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Radioisotopic data and geodynamic interpretations in the eastern part of the Balkan Peninsula

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Application of isotopic methods for dating igneous and tectonometamorphic events

Reuslts of radiogeochronological studies on the igneous and metamorphic rock complexes can be effectively interpreted only when taking into account the possibilities and limitations of each method applied.

Igneous rocks are comparatively easily dated when have not suffered superimposed thermal or tectonothermal (metamorphic) events after their cooling. Concordant ages are usually obtained using the Rb-Sr, U-Pb and K-Ar methods. The Ar-Ar method may be crucial for understanding the cooling history. U-Pb dating of zircon cores may supply information about the source rocks, and initial Rb-Sr ratios and Sm-Nd data are important for petrogenetic interpretations.

When the igneous body has been subjected to post-intrusion tectonothermal events, its origin and evolution may be elucidated only with the aid of a complex of methods. The age of the intrusion may be obtained using isochrone methods: Rb-Sr whole-rock isochrone (the mineral isochrone reflect the time of superimposed metamorphism) and U-Pb zircon ages using the concordia-discordia diagram. In the second case, the upper concordia/discordia intercept is related to the intrusion age whereas the lower intercept gives the age of the superimposed metamorphism. In the most general case, K-Ar dates would be "mixed data" situated between the age of cooling and the time of superimposed metamorphism, and in case of full radiogenic Ar loss during the superimposed event, would date the latter. In such a case, the Ar-Ar method will supply information about the cooling history of this last tectonothermal event.

A single metamorphic event (or cycle) imposed over a sedimentary or volcano-sedimentary sequence would result in concordant ages obtained by different isotopic methods. Considerable difficulties arise when trying to date polymetamorphic complexes with a long and controversial history. Unfortunately, such is the case with most of the polymetamorphic rocks exposed in the central parts of the Balkan Peninsula.

The present overview aims to compare the information obtained during the last years when extensive new data have been published. The reference list contains (due to the very limited space) only a selected fraction of the various sources used. The author apologizes for the forceful omission of many valuable sources that will be fully cited in a following extended publication.

Principal tectonic units

The tectonic units of Bulgaria and the Balkan Peninsula have been subject of numerous studies and many controversial ideas. Here I follow (Fig. 1) the subdivision exposed by Zagortchev (1994). In the Late Cretaceous tectonic setting, the principal tectonic and geodynamic zones are the volcanic island arc of the Srednogorie, and the complexly-built edifice of Morava-Rhodope ("plateau" situated NE of the Vardar

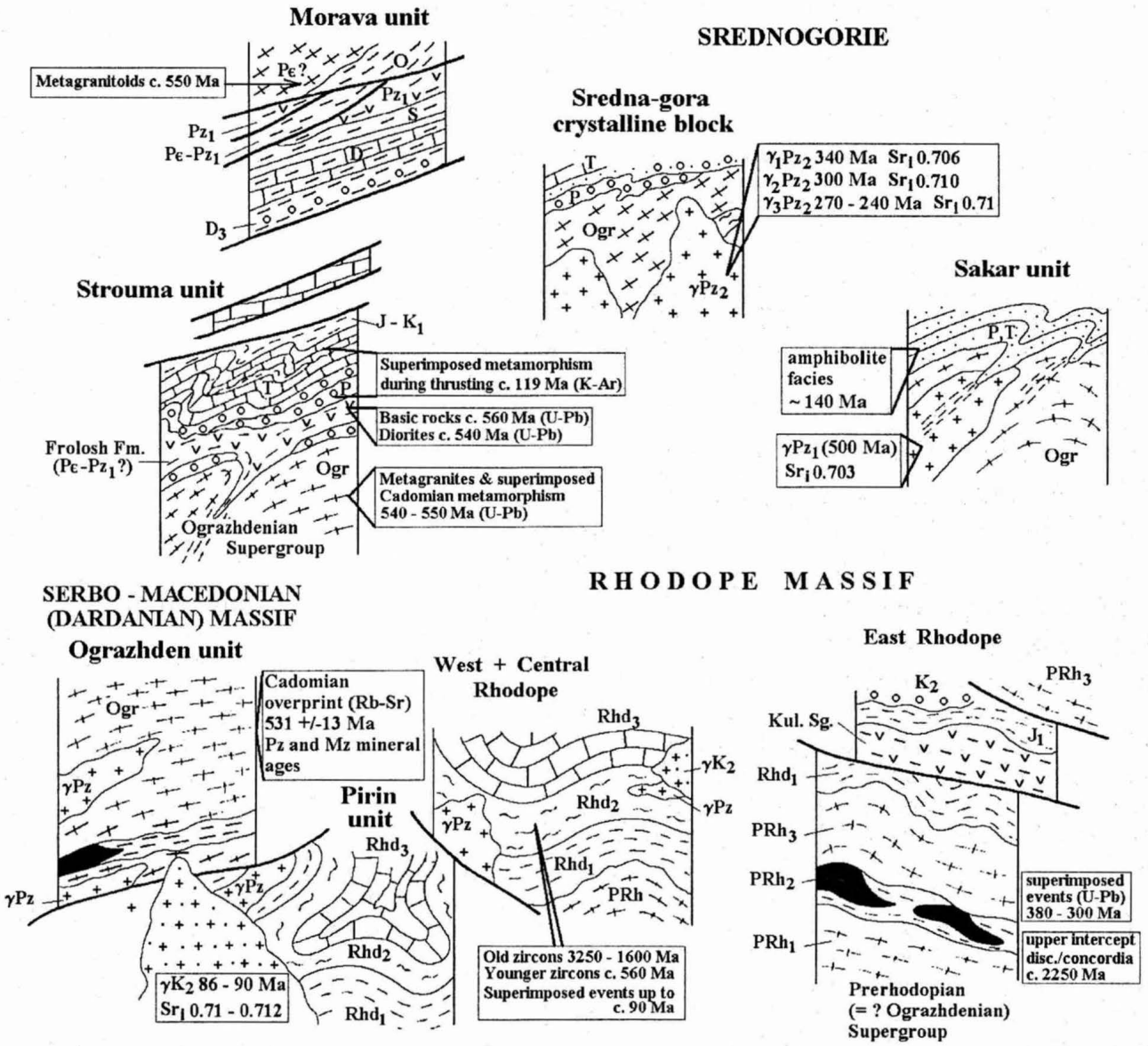

Fig. 1. Principal tectonic units (modified after Zagortchev, 1994) and ages based on radioisotopic data

Suture). Several pre-Mesozoic fragments built up the basement of the Srednogorie, the most important and best studied being the Sredna-Gora crystalline block (Sushtinska & Surnena Sredna-gora Mts.) and the Sakar unit. The "plateau" is built up of several pre-Mid-Cretaceous units assembled as a result of the Mid Cretaceous orogeny, and namely, the Morava (allochthonous), Strouma (parautochthonous) and Ograzhden (allochthonous) units, and the Rhodope massif (Pirin — Pangaion, Western + Central Rhodope and East Rhodope). Most of these units exhibit a pre-Cadomian high-grade (amphibolite facies) basement reworked during the Cadomian and Hercynian orogenies, and overprinted at a different degree by the Alpine tectonic and metamorphic events. The radioisotopic data reflect these events, traces from the older events being naturally greatly obliterated by the younger ones. The most important radiogeochronological data are shown in Fig. 1, and a synopsis of all data available to me is made in Fig. 2.

Pre-Cadomian data

The evidence about the pre-Cadomian evolution is scarce. The distinction between a Prerhodopian (?= Ograzhdenian) and a Rhodopian Supergroup (s. Kozhoukharov in Zoubek et al., eds., 1988) has been widely accepted although doubts are thrown on the exact dating of these supergroups and their subdivisions. The protolith of the Rhodopian Supergroup should be referred according to akritarch data at least to the lower and middle parts of the Neoproterozoic (and probably, also to the

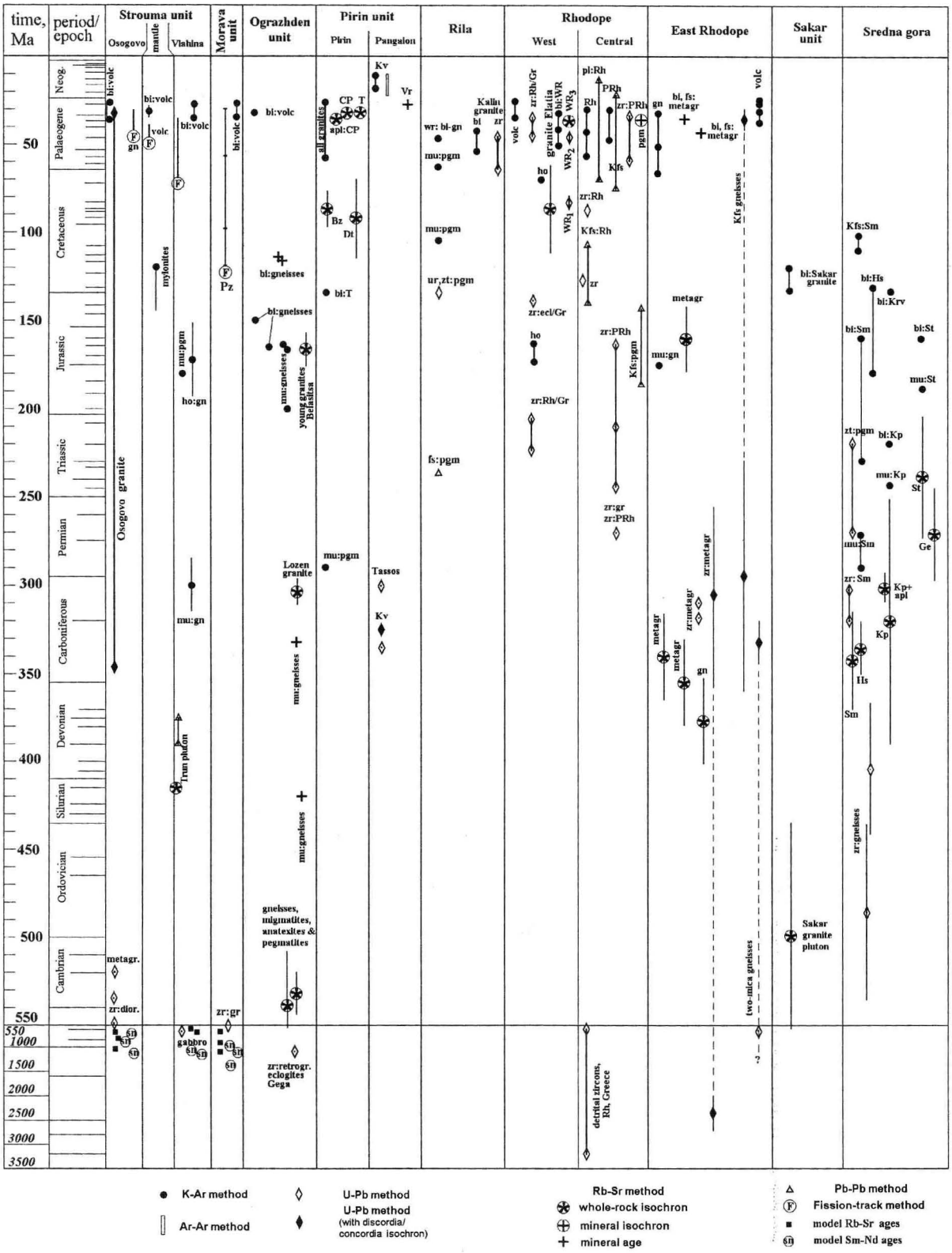

Fig. 2. Correlation chart of the radioisotopic data for the principal tectonic units

upper parts of the Mesoproterozoic). A large part of the Rhodopian rocks have a parametamorphic character. A recent study on zircons from the equivalents of the Rhodopian Supergroup in the Southern Rhodopes on Greek territory revealed a surprisingly high percentage of pre-Cadomian (3230 — 1600 Ma) and Cadomian (up to 560 Ma) ages (Liati, Gebauer, 2001). Obviously, even if entirely detrital, these zircons point at a closely situated source that

might be the Prerhodopian Supergroup. A Concordia-discordia study on zircons from the latter (East Rhodope: Peytcheva, v. Quadt, 1995) yielded an upper intercept of about 2250 Ma that can be considered as crystallization time. In the Osogovo-Lisets part of the Strouma unit, model Sm-Nd and Rb-Sr dates of 1400 — 1100 Ma have been obtained for the gneisses intersected by the Cadomian granitoids (data of v. Quadt and Graf in Graf, 2001). In the Ograzhden unit, N. Zidarov and collaborators reported an age exceeding 1.1 Ga. Thus, although scarce and imperfect, the evidence points at a pre-Cadomian age both for the protoliths and the oldest metamorphism of the Prerhodopian (+ Ograzhdenian) and the Rhodopian Supergroup.

Cadomian events

The Cadomian data are more numerous (Fig. 2). In the Central Rhodope (Liati, Gebauer, 2001), East Rhodope (Пейчева et al., 1992), Sakar (Lilov, 1991), Ograzhden (s. Загорчев et al., 1989) and Osogovo-Lisets (Graf, 2001), Rb-Sr whole-rock isochron data and U-Pb dating of zircons yielded typical Cadomian (late Panafrican) ages ranging between 570 and 500 Ma both for metagranites and for their reworked host rocks. It is of utmost interest that most of the granites have very low (0.702 — 0.704) initial Sr ratios that point at a source situated in the upper mantle or lower depleted crust. U-Pb ages of about 480 Ma reported recently from the Sredna-gora crystalline block may be regarded as rejuvenated Cadomian ages, too. The stratigraphic check for these ages comes from the Osogovo-Lisets area (Strouma unit) where the Cadomian Bosilegrad granite is covered with depositional unconformable contact by the Lower Ordovician metapsammitic formation.

Another set of Cadomian data are obtained from the diabase-phyllitoid Frolosh Formation, the related basic rocks (Razhdavitsa norite — c. 557 Ma, Graf, 2001) and the Strouma diorite formation. The position of these rocks is controversial. However, they cover now with tectonized contact the Ograzhdenian Supergroup, and their greenschist-facies metamorphism is superimposed as diaphthoresis in the underlying Ograzhdenian migmatites.

Hercynian events

The Hercynian (Variscan) events are well documented (Figs. 1, 2). The igneous rocks are represented mostly by granitoids. The three granite complexes in the Sredna-gora crystalline block (s. Загорчев et al., 1989) are dated correspondingly at c. 340, 320-300 and 277-240 Ma. Here we should mention also the newly-reported (N. Zidarov and co-workers) old granite (c. 300 Ma) in the Ograzhden unit (Belasitsa). The Kavala (Symvolon) granite in the Pirin-Pangaion unit yielded (data published by Kokkinakis, 1980, and Dinter et al., 1995) c. 335 Ma old zircons and a similar upper concordia/discordia intercept. The Osogovo granite pluton is also of Hercynian age — the upper concordia/discordia intercept on the diagram for the U-Pb zircon data corresponds to 347 Ma (Graf, 2001).

Numerous Hercynian ages have been recently reported in the East Rhodope Mts. They range between 245 and 377 Ma, and have been obtained by Rb-Sr whole-rock isochrones, and by U-Pb studies on zircons. The authors claim in most cases that the rocks analyzed were metagranites, and that (Peytcheva, v. Quadt, 1995) they may prove the East Rhodope as a Hercynian orogen. An alternative explanation may be that these ages are another indication for a Hercynian reworking and recycling of the pre-Cadomian and Cadomian crust in the area.

Alpine *s.l.* events

Well-dated Alpine events are referred to:

— Jurassic subduction in the border of the Vardar zone: c. 160 Ma old granites in the Belasitsa Mt. (Ograzhden unit);

— Jurassic? or Mid- to Late Cretaceous events in the Sakar unit: 144 — 136 Ma old amphibolite-facies metamorphism in the Triassic of the Sakar unit, and superimposed (K-Ar ages on biotite: between 140 and 105 Ma) in the Precambrian and Cadomian metamorphics and granites;

— very low-grade to greenschist-facies metamorphism (illite, chlorite, pyrophyllite) in Permian and Triassic formations in the strongly folded and thrusted (in Mid-Cretaceous times) parts of the Strouma unit: c. 120 Ma (K-Ar dating in slates and mylonites);

— Late Cretaceous granites in the Pirin and West Rhodope (Elatia, North-Pirin, Daoutov): Rb-Sr whole-rock isochrones of about 88 Ma;

— Palaeogene (mostly Early Oligocene: 34 — 30 Ma) granites (Central Pirin, Teshovo, Vrondou; small bodies in Rila) in the Rhodope region coeval with the widespread volcanic activity.

Among the unresolved problems we can list the following:

— U-Pb and Rb-Sr data about a Mid-Cretaceous? metamorphism superimposed over the Rhodopian metamorphics in Central Rhodope Mts.;

— the age of some "South-Bulgarian granites" (Rila-West Rhodope batholite);

— Palaeogene ages obtained for pegmatites and migmatites in the Madan-Davidkovo dome.

Conclusions

The radioisotopic data obtained recently in the eastern parts of the Balkan Peninsula confirm the presence of a Precambrian basement reworked to a different degree by the Cadomian (late Panafrican), Hercynian and Alpine tectonothermal events.

The earliest Precambrian crust in the region was of Archean(?) and Palaeoproterozoic age. It is uncertain whether such a crust is still existing as rock bodies or fragments, or has been entirely recycled during later orogenies. However, a surprisingly high number of Archean and early Proterozoic zircon detrital(?) grains (Liati, Gebauer, 2001) within the equivalents of the Rhodopian Supergroup points at the presence of such crust in late Proterozoic times. The comparatively high (0.706 and higher) initial Sr ratios obtained for the Cadomian rocks in the Ograzhden unit and the Prerhodopian Supergroup in the Rhodope massif are also consistent with an older Precambrian age. Model "ages" of 1400 to 1100 Ma have been suggested for the Lisets and Osogovo gneisses (Graf, 2001).

The Cadomian recycling was most intense, and lead to an almost full "resetting of the radioisotopic clock" testified by most of the methods applied. Neoproterozoic to Cambrian(?) rifting(?) and formation of an island arc with basic igneous activity and considerable mantle contribution (Frolosh Formation, Strouma diorite formation) was coeval with intrusion in the Sakar and Strouma (Osogovo-Lisets) units of Cadomian (c. 550 — 500 Ma) granites of upper mantle or depleted lower crust signature (initial Sr ratios of 0.702 — 0.704). Thus, a continental crustal fragment ("Thracian massif") and a volcanic island arc with ophiolite igneous activity may be inferred in close neighborhood (Zagorchev, 1994) in late Neoproterozoic to earliest Cambrian times.

Hercynian igneous events are recorded both as presence of volcanic occurrences in the Early Devonian and granitic bodies intruded in Upper Devonian to Lower Carboniferous formations, and by isotopic dating of granites in the Sredna-gora crystalline block, and the Ograzhden, Osogovo and Pirin-Pangaion units. Hercynian tectonometamorphic events in the Rhodope (s.s.) and the East-Rhodope units are still not well constrained and understood. Initial Sr ratios for the best studied granite complexes in the Sredna-gora crystalline block point at a consecutive replacement of mixing and mingling basic and acid magmas of upper mantle to lower crustal origin (the acid magmas with an initial Sr ratio of 0.706 and an age of c.340 Ma) towards leucogranites of typical crustal anatectic origin with initial Sr ratios of c. 0.71 and an age of 300 — 250 Ma (post-tectonic Late Palaeozoic to earliest Triassic magmas that could be coeval with latest Carboniferous? to Triassic quartz-porphiries).

Alpine igneous and tectonothermal events are proven both with stratigraphic and isotopic evidence. Triassic to Jurassic igneous activity was abundant in the Vardar zone and the Circum-Rhodope belt, and apparently ended by Late Jurassic times when the ophiolites were sealed by Tithonian calpionellid-bearing conglomerate and limestone. The last granitic occurrences directly related to that activity are proven within the "Serbo-Macedonian massif" (Ograzhden unit included) with ages varying from 160 to 150 Ma. The next event is related to the same subduction accompanied by opening of the Srednogorie volcanic island arc (Coniacian to Campanian igneous activity with mantle signature — Sr_i about 0.704) and the coeval elevated arc ("plateau") of the Morava-Rhodope zone (granites with Sr_i about 0.710 — 0.711 in the Rhodope *s.l.* and Pirin). The extensional collapse of the Alpine orogens in late Eocene to Oligocene times lead also to an extensive igneous activity: trachyandesites to rhyolites, with intrusive homologues of gabbros to monzonites and mixed mantle to crustal signatures (Sr_i about 0.706) in the Southern (Greek) Rhodopes, to granites with a clear crustal anatectic signature in Pirin (Sr_i about 0.712).

Problems of the Alpine metamorphism are less clear. The Alpine amphibolite-facies metamorphism in the Triassic cover of the Sakar unit is superimposed as a tectonothermal event also in the pre-Cadomian metamorphic basement and Cadomian granites. The same is observed in respect of the low-grade to greenschist facies metamorphism in the Permian and Triassic superimposed as greenschist-facies metamorphism in the pre-Ordovician basement. However, persistent Pb-Pb and Rb-Sr data concerning Mid-Cretaceous, Late Cretaceous and

Palaeogene tectonothermal (tectonic and metamorphic) overprints in different parts of the Rhodope are still not sufficiently studied, and remain open for further studies.

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