The norito-granitic zone of Puntervoll-Lia (Rogaland anorthosite province, S. Norway): evolution of a genetic model (http://hdl.handle.net/2268/249881)

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Abstract

The norito-granitic zone is a thin septum of highly deformed banded rocks squeezed between two anorthosite massifs, the Egersund-Ogna (EGOG) and the Håland massifs. The dominant lithologies are a norito-anorthosite association gradationally passing into a norito-granitic association. A first genetic model was proposed in which a norite intruded in the foliated margin of the EGOG anorthosite was migmatitized and metasomatically transformed into an anorthosite. This model was not confirmed by later studies and finally the norito-anorthosite association was considered as a particular facies of the anorthosite margin. New studies of the Glypstad septum between EGOG and the Bjerkreim-Sokndal layered intrusion reveal that the norito-granitic association results from the deformation of a magma in which anatectic melts were mingled with a high-alumina basalt, parental to the EGOG anorthosite.

Keywords

Anorthosite, contact metamorphism, ultra-high temperature, parental magma, mingling process, anatexis

Introduction

In the Rogaland anorthosite province, a complex series of banded gneisses separates the Egersund-Ogna (EGOG) and the Håland anorthosite massifs (Fig. 1). It has been named the Norito-Granitic Zone by Paul Michot.

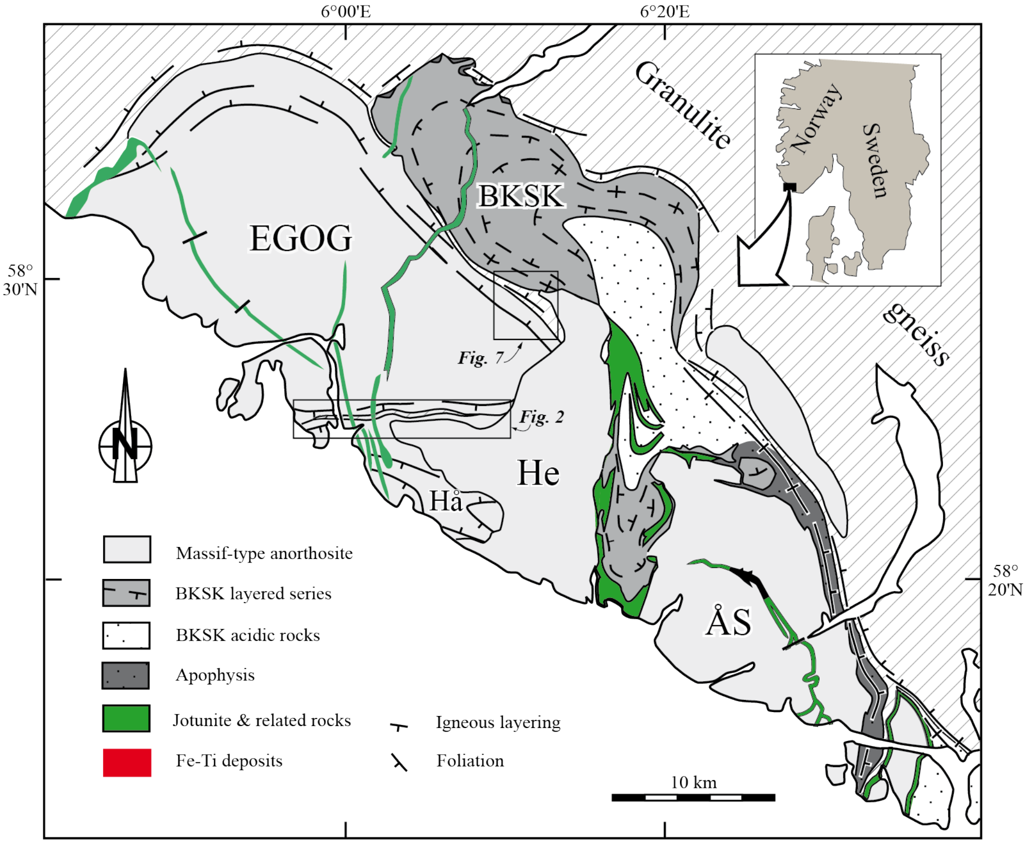

Fig. 1: Geological map of the Rogaland anorthosite province (after Michot and Michot, 1969). Abbrev. : EGOG : Egersund-Ogna anorthosite ; Hå : Håland anorthosite ; He : Helleren anorthosite ; ÅS : Åna-Sira anorthosite ; BKSK : Bjerkrem-Sokndal layered intrusion.

When Paul Michot arrived at Egersund in 1937, on his first day of field work, he met a sailor who invited him to visit some occurrences of Fe-Ti ores at a walking distance south of the town. Both walked along the lane to Puntervoll and Hegdal (Fig. 2) in the Egersund anorthosite when they came across quartz-bearing gneisses. Michot was very intrigued (Michot, pers. comm.) because on the available geological maps of Kolderup (1896, 1914) such rocks were not mentioned. This observation was the starting point of his work in Rogaland. He soon discovered that these quartz-bearing gneisses were associated with noritic rocks to form a norito-granitic banded series parallel to and in contact with the foliated hypersthene-bearing margin of the EGOG anorthosite (Michot, 1939b, a). Ilmenite deposits were closely associated with this series (Michot, 1939c).

After the 2nd world war, Michot returned to Egersund and made a detailed field work and petrographic study of the area that emerged in a short and synthetic paper (Michot, 1955). A geological map of this norito-granitic zone was sketched (Fig. 3) and published not by him but by one of his student (Hubaux, 1960).

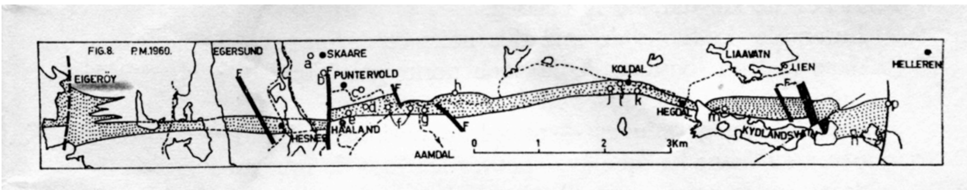

Fig. 2: The norito granitic zone of Puntervoll-Lia from Eigerøy to the Kydlandsvatn (after Fig. 8 in Michot, 1960).

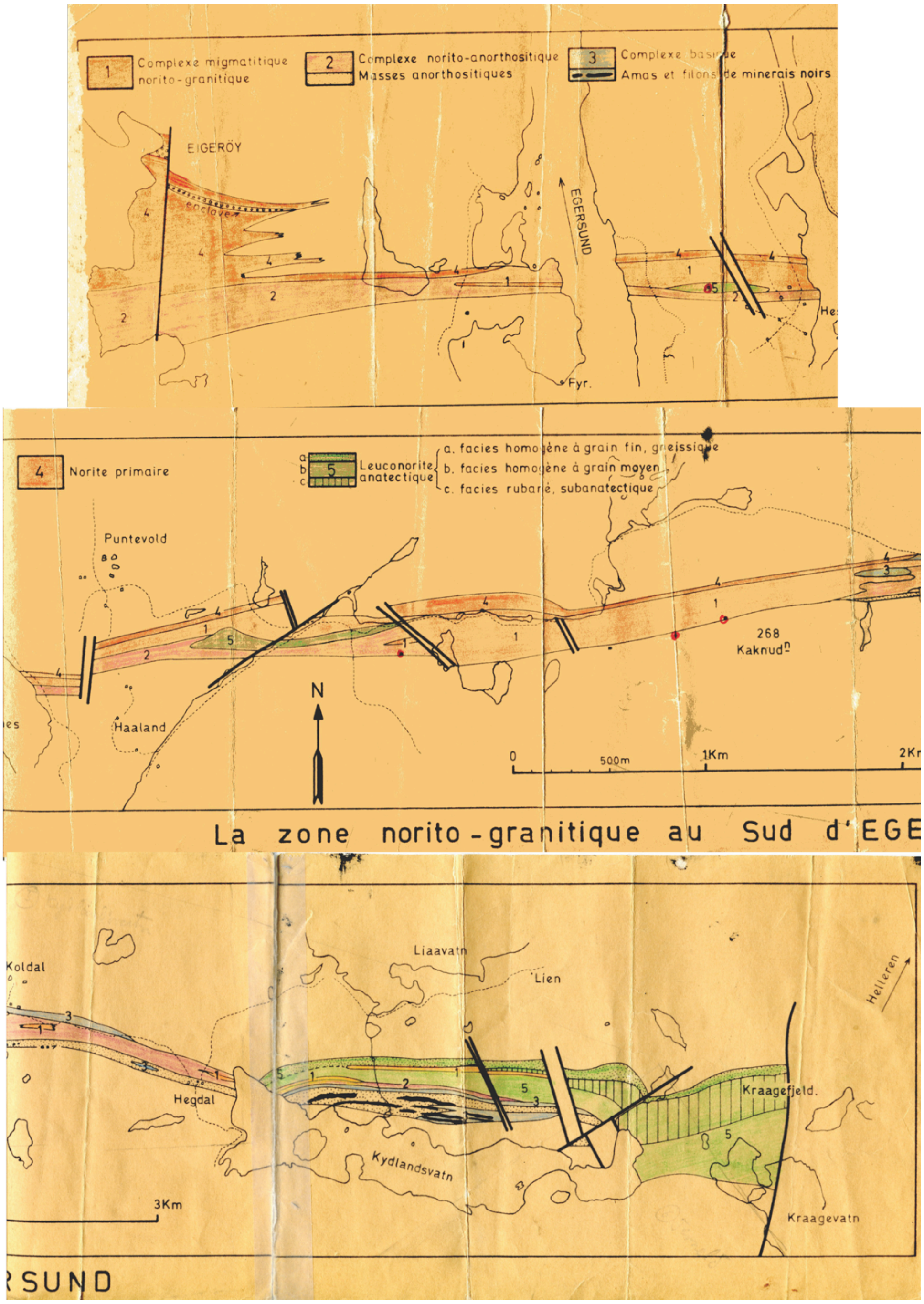

Fig. 3: Geological sketch map of the norito-granitic zone drawn by Michot (unpublished).

The norito-granitic zone of Puntervoll-Lia

This series of banded rocks extends on c. 15 km from the sea coast to the Kydlandsvatn and is 200-250 m thick (Figs. 2 and 3). It outcrops along the contact between the EGOG and the Håland anorthosite massifs. As summarized in Michot and Michot (1969), the banded gneisses are made up of beds or strips (Fig. 4) with lithologies varying from "unaltered to scarcely contaminated norite and leuconorite to granite, with all intermediary stages (quartz-bearing norite and leuconorite, tonalite, granodiorites, adamellites, mangerites). They also contain quartz-rich and hypersthenic layers, beds and masses of black ores. These different rocks are associated in four well-defined kinds of assemblages whose structure is always clearly oriented:

a. the noritic association that is made up of norite/leuconorite locally layered with the formation of lenticular aggregates of plagioclase surrounded by a border of large hypersthene grains;
b. the norito-anorthositic association that includes norites and leuconorites similar to the noritic association plus anorthosite layers (and accessory plagioclase-pyroxene granofels);
c. the norito-granitic association that contains a series of rocks varying from a noritic and leuconoritic types (again identical with association a) to leucogranite;
d. the mafic association that consists of several types of norites and leuconorites plus plagioclase-pyroxenite granofels, hypersthenites and ilmenitites".

As shown in Fig. 3, these rock associations vary in space. Close to the sea coast, the norito-anorthositic association dominates, then passes, further east, to the norito-granitic association up to Koldal to return to the norito-anorthosite association from Koldal to the Kydlandsvatn where anorthosites and various types of leuconorites are interleaved with layers of ilmenitites. The noritic association, also called the "primary norite", extends at the contact with the EGOG foliated margin from the sea coast to Koldal.

As noted by Michot (1939b) the rocks are banded and highly strained and deformed namely by asymmetrical microfolds (small scale isoclinal folding). The bands or strips show thicknesses varying from less than 1 cm to several dm (Fig. 4). Another very important observation is the transition within a single band at the m-scale from an anorthosite layer to a granite layer by progressive lateral increase of quartz and K-feldspar (Michot, 1955, 1960, p. 43).

Fig. 4: The norito-granitic association (close to Koldal). a: The quartzo-feldspathic bands with cm to dm thicknesses are brought out by erosion in contrast with the noritic bands that form hollows. The bands appear intensely deformed and stretched along the foliation plane. A late granitic dyke cuts across the structure. b: Very fined grained strips of granitoid material in norites. Another cross-cutting dyke is exposed.

The metasomatic model

In a first interpretation of this zone, Michot (1939b) suggested a mixing process between a noritic and a granitic magma but, later (Michot, 1955), influenced by the theory of metasomatism which was popular at the time (see e.g. Barth, 1962 for a review), Michot considered that a noritic intrusion was migmatitized and metasomatically invaded by K and Si in the solid state. This supply of chemical elements determined the formation of the granite bands in the norite with the removal along the deformation plane of the ferromagnesian elements of the norite to leave behind an anorthosite residue. The norito-anorthosite association was thus the transformation of the norito-granitic association with the development of metasomatic anorthosites and, further on, of a front in which the mafic minerals/elements were concentrated (Michot, 1955, 1956) (Fig. 5).

This model for the origin of the Fe-Ti oxide ores was adopted by (Michot, 1956; Hubaux, 1960) but indirectly challenged by Duchesne (1969, 1973) who noted that the ore bodies were concentrated in the Håland anorthosite massif at the limit with the norito-granitic zone and, most importantly, had compositions similar to ore bodies within the Helleren massif (e.g. Jerneld deposit) or within the Åna-Sira massif (e.g. Storgangen deposit) (see also Duchesne, 1999; Duchesne and Schiellerup, 2001).

The Lakkssevelefjeld-Koldal intrusion

Michot (1957) extended the norito-granitic zone to the Laksseveleflell-Koldal intrusion, a noritic intrusion between the EGOG anorthosite and its northern envelope of gneiss, and between the Bjerkreim-Sokndal (BKSK) layered intrusion (Fig. 1). According to Michot (1960, 1969), this norite was affected by the same migmatitization process as the norito-granitic zone.

In their survey of the EGOG massif (Maquil and Duchesne, 1984) did not confirm the occurrence of a continuous norite intrusion at the northern margin of EGOG but corroborated the development of a septum of migmatitic gneisses between the BKSK intrusion and the EGOG massif.

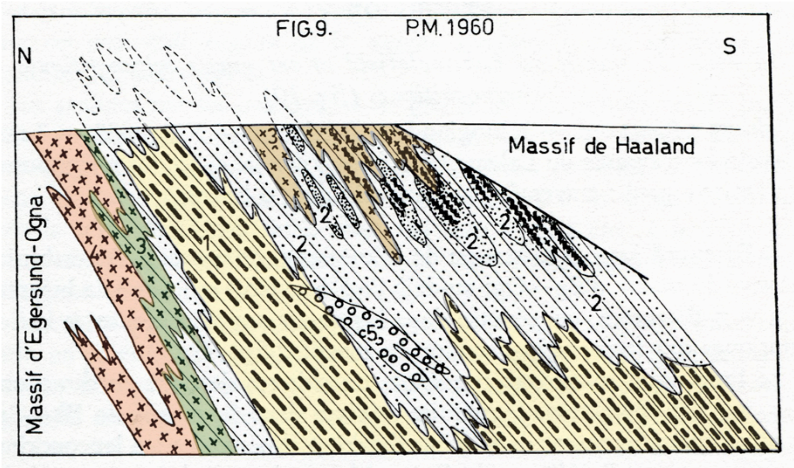

Fig. 5: Schematic cross-section in the norito-granitic zone. 1: norito-granitic complex; 2: norito-anorthositic complex (anorthositisation zone); 2': anorthosite lenses; 3: basic complex (calco-ferromagnesian front); 4: norite and leuconorite (primary rock); 5: anatectic leuconorite formed with the norito-anorthosite complex by homogenisation of the latter; zig-zag lines: ilmenitite seams (after Fig. 9 in Michot, 1960).

The norito-anorthosite facies

Detailed field work on the western part of the norito-granitic zone on Eigerøy revealed that the mafic intrusion, considered by Michot as the "primary norite" (Fig. 3) was in fact a layered intrusion the Loyning intrusion cross-cutting the foliated margin of the EGOG anorthosite massif (Vander Auwera et al., 2006), and that the latter massif was in direct contact with the Håland massif, without insertion of a noritic component. It thus came possible to offer a new interpretation for the norito-anorthosite association. From the detailed survey of the EGOG massif (Duchesne et al., 1985) the concept of a diapiric emplacement progressively emerged. A plagioclase crystal mush containing high-alumina orthopyroxene megacrysts (HAOM), crystallized in a deep seated magma chamber (Emslie, 1975, 1991), has diapirically risen, lubricated by interstitial liquid, up to the final level of emplacement to form the central part of the massif and this movement has deformed the margin of the intrusion. The concept of a diapiric emplacement with a synemplacement deformation developed by Martignole and Schrijver (1970) was thus applied to the EGOG massif (Duchesne and Maquil, 1981; Maquil and Duchesne, 1984; Duchesne et al., 1985; Duchesne et al., 1987; Barnichon et al., 1999; Duchesne et al., 2008; Charlier et al., 2010). In this model the formation of the norito-anorthosite association can thus result from simple mixing between the anorthosite mush and a leuconoritic or noritic melt in a highly strained zone. This is the reason why the norito-anorthosite association is now considered as a particular facies of the EGOG massif in Fig. 6 (Marker et al., 2003; Duchesne and Liégeois, 2015). Finally, the geological map of Marker et al. (2003) portrays the norito-granitic association as banded gneisses in the Puntervoll-Lia area and in the septum at the margin with the BKSK intrusion.

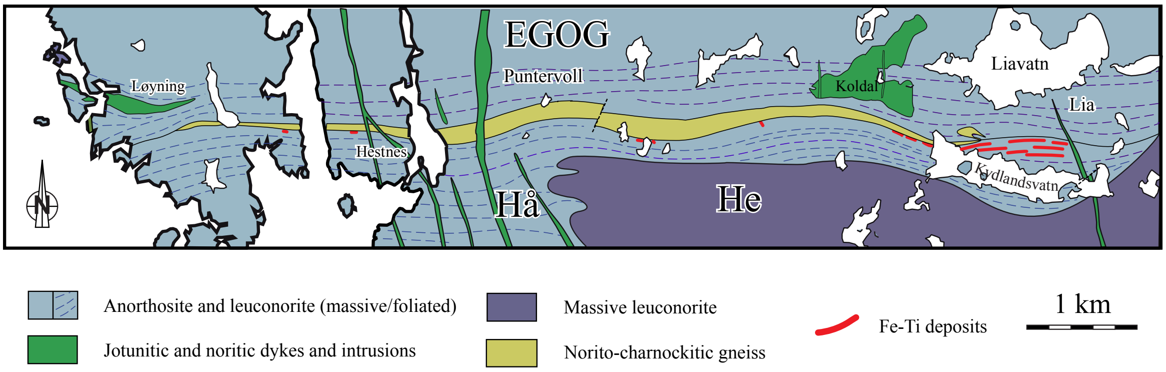

Fig. 6: Geological sketch map of the Norito-granitic (charnockitic) Zone (after Duchesne and Liégeois, 2015).

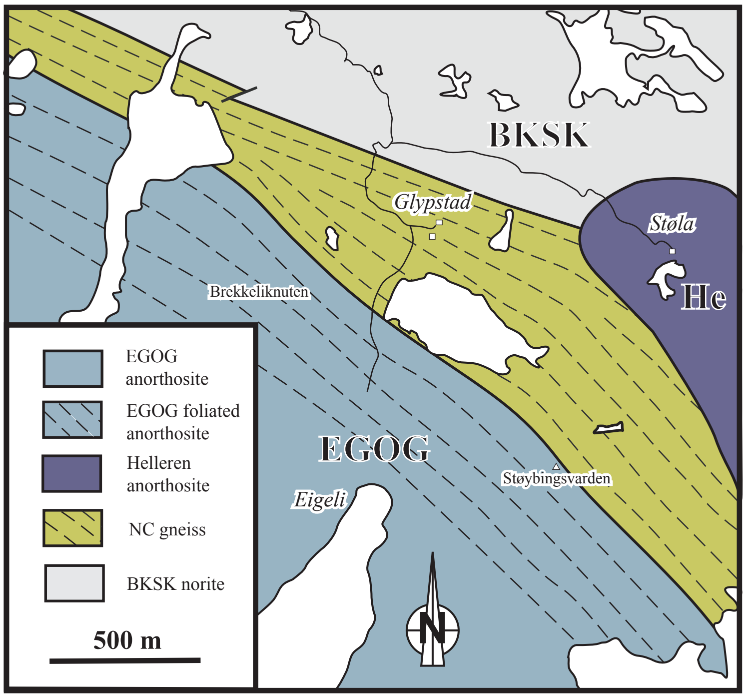

Fig. 7: Geological sketch map of the septum between the EGOG and BKSK intrusions in the Glypstad area (after Duchesne, 2020).

A new model

New field, petrographic and geochemical studies in the septum between EGOG and BKSK close to Glypstad (Duchesne, 2020) (Fig. 7) show that the norito-granitic association has strong resemblance with the banded gneisses that are a major component of the country/wall rocks of the Rogaland anorthosite province. They are particularly similar to banded gneisses in the Farsund shear zone that outcrop along the southeastern contact of the province (Duchesne and Hertogen, 2020). Paradoxically, this similitude concerns only the banded structure inherited from strong deformation in granulite facies conditions, not the geochemical compositions of the mafic and felsic rocks. Actually, the dominant noritic rocks are not compositionally equivalent to any amphibolitic gneiss but have high-alumina basaltic compositions very close to the presumed parental magmas of the EGOG anorthosite. The quartzo-feldspathic rocks range in composition from granite to diorite but all show high positive Eu anomalies and low HFSE contents, features characteristic of anatectic melts rapidly extracted from their source and differentiated by filter press in the emplacement process. The intrusion of the HAOM-bearing crystal mush of the EGOG margin was accompanied by infiltrations of high-alumina basalt (the parental magma) in the wall rocks and triggered anatectic melting in UHT conditions. These magmas were mingled with the basalt and formed a sort of emulsion with bubbles of cm- to decam-sizes. This complex was then deformed and stretched during cooling down to the subsolidus stage by the ballooning of the EGOG intrusion to yield the norito-granitic association.

Concluding remark: a new type of migmatites

The norito-granitic association attests that a new type of migmatites can be defined. In UHT conditions two mafic and felsic magmas mingle, without chemical interaction and hybridization, and this mixture ("migma") is deformed to finally produce a mylonitic association of leucosome (the felsic protolith) and melanosome (the mafic protolith). In his first interpretation of the zone, Michot (1939a) was very close to the new proposed model when he mentioned "lit par lit" injections and concluded "*Il semble qu'on ne puisse échapper à voir dans cette zone le résultat d'un mélange intime de produits auparavant différenciés et cristallisés en grande partie, remis ensuite en présence dans le mouvement d'intrusion*".

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