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A late Paleoproterozoic key pole for the Fennoscandian Shield: A paleomagnetic study of the Keuruu diabase dykes, Central Finland

R. Klein [a,*], L.J. Pesonen [a], I. Mänttäri [b], J.S. Heinonen [c]

[a] Department of Physics, P.O. Box 64, University of Helsinki, FI-00014 Helsinki, Finland
[b] Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland
[c] Department of Geosciences and Geography, P.O. Box 64, University of Helsinki, FI-00014, Finland

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ABSTRACT

We present an updated paleomagnetic pole and a new isotope age for the late Paleoproterozoic (Svecofennian) diabase dykes from Keuruu, Central Finland. The paleomagnetic results reveal a dual-polarity remanent magnetization with asymmetry, which we explain by an unremoved secondary component contaminating both normal (N) and reversed (R) vectors. The ChRM is carried by magnetite, most of which are primary grains crystallized from basaltic magma. The primary nature of the ChRM is further supported by positive baked contact tests. An R polarity dyke shows a U-Pb concordia age of 1870 ± 9 Ma. Zircons from another dyke of N polarity reveal a mean Pb-Pb age of 1867 ± 8 Ma. The combined N and R mean ChRM direction is D = 340.4°, I = 35.2°, α_{95} = 5.8°, k = 31.3, N = 21 dykes (yielding a paleomagnetic pole of Plat = 45.7°, Plon = 230.9°, A_{95} = 5.5°. This positions the Fennoscandian Shield at low latitudes (19.4°), and aligns with Superior Craton in a way that would naturally proceed into the 1.8–1.2 Ga NENA (North Europe–North America) configuration. Paleosecular variation analysis of N polarity dykes is consistent with the low latitude position of Baltica.

1. Introduction

Paleomagnetism, coupled with precise isotope age data, remains the only quantitative method to reconstruct Precambrian continents to a paleogeographic reference frame. Paleomagnetism provides paleomagnetic poles, which are used to construct apparent polar wander paths (APWP) and to assemble continents into their ancient positions. For this it is necessary to rely on key poles (Buchan, 2013), i.e. poles coupled with a precise age and supported by robust evidence of their primary nature. Only few poles of Baltica between 1.9 Ga and 1.7 Ga are precisely dated and can be regarded as key poles (Pisarevsky and Sokolov, 2001; Elming et al., 2009; Pisarevsky and Bylund, 2010).

The exact position of the Fennoscandian Shield during the Svecofennian orogeny is uncertain, due to a possible discrepancy between the age of crystallization and age of magnetization (delayed by ca. 10–20 Ma) of the slowly cooled Svecofennian (1.88–1.87 Ga) gabbros (Mertanen and Pesonen, 2005 and references therein) upon which position of the Fennoscandian Shield relies. To overcome the problems associated with the slow cooling syn-orogenic intrusions, we turn our focus on the post-orogenic mafic dykes in Finland (Pesonen, 1987). Mafic dykes are ideal for paleomagnetic studies for several reasons. First, they cool rapidly and therefore provide an accurate record of the Earth's magnetic field (e.g. Halls et al. (2007)). Second, they sometimes contain zircon and/or baddeleyite grains which are used to establish the precise crystallization ages of the dykes (e.g. Halls et al. (2007), French and Heaman (2010)). Third, the primary nature of the ChRM in dykes can be established by means of a baked contact test (Everitt and Clegg, 1962; Buchan, 2013).

Earlier paleomagnetic (Pesonen and Neuvonen, 1981; Palmu, 1982; Pesonen et al., 2012) studies have been carried out on early Proterozoic diabase dykes of Keuruu, central Finland. Paleomagnetic results from some of the dyke outcrops show a dual polarity characteristic remanent magnetization (ChRM) with asymmetry between normal and reversed directions. Pb-Pb isochron ages were measured for different combinations using Pb isotope ratios for total rock, titanite, zircon, 3.2–3.4 g/cm^3 mineral fraction, galena and pyrite, ending in a variety of results ranging from ca. 2.0–1.6 Ga, with a concordant age of 1876 ± 9 Ma concluded to be the age of the diabase (Kouvo, pers. comm.).

The aim in this study is (i) to obtain paleomagnetic data from all Keuruu diabase dyke outcrops, (ii) to explain the asymmetry between normal and reversed data, and (iii) to obtain a late Paleoproterozoic key pole for Baltica, which includes a precise U-Pb age

* Corresponding author.
E-mail address: robert.klein@helsinki.fi (R. Klein).

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and baked contact test. We further aim (iv) to discuss the implications of the pole in a late Paleoproterozoic paleogeographic reconstruction.

2. Geological background

The Keuruu diabase dyke swarm is situated within the Central Finland Granitoid Complex (CFGC) (Marmo, 1963; Marmo and Mikkola, 1964). The CFGC was formed 1.89–1.86 Ga ago during the peak phase of the Svecofennian orogeny, where the Svecofennian island arc system collided against the Archean craton Karelia (Nironen, 2003; Lahtinen et al., 2005). Granitoids are predominant rocks in the CFGC together with granodiorites, diorites and schists, as well as numerous gabbroic bodies. The U-Pb zircon age of the Keuruu granodiorite is 1.88 Ga (Huhma, 1986). The Keuruu diabase dyke swarm crosscuts these rocks (Nironen, 2003), as well as the Keuruu gabbro (Fig. 1).

The Keuruu dykes strike NW-SE (Fig. 1) and have near-vertical dips. Anisotropy of magnetic susceptibility results by Puranen et al. (1992) divide the Keuruu dykes into three groups based on magnetic fabric, namely horizontal (h), vertical (v) and mixed (m) orientations, which relates to the manner of magma flow of the dykes (Puranen et al., 1992). Puranen et al. (1992) suggested that fractionation of mafic magma in the upper part of the crust produced a low density (2600–2700 kg/m^3) tholeiitic magma. In a granodiorite surrounding with a density of ca. 2670 kg/m^3, the tholeiitic magma possibly reached its level of neutral buoyancy (LNB) near the present erosion level and intruded laterally along the LNB producing horizontal foliations and lineations parallel to the structural strike of the group h dykes. In a diorite or gabbro surrounding, with a slightly higher density of 2800–2950 kg/m^3, the LNB was located higher than the present erosion level resulting in group v dykes with weakly developed, gently plunging lineations and vertical foliations. Group m dykes possibly arose from buoyancy conditions between those of group h and v dykes.

Keuruu diabase dykes are chemically similar to each other, regardless of magnetic fabric, and they are also chemically similar to the gabbro of Keuruu (Fig. 2; Marmo and Mikkola, 1964; Puranen et al., 1992). Their low Ti and Zr contents at a given MgO are similar to those of some of the closest Svecofennian volcanic rocks, and largely distinct from generally more Ti- and Zr-enriched anorogenic mafic dyke swarms of southern Fennoscandia (Fig. 2). The coarser central parts of wider dykes are ophitic, subophitic or intergranular, containing plagioclase laths and hornblende grains (pseudomorphs after pyroxene) as the main minerals. The finer marginal parts are porphyritic in texture and contain fresh pyroxenes (orthopyroxene and augite) and some plagioclase phenocrysts (Puranen et al., 1992). The silicate matrix of the dykes includes biotite, chlorite, apatite, epidote, and titanite (Marmo and Mikkola, 1964; Puranen et al., 1992). A microscopic study of the Keuruu diabases revealed titanomagnetite as the predominant magnetic mineral (Puranen et al., 1992). The general lack of secondary mineral inclusions in these grains indicate their primary nature, although some secondary overgrowths and sporadic secondary grains (platy magnetite, hematite, pyrite, and pyrrhotite) have also been observed (Puranen et al., 1992). Thin section photographs of two of the samples of this study are presented in Fig. 3.

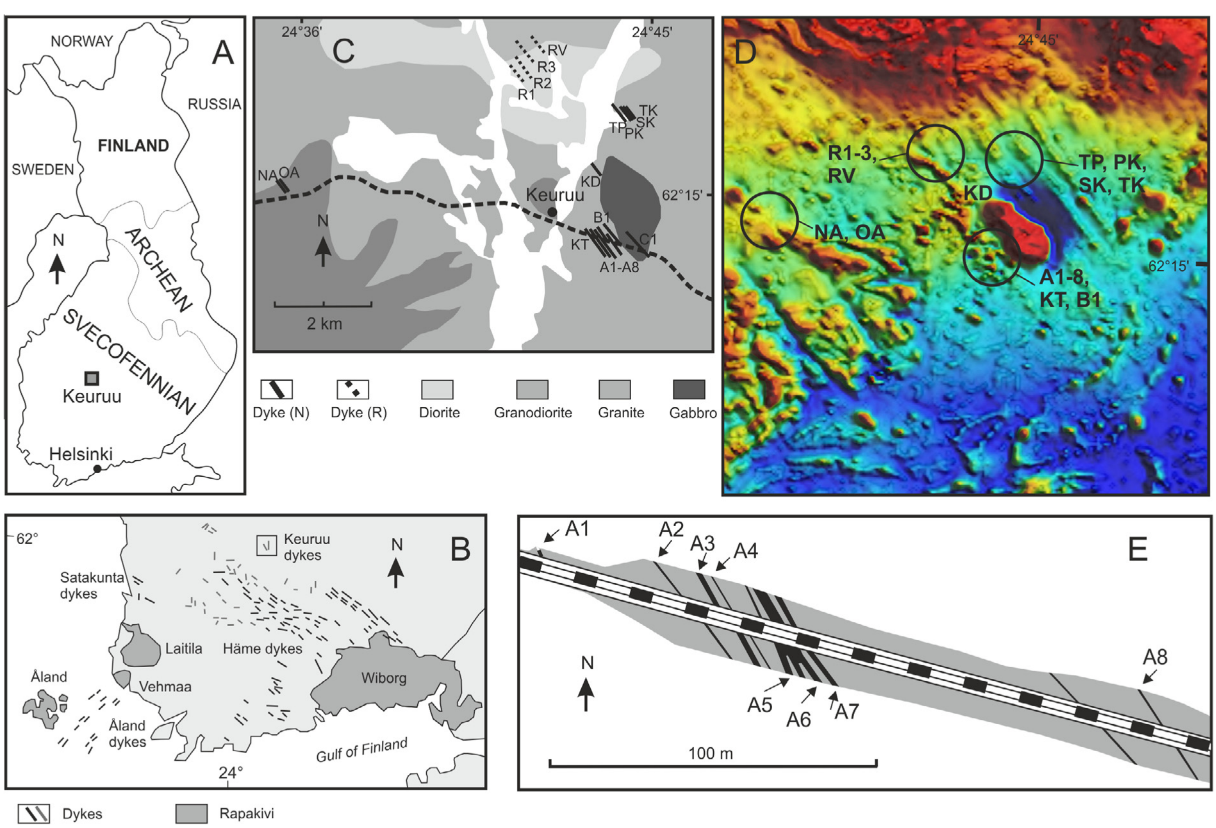

Fig. 1. (A) Simplified geological map of Finland (box show Keuruu study area). (B) Dyke map of Southern Finland (modified after Rämö and Haapala (2005)). (C) Geological map of the study area with the location of sampled dykes (modified from Puranen et al. (1992)). Normal (N) and reversed (R). (D) Aeromagnetic anomaly map of the study area (copyright: GTK airborne geophysical database). Nominal terrain clearance 30 m and line spacing 200 m. Flight line direction mainly N-S. Dyke outcrop sites encircled. SE-NW diagonal features in the bottom left corner of the aeromagnetic map corresponds with faults. (E) Close-up of the site of dykes A1-8, KT and B1 (the railway outcrop).