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U–Pb geochronology of Archaean volcanic-sedimentary sequences in the Kuhmo greenstone belt, Karelia Province – Multiphase volcanism from Meso- to Neoarchaean and a Neoarchaean depositional basin?

E. Lehtonen[a,*], E. Heilimo[b], T. Halkoaho[b], A. Käpyaho[c], P. Hölttä[c]

[a] Finnish Museum of Natural History (Geological Museum), University of Helsinki, P.O. Box 44, 00014, Finland
[b] Geological Survey of Finland, P.O. Box 1237, 70211 Kuopio, Finland
[c] Geological Survey of Finland, P.O. Box 96, 02151 Espoo, Finland

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ABSTRACT

The Kuhmo greenstone belt in eastern Finland is one of the most studied areas of the Karelia Province. A single-grain zircon U–Pb study of andesitic, trachyandesitic and dacitic volcanic rocks from the belt demonstrates multiple widely spaced ages of the rocks. The results show that the volcanic activity took place as two major episodes at ca. 2847–2836 Ma and ca. 2799–2792 Ma, both containing komatiitic members as well as volcanic-sedimentary units. Based on the geochronological results combined with previously published data, we propose a chronostratigraphic interpretation for the Kuhmo greenstone belt, dividing it into three units: the Nuolikangas and Siivikkovaara volcanic units, and the sedimentary Ronkaperä unit. The results support the previous interpretation that age period of 2.80–2.79 Ga was an important crustal forming episode in the Kuhmo area. The zircon populations in the uppermost sedimentary rocks contain >3.0 Ga zircon grains that are older than the volcanic rocks found in the greenstone belt. The youngest detrital zircon populations, ca. 2.73 Ga and 2.70 Ga in a conglomerate and a quartz sandstone, respectively, imply that they were deposited at least ca. 60–90 Ma after the last volcanic phase. Based on the detrital zircon record, it can be interpreted that during the deposition of the detritus of the sedimentary rocks belonging to the Ronkaperä unit, the Karelia subprovinces were likely juxtaposed together and acted as a source provenance for the detritus.

1. Introduction

The time spans of volcanic and sedimentary processes are crucial in understanding the evolution and tectonic settings of Archaean greenstone belts. Developments in single grain analysis methods for age determination have improved our understanding of the geological processes and evolution of Archaean greenstone belts (e.g., Pearson and Daigneault, 2009; Huhma et al., 2012a; Mueller et al., 2013). Within these belts, the time difference between the oldest and the youngest volcanic sequences may vary from tens to even hundreds of millions of years (e.g., Corfu et al., 1989; Dostal and Mueller, 2013; Furnes et al., 2013). For example in the East Pilbara terrane, Australia, volcanic stages up to 200 Ma have been recorded (Van Kranendonk et al., 2002).

Archaean greenstone belts can evidently represent various tectonic frameworks. The greenstone belts have generally been divided into autochthonous and allochthonous based on the internal structures of the belts and their relationships to juxtaposed tonalite-trondhjemite-granodiorite (TTG) gneiss complexes (Polat and Kerrich, 2000, 2006). In autochthonous models, the greenstone belts were formed in continental rift or continental platform settings (e.g., Hunter et al., 1998; Papunen et al., 2009), whereas allochthonous models favour horizontal tectonic transport and accretion of various types of oceanic crust, such as pieces of island arcs and oceanic plateaus (e.g., Puchtel et al., 1998, 1999; Furnes et al., 2013; Maier et al., 2013). In addition to these models, a model where Archaean cratons acts as active tectonic agents that collides with stiff basaltic oceanic plateaus has been proposed (e.g., Bédard et al., 2013). This model argues that no evidence exist for volcanic rocks having been formed in an island arc environment during the Archaean.

This study focuses on the Kuhmo greenstone belt, which forms the central part of the Suomussalmi-Kuhmo-Tipasjärvi greenstone complex in eastern Finland and is one of the most studied greenstone belts of the Karelia Province (Fig. 1). Previous studies in the area have concentrated on the petrology and geochemistry of mafic

* Corresponding author. Tel.: +358 503185287.
E-mail address: elina.lehtonen@helsinki.fi (E. Lehtonen).

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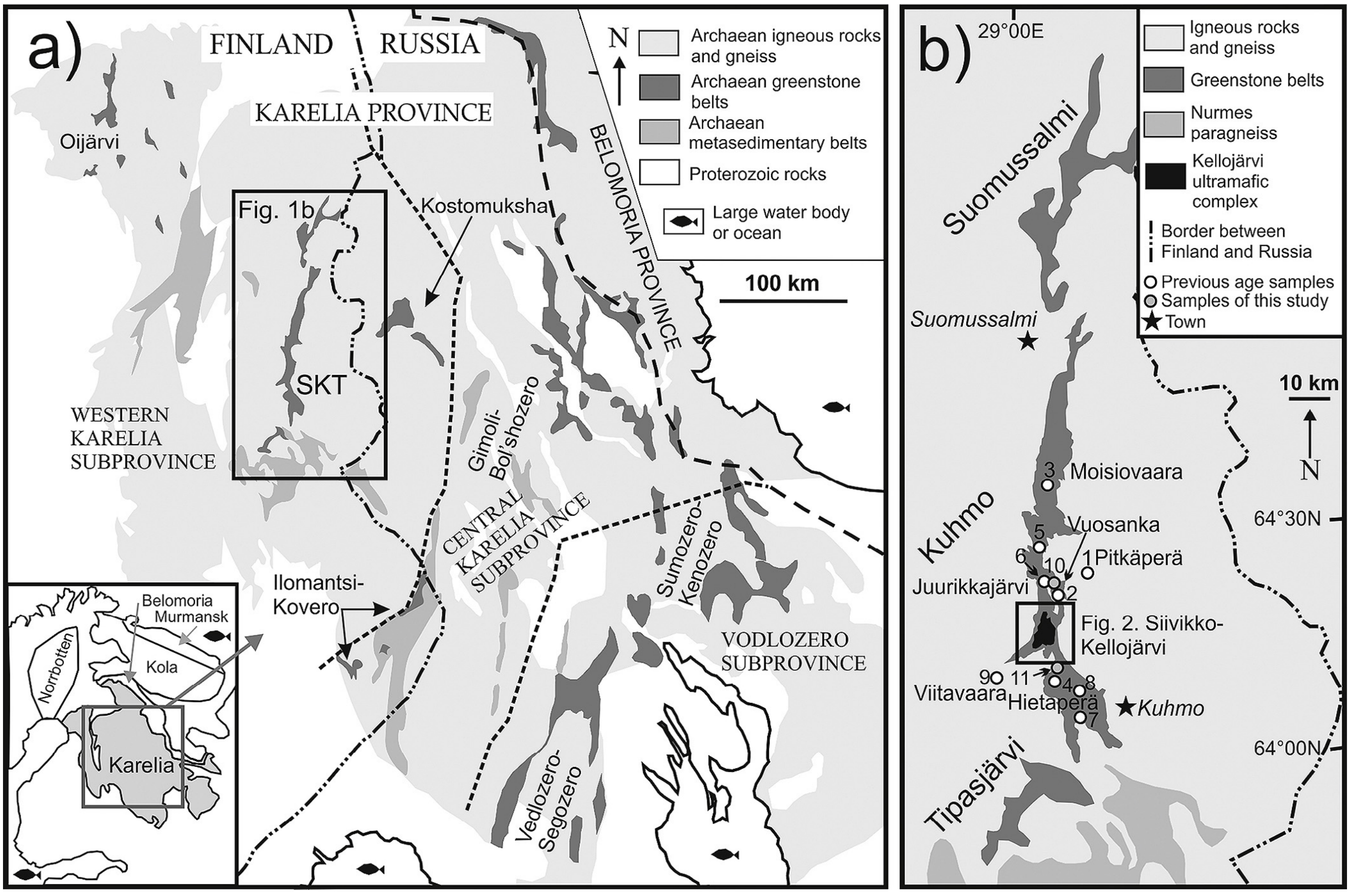

Fig. 1. Simplified maps of (a) the Karelia province. (b) The Suomussalmi-Kuhmo-Tipasjärvi greenstone belt complex. Sample points of Huhma et al. (2012a): (1) Pitkäperä intermediate volcanic rocks (A1213, A1254), (2) Hetteilä intermediate volcanic rock (A1773), (3) Moisiovaara gabbro (A976), (4) Katerma rhyolite (A511), (5) Arola quartzite (A1753), (6) Polvilampi rhyolite (A0788), (7) Rakennuslahti greywacke (83-PGN-90), (8) Petäjäniemi sedimentary rock (A1746); from Käpyaho et al. (2006): (9) Viitavaara tonalite (A1705). This study: (10) Juurikkajärvi conglomerate (A2205) and (11) Hietaperä quartz sandstone (A2206). The framed Siivikko-Kellojärvi area is shown in detail in Fig. 2, in which the other sampling locations of this study are marked. Lithologies simplified after Koistinen et al. (2001).

and ultramafic lithologies (e.g., Tulenheimo, 1999; Papunen et al., 2009; Maier et al., 2013). Extensive U–Pb geochronological and Sm–Nd isotope geochemical works has been published by Huhma et al. (2012a, 2012b). Previously proposed stratigraphical interpretations for the Kuhmo greenstone belt are lithostratigraphy and rock type stratigraphy (e.g., Papunen et al., 2009; Huhma et al., 2012a). Based on field observations and the presence of crustal contamination in ultramafic rocks, Luukkonen (1991) and Papunen et al. (2009) proposed that the Suomussalmi-Kuhmo-Tipasjärvi greenstone complex represents an intracontinental rift system. However, the Sm–Nd isotope studies from these greenstone belts have suggested that in the Kuhmo and Tipasjärvi belts significantly older continental crust did not exist, in contrast to the Suomussalmi belt (Huhma et al., 2012b). Maier et al. (2013) interpreted the primitive Zr/Nb and Nb/Th ratios of the Kuhmo and Tipasjärvi komatiitic rocks in the southern part of the complex as typical for an oceanic plateau. The elemental composition of the Suomussalmi greenstone belt komatiitic rocks in the northern part of the complex provided evidence for interaction with a continental basement, however, and may therefore have erupted in a continental rift environment (Maier et al., 2013). Although the development of a continental rift may take tens of millions of years (e.g., Petit and Déverchère, 2006), the autochthonous model for the Kuhmo belt has its drawbacks, because the surrounding TTG gneisses and granitoidic rocks are mostly of the same age or younger compared to the volcanic rocks of the greenstone belt (Käpyaho et al., 2006; Heilimo et al., 2011; Mikkola et al., 2011; Huhma et al., 2012a). Despite several studies, the tectonic evolution of the belt is still under debate.

In this paper, we present new single grain U–Pb isotope data on zircon grains from supracrustal rocks and associated plutonic rocks, supplemented with additional whole-rock geochemical analyses from the Kuhmo greenstone belt. The systematic geochronological data combined with the existing geological information allow us to propose a chronostratigraphic interpretation for the Kuhmo greenstone belt, as well as discuss their implications to the interpretations of the evolution of the belt.

2. Geological setting

The Archaean domains of the Fennoscandian Shield are divided into five crustal provinces (see inset in Fig. 1a): Karelia, Kola, Belomoria, Murmansk and Norrbotten (e.g. Gáal and Gorbatchev, 1987; Slabunov et al., 2006; Hölttä et al., 2014). A major feature of the Karelia Province is the presence of narrow and elongated, N–S-trending greenstone belts surrounded by abundant gneissic and migmatitic TTG areas. Only minor amounts of Palaeoarchaean rocks are present, and the oldest rock found in the Finnish part of the Archaean Karelia Province is the Siurua orthogneiss dated at ca. 3.5 Ga (Mutanen and Huhma, 2003). Based on differences in the lithology, geochronology, structures and radiogenic isotope systematics, the Karelia Province is divided into three subprovinces: the Western Karelia subprovince, the Central Karelia subprovince, and the Vodlozero subprovince (Slabunov et al., 2006; Hölttä et al.,