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The Vehmaa rapakivi granite batholith – an assemblage of successive intrusions indicating a piston-type collapsing centre

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Short Communication

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1. Introduction

The 700 km^2 Vehmaa rapakivi granite batholith is located in south-western Finland. It has a concentric structure and is composed of intrusions of five granite varieties (we use the terminology of the rock names according to the published geological map sheet, Lindberg & Bergman, 1993): pyterlite, coarse-grained porphyritic rapakivi granite, medium-grained porphyritic rapakivi granite, even-grained rapakivi granite, and porphyry aplite (Fig. 1). The granite types yield a concordant monazite U-Pb age of 1573 ± 8 Ma (even-grained granite of satellite intrusion) and a zircon U-Pb age of 1582 ± 4 Ma (pyterlite) (Lindberg & Bergman 1993). The batholith is surrounded by mica schists, hornblende gneisses, and quartz-feldspar gneisses, as well as syn-collisional tonalites and late-collisional K-rich granites and migmatites (Ehlers et al., 1993; Selonen & Ehlers, 1998; Väisänen & Hölttä, 1999).

In this short communication we discuss the structure and emplacement of the main Vehmaa rapakivi granite batholith as an assemblage of successive pulses of intrusions. The medium-grained porphyritic granite in the centre of the batholith is described in more detail than the other granite types. By careful mapping and by studying geophysical data, two successive intrusion pulses of almost identical types of the medium-grained granite, in contact with each other, have been defined. The two intrusive phases have not previously been described. We think that the mode of intrusion of these granites is important for the understanding the emplacement of the whole batholith, and suggests a more generally applicable model for other intrusions of rapakivi granite in Finland.

Recently, Haapala & Lukkari (2005) discussed the evolution of the small, zoned Kymi stock within the Wiborg rapakivi batholith, where both the scale of the intrusion, and the suite of rocks suggested an alternative mode of formation and intrusion. A closer examination of the geochemistry and petrology of the Vehmaa batholith will follow in the near future and is not included in this short note.

2. The Vehmaa rapakivi granite batholith

The main granite type in the Vehmaa rapakivi granite batholith is *pyterlite* with a typical rapakivi texture

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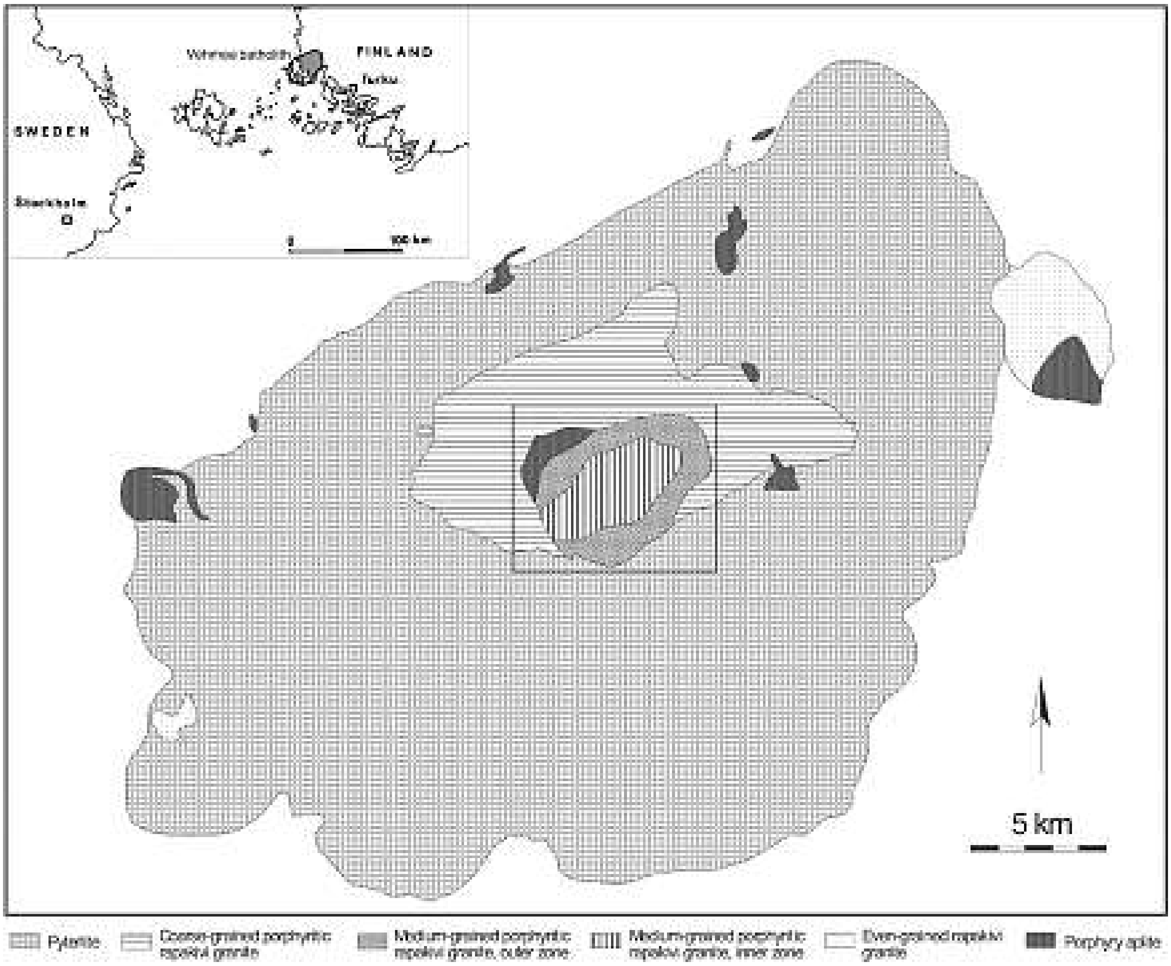

Fig 1. Geological map of the Vehmaa rapakivi granite batholith. Modified from Lindberg & Bergman (1993). Location of Fig. 5 is marked with a rectangle.

comprising potassium feldspar ovoids (2–5 cm in diameter), occasionally with plagioclase rims. The colour of the pyterlite varies from red to brown with greenish varieties. It is a hornblende rapakivi granite, composed of potassium feldspar, quartz, plagioclase, biotite, and hornblende (Lindberg & Bergman, 1993). Fluorite, apatite, zircon, and olivine are found as accessories. Composite pegmatite and aplite dykes (a few centimetres to half a metre wide) with quartz veins occur, as well as felsic and mafic igneous enclaves, and supracrustal xenoliths.

The *coarse-grained porphyritic granite* is characterized by large, mostly euhedral, potassium feldspar phenocrysts, 2–3 cm in length with occasional ovoids. The principal minerals are potassium feldspar, quartz, plagioclase, and biotite, whereas chlorite, fluorite, apatite, zircon, and opaques are accessories (Lindberg & Bergman, 1993). The granite is pale red to red with an occasional greenish tint; occasionally it is transected by aplite dykes.

A *medium-grained porphyritic granite* is exposed in the centre of the Vehmaa batholith. The porphyritic texture of the granite is defined by potassium feldspar phenocrysts (≤ 2 cm in length). It is a biotite rapakivi essentially consisting of potassium feldspar, quartz, plagioclase, and biotite with accessory chlorite, fluorite, apatite, zircon, muscovite and opaques (Lindberg & Bergman, 1993). A few potassium feld-

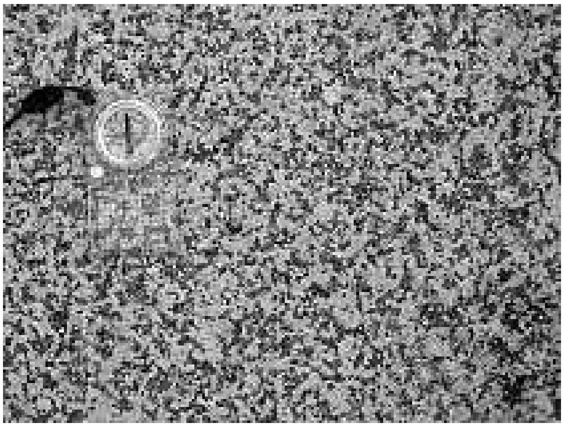

Fig 2. The medium-grained porphyritic granite of the outer zone. The texture is characterized by clusters of potassium feldspar phenocrysts. North-eastern part of the granite body.

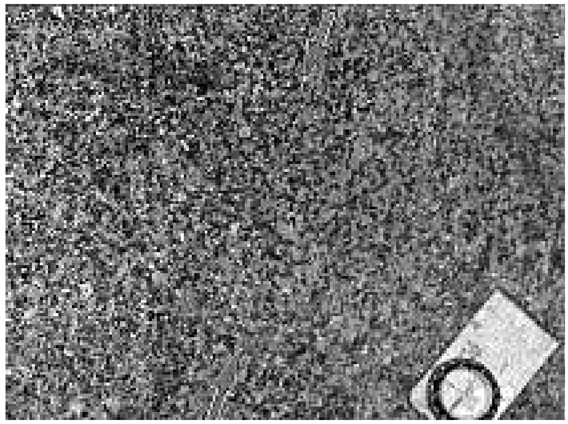

Fig 4. Contact between the medium-grained porphyritic granites of the outer and inner zones on outcrop. The contact is indicated with arrows. The granite of the inner zone is on the left of the contact. North-eastern part of the granite body.

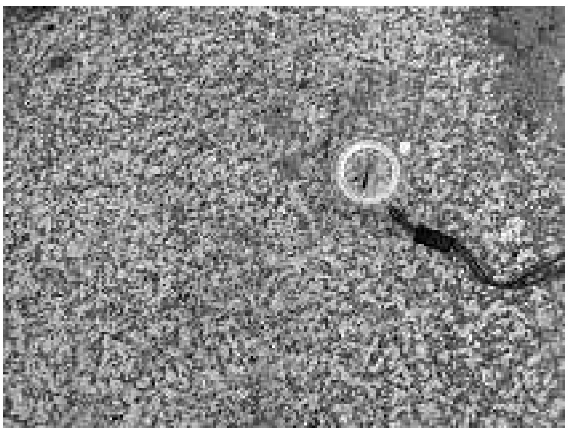

Fig 3. The medium-grained porphyritic granite of the inner zone. The texture is characterized by dispersed euhedral potassium feldspar phenocrysts. South-eastern part of the granite body.

spar ovoids occur. Rounded or lens-shaped aplitic felsic inclusions (< 50 cm in mean diameter) and occasional small mafic enclaves occur in the granite. Mafic layer-like schlieren rich in biotite are found at the southern and south-eastern margin of the granite body. They strike NE and are subhorizontal or dip gently ca 40–50° outwards.

The eastern contact against the porphyry aplite and the coarse-grained porphyritic granite dips ca 60° outwards. At its northern contact the medium-grained porphyritic granite cuts the porphyry aplite and the coarse-grained porphyritic granite (see also Lindberg & Bergman, 1993).

The medium-grained porphyritic granite is actually composed of two distinct but very similar zones of granite, defined on outcrops and by geophysical data as an *inner zone* and an *outer zone*, separated by a visible contact. In the granite of the *outer zone* the potassium feldspar phenocrysts occur as clusters in a net-like texture, with only a few separate euhedral crystals (Fig. 2). No preferred orientation of the phenocrysts has been observed in the outer granite and single potassium feldspar phenocrysts are seldom found in the matrix. In the *inner zone* of granite the potassium feldspars occur as separate euhedral grains (Fig. 3), also found dispersed throughout the matrix. Magmatic flow-structures and miarolitic cavities are in places visible in the inner zone. The contacts between the outer and the inner granite zones are sinuous and difficult to observe (Fig. 4), which is partly due to their generally gentle dip, and partly because the rocks are visually almost identical. On the magnetic map, the two granites are clearly distinguished (Fig. 5), obviously due to a difference in magnetite content.

A satellite intrusion, located in the eastern margin of the Vehmaa batholith is composed of *even-grained granite*. The red granite is a biotite granite with potassium feldspar, quartz, plagioclase, and biotite as

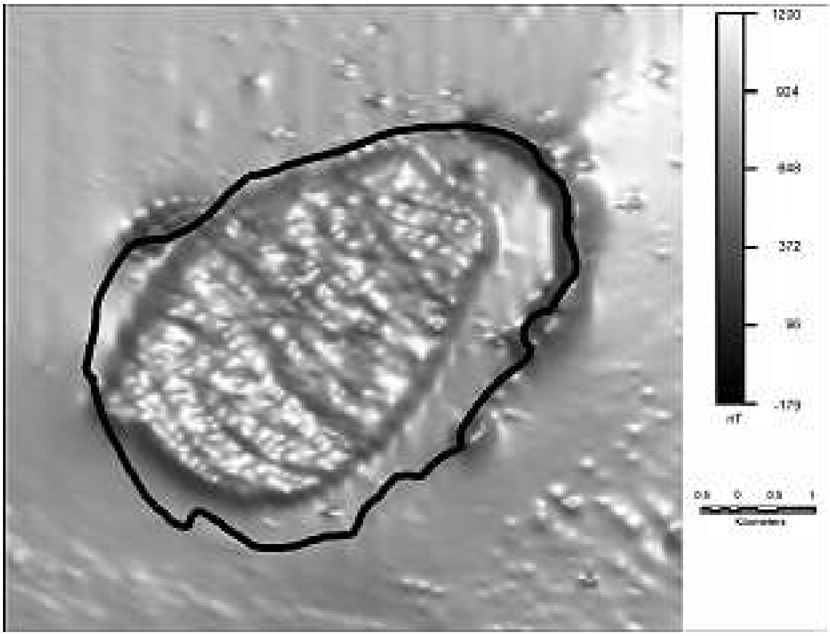

Fig 5. Grey scale aeromagnetic total intensity map showing the area of the two medium-grained porphyritic granites. The outer contact against the coarse-grained porphyritic granite is indicated with a black line. Magnetic map shading is from the northeast at 60° elevation angle. For location see Fig. 1. GTK data, Jouni Lerssi.

the main constitutes (Lindberg & Bergman, 1993). Miarolitic cavities, aplitic dykes and patches, red-coloured joints, and greisen-like veins occur.

The *porphyry aplite* typically occurs at the margins of different rapakivi types or at the margins of the batholith (Shebanov et al., 2000). It is a fine to medium-grained rock with sporadic unmantled ovoids and feldspar phenocrysts. The colour is typically grey or red.

3. Discussion

The contacts of the Vehmaa rapakivi granite batholith against the surrounding older Svecofennian rocks dip gently to moderately (20°–70°) away from the batholith (Kanerva, 1928). We have observed that the eastern contact of the medium-grained porphyritic granite dips ca 60° outwards and that the mafic layer-like schlieren in the S and SE parts of the granite are flat-lying or dip ca 40–50° outwards. Furthermore, the sinuous contact between the inner and the outer zones of the medium-grained porphyritic granite suggest a gently outward dipping contact. The geophysical data support the field observations and correspond to the observed geological contacts. Altogether, these facts indicate an assemblage of roughly concentric successive intrusions of gently dipping granite sheets, together building up the rapakivi batholith.

The medium-grained porphyritic granite occurs as two distinct intrusions in the centre of the batholith, forming almost a concentric pattern. Based on field relations the structure of the batholith indicates a normal zoning with the older magmatic phases at the margins and the younger ones in the centre. The porphyry aplites have intruded mostly as minor bodies and seem to be confined to contacts. The satellite intrusion at the eastern margin of the batholith occurs as a separate intrusion of even-grained granite.

The relative ages for the intrusions from the oldest to the youngest are: pyterlite, coarse-grained porphyritic granite, and the medium-grained porphyritic granite (Lindberg & Bergman, 1993). The even-grained granite of the satellite intrusion is younger than the pyterlite. Our observations indicate that the medium-grained porphyritic granites in the centre cut both the porphyry aplite and the coarse-grained porphyritic granite in the northern parts of the batholith.

It is suggested that the Vehmaa batholith was emplaced in two stages (Lindberg & Bergman, 1993).

The pyterlite and the subsequent coarse-grained porphyritic granite intruded in the first stage, whereas the second stage comprises the medium-grained porphyritic granite followed by the satellitic even-grained granite. The porphyry aplites in the pyterlite are the last intrusions of the first phase, whereas the porphyry aplite in contact with the coarse-grained porphyritic granite and medium-grained porphyritic granite began the second phase of intrusion. The U-Pb zircon and monazite ages overlap, but generally agree with the geological observations regarding the sequence of intrusions (Lindberg & Bergman, 1993).

Glazner et al. (2004) show examples of how large, seemingly homogeneous plutons can be formed by amalgamation of numerous smaller intrusions through time. The growth of a pluton proceeds with intrusion of individual increments of subhorizontal or subvertical sheets. The gently dipping intrusive contact between the two medium-grained porphyritic granites of the Vehmaa batholith indicates that they are distinct magmatic phases even if they are petrologically almost similar in composition. The concentric occurrence of the two zones suggest that the inner phase is younger than the outer phase, and indicate a build up of the batholith by successive additions of smaller intrusions. If the amalgamated smaller intrusions are petrologically and chemically similar to the previous pulses, and if the contacts (in the prevailing flat topography) are gently dipping, this mode of formation can be effectively camouflaged and overlooked.

The general lack of observed feeder dykes to the successive intrusions of rapakivi granite could be explained with a model of an intrusion with a plate or piston-type collapsing centre (Cole et al., 2005). This mechanism implies the progressive subsidence of blocks of older gneisses and successive repeated pulses of granite intrusion. The subsidence of gneiss blocks and subhorizontal sheet intrusions of rapakivi granites could have been partly controlled by the gently dipping schistosity in the surrounding supracrustal Svecofennian gneisses. A tentative model for intrusion of the Vehmaa granite batholith is presented in Fig. 6.

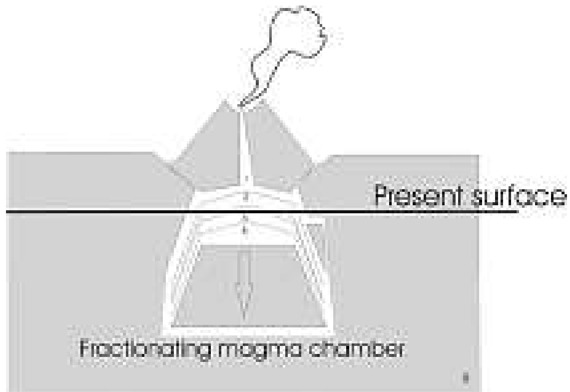

Fig 6. A sketch model for intrusion mechanism of the Vehmaa rapakivi granite batholith. Successive pulses of fractionated magma intrude in connection with the development of a collapse caldera, forming subhorizontal sheets of subvolcanic magma with steeper margins. The shape and dimensions of the magma chamber and collapsing blocks are hypothetical. The magma pulses are younging upwards.

A similar mode of intrusion has been described earlier for the small Fjälskär rapakivi granite in SW Finland, where conspicuous gently outward dipping ring dykes forms an umbrella-like pattern around the rounded stock (Ehlers & Bergman, 1984). A lack of brecciated contacts and often steeply to moderately dipping outer contacts coupled with subhorizontal multiple intrusions in the central parts of many rapakivi batholiths also support this type of intrusion mechanism. The presence of superficial volcanic varieties of rapakivi rocks along the fringes of, e.g. the Åland and Wiborg batholiths (Sederholm, 1890; Bergman, 1986; Eklund et.al.,1996), and their general character of multiple overlapping intrusion complexes, together suggest an emplacement mechanism related to the formation of syn-intrusional volcanic calderas, eroded today to expose their subvolcanic batholiths.

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