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GEOCHRONOLOGICAL CONSTRAINTS OF THE VARISCAN, PERMIAN-TRIASSIC AND EO-ALPINE (CRETACEOUS) EVOLUTION OF THE GREAT HUNGARIAN PLAIN BASEMENT

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Abstract: Core samples of metamorphic basement rocks from the Great Hungarian Plain (Tisza Megaunit) were studied by petrographic and geochronological methods (Ar-Ar, Rb-Sr, Sm-Nd). On the basis of microtextural features of Al_2SiO_5 polymorphs in metapelites a regional distribution pattern was found, which correlates with geochronological age groups. This pattern confirms the earlier established tectonic subdivision of the basement of the Great Hungarian Plain, except for the Algyő basement-high, which has to be considered to represent a separate unit. A muscovite concentrate from a granite sample of the Mecsek Subunit yielded a Variscan Ar-Ar age of 299 Ma. The medium-grade metapelites of the Villány-Bihar Subunit are characterized by kyanite porphyroblast and sillimanite. Typical Ar-Ar muscovite ages are ca. 310 Ma and prove a Variscan cooling age of the metamorphic assemblages. In the NE part of the unit ages in the range of 202–266 Ma indicate a later thermal overprint. The staurolite and andalusite-bearing gneisses of the Békés-Codru Subunit yielded Variscan cooling ages of ca. 320 Ma. In contrast, the rocks from the Algyő basement-high experienced their first metamorphic imprint in Early Permian time. Based on a Sm-Nd garnet isochron the high-temperature/low-pressure assemblages, including andalusite + K-feldspar ± sillimanite formed ca. 275 Ma. An amphibolite facies, eo-Alpine (Cretaceous) overprint in the stability field of kyanite + staurolite + garnet is proved by Ar-Ar muscovite ages in the range of 82–95 Ma. It was followed locally by an Early Tertiary deformation. Considering the lithologies and the metamorphic and structural evolution, the Algyő-high shows many similarities to the Saualm-Koralm Complex of the Austroalpine unit. Like the latter and the Baia de Aries nappe complex in the Apuseni Mountains, it obviously represents an eo-Alpine thrust sheet.

Key words: Tisza Megaunit, Hungary, basement, Variscan, Permian and eo-Alpine metamorphism, Ar-Ar, Rb-Sr and Sm-Nd geochronology.

Introduction

Numerous studies are dealing with the paleogeographical evolution of the ALCAPA region (internal Eastern Alps-Carpathians-Pannonian Basin: Neubauer 1992). Traditionally the pre-Alpine arrangement of the tectonic units is based on the facies evolution of the Mesozoic cover series (e.g. Haas et al. 1995). However recent petrological and geochronological studies result in detailed knowledge about most of the crystalline basement units, giving additional arguments for various tectonic reconstructions. These studies have shown, that besides a widespread Variscan metamorphic imprint, an eo-Alpine and also a Permo-Triassic imprint are important over large areas (Árkai 1991; Lelkes-Felvári et al. 1996, 2001; Thöni 1999; Hoinkes et al. 1999; Plašienka et al. 1999; Haas et al. 2001; Schuster et al. 2001).

The Pannonian Basin is located in the centre of the ALCAPA region. The main tectonic elements, forming the basement of this Tertiary basin are the Tisza Megaunit in the SE and the Pelsó Megaunit to the NW. They are separated by the mid-Hungarian line — a major tectonic element of regional importance with a complex history (Csontos & Nagymarosy 1998) (Fig. 1). Contradictory opinions exist about the Permo-Mesozoic location of the Tisza Megaunit. In the palinspastic reconstruction by Stampfli & Mosar (1999) the Tisza Megaunit is located between the Southalpine and the Austroalpine units. The European affinity of its Permo-Mesozoic cover series was recognized by Géczy (1973) and Haas et al. (1995). According to Buda (1992) and Buda et al. (1999) the granitoids of Mecsek Mts can be related to the Moldanubian Zone of the Central European Variscides.

Klötzli et al. (in print) assume a position of the Tisza Megaunit east of the Austroalpine units of the Eastern Alps, in the vicinity of the Bohemian Massif and the Carpathians. One reason for the contrasting opinions is the incomplete knowledge about the basement of the Pannonian Basin, which is mostly covered by Neogene sediments. Especially the area of the Great Hungarian Plain (GHP), located east of the river Danube is exclusively known from boreholes (Fig. 2).

In this paper petrological and geochronological data are given for the metamorphic rocks of the Tisza Megaunit, in the area of the Great Hungarian Plain. Geochronological age data prove a Variscan metamorphic imprint and give arguments for an eo-Alpine and also a Permo-Triassic imprint in some areas.

Geological setting

The basement of the GHP consists of metamorphic rocks, Permian and Mesozoic sediments and volcanic rocks. The

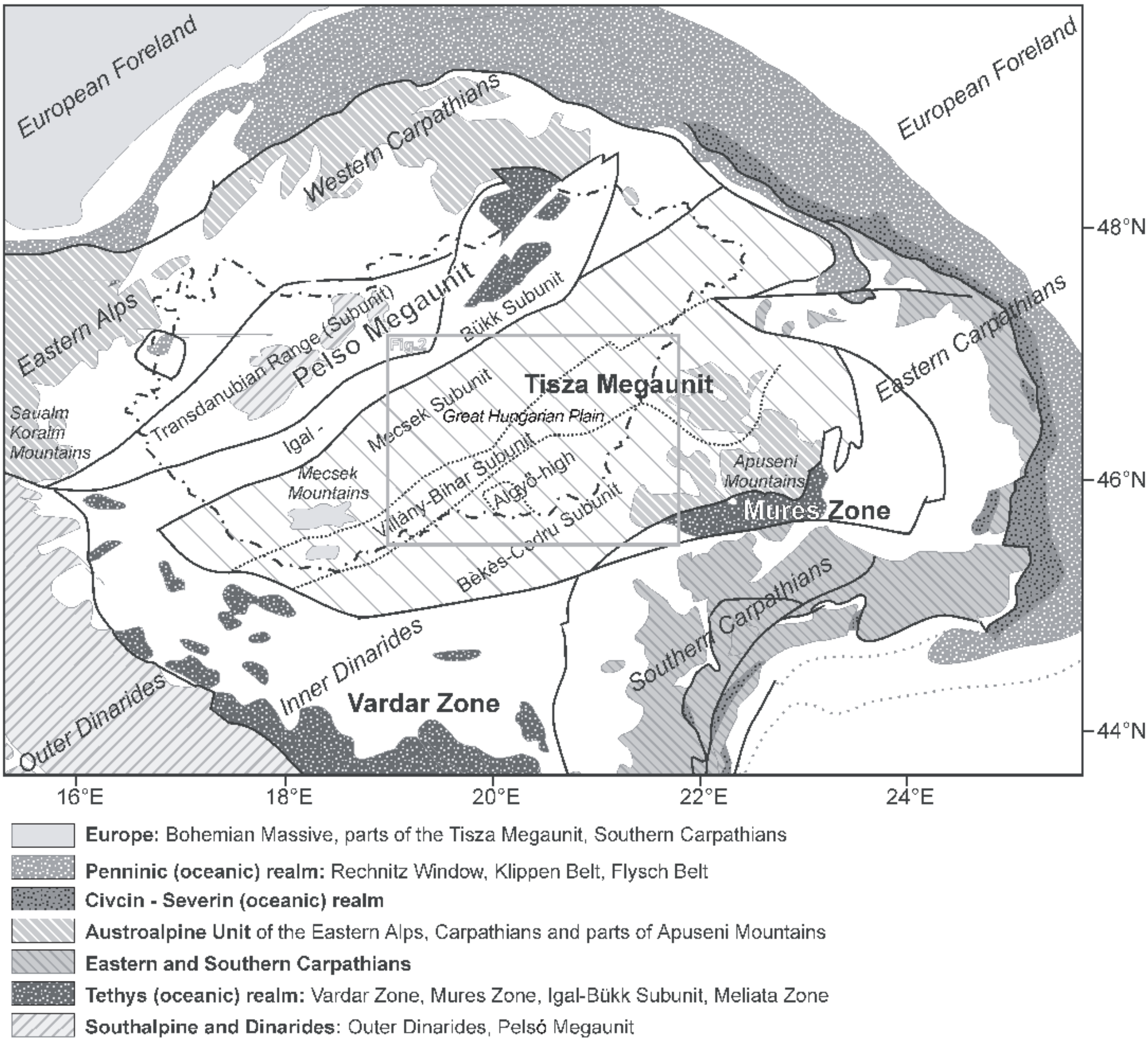


Fig. 1. Tectonic map of the ALCAPA region with the distribution of the pre-Tertiary outcrop areas.

presence of Carboniferous sediments was also discussed, but not proved by biostratigraphic data (Jámbor 1998). Sporadically occurring, overlying Permian rhyolites and sandstones were considered to prove a general pre-Alpine age of the medium-grade metamorphic evolution in the basement. Ubiquitous Lower Triassic sediments were considered as general overstep-sequences in all units (Kovács et al. 2000). Miocene conglomerates represent the most widespread sedimentary cover, containing the basement rocks as pebbles.

Szepesházy (1978) established the lithostratigraphic correlation of the sub-surface units in the GHP with the main tectonic units of the Apuseni Mountains (Romania). According to Szederkényi (1984) two main units make up the Tisza Megaunit, the Central Hungarian Autochthon and the South Hungarian Nappe. Fülöp (1994) distinguished three tectonic units on the base of crystalline rock-types and Mesozoic sedimentary facies zones (Fig. 2). These units, the Mecsek (MU), Villány-Bihar- (VBU), and Békés-Codru Subunits (BCU) represent Cretaceous tectonic units. The first two represent the autochthon of Szederkényi (1984) and the Kunságia Terrane of Kovács et al. (2000) respectively, whereas the latter is equivalent to the South Hungarian Nappe of Szederkényi (1984) and the Békésia Terrane by Kovács et al. (2000).

Szepesházy (1978) considered a pre-Assyntian (Baikalian) and Assyntian age of metamorpism, lacking any radiometric data that time. According to Árkai et al. (1985) a medium pressure first metamorphism was followed by a low pressure overprint. Szederkényi (1996) distinguished three metamorphic imprints: 1) A high-pressure event responsible for eclogites occurring in a narrow belt in the VBU, extending from SW Transdanubia to the east of the Tisza river. This event was assumed to be Caledonian in age (400–440 Ma). 2) The main metamorphic evolution was characterized by two Variscan stages: the earlier (330–350 Ma), related to medium pressure-medium temperature (MP–MT) conditions can be traced in the whole basement with frequent kyanite as the characteristic Al_2SiO_5 polymorph. The second phase occurring in the BCU was characterized by low-pressure (LP) con-

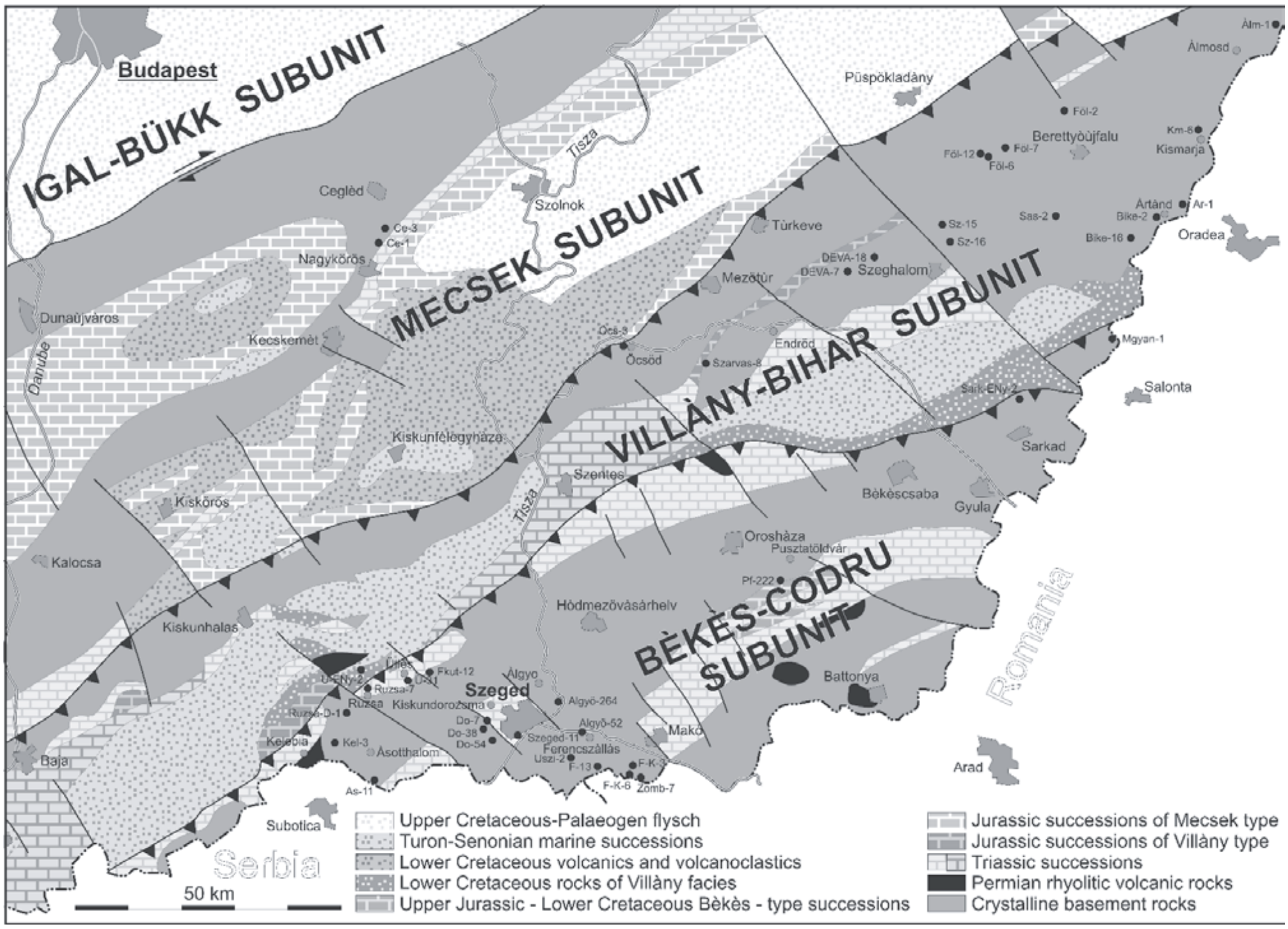


Fig. 2. Geological sub-surface map of the Great Hungarian Plain. The main structural elements and the locations of the investigated logs are shown.

ditions and radiometric ages in the range of 270–330 Ma. 3) Alpine ages of 75–64 Ma were interpreted as contact effects of Late Cretaceous magmatic bodies. However, the detailed correlation of geochronological data with metamorphic evolution and formation of mineral assemblages is still poorly understood.

Eo-Alpine regional metamorphism in the basement of the GHP was first reported by Árkai et al. (1998). It caused a very low — to low-grade — prograde metamorphism in the Permo-Mesozoic rocks beneath overthrust, polymetamorphic Variscan basement rocks, and tectonic slices along the main Alpine thrust zones. The K-Ar ages of fine-grained micas separated from basement rocks also show Alpine retrogression within strongly tectonized metamorphic slices (Árkai et al. 2000).

Analytical techniques

Amphibole and garnet used for isotope determinations were hand-picked under a binocular microscope. The coarsest muscovite and biotite (up to several mm) from the samples were separated on a vibrating table and by grinding in alcohol, and a fraction of 0.1–0.2 mm was analysed. The age dating was performed in the Laboratory of Geochronology, University of Vienna.

To remove surface contaminations mineral concentrates used for Sm-Nd and Rb-Sr analyses were leached in 2.5 M HCl before decomposition for 5 minutes at about 50 °C. Chemical sample digestion and element separation followed the procedure outlined by Thöni & Jagoutz (1992). Overall blank contributions are ≤ 0.2 ng for Nd and Sm, and ≤ 2 ng for Rb and Sr. Nd and Sm concentrations were determined by isotope dilution, using a mixed ^{147}Sm-^{150}Nd spike, and run as metals on a Finnigan®MAT 262 multicollector mass spectrometer. Nd was ionized using a Re double filament. Within-run isotope fractionation was corrected for ^{146}Nd/^{144}Nd = 0.7219. All errors quoted in Tables 1 and 2 correspond to 2σ of the block mean (1 block = 10 isotope ratios). The ^{143}Nd/^{144}Nd ratio for the La Jolla international standard during the course of this investigation was 0.511900 ± 6 (9 runs). Errors for the ^{147}Sm/^{144}Nd ratio are ±1 %, or smaller, based on iterative sample analysis and spike recalibration. Sr and Rb concentrations were determined using a VG® Micromass M 30 and Ta filaments. Through the course of this study the value for the NBS 987 Sr standard was 0.71011 ± 6 (12 runs). Maximum errors for ^{87}Rb/^{86}Sr ratios are estimated to be ±1 %.

For ^{40}Ar-^{39}Ar age determinations the mineral concentrates were irradiated at the 9MW ASTRA reactor at the Austrian Research Centre Seibersdorf or at the Institute of Isotopes Budapest and analysed using standard procedures with a VG-

Table 1: Sample localities, characteristic index minerals and age data of the investigated samples.

Sample	Log	Depth [m]	Subunit	Lithology	Index minerals	age			
						Method	**IA [Ma]**	**PA [Ma]**	**TGA [Ma]**
Cegléd-1/13	Ce-3		Mecsek	granite	K-Fs+Pl+Ms+Qtz	Ar-Ar Ms		299.0±3.9	295.3±4.5
Mezősas-2	Sas-2	2274–2280	VBU	retrograde eclogite	Grt	---------			
Öcsöd-3/1	Öcs-3		VBU	cataclastic micaschist	St	---------			
Öcsöd-3/2	Öcs-3		VBU	cataclastic micaschist	St	Ar-Ar Ms		317.1±3.4	314.2±3.5
Szarvas-8/4	Szarvas-8	3453–3460	VBU	micaschist	Ky+Grt+St	Ar-Ar Bt		293.0±1.9	280.0±3.2
Szarvas-8/4	Szarvas-8	3453–3460	VBU	micaschist	Ky+Grt+St	Ar-Ar Ms		316.8±3.1	316.2±3.5
Szeghalom-15/4	Sz-15		VBU	micaschist	Ky+Sil	---------			
Szeghalom-176/4	Sz-176		VBU	biotite-amphibolite	Hb	Ar-Ar Hb		309.7±6.0	309.4±7.3
Biharkeresztes-16/1	Bike-16	1521–1523	VBU	micaschist	Sil	Ar-Ar Ms		308.0±3.2	306.5±3.3
Ártánd-1/10	Ar-1	2824	VBU	micaschist	Ky+Sil	Ar-Ar Ms		-------------	297.0±2.3
Álmosd-1/10	Ŕlm-1	2824	VBU	micaschist	Grt+St	Ar-Ar Ms		202.0±1.7	194.2±1.7
Földes-6/2	Föl-6	2296–2300	VBU	biotite-amphibolite	Bt+Hb+Pl	Rb-Sr Bt	200±2		
Földes-6/2	Föl-6	2296–2300	VBU	biotite-amphibolite	Bt+Hb+Pl	Ar-Ar Bt		222.7±1.7	215.6±1.9
Földes-12/3	Föl-12	1924–1932	VBU	micaschist	St-Grt	Ar-Ar Ms		266.4±3.3	264.8±3.4
Ruzsa-7/8	Ruzsa-7	2859	BCU	gneiss	And+St	Ar-Ar Ms		321.5±3.7	317.0±4.1
Ruzsa-D-1/3	Ruzsa-D-1	1570–1571	BCU	gneiss	And+St	Ar-Ar Ms		318.0±3.6	314.0±3.7
Sarkadkeresztúr-ÉNY-2/4	Sark-ÉNY-2	4070–4073	BCU	gneiss	And+St	Ar-Ar Ms		305.3±2.0	303.3±2.3
Mezőgyán-1/5	Mgyán-1		BCU	gneiss	And+St	Ar-Ar Ms		319.2±4.7	315.9±5.2
Ásotthalom-11/2	As-11	1060–1066	BCU	gneiss		Ar-Ar Ms		319.8±2.7	318.2±2.9
Kelebia-3/9	Kel-3	1122–1126	BCU	gneiss		Ar-Ar Ms		321.2±2.1	291.5±2.1
Pusztaföldvár-222/6	Pf-222		BCU	mylonitic gneiss		Ar-Ar Ms		309.1±2.7	305.5±3.2
Szeged-11/6	Szeged-11		BCU	diaphthoritic mylonite		Ar-Ar Ms		317.4±3.4	301.2±3.7
Szeged-11/6	Szeged-11		BCU	diaphthoritic mylonite		Ar-Ar Ms+Chl		301.0±3.1	282.0±3.6
Dorozsma-7/10	Do-7		Algyő-high	mylonitic micaschist	Grt+Bt+Ms+Gr	Sm-Nd Grt	273±7		
Dorozsma-38/2/1	Do-38		Algyő-high	mylonitic micaschist	Grt1+Pl+Bt+K-Fs	---------			
Dorozsma-54/10/1/1	Do-54		Algyő-high	mylonitic micaschist	Grt1+Pl+Bt+K-Fs	---------			
Algyő-52/5	Algyő-52	2569–2572	Algyő-high	micaschist		Ar-Ar Ms		-------------	58.4±1.3
Újszentiván-2/9	Uszi-2	3395–3398	Algyő-high	micaschist		Ar-Ar Ms		85.5±1.2	84.1±1.3
Ferencszállás-K-6/3	F-K-6	2345–2351	Algyő-high	micaschist		Ar-Ar Ms		90.2±1.0	88.9±1.2
Ferencszállás-13/18	F-13	2570–2572	Algyő-high	micaschist		Ar-Ar Ms		82.4±1.4	81.3±1.5
Ferencszállás-K-3/5	F-K-3		Algyő-high	micaschist		Ar-Ar Ms		82.9±1.8	81.3±1.9
Kiszombor-7/4	Zomb-7		Algyő-high	micaschist		Ar-Ar Ms		-------------	95.2±1.8
Forráskút-12/6	Fkút-12	3136–3139	Algyő-high	micaschist		Ar-Ar Ms		-------------	70.2±1.4
Üllés-31/7/1	Ü-31	2959	Algyő-high	micaschist		Ar-Ar Ms		87.7±1.6	87.1±1.8

Table 2: Sm-Nd and Rb-Sr isotopic data from the Algyő basement-high and the Villány-Bihar Subunit.

Probe	Nd [ppm]	Sm [ppm]	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	±2sm
Do-7/10 L	70.2	22.9	0.1967	0.512036	0.000011
Do-7/10 Fs	36.6	6.01	0.0993	0.511884	0.000005
Do-7/10 Grt2	9.97	7.55	0.4578	0.511245	0.000014
Do-7/10 Grt1	10.9	7.45	0.4148	0.512446	0.000012
Sample	**Rb [ppm]**	**Sr [ppm]**	**$^{87}Rb/^{86}Sr$**	**$^{87}Sr/^{86}Sr$**	**±2sm**
Földes-6/2 whole rock	54.7	299.0	0.5296	0.70657	0.00009
Földes-6/2 Bt	183.7	17.61	30.440	0.79156	0.00006

5400 Fisons Isotopes® mass spectrometer. Age calculation was done after corrections for mass discrimination and radioactive decay using the formulas given in Dalrymple et al. (1984). The J-values are determined with internal laboratory standards, calibrated by international standards including muscovite Bern 4M (Burghele 1987) and amphibole MMhb-1 (Samson & Alexander 1987). The errors given on the calculated age of an individual step include only the 1σ error of the analytical data. The error of the plateau and total gas ages includes an additional error of ±0.4 % on the J-value, based on repeated measurements of the standard.

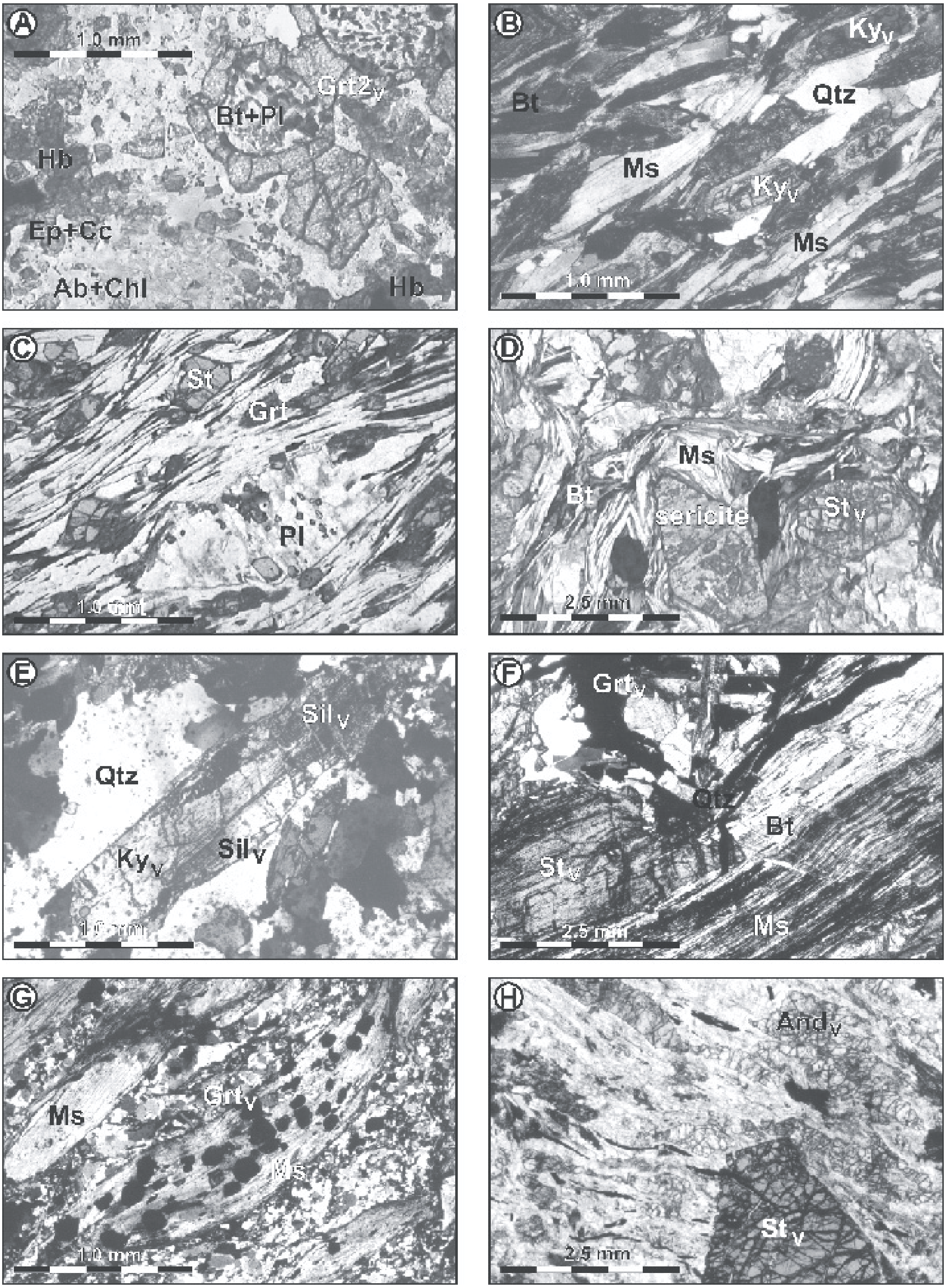
The samples used for isotope analyses are described in the Appendix.

Petrographic description

Crystalline rocks of the logs were investigated by petrographic and geochronological methods. During the first phase of this research more than a thousand thin sections were investigated from all the tectonic units mentioned above to get an overall picture of the main characters of the metamorphic rocks. It turned out that the microtextural features of Al_2SiO_5 polymorphs in metapelites are useful to group the rocks into regional units, which can be correlated with the geochronological age groups.

In the following section, we describe characteristic features of the investigated samples grouped according to the classical tectonic subdivision of the GHP of the quoted authors. Sam-

Fig. 3. Lithologies of the Villány-Bihar and Békés-Codru Subunits. **A** — Retrogressed eclogite, Mezősas-2/2274–2280 m. **B** — Kyanite-bearing micaschist, Szarvas-8/4. **C** — Staurolite-garnet-bearing micaschist, Szarvas-8/4. **D** — Cataclastic, staurolite-bearing micaschist, Öcsöd-3/1. **E** — Kyanite-sillimanite-bearing gneiss, Szeghalom-15/4. **F** — Staurolite-garnet-bearing micaschist, Álmosd-1/10. **G** — Mylonitic garnet micaschist, Földes-12/3. **H** — Staurolite-andalusite-bearing micaschist, Ruzsa-7/8. Photos A–E and H: plane-polarized light; F and G: crossed-polarized light. Lettering in the index of minerals refer to the proposed age of the mineral: V=Variscan, P=Permo-Triassic, A=eo-Alpine.


A
1.0 mm
Grt2V
Bt+Pl
Hb
Ep+Cc
Ab+Chl
Hb
B
KyV
Bt
Qtz
Ms
KyV
Ms
1.0 mm
C
St
Grt
Pl
1.0 mm
D
Ms
Bt
sericite
StV
2.5 mm
E
SilV
Qtz
KyV
SilV
1.0 mm
F
GrtV
Qtz
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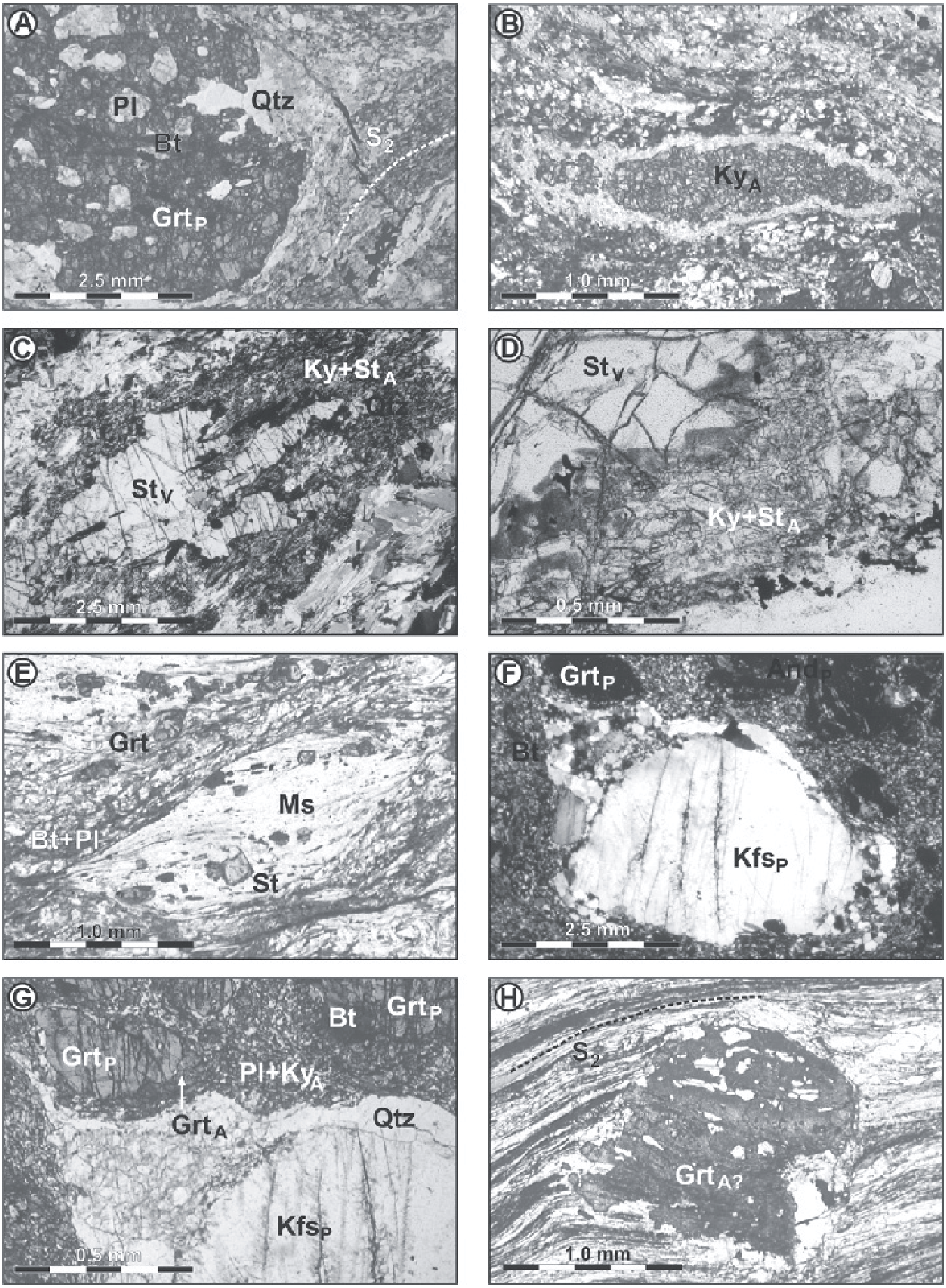
A
Pl
Qtz
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S_2
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B
Ky$_A$
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C
Ky+St$_A$
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2.5 mm
D
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Ky+St$_A$
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E
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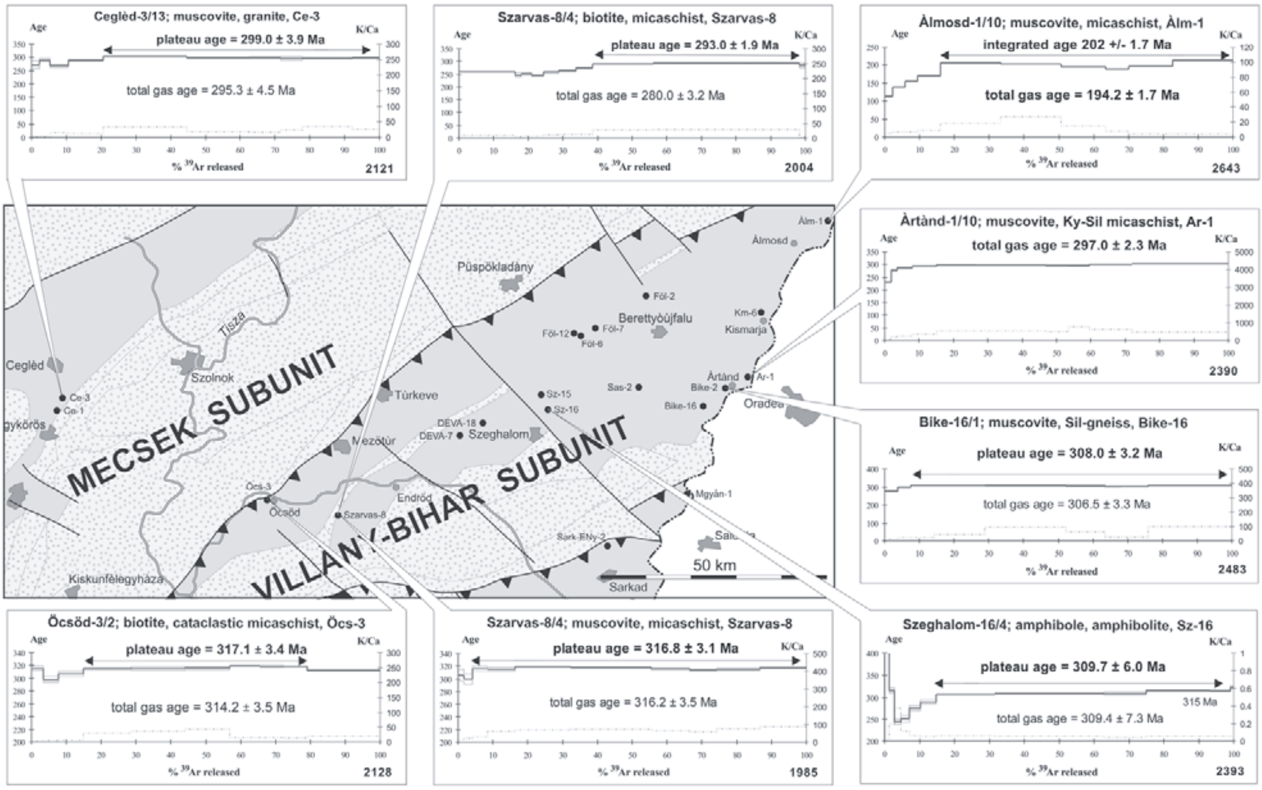

Fig. 5. ^{40}Ar-^{39}Ar age data from the Mecsek- and Villány-Bihar Subunit. Muscovites, biotite and hornblende yield ages in the range of 317±4 to 293±2 Ma. They represent Variscan cooling ages. The younger age from Álmosd is interpreted as a rejuvenated Variscan age.

ple locations and additional information are given in Table 1 and Figs. 5–8.

Mecsek Subunit

Metamorphic rocks of this subunit crop out outside the GHP, to the west of the river Danube in Transdanubia, in the Mórágy Hill. Starting from there a long, SW to NE directed granitoid range, flanked by gneisses and micaschists is known in the subsurface basement of the GHP. Al_2SiO_5 modifications were not described from this area until now.

Fig. 4. Lithologies of the Algyő basement-high. **A** — Mylonitic garnet micaschist, Dorozsma-38/2/1: Garnet porphyroblast (G_P) with large inclusions of biotite and plagioclase within a fine-grained mylonitic matrix (S_2) composed of biotite+plagioclase+quartz+chlorite. **B** — Mylonitic kyanite-biotite schist, Dorozsma-38/2/1: fine-grained kyanite pseudomorph after andalusite in a fine-grained biotite-rich matrix. The kyanite aggregate is replaced by sericite along the edges. **C–D** — Staurolite kyanite-bearing micaschist, Újszentiván-2/9. **E** — Garnet-staurolite-bearing S-C mylonite, Forráskút-12/6. **F–G** — Mylonitic garnet-K-feldspar-bearing micaschist, Dorozsma-7/10. **H** — Garnet-bearing micaschist with graphite pigment: Ferencszállás-K-6/3. The photos A–F and H: plane polarized light; G: crossed-polarized light. Lettering in the index of minerals refer to the proposed age of the mineral: V = Variscan, P = Permian–Triassic, A = eo-Alpine.

Villány-Bihar Subunit

The VBU is a composite subunit with internal thrusts, where cataclastic crystalline rocks were thrust over differently metamorphosed Mesozoic sedimentary and magmatic rock sequences (Pap 1990; Árkai et al. 1998). Sillimanite is widespread among Al_2SiO_5 polymorphs, and kyanite porphyroblasts occur in some lithologies. Retrogressed eclogites were described from several logs along a zone exceeding 50 km, parallel to the confining lineaments (M. Tóth 1995, 1997). A new occurrence of retrogressed eclogite was identified in the log Mezősas-2. At present it is the easternmost occurrence in this narrow eclogite belt.

Even if the high-pressure minerals are almost completely destroyed by later overprint, the eclogitic origin is documented by the microfabrics (Fig. 3A). The eclogite facies assemblage included $garnet_1$ + omphacite ± hornblende ± phengite + quartz + apatite + rutile. Garnets are up to 1 mm in diameter. In many cases they exhibit typical atoll-shapes with cores replaced by symplectites of biotite and plagioclase. The latter are interpreted as remnants of a Ca-rich, high-pressure $garnet_1$, which has been partly or fully replaced during an amphibolite facies overprint, whereas the rims ($garnet_2$) remained stable. Omphacite is not preserved. However the typical symplectite textures of diopside and plagioclase replacing omphacite are very common. Greenish hornblende crystals up to 1 mm are often surrounded by epidote and/or carbonate. During a greenschist facies overprint diopside has been replaced by fine-grained, faint green mineral aggregates including chlorite.

Essential rock-types of VBU are fine-grained biotite-plagioclase gneisses interlayered with coarse, K-feldspar-bearing augengneisses, amphibolites and biotite-amphibole gneisses. Subordinate micaschists contain kyanite porphyroblasts (Fig. 3B) and staurolite (Fig. 3C,D). Garnet is a common component in all lithotypes. Several pre- syn- and post-tectonic types can be distinguished. Small garnet inclusions in plagioclase are typical. Kyanite is present as up to some mm in size, and sometimes deformed porphyroblasts. It is often replaced by sericite or coarse-grained muscovite. In one case kyanite replacement by sillimanite has been observed (pers. comm. by Zachar; Fig. 3E). Sillimanite is generally associated with biotite flakes, occurring along borders of quartz rods and as microveins cutting earlier structures. Andalusite was found in one log forming a coarse-grained andalusite-quartz-vein.

In the NE part of the VBU Al_2SiO_5 polymorphs are not known. In the area of Álmosd coarse-grained micaschists and amphibolites are present (see also Árkai 1987). The micaschists are characterized by a mica-rich matrix and assemblages containing staurolite and garnet (Fig. 3F). Garnet forms round grains, often present as inclusions within staurolite. Garnet is also present as atoll-shaped crystals with cores replaced by biotite and quartz. Late staurolite idioblasts contain intrafolial folds marked by graphite pigment. Postkinematic biotite, muscovite and chlorite idioblasts measuring up to 8 mm crosscut the schistosity planes. Quartz-rich bands show static recrystallization with fine mica flakes and staurolite poikiloblasts with quartz inclusions. Near to Földes mylonitic micaschists (Fig. 3G), marbles and carbonate-micaschists occur together with amphibolites.

Békés-Codru Subunit

There is a distinct contrast compared to the northern subunit as no solitary kyanite porphyroblasts occur here, but instead andalusite porphyroblasts are common in a northernmost narrow zone. In other areas Al_2SiO_5 polymorphs were not found.

The coarse-grained andalusite-bearing gneisses contain augens of feldspars and coarse muscovite flakes embedded in a finer-grained mica matrix, often showing S-C structure. The main foliation (S_2) is defined by muscovite, biotite and idioblasts of ilmenite. Coarse mica flakes contain porphyroblasts of garnet, staurolite and plagioclase. The S_1 foliation occurs as relics of crenulations outlined by white mica within plagioclase. Garnet makes up solitary idioblasts in the matrix and is included in staurolite. It is partially replaced by coarse biotite flakes and/or chlorite. Staurolite idioblasts are marginally replaced along fractures by sericite and chlorite. Large biotite flakes are strongly kinked. Plagioclase occurs as augens, some of them with strong zoning and as porphyroblasts partially overgrowing also the main schistosity S_2. Andalusite porphyroblasts invade all pre-existing textures. They are partially replaced by sericite (Fig. 3H).

Algyő basement-high

In the surroundings of the village of Algyő a structural basement-high has long been known. In this area lithologies are varied with different types of gneisses, micaschists, amphibolites, chlorite schists, quartzites, pure and impure marbles. Most of the rocks exhibit clear indications for a polymetamorphic history, with the whole range of typical deformational microtextures. Minor texturally prograde rocks without later overprint also occur.

Banded, mylonitic gneisses represent a very characteristic lithology. They are fine-grained and dark-coloured, due to high biotite content and graphitic pigment. In between there are light-coloured layers of quartz and feldspar up to several cm thick. Pre-mylonitic garnet porphyroblasts up to 2 cm in diameter are frequent. Typically they contain coarse-grained inclusions of biotite and plagioclase (Fig. 4A), indicating a pre-mylonitic coarse-grained microtexture of the rocks. Porphyroblasts of K-feldspar and relics of staurolite occur in some cases. There are also patches of fine-grained kyanite (Fig. 4B). Szederkényi (1984) interpreted them as relics of pre-existing andalusite and our investigations support this idea. However they also partly represent former staurolite or sillimanite. Staurolite and K-feldspars attain more than 1 cm in diameter (Fig. 4C,F).

An overprint in the stability field of kyanite + staurolite + garnet occurred contemporaneously to a ductile deformation of the rocks. Deformation caused the development of a mylonitic foliation S_2, defined by fine-grained biotite, plagioclase and quartz (Fig. 4E), as well as by newly formed muscovite. The pre-existing garnet, staurolite and K-feldspar crystals acted as porphyroclasts with respect to S_2. In many cases the garnet porphyroblasts were broken and overgrown by a younger garnet generation. The latter is rich in inclusions and also present as tiny, anhedral grains in the matrix (Fig. 4F,G). The K-feldspars were ductilely deformed and are preserved as augens with subgrains along the crystal edges (Fig. 4F,G). Staurolite was partly or fully replaced by fine-grained idioblasts of kyanite and staurolite (Fig. 4C,D). The kyanite pseudomorphs are elongated within the mylonitic foliation. A greenschist facies retrogression of various degrees caused chloritization of garnet and the formation of chlorite and sericite in the matrix.

In logs from Ferencszállás graphite-rich micaschists occur with a fine-grained, mica-rich matrix overgrown by garnet porphyroblasts and large biotite flakes (Fig. 4H).

Geochronological results

The ^{40}Ar-^{39}Ar analytical data and age spectra are presented in Figs. 5–8, the Rb-Sr and Sm-Nd analytical data in Table 2 and Figs. 6 and 9. All geochronological analytical data are available from the authors.

Mecsek Subunit

Muscovite from a granitoid (sample Cegléd-3/13) yielded an Ar-Ar plateau age of 299±4 Ma (Fig. 5). This age is in agreement with other Variscan ages from this subunit (Klötzli et al. in print).

Villány-Bihar Subunit

From the eclogite zone an amphibole separate from an amphibolite (Szeghalom-16/4) has been dated. It yields a plateau type Ar release pattern with an age of ca. 310±6 Ma and an oldest age domain of 323 Ma. The low temperature steps show a staircase pattern with minimum ca. 250 Ma and an excess Ar content in the first two steps (Fig. 5).

Sillimanite and kyanite-porphyroblast bearing rocks supplied plateau-type Ar-Ar muscovite ages in the range of 297±2–317±3 Ma (Ártánd-1/10, Szarvas-8/4, Biharkeresztes-16/1), whereas an age of 293±2 Ma were obtained on a biotite (Szarvas-8/4). Also a muscovite concentrate, separated from a cataclastic micaschist from a tectonic slice near to the northern border of the unit, yielded a plateau-type age spectra with an age of 317±4 Ma (Öcsöd-3/2; Fig. 5). These data are in the range of typical Variscan cooling ages.

From the NE part of this subunit younger Ar-Ar ages have been determined (Fig. 6). Muscovite and biotite from Földes yield plateau type Ar-spectra of 266±4 Ma (Földes-12/3) and 223±2 Ma (Földes-6/2). Rb-Sr dating of biotite from a biotite-bearing amphibolite (Földes-6/2) yields 200±2 Ma (Fig. 6). Although there is no large spread in the $^{87}Rb/^{86}Sr$ ratio, the age is well defined, but it is either a typical Variscan or an Alpine age value. From a staurolite-garnet micaschist from Álmosd-1/10 a saddle-shaped Ar-Ar muscovite age pattern of ca. 202±2 Ma was obtained with a distinct rejuvenation at the outermost rim.

Békés-Codru Subunit

Plateau type Ar-Ar muscovite ages from the main part of this subunit are in the range of 305±3 Ma to 322±4 Ma, measured from coarse-grained andalusite-bearing gneisses (Ruzsa-7/8, Ruzsa-D-1/3, Sarkadkeresztúr-ÉNY-2/4, Mezőgyán-1/5; Fig. 7). Gneisses without andalusite from this subunit also fit this range (Ásotthalom-11/2, Kelebia-3/9).

Additionally, a log from Pusztaföldvár (P-222/6) with a narrow but rather intense ductile deformation zone, exhibiting postkinematic growth of white micas, was investigated. Muscovite yields a plateau-type age pattern of 309±3 Ma with no significant rejuvenation in the low temperature steps. From a diaphtoritic mylonite (Szeged-11/6) two separates of fine-grained (0.1–0.2 mm) white mica, contaminated by a small amount of chlorite were measured. The purer sample yielded an Ar-Ar age of 317±3 Ma, whereas the other gave 301±3 Ma.

Algyő basement-high

In this tectonic unit the age of the oldest mineral assemblage was determined by Sm-Nd analyses from garnet and kyanite-bearing mylonites (Dorozsma-7/10). The isochron, calculated from a porphyroclastic garnet separate (Grt_1) and a feldspar concentrate (Fs) yielded a Permian age of 273±7 Ma (Fig. 9). Additional analyses of a leached garnet (Grt_2) and the leachate (L) do not fit exactly to the isochron. However, all ages that can be calculated between the four data points are in the range of 287 to 242 Ma and indicate a Permian age.

The cooling age of the following, amphibolite-grade overprint was determined by Ar/Ar analyses on muscovites: six yielded plateau or plateau-type ages. Four of them fall into the narrow range of 82±1–88±2 Ma (Ferencszállás-K-3/5, Ferencszállás-13/18, Üllés-31/7/1, Újszentiván-2/9), and two spectra exceed 90 Ma and exhibit slightly disturbed and saddle-shaped patterns (Ferencszállás-K-6/3, Kiszombor-7/4). Compared with the other samples, they have the same crystallization and deformation history. The reason for the higher ages is uncertain. Limited rejuvenations of ca. 70 Ma in low-temperature steps are present in four of the samples. Two S-C mylonites, attaining biotite-grade at Forráskút-12/6 and chlorite-grade at Algyő-52/5 supplied saddle-shaped age pattern of the relict micas with distinctly lower total gas ages of 58±1 and 70±1, proving a distinct rejuvenation after the Late-Cretaceous cooling. The youngest ages from the low-temperature steps are 53 and 42 Ma respectively, which indicate an Early Tertiary deformation (Fig. 8).

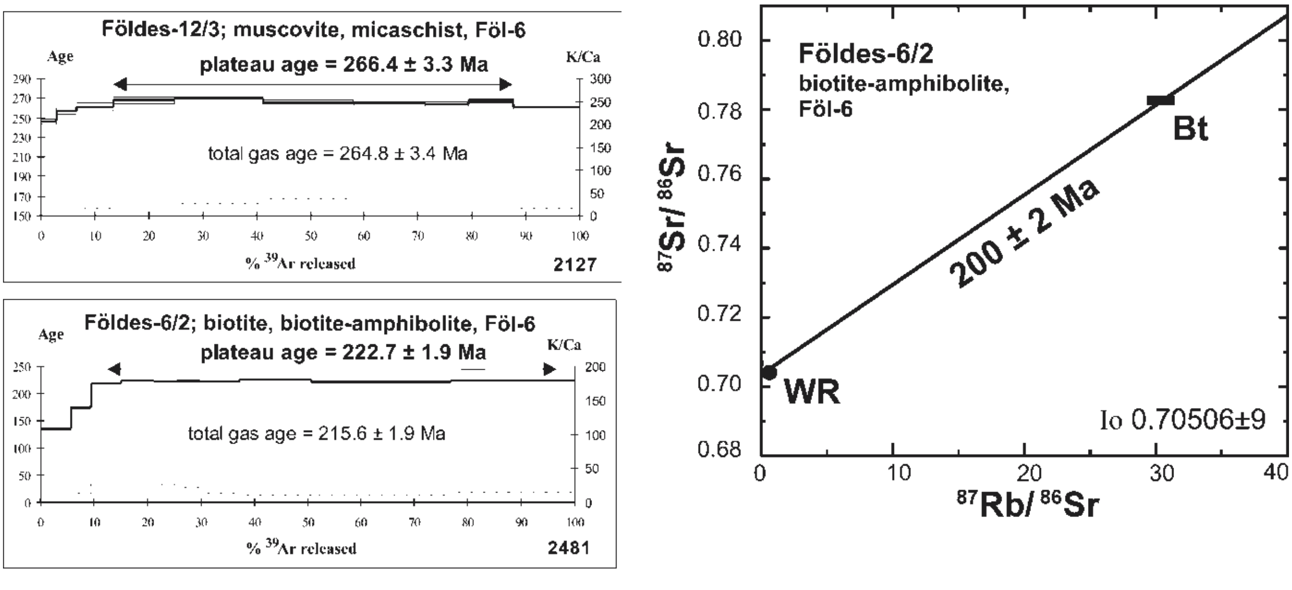

Fig. 6. Ar-Ar and Rb-Sr age data from Földes in the NE-part of the Villány-Bihar Subunit. The ages in the range of 266±3 Ma to 200±2 Ma are interpreted as rejuvenated Variscan ages.

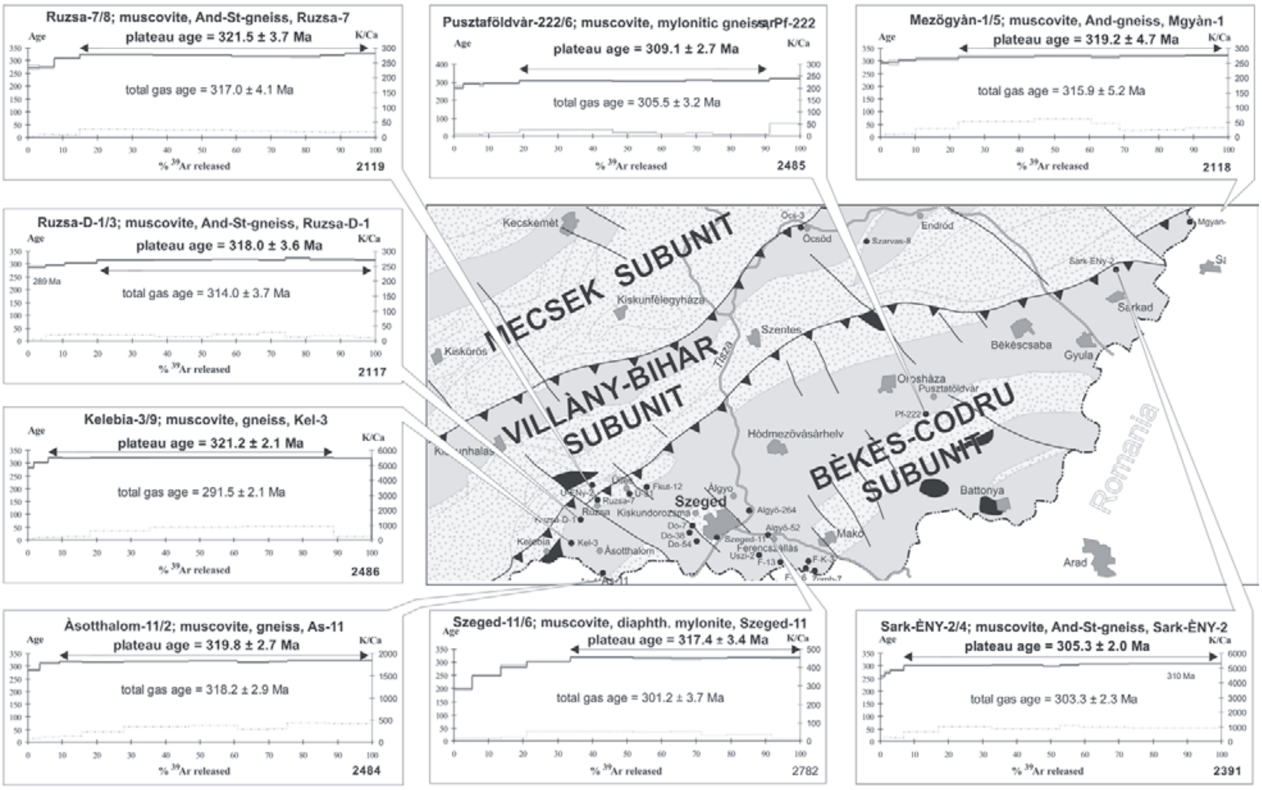

Fig. 7. Ar-Ar muscovite ages from the Békés-Codru Subunit. The age data in the narrow range of 323 Ma to 305 Ma reflect cooling ages of the Variscan tectonometamorphic event.

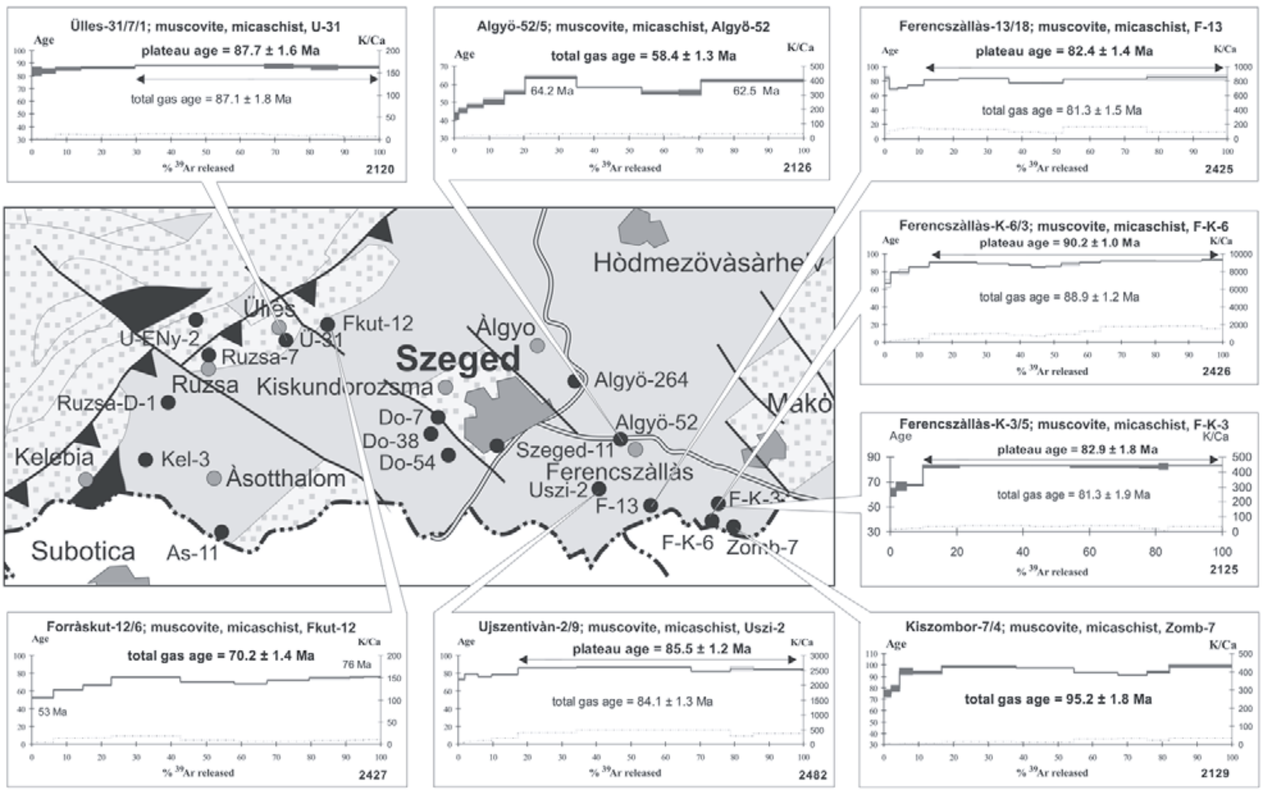

Fig. 8. Ar-Ar muscovite ages from the Algyő basement-high. The data in the range of 82 Ma to 95 Ma are interpreted as eo-Alpine cooling ages. The lower values (58–70 Ma, Algyő-52 and Forráskút-12) represent rejuvenated and disturbed spectra from relictic white micas from low-grade S-C mylonites, deformed during the Early Tertiary.

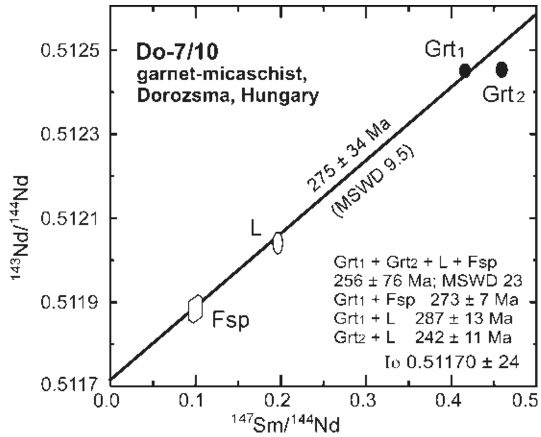

Fig. 9. Sm-Nd garnet isochron from the Algyő basement-high. The age is interpreted as the formation age of the high-temperature/low-pressure assemblage of the rocks.

Discussions

In this chapter the distribution of the Al_2SiO_5 polymorphs and the new geochronological age data is discussed, with respect to the established tectonic subdivision of the basement of the GHP. After that the metamorphic histories of the basement blocks are compared to each other.

Metamorphic evolution of the Villány-Bihar Subunit

The main stages of the metamorphic evolution in the VBU are an eclogite facies imprint preserved only within metabasic rocks, and a subsequent amphibolite- and greenschist facies overprint. The eclogite facies assemblage included garnet$_1$+ omphacite ± hornblende$_1$± phengite ± kyanite ± zoisite + quartz + apatite + rutile + ore. The eclogites exhibit several stages of retrograde overprints, causing the formation of different types of symplectites. During an amphibolite facies overprint most of the high-pressure minerals were destroyed and an assemblage including garnet$_2$+ diopside+plagioclase + biotite + hornblende$_2$+ ore developed. Greenschist facies retrogression is displayed by chloritization of diopside and the crystallization of epidote and carbonate.

M. Tóth (1997) proposed two distinct metamorphic cycles for the P–T–t evolution of the eclogitic rocks. In this model the first event caused the eclogite facies imprint, with pressures up to 10–12 kbar and 600–650 °C. For this event a Caledonian age was suggested (Szederkényi 1996). It was followed by exhumation to greenschist facies crustal levels. The subsequent amphibolite facies event and the following greenschist facies retrogression have been proposed to be Variscan in age. However, there are no geochronological age data available, giving the age of the eclogite facies event. From our petrographic investigations the eclogite facies assemblage and the overprinting amphibolite facies assemblage can be placed within the frame of a single clockwise P–T–t evolution path.

The investigated metapelites of the VBU show clear evidence of a medium- to high-pressure amphibolite facies metamorphic event. In the metapelites assemblages of garnet + kyanite + staurolite are followed by the formation of sillimanite and later greenschist facies retrogression. This clockwise P–T–t path can be correlated with the post-eclogite facies evolution of the eclogites. Cooling ages measured with several methods on different lithologies yielded ca. 308±3–317±3 Ma and point to a Variscan age of this tectonothermal event. As there are no indications for an older metamorphic assemblage in the country rocks, and as we could not find indications for a two stage metamorphic evolution in the eclogites we favour an early Variscan age of the eclogite facies event.

Several samples yielded Ar-Ar muscovite ages younger than typical Variscan cooling ages in the NE part of this subunit. A plateau type age of 297±2 Ma from Ártánd is only slightly younger, whereas coarse muscovite "fishes" from a mylonitic micaschist without kyanite from Földes yield a remarkably younger age (266±3 Ma). Important for the interpretation of this area is the Rb-Sr biotite age of 223±2 Ma from the same locality (see below). Also a muscovite from the texturally undisturbed amphibolite facies metamorphic rocks of Álmosd yielded a saddle-shaped Ar-Ar spectra of 202±2 Ma and a distinct rejuvenation in the low-temperature steps.

These younger ages of the NE part of the VBU might reflect an independent Permian event, or a rejuvenation of Variscan ages during a later, Cretaceous overprint.

One argument for a Permian–Triassic age comes from the geochronological age data: to open and fully reset the Ar-Ar isotopic system in muscovite, temperatures of at least up to 420 °C are necessary. At these temperatures a total reset of the Rb-Sr biotite ages can be expected. Therefore the Rb-Sr biotite age of ca. 220 Ma supports a Triassic cooling of the rocks. Ar-Ar muscovite ages in the range of 280 to 190 Ma together with Rb-Sr biotite ages of 225 to 150 Ma have been found in several parts of the Austroalpine crystalline basement unit, where the Cretaceous overprint did not exceed lowermost greenschist facies conditions. These data are interpreted as reflecting cooling from a high to a lower geothermal gradient, during a Permo-Triassic extensional event (Schuster et al. 2001). Our data from the VBU are definitely too scarce to justify such an interpretation. However, similar data were recently published from the Szeghalom structural basement-high (Balogh in M. Tóth et al. 2000). A series of ten K-Ar data on amphibole concentrates yielded three age groups of 315, 260 and about 220 Ma.

On the other hand several facts argue for an eo-Alpine overprint of the rocks: the existence of a Cretaceous event along the northern border of the VBU is well documented by Árkai et al. (1998). Fine-grained (<2 μm) mica from Mesozoic sediments situated beneath overthrust complexes, as well as from polymetamorphic rocks of the overthrust tectonic slices yielded Cretaceous ages in the range of 64 to 99 Ma. Very low- to low-grade metamorphic conditions were reached during mylonitic and cataclastic deformation of the rocks. In our data this Cretaceous overprint is hardly visible, because we investigated the coarse white mica flakes belonging to the main Variscan mineral assemblages. For example the cataclastic gneisses from log Öcsöd represent crystalline rocks thrust over Cretaceous metabasites. Its coarse-grained muscovite yielded an age of 317±3 Ma, but there is also a fine-grained sericite present in the sample, which has not been investigated during this study.

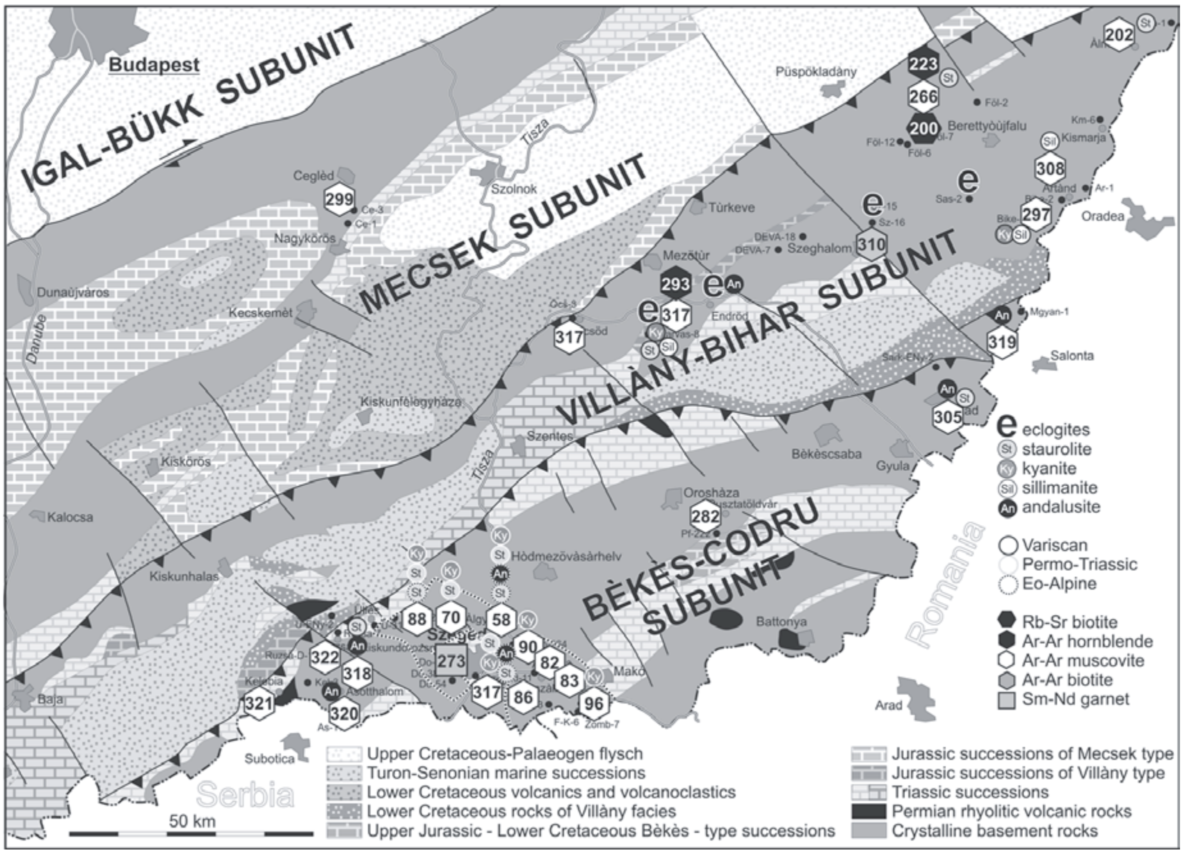

Fig. 10. Sub-surface map of the Great Hungarian Plain, showing the distribution of the index minerals and the geochronological age data. Kyanite porphyroblasts and sillimanite is restricted to the VBU, while andalusite porphyroblasts are widespread in the BCU. Kyanite and andalusite porphyroblast-bearing rocks of the VBU and BCU supplied exclusively Variscan ages. In the NE part of the VBU, in the area of Földes and Álmosd ages younger than typical Variscan cooling ages were found. The Algyő-high is characterized by ubiquitous kyanite aggregates, a Permian age of garnet porphyroclasts and middle Cretaceous to Tertiary Ar-Ar muscovite ages.

Another argument is that the Triassic facies evolution of the VBU is characterized by a clastic Upper Triassic (Keuper) succession. Such a sedimentary environment is not expected when a Permian lithospheric thinning associated with prograde metamorphism took place (Schuster et al. 2001).

However, at present we have to leave it open, whether the younger ages in the NE part of the VBU are due to rejuvenation caused by an eo-Alpine overprint or a prolonged cooling history during Permian–Triassic times. Further investigations are in progress to solve this question.

Metamorphic evolution of the Békés-Codru Subunit

Assemblages containing andalusite and staurolite indicate low-pressure amphibolite facies conditions along the northern border of the BCU from Ruzsa in the SW to Mezőgyán in the NE for the dominant metamorphic imprint. Muscovite from these coarse-grained assemblages yielded cooling ages in the range of 305–322 Ma. The same range was also obtained from rock types without andalusite. A mica-rich fraction from a mylonitic micaschist coming from Szeged, from the flank of the Algyő basement-high also fits this range, even if the Ar-pattern shows distinct rejuvenation in the low-temperature steps.

Metamorphic evolution of the Algyő basement-high

From the basement-high in the surroundings of Algyő a series of samples with characteristic features have been investigated, which are not known from other locations in the Tisza Megaunit. On the basis of the microfabrics at least two metamorphic events can be distinguished in most of the samples: in the samples from Dorozsma: a first, coarse-grained assemblage including garnet$_1$ + staurolite$_1$ + plagioclase + K-feldspar + quartz ± muscovite developed. Relics of kyanite aggregates render possible the former presence of andalusite and sillimanite. The occurrence of andalusite, sillimanite and K-feldspar clearly indicate high temperature/low pressure characteristics and high-amphibolite to granulite facies conditions. Considering the Sm-Nd garnet isochron age this association formed in Permian time at ca. 275 Ma.

Several previous papers deal with the P-T conditions of the first metamorphic imprint in the Algyő basement-high. Szederkényi (1984) found 570–630 °C at about 2 kbar in amphibolites from Algyő. In contrast Horváth & Árkai (2002) determined 520–560 °C and 8–10 kbar from Ferencszállás. The latter conditions are far outside the stability field of andalusite and sillimanite. A possibility to explain this misfit is to suppose that the Algyő basement-high itself is a composite unit. Partly it consists of rocks with a first Variscan assemblage of medium- to high-pressure characteristics, whereas other parts got their first imprint during a Permo-Triassic high-temperature/low-pressure event. At first sight this interpretation might seem to be unlikely, but in the Austroalpine unit such a situation has been observed (Schuster et al. 2001) (see also discussion below).

The second event caused the formation of the main assemblage garnet$_2$ + kyanite ± staurolite$_2$ + plagioclase ± muscovite + quartz and a contemporaneous mylonitization of the rocks. With respect to the equilibrium assemblage kyanite + staurolite + garnet, medium-pressure amphibolite facies event can be assumed. Recently conditions of 650–680 °C at 5–9 kbar have been published for this overprinting event (Horváth & Árkai 2002). At present the exact timing of the peak of this metamorphic imprint is unknown. However, all investigated samples yielded Ar-Ar muscovite cooling ages in the range of 82 to 95 Ma, without any older relics. Similar ages by Balogh & Pécskay (2001) were also reported. These data indicate an eo-Alpine age of the imprint. After the metamorphic peak a greenschist facies overprint occurred. It caused sericitization and chloritization during ongoing deformation. The intensity of this overprint is variable in the different samples. It might explain the younger Ar-Ar muscovite ages of 58 to 70 Ma.

Algyő basement-high and Austroalpine Saualm-Koralm Complex

On the basis of the new results the rocks from the Algyő-high exhibit a completely different evolutionary history compared to other basement rocks of the Tisza Megaunit. As mentioned in Lelkes et al. (2001, 2002) the very special lithologies of the Algyő-high resemble the metamorphic succession of the Saualm-Koralm Complex and the Strallegg Complex of the Austroalpine domain in the Eastern Alps. The latter forms eo-Alpine thrust sheets, which hold high tectonic positions in the eo-Alpine nappe stack (Weissenbach 1975; Frank 1987; Krohe 1987; Schuster et al. 2001). They were affected by Permo-Triassic lithospheric extension (Habler & Thöni 2000; Schuster et al. 2001), and an intense eo-Alpine tectonometamorphic overprint (Frank 1987; Thöni & Miller 1996). Lithospheric extension caused a high-temperature/low-pressure metamorphic imprint in the stability field of andalusite and sillimanite and the formation of gabbroic intrusions and numerous anatectic pegmatites. The Cretaceous overprint reached eclogite and following amphibolite facies conditions and the pre-existing andalusite and sillimanite were replaced by kyanite aggregates. This was accompanied by mylonitization during exhumation processes including N- to NW-directed thrusting.

The microtextural features of the Algyő basement-high are very similar to those of the Saualm-Koralm Complex and give additional argument for the metamorphic history discussed above.

Contrasting metamorphic evolutions

In the past, several authors proposed pre-Variscan metamorphic evolution for parts of the crystalline basement in the GHP. However, at present either geochronological age data or undoubted microtextural observations prove such interpretations.

The oldest available age data in the range of 300 Ma to 330 Ma have been measured on hornblende and muscovite by the K-Ar and Ar-Ar method. As they derive from medium-grade rocks, they have to be interpreted as metamorphic cooling ages. They indicate a Variscan age of the dominant tectonothermal imprint. At present nothing is known about the exact timing of the eclogite facies event, or about the timing of the metamorphic peak in the VBU or BCU.

For the understanding of the Variscan geodynamic evolution of the area, it would be important to know if the andalusite in the BCU developed contemporaneously to the pressure peak and the kyanite formation, or synchronously to the temperature peak and the sillimanite formation in the VBU. In the first case a completely different tectonic setting is evident, whereas in the second case only different metamorphic conditions during the exhumation of the rocks can be assumed. However, as kyanite porphyroblasts overgrown by sillimanite and andalusite occur in different basement blocks, and no other Al_2SiO_5 polymorph have been found in the andalusite-bearing lithologies, there is no microtextural evidence about the relative age relationship of these minerals in the units of the GHP. This is in contrast to the SW part of the Tisza Megaunit in Transdanubia: in the Mecsek Subunit both kyanite and andalusite are known from the same rock and andalusite is a late crystallization phase overgrowing kyanite (Lelkes-Felvári et al. 1989; Török 1990).

A key point in understanding the contrasting histories of the Algyő basement-high with respect to the surrounding BCU, are the ages of the andalusite-bearing mineral assemblages. In the BCU andalusite is well preserved and like the coexisting garnet, it is Variscan in age. On the other hand, in the Algyő-high andalusite is totally transformed into kyanite aggregates during the eo-Alpine tectonothermal event; one would conclude that lithologies from the BCU were the precursor rocks of the Algyő-high. The important observation, that the first generation of garnet in the Algyő basement is Permian in age — although only demonstrated up to now in a single sample — is not compatible with this assumption. The Permian garnet age is likely also because of the remarkable analogies of the Algyő-high and the Austroalpine Saualm-Koralm Complex.

There is another remarkable difference in the tectonic evolution of the different crustal blocks in the GHP. In the VBU Lower Permian rhyolites are only described from one restricted area, and tectonic contacts of the Mesozoic sediments to the crystalline basement rocks are proved in several places. As the rocks cooled down at about 310 Ma, they stayed in a shallow crustal level since that time, and we do not know when they reached the surface. In contrast, in the BCU Lower Permian rhyolites and Lower Triassic redbeds are overlying the basement with a sedimentary contact (Majoros 1998). For this reason the basement rocks formed the surface in late Paleozoic times. As the Algyő-high experienced a Permian metamorphic imprint, located in middle crustal levels at that time, consequently, there are no Permian-Triassic sediments in stratigraphic contact.

Tectonic relationships

According to Tari et al. (1999) the Algyő basement-high represents a metamorphic dome, which formed as a core complex during Miocene extensional processes. In this model the lower part of a Variscan crustal section experienced a thermal overprint in Cretaceous times and was exhumed by a Tertiary fault system. On the basis of the new data such an interpretation is unlikely with respect to the contrasting evolution of the surrounding BCU. As mentioned before, the rocks of the Algyő-high are not the result of eo-Alpine, overprinted lithologies of the BCU. Furthermore, they experienced not only a Cretaceous thermal overprint, but also mylonitic deformation. Therefore the proposed scenario would only be possible when the BCU would have been thrust onto a basement wedge with the characteristics of the Algyő-high. This must have happened after the eo-Alpine tectonothermal event, and prior to the formation of the core complex.

Therefore we interpret the Algyő sequence as a tectonic outlier of a Cretaceous metamorphic nappe system. A similar interpretation has been already proposed by Dimitrescu (1995), on the basis of lithological correlation. He compared the sequence of the Algyő basement with the Biharia Unit, considered of that time the uppermost unit of the Biharia nappe system in the Apuseni Mountains (Balintoni 1994). Both units are characterized by carbonates, completely lacking in the surrounding basement. Cretaceous Ar-Ar ages were reported from the uppermost nappe of the Apuseni Mountains (Baia de Arieş nappe-complex, Soroiu et al. 1969; Dallmeyer et al. 1994, 1996, 1999). The exact timing of the emplacement of this nappe, resting on top of a Variscan metamorphic basement is unknown. As the Variscan basement of the BCU shows a weak, low-temperature hydrothermal alteration, we can exclude emplacement during the eo-Alpine tectonometamorphic event. The emplacement of the Algyő-high is definitely younger than the main cooling of the rocks, which is dated at ca. 80 Ma. The Ar-Ar age spectra of some micas show indications for a younger thermal overprint causing minor rejuvenation up to 40 Ma. A possible solution would be that the final emplacement of this unit occurred in the Early Tertiary.

Conclusions

The observed distribution of the Al_2SiO_5 polymorphs and the new geochronological age data confirm the established tectonic subdivision of the basement of the GHP, except for the Algyő basement-high, which has to be excluded from the VBU and considered as a separate unit.

The distribution of the Al_2SiO_5 polymorphs shows a clear regional distribution: kyanite porphyroblasts together with sillimanite are restricted to the VBU, while andalusite porphyroblasts are widespread in the BCU. The Algyő-high is characterized by ubiquitous kyanite aggregates, which are interpreted as pseudomorphs after pre-existing andalusite and minor sillimanite and staurolite.

A granite of the Mecsek Subunit yielded an Ar-Ar muscovite age of ca. 300 Ma. Variscan cooling ages of ca. 310 and 320 Ma were found in the VBU and BCU, indicating Variscan formation ages for the observed assemblages. Only in the NE part of the VBU (Földes and Álmosd) were ages younger than typical Variscan cooling ages measured. They indicate a Permo-Triassic, or an eo-Alpine thermal overprint.

In the Algyő basement-high a first Permo-Triassic HT/LP event, with peak conditions at about 275 Ma is proved at least for some lithologies. The Ar-Ar mica ages from this unit are exclusively younger than middle Cretaceous. They demonstrate the age of cooling after the amphibolite facies imprint and subsequent deformational overprint of the rocks. Considering the metamorphic and structural evolution, the Algyő-high shows many similarities to the Saualm-Koralm Complex of the Austroalpine. Similarly to the Baia de Arieş nappe-system in the Apuseni Mountains, they might represent an eo-Alpine thrust sheet. It took place on top of the BCU after the cooling of the rocks, in latest Cretaceous or Tertiary times.

The observed zonal distribution argues for distinct metamorphic histories of the different tectonic elements of the Tisza Megaunit. This implies that this terrane is not as homogeneous in a tectonic sense, as it has been presented in parts of the literature.

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Appendix

Thin section description of the samples investigated by geochronological methods. Mineral names are abbreviated according to Kretz (1983).

Mecsek Subunit

Cegléd-1/13: Medium-grained granite with mineral assemblage of Kfs+Pl+Qtz+Ms+Bt+Zrn. Ms is well preserved and up to 7 mm in size. Kfs is altered. Bt is replaced by Chl+Cc+ore.

Villány-Bihar Subunit

Öcsöd-3/2: Cataclastic St micaschist. The coarse-grained matrix is composed of Bt+Ms+Pl+Qtz. St forms idioblasts up to 3 mm partly replaced by sericite.

Szarvas and *Ártánd* area: Ky bearing, fine- to medium-grained Qtz-micaschists, Pl gneisses *(Szarvas-8/4)* and Mc gneisses *(Ártánd-1/10)*. The main foliation (S_2) is defined by micas and elongated Qtz rods. Relics of S_1 are outlined in Pl microaugens by inclusions of Qtz, St, Grt and Bt. Pl is rarely zoned (Ártánd). Postkinematic Ky idioblasts are partially replaced by Ms and sericite. St idioblasts contain Bt inclusions and are partially replaced by sericite. Sil fibres are associated to Bt. Grt makes up small idioblasts and atoll-like crystals with cores filled up by Ms+Bt+Sil.

Biharkeresztes-16/1: Coarse-grained Sil-Pl gneiss. Mica-rich layers contain deformed Bt flakes and subordinate Ms. Abundant Sil is associated with Bt. Pl xenoblasts are replaced by sericite. Spn idioblasts are evenly distributed. Late carbonate veins crosscut the rock.

Földes-6/2: Fine-grained mylonitic Bt-amphibole gneiss. Fine laminae composed mainly of acicular Am, some Bt and ore alternate with fine-grained Qtz-rich layers and coarser, Bt-rich layers containing also Cal granoblasts.

Földes-12/3: Fine-grained mylonitic Bt-Ms gneiss with Pl-microaugens attaining 3.5 mm. Recrystallized polycrystalline Ms-fishes are embedded in a Qtz matrix with very fine-grained Bt, some Ms and some small Pl granoblasts. Grt idioblasts (0.75 mm) are included in Ms and Pl, bigger crystals occur in the matrix.

Álmosd-1/9: Micaschist. Within a fine-grained Mu-rich matrix Grt (4 mm) and St (9 mm) porphyroblasts occur. The S_i of Grt idioblasts are strongly discordant to the S_e of the matrix. The cores of some atoll shaped Grt crystals are filled with coarse Bt+Qtz. Small, round Grt (2 mm) are included in St. Late St idioblasts contain intrafolial folds marked by Gr. Bt idioblasts up to 8 mm crosscut the schistosity planes. Qtz-rich bands show static recrystallization, containing fine mica flakes and St poikiloblasts.

Szeghalom-176/4: Bt-amphibole gneiss, composed of nematoblasts of Am (up to 2 mm), Bt flakes and granoblastic Qtz and Pl with relict zoning. Grt up to 2.5 mm is partially or completely replaced by Pl, with Grt relics as small islands. Pl is partially replaced by sericite. Bt up to 4 mm is almost completely replaced by Chl and Spn.

Békés-Codru Subunit

Ruzsa-7/8, Ruzsa-D-1/3, Sarkadkeresztúr-ÉNY-2/4, Mezőgyán-1/5: Coarse-grained And-bearing gneisses, often showing S-C structures. Fs augens and coarse Ms flakes are embedded in a finer-grained mica matrix rich in Bt. The main foliation (S_2) is defined by the micas, containing porphyroblasts of Grt, St and Pl. Relic of a crenulated cleavage S_1 is outlined by Ms inclusions within Pl. Grt makes up solitary idioblasts in the matrix or small inclusions in St. It is partially replaced by coarse Bt flakes and/or Chl. St is marginally replaced by sericite and Chl. Bt flakes are strongly kinked. Zoned Pl augens, occur also as late porphyroblasts including partially also S_2. And porphyroblasts invade all preexisting textures. Idioblasts of Ilm are included in the porphyroblasts and the matrix.

Kelebia-3/9: Pl gneiss with micro-augen texture. Elongated, polycrystalline augens of Pl (up to 3.5 mm) contain idioblasts of Grt (0.25 mm), green Bt, Ms and Ap inclusions. Bt flakes (2 mm) are dispersed, small flakes of Ms occur in Qtz-rich domains and are intergrown with Bt in mica-rich domains.

Ásotthalom-5/6: Garnet-bearing Ms-Bt gneiss. Fine-grained mica-rich layers contain deformed Bt flakes (up to 4 mm), partially altered to Chl, Ms flakes crowded with small, postkinematic Ms. Grt up to 5 mm is replaced by Bt. Subhedral grains of Pl (3.5 mm) are surrounded by Bt. Polygonal Qtz-rich layers contain small Ms flakes.

Pusztaföldvár-222/6: Coarse-grained garnet-bearing micaschist with strong Ms recrystallization. Bt is completely replaced by Chl and Spn aggregates. Grt (2.5 mm) is replaced by Chl. Within a narrow ductile shear zone Ms suffered grain size reduction and Chl and Cal appear as a new mineral phase.

Szeged-15/5: Mylonitic micaschist with quartz ribbons. In the Ms-rich, fine-grained matrix some Chl is present making up postkinematic flakes and lenses along opacitic seams. Elongated porhyroclasts of Grt (up to 1 cm) are replaced by carbonate and Chl. Pl xenoblasts contain Ep aggregates.

Algyő basement-high

Algyő-52/5: Mylonitic S-C quartz-micaschist. Qtz and mica-rich bands alternate. It is cut by thin penetrative shear-plains with grain-size reduction. Mica-rich bands are composed of deformed, recrystallized Ms and Bt fishes set in a finer-grained matrix of decussate flakes of Ms and Bt. Grt is broken, elongated and partially replaced by Ms+Bt+Chl+ore. Pl forms polycrystalline augens and lenses with Bt inclusions and recrystallized mosaic structures.

Ferencszállás-K-3/5: Micaschist, gently folded with anastomosing very fine, brittle, chloritic shear planes. In the matrix composed of decussate flakes of Ms and finer-grained Bt round, broken Grt porphyroclasts occur. They are up to 3 mm and partially replaced by Bt and Chl.

Ferencszállás-K-6/3: Banded, fine-grained, slightly folded micaschist. Late idioblasts of Grt (up to 2.5 mm) include folded trails of Gr, slightly discordant to S_e. Further they make up atolls with Qtz and Bt-rich cores. Chl flakes (1.5 mm) occur in the pressure shadows of Grt. Qtz-rich bands show static recrystallization.

Ferencszállás-13/18: Banded Ms-Bt paragneiss with mylonitic foliation. Mica-rich bands composed of decussate Bt+Ms flakes alternate with Qtz-rich bands with granoblastic textures. Pl contains relics of earlier folds enhanced by Bt flakes. Prekinematic porphyroblasts of Grt are up to 4 mm and show inclusions of Bt and Rt.

Üllés-31/7: Crenulated micaschist. Mica-rich bands of decussate flakes of Bt+Ms alternate with Qtz+Pl-rich bands. Two generations of St can be distinguished: St_1 attaining several mm occur as isolated relics with uniform optical orientation within aggregates of Ky±St. They often have dark, fluid-inclusion-crowded rims. Small idioblasts of St_2 occur in the mica-rich, Gr-bearing matrix. Some are intergrown with Ky, containing inclusion-rich cores. Grt_1 is broken and partly replaced by Chl. Inclusion-rich cores are surrounded by clear rims composed of several adjoining tiny crystals. Late shear plains S_2 marked by Bt crosscut the mylonitic foliation S_1.

Újszentiván-2/9: Plagioclase gneiss. Relic microfolded schistosity (S_1), outlined by Gr pigment is enclosed in Pl and St. Anhedral grains of Pl (5 mm) and porphyroblasts of Grt and St are set in a matrix, composed of postkinematic flakes of Ms and Bt. St relics (up to one cm) are surrounded by Ky aggregates and sericite. Grt_1 (6 mm) contains Ilm and Qtz inclusions. Broken parts surrounded by strings of Grt_2 also make up glomeroblasts.

Kiszombor-7/4: Crenulated micaschist. Ms and Bt with strong postkinematic crystallization make up mica-rich layers. Qtz-rich granoblastic bands bear some anhedral Pl. Broken and round Grt crystals up to 2.5 mm in size are partially replaced by Chl and Bt.

Forráskút-12/6: Mylonitic micaschist with S-C structure. Coarse, polycrystalline Ms fishes and small augens of Pl are embedded in fine-grained Qtz-rich granoblastic matrix with a penetrative schistosity, containing very fine-grained Bt flakes. Small idioblasts of St (single crystals or crystal groups, 0.25–0.5 mm) are cut by shear plains. Euhedral rims of Grt idioblasts (up to 0.8 mm) contain inclusions from the mylonitic matrix.

Dorozsma-7/10: Fine-grained, strongly foliated mylonitic micaschist to gneiss. Porphyroclasts of Grt_1, Kfs and Pl are embedded in a fine-grained matrix composed of Ky+Bt+Qtz. Grt_1 shows inclusions of coarse-grained Bt and Pl. Kfs forms up to one centimetre large crystals with recrystallization at the crystal edges. The second Grt generation (Grt_2) is rich in tiny inclusions, and forms rims around pre-existing Grt_1 and small idioblasts in Qtz-rich domains.

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