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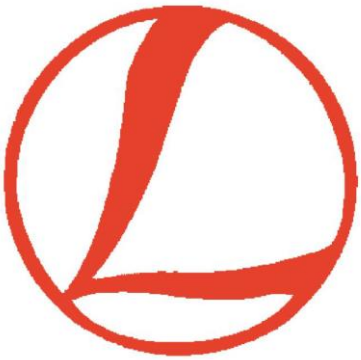

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U-Pb zircon, monazite and xenotime geochronology of cordierite-anthophyllite and felsic volcanic rocks in Orijärvi, southern Finland

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We sampled one felsic volcanic rock from the lower part of the Kisko formation and two cordierite-anthophyllite rocks from Orijärvi and Iilijärvi for U-Pb dating. The felsic volcanic rock yield a zircon $^{207}Pb/^{206}Pb$ weighted average age of ~1.89 Ga. The oldest zircons from the Orijärvi cordierite-anthophyllite rock give a weighted average age of ~1.89 Ga. The monazite from the same sample yield a concordia age of ~1.80 Ga and the xenotime yield a concordia age of ~1.82 Ga. The Iilijärvi cordierite-anthophyllite rock gives a monazite concordia age of ~1.82 Ga. This implies that two metamorphic pulses are recorded in the samples.

Keywords: geochronology, U-Pb, zircon, monazite, xenotime, cordierite-anthophyllite rock, felsic volcanic rock

1. Introduction

The Orijärvi area in southern Finland is historically and geologically important: it was the site of the first copper mine in Finland opened there in 1757 (Poutanen 1996). Orijärvi was also the area from where Pentti Eskola developed the theory of metamorphic facies (Eskola 1914, 1915). Since then the Orijärvi area has been a target for numerous studies focused on ore geology, geochronology, petrology, geochemistry and structural geology (eg., Latvalahti 1979, Väisänen & Mänttäri 2002, Skyttä et al. 2006, Pajunen 2008, Väisänen & Kirkland 2008, Nironen et al. 2016, Kara et al. 2018).

A special interest has been the cordierite-anthophyllite, quartz-cordierite as well as garnet and andalusite-bearing rocks which represent the metamorphic equivalents of hydrothermally altered volcanic-sedimentary rocks which are associated with the Cu-Zn-Pb mineralisations (Smith et al. 1992, Rajavuori & Kriegsman 2002, Ratsula 2016). The hydrothermal alteration is regarded to have been acting simultaneously with volcanism or at least before the regional deformation and metamorphism at c. 600 °C and 3 kbars (Latvalahti 1979, Schneiderman & Tracy 1991). The age of the metamorphism is, however, unknown. Orijärvi forms a triangular shaped low-strain area bounded by shear zones where early-stage deformation is well-preserved and the metamorphic grade is lower than outside the triangular area where the rocks are migmatitic (Ploegsma & Westra 1990, Skyttä et al. 2006).

We sampled two cordierite-anthophyllite rocks (CARs) and one felsic volcanic rock (FVR) for dating and separated zircons, monazites and xenotimes from CARs and zircons from FVR. This was done to gain better understanding of the timing of the volcanism, alteration and metamorphism. One CAR sample was collected from the vicinity of the Orijärvi mine and another CAR sample was sampled from the Iilijärvi mineralised zone 600 m to the north. The unaltered FVR was sampled from the lower part of the Kisko formation, stratigraphically above the altered rocks. Sample locations are indicated in Fig. 1.

2. Geological setting

The bedrock of Orijärvi is composed of mafic to felsic volcanic rocks and metasedimentary rocks (Kähkönen 2005). These supracrustal rocks are also accompanied with bimodal igneous rocks that represent magma chambers to the volcanic rocks (Väisänen and Mänttäri 2002, Kara et al. 2018). Based on the structural and geochemical features, bedrock in Orijärvi has been divided into four formations: the Orijärvi, Kisko, Toija and Salittu formations (Fig. 1).

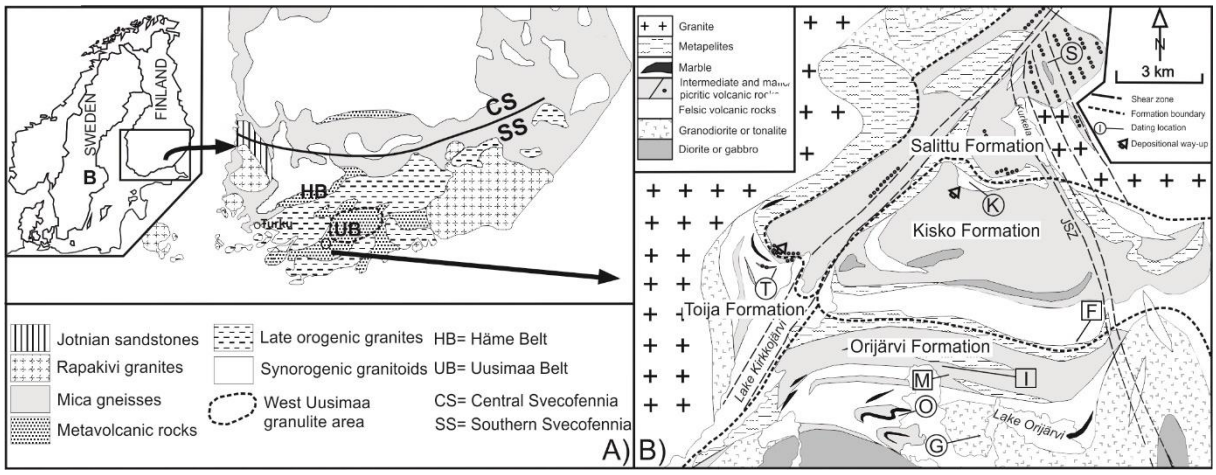

Figure 11. (A) Simplified geological map of southern Finland and (B) geological map of the Orijärvi area with previous and new sample locations indicated with circles and squares. F = felsic volcanic rock, M = Orijärvi (mine) cordierite-anthophyllite rock, I= Iilijärvi cordierite-anthophyllite rock, G = Orijärvi granodiorite (Väisänen et al. 2002), K= Kisko dacite (Väisänen & Mänttäri 2002), O = Orijärvi rhyolite (Väisänen & Mänttäri 2002) S = Salittu gabbro (Väisänen & Kirkland 2008), T = Toija felsic volcanic rock (Väisänen & Kirkland 2008). Figure is modified from Väisänen & Kirkland (2008).

The Orijärvi formation is stratigraphically the lowest one. It includes the Orijärvi granodiorite which contains mafic enclaves and shows signs of magma mingling (Kara et al. 2018). The volcanic and sedimentary rocks around the granodiorite are intensively hydrothermally altered. The zircon U-Pb age of unaltered Orijärvi rhyolite is 1895.3±2.4 Ma while the Orijärvi granodiorite is dated at 1898±9 Ma (Väisänen et al. 2002).

To the north and stratigraphically above of the Orijärvi formation lies the Kisko formation. Rocks of the Kisko Fm. are mainly felsic, intermediate and mafic volcanic and sedimentary rocks. Gabbros and plagioclase porphyries intrude the volcanic-sedimentary rocks. A dacite from the upper part of the formation yielded a U-Pb zircon age of 1878.2±3.4 Ma (Väisänen and Mänttäri 2002).

To the west and north lies the Salittu formation composing of ultramafic and mafic lavas (Schreurs et al. 1986) intercalated by metapelites and marbles. Tonalites, granoriorites and gabbros crosscut the lavas. Based on the field relationships, the Salittu formation is thought to have deposited around 1875 Ma (Väisänen and Kirkland 2008, Nironen et al. 2016).

The westernmost subarea is the Toija formation. It consists of rhyolites and pillow-basalts with metapelite and marble intercalations. The felsic volcanic rock yielded a zircon age of 1878±4 Ma with metamorphic 1815±3 Ma rims (Väisänen and Kirkland 2008).

3. Results

The U-Pb analyses were performed in the Finnish Geosciences Research Laboratory at the Geological Survey of Finland in Espoo.

Kisko felsic volcanic rock

Prismatic zircons are partly metamict, hampering the choice of intact domains for analyses spots. Consequently, many analyses are slightly discordant. However, the $^{207}Pb/^{206}Pb$ ages give a coherent weighted average age of ~1.89 Ga.

Orijärvi cordierite-anthophyllite rock

Zircons occur in many morphological types and grains are metamict and rich in inclusions. Most analyses are discordant and their $^{207}Pb/^{206}Pb$ ages form a declining trend of ages from 1901 Ma to 1786 Ma. Five oldest analyses form a distinct group and yield a weighted average age of ~1.89 Ga.

Monazites comprise both elongated and rounded grains. They yield a concordia age of ~1.80 Ga. Xenotimes are all rounded in shape and yield a concordia age of ~1.82 Ga

Iilijärvi cordierite-anthophyllite rock

Only few zircons were recovered and they all are highly discordant. Monazites are mostly rounded save a few prismatic grains. The analyses are mostly concordant and yield a concordia age of ~1.82 Ga.

4. Discussion and conclusions

The age of the Kisko felsic volcanic rock, ~1.89 Ga, is only slightly younger than the age of the Orijärvi rhyolite at 1895.3±2.4 Ma. This implies that the volcanism in the lower part of the Kisko formation continued after the deposition of the Orijärvi formation, without any hiatus in the volcanic activity as previously assumed. This also brings into question whether the previously argued stratigraphic position of the 1878±4 Ma Kisko dacite is valid (c.f. Väisänen and Mänttäri 2002, Nironen et al. 2016).

The oldest ~1.89 Ga zircon from the Orijärvi cordierite-anthophyllite rock is regarded as an igneous age of the protolith while the rest of the grains are modified by hydrothermal and metamorphic processes. The monazite and xenotime yield ages of ~1.80 Ga and ~1.82 Ga which we regard as metamorphic. The Iilijärvi monazite, however, yield an age of ~1.82 Ga, i.e., about 20 Ma older than the monazite from the Orijärvi sample even though the locations are only about 600 m apart.

The 1.82 Ga age of metamorphism and associated anatectic magmatism is common outside the Orijärvi triangle (Mouri et al. 2005, Skyttä and Mänttäri 2008, Väisänen and Kirkland 2008) related to regional granulite facies metamorphism. This implies that the lower grade Orijärvi triangle was metamorphosed simultaneously.

The 1.80 Ga metamorphism is more ambiguous but not unique. The metamorphic zircon from a gabbro within the Salittu formation yield an age of 1792±5 Ma (Väisänen and Kirkland 2008) and the titanite from the 1878±4 Ma Kisko dacite was 1798±3 Ma in age. In general, the magmatic 1.80 Ga activity is well documented in southern Finland (e.g., Rutanen et al. 2011) and it might have thermal consequences.

We conclude that the oldest volcanism in the Kisko formation started at ~1.89 Ga. The regional metamorphism in the Orijärvi triangle has had two different events at 1.82 Ga and ~1.80 Ga.

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