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Paleomagnetic and geochronological studies on Paleoproterozoic diabase dykes of Karelia, East Finland—Key for testing the Superia supercraton

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ABSTRACT

Paleomagnetic results are presented for two Paleoproterozoic mafic dykes in the Taivalkoski area in northern Karelia Province of the Fennoscandian shield where, based on K-Ar data, the crust has seen minimal effects of the otherwise pervasive 1.8–1.9 Ga Svecofennian orogeny. Within this study a new U–Pb baddeleyite age of 2339 ± 18 Ma has been determined for one of the E–W trending dykes (dyke AD13).

The paleomagnetic results show that a strong Svecofennian overprinting is pervasive in the area. Upon thermal or AF demagnetization four remanence directions were obtained. Most typical are the secondary Svecofennian remanence direction A (intermediate down to the NNW) and remanence direction B (intermediate down to the NNE). Component *D* (D = 115.4°, I = 50.5°, α_{95} = 2.6°) yielding a virtual geomagnetic pole (VGP) *D* (Plat = −19.5°N, Plon = 263.3°, A_{95} = 3.1°) is obtained from baked rocks for dyke WD, and based on a positive baked contact test is interpreted to represent the primary magnetization dating from about 2.4 Ga. Dyke AD13 carries only secondary *A* and *B* components, its unbaked host migmatites carry reversed *A* (A_R) component, and the baked host rock carries a component D' (D = 134.5°, I = −7.3°, α_{95} = 8.8°), which yields a VGP pole D' (Plat = −20.4°N, Plon = 257.3°, A_{95} = 7.6°), possibly representing magnetization at 2.3 Ga.

The new paleomagnetic data from the Karelia Province compared to similar-aged paleomagnetic data from the Superior Province does not support the recently proposed Superia configuration, based upon dyke swarm trajectories.

1. Introduction

The Paleoproterozoic era from the amalgamation and dispersal of a possible Neoarchean supercratons named Superia, Vaalbara, and Sclavia or supercontinent Kenorland (e.g. Bleeker, 2003) to the formation of the 1.9–1.8 Ga supercontinent Nuna (a.k.a. Columbia, Hudsonland) might represent the first supercontinent cycle. Supercontinent cycles have shown to have intriguing temporal relationships with core, mantle, crust, oceans, atmosphere and early evolution of life (Reddy and Evans, 2009). However, this first supercontinent cycle and moreover the proposed first Neoarchean supercratons are currently lacking in paleogeographic detail. Several recent and ongoing studies have produced high-quality Precambrian paleomagnetic data, and a paleogeography is becoming defined for the interval of 2.7–1.8 Ga. For example the paleomagnetic apparent polar wander (APW) paths for Vaalbara supercraton, being reconstruction of Kaapvaal and Pilbara cratons (de Kock et al., 2009), and Slave craton, joining possibly Dharwar, Wyoming and Zimbabwe cratons as part of Sclavia supercraton until 2.0 Ga (Bleeker, 2003), are beginning to take form (Buchan et al., 2009; Mitchell et al., 2010). Recently published and preliminary new paleomagnetic data show that Superia comprises the Superior craton and it might have included Kola, Karelia, Wyoming, and Hearne, as indicated by the large igneous province (LIP) magmatic “barcode” record (Ernst and Bleeker, 2010). From these the Superior craton has both the most extensive magmatic barcode record and paleomagnetic data set. Based on these Bleeker and Ernst (2006) have presented a model of a long-lived (2.7–2.0 Ga) supercraton Superia where the Superior, Wyoming, Hearne, Karelia and Kola cratons are tightly joined based on matching of two or more coeval 2.5–2.1 Ga dyke swarms on each craton (see also Ernst and Bleeker, 2010). However the data from different cratons

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are sparse and due to the complexity of the overprint patterns on the ca. 2.45 Ga units of the Karelia craton, Bleeker and Ernst (2006) did not include the paleomagnetic information from the Karelia craton in their model. The Karelia craton around the Taivalkoski area both in Finland and Russia has suffered multiple remagnetization events, the most severe one caused by the Svecofennian orogeny at ca. 1.9–1.8 Ga (e.g. Khramov et al., 1997; Krasnova and Gooskova, 1995; Mertanen, 1995; Mertanen et al., 1989, 1999). This remagnetization has been recognized in most Karelia formations and was originally named as component *A* in the 2.45 Ga layered intrusions in Finland (Mertanen et al., 1989). The layered intrusions carried two other overprints, the other one named as component *B*, which was thought to be related to the vaning stage of the Svecofennian orogeny at ca. 1.75 Ga, and the other one component *E* that was regarded to be ca. 2.1 Ga based on apparent polar wander (APW) path. The characteristic remanence component of the layered intrusions, thought to be the primary 2.45 Ga magnetization, was named as component *D* (Mertanen et al., 1989). Later, in 2.44 Ga mafic dykes in Russian Karelia another *D*-like component, but with lower inclination, was revealed and it was named as component *D*′ (Mertanen et al., 1999). Since then, a debate has been going on, whether component *D* with higher inclination or component *D*′ with lower inclination represents the primary 2.45 Ga remanence in the Karelia craton. This question has importance because component *D*′ would place the Karelia and Superior cratons together unlike component *D*. In this paper we use the names *A*, *B*, *D* and *D*′ in the same sense as in the papers by Mertanen et al. (1989, 1999).

So far most of the paleomagnetic data (e.g. Mertanen et al., 1999, 2006a,b; Mertanen and Korhonen, 2011) obtained for Karelia negate the tight Superia fit of Karelia and Superior at 2.50–2.45 Ga. In order to get more evidence on the paleoposition of the Karelia craton at 2.5–2.0 Ga, and to test the proposed Superia model (Bleeker and Ernst, 2006; Ernst and Bleeker, 2010) paleomagnetic and rock magnetic studies on several Paleoproterozoic mafic dykes, especially in the Taivalkoski area in northern Finnish Karelia, have been carried out. Herein we also report a U–Pb baddeleyite age for a dyke which also forms one of the key paleomagnetic sites for this study.

2. Geological setting, sampling and measurements

2.1. Geology and sampling

The eastern Fennoscandian shield comprises the Archean basement complex (3.5–2.6 Ga) and the Paleoproterozoic cover (Fig. 1). The Archean continental core of the Fennoscandian Shield was formed at ca. 3.5–3.2 Ga and it can be divided into the Karelia and Kola Provinces. The Archean Belomorian Province is located between these cratonic domains (Gaàl and Gorbatschev, 1987; Bogdanova, 1996; Slabunov et al., 2006; Hölttä et al., 2012). The study area is located in Taivalkoski area in the northern part of the Lentua Complex of the Western Karelia subprovince (Hölttä et al., 2012), consisting of Archean granitoids and greenstone belts, partly covered by Paleoproterozoic sedimentary formations (Fig. 1). This region was selected because regional K-Ar studies on biotite and hornblende, showed that it was one of the few places where Archean ages survived in hornblende, being close to the zircon ages (Kontinen et al., 1992). This observation implies that the degree of Svecofennian overprinting may be less in this region, thus offering the possibility that paleomagnetism could see through the metamorphism. From the Late Archean onwards (since ca. 2.5 Ga) the Belomorian belt in the northeast and the Proterozoic Svecofennian orogen in the southwest were molded against the Karelia craton (Gaàl and Gorbatschev, 1987; Gorbatschev and Bogdanova, 1993; Bogdanova, 1996).

The entire Karelia craton is cut by voluminous NW-, E- and NE-trending dyke swarms and intrusions/sills that extend from Finland to Russia (e.g. Vuollo, 1994; Amelin et al., 1995; Vuollo and Huhma, 2005). An extensive geochronology and geochemistry campaign summarized in Vuollo and Huhma (2005) provided an improved understanding of these Paleoproterozoic mafic dykes (Fig. 1). Dykes can be divided into at least five main groups with approximate ages of 2.45 Ga, 2.32 Ga, 2.2 Ga, 2.1 Ga, and 1.98 Ga (e.g. Vuollo and Huhma, 2005). Subsequent U–Pb dating identified additionally 2.5 Ga dykes in the Vodlozero terrane of the Karelia province in northwestern Russia (Bleeker et al., 2008). A significant sign of the break-up event on a possible Neoarchaen supercraton is the existence of generally NNW-trending 1.98 Ga tholeiitic and Fe-tholeiitic dykes intersecting Archean northern Karelia and Paleoproterozoic Central Lapland. Later, juvenile continental crust was formed in the present southwestern Fennoscandia during the Svecofennian orogeny at 1.92–1.77 Ga (Gaàl and Gorbatschev, 1987; Gorbatschev and Bogdanova, 1993; Lahtinen et al., 2005; Korja et al., 2006). The Archean core and the Paleoproterozoic units of the Karelia Province were for the most part deformed and metamorphosed during this orogeny.

Tens of Paleoproterozoic diabase dykes were sampled from the Taivalkoski area in the Karelia Province in Finland (Fig. 1) but only two of them (WD and AD13) provided possible primary magnetization directions. Host rocks to the dykes are mainly Archean migmatitic tonalite-trondhjemite-granodiorite (TTG) gneisses and these were sampled in several sites for baked contact tests (Everitt and Clegg, 1962). Samples for paleomagnetic study were taken as block and core samples and oriented using magnetic and/or sun compasses. A block sample for geochronology was taken from dyke AD13.

2.2. Paleomagnetic measurements

Paleomagnetic measurements were carried out at the University of Toronto, Canada (UT); at the Solid Earth Geophysics Laboratory of the University of Helsinki, Finland (UH); and at the Paleomagnetic laboratory of the Geological Survey of Finland, Espoo (GTK). Stepwise alternating field (AF) demagnetizations were done using single-axis demagnetizer with maximum field up to 160 mT, coupled with 2G–DC (UH) or 2G-RF (GTK) SQUID magnetometer, AGICO–LDA–3 AF demagnetizer with maximum field up to 100 mT (UH) and Schonstedt SD-1 demagnetizer up to 100 mT (UT and GTK). Stepwise thermal demagnetization was performed using Schonstedt TSD-1 or homemade furnaces (GTK, UH and UT. To isolate different remanence components, standard multicomponent analyzing methods, principal component analysis (Kirschvink, 1980; Leino, 1991), and the intersecting great circle-technique with end-point analysis (Halls, 1976, 1978) were applied to the data. Mean remanence directions and pole positions were calculated using Fisher (1953) statistics. The paleogeographical reconstructions were plotted with the GMAP program (Torsvik and Smethurst, 1999).

The nature of the magnetic carriers was studied by thermomagnetic analysis of selected specimens using the Agico's CS3-KLY-3S Kappabridge system (UH), which measures the bulk susceptibility (k) of the samples during heating up to 700 °C and cooling back to room temperature (in Argon Gas). Curie temperatures were determined using the Cureval 8.0 – program (www.agico.com).

2.3. Geochronology

The sample from the diabase dyke AD13 contains both coarse and fine-grained portions. It was considered whether the coarser material could be xenolithic, and hence being older material picked