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Petrogenesis of the Upper Jurassic Monopigadon pluton related to the Vardar/Axios ophiolites (Macedonia, northern Greece) and its geotectonic significance

Antonis Koroneos *

Department of Mineralogy, Petrology and Economic Geology, School of Geology, Aristotle University of Thessaloniki, GR-541 24 Thessaloniki, Greece

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ABSTRACT

The origin, evolution and geotectonic setting of the Upper Jurassic Monopigadon granitoid pluton (Chalkidiki, Central Macedonia) are studied. The pluton is composed of slightly peraluminous to peraluminous high-K calc-alkaline biotite granodiorite (BGrd), biotite granite (BGr), leucogranite (LGr) and aplites (Apl). Enclosed rocks (Enc) are mostly xenoliths, surmicaceous enclaves and biotite clots occurring frequently in BGrd and BGr. Serpentinite bodies as well as amphibolite and calc-silicate hornfelses are exposed as inliers in the pluton. The granitoids are characterized by relatively low Sr contents (< 180 ppm) and low Sr/Y ratio (0.4–6.4). REE are enriched in the granitic rocks (La_{CN}=89–148, Lu_{CN}=6–25) and the enclaves (La_{CN}=19–55, Lu_{CN}=15–18). The $(La/Lu)_{CN}$ ratio ranges from 10.5 to 4.9 in BGrd, from 11.1 to 3.8 in BGr and from 11.3 to 25.7 in LGr. The BGrd and BGr show similar LILE-enriched, spiked patterns with negative anomalies at Ba, Ta, Nb, Sr and Ti and a positive anomaly at Pb, while the patterns of LGr show higher Ta, Nb, Sr, Ti negative and Pb positive anomalies. Sr initial isotopic ratios vary from 0.7147 to 0.7174 in BGrd, are relatively constant at 0.7105–0.7113 in BGr, and range from 0.7213 to 0.7340 in LGr, while they are lower in the enclaves (0.7087–0.7094). BGrd shows the lowest ε_{Nd} values (− 8.31 to − 6.43), while it ranges from − 6.11 to − 4.26 in BGr and from − 3.37 to − 0.89 in LGr. Late Triassic to Late Jurassic intrusion zircon ages are reported for the Monopigadon pluton, which is unconformably overlain by Kimmeridgian–Tithonian limestones, whereas fragments of the plutonic rocks occur in the limestones. The geochemical variability of the BGrd is reproduced by two different AFC models having the same parental magma and assimilation/fractionation ratio but different assimilated end members. Geochemical modelling suggests that the BGr variability could be reproduced by two different FC models having the same parental magma but with different fractionating assemblages. The BGrd and BGr have similar sources and they likely originated by partial melting of middle-lower crustal rocks with intermediate-basaltic compositions, such as amphibolites, andesites and basalts. Felsic garnet granulites and metapelites are candidate source rocks for LGr. It is suggested that the Monopigadon plutonic rocks originated by melting of an inhomogeneous crust in a volcanic arc environment due to the heating of mantle-derived magmas, which, however, had not mixed or mingled with the crustal melts.

1. Introduction

The study of granitic rocks related, either genetically or from a tectonic point of view, with ophiolites is of particular interest, as it can give information on the genesis and evolution of oceanic crusts. Thus, if both the age and the genesis of such rocks are well constrained, critical information on different stages of oceanic crusts can be achieved. In particular, the age of granites that originated either by differentiation of basaltic magma (e.g. Floyd et al., 1998; Luchitskaya et al., 2005) or by partial melting of amphibolites in the proximity of a spreading centre (Flagler and Spray, 1991; Luchitskaya et al., 2005) gives indirectly the age of the oceanic crust. Granites formed in an island arc potentially constrain the time that the ocean begins to close or at least the age of an intra-oceanic arc onset (e.g. Defant and Drummond, 1993; Scarrow et al., 2001). Finally, granites originated by partial melting of continental material during the obduction of the oceanic crust constrain the age of the ocean closure (e.g. Buchan et al., 2002; Li et al., 2008). Since magma sources, magma evolution and consequently the geochemical features related with the above-mentioned geotectonic environments are distinguishable

* Tel.: +30 2310 998515; fax: +30 2310 998549.
E-mail address: koroneos@geo.auth.gr

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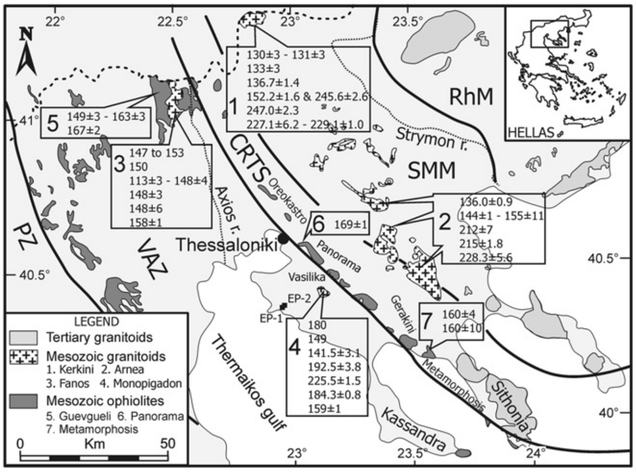

Fig. 1. Geological sketch map of central Macedonia (northern Greece) with locations of the investigated Monopigadon pluton, along with other Mesozoic granitoids and ophiolites. PZ, Pelagonian zone; VAZ, Vardar/Axios zone; CRTS, Circum Rhodope Thrust System; SMM, Serbomacedonian massif; RhM, Rhodope massif (Christofides et al., 2000 with modifications). EP-1 and EP-2, drilling-core samples taken during the investigation of the Epanomi gas field.

their study can potentially correlate granites with stages of ocean formation and evolution (Li and Li, 2003; Šarić et al., 2008).

The ophiolite complex exposed in the NW–SE trending Vardar/Axios zone is characterized by granitic rocks in relationship with the ophiolites. In particular, in central Macedonia of northern Greece (Fig. 1), it is intruded by the Upper Jurassic Fanos granite (Borsi et al., 1966; Bébien, 1982; Pearce, 1989; Christofides et al., 1990; Soldatos et al., 1993; Anders et al., 2005; Šarić et al., 2008) and the Monopigadon pluton (Christaras, 1986; de Wet, 1989; Michard et al., 1998a, 1998b).

Although the age of the Monopigadon pluton has been studied in detail, its geochemistry and geotectonic setting have been only partially considered (Christofides et al., 2000; Koroneos et al., 2001). However, its age and genesis as well as its relationship with the ophiolitic rocks are critical for any proposed geotectonic model. The present study aims at investigating the origin and evolution of the Monopigadon pluton based on mineralogical, petrographical, geochemical, isotopic and geochronological data. The results presented will be also used to constrain and clarify the geotectonic environment of the pluton and to determine its relationship with nearby ophiolites, contributing thus to the efforts made to better understand the tectonomagmatic evolution of the Vardar/Axios zone.

2. Regional setting and field relations

The Vardar/Axios zone (Fig. 1) is widely considered as the ocean suture zone derived from the opening and destruction of the Tethyan Ocean. It has been divided (Mercier, 1968) into three subzones from west to east: the Almopias, Paikon and Peonias subzones.

The Paikon subzone includes remnants of either a Jurassic island arc complex westerly of the marginal basin represented by the Guevgueli Ophiolitic Complex (GOC; Peonias subzone; Bébien et al., 1994) or as a subduction-related volcanic arc developed in Mid-Late Jurassic time (Robertson, 2002; Brown and Robertson, 2004). The Peonias subzone to the east is separated from the Serbomacedonian massif by the Circum Rhodope Thrust System (Tranos et al., 1999), into which rocks of divergent origin and environment, i.e. of oceanic, marginal, arc type (Chortiatis Magmatic Suite, see below) and continental are incorporated. The GOC (Bébien, 1977, 1982, 1983) is intruded by the Fanos granite (Christofides et al., 1990; Anders et al., 2005). Several exposures of ultramafic and mafic rocks around Thessaloniki and in Chalkidiki peninsula (Fig. 1) have been considered as the southern extension of the GOC (Mussallam and Jung, 1986; Ricou et al., 1998), and this extension is also supported by geophysical exploration (Kyriakidis, 1989; Savvaidis et al., 2000) and deep drilling in the Thermaikos Gulf (Lachelos, 1986). The complicated geotectonic setting of the GOC is clearly seen in the different interpretations already proposed. Indeed, Michard et al. (1998a) considered an island arc for parts of the Peonias subzone (Kassandra and Sithonia exposures), whereas Ricou et al. (1998, and references therein) interpreted different exposures to represent either volcanic arc (Guevgueli arc; Guevgueli, Oreokastro, Kassandra and Sithonia) or ocean floor (Vassilika, Gerakini and Metamorphosis). Some of the ophiolitic bodies are in close relationship with the Chortiatis Magmatic Suite. The latter, preceding the ophiolites, has calc-alkaline affinities, and consists mainly of tonalites and trondhjemites.

A characteristic feature of the GOC is the existence of some Mesozoic granitoids. The Monopigadon pluton is one of these granitoids occurring close to the village of Monopigadon in Chalkidiki (Fig. 2) and occupying an area of about 10 km^2. However, its size could be much greater taking into account the findings in deep drillings (EP-1 and EP-2) performed for the investigation of the Epanomi gas field (15 km SW of Monopigadon, Fig. 1Roussos, 1993; Sousounis, 1993), and the seismic profiles made for the same purpose by DEP-EKY (Petroleum Public Company). The drillings reached a granodioritic rock, at ca. 3400 m depth, beneath the Petralona limestones (Fig. 2).

The Monopigadon pluton is mostly covered by Tertiary and Neogene sediments that obscure significantly the contacts of the pluton with country rocks. The exposed Mesozoic rocks that are in contact with the pluton are the recrystallized Petralona reef limestones of Kimmeridgian–Tithonian age overlain by Upper Jurassic–Lower Cretaceous metaclastic rocks, the Prinochori Beds. These sedimentary rocks have been deposited onto a Paleozoic crystalline basement, the Stip-Axios Unit (de Wet, 1989). Only a relict part of it, made up of schists and gneisses, is exposed in the area (Fig. 2). More precisely, the Petralona limestones along with

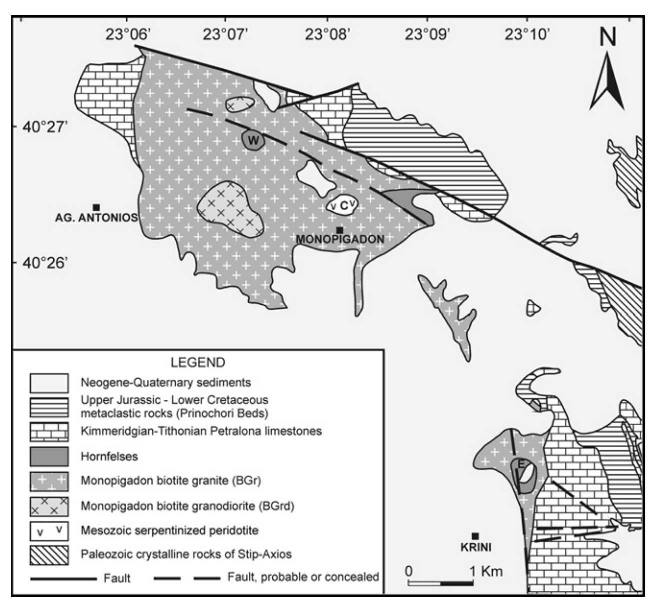

Fig. 2. Geological sketch map of Monopigadon pluton. W, C and E: western, central and eastern bodies enclosed in the plutonic rocks. (IGME, 1978 with modifications).