Geochemical characteristics and Tectonic significance of Permo-Triassic Silicic Volcanic rocks from Circum-Rhodope Belt, Vardar (Axios) Zone, northern Greece

A. Asvesta[1], S. Dimitriadis[2]

(1) Department of Geotechnology and Environmental Engineering, Western Macedonia University of Applied Sciences, Kila, 50100 Kozani, Greece, asvesta@teiwm.gr & argyasve@gmail.com
(2) Department of Geology, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

Introduction and Geological setting

The Circum-Rhodope Belt (CRB) in Greece comprises the eastern part of Peonias subzone of the Vardar (Axios) Zone. It is a complex imbricated belt that borders the Palaeozoic high-grade crystalline basement of Serbo-Macedonian massif. It mainly consists of Upper Palaeozoic to Mesozoic greenschist-facies metamorphosed sedimentary successions, igneous rocks and ophiolites (Asvesta and Dimitriadis, 2010; Meinhold and Kostopoulos, 2013; and references therein), among them, a Permo-Triassic Silicic Volcano-Sedimentary (SVS) succession that crops out discontinuously in NNW-SSE direction. The SVS succession is an important part of the CRB, as it probably represents the early stages of the opening of a post-Variscan, neo-Tethyan oceanic strand (Vardar -Axios- oceanic basin) which was finely eliminated during some stage of the Tertiary Alpine orogeny (Asvesta, 1992; Dimitriadis and Asvesta, 1993; Asvesta and Dimitriadis, 2010, 2013). The SVS succession is laid stratigraphically between the Permian Examili Formation (terrigenous sediments) and the Triassic Svoula Formation (neritic carbonate sediments). From base to top it comprises mainly rhyolitic to rhyodacitic pyroclastic rocks, aphyric and porphyritic lavas, as well as domes intruded and sills embedded into formerly wet unconsolidated neritic carbonate sedimentary facies forming peperites, hyaloclastites and polymictic epiclastic sedimentary rocks. This facies architecture suggests an acid volcanic activity in a transitional subaerial-coastal to shallow submarine environment, which was still active when the neritic carbonate sedimentation began (Asvesta and Dimitriadis, 2010, 2013). Moreover, minor occurrence of tholeiitic basalts and dolerites (Triassic Rift Basic Volcanics: Asvesta, 1992; Dimitriadis and Asvesta, 1993; Asvesta and Dimitriadis, 2013) are temporally and spatially related with the SVS succession, as they are found interstratified with the Upper Triassic pelagic chert and carbonate sediments of Metallikon and Megali Sterna units as well as in the Akritas rhyodacitic lavas of the SVS succession.

Results and Discussion

Silicic Volcanic rocks (63 samples) from the SVS succession, outcropping near the villages Akritas, Metallikon, Kolchida, Nea Santa and Sana, were studied geochemically for major and trace elements in order to investigate their origin and geotectonic environment. The rocks (SiO_2 range from 62.30 to 85.42 wt.%) are classified predominantly as rhyolites, rhyodacites and much less as dacites (Figure 1a). They are corundum-normative, peraluminous (molar A/CNK ratios range from 0.99 to 1.37), enriched in total alkalis, depleted in MgO and CaO and have high FeO_t/MgO ratios. They are enriched in HFS elements, like Zr, Nb and Y.

On primordial mantle normalised multi-element spider diagrams (Figure 1b), samples of all areas show similar patterns revealing origin from the same magma. It is indicated that feldspar (negative Ba and Sr anomalies), apatite (negative P anomaly) and Fe-Ti oxides (negative Ti anomaly) were fractionated from the magma. The presence of significant positive Th and Pb anomalies indicates evidence of a significant crustal component in their magma source. In granite discriminate diagram of Whalen *et al*. (1987), all samples of the volcanic rocks fall almost exclusively in the field of A-type granite (Figure 1c). On the tectonic discrimination diagram (Y+Nb) *vs.* Rb for granites, the majority of samples lie in the within-plate granite field but all the samples straddle at the triple junction boundary of the within-plate, volcanic arc and syn-collision granites (Figure 1d) that is the post-collision granite field (Pearce, 1996). This also provides support for an A-type character magma, as A-type is considered emplaced in post-collisional or within plate settings; i.e., an extensional environment (Whalen *et al*., 1987; Eby, 1992).

Eby (1992) divided the A-type granitoids into two groups (A1 and A2). Granitoids that are associated with true anorogenic (within plate) settings and interpreted as differentiates of basaltic magma derived from an OIB-like source (A1 group: Y/Nb<1.2), and granitoids that are often emplaced in post-collisional, post-orogenic settings and were derived from the subcontinental lithosphere or lower crust (A2 group: Y/Nb>1.2). All samples of the studied silicic volcanic rocks surpass the 1.2 value of Y/Nb ratios (1.87-4.75, average 3.36) and plot in the A2 granite field (Figure 1e) on the (Nb-Y-Ce) discrimination diagram of Eby (1992), implying dominant crustal magma sources derivation and emplacement in a post-collisional environment. Furthermore, Ce/Nb *vs.* Y/Nb discrimination diagram is used to estimate possible genetic links of the A-type granitoids with crustal sources or mantle-derived magmas (Eby, 1992). In this diagram, the rhyolite samples plot well into the field for rocks derived by crustal anatexis, characteristic for A2 group (Figure 1f). The sources, from which these granitoids were extracted, were originally formed by subduction or continent-continent collision (Eby, 1992).

The role of mantle-derived mafic magmas, to provide heat and/or material, seems essential in the generations of the A-type granitoid melts (Eby, 1992). The investigated silicic volcanic rocks have relatively high magma temperatures (average Zr saturated temperature: T_{zr}=886°C) indicating that the crustal source rocks should have been underplated and heated by mantle-derived mafic magmas. The presence of the nearby minor outcrops of tholeiitic basalt and dolerite with a transitional MORB to within-plate character (Triassic Rift Basic Volcanics: Asvesta, 1992; Dimitriadis and Asvesta, 1993; Asvesta and Dimitriadis, 2013) provides supportive evidence for the existence of underplating magmatism. Furthermore, limited magma mixing microtextures in dacites and mafic microgranular enclaves in rhyolites of Metallikon area support the coexisting mafic and felsic volcanism. The Triassic volcanism in CRB was in fact bimodal (A2-subtype rhyolites-dacites and minor tholeiites).

Moreover, A2-subtype post-collisional granites (Arnea and Kerkini suits) of Late Permian to Early Triassic age have intruded the nearby western Vertiskos unit of Serbo-Macedonian massif (Poli *et al.*, 2009) and are likely the deep level equivalents of the Permo-Triassic volcanic rocks studied here (Poli *et al.*, 2009; Asvesta and Dimitriadis, 2010).

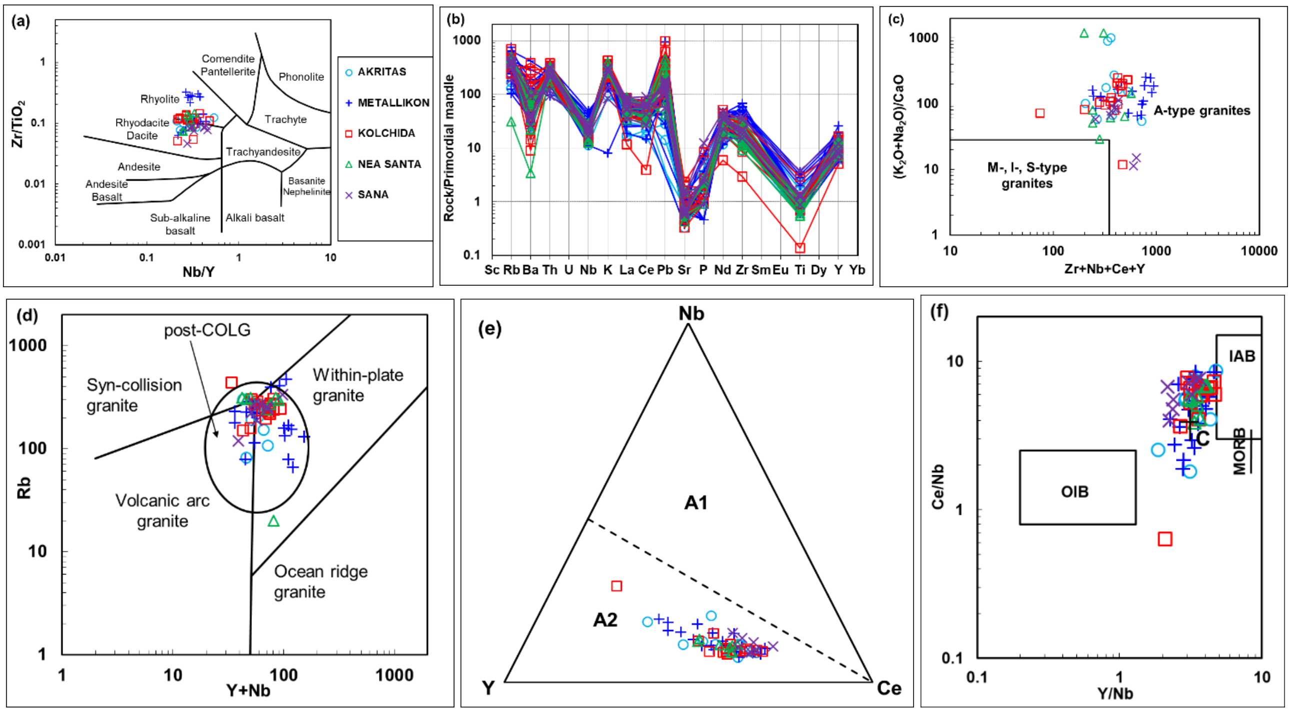

Figure 1. (a) Zr/TiO₂ *vs.* Nb/Y classification diagram (Winchester and Floyd, 1977), (b) primitive mantle normalised trace element patterns (normalisation values after Sun and McDonough, 1989), (c) (K₂O+Na₂O)/CaO *vs.* (Zr+Nb+Ce+Y) discrimination diagram (Whalen *et al*., 1987), (d) tectonic discrimination diagram (Y+Nb) *vs.* Rb for granites, post-COLG=post-Collision Granites (Pearce, 1996), (e) Nb-Y-Ce ternary diagram (dashed line corresponds to Y/Nb ratio of 1.2) (Eby, 1992), (f) Ce/Nb *vs.* Y/Nb discrimination diagram, OIB: oceanic island basalts, black cross labelled C: average crustal composition, IAB: island arc basalts, MORB: mid-ocean ridge basalts (Eby, 1992).

Conclusions

The Permo-Triassic Silicic Volcanic rocks from Circum-Rhodope Belt are A2-subtype rhyolites-dacites and are probably the extrusive facies of the coeval and similar geochemically Arnea and Kerkini granites. It is suggested that silicic volcanism in CRB was evolved during a post-collision extensional stage of a Variscan progeny, leading to attenuated continental lithosphere and continental rifting during the Permo-Triassic which created the Vardar (Axios) oceanic strand. Silicic magma was produced by crustal anatexis of Serbo-Macedonian basement (Vertiskos unit) that was underplated and heated by mantle-derived mafic magma, represented by the minor dolerites and basaltic extrusions in the CRB.

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