SHORT NOTE

BONINITES FROM THE KOPAONIK AREA (SOUTHERN SERBIA): NEW EVIDENCES FOR SUPRASUBDUCTION OPHIOLITES IN THE VARDAR ZONE

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ABSTRACT

Fragments of Jurassic oceanic basins are preserved along two main alignments in the Dinaric-Hellenic belt. The western alignment, extending from western Greece to Croatia, is relatively well known, whereas the eastern, represented by the ophiolites of the Vardar zone, running from eastern Greece to Serbia, has been poorly investigated. In this paper, we provide new evidences for the occurrence of boninitic lavas in the Kopaonik area belonging to the Vardar zone. These rocks have been found in a sheeted dyke complex closely associated to harzburgitic mantle tectonites. This finding implies that, in contrast with previous interpretations, the Vardar zone is characterized by ophiolites originating in a suprasubduction zone setting. The occurrence of boninitic rocks gives important constraints for the geodynamic recostruction of the Dinaric-Hellenic belt.

INTRODUCTION

Ophiolites represent fragments of oceanic lithosphere located along the main suture zones of the collisional belts. Their study can provide useful data for the geodynamic reconstruction of the collisional belts in order to assess the location, as well as the petrological and geological features, of the fossile oceanic areas.

In the Dinaric-Hellenic belt ophiolites are widespread, mainly as huge nappes located along two main, north-south-trending alignments. In the easternmost alignment, corresponding to the Vardar zone, ophiolites are generally interpreted as a lithosphere representative of an oceanic basin located between the Eurasia and Adria plates. However, their petrological features are poorly known and suitable informations about their geodynamic setting are still lacking.

The occurrence of boninitic rocks from the ophiolite sequence of Vardar zone is reported in this paper for the first time. This finding will provide useful constraints for the geodynamic evolution of the Dinaric-Hellenic belt.

GEOLOGICAL SETTING

The Dinaric-Hellenic belt is a 2000 km-long alpine orogenic chain originated from the convergence between the Adria and Europa plates. Its long-lived history (e.g. Dimitrijevic and Dimitrijevic, 1973; Robertson and Karamata, 1994; Pamic et al., 1998; Dimitrijevic, 2001; Pamic et al., 2002; Bortolotti et al., 2004 and many others) includes a Triassic rifting followed by a ?Late Triassic-Early Jurassic oceanic opening with development of Mid-Ocean Ridge (MOR) oceanic lithosphere. In the geodynamic reconstructions proposed for the Early Jurassic, one or more oceanic basin(s) between the Europe and Adria plates are postulated. During the latest Early Jurassic, the change in the Eurasia-Adria plates motion, resulted in an intraoceanic subduction leading to the development of a new oceanic lithosphere in a suprasubduction zone (SSZ). Therefore, two different types of oceanic lithosphere (MOR and SSZ) were coexisting between the Eurasia and Adria plates. In the Late Jurassic, the continuous plate convergence led to the obduction of ophiolites onto the continental margins before the complete closure of the oceanic areas during the Early Cretaceous or Tertiary. The convergence, mainly characterized by west-verging deformations, affected the continental areas during the Tertiary.

The fragments of the Jurassic oceanic basins are preserved along two main alignments in the Dinaric-Hellenic belt. The western alignment, running from western Greece to Croatia, is relatively well known, whereas the eastern one, extending from eastern Greece to Serbia, is less investigated. This alignment is represented by the ophiolites preserved in the Vardar zone (Robertson and Karamata, 1994; Trubelja et al., 1995; Dimitrijevic, 2001), i.e. a composite terrane consisting of both continental- and oceanic-derived slices. The Vardar zone ophiolites are generally regarded as remnants of MOR lithosphere (Robertson and Karamata, 1994; Trubelja et al., 1995), though their origin in a back-arc basin is suggested by Pamic et al. (2002).

The study area, belonging to the External Vardar zone, is located east of Kopaonik Mts. (Fig. 1b) in southern Serbia (Urosevic et al., 1973). Ophiolites (Fig. 1c) occur as a huge nappe lying at the top of the tectonic pile (e.g. Dimtrijevic, 2001). They are thrust onto the Brzece unit represented by the Upper Cretaceous ophiolite-bearing flysch. The Brzece unit is, in turn, thrust onto the "Central Kopaonik Series", consisting of Late Triassic amphibolites, phyllites and marbles. The Triassic metamorphic rocks are intruded by Lower Oligocene I-type granitoid rocks (Dimitrijevic, 2001). In the eastern zone of the Kopaonik area the ophiolites are thrust by the Brus unit, made up of Late Cretaceous turbidite deposits.

In the Kopaonik area the ophiolites are mainly represented by strongly serpentinized mantle harzburgites and minor intrusive and sheeted dyke complexes. The study samples were collected near the Grcak village (geographic coordinates: 20°57' E and 43°28' N), where sub-parallel basaltic dykes showing one-way vitrophyric chilled margins and ranging in width from 40 to 100 cm are exposed.

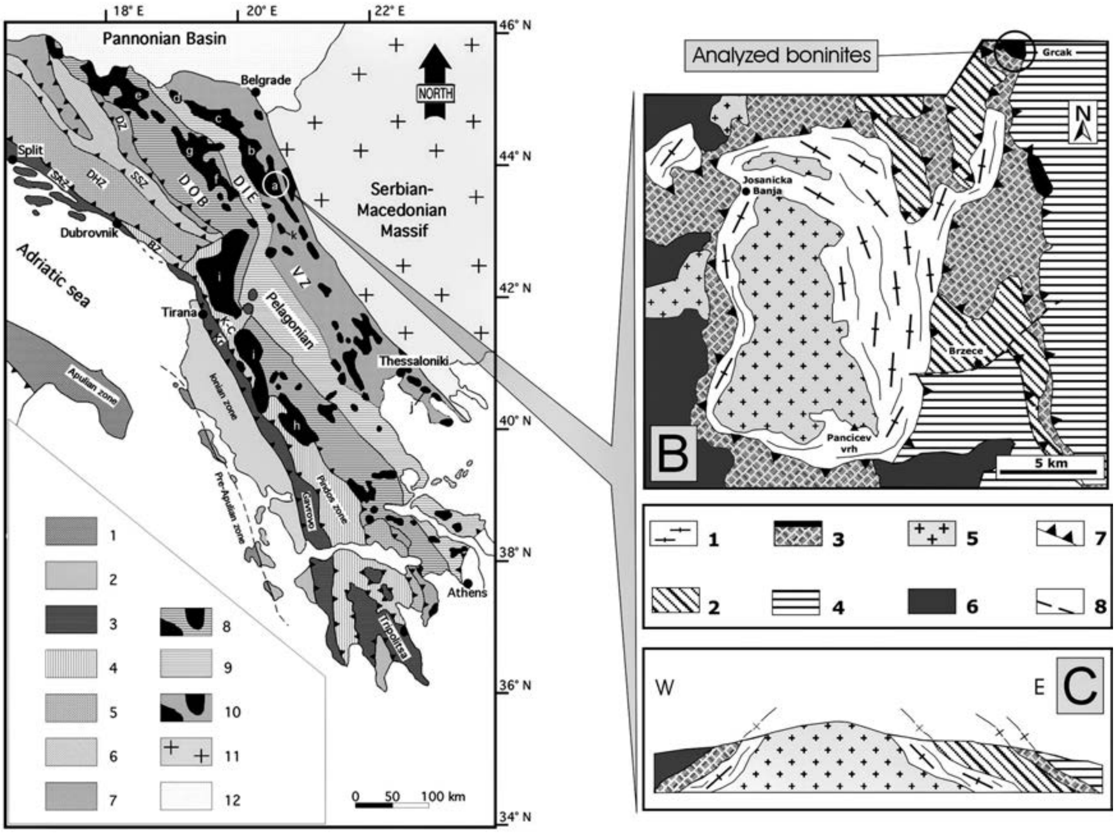

Fig. 1 - A. Tectonic sketch of the Dinaric-Hellenic belt after Bortolotti et al. (2004). Legend and abbreviations: 1 = Apulian and Pre-Apulian zone; 2 = Ionian zone; 3 = South-Adriatic zone (SAZ), Kruja (Kr), Gavrovo, Tripolitsa; 4 = Budva zone (BZ), Krasta-Cukali (K-C), Pindos; 5 = Dalmatian-Herzegovian (DHZ) zone; 6 = Sarajevo-Sigmoid zone; 7 = East Bosnian-Durmitor zone; 8 = Dinaric ophiolite belt (DOB); 9 = Drina-Ivanjica and Pelagonian zone (DIE); 10 = Vardar zone (VZ); 11 = Serbian-Macedonian Massif; 12 = Pannonian basin. Ophiolites: a = Ibar; b = Troglav; c = Maljen; d = Zvornik; e = Krivaja-Konjuh; f = Bistrica; g = Zlatibor; h = Pindos; i = Mirdita; j = Chalkidiki; k = Goles.
B. Simplified geological sketch-map of the Kopaonik area after Urosevic et al. (1973). 1 = Metamorphic complex of Kopaonik; 2 = Brzece unit (ophiolite-bearing turbidites); 3 = Ophiolites (ultramafic and mafic rocks); 4 = Brus unit (flysch); 5 = Kopaonik granitoid; 6= Volcanic rocks; 7 = Thrusts; 8 = Faults.
C. Interpretative E-W geological section of the Kopaonik area after Urosevic et al. (1973).

PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS

All studied samples are affected by low-grade ocean-floor metamorphism. Clinopyroxene is transformed into tremolite, plagioclase is generally saussuritized and rarely transformed into albite, whereas fine-grained groundmass is commonly replaced by clay minerals. Most of the studied rocks are porphyritic, with clinopyroxene phenocrysts set in intergranular (rarely sub-ophitic) groundmass, where clinopyroxene and plagioclase microlites are recognized. Accessory phases are represented by interstitial Fe-Ti oxides. Few samples display coarse-grained doleritic texture with euhedral clinopyroxene and subhedral-interstitial plagioclase. Veins filled by quartz-zeolites-epidote assemblages are locally observed.

Whole-rock major and trace element analyses (Table 1) were performed according with the methods reported in Saccani et al. (2004a).

The analyzed samples range from basalt to basaltic andesites and display high Mg#, as well as relatively high MgO and CaO contents, coupled with low concentrations of HFSE, such as TiO_2, P_2O_5, Zr, and Y (Table 1). They display Ti/V ratios lower than 10 (Table 1), which are typically observed in very low-Ti basalts from the Albanide-Hellenide ophiolites (Saccani et al., 2004b and references therein).

In general, the studied dykes display geochemical features that are compatible with those of very low-Ti (boninitic) basalts (Beccaluva et al., 1984). In particular, MORB-normalized HFSE concentrations (Fig. 2a) display rather depleted patterns at about 0.07-0.5 x N-MORB contents (Sun and McDonough, 1989). REE exhibit the U-shaped patterns typical of boninites (Fig. 2b) with medium-REE (MREE) ranging in concentration between 1 and 5 x chondritic abundance (Sun and McDonough, 1989). However, two groups of samples can be distinguished on the basis of their different enrichment in LREE with respect to HREE and absolute REE concentrations (Fig. 2b). The first group of samples (KP30, 31, 32) is characterised by a definite LREE enrichment with respect to heavy rare elements (HREE), with LREE ranging from 4 to 10 x chondrite and La_N/Yb_N = 0.97-1.64; these samples are also relatively less depleted in HFSE (Fig. 2a). LREE enrichments are not related to fractionation processes, as they are observed in the rather primitive sample KP30 (e.g. Mg# = 85.3). The second group (KP28, 29, 35, 36), though displaying a marked enrichment in LREE with respect to MREE, are characterised by a clear depletion of LREE with respect to HREE (Fig. 2b) and a stronger depletion of HFSE when compared with basaltic rocks of the first group (Table 1 and Fig. 3). LREE approximately range from 1 to 3 x chondritic abundance and La_N/Yb_N ratios are between 0.55 -0.62. Sample KP29 displays a marked Eu positive anomaly, which is in agreement with its coarse-grained doleritic texture with abundant interstitial plagioclase.

According to Pearce and Norry (1979), the Zr/Y ratios (Table 1) of the studied boninitic dykes are consistent with a genesis from variably depleted mantle sources.

Table 1 - Bulk-rock major and trace element analyses of boninitic dykes from the Kapaonik ophiolites

Sample	KP28	KP35	KP29	KP36	KP32	KP31	KP30
Rock	Bas	Bas	Bas	Bas	Bas	BAnd	Bas
XRF analyses:							
SiO_2	44.10	48.31	49.36	49.14	52.32	54.63	51.73
TiO_2	0.15	0.18	0.07	0.19	0.30	0.22	0.15
Al_2O_3	9.90	8.68	16.66	12.95	10.53	12.32	11.29
Fe_2O_3	0.92	1.10	0.58	1.37	1.21	1.09	0.58
FeO	6.11	7.31	3.90	9.12	8.03	7.29	3.84
MnO	0.19	0.16	0.09	0.16	0.16	0.12	0.12
MgO	22.76	21.99	12.28	15.39	14.42	11.25	15.52
CaO	11.16	7.75	10.19	5.43	7.54	6.07	14.99
Na_2O	0.14	0.52	2.03	2.47	1.61	2.92	0.67
K_2O	0.01	0.07	1.18	0.21	0.24	0.02	n.d.
P_2O_5	0.02	0.02	0.02	0.02	0.03	0.03	0.03
L.O.I.	4.64	4.08	3.60	3.48	3.16	3.19	4.13
Total	100.10	100.16	99.97	99.91	99.54	99.17	100.05
Mg#	86.9	84.3	84.9	75.0	76.2	73.3	85.3
Zn	42	63	23	52	59	38	19
Cu	10	24	55	9	18	32	8
Ni	125	476	102	233	226	121	151
Co	45	68	28	51	49	42	28
Cr	249	1082	140	482	723	283	175
V	216	225	140	251	270	275	141
Rb	n.d.	4	34	7	7	4	n.d.
Ba	8	18	133	29	44	25	n.d.
Sr	2	77	254	63	135	30	6
Zr	9	9	5	6	23	20	27
Y	11	9	8	10	13	11	11
ICP-MS analyses:							
Sc	31.7	33.8	27.8	38.0	36.9	35.5	21.4
La	0.69	0.67	0.48	0.73	2.03	2.00	1.33
Ce	1.58	1.47	1.11	1.57	4.64	4.44	3.02
Pr	0.16	0.18	0.13	0.14	0.49	0.44	0.36
Nd	0.72	0.67	0.63	0.66	2.11	1.75	1.76
Sm	0.24	0.19	0.19	0.21	0.65	0.58	0.52
Eu	0.08	0.12	0.18	0.09	0.19	0.14	0.13
Gd	0.28	0.40	0.40	0.40	0.66	0.50	0.47
Tb	0.06	0.08	0.07	0.08	0.16	0.11	0.10
Dy	0.64	0.67	0.48	0.78	1.23	0.95	0.71
Ho	0.19	0.20	0.15	0.22	0.33	0.28	0.18
Er	0.59	0.60	0.46	0.66	1.04	0.83	0.51
Tm	0.11	0.11	0.08	0.13	0.20	0.15	0.09
Yb	0.89	0.82	0.55	0.94	1.50	1.06	0.61
Lu	0.14	0.12	0.09	0.16	0.22	0.16	0.09
Nb	0.69	0.61	0.46	0.58	1.18	1.13	0.84
Hf	0.28	0.27	0.19	0.27	0.58	0.61	0.67
Ta	0.17	0.14	0.12	0.10	0.11	0.10	0.13
Th	0.28	0.24	0.13	0.21	0.45	0.70	0.43
U	0.16	0.12	0.07	0.13	0.17	0.34	0.16
Ti/V	4	5	3	5	7	5	7
Zr/Y	0.8	1.0	0.7	0.6	1.7	1.8	2.5
$(La/Sm)_N$	1.86	2.31	1.65	2.28	2.02	2.22	1.64
$(La/Yb)_N$	0.56	0.59	0.62	0.55	0.97	1.36	1.57

Abbreviations: Bas = basalt; BAnd = basaltic andesite; Mg# = molar Mg/(Mg+Fe)*100; n.d. = not detected. Normalization values for REE ratios are from Sun and McDonough (1989).

In the Cr versus Y diagram (Pearce, 1983), three possible mantle sources are considered (Fig. 3), according to the model of incremental batch melting from a MORB-type source proposed by Murton (1989). The boninitic rocks studied in this paper are compatible with approximately 10% partial melting of source M3. This source corresponds to a very refractory mantle residue calculated after about 12% melt extraction from M2, which in turn, represents a mantle source that experienced previous 20% MORB melt extraction (Murton, 1989). It should also be noted that the M3 source corresponds to a depleted harzburgite compositionally very similar to those found in the Albanide-Hellenide ophiolites (e.g., harzburgite PE9 in Fig. 3). An origin of Kapaonik boninites from partial melting of depleted mantle harzburgites is also consistent with the observed overall HFSE depletion (Fig. 2a). Nonetheless, the variable LREE enrichment (Fig. 2b) can be interpreted as resulting from variable enrichment in the most incompatible elements (LREE and LFSE) from subduction-derived hydrous fluids.

The REE distribution of the rather primitive KP35 very low-Ti basalt and mantle harzburgite PE9 is used to model the possible mutual relationships between melt and source (Fig.

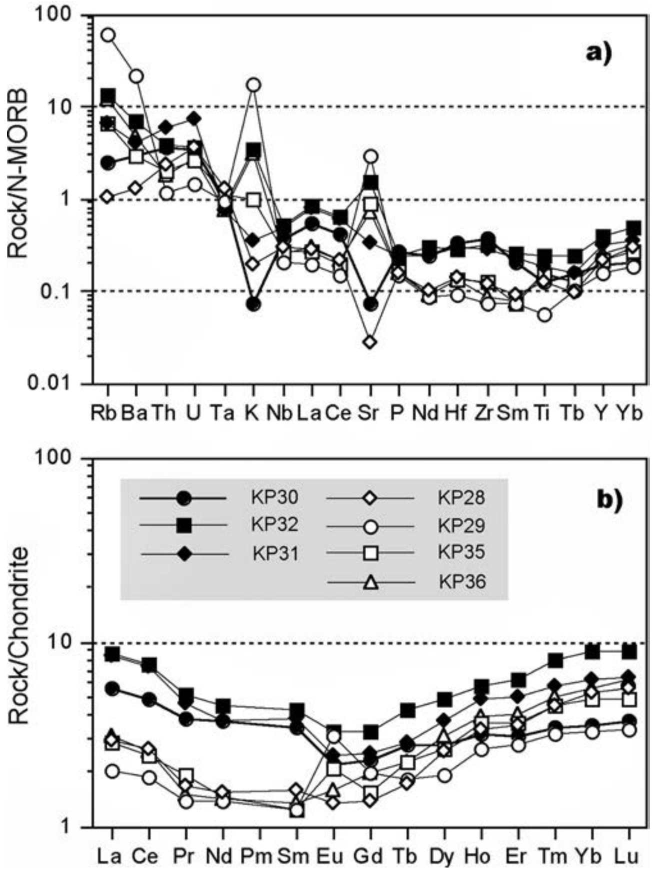

Fig. 2 - N-MORB normalized incompatible element compositions (a) and chondrite-normalized REE compositions (b) for the boninitic dykes from the Kapaonik ophiolites. Normalization values are from Sun and McDonough (1989).

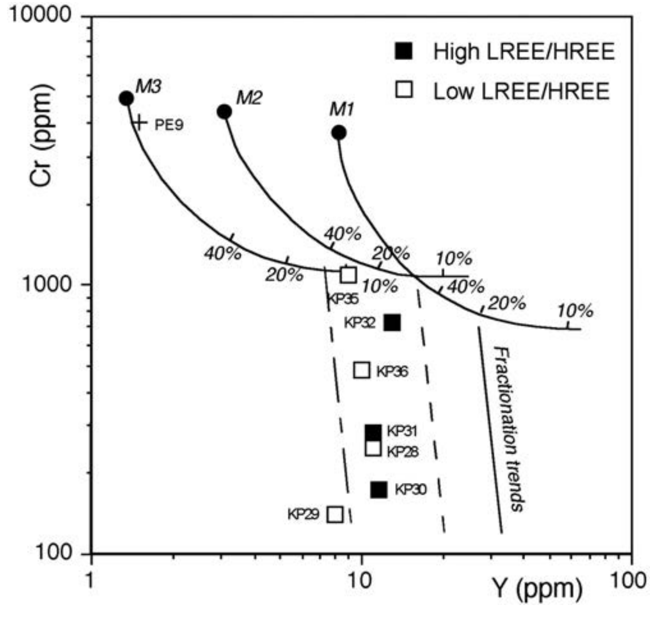

Fig. 3 - Cr vs. Y diagram (Pearce, 1983) for boninitic dykes from the Kapaonik ophiolites. Mantle source compositions and melting paths for incremental batch melting are from Murton (1989). M1: calculated MORB source; M2: residue after 20% MORB extraction; M3: residue after 12% melt extraction from M2.

4). Sample KP35 corresponds to a theoretical melt (L-10%) resulting from about 10% partial melting of the source S (Fig. 4). According to Beccaluva et al. (1984), this source is in turn modelled from harzburgite PE9 enriched in LREE by subduc-

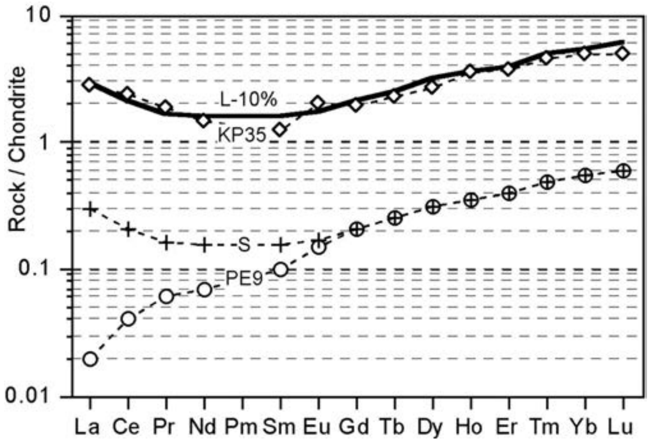

Fig. 4 - Chondrite-normalized (Sun and McDonough, 1989) REE patterns for the harzburgite PE9 (Vourinos, Greece) and very low-Ti basalt KP35 from Kaponik ophiolites. The patterns of a melt (L-10%) corresponding to 10% equilibrium partial melting of a hypothetical harzburgitic mantle source (S) modelled according to Beccaluva et al. (1984) are also shown.

tion-related fluids (Fig. 4). The different enrichments in LREE observed in the Kapaonik boninites, most likely reflect variable enrichments of the mantle sources by subduction-derived hydrous fluids. Fractional crystallization processes responsible for the genesis of more evolved basalts are behind the scope of this paper and will be described elsewhere.

In summary, the possible scenario for the genesis of the Kapaonik boninitic dykes is partial melting of harzburgitic mantle sources, which underwent variable enrichment in LILE and LREE by SSZ fluids.

DISCUSSION AND CONCLUSIONS

The geodynamic setting of the Vardar ophiolites is still a matter of debate, owing to the lack of reliable data on their geochemical affinity. According to Roberston and Karamata (1994), basalts from the Vardar zone, showing MORB and within-plate affinity, are regarded as derived from a mid-Late Triassic to lowermost Late Jurassic oceanic crust. The Vardar ophiolites have been interpreted as an oceanic lithosphere generated in a MOR setting by Trubelja et al. (1995) on the basis of their geochemical features. By contrast, Pamic et al. (2002) suggest a different origin of the MOR-type Vardar ophiolites, considered as a Cretaceous oceanic lithosphere originating in a SSZ setting, during a mature stage of spreading in a back-arc basin.

In this paper, we document the occurrence of boninitic rocks in the Vardar zone. These rocks have been found as dykes in a sheeted dyke complex, closely associated with harzburgitic mantle rocks. The boninite lavas are regarded as derived from melting of a strongly depleted source represented by SSZ mantle harzburgites (Beccaluva and Serri, 1988). Boninites are generally emplaced in intraoceanic forearc settings, typically forming the basement of arc volcanoes, and their formation is related to subduction inception, slowed convergence and slab rollback leading to arc splitting and/or forearc extension and spreading. The common thread is a rapid extension of the overriding plate and upwelling of the mantle leading to volatile-fluxed decompression melting of severely depleted mantle rocks.

This finding of boninites indicates that the Vardar zone, beside the occurrence of MOR-type ophiolites, is also characterized by ophiolites originating in a SSZ forearc oceanic basin. Although their relationships with the MOR ophiolites are still unresolved, the occurrence of boninitic rocks implies that SSZ processes affected some portions of the Vardar ocean, thus providing further constraints for the geodynamic recostruction of the Dinaric-Hellenic belt.

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