



## *Review*

*of the member of the dissertation council for the dissertation of **Ivanova Ekaterina Sergeevna** on the topic: “(U, Th)-He dating of pyrite for determination of the sulphide mineralization age on example of the Toupugol-Channeishor gold deposit, Polar Ural”, submitted for the degree of candidate of geological and mineralogical sciences in scientific speciality 1.6.4 Mineralogy, Crystallography. Geochemistry, geochemical methods of prospecting for ore deposits.*

The aim of this scientific work is to determine the time/s of ore formation by directly using the ore mineral pyrite. This is a very important task since classical dating methods cannot use ore minerals, but use other minerals that may be formed not at the same time as ore formation occurred. The method is really new and it is important to test this method on further ore deposits that are well characterised.

In **Chapter 1** (Basics of the (U, Th)-He method, 17 pages) the author well explains the history and development of this method. The conditions of a closed system and pitfalls for dating with this method are well explained based on a thorough literature study. In **Chapter 2** ((U,Th)-He isotope system of pyrite) the importance of the high closure temperature for this mineral is explained as well as what is known where U and Th may be situated in the crystal structure or mineral inclusions. In the following **Chapter 3** (Methods) the author explains and describes all used methods in this study. The geology of the working area is described in **Chapter 4** along with very good geological maps and sample locations for all three investigated detailed areas. The description of all rock types is very concise and detailed. At the end of this chapter published  $\delta^{34}\text{S}$  values of pyrites are given. In **Chapter 5** a detailed description of the mineralogy and petrology of all types of rocks is presented that is based on a very thorough characterization of 91 thin sections. All secondary alteration processes are also well described. At the end of this chapter an interpretation of rock formations and alterations in time is given for the regional scale. **Chapter 6** (chemical composition of pyrite) presents a very detailed investigation of sampled pyrites including such topics as chemical zonation and mineral inclusions and differences for the three studied regions are well documented. The section “interpretation” gives a very good explanation of these differences. Based on these observations a

correction for the dating method is suggested: to ensure that all micro-inclusions will be dissolved before the concentrations of U and Th are determined. This is the first conclusion for defense of this dissertation. **Chapter 7** (Results of dating pyrite) is the longest chapter (29 pages) and presents and discusses all 45 analyses of (U, Th)-He dating on pyrites. These new results are not easy to interpret because the ages often show a large scatter. The newly obtained ages are not in conflict with geological observations and former dating results (second statement for defense), but even add new times of formation and transformation of pyrites (third statement for defense). This is one of the very important outcomes of this study.

In summary, this study presents a very detailed analysis of rocks, their mineralogical-petrological investigation, the separation and detailed investigations of pyrite grains, important changes for this dating method (section 6.5), and a lot of new dating results on pyrites that are combined in the Figure 7.10. Therefore, this work provides new results (e.g. new times for formation and transformation of pyrites) and demonstrates important differences for the three investigated regions (Karernoje, Novogodee-Monto, Petropavlovskoje). Based on such detailed investigations Ekaterina Sergeevna Ivanova presents new ideas for the search of new (until now not known) possible ore deposits.

The work is very well written and structured, it is easy and interesting to read. All three defined conclusions are new and based on the detailed analyses of this study. They are very important for further studies and (U, Th)-He dating of pyrites.

There are really only very few places where I wished a more detailed explanation (for instance for Re-Os dating: analytical methods, how much material (mg) was used, was it pure pyrite or whole rock?). I have only a few questions where it would be interesting to know the answer:

**Question 1:** Dating for the deposit Novogodnee-Monto, sericite-quartzitic metasomatites. You define two age groups:  $396 \pm 5$  Ma ( $n=3$ ) and  $293 \pm 4$  Ma ( $n=5$ ). For the first group, two analyses are not included (444 M and 418 Ma). This is not described and discussed. Do you have an explanation for this?

**Question 2:** You divide for all three regions the ages in subgroups (as for example in my question 1), but in your final compilation (Fig. 7.10) you did not distinguish the age groups. Can you please explain why?

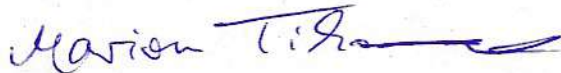
**Question 3:** The dating of magmatic rocks was not very successful and resulted in large scatter of ages. Probably, other dating methods (e.g., U-Pb on zircons) are better suited for dating these rocks. It would be interesting to know what was the hope to date such samples by (U, Th)-He method of pyrite?

Based on the arguments given above I have no doubt that the dissertation of Ekaterina Sergeeva Ivanova ““(U, Th)-He dating of pyrite for determination of the sulphide mineralization age on example of the Toupugol-Channeishor gold deposit, Polar Ural” meets the requirements of scientific speciality 1.6.4 Mineralogy, crystallography. Geochemistry, geochemical methods of prospecting for deposits.

The dissertation is a scientific qualification work that resolves an important scientific problem (new pyrite formation and transformation ages) and provides innovative ideas.

No violations of paragraphs 9 and 11 of the Order No.11181/1 as of November 19, 2021 "On the Procedure for Awarding Academic Degrees at St. Petersburg State University" have been detected.

The dissertation meets the criteria of dissertations for the academic degree of candidate of sciences, established by the specified Order. The dissertation is recommended for the defense at St. Petersburg State University.



Member of the dissertation council

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Herewith, the personal signature of Tichomirowa, M...... is certified.

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