



Tracking the evolution of Balkan crust: Episodic magmatism and peri-Gondwana crustal recycling from zircons and rutiles in basement rocks and beach placers

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The Balkan is a collage of Peri-Gondwana Cadomian and Avalonian terranes that were formed on the late Neoproterozoic active margins of the Gondwana supercontinent during Proto-Tethys subduction, rifted from it during the opening Paleo- and Neo-Tethys of oceans, and variably involved in Ordovician, Variscan, and Alpine orogenies. The Serbo-Macedonian (SMM) and the Rhodope massifs are major Balkan terranes that were episodically involved in Paleozoic, Mesozoic and Cenozoic phases of magmatism and metamorphism. These terranes therefore portray the prolonged evolution of the SE European continental crust over the course of ca. 600 Ma. In order to track the evolution of subduction, accretion and magmatism in these terranes, we measured zircon U-Pb-Hf and rutile U-Pb in basement rocks of the SMM and Rhodope as well as of beach placers from large river mouths draining the region towards the Aegean Sea (Strymon, Nestos and Evros Rivers). Basement igneous rocks of the SMM and circum Rhodope range in age from late Neoproterozoic (598 Ma), through Ordovician (460 Ma), Carboniferous (300 Ma), Triassic (250 Ma), Paleocene (65 Ma), and Miocene (ca. 23 Ma), thus demonstrating the episodic Paleo-Meso-Cenozoic crustal evolution of this terrane assemblage. Hf-in zircon shows evolution of the igneous signature from negative $\epsilon_{\text{Hf}}(t)$ values in the Ordovician towards positive values in the Eocene, grossly fitting the evolution trend of external orogenic belts towards more juvenile values. This igneous trend is however only a part of the whole Balkan crustal evolution picture, as the beach placer samples indicate that together with episodic igneous crustal addition, zircons from river mouths follow a progressive recycling trend bound by evolution lines of $\text{Hf-TDM}=0.7\text{-}1.7\text{Ga}$. This trend reflects, in our view, the ongoing recycling of the Cadomian/Avalonian basement of the SMM and Rhodope that served as the initial crustal ingredients, and few outcrops of it have survived. Some extent of crustal addition on this evolving Cadomian/Avalonian substrate brings about the shallow rise in $\epsilon_{\text{Hf}}(t)$ values we observe in the igneous basement rocks. We propose that episodic recycling of Peri-Gondwana crust during subduction of Tethyan/Rheic oceans and subsequent terrane accretion, together with variable igneous addition, was widespread also in other European Cadomian/Avalonian domains since the late Neoproterozoic.