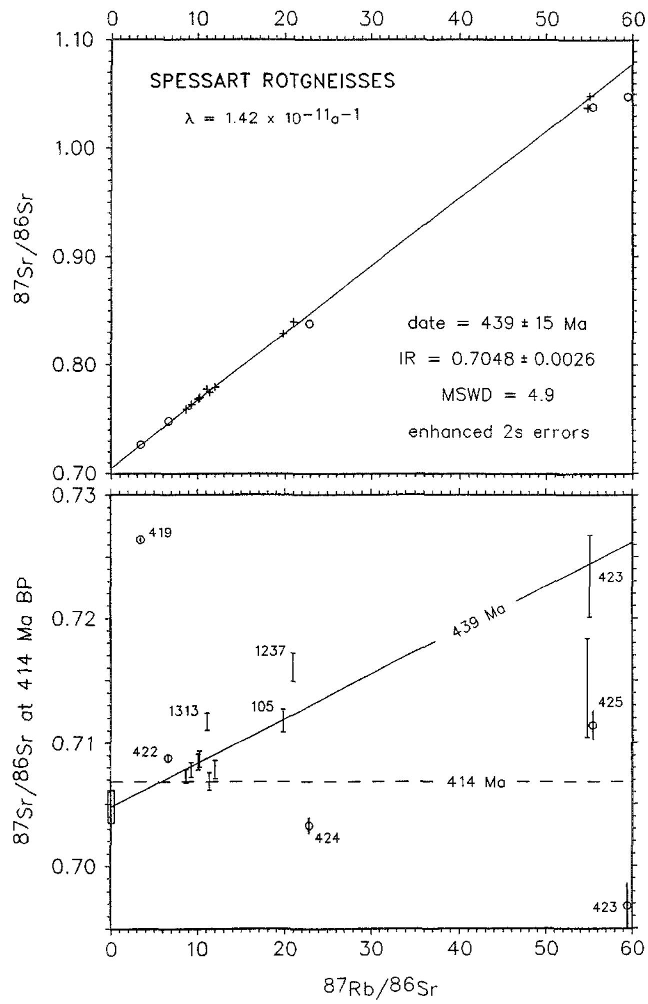

Fig. 6. Isochron plots of the Rb-Sr analyses. Upper part: Conventional *Nicolaysen* (1961) diagram. The regression line is defined by the 11 analyses of Table 3 (crosses); the analyses of *Lippolt* (1986) are given for comparison (open circles). Lower part: Extended-scale presentation by subtracting the gain of radiogenic Sr since 414 Ma, the date originally derived by *Lippolt* (1986) from his five anlyses represented by open circles. Consequently, the 414 Ma regression line is horizontal in this plot (dashed line). Error bars in this plot represent ± 1 standard errors

ing to the criterion of *Wendt* (1989) and *Wendt* and *Carl* (in press), with nine degrees of freedom one expected a MSWD in the range of $1 \pm 2\sqrt{2/(11-2)}$, i.e. MSWD $\approx 1 \pm 0.9$.

This means that

- the rocks are derived from different batches of granitic magma which intruded roughly at the same time and/or
- the Sr isotopes were not homogenized in the granitic magma and/or
- the rocks did not behave as closed systems to Rb and Sr during Variscan metamorphism.

The first possibility seemed to be indicated by the wide range of Rb/Sr ratios mentioned above which cluster in three different intervals. However, a significant scatter is observed in all three groups: If we regress only the 7 samples of the group with low Rb/Sr ratios, we end up with a similar date (439 ± 40 Ma, IR 0.705 ± 0.006) and an MSWD of 5.6. The same holds true, if we include the two samples with medium Rb/Sr ratios. Moreover, it should be noted that the wide spread in the Rb/Sr ratios is mainly due to a variation in the Sr, rather than the Rb contents

(Table 3). This may suggest a postmagmatic, e.g. metamorphic Sr loss, according to the third possibility. In the latter case, the date of 440 Ma would be a mininum estimate of the intrusion age, as one often observes losses radiogenic Sr roughly proportional to the Rb/Sr ratio, leading to "rotated isochrons" (e.g. *Wendt* et al., 1970).

Discussion

The oldest radiometric records so far available in the Spessart Crystalline Complex are the Rb-Sr whole-rock dates for the orthogneisses of the Rotgneiss complex. Despite the uncertainties resulting from the wide scatter of the data points around the regression line in the Nicolaysen diagram, an Ordovician to Silurian intrusion age of the granitic protolith can be inferred.

According to their chemical characteristics the orthogneisses are derived from S-type granitoids, although the IR of 0.705 is remarkably low. The trace element characteristics are consistent with an emplacement into a post-collision geotectonic environment (*Okrusch* and *Richter*, 1986) according to the systematics evaluated by *Pearce* et al. (1984). This would conform to a phase of extensional tectonics at the end of the Caledonian orogeny (*Weber*, 1984). In the simplified, H_2O saturated granite system Qz-Or-Ab(-An) the data points plot close together in the vicinity of the melting minimum at low water vapour pressures (≤ 1 kbar) indicating that the precursor granitoids intruded into a relatively shallow level, probably less than 4 km (*Okrusch* and *Richter*, 1986).

Judging from the paleontological evidence recorded by *Reitz* (1987), part of the Geiselbach formation is of Silurian age whereas the underlying Mömbris formation is regarded as Cambro-Ordovician as inferred from lithostratigraphic correlations (*Matthes*, 1954; *Bederke*, 1957; *Hirschmann* and *Okrusch*, 1988). Hence sedimentation was still going on while the granite magma was being intruded in deeper levels of the Mömbris-Geiselbach sediment pile. If we assume a normal stratigraphic succession, the cover of the granitoids, consisting of the Mömbris, and part of the Geiselbach formation, amounts to roughly 3 km (*Hirschmann* and *Okrusch*, 1988). Allowing for a reduction of the initial bed thickness by tectonic strain, this value should be increased approximately by a factor of 2, but still compares well with the shallow level of intrusion estimated on the basis of petrological criteria.

The volcanic protoliths of the metabasites in the belt of Aschaffenburg-Feldkahl-Rottenberg, presumbably intruded or ejected after the intrusion of granitoids, reveal a calc-alkaline affinity (*Hesselmann*, 1982; *Nasir*, 1986; *Nasir* and *Okrusch*, in prep.) This would testify to an island-arc geotectonic environment as a result of renewed compressional tectonics at the beginning of the Variscan Orogeny (*Weber*, 1984).

During the Variscan orogenetic processes, the Proterozoic and Lower-Paleozoic volcano-sedimentary sequence, the Silurian/Devonian granitoids, and the later calc-alkaline volcanites were metamorphosed at temperatures of about 600 °C and pressures of about 6 kbar (*Okrusch*, 1983, 1990) corresponding to a burial at a depth of about 20 km . The K-Ar dates presented in Table 2 and by *Lippolt* (1986, Table 6) are related to the geologic history which started at or after the peak of the Variscan metamorphism and the syn- to posttectonic pegmatite emplacement. The dates show no systematic differences, neither for the three minerals, nor for the rock types, nor for the lithostratigraphic units. Considering this fact and maintaining the conventional estimates for the closing temperatures of the K-Ar systems, i.e. about 500 °C for hornblende, about 350 °C for muscovite, and about 300 °C for biotite (e.g. *Hart*, 1964, *Gerling* et al., 1965; *Purdy* and *Jäger*, 1976; *Dodson*, 1973), our dates suggest a rapid uplift and cooling, from 500 to 300 °C, of the Spessart Crystalline Complex. The age of uplift would be 327 ± 2 Ma if we rely on the two hornblendes and the single muscovite with the oldest dates, or 321 ± 1 Ma using the 11 hornblendes, muscovites and biotites of the main group. The 5 mica dates of *Lippolt* (1986) average to a similar date of 320 Ma. According to the Carboniferous time-scale of *Hess* and *Lippolt* (1986, Fig. 4) the cooling took place at the Dinantian/Namurian boundary or in the Namurian A. The two hornblendes and the single muscovite with the oldest dates averaging at 327 ± 2 Ma may be relics of an earlier stage in the metamorphic history.

The assumed closing temperatures of hornblende, muscovite, and biotite are within the range of the greenschist facies. Therefore, one could assume that the age of about 320 Ma refers to the retrogressive overprint under greenschist-facies conditions which affected parts of the Spessart Crystalline Complex (*Matthes*, 1954). However, the dated minerals are virtually unaffected by retrograde alteration. Experience in polymetamorphic areas, (e.g. in the Tauern Window: *Raith* et al., 1978) shows that hornblendes are not completely reset by a metamorphic overprint, even under amphibolite facies conditions, unless the metamorphic assemblage has been fully re-equilibrated, especially under the influence of deformation. We therefore assume that our dates are closely related to the culmination of the amphibolite facies metamorphism which, as a consequence, would belong to the Sudetic phase of the Variscan orogeny.

Nearly the same cooling age is indicated for the adjacent parts of the Mid-German Crystalline Rise, namely for the Böllstein Odenwald in the south-west (*Lippolt*, 1986) and for the hidden basement of the Rhön Volcanic Complex in the north-east (*Schmidt* et al., 1986). This age is also well established in the Saxothuringian of the Fichtelgebirge and the Moldanubian realm immediately to the south (e.g. *Kreuzer* et al., 1989). In contrast, the northern Bergsträsser Odenwald, further to the south-west, yielded early Carboniferous hornblende dates around 342 Ma (*Kreuzer* and *Harre*, 1975, recalculated; *Hellmann* et al, 1982: *Rittmann*, 1984). Moreover, critical assemblages and migmatite phenomena in the Bergsträsser Odenwald testify to metamorphic peak conditions differing from those in the Spessart crystalline complex, i.e. lower pressures of about 3 kbar and higher temperatures up to 700 °C (e.g. *Okrusch*, 1990). These differences indicate a diverging metamorphic history for different parts of the Mid-German Crystalline Rise.

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