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Origin of sediments during Cretaceous continent–continent collision in the Romanian Southern Carpathians: preliminary constraints from $^{40}Ar/^{39}Ar$ single-grain dating of detrital white mica

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Abstract: Single grains of detrital white mica from the lowermost Upper Cretaceous Sinaia Flysch have been dated using the $^{40}Ar/^{39}Ar$ technique. The Sinaia Flysch was deposited in a trench between the Danubian and Getic microcontinental pieces after the closure of the Severin oceanic tract. The Danubian basement is largely composed of a Panafrican/Cadomian basement in contrast to the Getic/Supragetic units with a Variscan-aged basement, allowing the distinction between these two blocks. Dating of detrital mica from the Sinaia Flysch resulted in predominantly Variscan ages (329 ± 3 and 288 ± 4 Ma), which prove the Getic/Supragetic source of the infill of the Sinaia Trench. Subordinate Late Permian (263 ± 8 and 255 ± 10 Ma), Early Jurassic (185 ± 4 and 183 ± 3 Ma) and Late Jurassic/Early Cretaceous (149 ± 3 and 140 ± 3 Ma) ages as well as a single Cretaceous age (98 ± 4 Ma) are interpreted as representing the exposure of likely retrogressive low-grade metamorphic ductile shear zones of various ages. Ductile shear zones with similar $^{40}Ar/^{39}Ar$ white mica ages are known in the Getic/Supragetic units. The Cretaceous ages also show that Cretaceous metamorphic units were already subject to erosion during the deposition of the Sinaia Flysch.

Key words: provenance study, nappe stacking, retrogressive shear zone, Ar-Ar dating, white mica.

Introduction

Provenance studies based on dating of detrital minerals enables the establishment of the source, especially when the hinterland is distinct in the age of crystalline basement rocks (e.g. Dallmeyer & Takasu 1992; Capuzzo et al. 2003; Hodges et al. 2005; Neubauer et al. 2007; von Eynatten & Dunkl 2012 for review). Such studies also allow monitoring of tectonic processes in the source region as well as their tectonothermal history when sufficient data are known in the respective source regions (Ruhl & Hodges 2005).

The results of recent field work and collaborative $^{40}Ar/^{39}Ar$ dating of detrital white mica from the synorogenic Upper Cretaceous Sinaia Flysch Formation in the Southern Carpathian orogen have enabled conclusions as to the origin of sediments deposited in that synorogenic trench. These new data demand significant revision of previous interpretations of the tectonothermal evolution of the Southern Carpathian orogen, and provide constraints for regional Late Cretaceous geodynamics.

Geological setting

The Southern Carpathian orogen is comprised of a sequence of metamorphic basement nappe complexes structurally separated by variably metamorphosed intercalations of Upper Paleozoic and Mesozoic "cover" sequences (e.g. Burchfiel 1976, 1980; Kräutner et al. 1981, 1988; Săndulescu 1984; Kräutner 1993; Berza & Iancu 1994; Iancu et al. 2005; Schmid et al. 2008; Balintoni et al. 2010, 2011; Balintoni & Balica 2012). Their palinspastic origins were between the European plate (Moesian promontory) and the Vardar-Mureş oceanic domain (a western extension of the Tethys) exposed to the west and north of the present-day Southern Carpathians (Fig. 1) (e.g. Channel & Kozur 1997).

The tectonostratigraphic succession exposed within the Southern Carpathian orogen comprises four major nappe complexes (Iancu et al. 2005 and references therein). From structurally lower to higher parts, these include (Figs. 1, 2): (1) The Danubian nappe complex (with Cadomian granitoids, and medium-grade metamorphic sequences with granulite-like gneisses, orthogneisses and meta-granitoids — Liegois et al. 1996; Balintoni et al. 2011; Balintoni & Balica 2012); (2) the Jurassic/Cretaceous Severin ophiolite-bearing unit; (3) the Getic nappe complex (with mainly Variscan medium-grade metamorphic sequences with orthogneiss, paragneiss and garnet-micaschist); and (4) the Supragetic nappe complex (mainly Variscan medium-grade metamorphic sequences). The Danubian nappe complex is locally structurally separated from the Getic nappe complex by the Severin Nappe that includes Jurassic rift and Cretaceous deep-water sedimentary sequences, namely the so-called Sinaia Flysch (Burchfiel 1976; Săndulescu 1984; Iancu et al. 2005). Sedimentary sequences have been interpreted as records of the Jurassic separation of an originally combined Danubian/Getic continental basement and comprise several facies realms (Fig. 2). The chronology of the assembly of the present nappe architecture

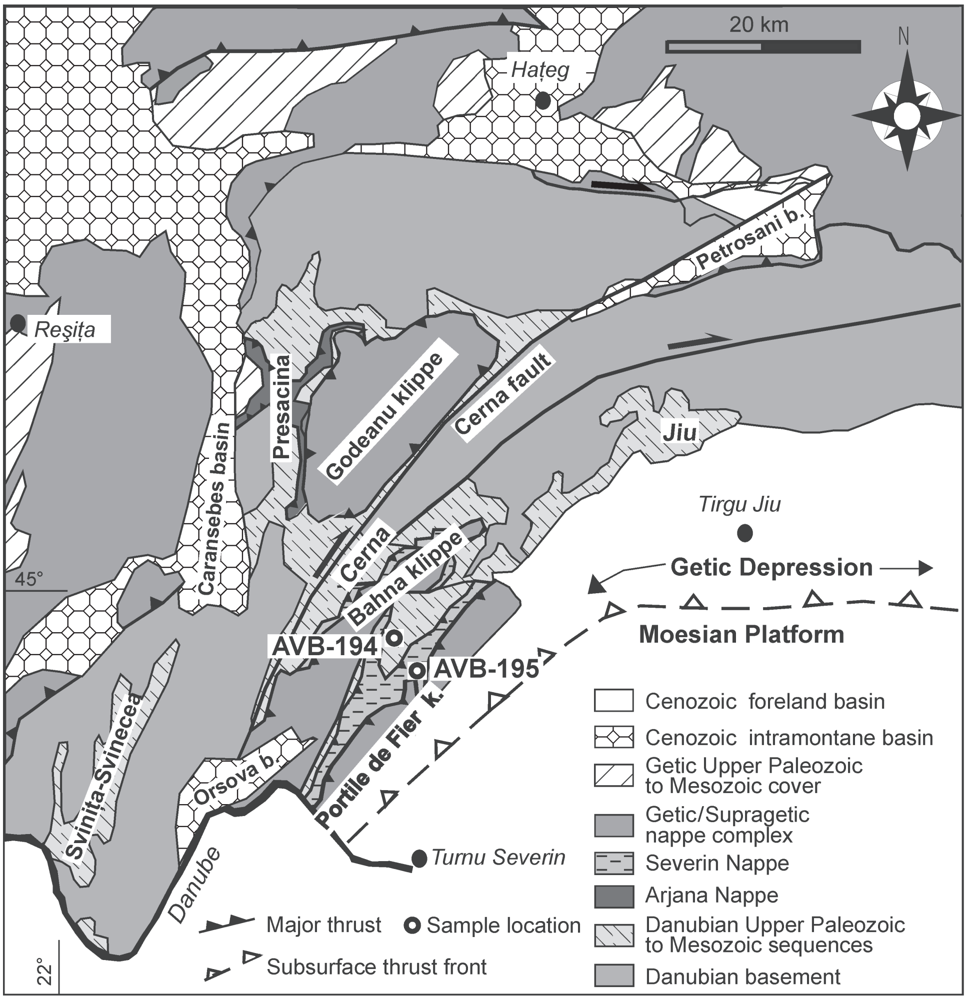

Fig. 1. Simplified tectonic map of the Southern Carpathian orogen (modified after Bojar et al. 1998 and mainly based on Berza et al. 1994). **b.** — basin, **k.** — klippe.

generally resembles that of Austroalpine units in the Eastern Alps and Western Carpathians, and resulted from mid-Late Cretaceous nappe assembly (e.g. Burchfiel 1980; Săndulescu 1984; Dallmeyer et al. 1996, 1998; Bojar et al. 1998; Neubauer 2002).

In detail, the Danubian nappe complex comprises several Alpine nappes (Berza et al. 1994; Iancu et al. 2005). Tectonically lower nappes consist of Cadomian medium-grade metamorphic sequences (Lainici-Păiuş Group) intruded by discordant granitic plutons also of Cadomian age. Structurally higher Alpine Danubian nappes include the Drăgşan Amphibolite Group, which is also intruded by granitoids (Berza & Iancu 1994). The Drăgşan Amphibolite is tectonically juxtaposed with Ordovician to Mississippian, low-grade metasedimentary units along ductile shear zones. Structural relationships within the contrasting upper Danubian nappes have been interpreted to at least partially record a Variscan tectonic evolution because Jurassic sequences locally stratigraphically overlie all crystalline nappe units (e.g. Iancu et al. 2005; Ciulavu et al. 2008). Three cover domains are distinguished in the Danubian realm. These are from west to east: the Sviniţa-Svinecea, Presacina and Cerna-Jiu domains. The Presacina domain includes rift volcanics. Previous geochronological results of mineral dating reported from the Danubian basement sequences include Late Proterozoic U-Pb zircon ages of augengneiss and granitoids ranging from 811.3±2.2 to 582±7 Ma, and an 825±156 Ma Sm-Nd whole rock age for the Drăgşan Amphibolite (Grünenfelder et al. 1983; Pavelescu et al. 1983; Liegeois et al. 1996; Balintoni & Balica 2012). K-Ar ages reported for whole-rock samples and concentrates of amphibole, muscovite and biotite display a range between ca. 550 and 70 Ma (Grünenfelder et al. 1983; Kräutner et al. 1988; Ratschbacher et al. 1993; Dallmeyer et al. 1996, 1998; Bojar et al. 1998). Considered together, the available radiometric results have been interpreted as a record of the effects of penetrative Cadomian/Baikalian (late Precambrian) tectonothermal activity (e.g. Balintoni & Balica 2012), which has been variably and only locally overprinted by retrogressive Variscan (Late Paleozoic) and/or Alpine tectonothermal events (e.g. Kräutner et al. 1988; Bojar et al. 1998; Willingshofer et al. 2001). The exact age of the Alpine metamorphic overprint is still unresolved, and is generally within very low-grade conditions to at

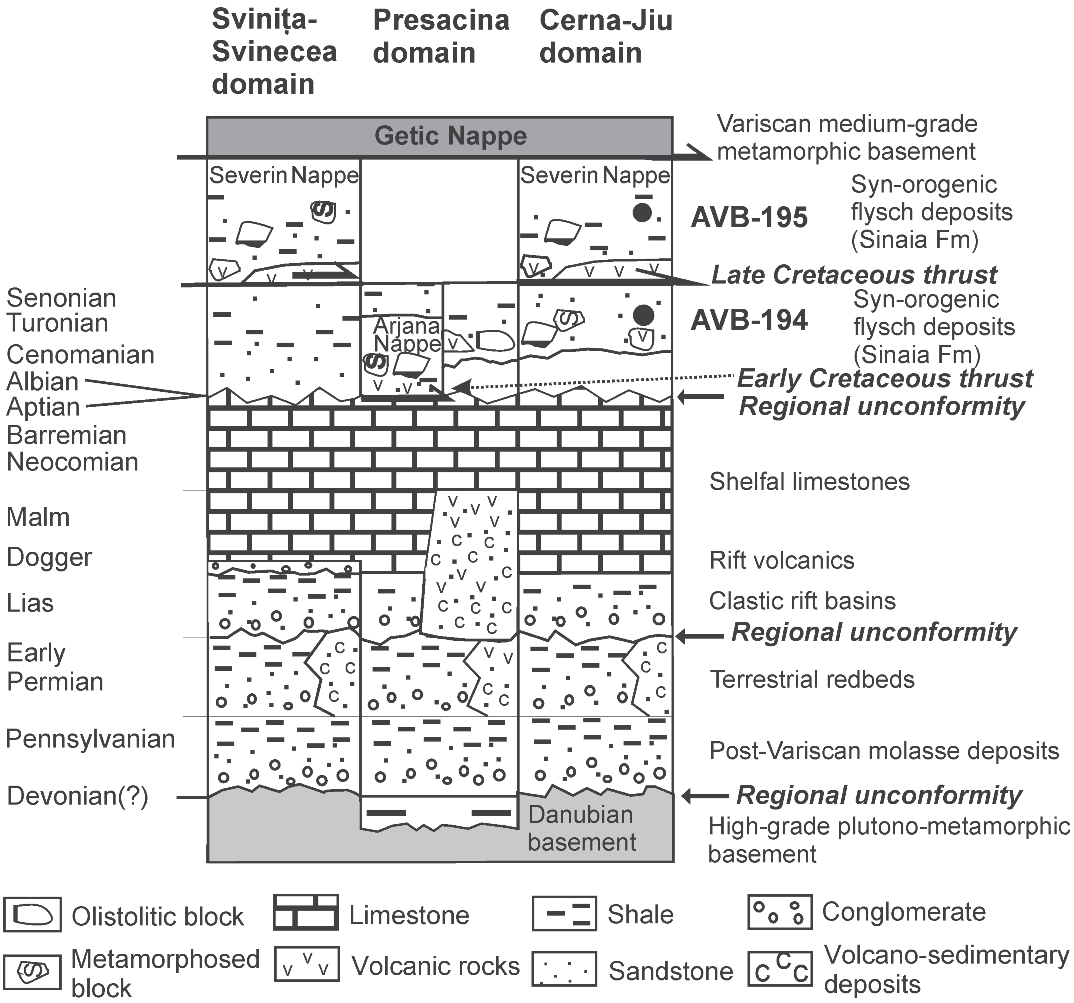

Fig. 2. Simplified stratigraphic sections of individual units exposed within the Danubian and Getic nappe complexes within the Southern Carpathian orogen (modified after Bojar et al. 1998).

most upper greenschist facies metamorphic conditions (Iancu et al. 2005; Ciulavu et al. 2008; Bojar et al. 2010). Age data for Alpine metamorphism are scarce (Kräutner et al. 1988; Ratschbacher et al. 1993). The $^{40}Ar/^{39}Ar$ and K-Ar ages argue for a succession of events starting at ca. 100 Ma with ductile shear zone formation and continuing with extension shear zones, which formed at 80 Ma in northernmost areas (Neubauer et al. 1997). The youngest ages are at around 70 Ma (Grünenfelder et al. 1983; Ratschbacher et al. 1993) displaying terminal tectonic events. Combining radiometric ages with the stratigraphic ages of sedimentary cover units, a two-stage history of Alpine nappe assembly was presented (Bojar et al. 1998; Schmid et al. 1998; Iancu et al. 2005).

The Severin ophiolite comprises Jurassic rift and ophiolite successions. The ophiolite is overlain by the Sinaia Flysch displaying the overthrusting by the Getic Nappe. The Sinaia Flysch ranges in stratigraphy from Late Jurassic to Aptian (Pop 1996) and comprises mainly turbiditic limestone and sandstone beds and marly/shaly interlayers. Bojar et al. (1998) found zircon fission track ages ranging between 220 ± 27 and 188 ± 19 Ma in sandstones from the Sinaia Flysch.

The Getic Nappe largely comprises Variscan medium-grade metamorphic sequences (locally eclogite-bearing paragneisses and micaschists intruded by pegmatites) and minor granites (Kräutner et al. 1988; Iancu & Mariuntu 1994). Published radiometric results include an upper intercept, 1100–1000 Ma U-Pb zircon age for gneiss, and a lower intercept 310 Ma U-Pb zircon age for granite (Pavelescu et al. 1983). A discordant granite yielded a U-Pb zircon age of ca. 350 Ma (Stan et al. 1992). K-Ar ages range between 350 and 70 Ma (Grünenfelder et al. 1983; Kräutner et al. 1988; Ratschbacher et al. 1993). Conventional multi-grain $^{40}Ar/^{39}Ar$ dating of white mica revealed a Variscan age of the penetrative amphibolite-grade metamorphism with white mica ages of ca. 320–290 Ma (Dallmeyer et al. 1996, 1998), which represent the age of cooling through the Ar retention temperature of white mica at ca. 425 °C according to Harrison et al. (2009).

The Supragetic Nappe includes medium-grade metamorphic sequences that have been partially retrogressed along distinct, locally penetrative ductile shear zones. Low-grade sequences include fossiliferous Cambrian to Silurian, and Upper Devonian to Mississippian successions in north-western sectors of the region (Kräutner et al. 1988). Vast areas are characterized by monotonous micaschist, plagioclase-rich paragneiss and augengneiss. Conventional multi-grain $^{40}Ar/^{39}Ar$ dating of white mica revealed the Variscan age of the penetrative amphibolite-grade metamorphism with white mica ages of ca. 320–290 Ma (Dallmeyer et al. 1996, 1998). Retrogressed ductile shear zones were dated and interpreted as records of an event at ca. 200 Ma (ca. Triassic/Jurassic boundary (Dallmeyer et al. 1998)). Low-grade metamorphic Pennsylvanian cover successions also argue for an Alpine metamorphism dated to ca. 119 Ma (Early Cretaceous) (Dallmeyer et al. 1996). Dragusanu & Tanaka (1999) found similar K-Ar mineral ages of 188 ± 3 and 119 ± 2 Ma in the Supragetic domain in the east.

$^{40}Ar/^{39}Ar$ analytical methods

Preparation of the mineral concentrates was performed at the University of Graz. Preparation for irradiation, $^{40}Ar/^{39}Ar$ analyses, and age calculations were carried out at the ARGONAUT Laboratory of the Geology Division at the University of Salzburg using methods similar to those described in Ilic et al. (2005). Mineral concentrates were packed in aluminium-foil and loaded in quartz vials. For calculation of the J-values, flux-monitors were placed between each 4–5 unknown samples, which yielded a distance of ca. 5 mm between adjacent flux-monitors. The sealed quartz vials were irradiated in the MTA KFKI reactor (Debrecen, Hungary) for 16 hours. Correction factors for interfering isotopes were calculated from 10 analyses of two Ca-glass samples and 22 analyses of two pure K-glass samples (Wijbrans et al. 1995), and are: $^{36}Ar/^{37}Ar_{(Ca)} = 0.00026025$, $^{39}Ar/^{37}Ar_{(Ca)} = 0.00065014$, and $^{40}Ar/^{39}Ar_{(K)} = 0.015466$. Variations in the flux of neutrons were monitored with the DRA1 sanidine standard for which a $^{40}Ar/^{39}Ar$ plateau age of 25.03 ± 0.05 Ma has been reported (Wijbrans et al. 1995). After irradiation the minerals were unpacked from the quartz vials and the aluminium-foil packets, and handpicked into 1 mm diameter holes within one-way Al-sample holders. $^{40}Ar/^{39}Ar$ analyses were carried out using a UHV Ar-extraction line equipped with a combined MERCHANTEK^{TM} UV/IR laser ablation facility, and a VG-ISOTECH^{TM} NG3600 Mass Spectrometer.

Total fusion analyses of single grains were performed using a defocused (~1.5 mm diameter) 25 W CO_2-IR laser operating in Tem_{00} mode at wavelengths between 10.57 and 10.63 μm. The laser is controlled from a PC, and the position of the laser on the sample is monitored through a double-vacuum window on the sample chamber via a video camera in the optical axis of the laser beam on the computer screen. Gas clean-up was performed using one hot and one cold Zr-Al SAES getter. Gas admittance and pumping of the mass spectrometer and the Ar-extraction line are computer controlled using pneumatic valves. The NG3600 is a 18 cm radius 60° extended geometry instrument, equipped with a bright Nier-type source operated at 4.5 kV. Measurement was performed on an axial electron multiplier in static mode, peak-jumping and stability of the magnet are controlled by a Hall-probe. For each increment the intensities of ^{36}Ar, ^{37}Ar, ^{38}Ar, ^{39}Ar, and ^{40}Ar were measured, the baseline readings on mass 35.5 are automatically subtracted. Intensities of the peaks were back-extrapolated over 16 measured intensities to the time of gas admittance either by a straight line or a curved fit. Intensities were corrected for system blanks, background, post-irradiation decay of ^{37}Ar, and interfering isotopes. Isotopic ratios, ages and errors for individual steps were calculated following suggestions by McDougall & Harrison (1999) using decay factors reported by Steiger & Jäger (1977). Age calculations were carried out using ISOPLOT/EX (Ludwig 2001).

Petrography of investigated samples

Two samples from different localities were investigated (see Figs. 1 and 2 for sample locations). Both samples are from the Sinaia Formation of the Severin Nappe exposed to the east (sample AVB-194) and west (sample AVB-195) of the Getic Bahna klippe. The area belongs to the Cerna-Ciu domain. According to geological maps, sample AVB-194 is a Turonian to Senonian sandstone of the cover of the Danubian Unit (location: N 44°54′08″, E 22°41′09″). Sample AVB-195 is likely an Aptian sandstone close to the Severin ophiolites (location: N 44°52′38″, E 22°41′56″) representing the cover of the Severin Nappe.

Sample AVB-194 is an immature arkose arenite with angular clasts with a grain size ranging from 0.1 to 0.5 mm. The main constituents are quartz, K-feldspar, plagioclase and some white mica, degraded chlorite and garnet. K-feldspar (in part microcline) and plagioclase (in part oligoclase according to optical properties), are both only slightly sericitized and together constitute ca. 30 percent, with a slight dominance of K-feldspar. White mica is sometimes intergrown with slightly degraded biotite. Garnet clasts are often chloritized. Lithic components are rare and a sericite–chlorite occurs in several signs. The subordinate matrix is composed of fine-grained quartz/feldspar, sericite and chlorite.

Sample AVB-195 is a carbonate sandstone with a low percentage of siliciclastic material and calcite cement. The clasts are 0.1 to 0.4 mm in size. Among the limestone clasts, micritic clasts are dominant, while microsparite and monocrystalline calcite clasts are rather rare. The siliciclastic fraction (< 10 percent) is composed of unaltered feldspars (polysynthetically twinned plagioclase and K-feldspar), quartz, white mica and rare biotite as well as rutile and Cr-spinel. Among the lithic clasts, phyllite, greenschist and slate dominate.

In summary, although largely different with respect to carbonate clast content, both samples are dominated by non-retrogressed clasts like plagioclase (in part oligoclase), which could best represent an amphibolite facies grade metamorphic succession with lithologies like gneiss and micaschist. Low-grade clasts (e.g. phyllite) are subordinate.

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

The grain size fraction 125–160 μm was selected to also find possible fine-grained micas from Early Cretaceous-aged low-grade metamorphic rocks. The selected grain size is too small to perform step-wise heating experiments. Dating re-

Table 1: $^{40}Ar/^{39}Ar$ step-wise heating results of detrital white mica.

Sample 1 (field no. AVB-195)			**J-Value: 8.588 ± 0.078**						
Grain no.	$^{36}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar^{b}$	$^{37}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar^{a}$	$\%^{40}Ar^{*}$	**Age [Ma]**	**Error [Ma]**
	measured	**1-sigma**	**corrected**	**1-sigma**	**measured**	**1-sigma**			**1-sigma**
1	0.00265	0.00031	0.10449	0.00028	3.321	0.091	76.4	98.4	3.6
2	0.00205	0.00024	0.17616	0.00023	4.229	0.070	85.7	139.4	2.9
3	0.00590	0.00090	0.06666	0.00086	8.594	0.267	79.7	254.7	9.6
4	0.00368	0.00075	1.06172	0.00075	8.094	0.221	86.6	263.0	8.0
5	0.00359	0.00026	0.78637	0.00028	8.588	0.078	87.7	280.1	3.7
6	0.00180	0.00031	0.03937	0.00038	8.300	0.092	93.6	286.3	4.1
7	0.00028	0.00041	0.40478	0.00030	7.848	0.122	98.9	287.2	4.9
8	0.00287	0.00033	0.16035	0.00028	8.809	0.098	90.4	293.2	4.3
9	0.00004	0.00032	0.53313	0.00047	8.109	0.096	99.9	298.8	4.3
10	0.00121	0.00038	1.28402	0.00027	8.444	0.113	95.8	300.6	4.7
11	0.00189	0.00041	0.05693	0.00057	8.855	0.122	93.7	304.2	5.0
12	0.00201	0.00075	0.46551	0.00090	9.016	0.224	93.4	309.6	8.1
13	0.00017	0.00041	0.92277	0.00032	8.614	0.122	99.4	315.7	5.0
14	0.00008	0.00026	0.03596	0.00029	8.677	0.077	99.7	316.3	3.9
15	0.00015	0.00028	0.27945	0.00037	8.820	0.084	99.5	321.0	4.1
16	0.00057	0.00026	0.02164	0.00028	9.077	0.076	98.2	324.7	3.9
Sample 2 (field no. AVB-194)			**J-Value: 8.5884 ± 0.077**						
1	0.00133	0.00032	0.02556	0.00045	8.934	0.096	95.6	312.5	4.1
2	0.00112	0.00022	0.00920	0.00029	8.845	0.064	96.3	311.6	3.4
3	0.00076	0.00021	0.00588	0.00026	8.323	0.063	97.3	297.5	3.3
4	0.00065	0.00031	0.07927	0.00042	8.696	0.093	97.8	311.5	4.1
5	0.00104	0.00016	0.02274	0.00017	8.588	0.049	96.4	303.8	3.0
6	0.00169	0.00021	0.24884	0.00023	8.859	0.063	94.4	307.1	3.3
7	0.00005	0.00016	0.12754	0.00020	8.491	0.047	99.8	310.6	3.0
8	0.00142	0.00026	0.04951	0.00033	4.322	0.078	90.3	149.3	3.2
9	0.00103	0.00018	0.17408	0.00021	5.128	0.053	94.1	183.3	2.5
10	0.00159	0.00020	0.06423	0.00028	9.484	0.060	95.0	328.5	3.4
11	0.00103	0.00018	0.16080	0.00023	8.661	0.054	96.5	306.6	3.1
12	0.00139	0.00032	0.28068	0.00032	5.259	0.093	92.2	184.6	3.7
13	0.00271	0.00064	0.88424	0.00062	9.863	0.191	91.9	332.4	6.9
14	0.00245	0.00067	0.47814	0.00081	10.866	0.200	93.3	366.9	7.2
15	0.00152	0.00102	4.13000	0.00090	8.690	0.302	94.8	313.9	10.5
16	0.00046	0.00046	0.70924	0.00054	8.500	0.137	98.4	308.5	5.3
17	0.00074	0.00033	0.22917	0.00027	9.058	0.099	97.6	323.2	4.3
18	0.00112	0.00023	0.43878	0.00023	8.770	0.067	96.2	310.2	3.4
19	0.00151	0.00035	0.74211	0.00034	8.925	0.103	95.0	312.4	4.3
20	0.00246	0.00042	1.49037	0.00042	9.407	0.125	92.3	321.2	5.0
21	0.00209	0.00044	0.55796	0.00040	9.366	0.130	93.4	321.0	5.1
22	0.00086	0.00031	1.07124	0.00032	7.974	0.093	96.8	287.6	4.0

a — measured, **b** — corrected for post irradiation decay of ^{37}Ar (half-live = 35.1 days). $^{40}Ar^{*}$ — radiogenic ^{40}Ar.

sults are shown in Table 1 and, graphically, in Fig. 3. The data are treated by statistical methods proposed by Sircombe (2004), which include the age and the error of age.

Twelve from a set of sixteen grains of AVB-194 gave age values of 325 ± 4 to 280 ± 4 Ma. A further grain yielded an age of 98 ± 4 Ma with a relatively low proportion (76 %) of radiogenic ^{40}Ar. Another grain gave an age of 140 ± 3 Ma, and two further grains yielded ages of 263 ± 8 and 255 ± 10 Ma.

Eighteen grains of sample AVB-195 yielded age values ranging between 329 ± 3 and 288 ± 4 Ma. A further grain gave an older age of 367 ± 7 Ma. Three grains gave younger ages with 185 ± 4, 183 ± 3 and 149 ± 3 Ma. Because of the high proportion of radiogenic ^{40}Ar, these ages are considered to be geologically significant.

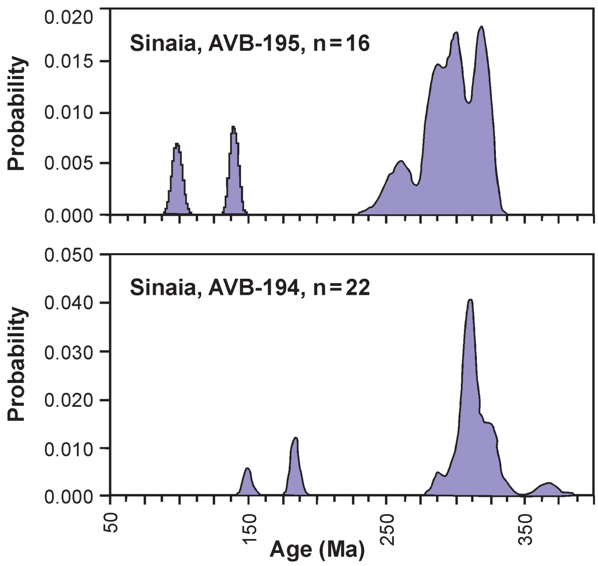

Fig. 3. Histograms showing the new $^{40}Ar/^{39}Ar$ single-grain ages of detrital white mica.

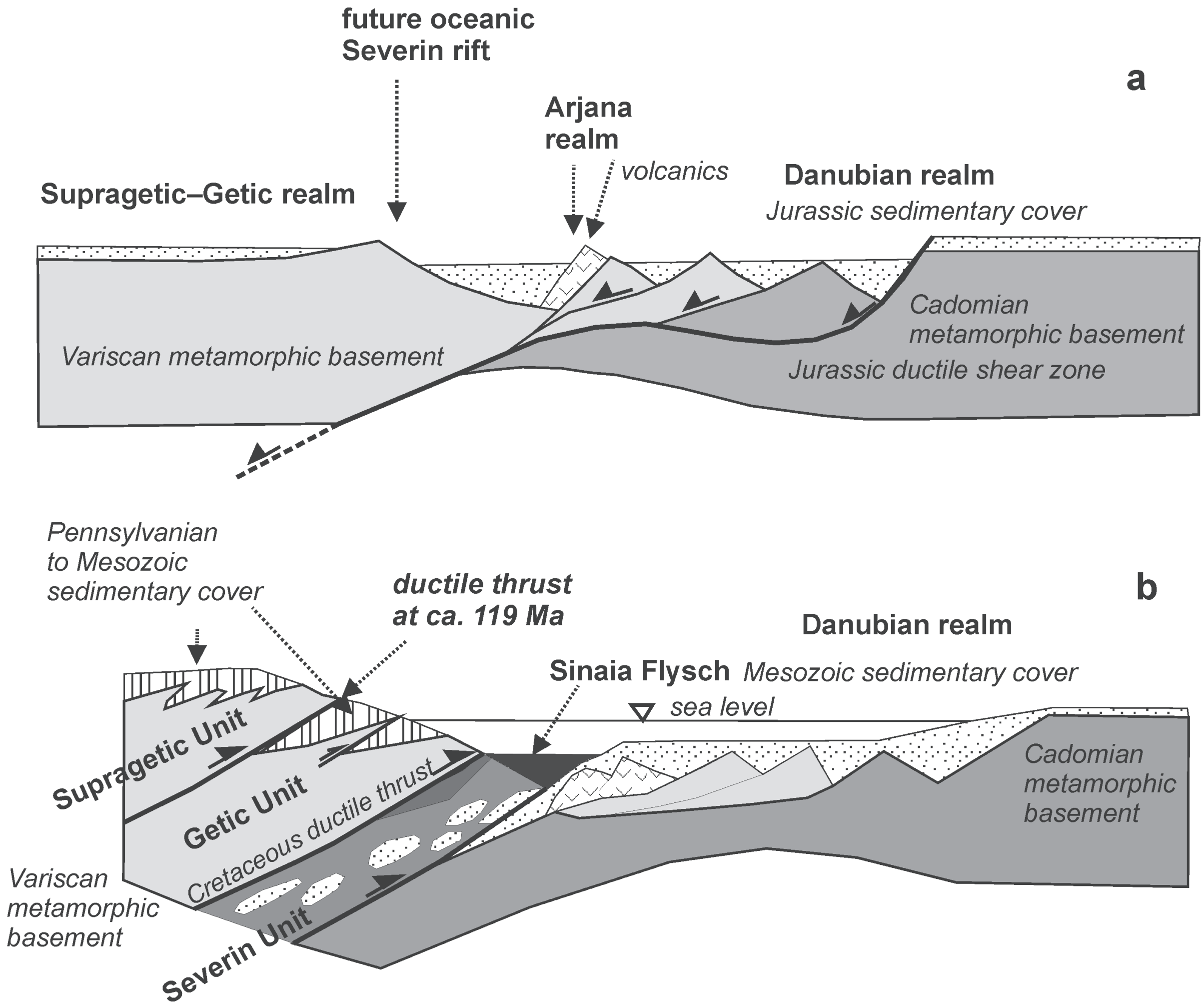

Fig. 4. Model for the Late Cretaceous tectonic evolution of units exposed within the Danubian window of the Southern Carpathian orogen. **a** — Simplified Middle Jurassic paleogeographic section displaying the rift stage. **b** — Early Late Cretaceous paleogeography due to age dating results.

Discussion

The new single-grain $^{40}Ar/^{39}Ar$ ages of detrital white micas from sandstones collected within the Sinaia Flysch of two different units, namely the cover of the Danubian realm and of the Severin Nappe, are very similar to previously reported multigrain $^{40}Ar/^{39}Ar$ and to most K-Ar ages from Getic and Supragetic basement units reported during the last decades (Kräutner et al. 1988; Dallmeyer et al. 1996, 1998; Neubauer et al. 1997; Dragusanu & Tanaka 1999 and references therein). Most are Variscan ages, but a low percentage is younger (see below), making them similar to those recorded by zircon fission track ages (Bojar et al. 1998; Fügenschuh & Schmid 2005) and $^{40}Ar/^{39}Ar$ white mica ages from the Getic basement (Dallmeyer et al. 1998). This argues for a source-sink relationship between the Getic/Supragetic basement units and the Sinaia Formation (Fig. 4a,b). Consequently, the Sinaia Flysch is considered to represent the infill of a basin on the lower plate, which was progressively overridden by the Getic/Supragetic nappe complex representing the terrestrial source.

The Sinaia Flysch (or Formation) was deposited in a trench located between the Danubian and Getic microcontinental pieces after the closure of the Severin oceanic seaway (e.g. Bojar et al. 1998 and references therein). $^{40}Ar/^{39}Ar$ single grain ages of detrital white mica from the early Late Cretaceous Sinaia Flysch clearly demonstrate the predominance of Variscan ages (329 ± 3 and 288 ± 4 Ma). These ages can be linked to a source from the Getic/Supragetic source with its Variscan $^{40}Ar/^{39}Ar$ white mica ages in metamorphic rocks and exclude the Panafrican/Danubian block as a possible source for the infill of the Sinaia Trench (Fig. 4b).

Subordinate ages with Late Permian (263 ± 8 and 255 ± 10 Ma), Early Jurassic (185 ± 4 and 183 ± 3 Ma) and Late Jurassic/Early Cretaceous (149 ± 3 and 140 ± 3 Ma) as well as a single late Early Cretaceous age (98 ± 4 Ma) were also found. These ages are considered to represent either (1) Variscan mica grains, which were variably reset by subsequent thermally induced overprint during the Triassic/Jurassic or (2) Early Cretaceous or new grains formed within local ductile shear zones within greenschist facies conditions. The Permian, Early Jurassic and Early Cretaceous ages closely resemble ages reported from retrogressive, low-grade ductile shear zones by Dallmeyer et al. (1998). The small selected grain size does not allow for step-heating to be carried out on single grains in order to discriminate between these two possibilities. The ages are considered to be geologically significant because similar Permian to Cretaceous ages were actually found along ductile shear zones within the Getic Unit (Dallmeyer et al. 1996, 1998). The ages around 185–183 Ma are similar to zircon fission track ages reported by Bojar et al. (1998) and are interpreted as records of tectonothermal events during rifting and opening of the Severin oceanic seaway (Fig. 4a). Willingshofer et al. (2001) reported a variety of similar zircon fission track ages from the Getic basement, which are similar to all the above-mentioned age groups (Fig. 4). The Early Cretaceous mica ages (140±3 Ma and 98±4 Ma) also demonstrate the exposure of Cretaceous-aged metamorphic units during the Late Cretaceous. Similar K-Ar muscovite (99±5 Ma — Ratschbacher et al. 1993), zircon fission track ages (145±10.8 Ma and 88.3±8.5 Ma — Fügenschuh & Schmid 2005) from upper Danubian and Getic Units and apatite fission track age populations (150±22 Ma, 125±17 Ma, 102±9 Ma) from sandstones of the Oligocene Petroşani Basin (Fig. 1; Moser et al. 2005) were also reported. We consider these detrital muscovites to have their origin either in the Supragetic, Getic and/or in upper Danubian tectonic units, which were overthrust during the late Early Cretaceous. This question remains open and requires further consideration and work.

Finally, Wiesinger (2006) records a similar Variscan age group from Upper Cretaceous infill of Gosau-type basins in the Haţeg Basin, which formed on top of the Getic Nappe and in the Apuseni Mountains. This indicates the dominance of Variscan sources in the Carpathians.

Conclusions

$^{40}Ar/^{39}Ar$ single grain dating of detrital white mica from the lowermost Upper Cretaceous Sinaia Formation resulted in predominant Variscan ages (329±3 to 288±4 Ma) representing the Getic/Supragetic source of infill of the Sinaia Trench. Subordinate ages with Late Permian (263±8 and 255±10 Ma), Early Jurassic (185±4 and 183±3 Ma) and Late Jurassic (149±3 and 140±3 Ma) as well as a single Cretaceous age (98±4 Ma) likely represent the exposure of ductile shear zones of various ages, including the exposure of low-grade metamorphic units. These Late Permian and Mesozoic ages are considered to be geologically significant because of similar ages in corresponding basement units.

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