

# Intrusive meta-anorthosite/leucodiorite from the Precambrian of Akershus, SE Norway

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In the Precambrian of SE Norway there occur bodies of medium-grained meta-anorthosite in which the mafic minerals are concentrated in schlieren. It is a basic-intermediate rock type, and an igneous origin is strongly suggested by the plot Niggli al-alk against c. This interpretation is supported by structures that are believed to represent cumulus textures in an originally coarse-grained anorthosite/leucodiorite. The intrusive rock was folded (and refolded) and recrystallized in the amphibolite facies.

The rock type is distinctive, and its occurrence in other areas could be very useful for correlation with Precambrian complexes in S Norway and SW Sweden.

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## Field relations

In the polydeformational Precambrian gneiss complex southeast of Oslo (Pedersen et al. 1978) there occur several bodies and layers of a distinctive white plagioclase gneiss or meta-anorthosite that are shown to be of intrusive origin. In addition ultramafic rocks with some affinity to the meta-anorthosite have been observed at two localities (Fig. 1).

The main outcrop of the meta-anorthosite is found at Nordby east of Bunnefjorden (UTM-reference 32V NM 98 22); this covers an area of approximately 300 × 1500 m. The surrounding gneisses consist of a monzogranitic biotite augen gneiss interfolded with 100–300 m broad layers of a finer grained psammitic semipelitic biotite-muscovite paragneiss that delineate the regional structure of the area. The general strike of the foliation is east-west (85–100°) with a moderate northerly dip (40–60°).

The mesoscopic structures are marked by numerous concordant garnet amphibolites. An analysis of the structures in the augen gneiss has shown two deformation episodes – isoclinal folding around a northeast axis later followed by folding giving rise to the northwest-plunging axes most commonly found (Graversen 1973). Both the meta-anorthosite and the ultramafic rocks have been folded and recrystallized under amphibolite facies conditions together with the surrounding gneisses.

During the regional deformation the primary contact relations between the anorthositic

bodies and the surrounding rocks were obliterated. The schlieren in the meta-anorthosite/leucodiorite are now parallel to the contact with the surrounding gneiss and to the gneiss foliation itself. In a metre-broad zone at the contact the meta-anorthosite/leucodiorite is finer grained and the mafic schlieren are extremely flattened, so structurally there is a gradual transition to the gneiss.

## Petrography

On weathered surfaces the anorthositic gneiss shows a mottled black and white appearance, although there is some variation in the amount of the dark minerals present and the way they are arranged. The groundmass of this gneiss is composed of medium-grained massive plagioclase (An<sub>25–35</sub>) with no preferred orientation. The main part of the dark minerals (biotite and amphibole) is usually concentrated in schlieren about 10 cm long and a few cm broad, and around the schlieren there is often found a zone free of mafic minerals. The schlieren exhibit a flame or flaser-like structure (Fig. 2) like those illustrated by Berthelsen (1960, fig. 37) from gabbro-anorthosites in the Archean gneiss complex of west Greenland. A few observations from localities with little deformation show that the structure stems from an original cumulate texture with cumulus feldspar up to about 5 cm large and mafic aggregates which on deformation have become schlieren.

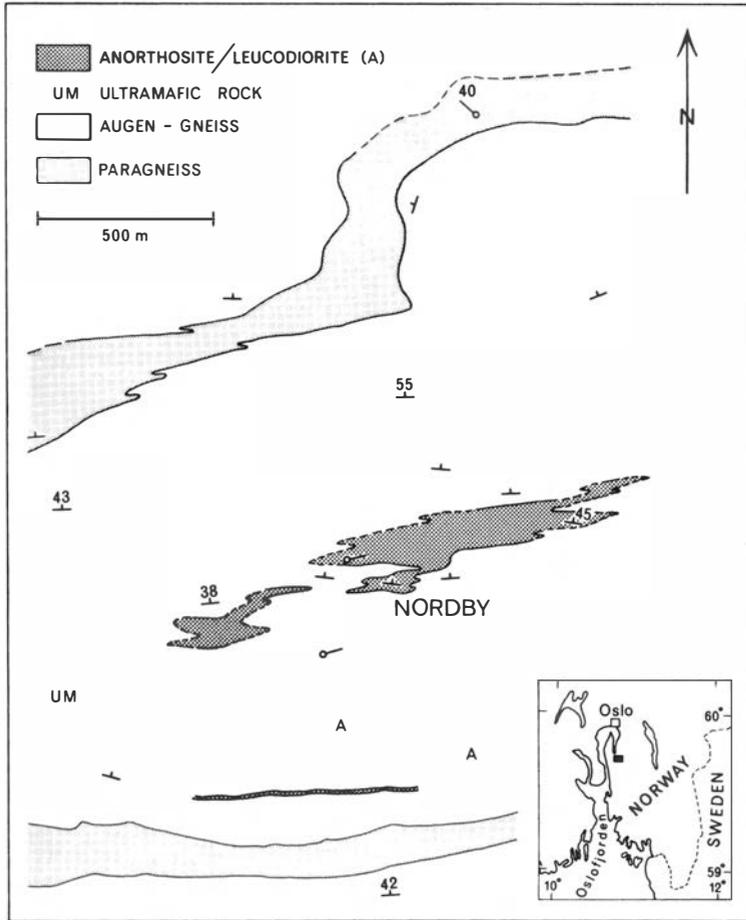


Fig. 1. Geological map of the Nordby area 25 km south of Oslo.

The dark minerals in the groundmass show some orientation parallel to the dark schlieren but quite often they have a more random orientation in keeping with the massive appearance of this part of the rock. The amount of mafic minerals varies from less than 5% to about 15–20% with a maximum value at 25%, this variation giving rise to a crude layering in the rock; most outcrops, however, show a variation between 10 and 20% and 15% has been estimated as a mean value.

The coarse character of the rock and the variation in the content of mafic minerals make it difficult to determine the modal composition, but the rock appears to correspond to an anorthosite (oligoclase-andesinite)-leucodiorite transition, according to the terminology of Streckeisen (1974).

*The plagioclase groundmass.* – In this the following minerals have been observed (in order of decreasing abundance): plagioclase, anthophyllite-gedrite, biotite, garnet, phlogopite (?), muscovite, chlorite, staurolite, rutile, zircon, ilmenite, magnetite, pyrrhotite, pyrite, and hematite. The plagioclase is granular and medium-grained with most grains around 3–4 mm, but the total size range is 1–6 mm. The grain boundaries are planar or sometimes slightly curved. Zoning in the commonly clouded plagioclase has not been observed, and most grains show lamellar albite twinning or Carlsbad-albite twins. The An-content has been determined from the extinction angles and the values are fairly constant at about  $An_{30}$  in all the grains measured, with deviations from this value lying within 5 percent. The dominance of an oligoclase-

andesine plagioclase has been confirmed by a chemical analysis of the feldspar fraction (Table 1, 4<sub>1</sub>), which gave a result close to oligoclase/andesine (Game & Howie *in* Deer et al. 1966, table 31). Amphibole crystals together with biotite accompany the plagioclase outside the mafic schlieren giving rise to a disperse foliation parallel to the foliation indicated by the schlieren. Phlogopite(?) with acicular rutile inclusions concentrated in colourless zones may also be present.

*The mafic schlieren.* – They are composed mainly of a fibrous amphibole matrix in which single subhedral-euhedral amphibole crystals occur cutting the matrix structure, but on the whole still parallel to the schlieren. A distinct parting parallel to {001} appears in prismatic sections of the larger crystals, and some crystals are broken along the parting planes. The amphibole is biaxial positive, and shows feeble pleochroism from grey ( $\alpha = \beta$ ) to pale brown ( $= \gamma$ ), and parallel extinction in prismatic sections. These characters indicate an iron-rich anthophyllite or a gedrite; in agreement with this the chemical analyses of the ultramafic rocks and the mafic fraction of the leucodiorite/anorthosite show low Na<sub>2</sub>O and CaO contents and high MgO, FeO + Fe<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> contents (Table 1).

Rutile with remnants of ilmenite is present in all sections examined, both in the plagioclase host and in the mafic schlieren where it is most frequent. Where ilmenite is not altered to rutile it often shows exsolution hematite. A few grains of pyrite sometimes associated with ilmenite or pyrrhotite have been observed. Furthermore hematite is present in minor amounts either as a reaction zone surrounding pyrite or as a vein-filling mineral.

Staurolite is present in two specimens (MM 4028–29) both in the plagioclase host and in the mafic schlieren, in both cases in equilibrium with the other minerals present. Alteration along irregular cracks is typical and some grains are poikiloblastic with quartz and plagioclase inclusions. The staurolite is pleochroic from colourless ( $= \alpha$ ) to golden yellow ( $= \gamma$ ).

Although garnet has not been observed in any of the thin sections, it is widely distributed in some areas where it may occur in zones (fracture zones?) with euhedral crystals up to 8 cm in diameter. The garnets have in some cases grown across the contact between the mafic schlieren

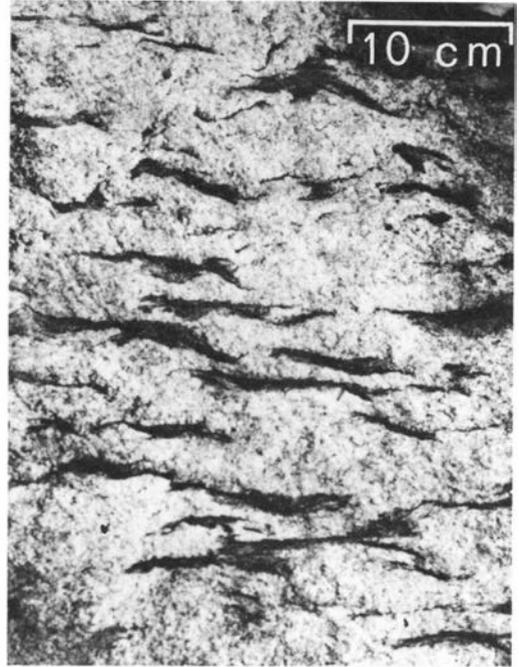


Fig. 2. Strongly deformed mafic schlieren in meta-anorthosite/leucodiorite.

and the plagioclase host; there is no sign of later rotation.

Chlorite is a common retrograde mineral replacing especially the anthophyllite-gedrite in the mafic schlieren but biotite and garnet may also be affected.

*Mafic-ultramafic rocks.* – Both in the anorthosite/leucodiorite and in the surrounding gneiss there occur concordant mafic-ultramafic rocks in layers of a few metres thickness. Due to their small size combined with the relatively bad exposure not so much is known about them, but their mineralogical composition combined with their general appearance suggest a close relationship to the anorthositic body.

The ultramafic rocks are composed mainly of anthophyllite-gedrite (90%), with plagioclase in minor amounts and quartz, rutile and ilmenite as accessory constituents. One sample (MM 4034) shows a fairly high rutile content – around 3 vol.% associated with 0.2–0.5 vol.% ilmenite remnants. Unaltered ilmenite with hematite is dominant in other samples (MM 4013, MM 4078). The mineralogical and chemical composi-

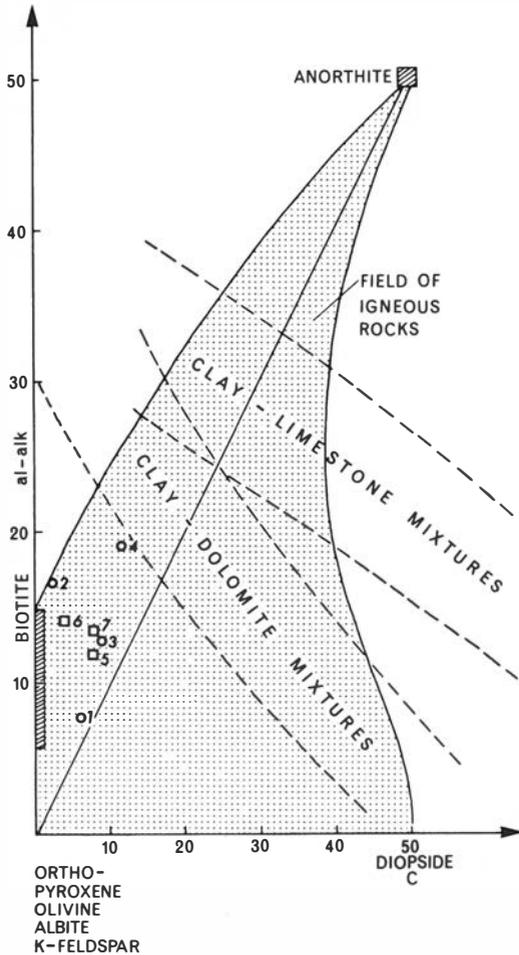


Fig. 3. Plot of Niggli al-alk against c for the analysis in Table 1. The samples plot in the igneous field outside the areas of sedimentary rocks. (After Leake 1969.)

tions are otherwise fairly similar to the composition of the mafic schlieren in the meta-anorthosite/leucodiorite.

## Geochemistry

No marked mineralogical or chemical changes have been observed in the surrounding augengneiss approaching the anorthositic rocks, and it is assumed that the latter rocks recrystallized as a closed system. This is also demonstrated in anorthosite along the contact where the addition of a little quartz is the only change that has been observed. The chemical composition ought therefore to reflect the origin of the anorthosite.

The chemical analyses (Table 1) of the anorthosite/leucodiorite show a basic-intermediate rock type, and an igneous origin for the anorthositic and related mafic-ultramafic rocks is strongly suggested by the Niggli al-alk plot against c in Fig. 3 (Leake 1969). The samples plot in the lower left corner of the igneous field and outside the sedimentary areas, and although the variation of the An-content in the plagioclase is very limited, there is some spread parallel to the plagioclase line. For igneous rocks, Leake (1969) has demonstrated a positive correlation of the Cr and Ni content plotted against the Niggli mg. The values presented in Table 2 show some positive correlation, but the small number of analyses does not allow a definite conclusion from this material.

In order to illustrate the relation between the content and composition of the plagioclase and mafic minerals the chemical analyses and normative minerals have been plotted on AFM and An-Ab-Or diagrams (Fig. 4).

The plot of the normative feldspars (Fig. 4A) shows a concentration of the anorthositic rocks towards the Ab corner; this concentration is in agreement with the small variation of the An-content measured optically in thin sections, but the normative An-content is lower. In the related mafic-ultramafic rocks the normative An-content of the feldspar is higher and more varied; these values lie close to the thin section observations.

In the AFM diagram (Fig. 4B) the anorthositic and mafic-ultramafic rocks lie close to a straight line from the alkali-corner to a point about halfway between the magnesia and iron corners. This indicates a constant composition of the ferromagnesian minerals independent of the plagioclase content. The plot of one of the anorthositic samples (4, MM 15315) and its separated light ( $4_1$ ) and dark ( $4_2$ ) fractions confirms the relation between the anorthositic and the mafic-ultramafic rocks.

The trace element contents are shown in Table 2. The anorthositic samples on the whole show values that contrast with those for the related mafic-ultramafic rocks; the greatest differences are shown by Ba, Sr, and Zr contents (highest in the anorthositic rocks), and Cr, V, Co, Zn, and Ni contents (lowest in the anorthositic rocks). When the trace elements of the dark fraction of the anorthositic rocks are viewed separately they show a variation very similar to that in the mafic-ultramafic samples, but the actual values

Table 1. Chemical composition of anorthosite/leucodiorite and mafic-ultramafic rocks.

	1	2	3	4	4 <sub>1</sub>	4 <sub>d</sub>	4 <sub>1+d</sub>	1-4	5	6	7
SiO <sub>2</sub>	58,71	46,94	64,93	63,67	67,85	36,72	63,01	58,56	50,69	45,41	48,15
TiO <sub>2</sub>	0,48	0,59	0,07	0,28	0,08	1,75	0,33	0,36	1,92	0,76	1,58
Al <sub>2</sub> O <sub>3</sub>	21,49	19,87	21,24	20,12	20,19	22,82	20,57	20,68	15,66	15,19	15,78
Fe <sub>2</sub> O <sub>3</sub>	0,87	1,44	0,34	0,19	0,20	1,03	0,33	0,71	6,74	1,52	1,48
FeO	2,54	10,19	0,39	1,91	0,10	12,08	1,90	3,76	7,15	14,00	11,25
MnO	0,03	0,19	0,02	0,01	0,02	0,08	0,03	0,06	0,29	0,31	0,23
MgO	2,92	12,17	0,46	1,62	0,18	11,87	1,93	4,29	7,36	16,12	10,86
CaO	1,70	0,93	2,13	2,80	2,77	2,07	2,67	1,89	2,77	1,79	3,07
Na <sub>2</sub> O	8,88	4,08	9,30	7,36	8,00	1,64	7,46	7,41	4,66	1,89	3,29
K <sub>2</sub> O	0,85	0,41	0,48	0,69	0,52	1,23	0,63	0,61	0,17	0,16	0,66
H <sub>2</sub> O <sup>-</sup>	0,06	0,14	0,06	0,15	0,01	0,31	0,06	0,10	0,14	0,19	0,19
H <sub>2</sub> O <sup>+</sup>	1,14	2,94	0,62	1,29	0,49	7,77	1,58	1,50	2,20	2,45	2,81
CO <sub>2</sub>	0,26	0,00	0,10	0,21	0,20	0,64	0,27	0,14	0,10	0,04	0,06
P <sub>2</sub> O <sub>5</sub>	0,01	0,11	0,03	0,06	0,03	0,28	0,07	0,05	0,18	0,27	0,20
S	0,01	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,04	0,00	0,00
	99,95	100,00	100,17	100,36	100,64	100,30	100,84	100,12	100,05	100,10	99,61

Sample number

1.	MM 4029	Anorthosite/leucodiorite	4 <sub>1</sub>	15315,	light fraction
2.	MM 4055	" "	4 <sub>d</sub>	15315,	dark fraction
3.	MM 4071	" "	4 <sub>1+d</sub>	15315,	calculated from
4.	MM 15315	" "			85% 4 <sub>1</sub> , 15% 4 <sub>d</sub>
5.	MM 4013	Mafic-ultramafic rock	1-4		mean value of
6.	MM 4034	" "			analyses 1-4
7.	MM 4078	" "			

Analysist: G.C.Faye, Norges geologiske Undersøkelse, Trondheim, Norway

Table 2. Quantitative spectrographic analyses of minor elements (ppm) in anorthosite/leucodiorite and mafic-ultramafic rocks.

	Zr	Y	Sr	Rb	Zn	Cu	Ni	Cr	Ba	Co	Ag	V	Mo	Sn	Pb
1.	377	81	82	33	29	n.d.	8	23	519	6	<1	30	<1	<30	<30
2.	785	40	49	23	76	n.d.	32	64	394	30	<1	200	<1	<30	<30
3.	16	13	198	5	18	15	n.d.	2	442	3	<1	<3	<1	<30	<30
4.	313	37	204	30	18	2	10	36	315	10	<1	30	<1	<30	<30
4 <sub>1</sub> .	218	12	223	18	n.d.	n.d.	n.d.	n.d.	195	<3	<1	3	<1	<30	<30
4 <sub>d</sub> .	252	110	73	83	249	2	92	219	181	80	<1	200	<1	<30	<30
5.	138	30	81	1	126	9	56	212	156	80	<1	300	<1	<30	<30
6.	280	68	25	10	134	n.d.	43	59	3	80	<1	300	<1	<30	<30
7.	109	28	124	49	99	n.d.	57	180	147	60	<1	200	<1	<30	<30

Explanation of index numbers in Table 1.

Analysist: G.C.Faye, Norges geologiske Undersøkelse, Trondheim, Norway

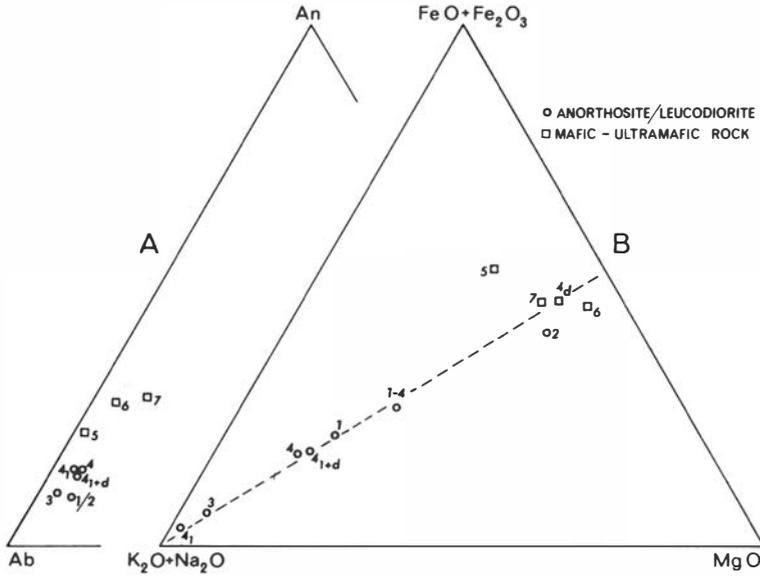


Fig. 4. An-Ab-Or and AFM diagrams of the whole rock analyses in Table 1. See text for discussion.

are higher. It is therefore most likely that the differences only reflect the varying amount of mafic minerals and thus the data support a close genetic relationship between the anorthositic and mafic-ultramafic rocks.

### Primary structures and their deformation

In general, primary structures in the anorthositic bodies and their contact relations with the surrounding gneiss were obliterated during the regional deformation. However, inside the largest body there are a few little deformed patches in which the structures recall weakly deformed cumulate textures (Fig. 5), with the same appearance as cumulate textures illustrated by Myers (1973, fig. 12) and Windley et al. (1973, fig. 22) from leucogabbros in the Fiskensæstet anorthosite complex in West Greenland. The present plagioclase shows a medium-grained polygonal mosaic, but the outlines against the dark minerals (Fig. 5) suggest an original coarse-grained plagioclase cumulate with plagioclase primocrysts up to about 5 cm. The interpretation of the present structures as modified original igneous texture is further supported by a comparison with progressively deformed cumulate textures (Fig. 6) as exemplified by anorthosite

samples (GGU 12 56 11 and 12 46 64) from the Fiskensæstet area.

Where the foliation displayed by the schlieren can be followed into the little deformed areas, it becomes evident that the mafic schlieren (Fig. 2) in the anorthositic gneiss represent interstitial mafic material from the original cumulate, later deformed during the regional folding of the area. The present compositional banding expressed by

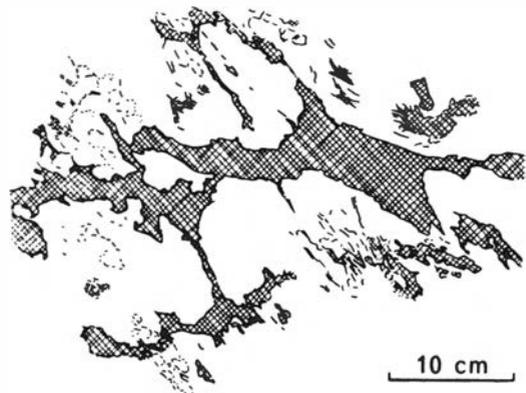


Fig. 5. Detail of little deformed mafic schlieren in leucodiorite. The drawing underlines the sharp edges and corners typical for the limitation of the interstitial mafic minerals seen in only weakly deformed cumulate textures. For comparison see Fig. 6.

the varying content of mafic minerals, and the 10–30 cm thick – now discordant – mafic layers might then be a relic primary structure representing an early layering surviving from the original intrusion.

## Conclusions

The chemical data and the interpretation of the structures in the anorthositic rocks demonstrate an igneous origin for the anorthositic bodies. The original intrusive rock recrystallized in a lower amphibolite facies environment, and the chemi-

cal analyses show a homogeneous rock with no differentiation on a regional scale. The original shape of the intrusion is difficult to determine since no marker horizons are present, but the interpretation of the map suggests that there are one or two folded (and refolded) intrusive sheets.

Bodies of meta-anorthosite/leucodiorite of the type in question have not previously been recorded in Precambrian complexes of southern Norway and southwestern Sweden. Since the rock type is very distinctive, its presence could be a useful aid to correlation if occurrences were to be found in other areas.

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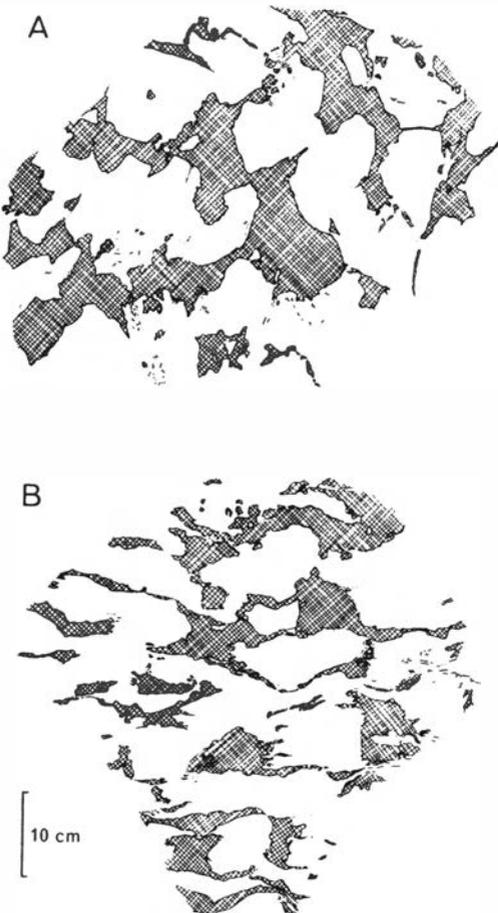


Fig. 6. Undeformed (A) and moderately deformed (B) meta-leucogabbro (GGU 125611 and 124664) from the Fiskensæset anorthosite complex West Greenland. Although the plagioclase primocrysts are entirely recrystallized the outer shapes of the igneous plagioclases are still visible during the first stages of deformation. (Drawn from photos.)

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