THE ANORTHOSITIC COMPLEX OF HÅLAND–HELLEREN

By

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Introduction.

This paper is an abstract of a more comprehensive work published in the mémoires de l'Académie royale de Belgique (J. Michot, 1961). It records information obtained from geological researches carried out in the Egersund area (southwestern Norway) from 1952 to 1958 during six successive summers, each of five or six weeks. The material collected during the field work was studied at the University of Liège (Belgium) in the department of Geology, Petrology and Geochemistry directed by Prof. P. Michot.

The author wishes to acknowledge the help and interest of Prof. T. F. W. Barth of the Geological Museum, University of Oslo, in whose department he had the opportunity to spend a few months in 1953—1954. He also wishes to thank Prof. N.-H. Kolderup who kindly introduced him to the Bergen area. Thanks are also due to Director R. Brun and to I. Dybdahl, S. A. Titania in Sokndal, for providing working facilities during his stays in the Egersund District.

The object of this work is to present briefly the geology and petrology of the anorthosito-leuconoritic complex of Håland—Helleren and thus to contribute to the knowledge of the phenomena operating in the deep zones of the earth's crust. It will be shown that the basic anatexis, locally mentioned in the Egersund area (P. Michot 1955b), is in fact widespread in this area. Indeed, it is a regional process resulting in the separation of a liquid phase, the anatectic leuconorite, from a residual solid phase the para-anatectic anorthosite. Using a term proposed by J. J. Sederholm, the author will call this process basic palingenesis (J. Michot, 1960).

General Geology.

The Håland—Helleren anorthosito-leuconoritic complex belongs to the basic igneous province of southern Rogaland (C. F. Kolderup, 1896, 1914; T. F. W. Barth, 1936, 1945). It is situated between Egersund and Sokndal with its northeastern end extending northward in the direction of Helleland (map, Plate 1).

In the north, between the sea and Helleren, it borders on the norito-granitic band, further east on the anorthositic body of Egersund—Ogna, and in the northeast and the east on the Bjerkreim—Sokndal body. In the south and the west it disappears under the sea.

This complex consists of three main geological units which are, from oldest to youngest:

(I) the Håland anorthosito-leuconoritic body;

(II) the Åseheia and Augendal intrusives;

(III) the Åmdal—Helleren—Rødland anorthosito-leuconoritic body.

These units are cut by dykes of norite, monzonorite, monzonite, and granitic pegmatite trending mostly north-south, and by doleritic dykes trending approximately west-east.

The mineral facies.

The rocks surrounding and constituting the area, whether of a sedimentary or eruptive origin, belong to the granulite facies or more accurately to the facies named mangeritic by P. Michot, and which is typical of the deep catazone (P. Michot, 1948).

This facies is characterized by the instability of muscovite and partially of biotite, and by the stability of associations containing plagioclase (andesine or sodic labradorite), potash feldspar, hypersthene, diopside and quartz. In rocks sufficiently rich in alkalis, the association includes a special feldspar: the mesoperthite.

The geological processes which have determined the formation of this province have developed, or have come to an end, within the deep catazone.

I. The Håland anorthosito-leuconoritic body.

The lithological composition of the body is fairly simple: light and dark leuconorites and, in places, norites as well as anorthosites. The types of association and the structural relations differ, however from one place to another. Two parts are to be considered:

1. the northern part covering the northern and the middle part of the body, characterized by an almost regular gneissic structure or a distinct irregular banding trending approximately west-eastward;
2. the southern part made up of folded gneisses of a more intricate arrangement.

The two parts gradually pass from one to the other by mutual interpenetration: lenses a few meters long typical of the southern part are embedded in the rocks of the northern one.

1. The northern part.

The northern part mainly consists of two lithofacies both representing the extreme members of a series of associations in which the anorthositic and leuconoritic rocks are present in variable proportions. The first lithofacies — gneissic leuconorite — is to be found on the northern border of the Håland body, the second one — anorthosite with pseudo-inclusions of leuconorite — is situated in its middle part.

The different types of association of anorthositic and leuconoritic rocks are connected with the west-eastward gneissic structure which is characteristic of this area (fig. 1). One type can be seen in an anorthositic rock containing regularly shaped lenticular leuconoritic patches ranging in length from 0.10 to 0.80 m, and sometimes even 1 m (anorthosite with pseudo-inclusions of leuconorite).

These patches show gneissic structure parallel to their major axis which itself remains constantly parallel to the structure of the encasing

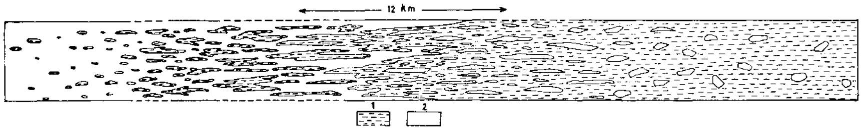

Fig. 1. Anorthosite-leuconorite association in the northern part of the Håland body. 1: leuconorite; 2: anorthosite.

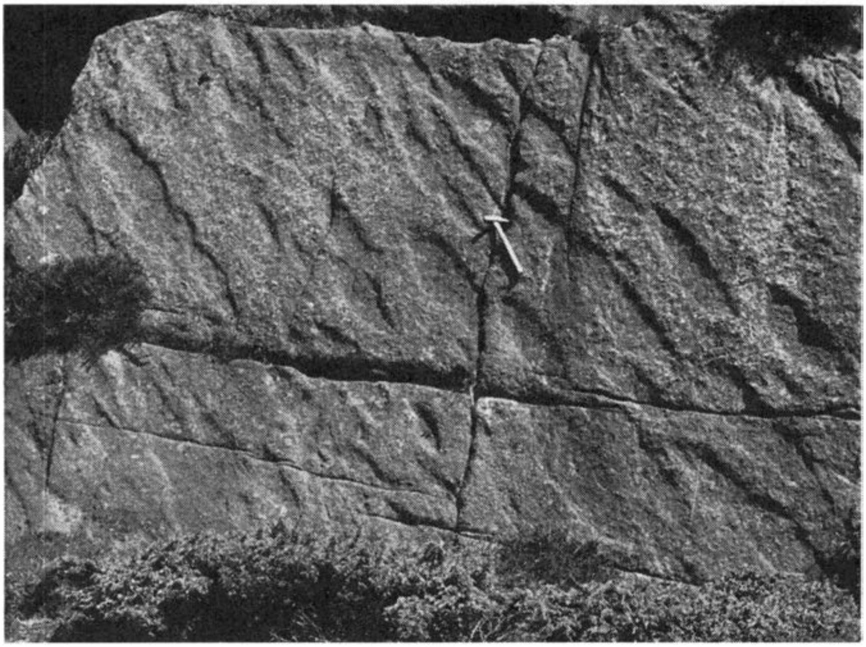

Fig. 2. Anorthosite with pseudo-inclusions of leuconorite.

rock. They sometimes extend into the anorthositic rock through a number of tiny stringers of dark minerals also elongated in the same direction. Therefore they do not present the aspect of true xenoliths (fig. 2).

Along the strike this type of association gradually changes into a succession of lenticular anorthositic beds, 0.30 to 1 m thick and several meters long, alternating with gneissic leuconoritic beds more irregular in shape but of similar thickness. The latter contain locally smaller anorthositic lenses which are sometimes 1 m long. The gneissic structure of the leuconorite follows the borders of the anorthositic beds or lenses and their irregularities and crosses some of the fractures.

Eventually this type changes into gneissic leuconorite with a few lenticular anorthositic inclusions. In places, e.g. on the Kaknuden and on the northern shore of the Kudlandsvd, the inclusions become so numerous as to form a real igneous breccia (basic agmatite). Inclusions of different shape and composition are to be found: massive anorthositic rocks, anorthositic and leuconoritic gneisses. All these xenoliths have sharp angular or sometimes rounded outlines which cut their internal structure. Frequently the structural planes of the xenoliths are set at random in the gneissic leuconorite, and show no relation to the gneissic structure of the encasing rock. Their volume may reach 30—50 cubic meters.

In another place (Hesnes) the gneissic leuconorite, the same which cements the breccia, intrudes into the surrounding rocks of the norito-granitic band.

Petrographical study.

A n o r t h o s i t e occuring as (1) rock masses embedding the leuconoritic patches (2) beds or lenses alternating with the gneissic leuconorite (3) xenoliths in the igneous breccia, is made up of plagioclase in the composition range An 40 to An 45.

This plagioclase exhibits isometrical or rarely elongate grains with very irregular and sometimes strongly indented outlines. All grains are twinned according to the albite and pericline laws the twins being usually poorly developed and very rarely straight. They very often include thin antiperthitic stringers (0.01 to 0.08 mm in diameter, 0.1 to 0.2 mm long) extending in three directions but sometimes limited to the border of the twins (J. Michot, 1958). Moreover they contain very thin needles of rutile covered with a brownish film, as well as thin dust of pyroxenes and black ore. They are frequently slightly deformed with curved twins exhibiting undulatory extinctions (fig. 3).

These anorthositic rocks have a texture that corresponds neither to the texture of an igneous rock in which the plagioclase forms well developed plates or laths, nor to the texture of a gneiss in which the minerals are orientated more or less parallel to one another either geometrically or optically. Hence neither the term anorthosite which is often given to the plagioclasic rocks of igneous origin nor the term anorthositic gneiss seems to fit them. The term granofels as proposed by R. Goldsmith (R. Goldsmith, 1959) would seem to be appropriate if the anorthositic qualification is added (J. Michot, 1959).

T h e l e u c o n o r i t e consists of plagioclase of a first type, identical to that of the anorthositic granofels, disseminated in layers of a second type of plagioclase in association with hypersthene of a

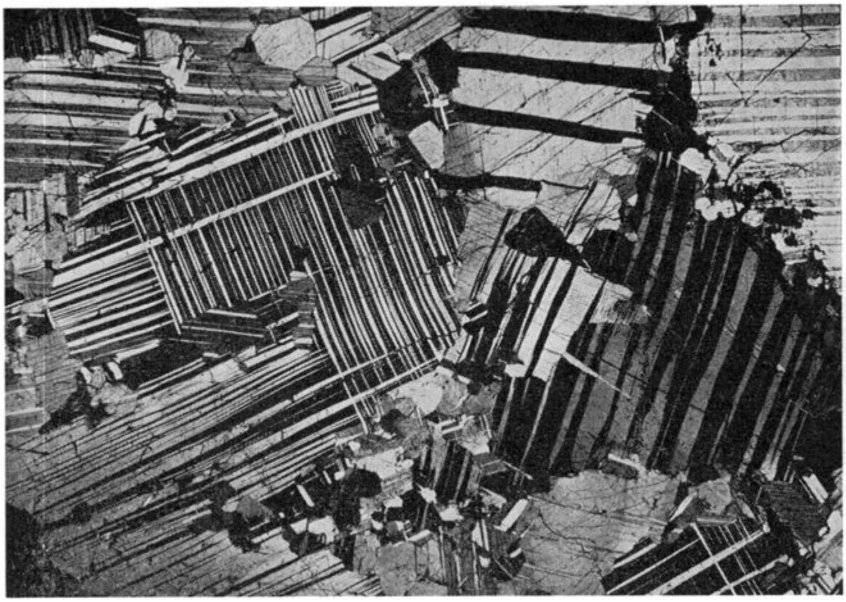

Fig. 3. Anorthositic granofels—Plagioclase of the first type. Nicols +; 11x.

poecilitique interstitielle texture (P. Michot, 1939b), a little diopside and black ore. The second type of plagioclase appears in small grains with regular outlines and clear extinctions, non-antiperthitic and without any dust; the composition varies between 40 and 45% An.

The microscopical study clearly indicates that the plagioclase of the first type is older than the plagioclase of the second type and the ferromagnesian minerals. It also is previous to the gneissic structure which characterizes the leuconorite.

Conclusion: the basic anatexis.

The anorthosite-leuconorite association is characterized by mutual reciprocal relations of these two rocks.

This association may be explained as the result of a differential migration of minerals mainly ferromagnesians and plagioclase of the second type, leaving behind a residue of plagioclase of the first type.

Probably a differential melting, i.e. anatexis, has occured in a pristine rock containing such minerals. Indeed, at the moment of the melting, a eutectoid leuconoritic melt is generated leaving a solid residue composed of the mineral, the quantity of which in the rock is superior to that fixed by the eutectic point, here the plagioclase.

The different types of anorthosite-leuconorite association, are formed by a mechanical differentiation under the influence of shear. The leuconoritic liquid generated by the melting was squeezed out, carrying with it a great number of deformed residual plagioclases (plagioclase of the first type), forming homogeneous masses, sometimes intruding into the country rocks (Hesnes), and sometimes embedding inclusions of residual anorthosite.

Anorthositic granofels left behind during this process in a nearly pure state but locally containing remains of the anatectic liquid (anorthosite with pseudo-inclusions of leuconorite) is the nearest approach to a solid residue.

Anorthositic granofels represents an agglomerate of the residual plagioclases (para-anatectic anorthosite; P. Michot 1956). Leuconorite represents the concentration of the interstitial anatectic liquid (anatectic leuconorite).

2. The southern part.

This part of the Håland body is composed of anorthositic and leuconoritic rocks in various associations. They often appear as a series of alternating beds 0.30—0.40 m to 1 m thick, made up of anorthositic and leuconoritic granofels, leuconoritic, sometimes noritic, gneisses with small lenses of granulated hypersthene, and gneissic leuconorite; they also form layers 0.05 to 0.20 m or even stripes 0.01 to 0.02 m thick resulting in finely zoned or banded rock types.

On a large scale, the structure of the southern part shows wide undulations. On a smaller scale, the gneissic structure, characterized by the attitude of the ferromagnesian minerals and the small anorthositic lenses parallel to the general trend of this area, is in some places fairly isoclinaly folded with almost horizontal axial planes.

The relation of the gneissic leuconorite to the anorthosito-leuconoritic beds and layers merits special mention (fig. 4).

Locally rather thick beds of leuconoritic granofels contain one or two layers of anorthositic granofels. Along the strike the leuconoritic granofels slowly grades into a gneissic leuconorite whereas the

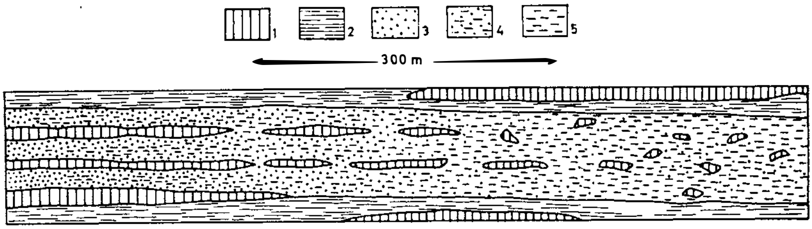

Fig. 4. Relation of the anorthosito-leuconoritic beds and layers to the gneissic leuconorite in the southern part of the Håland body.
1: anorthositic granofels; 2: leuconoritic gneiss; 3: leuconoritic granofels; 4: leuconoritic granofels and gneissic leuconorite; 5: gneissic leuconorite.

intercalated anorthositic layers thin away, break up, and are finally replaced by a series of lenses the length of which varies from 0.50 m to 4 or 5 meters. Further on, the gneissic leuconorite forms a well individualized bed in which small anorthositic inclusions are scattered about.

In the neighbourhood of Mong, a bed of gneissic leuconorite 1 m thick occurs in a series of beds of anorthositic granofels and leuconoritic gneisses. At a special point, the gneissic leuconorite widens, grows thicker and thicker, and intrudes into the surrounding beds. Southeast of Odden, a similar leuconorite constitutes the cement of a breccia which extends over several hundred square meters, and whose inclusions, scattered at random, represent blocks of the gneissic rocks typical of the southern part.

These observations show that the gneissic leuconorite which often forms stiff concordant beds in places behaved as an extremely movable magmatic unit elsewhere.

Petrographical study.

The anorthositic rocks are composed of the same type of plagioclase as that which forms the anorthositic granofels of the northern part.

The leuconoritic rocks are of two types. (1) The gneissic leuconorite is equivalent to the leuconorite previously described and characterized by hypersthene with poecilitique interstitielle texture. (2) Leuconoritic granofels and leuconoritic gneisses carry plagioclase of the first type associated with hypersthene, sometimes diopside, of a prismatic habit. This habit is often observed in the norito-granitic band whose origin is connected to a metamorphic process (P. Michot, 1955a).

Consequently, leuconorites of type 2, forming the major part of the leuconoritic rocks of the southern part, could be of the same origin.

Conclusion.

The transitions observed between the leuconoritic granofels and the gneissic leuconorite, and the fact that the original arrangement of the anorthositic beds or lenses are often preserved, indicate an incipient mobilization of a solid unit towards a magmatic moving one. This mobilization is the expression of an anatectic phenomenon which occurs in the southern part in its formal stage.

The nature of the preexisting rock complex is indicated by observations in the region of Augendal: by the abundance of the beds of anorthositic granofels, by the intercalations of leuconoritic granofels as well as by the presence of small lenses of granulated hypersthene, the rocks become identical with the gneissic border of the anorthositic body of Egersund—Ogna (P. Michot, 1939a).

GENERAL CONCLUSION.

The Håland body is divided into two parts corresponding to two phases of the anatectic phenomenon. The southern part reveals an incipient anatexis whereas, in the northern part, the anatexis has developed on a larger scale, resulting in the production of gneissic anatectic leuconorite and, simultaneously, of para-anatectic anorthosite.

The rocks of the two parts are of a similar nature; this seems to indicate that the Håland body initially formed a homogeneous unit similar to the anorthosito-leuconoritic gneissic border of the Egersund—Ogna body. Consequently it is inferred that the Egersund—Ogna body, the oldest unit of Rogaland, once extended southward to the sea in the direction of Sokndal. Subsequently, south of Egersund, anatectic phenomena interfered and created new types of rock.

II. The Åseheia and Augendal intrusives.

The Åseheia and Augendal intrusives are dark leuconorites, constituting the second main unit within the basic complex studied here. They appear in two places, the first to the northwest, the second to the southeast of the large protuberancy of the third unit, the Åmdal—Helleren—Rødland body, in the west part of this complex.

The dark leuconorites represent typical magmatic intrusions clearly posterior to the anorthosito-leuconoritic body of Håland. They cut across the gneissic or layered structure of this body and contain xenoliths of it and of other rocks very similar to those of the norito-granitic band.

Locally, the dark leuconorites pass into the rocks of the Håland body which they slightly assimilate. This assimilation seems to be responsible for the existence of two main types of leuconorites: a fine-grained and a medium-grained type. The phenomenon is obvious in the surroundings of the gneissic leuconoritic xenoliths which lie within the fine-grained leuconorite; the rock in between is always made up by a medium-grained leuconorite.

Petrographical study.

The dark leuconorites have the same mineralogical composition and the same texture as has the leuconoritic anatectic rock of the Håland body. The minerals that form the association including plagioclase of the second type, pyroxenes (hypersthene and diopside) and black ore, constitute a more important part of the rocks. In this association the hypersthene has a well developed poecilitique interstitielle texture, especially in the fine-grained leuconorite (fig. 5).

Conclusion.

The Åseheia and Augendal magmatic unit is the result of a melting similar to that which generated the anatectic rocks of the Håland body. But in this case the quantity of the molten part was more important, and the residual plagioclases less important quantitatively. The magma, whose mobility was probably rather great, became more completely separated from the residual anorthositic part and was able to intrude the Håland body.

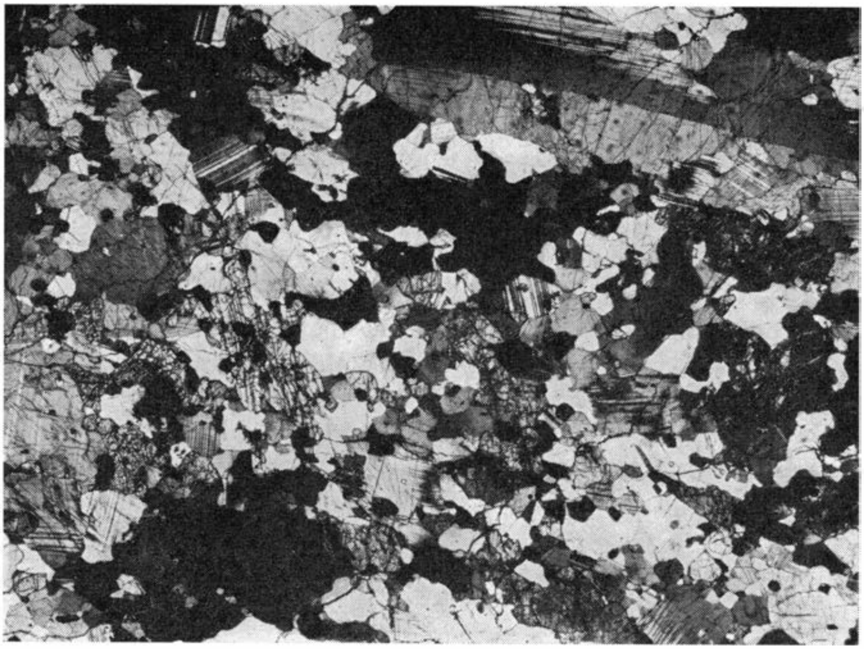

Fig. 5. Anatectic leuconorite of the Åseheia intrusive. Plagioclase of the first type (upper right corner) surrounded by the anatectic association in which hypersthene shows a poecilitique interstitielle texture (center). Nicols + ; 8x.

III. The Åmdal—Helleren—Rødland anorthosito-leuconoritic body.

The Åmdal—Helleren—Rødland body (Å—H—R) is the largest studied unit. It extends from north to south, between the Helleland region and Rekefjord, over approximately 20 km, and from west to east, between Åmdal and Barstad, over about 12 km.

On the west, it intrudes into the two units described above and reaches the neighbourhood of Åmdal (protuberancy of Åmdal). On the northwest, it cuts across the norito-granitic band and the Egersund—Ogna body; on the northeast, it forms protuberancies intruding the migmatitic band of the Lakssvelefjell and the leuconoritic and noritic horizons of the inferior part of the Bjerkreim—Sokndal body (protuberancies of Støla and Rødland); on the east, it is cut by the monzonorite of Eia which represents the last magmatic phase of the same body. Finally, on the south, it slopes down under the sea.

The contacts and the xenoliths indicate that the Å—H—R body is a magmatic unit with a well defined transgressive character. The central part is a coarse-grained anorthosite with sometimes very large euhedral crystals, containing in places patches of leuconorite; the border part is a medium-to coarse-grained leuconorite, which is also found in the protuberancies of Åmdal, Støla, and Rødland.

The relations between the leuconorite and the anorthosite are analogous to those found in the northern anatectic part of the Håland body: indeed, the association anorthosite-leuconorite is in both places characterized by the reciprocal relations between these two rocks. The leuconoritic border of the body contains coarse-grained anorthositic inclusions. In its central part the relative proportions of the two rocks become more or less equal and finally, in the center, the anorthosite forms a rather huge and homogeneous unit locally containing patches of leuconorite.

Petrographical study.

The component minerals and the texture of the leuconorite are identical to those of the anatectic rocks of the Håland body and of the Åseheia and Augendal intrusives: the plagioclase of the first type, sometimes rather coarse, is older than the associations formed by plagioclase of the second type, hypersthene of a poecilitique interstitielle texture, diopside and black ore. The coarse-grained anorthosite shows plagioclases of the first type, i.e. similar to those of the residual para-anatectic rocks of the Håland body.

Conclusion.

The formation of the anorthosito-leuconoritic body of Å—H—R also would seem to be connected with the leuconoritic anatectic process. The volume of rock here affected is very great, and the residual masses are very coarse. Indeed, in the central area of the body, and in the coarse-grained anorthositic inclusions contained in the leuconorite, plagioclases from 20 cm to 1 m long are common. They are of identical composition and never show any zoning. The physical conditions during the anatexis must have been very stable for a very long period of time.

The pristine substrate on which the anatectic processes have worked can only be surmised; it seems possible to relegate it to rocks of the same type as those of the masses of the Håland body, i.e. gneisses similar to the gneisses on the inward border of the Egersund—Ogna body, and also to leuconorites and norites forming the inferior part of the Bjerkreim—Sokndal body.

General Conclusion.

The geological and petrographical study of the anorthosito-leuconoritic complex of Håland—Helleren indicates that the deep zone of the earth's crust is the locale of a leuconoritic anatectic process of a regional extent: the basic palingenesis.

This process, in its initial phase, more or less modifies the structure and composition of the ancient rocks (Håland body); at greater intensities leuconoritic liquids are mobilized and large masses of para-anatectic anorthosite are formed (Åseheia and Augendal intrusives, Åmdal—Helleren—Rødland body).

The palingenetic phenomena started and developed later than the several stages of folding; they belong to the final stages of the regional plastic deformation.

The basic palingenesis throws new light on the problem of the origin of the large anorthositic masses. Indeed, the anatexis, in conjunction with the squeezing out of the dark components of a leuconoritic rock, accounts for the accumulation in large bodies of plagioclasic residues.

And so we come to a conclusion which corroborates the views expressed by P. Michot in his presidential address to the Société géologique de Belgique (P. Michot, 1956): «déjà effective dans la catazone profonde, l'intensité de ce phénoméne (l'anatexie leuconoritique) ne peut que croître dans les milieux plus profonds encore, pour produire, non seulement des magmas régénérés, mais encore et surtout pour engendrer de grandes masses anorthositiques de caractère paraanatectique. Ces derniers produits viendront ainsi s'ajouter aux anorthosites d'origine magmatique directe, pour constituer en profondeur, plus exactement dans les tréfonds de l'écorce terrestre ... de puissantes unités géologiques, douées d'une réelle individualité ...».

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PLATE 1

Plate 1.

Geological map of the anorthosito-leuconoritic complex of Håland–Helleren

1—5: Håland body. — 1: anorthosito-leuconoritic gneisses (anorthositic granofels, leuconoritic gneisses and granofels, noritic gneiss); 2: anatectic leuconorite and para-anatectic anorthosite; 3: anorthosite with pseudo-inclusions of leuconorite; 4: anorthosite; 5: basic agmatite.

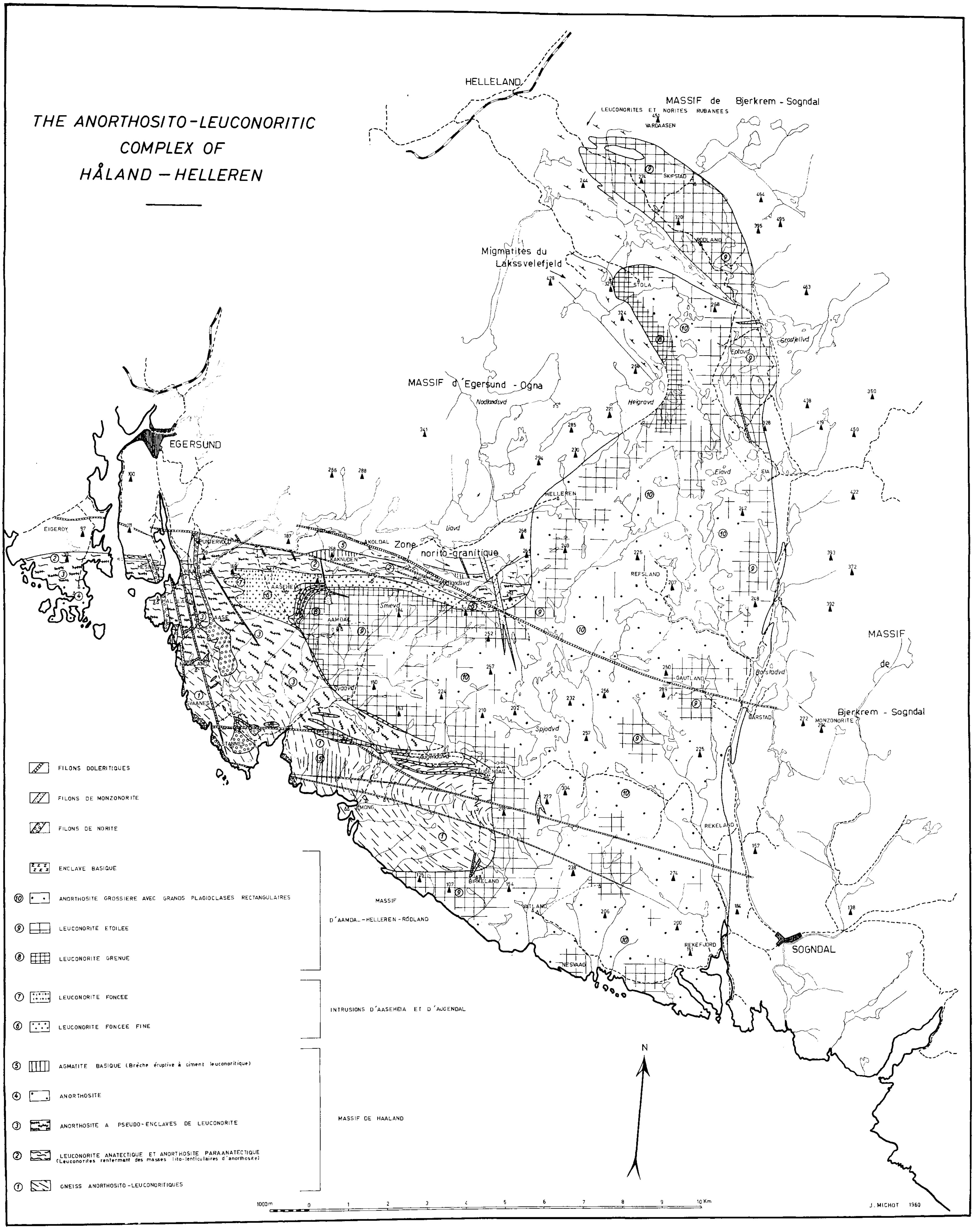
6, 7: Åseheia and Augendal intrusives. — 6: fine-grained leuconorite; 7: medium-grained leuconorite.

8—11: Åmdal—Helleren—Rødland body. — 8: coarse-grained leuconorite; 9: leuconorite; 10: coarse-grained anorthosite; 11: basic inclusions.

12: noritic dykes.

13: monzonoritic dykes.

14: doleritic dykes.


THE ANORTHOSITO-LEUCONORITIC
COMPLEX OF
HÅLAND – HELLEREN
HELLELAND
MASSIF de Bjerkrem - Sogndal
LEUCONORITES ET NORITES RUBANEES
VARDAASEN
SKIPSTAD
RODLAND
Migmatites du
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FILONS DE NORITE
ENCLAVE BASIQUE
⑩ ANORTHOSITE GROSSIERE AVEC GRANDS PLAGIOCLASES RECTANGULAIRES
⑨ LEUCONORITE ETOILEE
⑧ LEUCONORITE GRENUE
⑦ LEUCONORITE FONCEE
⑥ LEUCONORITE FONCEE FINE
INTRUSIONS D'AASEHEIA ET D'AUGENDAL
⑤ AGMATITE BASIQUE (Brèche éruptive à ciment leuconoritique)
④ ANORTHOSITE
③ ANORTHOSITE A PSEUDO-ENCLAVES DE LEUCONORITE
② LEUCONORITE ANATECTIQUE ET ANORTHOSITE PARAANATECTIQUE
(Leuconorites renfermant des masses lito-lenticulaires d'anorthosite)
① GNEISS ANORTHOSITO-LEUCONORITIQUES
MASSIF DE HAALAND
N
1000 m 0 1 2 3 4 5 6 7 8 9 10 Km
J. MICHOT 1960