Insights into the tectonic evolution of the Svecofennian orogeny based on *in situ* Lu-Hf dating of garnet and apatite from Olkiluoto, SW Finland

by

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General

This manuscript has been previously reviewed by two experts and I have had an opportunity to see their assessments. Therefore, I have tried not to repeat their comments. However, because I agree with the notion of Reviewer 2# that the samples and their analytical results should be treated separately, I added my views to the same topic. While reading, I also made some small formal comments on language etc., they can be skipped if inappropriate.

The main topic here is dating of different phases of metamorphism by in-situ Lu-Hf method on garnet and apatite. The latter was also dated by U-Pb method. This method is quite novel and therefore, as far as I understand, still in initial stage. Therefore, the results may contain shortcomings that are not yet fully understood. By this I mean e.g., the very large errors the method yields. Or maybe the instruments used are not yet sensitive enough for high resolution.

The garnet dating from leucosome and mesosome failed to decipher the two metamorphic events that were previously dated by U-Pb method from zircons in leucosomes. All the garnet analyses combined gave a "pooled" age of 1834 ± 17 Ma. Meaningfulness of such approach can be questioned. This is further discussed below in detailed comments. Despite this quite critical review, I see this method promising and at this stage even the difficult cases are good to publish for the use of future developments.

The apatite was dated by in-situ Lu-Hf and U-Pb. These data are highly welcome to regional metamorphic studies as they are rarely used in this part of the Precambrian world.

Detailed comments

line 26-30: repetitive use of the word "polymetamorphism"

31-34: There is a bold statement arguing that Lu-Hf garnet method represents the metamorphic age of the rock better than the U-Pb monazite or zircon. This can be questioned. Lu-Hf garnet is still quite a new and incompletely understood method which so far gives quite large errors. U-Pb zircon in leucosome is a widely used and well-known method to date peak metamorphism (it is assumed that melting is coeval with peak metamorphism and zircons crystallise in the melt, hence the connection) with high precision. Monazite is another story…

38-39: It is stated that "at least one, possibly two, significant metamorphic events". According to previous investigations, it is quite convincingly shown that there are at least two metamorphic events in the region. I will come back to this this later while commenting Chapter 5.1.

83-84: Yes, crustal thickening took place, but neither of the cited articles argued that it caused the peak metamorphism and melting. Instead, Mäkitie et al. stated that the heat source is unknown and Chopin et al. said that the melting is related to channel flow.

90-92: Transpressional: Ehlers et al. 1993 (Precambrian Res.) were the first to describe the transpressional tectonics in this part of the world; should be cited.

102. No good to start a chapter with a reference. Change the word order.

123-125. About the two metamorphic events, see comment line 390.

137: "This study includes whole rock geochemistry of the different lithological units". See my comment on line 272.

138-139: "in the first metamorphic phase in Olkiluoto (Engström et al., 2022)". Because these two phases are repeatedly mentioned, it could be appropriate to call them, e.g., the first metamorphism (M1, older) and the second (M2, younger).

145-146: In this ms. a migmatitic rock is divided into the leucosome and matrix. In the common migmatite terminology these are called the leucosome and mesosome.

158-160: In this sample description it clear that different types of garnets occur in the mesosome vs. leucosome. See later comment.

180: Chapter 3.3. These analytical methods are already published in the cited report which is openly available online.

188: Do you mean "The second largest" ?? or maybe "Another large garnet" ??

272: Chapter 4.1. The whole chapter is a little bit strange for several reasons. The authors do not have own data but refer to the data in Kärki & Paulamäki (2006) report, which is already published and available online. The data tables are not in the report, so this maybe is what the authors mean in the Acknowledgements by expressing their gratitude to Posiva Oy for access to the data. Here the authors only use some major elements and show the TAS and AFM diagrams. The TAS diagram was also shown in the original report (but not the AFM diagram). These data are not used in the later discussion. The data seem to have no value for the topic of this ms., at least it is not described.

276: …then…?

324: Chapter 4.3. These garnet ages are the core of the ms. I will come back to these later in Discussion.

328: …the age calculations…

328-229: …When all the data are plotted…

332 and 334: Give the MSWDs also for the core and rim ages. I explain later why on line 390.

334: not identical age, just overlapping within errors.

341: "Given the overlap in uncertainty, the proximity and similarity of the samples," This sentence can be removed, these are already described earlier and complicate the sentence, when it continues with "if"

342: …data are…

347: (…MSWD = 1.5). According to Fig. 9A it is 1.6

348-349: These ages are not identical, just overlapping within errors.

353: …isochron age -> lower intercept age

390: Chapter 5.1. In this chapter the age determinations are discussed. In the earlier paper from the same locality (Engström et al. 2022), the metamorphism was dated by U-Pb zircons from two leucosomes in the migmatitic metapelites as 1858 ± 7 Ma and 1851 ± 8 Ma. As no younger zircons were found, the leucosome must have been related to the first melting episode, M1 (cf. Saukko et al. 2020). The second metamorphism M2 in Engström et al. (2022) was less precisely defined at 1.82-1.78 Ga. Just a few kilometres S of Olkiluoto in Rauma, Vehkamäki et al. (2021, Inst. Seism., Univ.Helsinki, Rep. S-71) dated zircons of two populations from the leucosome in a migmatitic metapelite; 1.86 and 1.83 Ga. Towards the W in central Sweden Högdahl et al. (2012) also dated two metamorphic events at 1.87-1.86 Ga and 1.82-1.80 Ga. The younger M2 is ubiquitous in southern Finland and central Sweden, described in numerous studies. It is the older M1 that has only lately emerged from behind the strong M2 overprint.
On the basis of the previous age determinations reviewed above, it is very likely that these events also prevailed in Olkiluoto, as proposed by Engström et al. (2022). In the present study, the authors have dated two types of garnets; small garnets in the mesosome and large garnets in the leucosome. In the sample description and also later it is speculated whether the garnets are of different generations. In fact, the face value age (without error) for the small garnets is 1857 Ma and 1829 Ma for the big garnet, which is further divided into 1828 (±11) Ma for the core and 1829 (±21) Ma for the rim domains. It is a pity that the MSWDs for these analyses were not shown, but I guess is that the core age has the lower one. Looking at these ages without errors, they are exactly what might be expected for the M1 and M2. Now the problem is the very large errors in the ages. To solve this the authors chose to use a pooled age of all the analyses to get smaller errors (result 1834 ± 17 Ma). This is a highly questionable way to use the data. It seems that the sampling was not structurally controlled to separate possible different garnet generations. To the S of Olkiluoto in the Turku area, two generation of garnets were described, the first elongated syn-D2 garnet was deformed in D3 which in turn was coeval with leucosome containing large garnets (Väisänen & Hölttä 1999; Fig. 14g). This might be the case in Olkiluoto, too. But the major problem here is not the sampling, but the resolution of the Lu-Hf garnet method, which is incapable of solving so detailed a problem.

392: …all the analyses…

394: …, ~~then~~…

396: these ages are not identical, just overlapping within error

409: …the(se) data form…

417: …in the U-Pb and…

426: …The zircon U-Pb…

475: Fig. 11. Why is the Turku granulite area skipped from the examples in Figure. It is anyway isotopically and metamorphically well-studied migmatite area close to Olkiluoto.

499: …in the Häme Belt…

509: "reaching slightly deeper crustal depth than the Häme Belt" ? what does this mean?

512: …the Uusimaa Belt…

513: …the anatectic melts (or melting)

514-515: “indicates that the whole southern Finland domain was subjected to a long hot orogenic evolution with several crustal-scale melt pulses”. Chardon et al. 2009. Tectonophysics 477, describes this nicely, worth citing

517: Chapter 5.3. This chapter shortly summarises the present knowledge of the chapter title, focusing on the shear zones, but it hard to understand how this literature review is connected to the data in the ms., garnet and apatite age determinations.

519 and 521: back-arc vs backarc … Be consistent with writing style

528: Additionally, additionally what? unclear

531: …show that…

574: “similarities between the Olkiluoto site and Häme Belt, and the differences to Uusimaa Belt.” What actually are the real differences between the Häme and Uusimaa belts? So big that they are part of the main conclusions? This topic is not clearly discussed in the ms. There are evidently differences in erosion levels, but what else? If this refers to the metamorphic ages, two metamorphic events are found also in the Uusimaa Belt, 1.86 and 1.83 Ga (Väisänen et al. 2021, Inst.Seism., Univ Helsinki, Rep. S-71). The protolith ages are also the same, 1.86 Ga.

623: References: Many references occur twice in the list, e.g., Lahtinen et al. 2005, and many others. Delete the extra.

624: page numbers missing

714: page numbers missing. Check all the similar references

796: Pitkälä…This is an unpublished MSc thesis. A published document should be used: Pitkälä et al. 2018. Inst.Seism., Univ Helsinki, Rep. S-67.

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