Radiometric K/Ar data as evidence of the geodynamic evolution of the Ždraljica Ophiolitic Complex (central Serbia)

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Abstract. The study presents age data and petrologic characteristics of igneous rocks of the Ždraljica ophiolitic complex (ŽOC), situated in central Serbia, 150 km south of Belgrade. The complex consists predominantly of a MORB/VAB-like tholeiitic suite, represented mostly by gabros and diabases. The tholeiitic suite is intruded by calcalkaline intermediate and acid magmas of a VA-affinity, which presumably formed in a pre-collisional setting. The whole complex is intruded by peraluminous granite magmas. The crystallization age of the calc-alkaline pre-collisional quartzdiorite is 168.4±6.7 Ma and it post-dates the formation of the here exposed oceanic crust. Geological evidence suggest that the emplacement of the complex occurred during the Upper Jurassic. With respect to their petrology and age, the Ždraljica ophiolitic rocks are similar to the south Apuseni Mts. ophiolites, situated to the north, and to the Kursumija and Guevgeli ophiolites, situated to the south. All these ophiolites probably formed as parts of a single Jurassic belt, which can be termed the eastern branch of the Vardar Zone.

Key words: Vardar zone, Jurassic, ophiolites, K/Ar data, geodynamic, subduction, collision.

Introduction

Ophiolitic complexes are remnants of the oceanic lithosphere which where obducted onto colliding continental plates. They give precious information about the composite evolution of the oceanic crust/lithosphere, including spreading, lateral movements and closure of oceanic realms by subduction and obduction processes. These phases of the oceanic evolution were followed by metamorphic processes which usually make the investigation of magmatic processes very difficult.

The various ophiolites of the central and western Balkan Peninsula, mostly occurring in Serbia and Bosnia, and southward to the F.Y.R. of Macedonia and Greece, belong to a planetary ophiolitic zone connecting the Alpian and Himalayan orogenic belts (e.g. Coleman, 1977). Their nature has been a matter of ongoing debate, especially regarding the number of inferred paleo-oceanic domains which existed during the Mesozoic in this region. Most authors generally distinguish Dinaride and Vardar Zone ophiolites. They are regarded as belonging to separate sutures, situated in the west

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and in the east of the Drina–Ivanjica–Pelagonian block, respectively (e.g. Karamata et al., 1999, Karamata et al., 2000b, Resimic-Saric et al., 2000). While there is consensus for the Jurassic age of the emplacement of the Dinaride ophiolites, the ophiolites of the Vardar Zone are still the subject of various interpretations. For a long time the Vardar Zone ophiolites were regarded as being entirely Jurassic in age (Ciric, 1996). During the last decades, evidence appeared that the Vardar Zone itself is a composite suture. This conclusion was mainly derived from geological observations that the ophiolites of the western part of the Vardar Zone are connected to a Sennonian olistostrome mélangé (Karamata et al., 2005 and references therein), but those in the eastern part are covered by transgressive Tithonian limestones. On this basis, Karamata et al. (1999, 2000a) distinguished the eastern and western branches of the Vardar Zone, which are separated by the almost north-south stretching Kopaonik unit. They regarded the eastern branch as a relict of the main Vardar Ocean, which was closed in the Upper Jurassic, and the western one as a younger oceanic realm, closed in the Upper Cretaceous.

In this paper, the K/Ar radiometric ages of the Zdraljica ophiolitic complex (hereafter ZOC) are presented and discussed. The complex is located near Kragujevac in central Serbia, about 150 km south of Belgrade and it covers about 30 km² (Fig. 1). This ophiolite complex is geotectonically situated along the easternmost margin of the Vardar Zone and shares the following general characteristics of the ophiolites of the eastern branch of the Vardar zone (Karamata et al., 1999): (i) they are predominantly composed of igneous members of ophiolites, (ii) they are characterized by rare exposures of peridotitic bodies commonly severely serpentinized, (iii) they contain various granitic rocks, and (iii) their overlap sequence is Upper Jurassic in age (e.g. Karamata et al., 2005).

Analytical procedure

The radiometric K/Ar data was obtained using a magnetic sector mass spectrometer designed in the Institute for Nuclear Research ATOMKI of the Hungarian Academy of Sciences in Debrecen (Hungary). The analytical procedure was given in detail by Balogh (1985).

The instrument works in the static mode with a radius 150 mm and a deviation of 90°. For the Ar-analysis, the line for the Ar-extraction was also used. The most suitable samples were crushed, care being taken that the smallest grain size was not less than 0.05 mm. Dusty material was avoided because it increases the binding of atmospheric argon to the particle surfaces, which leads to an increase of the Ar-content of the samples. For the whole rock analyses, the samples were only roughly crushed, but for mineral analyses separation by firstly an electromagnetic separator and subsequently by heavy liquids was performed. In the final stage, the most fresh grains were picked out under binocular lenses.

Fig. 1. Geotectonic position of the Zdraljica ophiolitic complex (ZOC). The terrane boundaries and distribution of Mesozoic ophiolites are given by Karamata et al. (1994) and Dimitrijevic (1992).

Petrography and Geochemistry

Igneous rocks of the ZOC can be divided into two petrogenetically different rock suites: (1) a predominant suite of tholeiitic affinity and (2) a subordinate suite of a calc-alkaline affinity (Resimic, 2000).

Tholeiitic affinity suite

The tholeiitic suite is represented by massive gabbros and diabases with subordinate cumulitic gabbros and peridotites. Basalts and plagiogranites are very rare. The whole suite was metamorphosed under low- to medium-T conditions. Therefore, some rocks can be classified as spilites, metadiabases or even greenschists.
Although the ŽOC is a dismembered complex, an almost complete oceanic crust section can be reconstructed. The deepest part of the ŽOC is represented by highly serpentinized cumulitic wherlites, which developed as rare pods and layers within gabbros. They are allotriomorphic and orthocumulitic in texture, composed of olivine (Fo96.73) and diopside (Mg# 89.8). Gabbros appear as irregular blocks or sheets of massive and cumulitic facies. Texturally, they are coarse-, rarely fine-grained and poikilitic to coarse-grained ophitic and orthocumulitic, and contain plagioclase (fresh: 63.8–97.6 % An or albited: 3.7–19.6 % An), clinopyroxene (diopside with Mg# 73.0–93.3 and augite with Mg# 62.4–86.7) and, very rarely, totally serpentinized olivine. The accessories are magnetite, spinhe, and apatite. Secondary minerals are epidote, uralite, chlorite, tremolite, calcite, serpentine, pyrite and, rarely, magnesiohomblenble. Diabases appear as single dykes or dyke-swarms intruding gabbros or irregular massive bodies. They show ophitic, intergranular or interstitial textures. The main mineral phases are plagioclase (70.2–85.7 % An) and augite (Mg# 61.3–80.2), while accessories are magnetite, serpentine and altered glass. Metamorphosed diabases are mostly composed of albite (2.3–6.9 % An), epidote/zoisite, uralite, tremolite, magnesiohomblenble, calcite and pyrite. Basalts mainly occur as pillow lavas and, primary and redeposited, hyalloclastites. They have glomeroporphytic, ophitic, aphric and interstitial textures. Phenocrysts are albitized plagioclase (7.7–11.7 %An), relics of augite (Mg# 60.2 and 77.7), opaques and serpentinized olivine, while the groundmass is composed of chloritized glass and micro-lites of plagioclase. Plagiogranites occur as single dykes or sill-like intrusions and irregular glassy nodules within diabases and fine-grained gabbros. They display hypidiomorphic and fine-grained granular texture. They are composed of albite and quartz, accessories are magnesiohomblenble, magnetite and apatite, while epidote/zoisite and chlorite are secondary products.

The geochemical characterization of these suite is given in detail in Resimic (2000) and Resimic-Šarić et al. (2004) and will only be summarized here. According to their major element composition, these rocks show a tholeiitic affinity (Irvine & Baragar, 1971). Their MORB characteristics are suggested by HFSE ratios, e.g. Zr/Y (around 2.5) and Ti/Y (around 240) (Saunders & Turney, 1984). On Nb*2–Zr*4–Y (Messede, 1986) and V vs. Ti (Shervais, 1982) diagrams these rocks occupy both MORB and VAB fields. This is confirmed by the chemical compositions of clinopyroxenes plotted on Ti+Cr vs. Ca (Letterier et al., 1982) and F$_2$ vs. F$_3$ (Nisbet & Pearce, 1977) diagrams. In addition, the plagiogranites show an ORG affinity according to (Y+Na) vs. Rb and Y vs. Nb (Pearce et al., 1984) discrimination diagrams. Geochemical modeling shows that the most primitive rocks of the tholeiitic suite could have originated from 10–15 % non-modal batch melting of a spinel-lherzolite (Ol$_5$-Opx$_{25.2}$-Cpx$_{13}$-Sp$_{2.5}$) source. The most important process of magma modification was fractional crystallization (F=0.6), with the fractionating assemblage: P$_{52.9}$-Cpx$_{12.5}$-Olx$_{26.1}$-Ttn$_{2.9}$-Ap$_{4.4}$-Mt$_{1.0}$.

**Suite of calc-alkaline affinity**

The calc-alkaline affinity suite is predominantly represented by leucocratic granodiorites and granites and by rare quartzdiorites and quartzmonzodiorites. These rocks have a similar mode of occurrence. They generally appear as irregular bodies or smaller dykes, which show sharp and sheared boundaries in contact with gabbros.

Leucocratic granodiorites and granites are hypidiomorph- morphic medium- to coarse-grained in texture. Poikilitic, perthitic and granophitic textures are also observed. They consist of quartz, K-feldspar, albite (0–6.9 % An), chloritised biotite and amphibole. Accessory phases are apatite, magnetite, and zircon, while sericite and chlorite are alteration products. Quartzdiorites and quartzmonzo- diorites show a medium-grained, hypidiomorphic texture. The main minerals are plagioclase (48.1–42.2 % An) and magnesiohomblenble (Mg# 0.63–0.74), while K-feldspar is very rare and occurs only as interstices in quartzmonzodiorites. The accessories are sphen, paratite, zircon and opaque minerals.

Geochemically, both the leucocratic granodiorites/gran- ites and the quartzdiorites/quartzmonzodiorites are calc-alkaline and differ from plagiogranites in having higher LILE and lower HFSE and Cr, Ni contents. However, the leucocratic granodiorites/granites are peraluminous and have a similar composition to the Furka and Fanos granitoids found more to the south in the F.Y.R. of Macedonia and Greece, respectively. These granitoid rocks occur within the ophiolitic complexes which geotectonically belong to the eastern branch of the VZ. In addition, the ŽOC leucocratic granitoids show syn- to postcollisional character (Harris et al., 1986, Pearce et al., 1984), as do the Furka and Fanos granitoids (Sotrajanova, 1967, Christofides et al., 1990). On the other hand, the ŽOC quartzdiorites and quartzmonzodiorites are metaluminous and are akin to VA-granitoids, i.e. they show a pre-collisional character on the above mentioned discrimination diagrams.

**K/Ar data of the ŽOC**

The K/Ar radiometric age determinations of the whole rock (w.r.) samples and the mineral separates (amphibole, plagioclase and K-feldspar) from both the tholeiitic and calc-alkaline suites of the ŽOC are presented in Table 1 and Fig. 2. There is a wide range of age data (168.4–77.3 Ma), which probably mark various events in the evolution of the ŽOC. Thus, these radiometric data can be interpreted as showing: (a) the age of igneous processes and (b) the time of various metamorphic events.
The oldest ages were obtained on amphiboles from the quartz-diorite samples. The value of 168.4±6.7 Ma (sample V-306/7) most likely represents the age of intrusion of the quartz-diorite magma. The effects of certain rejuvenation can be taken into consideration because partial chloritization of the amphibole from the quartz-monzodiorites could have caused some loss of radiogenic Ar. This can explain the younger estimate of 145.2±5.7 Ma for the amphibole from sample V-353c.

Amphiboles from a gabbro sample (8-B) revealed an age of 152 Ma but with a very high error of ±21 Ma. It is not likely that the crystallization age of these rocks is lower than 152 Ma because this gabbro is intruded by the above mentioned quartz-diorites. Therefore, this estimate indicates some metamorphic overprints and may represent the age of the emplacement of the Zdraljica ophiolites. The much younger whole-rock age of 136±7.7 Ma obtained on a whole-rock diabase sample for certain post-dates the age of ophiolite emplacement.

The ages of the feldspars from all lithologies of the ZOC revealed a similar range of 120.7–127 Ma. These ages suggest that the whole ZOC underwent a metamorphic overprint during the Cretaceous. Of the dated minerals, K-feldspar loses Ar at the lowest temperature (130±15° C) and this is in accordance with the youngest ages measured on the K-feldspar from the leucocratic granite.

Discussion and concluding remarks

The ophiolites of Zdraljica predominantly consist of tholeiitic MORB-affinity igneous rocks, which represent slices of the ancient oceanic crust. The crystallization age of these rocks could not be directly radiometrically dated by the K/Ar method. All the K/Ar estimates on tholeiitic rocks are younger than the presumed emplacement age of the ophiolites. The time of emplacement can be inferred from the fact that the ZOC is associated with a Middle/Upper Jurassic diabase-chert formation (Markovic et al., 1968, Dolic et al., 1981) and that its immediate overstep sequence is represented by Tithonian limestones and Lower Cretaceous paralysches (Markovic et al., 1968; Dolic et al., 1981).

The magmatic age of the ZOC can possibly be inferred on the basis of the crystallization age of the calc-alkaline quartzdiorites, which was estimated at around 168 Ma. These rare rocks are metaluminous and show a pre-collisional VA-character. This can indicate that at least some parts of the ZOC are relics of an immature island arc. In this context, the minimal formation age of this oceanic crust can be regarded as Middle/Late Jurassic. On the other hand, the crystallization age of the leucocratic granitoids cannot be inferred from the available K/Ar data. Their geochemical characteristics suggest that they formed under a syn- to post-collisional setting, i.e. after the emplacement of the ZOC. As mentioned above, petrochemically similar counterparts are the Furka and Fanos granitoids which occur more to the south, within the Guevgeli ophiolitic complex. The Fanos granite was dated 148±3 Ma (K/Ar on biotite; Spray et al., 1984) and 150±2 Ma (K/Ar and Rb/Sr on biotite; Borsi et al., 1966). These ages can correspond to the time of intrusion of Zdraljica leucocratic granitoids in the syn- to post-collisional phase following the emplacement of ophiolites.

The above presented data concerning the Zdraljica ophiolite complex support the interpretation based on the existence of two-branches within the Vardar Zone. In many geotectonic interpretations, the ophiolites of the Vardar Zone were generally believed to be related with Jurassic igneous sequences situated more to the north in the South Apuseni (Bleahu et al., 1981;
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References


Nicolae, 1995; BORTOLOTTI et al., 2002, and references therein). They are mainly based on K/Ar Upper Jurassic ages available for south Apuseni (Mures) ophiolites (167.8±5 Ma – NICOLAE et al., 1992). In addition, south Apuseni ophiolites are associated with radiolarian cherts of Callovian to Oxfordian age (LUPU et al., 1995). However, these interpretations did not take into account that only the eastern part of the Vardar Zone ophiolites can be considered as a continuation of these occurrences. In this context, important evidence is provided by this study. For instance, the following characteristic of the Ždraljica ophiolitic segment is similar to the south Apuseni ophiolites: (i) the Ždraljica ophiolitic segment is dominated by igneous members with only subordinate peridotites, (ii) it was formed as a MORB-type oceanic crust in Middle Jurassic, (iii) it contains calc-alkaline rocks of a VA-signature, which presumably originated in a pre-collisional setting, (iv) the whole ophiolitic unit was intruded by leucocratic peraluminous granites after the emplacement, and (v) its overstep sequence is represented by Titonian limestones and Lower Cretaceous flysch. The southern continuation of the eastern branch of the Vardar Zone are the Kuršumlija (south Serbia) ophiolites. The Kuršumlija ophiolites are situated only about 150 km southwards from the ŽOC. They are very similar to south Apuseni ophiolites also meet the above summarized characteristics (e.g. IVANOVSKI, 1970). It is worth noting that the specific geotectonic position of the Guevgeli ophiolites with respect to more westwardly situated Vardar ophiolites was emphasized in the seventies by MERCIER (1973).

The presented data set is not sufficient to explain the age and formation of the Ždraljica ophiolites in detail. However, there is evidence that this is a specific Jurassic ophiolitic section with possible dismembered counterparts in the north and in the south. They probably represented (an) oceanic domain(s) situated along the southern European margin during the Jurassic. After the closure and accretion, they probably formed as a unique ophiolite belt. The southern part of the belt more or less preserved its continuation, while the northern parts came into the present position during the tectonic escape of Adria-related microplates during the Late Paleogene–Early Neogene.


Резиме

Радиометријске K/Ag старости као доказ геодинамичке еволуције Ждралчког офилитског комплекса (централна Србија)

Офилитски комплекс Ждралче (ЖОК) налази се надомак Крагујевца, око 150 км југо од Ђабрада. Геотектонски, он припада главном (источном) ободу Вардарске зоно.

Магматске стене ЖОК-а могу се подсетити на свиту топчастог афинитета, која доминира, и свиту калко-алкалних карактеристика. Топчанска свита представљена је масивним габровима и дијабазима, подређено кумулатним габровима и периidotитима, док су базалти и плагиогранити веома ретки. Ове стене показују MORB-карakterистике према садржајима HFS елемената, ипс. Zr/Y (~2.5) и Ti/Y (~240). На дијаграмима Nb*2-Zr/4-Y и V vs. Ti заузимају поља и MORB-а и VAB-а, што је потврђено и хемијским саставом пироксената на дијаграмима Ti+Cr vs. Ca и F1 vs. F2. Плагиогранити...
покazuju ORG afinitet. Kalko-alkalna svita
представљена je претежно леукократним гранити-
ма и гранодиоритима и ретким кварцидндиоритима. Према геохемијским одли-
кама ове стене се разликују од плагигранита по
већем садржају LILE и мањем HFSE, Cr и Ni. Леукократни гранити и гранодиорити су пералу-
минацијски и слично су састава као гранити Фурке
(Македонија) и Фаноса (Грчка). Ову сличност
птоврђује и њихов син- до пост-колизиони карак-
тер. Са друге стране, кварцидндиорити и кварцидн-
диорити су метаалуминијски, блински VA грани-
тоцима и показују пре-колизиони карактер.

Старост кристализације полетичких стена MORB
афнитета није директно одређена K/Ar мерењима.
Све добијене старости су млађе од претпостав-
љеног времена смештаја ЖОК-а које је одређено
на основу чињенице да је ЖОК асоциран са сред-
њо/горњојурском дијабаз-рољаном формацијом
и да оверстеп сењевица представљају титонски
крећачи и доњокредни параплини.

Старост магматских процеса од oko 168 Ma
укају кристализацију калко-алкалног преколи-
зионог и метаалуминијског кварцидндиоритог VA-афн-
итета. Ово укажује да су барем неки делови ЖОК-а
реликти незрелог острожског лука, односно, да се
као минимална старост образовања океанске коре
може сматрати средњо/горња јура. С друге стране,
време кристализације леукократних гранитоцида
није се могла добити радиометријским K/Ag дато-
вањем. Њихове одлике, међутим, укажу да су обра-
зовани у син- до постколизионим условима, однос-
но, после смештања ЖОК-а, слично гранитима
Фурке и Фаноса. Старост гранита Фаноса износи
148 ± 3 Ma (K/Ag на биотиту и 150 ± 2 Ma (K/Ag и
Rb/Sr на биотиту). Ове старости могу би да одгово-
равају и времену интрузионог Ждраличких леуко-
кратних гранитоцида у син- до пост-колизионој фази
која је пратила смештај офилолита. Приказани подаци о ЖОК-у потврђују интерпретацију о постојању два одсека унутар Вар-
дарске зоно – источни или главни за који се сматра
да је затворен током јура и западни који је затворен
у крети. Наиме, ЖОК има одлике које су карактер-
истичне и за друге офилоске комплексе унутар
источног обода Вардарске зоно. У многим геотек-
тонским интерпретацијама офилоли жужих Апун-
сеа сматрају се делом јурске магматске севеште
Вардарске зоно, главном на основу K/Ag горњо-
јурских (167.8 ± 5 Ma). Поред тога ови офилолити су
асоцирани са радиоларитима каловије до оке-
фордског старости. Ове интерпретације, међутим,
нису узимале у обзир да се само у источном ободу
Вардарске зоно налазе појаве офилолита које пред-
стављају континуитет. Слеђеће карактеристике
ЖОК-а су сличне са одликама офилолита јужних
Апунсеа: (a) комплексе је изграђен главном од маг-
матских чланова офилолита, (b) океанска кора
MORB-типа образована је у средњој јури, (в) ком-
плекс садржи калкоалкалне стена VA афнитета,
које су вероватно преколизионог карактера, (g)
цела офилолска севена је после смештаја интру-
дувана леукократним пералуминозним гранитоциди-
ма и (d) оверстеп секвенци је представљена титон-
ским крежачима и доњокредним флином. Наста-
вак источног обода Вардарске зоно на југ пред-
стављају офилолити Куршумлије и Беввелјије.

Приказани сад падатак није довољан да се
detaлино објасне старост и настанак ЖОК-а.
Међутим, доказано је да је рећ о специфичном јурску
офилолиту који се на север и југ наставља са
сличним појавама. Сви они вероватно представљају
један или више јурских океанских домена дуж јужне
европске маргине, који су после затварања и акре-
зије образовали јединствен офилолски појас. Јуж-
ни део овог појаса сачуван је мање-више свој конти-
нуитет, док је његов северни део дошао у данашњи
положај за време горњег палеогена–доњег неогена.