Int J Earth Sci (Geol Rundsch) (2016) 105:2171–2173
DOI 10.1007/s00531-016-1378-0

REPLY

Reply to: Bonev N, Spikings R and Marchev P (2016) Comment on Georgiev et al. "Structure and U–Pb zircon geochronology of an Alpine nappe stack telescoped by extensional detachment faulting (Kulidzhik area, Eastern Rhodopes, Bulgaria)"

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Received: 4 July 2016 / Accepted: 7 July 2016 / Published online: 23 July 2016

Introduction

Bonev et al. (2016) comment on our article (Georgiev et al. 2016), expressing their disagreement regarding some of the conclusions. We are grateful that they give us the opportunity to clarify some points in our original article that were obviously not well enough explained. The criticism refers mainly to three questions. We will discuss these in the following, in the same order as they appear in the conclusions chapter of the comment.

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Is the uppermost tectonic unit (Unit IV) a displaced piece of the lowermost one (Unit I)?

Of the four superposed tectonic units in the study area, the uppermost (Unit IV) is lithologically similar to the lowermost (Unit I). Both are formed dominantly by orthogneiss. In an earlier article, Bonev et al. (2010) had shown that the orthogneisses of units I and IV display similar trace element patterns and therefore interpreted Unit IV as an equivalent of Unit I emplaced by an overthrust on top of the other units. Our new U–Pb zircon dating, however, showed that the orthogneiss of Unit I was formed from a Late Carboniferous protolith, and the orthogneiss of Unit IV from a Neoproterozoic protolith. These rocks are of different ages, and their lithological and geochemical similarity is a mere coincidence. In their comment, Bonev et al. (2016) again demonstrate the geochemical similarity (their Fig. 1) and write that this "allows some caution to be expressed relative to the age of 581 Ma" determined by us. We do not share this opinion. On the contrary, we think that more caution would be necessary in interpreting geochemical data. To illustrate this, we show in Fig. 1 the compositions of the three orthogneisses that Bonev et al. (2016) show in their Fig. 1b (in order to demonstrate their similarity), together with the average composition of the upper continental crust (thick blue line) after Wedepohl (1995) and the composition of JG-1 (thick red line), a common granodiorite standard from Japan after Ando et al. (1971). The similarity between the patterns of the three Bulgarian orthogneisses is not larger than the similarity between any of them and the granodiorite from Japan, and all of them are similar to the average composition of the upper continental crust. These concentrations reflect fundamental differentiation of our planet and are not capable of fingerprinting a certain origin.

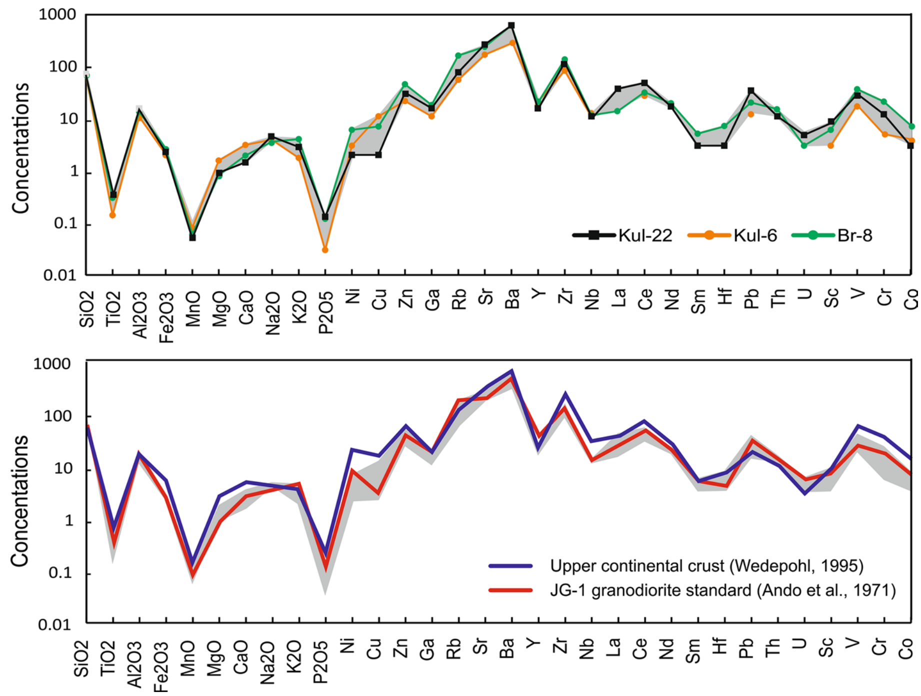

Fig. 1 Abundance of major and trace elements (oxides in weight percent, elements in ppm). At the top is the redrawn Fig. 1b of Bonev et al. (2016); the same chart below shows the average composition of the upper continental crust after Wedepohl (1995) and the composition of a granodiorite standard from Japan JG-1 after Ando et al. (1971). The *gray* fields envelop the data presented on the *top* chart. See text for discussion

There is no evidence for a correlation between Units I and IV.

Is the greenschist-facies metamorphism of Unit II prograde or is it a retrograde overprint on higher-grade metamorphic rocks? And was Unit II affected by monophase or polyphase metamorphism?

Our thermodynamic modeling combined with U–Pb zircon dating and Ti-in-zircon thermometry showed that rocks from Unit II experienced high-grade metamorphism at two times, in the Jurassic (ca. 150 Ma) and the Late Cretaceous (ca. 70 Ma). We did, however, not suggest that the rock stayed under these conditions from 150 to 70 Ma as understood by Bonev et al. (2016) ("80 Ma continuous peak pressures and temperatures"). The Jurassic and the Late Cretaceous metamorphism are two different events. The complex metamorphic evolution of Unit II deserves comprehensive petrological studies for specifying PT-conditions of the two metamorphic events. The field, hand specimen, and thin section photographs shown by Bonev et al. (2016) are not sufficient to demonstrate the absence of higher-grade metamorphism preceding the very strong greenschist-facies overprint. We acknowledge that Ti-in-zircon thermometry and mineral inclusions in the dated zircons do not give enough information to reconstruct the complex metamorphic evolution of Unit II. Certainly, more work is needed and detailed petrological studies could specify the P–T-time paths of the two metamorphic events. However, the presence of several generations of folds and related penetrative foliations overprinting each other in Unit II is evidence for a polyphase tectono-metamorphic evolution of the rocks. This is also supported by the microstructural observation of different mineral assemblages related to the different overprinting structures.

Are the low-angle contacts between the tectonic units thrusts or extensional detachment faults?

We used structural observations, in particular the up-section transition from mylonites to cataclasites to unconsolidated fault breccias and gouges, to demonstrate that the low-angle tectonic contacts in the area are parts of an extensional fault system. In their comment, Bonev et al. insist on the thrust nature of these contacts and state that the Kulidzhik area represents "a north-directed nappe stack in greenschist-facies conditions involving crustal and arc-related ophiolite rocks that were thrust emplaced in Late Jurassic time…". We will not repeat our structural observations but only mention that the assumption of a Jurassic nappe stack is impossible to reconcile with the geochronological data. At 150 Ma, Unit IV had already cooled below ca. 350 °C (Bonev et al. 2010), while rocks of Unit II were experiencing higher-grade metamorphism. Thrusts emplace hotter rocks on cooler rocks and not vice versa. Therefore, if the tectonic contacts were Jurassic (which we do not assume), they should not have been thrusts but extensional faults. Moreover, according to Bonev et al. (2010), muscovite Ar/Ar ages from schist belonging to the footwall of the "Kulidzhik thrust" (our Kulidzhik detachment) show exhumation at ca. 40 Ma. Thus, the "Kulidzhik Thrust" separates two units that have recorded different cooling history, with older (Jurassic ~ 150 Ma) cooling ages above the fault zone and younger (Eocene ~ 40 Ma) cooling/exhumation ages beneath it. Thus, the interpretation of the Kulidzhik Detachment Fault as a thrust, separating gneisses of Unit IV in the hanging wall from anchizonal (Unit III) to greenschist-facies rocks (Unit II) in the foot-wall is impossible.

To conclude, we think that the majority of our results is not affected by the criticism formulated in the comment. We trust that the discussion will stimulate further work on the Kulidzhik area in the Eastern Rhodopes.

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