

ASGER BERTHELTSEN AND T. N. N. MURTHY

STRUCTURAL RELATIONS
BETWEEN SUPRACRUSTAL AND
GRANITOID ROCKS
IN NORTH-EASTERN ORUST,
WESTERNMOST SWEDEN

WITH 13 FIGS. AND 1 PLATE



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CONTENTS

	Page
1. Introduction	4
1.1 Regional outlines	4
1.2 Acknowledgements and division of work	5
2. Lithology of the mapped units	6
2.1 The supracrustal schists and gneisses	6
2.2 The amphibolitic and hornblendic schists	6
2.3 The marginal, granitic gneiss	8
2.4 The augen gneisses	9
3. Description and analysis of the Assmunderöd structure	10
3.1 The median and southern parts	10
3.2 The northern part	11
3.3 The kinematic evolution of the granitoid body	18
4. The Myckleby structure and the supracrustals to the north	20
4.1 Structures of the Myckleby augen gneiss	20
4.2 Structures in the supracrustals north of the Myckleby augen gneiss	20
5. Kinematic correlations between the Assmunderöd and Myckleby structures	22
6. References	26

1. INTRODUCTION

1.1. Regional Outlines

The Precambrian bedrock of the two islands, Tjörn and Orust, north of Gothenburg (Göteborg), comprises two contrasting major rock units: 1, a series of supracrustal schists and gneisses, and 2, a "suite" of plutonic looking rocks among which granitoid rocks predominate.

The supracrustal rocks form part of the so-called Stora Le – Marstrand series. The rocks of this series extend in a N-S trending belt from east of Gothenburg, through Tjörn and Orust and northwards across the Swedish-Norwegian border into Østfold (Lundegårdh, 1951, 1953, 1958, and 1964; Bergström, 1963; Larsson, 1956; Magnusson, 1963). The rocks of this supracrustal series underwent folding and metamorphism during a pre-Gothian (probably Svecofennian) orogeny, and also suffered succeeding metamorphic and tectonic overprints (Lundegårdh, 1964, 1966; Magnusson, 1963).

The stratigraphic position of the granitoid and associated rocks of Tjörn and Orust is controversial. From Tjörn, Bergström (1963) describes the supracrustal rocks as overlying the granitoid rocks, the latter here mainly represented by granitic gneiss, augen gneiss and augen granite, and appearing in antiformal

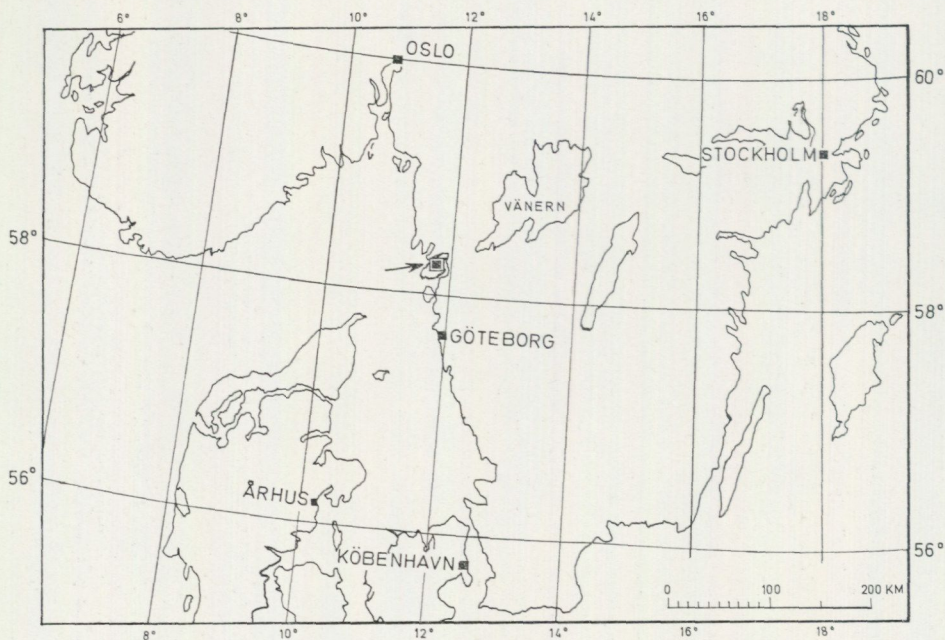


Fig. 1: Map showing location of Orust and the area covered by Plate 1.

structures. Bergström (op. cit.) interprets the granitoid rocks as formed through granitisation, in part leading to complete mobilisation, of the lower part of an originally thicker sequence of supracrustals. In places Bergström found relic graded bedding in the supracrustals showing that these normally face upwards, and he reports several cases of transitional contacts between the "lower" granitoid rocks and the "upper" supracrustals.

In the north-eastern part of Orust (see Fig. 1 and Plate 1) more complex structural relations between the "lower" and the "upper" units are met with; here the granitoid rocks both overlie and underlie the supracrustals.

The present investigation is an attempt to clarify this intricate structural setting, thereby contributing towards a better understanding of the emplacement of the augen gneisses.

1.2. Acknowledgements and Division of Work

The mapping of north-eastern Orust was started on the kind advice of Dr. Lars Bergström, Chalmers University of Technology, Gothenburg, who is wholeheartedly thanked for much help and inspiring discussions. The field work was undertaken by the junior author (T. N. N. M.) in the summers of 1966, 1967 and 1968, the senior author only paying shorter visits to the area. "Economic maps" at 1:10 000 (prepared directly from aerial photographs) served as a base for mapping, and only selected areas have been mapped in greater detail (1:2 000) on enlarged copies. The gentle and low relief of the region and the relatively large size of the structures mapped enabled us to perform a structural analysis, although no topographic contours are shown on the available maps.

The petrographic descriptions have been kept at a minimum, because the study of about 40 thin sections made it clear that Bergström's (1963) pertinent and detailed descriptions of the mineralogy of the rocks from the neighbouring island, Tjörn, also cover most of the Orust rocks.

Both authors have contributed to the structural analysis and interpretation, while the senior author had the main responsibility for the preparation of the manuscript.

During his study stay at the geological institutes of first Aarhus University and later Copenhagen University, the junior author has gratefully benefited from a scholarship from the Danish Ministry of Education and the Danish Ministry of Foreign Affairs. His sincere thanks also go to Mr and Mrs Allan Nilsson and Mrs Märta Jansson for their great hospitality at Slussen and Rålands.

We are both grateful to director, Dr. P. H. Lundegårdh, and State geologist, Dr. W. Larsson for inspiring guidance on excursions in adjoining parts of the western Swedish Precambrian.

2. LITHOLOGY OF THE MAPPED UNITS

2.1. The supracrustal schists and gneisses

In the north-western part of the area mapped (see Plate 1), supracrustal schists and gneisses circumscribe an elongated area made up of granitoid rocks, here called the *Assmunderöd structure*. South-east of this structure and only separated from it by a narrow belt of supracrustal rocks, granitoid rocks appear again in the larger *Myckleby structure* of which only the northern part has been mapped in detail. Reconnaissance work, however, suggest that it extends southwards beyond Varekil, i. e. close to Tjörn.

The supracrustal rocks of north-eastern Orust comprise mainly fine- to medium-grained schists and gneisses with conformable veins of quartz or quartzo-feldspathic material. Where the veins are particularly abundant, veined gneisses may result. The veins obey the same fold pattern as the enclosing, more finegrained rock and may show thickening in the hinges.

The most commonly occurring supracrustal rocks are rich in quartz (33–50 %), carry oligoclase as the dominant feldspar and usually contain both muscovite and biotite. The two micas, which are intergrown, may amount to 40–50 % in the schistose type, but may decrease to about 10 % in some gneisses. Potassium feldspar, epidote, sphene, apatite, zircon and opaque minerals form common minor or accessory constituents, while garnet is of more sporadic occurrence.

Locally, inpersistent layers of flaser- to augen-textured medium- to coarse-grained gneisses are met with in the supracrustal sequence. In such gneisses, microcline forms xenoblastic as well as interstitial grains, but oligoclase is still the dominant feldspar, and muscovite prevails over biotite.

2.2. The Amphibolitic and Hornblendic Schists

Amphibolitic and hornblendic schists have been encountered at several localities in both supracrustal and granitoid rocks. Their schistose structure is mainly caused by preferred nematoblastic development of hornblende and lepidoblastic biotite. In general, hornblende constitutes some 40–60 %, plagioclase 30–15 %, while biotite is found in highly varying amounts and garnet may or may be not present. Quartz usually forms 5–10 %, and epidote minerals, sphene, apatite and opaque minerals are minor or accessory constituents. The plagioclase usually is a somewhat saussuritised oligoclase (c. 20 % An), but in larger and zoned grains An contents up to 40 % have been found. Extremely hornblende-rich types may be devoid of plagioclase, but then carry about 10 % of clinozoisite. Secondary chloritisation and introduction of carbonate minerals may be seen in some thin sections.

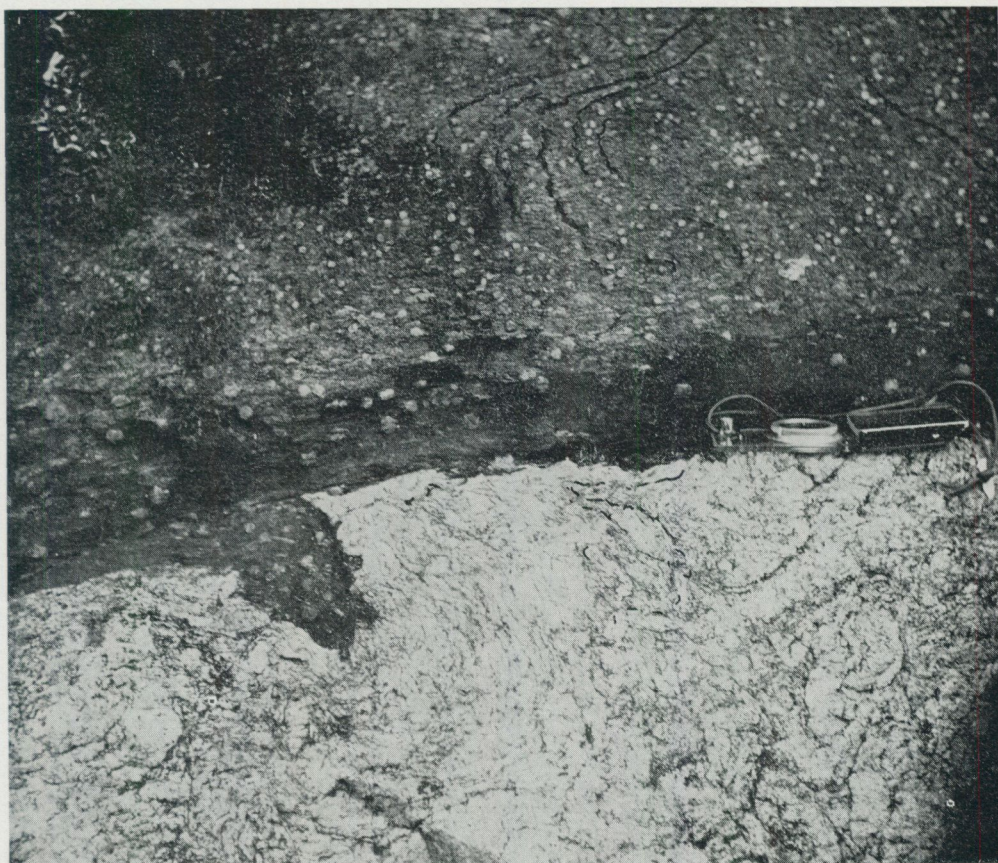


Fig. 2: Internally folded garnet amphibolite showing relic intrusive contact towards folded and veined supracrustals. About 2 km north of Skala, west flank of A-A₁ structure (see Fig. 11).

Several field observations – this counts also for west Orust (A.B.) – indicate that these basic schists fall into two groups of different ages:

a, Some amphibolites may be considered part of the supracrustal sequence, since they contain conformable veins or layers of quartzo-feldspathic material and are conformably intercalated with and folded together with supracrustal rocks.

b, Although schistose and internally folded, other amphibolites show no sign of migmatitic veining, but exhibit relic intrusive contacts towards veined and folded supracrustals (Fig. 2) or towards augen-bearing granitoid rocks (Fig. 4). This group of amphibolites most probably originates from basic sills or dykes, the intrusion of which *postdates* an older plutonic episode with folding, metamorphism and emplacement of granitoid rocks, and which *predates* a younger episode with deformation and metamorphism.



Fig. 3: East coast of small bay at Slussen. In the lower part of the cliff thin schist layers in granitic gneiss; higher up more massive granitic gneiss with scattered augen.

2.3. The Marginal, Granitic Gneiss

The granitoid rocks of the Assmunderöd structure have a marginal belt of pink to grey, medium-grained, granitic gneiss with an outcrop width varying from less than one to more than 500 metres. Its contact to the supracrustals is well defined and may also be well expressed in the morphology (Fig. 3). The contact to the augen gneiss, which occupies the central (and major) part of the structure, is transitional and is indicated by an increase in augen, grain size, and mafic constituents. In spite of its gradational nature, this contact is often well marked in the landscape.

The marginal, granitic gneiss is leucocratic, its mafic constituents, muscovite and/or biotite, rarely exceeding 5 % of the rock. Among the light minerals, quartz makes up between 35 and 40 %, microcline about 50 %, while plagi-

clase (albite-oligoclase) only amounts to some 10 to 15 %. Sphene, apatite and zircon form sparse accessories.

Up to 100 metres long and 10 metres wide lenticles of a similar granitic gneiss have also been found locally along the margin of the Myckleby structure, but not as a continuous layer.

2.4. The Augen Gneisses

Although the augen gneisses of the Assmunderöd and the Myckleby structures are fairly similar as to their mineralogical composition, they show textural differences.

In the Assmunderöd augen gneiss, the shape of the augen contributes a strong lineation to the rock. When viewed in the direction of the lineation, the augen are rounded (3–5 cm in diameter) or are drawn out and flattened in the plane of the foliation. The more sheared and foliated types are usually met with in the outer part of the augen gneiss body.

The augen gneiss of the Myckleby structure is less coarsegrained, slightly richer in mafics and often contains smaller augen (about 2 cm) indicating a foliation but being devoid of linear arrangement. In strongly sheared varieties, however, a lineation has been produced. Close to its contact, the Myckleby



Fig. 4: Xenolith of supracrustal, fine-grained gneiss in marginal facies of Myckleby augen gneiss; near Näs.

augen gneiss contains xenolithe of supracrustal rocks (Fig. 4) similar to the ones described by Bergström (1963) from the augen granite of Tjörn.

The augen gneisses of the Assmunderöd and the Myckleby structures both vary from granitic to granodioritic composition. Most augen are glomeroblasts made up of microcline, plagioclase and quartz (or of solely the last two minerals), but poikiloblastic development of microcline is evident in some augen, and one-grain augen of microcline have been observed as well. Along the margins of drawn out and elongated augen, blastocataclastic textures are present. The plagioclase is a sericitised oligoclase with a more clear albitic rim, and in places it is strongly corroded by microcline, and myrmekite is abundant. The larger quartz grains show undulatory extinction. The mafics rarely exceed 15 % of the rock. Besides biotite, which may be chloritised, muscovite occurs in small quantities in some specimens. Poikiloblastic or sieve-textured grains of garnet occur in a few samples. Epidote and metamict allanite form common minor constituents, while sphene, apatite, zircon and opaque minerals are found as accessories.

The only mineralogical difference that has been noticed between the Assmunderöd and the Myckleby augen gneiss is that in the latter apparently untwinned grains of perthitic potassium feldspar occur side by side with poorly or typically cross-hatch twinned microcline. From the augen gneisses of Tjörn, Bergström (1963) describes both twinned and untwinned microclines.

3. DESCRIPTION AND ANALYSIS OF THE ASSMUNDERÖD STRUCTURE

3.1. The Median and Southern parts

The complexity of the Assmunderöd structure makes it necessary to describe its medium, southern and northern parts separately. The median part of the structure is defined as that part lying north of the two lakes Assmunderöd-vatten and Grindsbyvattnet and south of a line from Ödsmål to Backa (see Plate 1).

The median and southern parts of the Assmunderöd structures can be considered as the core of a (more or less) S-plunging antiform, which is mantled by supracrustals and is strongly overturned to the west. Due to the southward plunge of this structure, the marginal granitic gneiss shows a nose just north-east of Gård. In the western part of the structure, the overturning has caused the granitic gneiss to overlie supracrustals, while in the east (between Backa and Grindsbyvattnet) it dips "normally" below supracrustals.

In the median part of the Assmunderöd structure there exists a close agreement between the orientation of measured linear elements and that of the axes constructed from foliation readings of different subareas. The attitude

of the foliations measured in the marginal gneiss of the overturned western flank tends to be parallel to the axial plane of the overturned antiform.

In the southern part, however, more complex relations are met with. Here, a younger refolding producing open folds with E-plunging axes have been superimposed on the originally S-plunging tight hinge zone of the antiform. The style of these superimposed folds is well demonstrated by the sinuous course of the gneiss-supracrustal contact south-west of Grindsbyvattnet. Stereograms drawn from subareas in and around the southern nose therefore only reveal π -zones corresponding to E-plunging axes.

The superimposed nature of the E-plunging folds is brought out by the fact that the more or less axial-plane-parallel foliation, which developed in the marginal granitic gneiss in response to the rise of the overturned antiform, has become folded on E-plunging axes here in the south. That the refolding also worked on a smaller scale can be seen from the microfolded augen occurring scattered in the granitic gneiss exposed in the eastern part of the nose (north-east of Gård).

Disregarding the younger refolding, the general picture thus arrived at is that the granitoid rocks of the median and southern parts of the Assmunderöd structure are involved in a relatively simple antiformal structure. To the east, this antiform is limited by supracrustals occupying a narrow synform which also shows more or less S-plunging axes and is overturned to the West; this makes granitoid rock reappear in the neighbouring Myckleby structure. In the south the synform is also influenced by the younger refolding as is also the antiform close by.

3.2. The Northern Part

Turning now to the northern part of the Assmunderöd structure, it is soon realised that the general picture of a simple antiformal structure no longer holds good. Just north-west of Backa, a large-scale infolding of the marginal granitic gneiss and the supracrustals is noticed. This infolding is inconsistent with the general antiformal shape of the granitoid body, although it obeys the same S-plunging axes as the main antiform.

The profile along the road leading eastwards from Slussen and its immediate surroundings presents further complications. In the western, overturned flank of granitic gneiss the measured foliations take the attitude of a S-plunging, asymmetric fold which indicates a drag with a sense opposite to what would be expected in an overturned antiformal flank. We shall return to the probable origin of this aberrant fold at a later stage in the analysis, meanwhile only recalling that the folded foliation may be considered to have developed originally as an axial-plane-slip foliation.

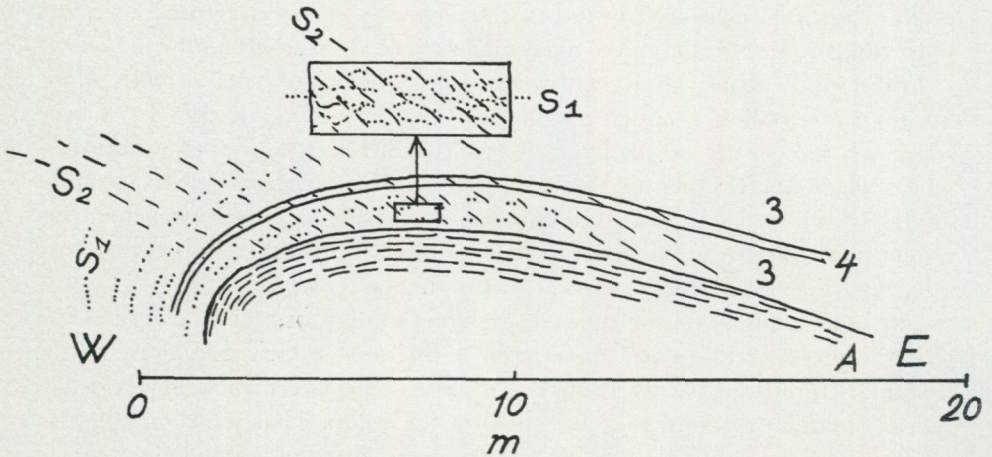


Fig. 5: Field sketch from the profile along the road north of Brunnefjäll showing the antiformal crest indicated by a sheet of amphibolite (A) and an aplite (4). The attitude of the S_1 and S_2 foliations observable in the augen gneiss (3) is indicated.

In this connection, the small scale folds developed in the supracrustals underlying the granitic gneiss west and northwest of Slussen must be considered. The asymmetry of these folds suggests that they are drag folds formed in an overturned, antiformal flank.

In the road section through the central part of the granitoid body (east of Slussen and north of Brunnefjäll) an antiformal arrangement of the augen gneiss becomes evident. The foliation thus takes a vertical position in the augen gneisses of the western, overturned part, and in the central core of the structure a westwards-tilted antiform can be seen.

This antiformal crest is made the more prominent by the occurrence of an amphibolite "layer" and a "layer" of aplite (Fig. 5). Both the aplite and the amphibolite are semi-concordant to a foliation (S_1) in the augen gneiss, and, like this foliation, they take part in the antiformal bend. In the augen gneiss, a foliation (S_2) more or less parallel to the E-dipping axial plane of the main antiform is moreover discernible. The 3–5 cm large augen of the gneiss are so-to-speak disposed in the space left in between the two intersecting sets of foliation planes, and the augen are strongly elongated in a direction parallel to the line of intersection between the S_1 and S_2 planes. The imperfect parallelism between the S_2 foliation planes and an "ideal axial plane" is clearly seen in the stereograms drawn from this part of the structure, because the lineations measured on augen show a wide scatter and also show shallow southerly plunges, while the axes constructed from readings of folded S_1 foliations show a constant and horizontal orientation.

During its folding, the amphibolite has developed a marked contact-parallel

foliation and schistosity. The total absence of an S_2 foliation in the amphibolite most probably is due to the greater ability of this rock to deform by means of contact-parallel flexural slip during those stages of deformation where slip movements produced the S_2 planes in the enclosing augen gneiss.

In detail, the amphibolite is slightly discordant to the S_1 foliation and it shows a sharp (although sheared) contact to the augen gneiss. Furthermore, there are no signs indicating that the basic rock has been exposed to feldspar-blastesis, granitisation or migmatitisation. All these relations suggest that the basic rock originally was a sill intruded into foliated augen gneiss, and that subsequently it became deformed and amphibolitised when, during a second episode of deformation, the tilted to overturned antiform with its related S_2 axialplane foliation arose. The amphibolite, therefore, could well correspond to the younger group of amphibolites which truncates the folded migmatitic veins in the supracrustal (see p. 7).

If this line of thought is correct, we have to face the possibility that the anti-formal shape of the granitoid body in the core and upper part of the Assmunderöd structure is younger than those processes which caused the original emplacement of the granitoid rocks within the supracrustals.

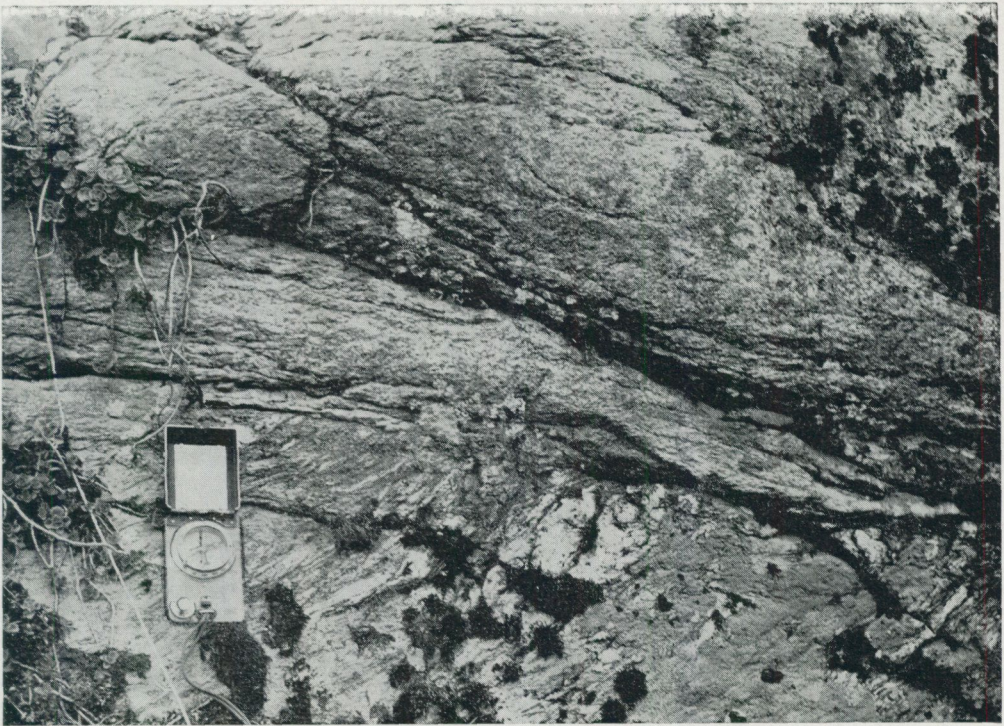


Fig. 6: Contact between intrusive aplite (upper half) and folded and veined supracrustals. South-east of Brunnefjäll and north of Backa, near house south of the Slussen-Syltenäs road,

Such a conclusion would depart considerably from the explanation offered for the granitoid rocks of Tjörn by Bergström (1963); according to Bergström the intensity of granitisation and feldspar-blastesis here was structurally controlled so that conversion of supracrustals into granitoid rocks took place principally in the anticlinal cores.

The possibility suggested above, that the structural development of the granitoid rocks comprises both an older and a younger episode, is supported by several observations on aplitic rocks occurring in and around the Assmunderöd structure. These aplites generally form sheets or sills and show intrusive relationships towards augen gneiss, the marginal granitic gneiss and the migmatitic supracrustals, but they are nevertheless influenced by younger deformation. Unfortunately, we have not found any intersection between aplites and amphibolites of the younger group, but we believe that the aplites



Fig. 7: Xenolith (X) of granitic gneiss in sheared, intrusive sheet of aplite. The lineation produced by the shearing shows southerly plunge. Locality close to that of Fig. 6.

were intruded prior to these amphibolites, i. e. towards the end of the first plutonic episode as a last expression of the processes causing the formation or *mise-en-place* of the main granitoid bodies.

Intrusive aplite occurs in the extreme southernmost part of the Assmunderöd structure, where it contains a big displaced inclusion of supracrustal schists. In the northern continuation of the infolded marginal granitic gneiss (north of Backa) a mappable sheet-shaped intrusion of aplite is found. This aplite truncates the folded veins of the supracrustals (Fig. 6) and contains xenoliths of granitic gneiss (Fig. 7). The aplite itself, however, is sheared and has become foliated and lineated. Its foliation is parallel to the axial planes of the small folds of the surrounding supracrustals, and its lineation is parallel to the axes of these folds (Fig. 7). The foliation affecting the aplite most probably can be compared to the S_2 foliation described above from the road section east of Slussen.

Aplites are also well exposed in the coastal cliffs south of Slussekilen, where the contact relations in the northernmost part of the Assmunderöd structure can be studied; Fig. 8.

North-east of Brunnefjäll, the outer contact of the marginal granitic gneiss takes a steeper position and becomes overturned before traced on to the coast of the eastern head of Slussekilen. On the north coast of the small, broad peninsula separating the eastern and western heads of Slussekilen, the marginal granitic gneiss is missing and the augen gneiss is in direct contact with underlying supracrustals. The contact is here strongly tectonised. Granitic gneiss appears again on the west coast of the peninsula, dipping eastwards below the augen gneiss occurring higher up in the cliffs.

This northernmost profile through the Assmunderöd structure thus gives the impression that the granitoid rocks synformally overlie the supracrustals, and this synform appears to be in structural continuity with the antiform of the median and southern parts of the structure. The overturned antiform described from the road section north of Brunnefjäll may thus be expected to contain synformal hinges in both flanks (cf. Fig. 9, III).

The supracrustals underlying the augen gneiss on the middle part of the peninsula on the south coast of Slussekilen are traversed by a metre-thick, semi-concordant sill of garnetbearing aplite which cuts off the lineated and stretched veins in the supracrustals but which nevertheless is influenced by posthumous shearing and is foliated. A little further west on the same peninsula an aplite (probably in continuation with the one just mentioned) is thrown into almost isoclinal recumbent folds together with the enclosing supracrustals. In spite of this folding, which obeys shallowly S-plunging folds, the locally cross-cutting contacts of the aplite are still observable and it can even be seen that the contacts truncate older S-plunging fold patterns in the schists (Fig. 8).

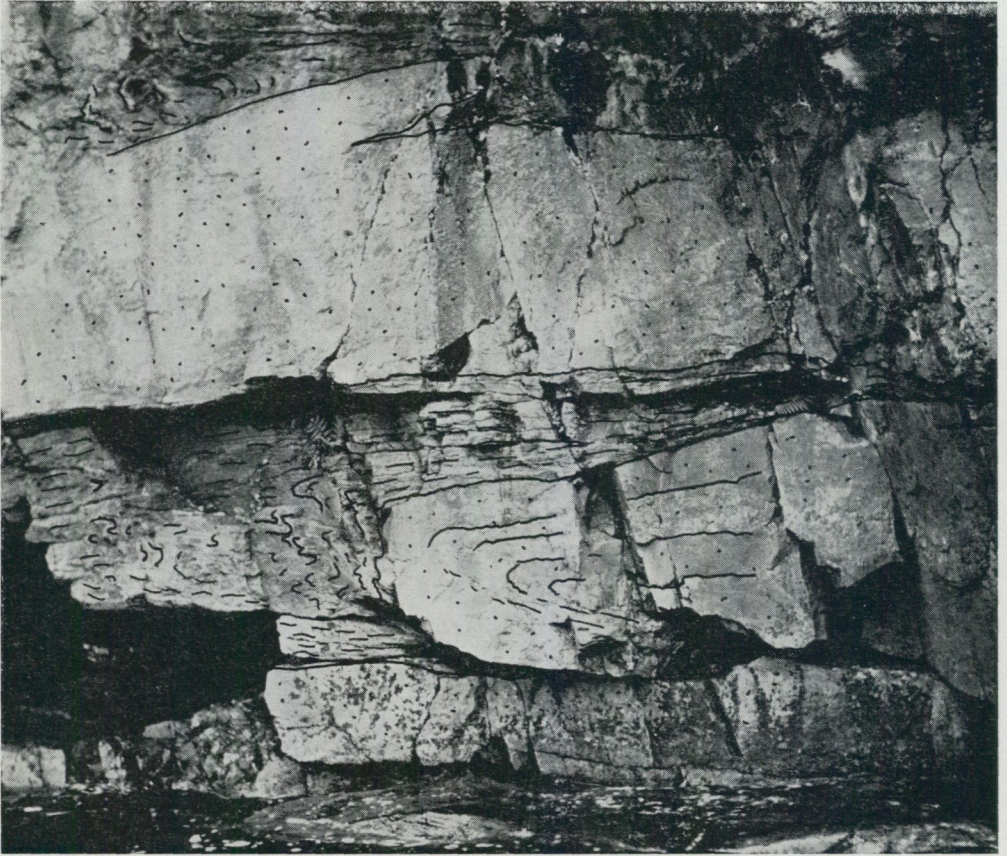


Fig. 8: Isoclinally folded aplite of intrusive origin in supracrustal schists. Western part of small peninsula on south coast of Slussekilen. Note that the aplite cuts off older folds in the schists. View towards south, i.e. the section is perpendicular to the fold axes. The exposure is about four metres high.

In the well foliated gneiss along the coast north-east of Slussen, thin semi-concordant sills of aplite are common. In places they have been sheared out into metre-long lenticles arranged with their longer axis parallel to the marked lineation developed in the augen occurring scattered in the surrounding gneiss where pegmatites with pinch-and-swell structures as well as irregular pods of pegmatite and quartz are also seen. Near Slussen the gneiss contains in addition narrow bands (isoclines?) of supracrustal rocks (Fig. 3). One such "layer", 25 cm broad, consists of an almost pure, finely banded quartzite, the only genuine quartzitic supracrustal rock so far met with in the mapped area.

The structures of the aplitic sills exposed in the section along Slussekilen just described therefore indicate that the post-aplitic deformation exerted its strongest influence along the western part of the granitoid structure. As stated

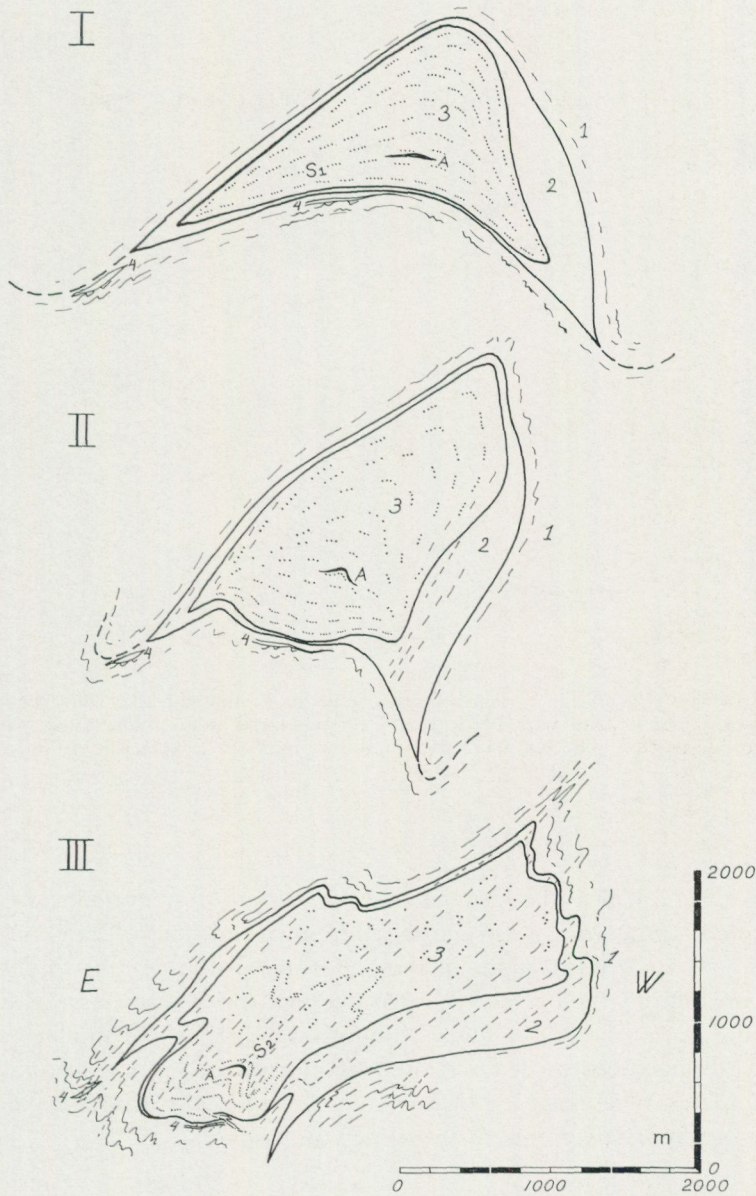


Fig. 9: Tentative reconstruction of the kinematic evolution of the Assmunderöd structure. I: phacolithic body emplaced during 1st episode of deformation. 1: folded and veined supracrustals; 2: granitic border facies; 3: S₁ foliated augen gneiss; 4: intrusive aplite, A: basic rock intruded semiconcordant to S₁. II and III: successive stages developed during the 2nd episode of deformation. By means of flow and shear folding the phacolithic body becomes squeezed into its present shape (III). All profiles are drawn perpendicular to the axes and on the assumption that the granitoid body kept a constant volume.

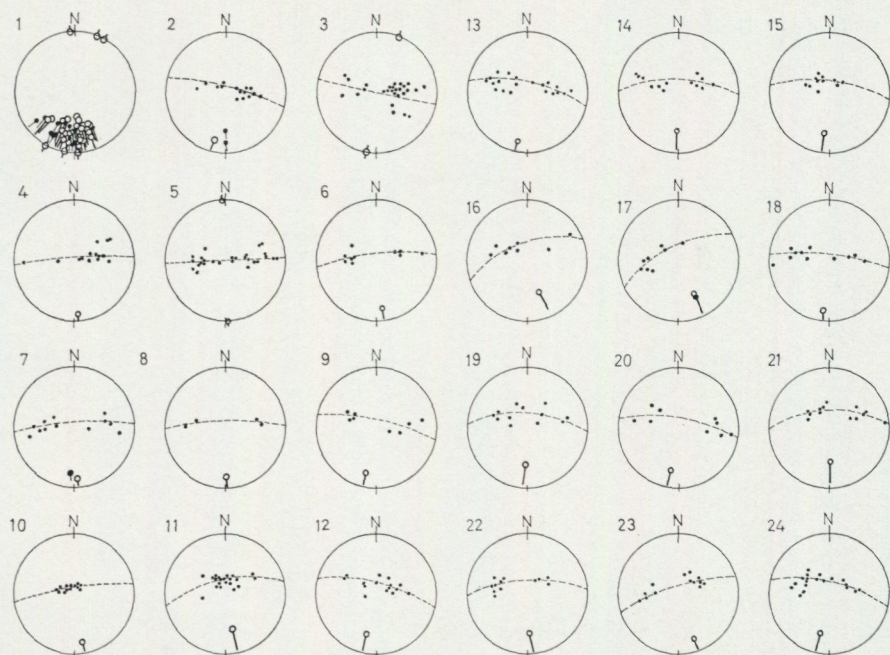


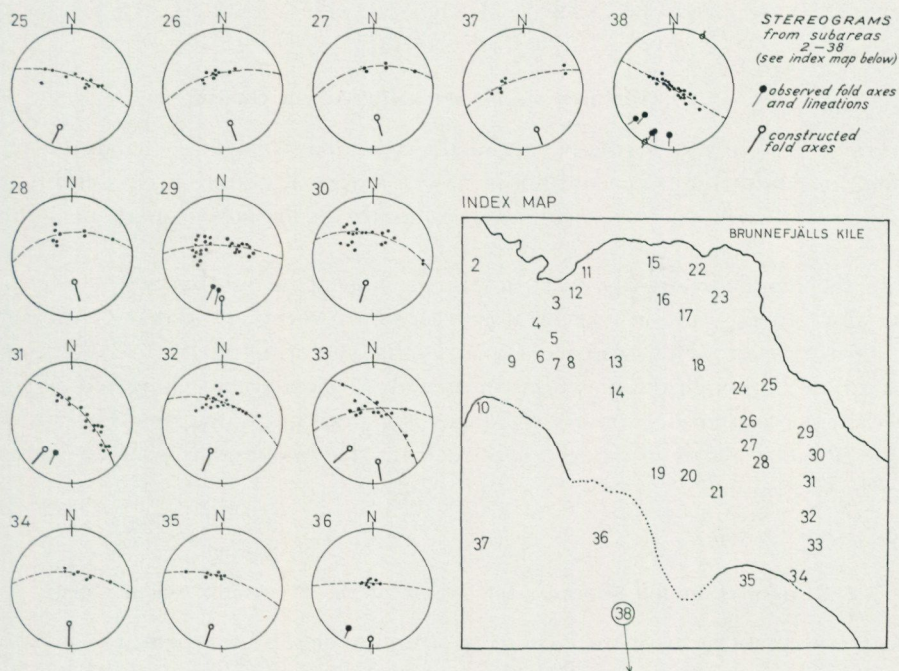
Fig. 10: Stereograms from the various subareas south of Brunnefjäll kile. Dots denote foliation/schistosity poles. Axes with black heads are measured small folds, those with open circles are constructed. The constructed axes shown in Plate 1 were derived in a similar manner.

above, we have to face the fact that the northernmost synformal part of the Assmunderöd structure is in structural continuity with the median and southern parts. Apart from a slight increase (from north to south) in the axial plunge, the entire structure and its surroundings appear homoaxial, although this feature obviously hides a metachronous development of similarly oriented axes and lineations as demonstrated by means of the young amphibolites and the aplites. The existence of homoaxially refolded isoclines in the surrounding supracrustals points to the same conclusion.

3.3. The Kinematic Evolution of the Granitoid Body

At this stage in the analysis we will return to the two aberrant structures so far left unexplained, but nevertheless crucial for the understanding of the disharmonic shape of the main structure.

How could an almost cylindrical body with combined antiformal and synformal shapes develop?



We can suggest no other solution than this one: the Assmunderöd structure owes its particular development to deformation of an originally phacolithic body from which the marginal wedging-out on the flanks is inherited in the "tails" shown by the so-called aberrant structures north of Backa and north of Slussen. These "tails" contribute a sort of arrow-head or arrow-point shape to the main structure (cf. Kranck, 1957, 1959).

This interpretation has been further specified in Fig. 9, where the successive stages of such an evolution have been sketched. As a starting point we could have chosen either a laccolith or a phacolith. The approximately cylindrical shape of the resulting structure urged us to prefer the latter alternative (see I of Fig. 9). Doing so, we were also able to explain the formation of the older foliation (cut by the young amphibolites and the aplites) as a synkinematic foliation formed during the mise-en-place of the phacolithic body, and we retained a possibility of combining Bergström's ideas on the origin of the granitoid rocks with our own line of thought if we admitted the possibility that the phacolithic body formed due to structurally controlled granitisation. On this assumption the only difference between Bergström's and our interpretation would be that he tells the first and we tell the last part of *one* long story.

4. THE MYCKLEBY STRUCTURE AND THE SUPRACRUSTALS TO THE NORTH

4.1. Structures of the Myckleby Augen Gneiss

Turning now to the northern part of the Myckleby structure, it may be recalled that in this unit no continuous belt of marginal granite occurs and that supracrustal rocks have been found as xenoliths in the augen gneiss near the contacts, e. g. close to Näs.

In the mapped part of the structure the augen gneiss appears to overlie the supracrustals, and in its central part, around Skörbo and Bågane, an open synform is seen. The constructed axis in this synform trends 30–210, being horizontal, although the lineations measured on sheared and elongated augen show wider scatter and southerly plunges (see stereogram no. 38 in Fig. 10 b). This situation recalls the one described from the Assmunderöd augen gneiss north of Brunnefjäll.

4.2. Structures in the Supracrustals North of the Myckleby Augen Gneiss

Do the mapped parts of the Myckleby structure simply represent a duplicate of the synformal, northern end of the Assmunderöd structure? In order to answer this question properly, the area of supracrustals lying north of the Myckleby structure and south of Brunnefjälls Kile has been surveyed more closely.

Because well defined marker horizons are not present the larger structures of the supracrustals can only be reconstructed by means of the mesoscopic patterns. The mapping (1:2 000) therefore included a detailed tracing of the banding and foliation in all exposures, in addition to observations on the attitude of drag folds and parasitic folds, and as complete as possible a coverage with structural readings.

In the resulting (here reduced) map Fig. 11, the observed outcrop pattern is drawn as full lines, while broken lines represent the probable extension into areas of no exposure. Fold axes have been constructed from different subareas in order to facilitate the structural interpretation. As seen from the combined stereogram (no. 1 in Fig. 10 a), the orientation of constructed axes conforms to that of the observed, although the latter show a wider scatter.

This detailed analysis brings out that in spite of the homoaxial relation between the Myckleby granitoid rocks and the adjacent supracrustals, the folds of the supracrustals can *not* be traced continuously from the coast of Brunnefjälls Kile southwards to the contact of the Myckleby structure. This is best evidence by the folds, the axial plane traces of which are lettered A–A₁, B–B₁, and C–C₁ (Fig. 11). In these complex folds, an antiform in the north changes through fan- or X-shaped patterns into a synform before the granitoid

contact is met with in the south; the synforms in the north change correspondingly through eyed structures into southern antiforms. Naturally, these three well documented cases were of great importance for interpreting the outcrop patterns in intervening areas of no exposure, and also for the drawing of the otherwise conjectural "median line" X-Y denoting the trace of an imaginary symmetry plane placed through neighbouring iso-plunging axial depressions evidenced by the fan-shaped and eyed outcrop patterns and their associated conjugate folds.

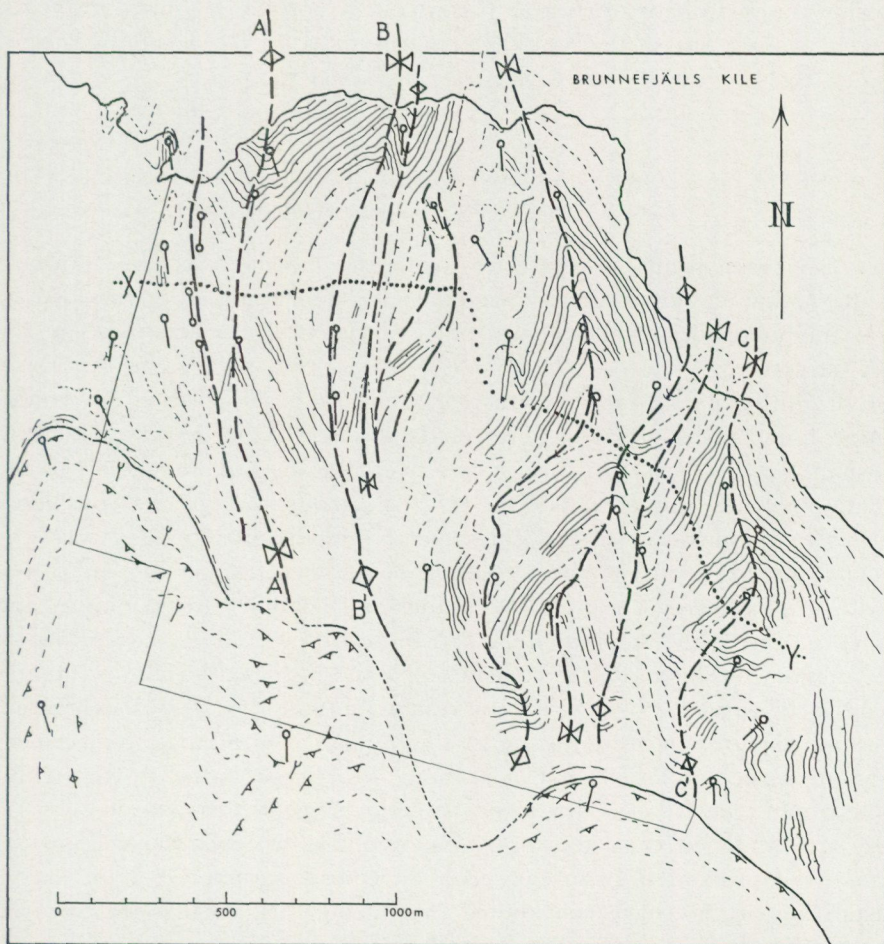


Fig. 11: Outcrop pattern in the supracrustals north of the Myckleby structure (compiled from mapping at 1:2000). Heavy broken lines indicate the traces of axial planes (A-A₁ etc.) of major antiforms and synforms. The dotted line X-Y ("median line") denotes the position of the iso-plunging axial depression in neighbouring structures. The fold axes are constructed (cf. the stereograms of Fig. 10); in the augen gneiss measured lineations are shown as well. The thin frame indicates the area covered by the tectonogram of Fig. 12.

In general, poor exposures around the "median-line" X-Y prohibit closer tracing of the actual turn-over around the symmetry plane of this supposed iso-plunging axial depression, but locally changes in plunge and trend suggest its presence.

This analysis, we think, makes it feasible, 1: that the southerly dips of the northern Myckleby structure evolved by means of an overturning and inversion of the contact caused by a diapiric rise of the Myckleby augen gneiss, 2: that this diapirism took place *after* the generation of an approximately N-S trending set of folds in the supracrustals because the iso-plunging, axial depressions most probably formed as a consequence of the oblique, northward-directed diapiric rise of the Myckleby augen gneiss. In the generalised tectonogram Fig. 12 we have tried to illustrate this conception.

5. KINEMATIC CORRELATIONS BETWEEN THE ASSMUNDERÖD AND MYCKLEBY STRUCTURES

How can these events be correlated with the kinematic scheme outlined for the Assmunderöd structure? The only means of doing so is provided by the amphibolites occurring amongst other places, in the supracrustals of the A-A₁ structure.

In the antiformal part of this structure, i. e. close to the north coast, amphibolite is found as sheared, semi-conformable sheets, while in the more southern, fan-shaped part of the structure, it has a definite discordant relation to the structures of the supracrustals (Fig. 1). If these observations are considered conclusive, the intrusion of the (subsequently amphibolitised) basic rock can be dated as younger than the formation of the axial depression. In consequence, the syntectonic growth of hornblende, foliation-parallel biotite, and garnet noticed in the amphibolite, could be related to the second episode of deformation. As shown by the barrel-shaped and S-shaped helicitic structures found in the garnets, this deformation resulted in flattening as well as internal rotation. The growth of biotite across the foliation and ultimate replacement of biotite by potassium feldspar (also filling microscopic veins) in the amphibolite would then fall in a late- to post-tectonic stage of this episode.

Apart from its effect on the young amphibolites, the second episode of deformation also exerted an influence on 1st episode structures of the supracrustals and it may have contributed to effacing their small scale features. This may be the reason why the earlier formed iso-plunging axial depression, although still being visible in the megascopic pattern, is only partially reflected by the small scale structures observable now (cf. Fig. 10 a and b).

We therefore think that the complex situation in the supracrustals north of the Myckleby granitoid body can be ascribed to the diapiric rise of the granitoid rocks of this unit during a final stage of the first episode of deformation.

The diapiric mobilisation of the granitoid rocks could then have been contemporaneous with the formation of the migmatitic veins in the bordering supracrustals as well as with the locally strong pegmatitisation attached to the complex structures around the "median line" X-Y, since this pegmatitisation has nowhere been found to influence the younger amphibolites.

It would now be tempting to try to *combine* what has been described and deduced from *each* of the granitoid structures into a *common kinematic picture*, although doing so we admittedly pass on to a more speculative stage in the analysis.

The more or less forceful diapiric emplacement of the Myckleby augen gneiss could then be linked with a simultaneous protrusion of granitoid rocks into a higher level, causing here the lateral emplacement of a phacolithic body

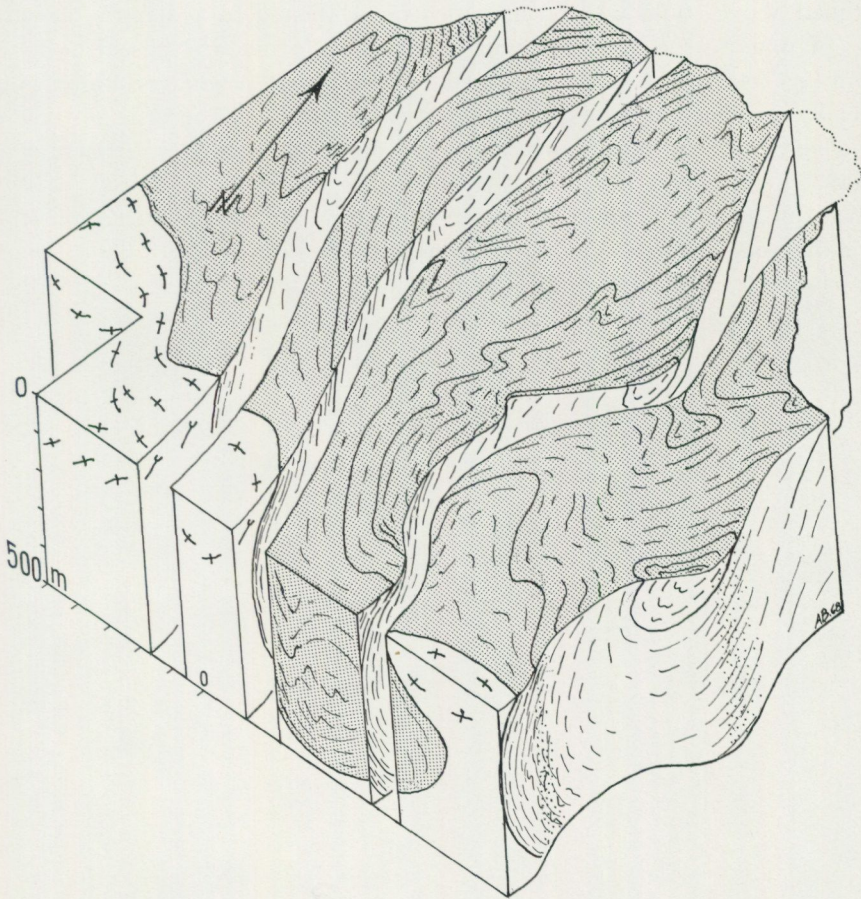


Fig. 12: Tectonogram illustrating the interpretation of the structures north of the Myckleby augen gneiss. For location see Fig. 11.

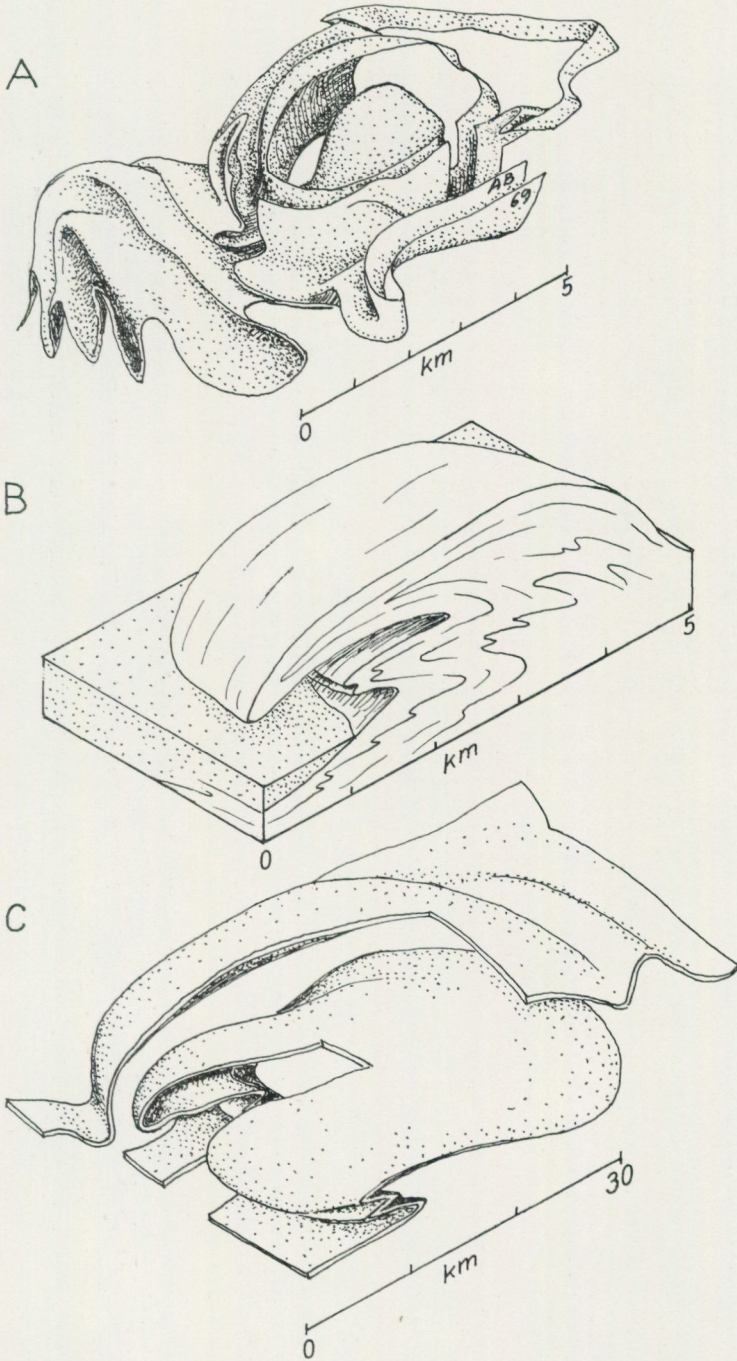
with a border facies of medium-grained granitic rocks and a central part of augen gneiss. In other words, the Assmunderöd structure could be viewed as representing the missing – now eroded – top part of the Myckleby structure.

It could be argued that the lateral component of the suggested diapiric movement is top great, but lateral spread of mobilised material is commonly met with in both halokinesis and granite diapirism as already stressed by Wegmann (1930) in his classic paper on diapirism in crystalline terrains. Impressive examples of mushroom- and lobe-shaped migmatite structures with lateral migration of mobilised material have also been described from the Caledonides of East Greenland (e. g. Haller, 1955, 1956), and tilted dome structures suggesting obliquely directed diapiric movements are known to occur in highly metamorphosed gneiss regions (see e. g. Escher and Burri, 1967, and Berthelsen, 1960). For comparison, these examples are shown in Fig. 13.

The kinematic evolution of the granitoid bodies of northeastern Orust outlined above could well be imagined to be related to a diapiric mobilisation of granitic rocks once forming part of a "primitive" basement to the Stora Le – Marstrand supracrustals, and actually such original relations would offer a relatively simple explanation of the structures observed, and are reconcilable with the results of the modern model-scale-true experimental tectonics (cf. Ramberg, 1967).

It is our hope that this contribution may stimulate further interest in structural mapping of more extensive regions, so that more evidence for or against the basement-cover hypothesis (Magnusson, 1963, p. 152) can be gathered.

Fig. 13: Examples of diapirically influenced structures. A: Tilted dome formed in larger recumbent structures, Tovqussaq area, W Greenland (redrawn from Berthelsen, 1960). B: Lobe-shaped structure where migmatites protrude into suprastructural rocks, Caledonides



of E Greenland (redrawn from Haller, 1956), C: Laterally migrating gneiss dome, NW Greenland (redrawn from Escher and Burri, 1967). All three diagrams are redrawn to be viewed from a similar angle.

6. REFERENCES

- BERGSTRÖM, L., 1963: Petrology of the Tjörn area in western Sweden. *Sveriges geol. Unders.*, Ser. C, Nr. 593. Årsbok 57, Nr. 4.
- BERTHELSEN, A., 1960: Structural studies in the Pre-Cambrian of western Greenland. Part II: Geology of Tovqussap nunå. *Meddr Grönland*, Bd. 123, Nr. 1.
- ESKOLA, P. E., 1949: The problem of mantled gneiss domes. *Quart. J. geol. Soc. Lond.*, Vol. 104, 461-476.
- ESCHER, A & BURRI, M., 1967: Stratigraphy and structural development of the Precambrian rocks in the area north-east of Disko Bugt, West Greenland. *Rapp. Grönlands geol. Unders.*, Nr. 13.
- HALLER, J., 1955: Der "Zentrale Metamorphe Komplex" von NE-Grönland. Teil I. *Meddr Grönland*, Bd. 73, Nr. 3.
- 1956: Probleme der Tiefentektonik: Bauformen im Migmatit-Stockwerk der ostgrönlandischen Kaledoniden. *Geol. Rdsch.*, Bd. 45, 159-167.
- KRANCK, E. H., 1957: On folding-movements in the zone of the basement. *Geol. Rdsch.*, Bd. 46, 261-282.
- 1959: Rock structures and fabric in the zone of plastic deformation. Rep. 20th Intern geol. Congr. Mexico, Section XI-A, 133-150.
- LARSSON, W., 1956: Kartbladet Värвик. *Sveriges geol. Unders.*, Ser. Aa, Nr. 187, 10-127.
- LUNDEGÅRDH, P. H., 1951: Petrology of the Onsala peninsula south of Gothenburg in western Sweden. *Geol. Fören. Stockh. Förh.*, Bd. 73, 161-199.
- 1953: Petrology of the Mölndal-Styrsö-Vallda region in the vicinity of Gothenburg. *Sveriges geol. Unders.*, Ser. C, Nr. 531. Årsbok 47, Nr. 2.
- 1958: Göteborgstraktens berggrund. *Sveriges geol. Unders.*, Ser. C, Nr. 553. Årsbok 51, Nr. 4.
- 1964: Sydvästra Sveriges äldsta gnejser. In Lundegårdh, P. H., Lundqvist, J. & Lindström M.: *Berg och jord i Sverige*. 56-141. Stockholm: Almqvist & Wiksell.
- 1966: The crystalline basement of Fennoscandia and its relation to other parts of Europe. *Freiberger Forschungshefte*, C 210 Sonderveranstaltungen, 85-91, Leipzig.
- MAGNUSSON, N. H., 1963: In Magnusson, N. H., Lundqvist, G. & Regnell, G.: *Sveriges geologi*. (4th edit.) 1-201. Stockholm: Svenska Bokförlaget.
- RAMBERG, H., 1967: Gravity, deformation and the Earth's crust. London and New York: Academic Press.
- WEGMANN, C. E., 1930: Über Diapirismus (besonders im Grundgebirge). *Bull. Comm. géol. Finl.*, N:o. 92, 49-76.

Kartan Plate 1 för spridning godkänd
i rikets allmänna kartverk
den 9 januari 1970

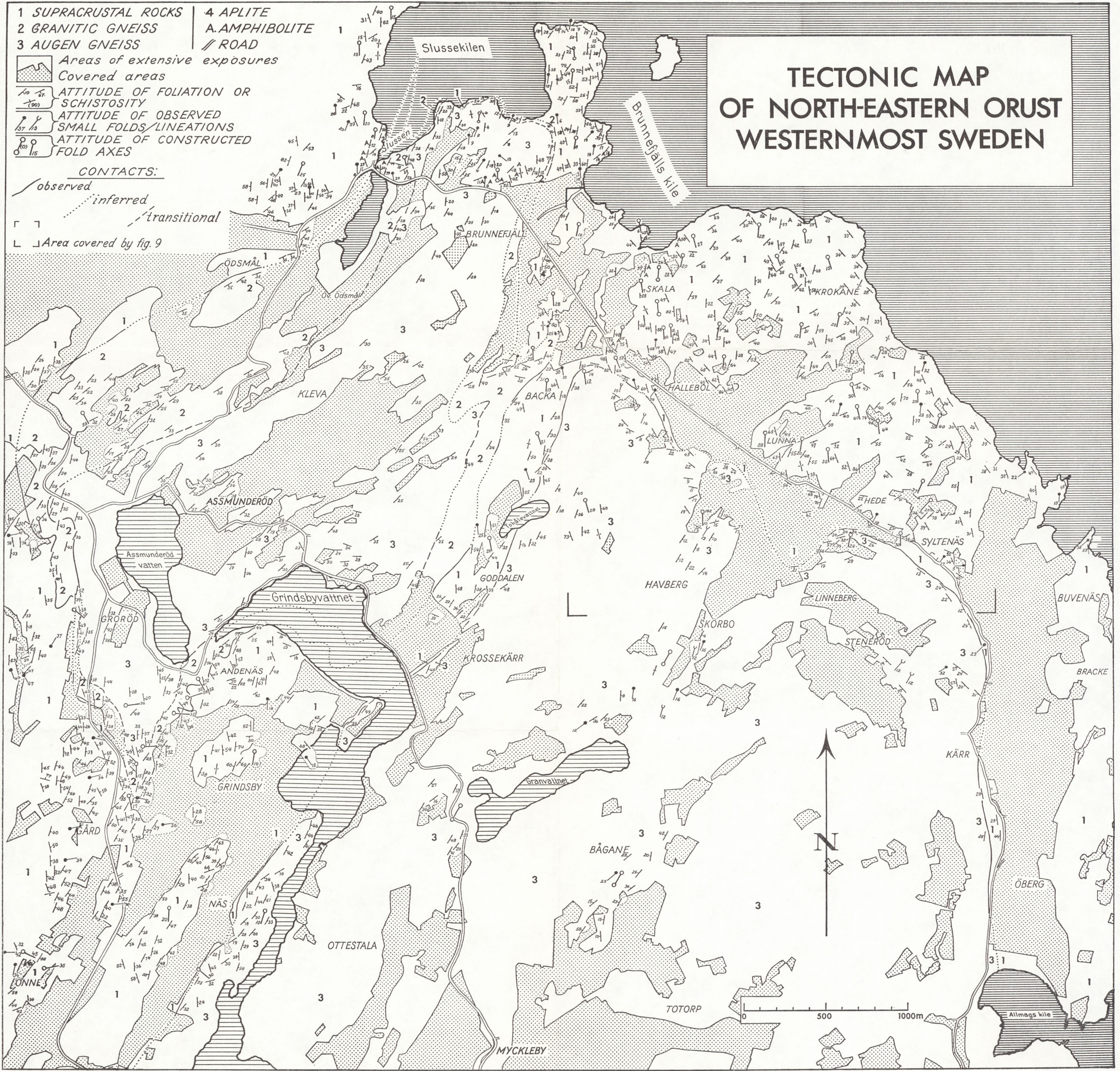
- 1 SUPRACRUSTAL ROCKS
- 2 GRANITIC GNEISS
- 3 AUGEN GNEISS
- 4 APLITE
- A. AMPHIBOLITE
- // ROAD

- Areas of extensive exposures
- Covered areas
- ATTITUDE OF FOLIATION OR SCHISTOSITY
- ATTITUDE OF OBSERVED SMALL FOLDS/LINEATIONS
- ATTITUDE OF CONSTRUCTED FOLD AXES

- CONTACTS:**
- observed
 - inferred
 - transitional

Area covered by fig. 9

TECTONIC MAP OF NORTH-EASTERN ORUST WESTERNMOST SWEDEN



PRISKLASS B

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