GLOBULITH
A NEW TYPE OF INTRUSIVE STRUCTURE, EXEMPLIFIED BY METABASIC BODIES IN THE MOSS AREA, SE NORWAY[1])

By
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Abstract.

Intrusion of basic magma into a regionally preheated gneiss complex has given rise to oddly shaped, globular to botryoidal, intrusions with associated contact anatexis and contact deformation whereby pseudoconcordant contacts developed on a local scale. The term globulith is introduced for this unusual type of intrusive structure. It is suggested that osmotic pressure contributed to the special intrusive mechanism of the globuliths. The structures of certain hyperites are compared with those of the Moss globuliths, and the analogy between globuliths and near-surface associations of basic and acid magmas are discussed.

Introduction.

Detailed mapping and structural studies of the Precambrian rocks of the Moss area were started by the author in 1965 in connection with field courses for geology students and as part of NGU's mapping programme in SE Norway (Berthelsen, 1967 a and b).

The predominant rock type in the Moss area (see fig. 1) is a pink, medium- to fine-grained biotite gneiss with conformable coarser migmatitic (? venitic) veins and an overall granitic composition. This rock type builds up a thick and rather monotonous series most probably representing original acid volcanics. These pink gneisses contrast clearly with a series of banded, grey gneisses carrying hornblende in addition

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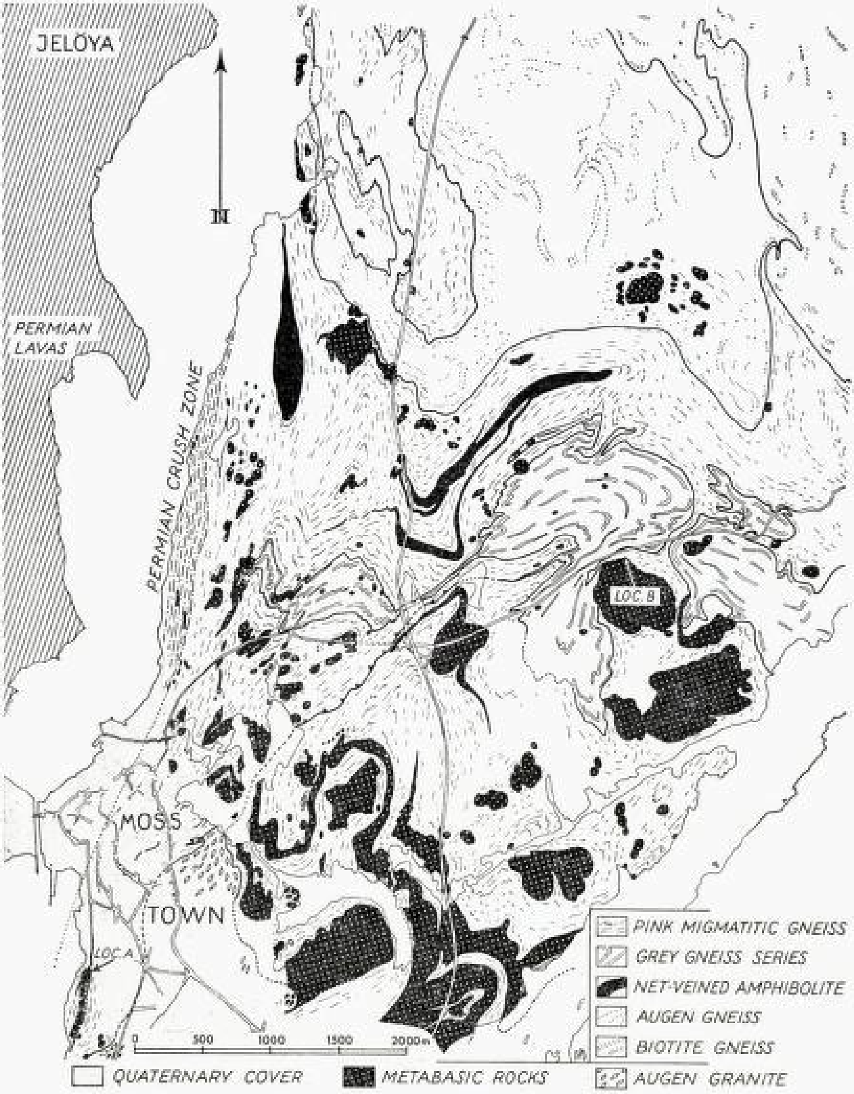

Fig. 1. Geological sketch map of the Moss area. Mapping by students participating in university field courses 1965—1969, L. Skov Andersen, P. Appel, B. Hageskov, K. Secher, M. Ghisler, E. Schou Jensen, I. Madirazza and A. Berthelsen. Compilation by the author. Amphibolites of the grey gneiss series are not differentiated. Metabasic rocks mostly stand for globuliths (with or without superposed deformation) but may include minor amounts of gneiss and other country rocks. Due to scale, Iddefjord pegmatites are not shown. Topography based on photogrammetric maps (1 : 5.000) kindly placed at disposal by Moss kommune.

to biotite and with common thin bands and thicker stratiform sheets of amphibolite. In some places garnetiferous gneiss bands also occur. Both the grey gneiss and the associated amphibolite are equigranular rocks with grain size about 1 mm, and migmatitic veins and schlieren are generally absent. The chemical composition of the grey gneiss proper corresponds of that of an average graywacke and this gneiss may be of sedimentary origin. An intrusive origin (as sills) of at least some of the amphibolitic bands and sheets is suggested by occasional slightly transgressive contacts.

Locally, for example around Lauersbakåsen, net-veined foliated amphibolite of medium to coarse grain and a thin layer of quartzite are complexly interfolded with the pink gneiss (see fig. 1; Berthelsen, 1967 a). Further to the north and the east the common pink gneiss gives way to augen gneisses with rod-like augen, and medium-grained grey, biotite gneisses.

In addition to these rocks, which are all believed to have been derived from original geosynclinal formations of sedimentary, extrusive or shallow-intrusive origin, there occurs a varied suite of basic rocks intruded under plutonic or abyssal to hypabyssal conditions. Their emplacement took place at different times, prekinematically, synkinematically, and postkinematically, in relation to at least two phases of folding.

Some of these basic bodies show such unusual shapes and contact relations that a separate description of their field features is justified.

Globulith, definition of the term.

«So ein Ding muss ich auch haben».

In order to characterise the unusual features of some of the basic bodies of the Moss area, a new term, *Globulith,* is introduced as a supplement to the existing vocabulary for types of intrusive structures. Although Daly (1933, p. 105–110) reserved chonolith as a «sack name» for those discordant igneous bodies which would not be covered by the then existing more specific terms (such as lopolith and laccolith) he also mentioned that once an additional type had been defined, it would automatically be removed from the «chonolith sack». The author considers the field features of some of the basic bodies of the Moss area to be so characteristic and unusual that the adoption of a special term is justified.

In accordance with the German saying quoted above, the author hopes that the new term may serve to direct attention to the various tectonic and petrological problems arising from the recognition of this new type of intrusive structure.

Definition: Globulith is defined as an intrusive body or a group of closely associated bodies of globular or botryoidal shape and with almost concordant contacts resulting from the effects of the intrusion/s on its/their immediate surroundings.

The Moss Globuliths.

The globuliths of the Moss area are made up of metagabbro, metadolerite and fine-grained metabasic types—all of which may grade into amphibolite—intruded into gneisses. The size of the intrusions varies from less than 10 metres to about one kilometre across. Several generations occur. The youngest globuliths were intruded after the last phase of folding affecting the region, but before the formation of pegmatite dyke swarms related to the emplacement of the late Dalslandian Iddefjord/Bohus granite. The older globuliths have preserved their primary structures less well due to superimposed tectonics. The full significance and the peculiarity of the Moss globuliths, therefore, were not realized until, during the field season of 1968, the postkinematic nature of some, i.e. the youngest, bodies was established.

The peculiarity of the Moss globuliths is not only their odd shape, but depend also on their special contact relations. Although the overall patterns of the larger intrusions are clearly discordant to the general country rock structures, their contacts are almost concordant or completely so on outcrop scale.

The pseudo-concordant nature of the contacts of the small as well as the big intrusions leads to the impression that they have become emplaced by forceful intrusion. The composition and corresponding densities of the intrusives and of the invaded rocks rule out the possibility of piercement diapirism, and another easy explanation, boudinage must be dismissed—once the postkinematic nature of some of the globuliths has been established.

The strong effect exerted by the globuliths on their immediate surrounding country rocks comprises not only contact metamorphism and metasomatism but also *contact anatexis* and *contact deformation.*

The term *contact anatexis* is used here in the sense of Rittmann (1967) as a designation for the local, contactbound anatectic phenomena related to the heat given off by a cooling and solidifying magma body. In this way the term is distinguished from regional anatexis which is related to, or is an extension of, regional metamorphism (Winkler, 1968).

Contact deformation refers to contortion, and formation of new textures and structures in the wall rocks and the outermost parts of the intrusion caused by stress differences directly due to the specific intrusive mechanism of the globuliths.

The plastic to fluid style of the structures produced by contact deformation around the Moss globuliths suggests a genetic relation between contact anatexis and contact deformation, i.e. softening of the wall rock through contact anatexis could be regarded as necessary for the development of contact deformation. However, intrusion of basic magma into unconsolidated, water-soaked sediments may also give rise to globulithic structures with contact deformation. An example of this high-level type of globulith is probably to be found in the gabbro intrusions recorded by Bondesen (in press) from the Ketilidian geosynclinal formations of SW Greenland.

Although all the basic rocks of the Moss globuliths have been exposed to regional metamorphism and have become wholy or partly adjusted to amphibolite facies conditions, they usually show well preserved igneous textures except in their most marginal parts. According to primary grain size and texture, metabasalt, metadolerite and metagabbro can be distinguished. In spite of some metamorphic alterations along the margins, chilled contacts are often noticeable. In the metagabbros patches of gabbro pegmatite are common. The mafic minerals of the gabbro pegmatite (now generally uralitic hornblende) often show a characteristic branching growth towards the interior part of the pegmatite.

Several metagabbros also show well preserved igneous banding and lamination. Banding of presumably primary origin has also been noticed in some metadolerites, but is as a rule less evident or less well developed in the medium-grained types.

It is probable that a simple relation exists between the grain size of the basic bodies and the degree of mobilization of the wall rocks. Coarse-grained metagabbro bodies without prominent chilled borders show less contact effects than bodies of finer grain or with prominent chilled margins.

So far, however, no clear relation between the size of an intrusion and its grain size has been established. Even small bodies may consist of extremely coarse (and even banded) metagabbro. A thin zone of amphibolitic migmatite usually separates such bodies from the surrounding gneiss, rendering the contacts more or less conformable.

The intrusion of the Moss globuliths appears to have taken place in a regionally preheated rock complex, i.e. under plutonic conditions with pressures and temperatures (and P_{H_2O}) not much below those required to start regional anatexis.

This assumption is made in order to explain the fact that even globuliths with diameters of less than 10 metres caused partial or complete anatexis of the wall rocks adjacent to the contacts. Some postkinematic globuliths intruded into pink, migmatitic gneiss (of granitic composition) are thus surrounded by a thin shell of porphyric granite of contact-anatectic origin. Porphyric granite also transects the marginal and interior parts of the basic bodies in the form of irregular veins and dykes. Where intensive, the back-veining may have caused a development of veritable intrusion breccias (where the intrusive rock is intruded by the mobilized wall rock). Because of contact deformation, some intrusion breccias have turned into oriented agmatites, as for example SW of Øreåsen. In other cases, the anatectic melt has formed hybrids with the remaining basic magma (e.g. at Dyrevegen at the Moss—Rygge municipal border).

However, not all intrusion breccias, where basic rocks are cut by acid veins, need be due to local contact anatexis. The acid phase may have been generated at an earlier stage and at a deeper level during the ascent of the basic magma, and the anatectic phase may thus have become allochthonous. Such an origin is invoked for those breccias where the quantity of the acid material is great and where signs of local contact anatexis are scarce.

As shown in fig. 2 the basic component may also take a pillowlike shape, where each pillow is distinctly scalloped. This structure appears identical to the basic pillows in granophyres of the Austurhorn intrusion, Iceland, as described by Blake, Elwell, Gibson, Skelhorn and Walker (1965), and it may indicate that basic magma chilled against allochthonous acid magma. In passing, it should be mentioned that intrusion breccias, where strongly tectonised, have lost most of their characteristic features and look like amphibolite-banded grey gneiss. Only when viewed along the axis/lineation can the fragmental shape of the amphibolite «bands» be discerned. These sheared breccias are convergent to the

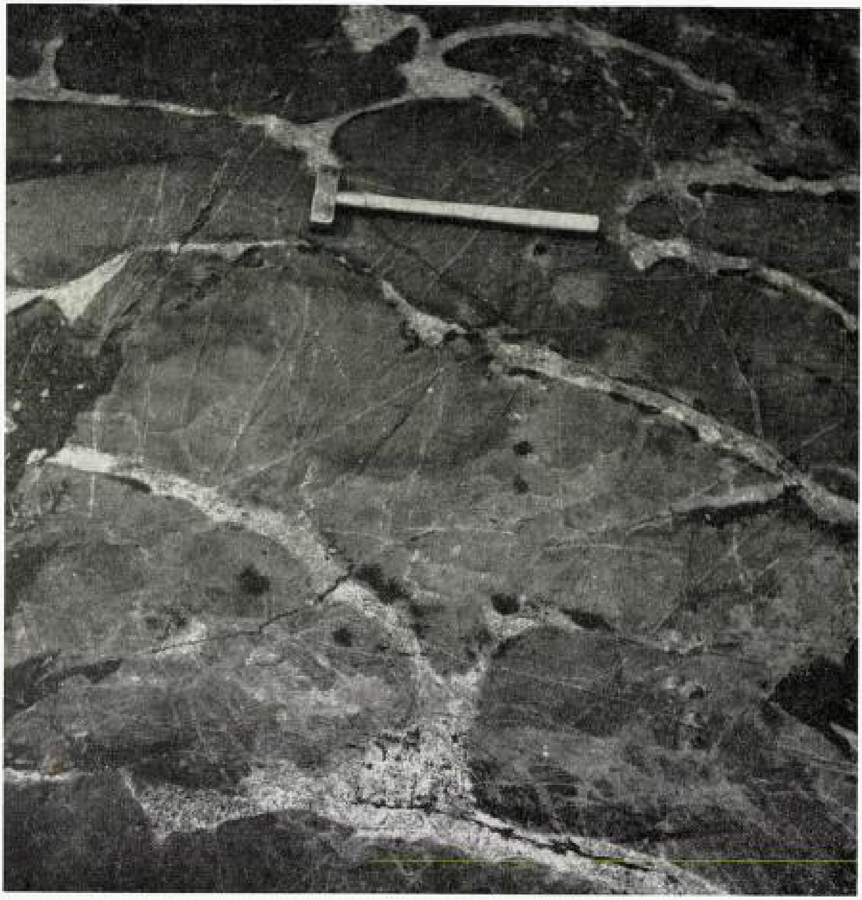

Fig. 2. Pseudopillows in a globulith at Gamlevegen (between Moss and Kambo). The basic «pillows» probably chilled against an anatectic, acid magma; compare Plate 7 a, b, and c and Plate 8 b in Blake et al. (1965).

rocks of the amphibolite-banded, grey gneiss series, which latter, however, is held to be of supracrustal origin.

In order to illustrate some of the typical features of globuliths more clearly, two localities are selected for description:

A) The profile at Klevevegen, southern part of Moss town.

B) The quarry south of Vålervegen, about 4 km east of Moss town.

The Klevevegen profile.

The profile at Klevevegen (see fig. 3) runs almost parallel to a N—S to NNE—SSW trending zone rich in globulithic intrusions of basic rocks. The zone is about 60 metres broad and is overlain and underlain by fairly uniform migmatitic pink gneisses with constant strikes and dips and with axes of small fold and lineations (e.g. rodding in the migmatitic veins) plunging uniformly to the west.

Due to the proximity in the nearby fjord of the Permian fault which borders the Oslo graben to the east, the basement gneisses near the coast show a steeper dip (50—60°) than further inland. Obviously a flexuring of the basement complex prceded or accompanied the Permian faulting which otherwise resulted in the production of a prominent crush zone which enters the coast north of Moss town and is extensively exposed in the coastal hills further north. Between Moss on the mainland and Jelöya a throw of 1500—2000 m has been estimated.

Apart from the monoclinal tilt accompanying this faulting the structures of the migmatitic pink gneisses surrounding the globulithic zone may be ascribed to the last phase of folding affecting the Moss region (the V_2-folding of Berthelsen, 1967 a).

The globulithic zone comprises a large number of individual globuliths of metadolerite grading into finer grained metabasic rocks towards their margins. Along the actual contact foliated amphibolite may also be developed. The structures of the country rock, the usual migmatitic pink gneiss, are much disturbed.

The shape of the separate globuliths may be ball-shaped, ovoid or complex bulbous. Their size varies from 50 to only a few metres. Their contacts are quite sharp, and immediately bordering the contact a thin shell of more or less sheared porphyric granite is generally found. The granite passes gradually into the surrounding gneiss which may carry augen up to a metre from the contact.

In the largest (and northernmost) body in the profile a dyke of porphyric granite cuts with knife-sharp contacts deep into the metabasic rocks. In the southern part of the profile it can be seen how the granite shell at the contact gives off a protrusion cutting obliquely into the basic body.

Another striking feature to be noticed in the profile is the manner in which the structures of the country gneiss have been forced to accommodate the external shape of the individual basic bodies. The otherwise constantly west-plunging axes and lineation have become accentuated through stretching and sweep plastically around the basic globuliths hereby locally attaining vertical to just overturned attitudes. Their deflection is clearly dependent on the bulbous shape of each basic body, and it disappears some distance off the contact.

It could also be argued that the entire structural setting of the globulithic zone should be explained by assuming a tectonic break-up of a once coherent sheet of basic rocks in connection with the last phase of folding whereby the axes and lineation in the «brecciated» zone became oriented according to the local shape of individual lumps of basic rock. Two facts, however oppose this explanation: 1) each globule shows clear signs of chilled contact quite regardless of the contact-methamorphic alterations, and 2) scalloped contacts devoid of axial control.

The porphyric granite of the shells surrounding the globuliths and the cross-cutting veins and dykes may show a sort of flow structure or preferred orientation of the feldspars. The augen occurring in the gneiss just outside the granite shell, however, also show a preferred orientation and this feature points to a close time relation between contact anatexis and contact deformation. In an exposure above and east of the profile, a dyke of porphyric granite cutting metagabbro has been exposed to late shearing together with the surrounding metabasic rock, but as a whole the post-intrusive tectonic influence appears negligible.

It may therefore be concluded that the deflection of the structures of the gneiss may be ascribed to the local pressure exerted by the swelling of the globuliths during their emplacement and we thus have an example of contact deformation of the wall rock around postkinematic intrusions.

An upper age limit for the emplacement of the globuliths at Klevevegen is given by the occurrence of cross-cutting, eastdipping pegmatite dykes belonging to a regional swarm related to the late Dalslandian Iddefjord/Bohus granite which forms extensive exposures about 20 km further to the SSE.

Fig. 3. Field sketch of the Klevevegen profile (loc. A, for location see fig. 1). The profile is about 75 metre long.

Fig. 4. Metabasic globuliths surrounded by wildfolded migmatites in the Vålervegen quarry (loc. B, for location see fig. 1). Drawn on polaroid photos in the field.

Fig. 5. Diagrammatic sketch showing the two types of globulithic structures seen at the localities A and B.

Fig. 3

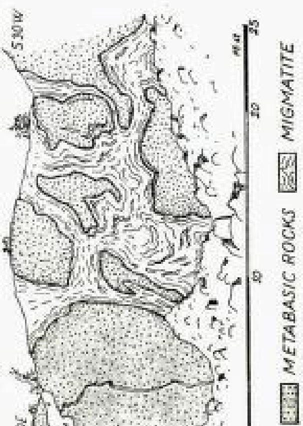

Fig. 4

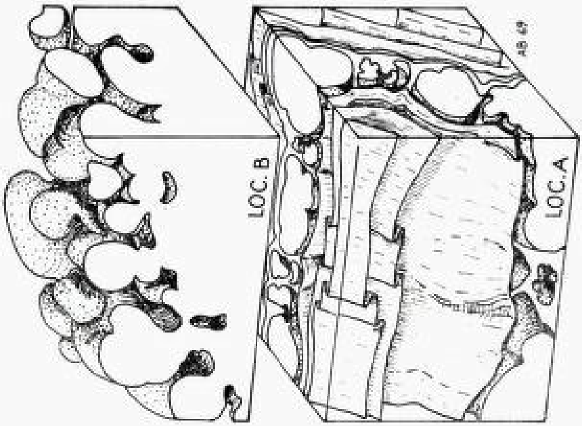

Fig. 5

In this connection it may be noted that the assumption that the globuliths intruded into a regionally preheated country rock (required to explain the anatectic contact effect of the smaller globuliths) is consistent with the updating of all basement rocks of SE Norway during the Dalslandian (Broch, 1964).

The quarry south of Vålervegen.

At the quarry south of Vålervegen, the detailed contact relations of a larger gabbro intrusion, measuring about half a kilometre across, can be studied. The intrusion has been mapped by P. Appel, who demonstrated its general discordant nature and overall semicircular outline on the map, see fig. 1.

As seen from fig. 4, the trend of the contact is, however, in detail highly irregular. The shape of the contact may be compared with that of a cauliflower, circular in general outline, but bulbous or botryoidal when studied in detail. The main gabbro body forms convex protrusions and bulbs each with its own chilled margin. Some of these marginal bulbous bodies appear to be rootless — at least no connection to main gabbro can be discerned even in the good three-dimensional exposures of the quarry.

The marginal bulbs are separated by interlobal space and pockets occupied by mixed, migmatitic gneisses displaying disharmonic folds with haphazardly oriented axes, i.e. true wild migmatites (cf. Berthelsen, Bondesen and Jensen, 1962). These gneisses carry appreciably greater amounts of hornblende and biotite and show a relatively larger grain size than the normal country rock. These features could be explained either by assuming a metasomatic contact effect from the basic magma or by postulating a basification through partial anatexis. Migmatitic veins may also occur in the marginal parts of the basic bodies trending more or lesss parallel to the contact. Such veins probably represent mobilized wall rock material introduced by means of back-veining but arranged in a contact-parallel manner because of the simultaneous contact deformation.

While the gneisses of the interlobal pockets became wildfolded due to irregular and changing compression of the mass between the growing basic bulbs, a flattening and stretching appears to have taken place around (and probably also in the marginal parts of) the convex basic lobes, because here foliated and lineated mixed gneisses and amphibolites developed.

The combined effect of the contact deformation and mobilization was the production of pseudo-concordant contacts. The relic chilled contacts observable in even satelitic bulbs, proves the primary origin (i.e. relation to the intrusive act and the solidification) of these features, which include formation of S- and B-tectonites indistinguishable from true orogenic tectonites in hand specimen.

In some of the larger marginal bulbs and in the central body of the Vålervegen gabbro, igneous banding has been noticed with steep attitudes more or less parallel to the contacts. This banding is primarily brought out by changing grain size. The apparent active pressure exerted by the individual bulbs renders it feasible that this banding signifies multiple intrusive action rather than cumulative crystal settling. The banding is cut by aplitic, acid dykes.

Summary and comparisons.

In the light of the two examples just described (see also fig. 5) it is evident that contact deformation may be extremely difficult to tell apart from superposed true orogenic (i.e. regional) deformations. This means that minor folds observed in and around globuliths should be studied in great detail and should only be used with the greatest precaution — if at all — when a structural analysis of the orogenic structure is attempted.

Since, in some parts of the Moss area, trails of globuliths (e.g. the globulith zone at Klevevegen) form the only «marker horizons» present, the recognition of the primary nature of contact deformation is of great importance for further structural work.

The occurrence of both deep-level (e.g. in the Moss area) and high-level globuliths (e.g. the Ketilidian gabbros) suggests that, during the emplacement of globuliths, the P_{H_2O} of the basic magma (? due to osmosis) underwent a rapid increase, which caused forceful swelling of the solidifying body and eventually squeezing out of not yet solidified magma in the form of satelitic bulbs or protrusions. In this connection it is interesting to note that scalloped contacts suggesting chill of basic magma against contact-anatextic acid melts appear best developed around satelitic bodies.

The recognition of a special globulithic type of intrusion in the Moss

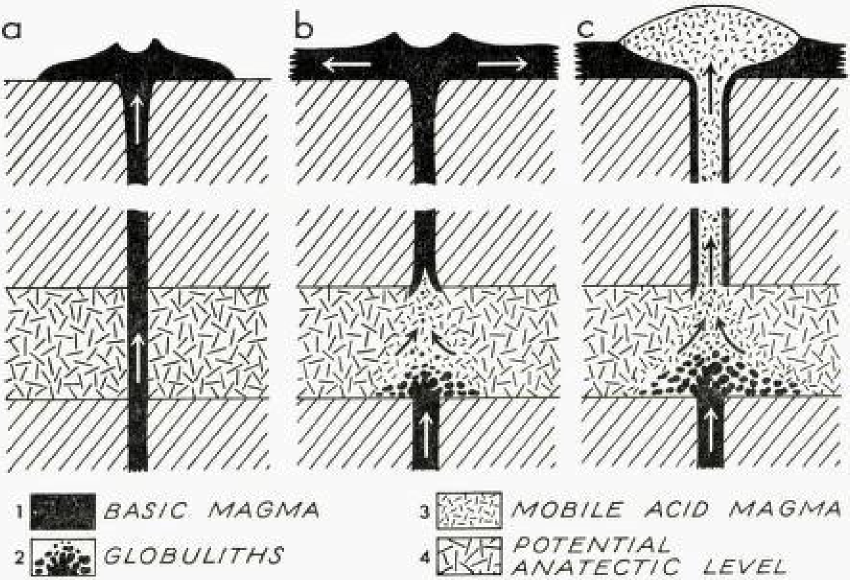

Fig. 6. Diagram showing the possible relation between deep level globulith (as in the Moss type area) and shallow level associations of basic and acid rocks. Redrawn from Blake et al. (1965) with minor changes.

area immediately raises the question whether or not this deep-level type of intrusive structure could be expected to occur in the metamorphic terrains of other regions.

It is most natural to start to look for globuliths among the basic rocks of the Bamle area SW of the Oslo graben, because for other reasons a structural continuity between this and the Moss area is to be expected. The gabbroic rocks of the Bamle area, often referred to as the hyperite group, grade from olivine gabbro and hyperites into schistose amphipolites (Bugge, 1943).

Judging from the rounded to bulbous outlines of the gabbroic bodies of, for example, the Søndeled district in the Bamle area (fig. 3 in Bugge, 1943, or fig. 2 in Barth and Bugge, 1960) and the apparent concordant contacts of the intrusions, it is tempting to suggest that these gabbroic and hyperitic bodies are globuliths. Going through Bugge's pertinent description, the author noted the following paragraph: «It is often difficult to say anything about the mechanism of intrusion, as it is impossible to know for sure to what extent the conformity has appeared during it» (Bugge, 1943, p. 40). Conceivably the idea of contact deformation was latent in Bugges's mind.

The cordierite-anthophyllite rocks occurring around the margins of the basic bodies of the Søndeled district were explained by Bugge by means of a Mg-metasomatism, the Mg having been leached from the amphibolites and gabbroic rocks. However, as recently suggested by Grant (1968), partial melting of common rocks could be a source of cordierite-anthophyllite-bearing assemblages, and since Grant explicitly refers to the Søndeled example, the author ventures to suggest that *contact* anatexis with ultimate restite formation could also explain the relative Mg-enrichment of these rocks.

The intrusive gabbro complex at Rackeby in SW Sweden (Stålhøs, 1958) also shows several features suggesting that at this locality it would be worth while testing the hypothesis formulated on basis of the Moss globuliths.

In this context, Blake, Elwell, Gibson, Skelhorn and Walker's (1965) point of view on intimate association of acid and basic magma fits like a key in the lock — if the Moss globuliths are looked upon as megapillows. The diagrammatic representation by Blake et al. of the possible relationship between, and origin of, a composite acid-basic complex of Austurhorn type is redrawn in fig. 6 with only slight modifications, the most important of which is that «Viscous acid magma» has been changed to «Potentitial anatectic level».

Following these lines of thought the Moss globuliths could be deep level analogues of the near-surface or surface examples of Austurhorn type. Some Moss globuliths, according to this scheme, would have originated in the potential anatectic level 4 of fig. 6, where the acid component will form the marginal or back-veining phase, while others examplify PT conditions corresponding to a somewhat higher level, where allochthonous anatectic material invades already solidified basic magma. The reason why several types representing different levels are represented side by side in one and the same terrain, is amongst others the wide time span covered by the invasion of basic magma.

But need globuliths or bodies suspected to be globuliths always consist of or contain basic rocks? Probably not. The shapes and contacts of several ultramafic bodies, which have usually been described as boudins without closer study, could also indicate that some ultramafic bodies were emplaced as globuliths. In surface exposures above the Kleveveg profile (Fig. 7) small basic globulithic bodies thus simulate the pattern

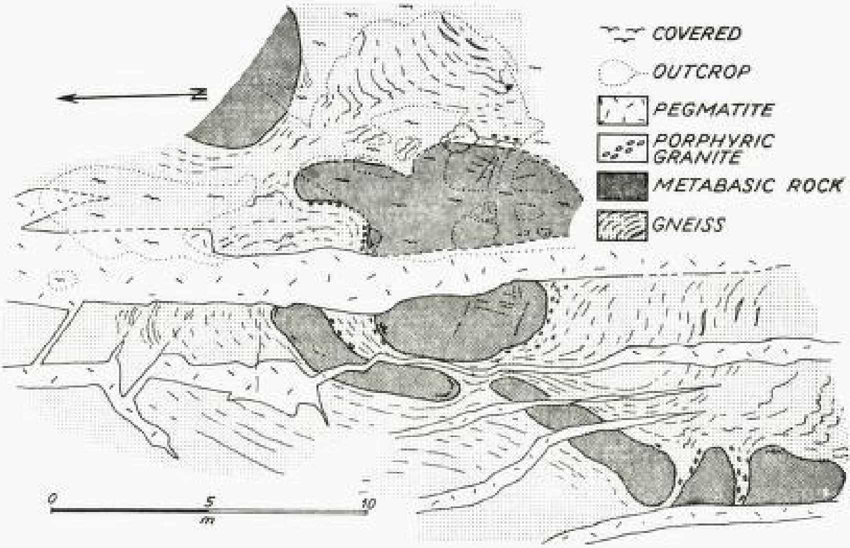

Fig. 7. Sketch map of exposures east of (and above) the Klevevegen profile (loc. A). Note how the small globuliths simulate boudin structures.

shown by great many ultramafic «boudins», and without the additional information obtainable in the vertical profils near by, these small basic globulithic structures no doubt would have passed on as boudins into the author's field notes.

However, returning once more the meaning of the German saying cited above it might in this context be relevant to recall its ironic undertone.

Coining the new term himself, the author ought to be the last to misuse it!

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Abbreviation: NGU = Norges Geologiske Undersøkelse.

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