Bulletin of the Geological Society of Finland, Vol. 96, 2024, pp 161–170 https://doi.org/10.17741/bgsf/96.2.003

SHORT COMMUNICATION

Detrital zircon geochronology of Paleoproterozoic metasedimentary rocks from Jämsä, Central Finland

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Abstract

In this short communication, we present new detrital single grain zircon U-Pb data for six metasedimentary rock samples from Jämsä, Central Finland. Four samples are from the southern parts of the Central Finland granitoid complex and two from metasedimentary rocks mixed with the volcanic belts bordering it to the south. Based on the obtained results, the detrital zircon populations of all the samples are similar, i.e. they are bimodal with peaks at 2.05–1.95 Ga and 2.90–2.70 Ga. The maximum depositional ages of the individual samples are interpreted as 1.93–1.90 Ga. Thus, the zircon populations are similar to both the Pirkanmaa migmatite belt, which borders the granitoid complex to the south, and the lowermost members of the volcano-sedimentary Tampere group to the west from our study area. The results further strengthen the similarities between the volcano-sedimentary successions in Tampere and Jämsä areas. Similarities between the detrital zircon populations within, and south of the Central Finland granitoid complex need to be taken into account in further refinements of regional tectonic models.

Keywords: Finland, Paleoproterozoic, Svecofennian, Central Finland granitoid complex, zircon, U-Pb, metasedimentary rocks, deposition age

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Editorial handling: Jarmo Kohonen (email: jarmo.kohonen@helsinki.fi)

1. Introduction

Following the pioneering works of Huhma et al. (1991) and Claesson et al. (1993), abundant data characterizing the detrital zircon populations of the voluminous paragneisses surrounding the Central Finland granitoid complex (CFGC) has been published (e.g. Lahtinen et al. 2009, 2017; Kotilainen et al. 2016; Mikkola et al. 2018a). These studies have established the uniformity of the detrital populations, as nearly all of them are bimodal with peaks at 2.8–2.7 Ga and 2.05–1.95 Ga. Also interpreted maximum deposition ages are similar and cluster at 1.92–1.91 Ga, regardless of geological or geographical location. Smaller paragneiss segments are relatively abundant also within the CFGC (Bedrock Map of Finland – DigiKP), but up to date, no data has been published concerning their detrital zircon populations.

This short communication includes new single grain detrital zircon U-Pb data from six samples that represent metasedimentary rocks from A) the southern parts of the CFGC and B) units interleaved with the volcanic belt bordering it to the south in Jämsä, Central Finland (Fig. 1). The results are compared to published detrital zircon data from the Pirkanmaa migmatite belt and the volcano-sedimentary Tampere group. The aim is to identify possible similarities and differences in detrital zircon populations in the samples from within and surrounding the CFGC, and to briefly discuss their implications for regional geological models.

2. Geological setting

Our study area is located in Jämsä, along the southern boundary of the Paleoproterozoic CFGC, which forms the core of the Svecofennian Province in Finland (Fig. 1). The CFGC consists mainly of granitoids but hosts also small metasedimentary and volcanic segments. To the south, the granitoid complex is separated from the Pirkanmaa migmatite belt by discontinuous belt of supracrustal rocks, both volcanic and metasedimentary.

The oldest magmatic phase preserved in the Svecofennian Province consists of 1930–1910 Ma calc-alkaline plutonic and volcanic rocks, which display island arc affinities (Lahtinen et al. 2005; Huhma et al. 2021). These rocks are preserved along the northeast boundary of the province. End of this older magmatic phase has been interpreted to mark the collision of island arc with the Archean Province (Nironen 2017 and references therein).

Based on whole-rock geochemistry and detrital zircon geochronology protoliths of the migmatitic paragneisses of the Pirkanmaa migmatite have been interpreted as greywackes deposited by turbidite currents prior to 1910 Ma (Claesson et al. 1993; Lahtinen et al. 2009, 2017; Mikkola et al. 2018a). Following deposition in a passive margin setting, these paragneisses have been interpreted as forming the accretionary wedge during subduction from present south (Lahtinen et al. 2005). West of our study area, the lowermost unit of the Tampere group, the Myllyniemi formation consists of unmigmatised greywackes and paraschists with deposition ages similar to those of the rocks in the Pirkanmaa migmatite belt (>1.90 Ga, Lahtinen et al. 2009). In addition to deposition ages, the detrital zircon age populations of the Pirkanmaa migmatite belt and Myllyniemi formation are similar, displaying a bimodal distribution with peaks at 2.05–1.95 Ga and at 2.80–2.70 Ga (Lahtinen et al. 2009).

The main magmatic phase of CFGC (1895–1875 Ma) consists of both granitoids and volcanic rocks with calc-alkaline affinities. The volcanic rocks of this phase west and east of our study area have been included in the Tampere group and Makkola suite, respectively (Kähkönen 2005, Kähkönen & Huhma 2012, Mikkola et al. 2018b). This division most likely reflects purely differences in the extent of detailed studies and outcrop density. The calc-alkaline phase has been explained in two fundamentally different ways: a) as continental arc type magmatism connected to subduction from south (Lahtinen et al. 2005; Nironen 2017; Mikkola et al. 2018c) or b) as heating and partial melting of lower and middle crust thickened

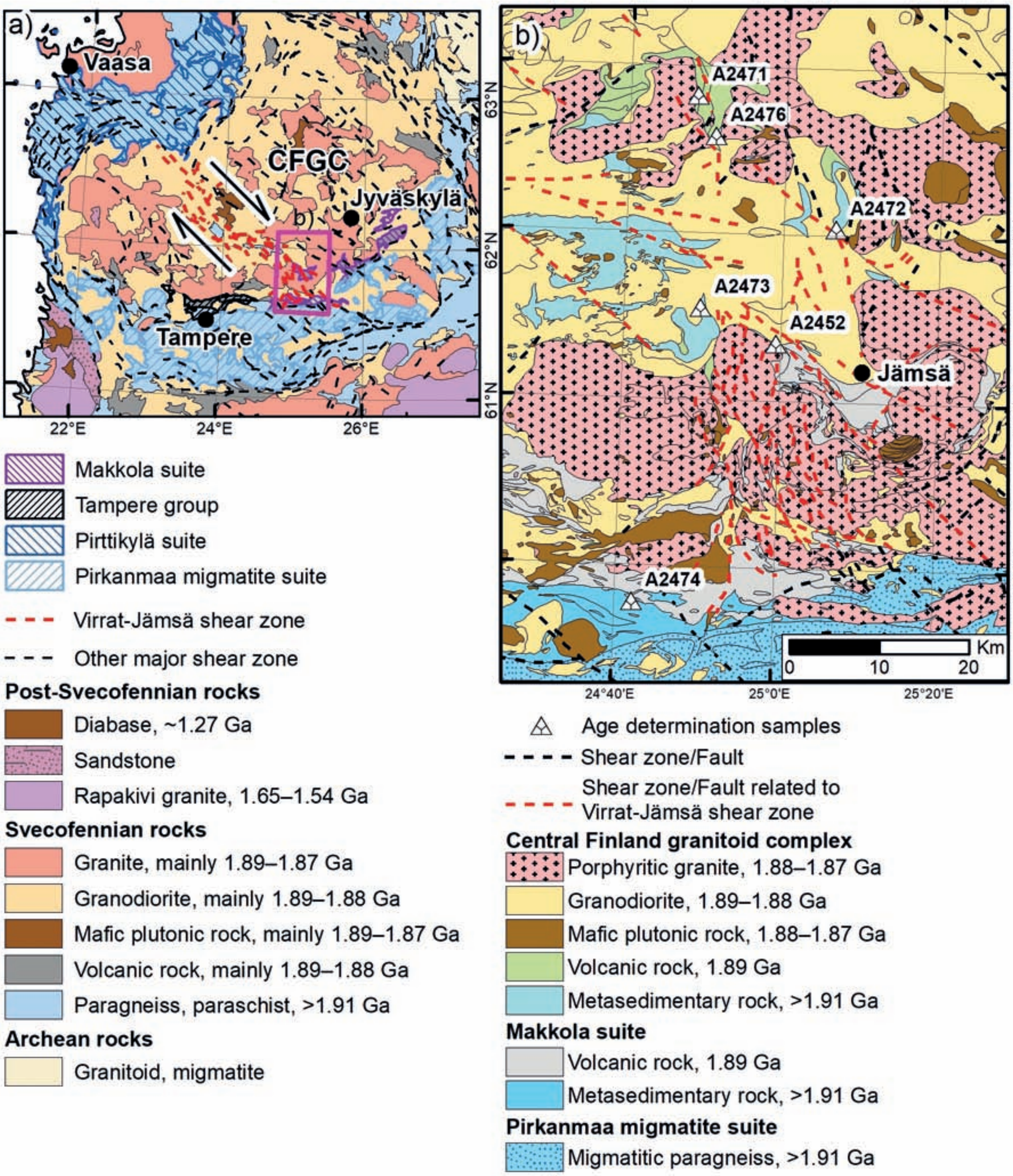

Fig. 1. a) Bedrock map of South and Central Finland. Map modified from Nironen et al. (2016). Purple polygon oulines areal extent of figure b). b) Bedrock map of the study area showing sample locations. Map modified fom Bedrock Map of Finland – DigiKP.

during an earlier collision (Nikkilä et al. 2016). The calc-alkaline magmatism does not display abrupt changes in composition and has been interpreted as a continuum spanning from tonalitic to leucogranitic compositions, formed in a maturing continental arc environment (Heilimo et al. 2018; Mikkola et al. 2018c). Only a small number of sediments deposited in fore arc setting during the subduction stage have been identified south of the CFGC (Lahtinen et al. 2009).

3. Methods and materials

All six age determination samples were crushed, separated and analysed in Geological Survey of Finland's (GTK) laboratory in Espoo. Following the separation, the zircon grains were mounted in epoxy, polished and imaged with Secondary Electron Microscope (SEM) for spot selection. The analyses were carried out using LA-ICPMS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) method. The used apparatus was Nu Plasma AttoM single collector ICP-MS connected to a Photon Machine Excite laser ablation system. Detailed description of the method can be found in Molnar et al. (2018). The following zircons were used as calibration and reference data: GJ-01 (609 ± 1 Ma, Horstwood et al. 2016), A1772 (2712 ± 1 Ma, Huhma et al. 2012) and A382 (1877 ± 2 Ma, Huhma et al. 2012).

In analytical session for A2452, zircon A382 was used as calibration standard and GJ-01 together with A1772 as control samples. In analytical sessions for samples A2471–A2476, GJ-01 was used for calibration and samples A382 and A1772 were used as control samples. For all sessions reference data provided results which overlap in error with the respective reported ages. All unknowns and reference data can be found in the Electronic Appendix A. Zircons containing >1 % of common lead or central discordance larger than 10 % were excluded from the data interpretation.

4. Results

4.1. Field observations

The paragneisses occurring within the CFGC are mainly variably migmatitic, although unmigmatised types can also be identified. The unmigmatised variants are spatially associated with volcanic segments and present two types: (1) homogeneous paraschists/ paragneisses lacking well-defined layering, and (2) psammitic paraschist with coarse plagioclase grains (Fig. 2a). The migmatitic variants have mainly banded appearance (Fig. 2b) and, in some cases, display small-scale variations in degree of partial melting, which could present original layering, with the more pelitic and fertile beds being more intensively melted.

Greywackes and variably layered paraschists (Figs. 2c, 2d) are the metasedimentary rocks that form, together with the volcanic rocks, the boundary between CFGC and Pirkanmaa migmatite belt in our study area. These rocks are migmatitic only in the vicinity of larger intrusions. Based on our observations on metasedimentary rocks and data in Heikura (2017) on the volcanic units, we regard the volcanic-sedimentary sequence south of Jämsä as the western continuation of the Makkola suite (Mikkola et al. 2016), see discussion for further details.

4.2. Age determinations

4.2.1. Unmigmatised samples from CFGC

Sample 2471 Huhkovuori is an unmigmatised greywacke found in association with volcanic rocks within the CFGC in northern parts of our study area. Altogether 17 spots from 16 grains were analysed (see Electronic Appendix A for images of analysed spots). Due to discordance or high common lead, 2 spots were discarded. The remaining $^{207}Pb/^{206}Pb$-ages span from 3.18 to 1.91 Ga, 12 out of 15 yielding ages from 2.06 to 1.91 Ga (Fig. 3). Based on the above we interpret 1.91 Ga as the maximum deposition age for this sample.

Sample A2476 Jama is an unmignatised paragneiss lacking disctinct layering and from the same area as sample A2471. Total of 34 spots from as many crystals were analysed. Three spots were excluded due to high common lead or discordance and one for anomalously large error. For the remaining spots $^{207}Pb/^{206}Pb$-ages vary from 2.87 to 1.88 Ga with clusters at 2.10–1.91 Ga and at 2.87–2.70 Ga (Fig. 3). As the rock is in the field cut by 1.89–1.88 Ga CFGC granitoids, the deposition age of this rock is likely to be close to 1.90 Ga.

Fig. 2. a) Unmigmatised greywacke stippled by coarse plagioclase grains, sample location A2471. b) Intensively migmatised paragneiss, sample location A2473. c) Layered unmigmatised paragneiss with alternating psammitic and pelitic layers, sample location A2452. d) Thinly layered, unmigmatised paraschist, sample location A2474. Length of compass in a), c) and d) is 12 cm, diameter of the coin in b) is 24 mm. See Electronic Appendix A for the outcrop coordinates.

4.2.2. Migmatitic paragneisses from CFGC

Sample A2472 Jäykkä is from one of the smaller migmatitic paragneiss domains within CFGC, lacking spatial association with volcanic rocks. Separated zircons are typically oscillatorily zoned and euhedral with varying width length ratios, some of the grains are clearly rounded (see Electronic Appendix A). Altogether 32 spots from 32 different zircon crystals were analysed, out of these two were discarded due to discordance. Majority of the remaining spots, 28 out of 30, yielded Paleoproterozoic $^{207}Pb/^{206}Pb$-ages varying from 2.07 to 1.89 Ga (Fig. 3), the remaining two spots being Neoarchaean (both 2.68 Ga). The youngest analysed grains do not, based on their morphology or composition, differ from the older ones, which makes estimation of the maximum age for this sample challenging, but our interpretation is that 1.91 Ga is the best possible estimate for it. The youngest observed ages could be caused by lead-loss during metamorphism.

Sample A2473 Niinimäki is an intensively migmatised paragneiss (Fig. 2b) from a northern end of a 10 km long and 5 km wide paragneiss domain, connected with a small volcanic subdomain at its western contact. Detrital zircon grains from this sample display oscillatory zoning and the grains are slightly rounded (see Electronic

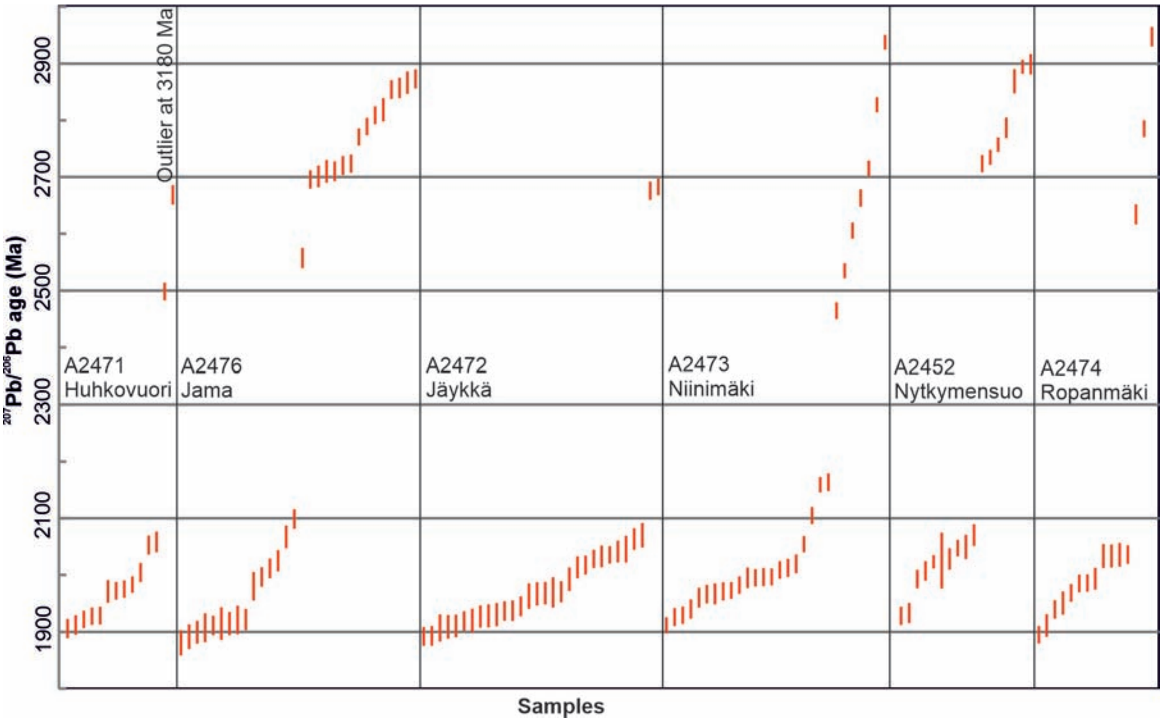

Fig. 3. $^{207}Pb/^{206}Pb$-ages of the analysed spots for all samples. Only spots interpreted as detrital are shown.

Appendix A). Total of 39 spots from 38 individual grains were analysed, out of these 7 were discarded due to high common lead or discordance. One of the points yielded an abnormally young age of 541 Ma and was excluded as contamination. The remaining spots yielded $^{207}Pb/^{206}Pb$-ages from 2.94 to 1.85 Ga with a distinct cluster at 2.02–1.96 Ga (Fig. 3). The two youngest ages are from a single grain displaying core-rim structure. The age of the rim, 1.90, could indicate metamorphism, whereas the 1.85 Ga age of the core must represent younger lead-loss. After exclusion of these points, the three youngest obtained ages are 1.93–1.91 Ga, which is also the best estimate of the maximum deposition age of this sample.

4.2.3. Metasedimentary members of the Makkola suite

Sample A2452 Nytkymensuo is from a layered sedimentary rock from the northern boundary of the Makkola suite in the study area. Bedrock in the area consists mainly of calc-alkaline felsic to intermediate volcanic rocks yielding ~1.89 Ga ages (authors' unpublished data). Separated zircons are mostly euhedral, but slightly rounded. Altogether 26 spots from 20 zircon grains were analysed. Out of these 8 were rejected due to high common lead or discrordance. The $^{207}Pb/^{206}Pb$-ages of the remaining spots vary from 2.90 to 1.90 Ga, with two clusters: at 2.07–1.93 Ga and 2.90–2.73 Ga (Fig. 3). The youngest age (1.90 Ga) is from a rim of an Archaean (2.76 Ga) core, and we interpret it as metamorphic. All other grains yield ages older than 1.93 Ga, which we interpret as maximum deposition age of this sample.

Sample A2474 Ropanmäki from the southwestern parts of our study area represents well preserved paraschists interbedded with the felsic to intermediate volcanic rocks of the Makkola suite. Separation produced only a small number of mostly rounded zircon grains. Total of 18 spots from as many zircon crystals were analysed, with $^{207}Pb/^{206}Pb$-ages from 2.95 to 1.90 Ga. Four of

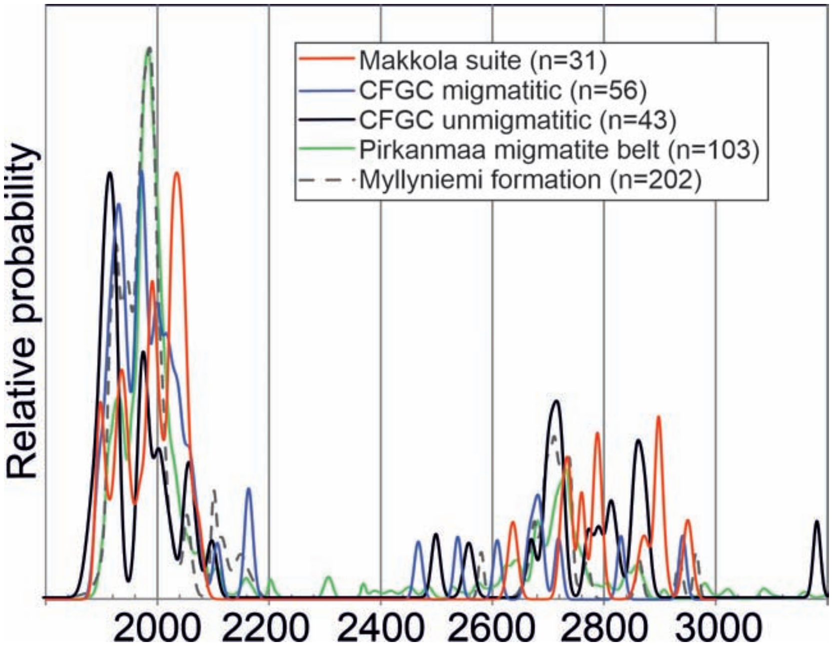

Fig. 4. Probability density curves for detrital $^{207}Pb/^{206}Pb$ ages from the studied samples assigned into three groups: sedimentary rocks associated with the Makkola suite, migmatitic paragneisses and unmigmatised metasedimentary rocks within the CFGC, which are spatially associated with volcanic units. Distribution patterns for the Pirkanmaa migmatite suite and the Myllyniemi formation (based on data from Lahtinen et al. 2009, 2017) are shown for comparison.

the analyses were discarded due to high common lead or discordance. It should be noted that 6 of the remaining analyses contain elevated common lead (0.5–1.0 %) but do not deviate in age or discordance from the others. The remaining spots yield $^{207}Pb/^{206}Pb$-ages from 2.95 to 1.90 Ga, with a Paleoproterozoic cluster at 2.04–1.95 Ga (Fig. 3). Although the two youngest spots do not differ morphologically or compositionally from the older ones, we regard them as likely representing metamorphic lead-loss and interpret 1.91 Ga as the maximum deposition age of this sample.

5. Discussion

All the three subgroups; Makkola suite metasedimentary rocks, migmatised paragneisses and unmigmatised paragneisses within the CFGC display similar bimodal detrital zircon age populations: Paleoproterozoic peaks at 2.10–1.90 Ga and Archaean peaks at 2.90–2.70 Ga (Fig. 4). The differences in the relative proportions of Archaean material and the slightly differing peaks in the Paleoproterozoic zircons are attributed to the relatively small number of grains analysed for this study. For discussion regarding the possible source areas of the observed different age groups see Lahtinen et al. (2023).

The distribution patterns of the detrital zircon ages also match those reported for the Myllyniemi formation, the lowermost sedimentary unit of the Tampere group, west of our study area, and those for the Pirkanmaa migmatite belt, south of our study area (Figs. 1 and 4). This provides further support to the correlation of the Makkola suite with Tampere group as in addition to the ages of volcanic rocks (Kähkönen & Huhma 2012, Mikkola et al. 2018b, authors' unpublished data) also the detrital zircon age patterns are similar in these two units. The latter clearly indicate deposition before the onset of volcanism (Lahtinen et al. 2009; this study).

The observation that similar detrital zircon age populations are present south of and within

CFGC has certain implications for regional geology. In the model of (see Lahtinen et al. 2009), the Myllyniemi formation and Pirkanmaa migmatite belt were deposited along the passive margin of Keitele microcontinent (proto-CFGC). Following the transformation from passive to active volcanic margin around 1.90 Ga, the volcanic units of the Makkola suite and Tampere group erupted and Pirkanmaa migmatite suite formed the accretionary prism.

Our northernmost samples are ca. 50 km north from the southern edge of CFGC (Fig. 1b). If they are to be correlated with the paragneisses surrounding CFGC, this distance, which is wider than that of an accreationary prism, would require strike-slip duplexing or significant E-W shortening. The latter is not supported by regional models building on N-S or SW-NE compression during the entire Svevofennian orogeny (e.g. Lahtinen et al. 2009, Nironen 2017). However, strike-slip displacement could be plausible explanation as the paragneisses now within CFGC could have been tectonically transported to their current location by the crustal scale Virrat–Jämsä shear zone (Luukas & Kohonen 2021, Bedrock map of Finland – DigiKP, Fig. 1). Based on the dextral nature of the shear zone, the paragneisses would however originate 100 km from NW and thus be part of the Pirttikylä suite and not of the Pirkanmaa migmatite suite (Fig. 1a). Based on model of Lahtinen et al. (2023) the Virrat-Jämsä shear zone possibly initiated already during regional D2 (1885–1875 Ma), peaked during the oroclinal stage (1875–1865 Ma) and remained active during D3 (1865–1850 Ma).

Dismissal of active subduction and oroclinal bending from the model would provide an alternative explanation. Partial melting of crust thickened during the 1.91 Ga collision could have produced the calc-alkaline granitoids and volcanic rocks of the CFGC formed without connection to active subduction (Nikkilä et al. 2016). Consequently, the paragneisses found within CFGC would represent units deposited before the collision of the island arc (proto-CFGC) with the Archaean province at 1.91 Ga (Nironen 2017).

6. Conclusions

Metasedimentary rocks within the CFGC display similar detrital zircon age patterns as the Pirkanmaa migmatite belt and Myllyniemi formation of the Tampere group, i.e. bimodal with Paleoproterozoic peaks at 2.05–1.95 Ga and Archaean peaks at 2.9–2.7 Ga.

The detrital zircon age populations of the metasedimentary rock units intermingled with arc volcanic rocks in Jämsä area indicate that they were deposited before the onset of the arc volcanism in the area, situation similar to the Tampere group further west.

Combined with the earlier structural interpretations, our zircon data indicate possibly up to 100 km of dextral displacement along the Virrat-Jämsä shear zone.

Acknowledgements

We would like to acknowledge the work done in GTK's isotope laboratory, at all stages of the work from zircon separation to keeping the mass spectrometer operational. Antti Mäkelä is thanked for participation in the field work and support for sampling. Constructive reviews by Dr Juha Köykkä and Dr Martiya Sadeghi in addition to editorial work by Dr Jarmo Kohonen helped us in improving this short communication.

Supplementary Data

Electronic Appendices are available via Bulletin of the Geological Society Finland web page.

Electronic Appendix A: Analytical data

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