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Paleomagnetic and rock magnetic study of the Mesoproterozoic sill, Valaam island, Russian Karelia

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Abstract

A paleomagnetic study of the Mesoproterozoic Valaam monzodioritic sill (U-Pb age ∼1458 Ma) was undertaken in an attempt to provide a new well dated paleomagnetic pole for Baltica and to test the proposed joint drift history of Baltica and Laurentia from 1.83 to ca. 1.26 Ga. Two components of natural remanent magnetization (NRM) were isolated in the sill with alternating field and thermal treatments. The first component is a low coercivity component of viscous origin with a direction similar to that of the Earth's present field at the sampling site. The second one (component **A**) with a high unblocking temperature/coercivity has a remanent magnetization direction of $D = 43.4^\circ$, $I = -14.3^\circ$, $\alpha_{95} = 3.3^\circ$, corresponding to a paleomagnetic pole of Plat. = 13.8°, Plong. = 166.4°, $A_{95} = 2.4^\circ$.

Rock magnetic and scanning electron microscopy (SEM) studies revealed that the main carrier of the magnetization **A** is medium sized primary titanomagnetite, with varying Ti-content. This component is interpreted to be of primary origin and it provides a new well dated (1458 +4/−3 Ma) pole for Baltica. This result supports the idea that Baltica and Laurentia drifted together during the interval from 1.76 to 1.26 Ga forming the core of the supercontinent Hudsonland (Columbia, Nuna).

Keywords: Paleomagnetism; Petrophysics; Apparent polar wander path; Baltica; Supercontinents; Hudsonland; Columbia; Mesoproterozoic

1. Introduction

The Fennoscandian Shield can be divided into a number of tectonomagmatic blocks, where the oldest parts are in the northeast. Since Archaean times the amalgamation of the once separated blocks has played an important role when the Fennoscandian shield was formed. The amalgamation took place during successive orogenic events, such as the Lopian (2.9–2.6 Ga), the Svecofennian (2.0–1.75 Ga) and the Gothian (1.75–1.55 Ga), respectively. After its final formation during subsequent accretional events, the continental crust of Fennoscandia underwent major reworking during the Sveconorwegian–Grenvillian (ca. 1.2–0.9 Ga) and Caledonian orogenies (ca.0.5–0.4 Ga) ago (Gorbatschev and Bogdanova, 1993).

In the past, both continents (e.g. Baltica) and shields (e.g. Fennoscandia) have comprised various supercontinents. The amalgamation of ancient continents into supercontinents and the following break-up of them have had major impacts on geology and environment: diversification of life, unique Paleo- to Mesoproterozoic climatic conditions including several glaciations, global changes in ocean chemistry, and long-lived mantle convection patterns giving rise to plumes and large igneous provinces (e.g. Condie, 2000, 2004; Dalziel, 1994; Karlström et al., 2001; Meert, 2002; Pesonen

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et al., 2003; Rogers and Santosh, 2002; Zhao et al., 2003, 2004 and references therein). There are geological and paleomagnetic evidences that since the Mesoproterozoic three supercontinent assemblies (Rodinia ca. 1050–750 Ma, Gondwana ca. 550–400 Ma and Pangea ca. 350–165 Ma) have existed (Pesonen et al., 2003 and references therein). Evidences for the pre-Rodinia supercontinents have become more controversial as the age of the geological formations increase, due to paucity of paleomagnetic data and inherent dating problems. However, most cratonic blocks show evidences of either collisional or accretional events between 2.1 and 1.8 Ga, which has led many researchers to propose that a Mesoproterozoic supercontinent Hudsonland (also known as Columbia or Nuna) did exist in the Early Proterozoic (e.g. Condie, 2004; Meert, 2002; Pesonen et al., 2003; Rogers and Santosh, 2002; Zhao et al., 2003, 2004 and references therein). The temporal and compositional overlap between the anorogenic magmatisms in west Baltica and in east Laurentia support the model of a Mesoproterozoic supercontinent, which included Baltica and Laurentia (e.g. Åhäll and Connelly, 1998). These anorogenic events in both continents took place during the time interval of 1.7–1.3 Ga. Moreover, the 1.6–1.5 Ga is a period of tectonic stability that reflects cratonization of the newly formed lithosphere (Karlström et al., 2001). During the periods 1.7–1.6 and 1.55–1.35 Ga intracratonic bimodal a-type magmatism took place; these involved granites and associated anorthosites and related accretional tectonism (e.g. Karlström et al., 2001; Åhäll and Connelly, 1998).

Several variations of supercontinent Hudsonland have been presented, which differ from Rodinia. For example, Pesonen et al. (2003) have suggested that Laurentia and Baltica were connected for ca. 600 Ma (from 1.83 to 1.27 Ga) forming, together with Amazonia and perhaps with some other continents, like Australia, the core of the supercontinent Hudsonland. Several other authors have suggested a variety of configurations and lifecycles of this supercontinent (e.g. Karlström et al., 2001; Meert, 2002; Zhao et al., 2004 and references therein).

In order to shed light into the assembly and life time of Hudsonland we have carried out a paleomagnetic study on Valaam monzodioritic sill in the eastern part of the Fennoscandian Shield, Russian Karelia. The opportunity is excellent since the U-Pb dating of the Valaam sill yield ages of 1459 ± 3 and 1457 ± 2 Ma (Rämö et al., 2001, 2005), which are nearly coeval with St. Francois Mountain (Mnt) intrusion (1476 ± 16 Ma), Michicamau intrusion (1460 ± 5 Ma), Harp Lake Complex (1450 ± 5 Ma) and the Belt Supergroup formations (1400–1470 Ma) in Laurentia.

This compatibility provides a unique case for testing the proposed long lasting (1.8–1.2 Ga) unity of Baltica and Laurentia.

The Valaam sill provides important material for a paleomagnetic study for two reasons. Firstly, its magnetization is stable, which was by a preliminary study by Pesonen (1998) and appears to be distinct of Jotnian diabases (1.26 Ga) and Subjotnian units (1.67–1.5 Ga). Secondly, there is a lack of well dated poles between 1.6 and 1.3 Ga for Baltica (Buchan et al., 2000; Pesonen et al., 2003). However, there are two problems concerning the paleomagnetic study of the Valaam sill. First the sill is in the middle of the Lake Ladoga forming an island (Valaam) with no other older (or younger) rocks to carry out baked contact test. Second, the sill is uniformly almost horizontal (dip ca. 0.2°) ruling out the fold test possibility to prove the primary nature for natural remanent magnetization. These problems can be partially overcome by comparing the Valaam results with those from somewhat older rocks in the north of Lake Ladoga (Sortavala-Jänisjärvi area), or with known Neoproterozoic to Phanerozoic overprints (Lubnina et al., 2005; Mertanen, 2005; Salminen et al., 2006; Shcherbakova et al., 2006). The rock magnetic and scanning electron microscope (SEM) studies are also used to give further support for the primary origin of the characteristic remanent magnetization (ChRM) in Valaam sill.

2. Geological background and the sampling

Valaam island is located in the middle of the Lake Ladoga, which belongs to Russian Karelia (Fig. 1). The northeastern part of the Fennoscandian Shield is composed of Archaean rocks, which extend to ca. 100 km north from Lake Ladoga. The central part of the Shield is composed of Paleoproterozoic rocks (Gorbatschev and Bogdanova, 1993; Vaasjoki et al., 2005). The Svecofennian orogeny (ca. 1.9–1.8 Ga ago) was the main modifier of the Archaean and Early Proterozoic crust of Fennoscandian shield. The latest major crustal increment of the Shield was the emplacement of mid-Proterozoic (ca. 1.67–1.54 Ga) rapakivi granites and associate mafic bodies and tholeiitic dyke swarms (Rämö et al., 2001, 2005). In Karelia such rocks outcrop along northeast and east coast of Lake Ladoga and in the Valaam island. Three phases of magmatic activity are distinguished in the north Ladoga region. During the first two phases, basaltic lavas were erupted. In the third phase, the monzodioritic Valaam sill, which includes syenitic dikes, intruded. Its estimated thickness is 130–150 m (Amantov et al., 1996). The U-Pb baddeleyite ages of 1459 ± 3 and 1457 ± 2 Ma for Valaam sill indicate that, at least