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March 15, 2021

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Evaluation report of the PhD-thesis entitled:

Subduction processes recorded by the Baltica outer margin in the Scandinavian Caledonides

submitted by **Michał Bukała** for defence for the degree of Philosophiae Doctor at the Akademia Górniczo – Hutnicza im. Stanisława Staszica w Krakowie

The thesis consists of an introductory part and four individual articles that were already published in international journals with impact factor. The introductory part covers scope of the thesis, used methods, summary of the results of the four articles, verification of the thesis, and future directions. This part describes the topic and outline of work and summarize the individual results and put them into a general context. The emphasis of the thesis is given to the four articles published in highly ranked journals such as Journal of Metamorphic Geology and Frontiers in Earth Science. The binding element of the four articles included in the thesis is clearly metamorphic evolution of the high pressure to ultra high pressure rocks in the context of orogenic evolution of the Scandinavian Caledonides. The results of the thesis are mainly based on high resolution petrography, number of various thermobarometry techniques, and geochronology combined with trace element geochemistry. As all four articles went through an independent review process, the scientific quality and clarity of the results presented in this thesis had been already proven.

Summary of the main results:

The first article aims to establish the relationship between dehydration reactions operating at the blueschist-to-eclogite facies transition and brittle failure. The process is nicely demonstrated in eclogite samples from the Tsäkkok Lens in the Seve Nappe Complex,

which preserve evidence for brittle failure, recorded by microfractures within the single garnet grains as well as mesofractures sealed by high pressure garnet or omphacite. The microfractures in garnet are associated with breakdown of lawsonite releasing large volume of water-dominated fluid that facilitated cracking. The microfractures in garnet are marked by microchannels, radially propagating from lawsonite pseudomorphs and displaying a significant Mg enrichment and a low-angle (<3°) misorientation. This detailed microscale study is accompanied by conventional thermo-barometry putting the conditions of the studied process near the quartz-coesite transition. The article presents a neat combination of modern analytical techniques including the high-resolution EBSD and petrography/mineral chemistry. The resulting model is scientifically sound and well justified.

The second article focuses on detailed characterization of metamorphic pressure-temperature evolution of eclogites from the Vaimok Lens again in the Seve Nappe Complex. This article represents a fine combination of several independent thermobarometry techniques and it is without hesitation my favorite article from the thesis. Applying the Zr-in-Rt thermometer on rutile inclusions and QuiG barometer on quartz inclusions present in garnet cores allowed to constrain pressure-temperature conditions of initial parts of the prograde rock evolution. Compositional zoning in garnet together with chemical composition of phengite and omphacite were used in conventional thermobarometry to infer ultra high pressure conditions in these rocks and their subsequent post peak evolution reflecting incipient exhumation. The results of these thermobarometry techniques are nicely accompanied/confirmed by the thermodynamic modeling, making the presented data highly reliable.

The third article focuses on migmatitic paragneiss and garnet amphibolite with suspected high pressure history from the Kittelfjäll in the Seve Nappe Complex, to unravel the timing of metamorphism. The studied rocks are strongly overprinted by decompression-driven partial melting at granulite-facies conditions. The studied rocks contain detrital zircon grains (paragneiss) which are overgrown by rims providing early Ordovician ages.

These rims were interpreted to have formed in the presence of melt, i.e. during the granulite facies metamorphism. The new zircon age presented in the thesis raises controversy/complication with respect to the previously reported early Ordovician age of monazite from the Saxnäs diamond-bearing gneiss to the south, which was interpreted as the age of ultra high pressure metamorphism. Obviously some further geochronological work in the broader area of the Seve Nappe Complex is needed.

The fourth article is a little detached from the other three articles, dealing with rocks from the Seve Nappe Complex, as it focuses on a high pressure granulite sample collected from the Western Gneiss Region in the Lower Allochton of the Scandinavian Caledonides. Despite the ultra high pressure record in the surrounding rocks, the studied granulite shows evidence for melting and thus seem to emphasize the importance of the exhumation related granulite facies re-equilibration of possibly originally high pressure rocks.

Questions to the candidate:

Despite all the articles included in the thesis went through the review process I have few additional questions. These are surely not meant as criticism but should serve as food for thoughts for future projects of the candidate.

Article 1: In the discussion, the authors state that “The remarkable textural coupling between microchannels and the misorientated garnet domains (i.e., low-angle boundaries ± hairline fractures) in the studied eclogites (Figure 4) is compatible with fluid percolation along pre-existing low-angle boundaries, which acted as fluid pathways in the garnet grain interiors.” The low angle boundaries were interpreted as coalescence planes formed during amalgamation of garnet cores. I am not so happy with this explanation.
If the authors meant amalgamation of garnet from multiple nuclei, it seems strange that the misorientations are exclusively so small and no high angle boundaries were detected in the studied garnet grains. An alternative explanation to form the low angle boundaries via crystal plasticity, was excluded by the authors. However, especially the garnet in Figure 4g,h seems to show some nice substructures in the form of subgrains that might indicate

crystal plasticity. One more hypothesis that could be explored is that the low angle boundaries formed during healing of cracks. Such process in garnet had been previously beautifully demonstrated by Griffiths T.A. et al. 2014 (CMP journal). Can these suggestions be relevant to your garnets?

Article 3: In the paragneiss samples, distinction between the mineral assemblages related to HP stage and subsequent granulite facies overprint is not so straight forward as an unambiguous HP phase could not be identified in the studied rocks and Si component in white mica does not exceed 3.15. Did you consider a possibility that kyanite is stable with melt suggesting that the granulite facies equilibration occurred at higher pressure conditions? This might be an important contribution to decipher the geochronological puzzle that you spotted. I mean mainly in the context of the referenced work of Petrík et al. 2018 who associated the Early Ordovician monazite age with UHP conditions in the nearby Saxnäs locality.
The authors report monazite to be present in all three migmatitic paragneiss samples. Did you attempt to date this monazite? And if yes with what result? I presume it should give the same age as the zircon rims or younger?

Article 4: In the discussion the authors state that “Rare inclusions of sodic clinopyroxene and phengitic mica are interpreted to have formed during the prograde to near peak-pressure stages of the P–T path.” The peak P-T conditions are then compared to those of nearby 3–4 GPa at 800–900 °C. However, the composition of the sodic clinopyroxene is used in the thermodynamic modelling to estimate P-T conditions of the granulite facies re-equillibraiton of the studied rocks. Can you comment on that?
The P-T estimate of the studied granulite coming from the calculated pseudosection is based on intersection of XNa in clinopyroxene, XMg in garnet and Xab in plagioclase. Why only the XMg component was selected in garnet and not e.g. also grossular component, knowing that the garnet is interpreted to re-equilibrate in the granulite facies conditions? I believe that the garnet composition should match the estimated PT conditions.

Recommendation:

In summary, the dissertation thesis submitted by Michał Bukała for the degree of Philosophiae Doctor is a very comprehensive, extensive, and original piece of work of high quality. Michał Bukała has demonstrated that he is capable of applying a large range of different microstructural and textural analysis techniques with deep insight into data acquisition, and that he is capable of interpreting the data in terms of metamorphic pressure-temperature evolution in the geodynamic context. The data set presented in the thesis appears to be of very good quality and volume, and represents a timely and very interesting piece of work, commensurate with high international standards.

In my opinion, the evaluated thesis of Michał Bukała clearly fulfills the requirements of a PhD thesis and I recommend that the thesis should be accepted for the defense for the PhD degree.

Sincerely,

doc. RNDr. Petr Jeřábek, Ph.D.