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Petrography and metamorphism in the Precambrian rocks of the Magnor area, S. Norway

By

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(With one geological map, one figure in the text, 5 tables and 2 plates)

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Contents

Abstract.

The rocks of the Magnor area comprise various red and grey gneisses, amphibolites and red, unfoliated granites. The gneisses and amphibolites most probably were sediments and basic intrusives, respectively, metamorphosed by regional metamorphism in the uppermost part of the almandine-amphibolite facies. Some features are reminiscent of granulite facies rocks, as for instance abundance of antiperthitic feldspar in the gneisses. The red granites were formed subsequently to the main metamorphism, probably by potash metasomatism acting on the gneisses. An episode of folding separates the regional metamorphism from the formation of red granites. Retrograde metamorphism is related to the socalled "mylonite zone" and is restricted to the easternmost gneiss areas.

By analogy with relations on the Swedish side of the border the rocks of the Magnor area are to be considered as Pre-Gothian in age.

Introduction.

The map area comprises the topographical map sheets Vestmarka and Stranden (AMS-series M 711, 1:50.000). These topographical maps were also used in the mapping together with aeromagnetic maps, scale 1:25.000. The latter showed very useful as the general trend of the gneisses and the outline of the basic rocks were revealed.

The investigations are part of a team work in the Pre-Cambrian of southeastern Norway carried out by geologists at NGU. The map presented is the result of observations made by several geologists and 3 weeks' field work by the writer in 1963—64.

Geologically the area comprises the gneisses immediately SW of Magnusson's "mylonite zone" (Magnusson, 1937a). The mylonite zone is of Gothian or Dalslandian age (for discussion see Gvein, 1967). A small part of the mylonite zone enters the map area in the easternmost corner (Fig. 1), but the rocks are not treated in this paper. On the geological map of Sweden (Magnusson et. al. 1957) the gneisses of the adjoining Swedish area are termed "alternating grey and red gneisses" and classified among the Pre-Gothian rocks of south-western Sweden. Detailed description of these rocks are, however, lacking from the immediately adjoining areas. From more eastern districts in Sweden some maps with descriptions have been printed. As an example is taken the map sheet Forshaga (Magnusson, 1937b) concerning rocks of the mylonite zone and the gneisses on both sides of the zone. Those on the western side, with a position comparable to the Magnor area, include the following rock types (a), amphibolites; (b) grey gneisses rich in plagioclase, partly with abundant bands of amphibolite, partly with red schlieren and partly with development of augens; (c) intermediate veined gneisses; (d) red gneisses in the grey veined gneisses. These rock terms could without difficulty have been used for the rocks of the Magnor area too, as it will appear from the map (Fig. 1) and the petrographical description. Great similarities in the mineral assemblages are obvious from a comparison of the described gneisses.

From the Norwegian side of the national border descriptions of the gneisses SW of the mylonite zone are scarce. Hjelle (1963) gives some modal analyses and a brief description of rocks with a corresponding position from the area S. of L. Mjøsa, some 100 kms further NW. In most respects they seem to be comparable to the present gneisses.

Petrography.

Gneisses.

The greater part of the map area is underlain by various gneissic rocks (Fig. 1) among which grey plagioclase gneisses are dominating areally. *The grey gneisses* are partly homogeneous rocks, partly veined or both types in alternation (see Fig. 2). Most common are veined gneiss with more or less parallel schlieren of quartzo-feldspathic material alternating with darker micaceous and, frequently, hornblendebearing layers. The boundaries between the dark and light portions of the gneiss may be sharp, as on Fig. 2, or more diffuse and irregular. Augen gneisses are relatively common, especially in connection with red granites occurring as discordant or subconcordant veins or as larger bodies in the gneiss area (see map, Fig. 1). The augens consist of red microcline in most cases. From field observations and microscopic studies it has been inferred that the red granite (veins) and the formation of augens in the gneisses are younger than the foliation of the gneiss and the main regional metamorphism (see later). Gneisses with plagioclase augens are less common except for a smaller area surrounding a quartz-dioritic rock type at Magnor. *Red gneisses* occur within a broad central area about L. Helgesjøen tapering northwards. Grey gneiss is present in smaller parts of this area. A strong red-colouring along joints is apparently related to tectonization younger than the gneiss foliation. In rare cases veins of quartz, chlorite and,

Fig. 2. Grey gneiss with concordant or subconcordant veins of quartz-plagioclase rock. The discordant veins sub-parallel with axial planes of folds are of granitic composition (red-coloured). 0,1 km W. of Bolfoss.

occasionally, small amounts of pyrite have been observed in red or grey gneisses, partly orientated along the axial plane of folds younger than the gneiss foliation.

Neither in the grey nor the red gneisses have rock types of doubtless sedimentary origin been observed. Although the grey gneisses are frequently micaceous they are rarely as high in mica as to exclude other possible origins.

The mineral assemblage of the gneisses shows remarkable constancy from place to place. Even rocks with distinctly different appearances show to consist of nearly the same mineral associations, although with variable proportions between the minerals. The following assemblage is valid for the grey gneisses in general:
Quartz + plagioclase + biotite ± potash feldspar ± hornblende ± almandine + magnetite and/or ilmenite ± epidote (+ sericite + apatite ± orthite).

Modal analyses of some typical specimens are listed in Table I, columns 1—8. Chemistry of a grey gneiss of the common type is found in Table II.

Table I.

Modal analyses of gneisses from the Magnor area.
(1–8: Grey gneisses, 9–10: Red gneisses.)

	1	2	3	4	5	6	7	8	9	10
Quartz	33	9	16	27	20	26	30	33	28	30
K-feldspar	5	5	3	2	—	3	—	1	39	36
Plagioclase[1])	53	37	65	43	56	55	47	43	24	14
(% An)	(29)	(36)	(28)	(35)	(23)	(30)	(39)	(33)	(25)	(?)
Biotite[2])	7	12	13	22	11	13	14	11	8	1
Hornblende	—	37	2	—	11	—	8	12	—	9
Garnet	—	—	—	1	2	1	—	—	+	+
Epidote + orthite	1	+	+	3	+	+	—	—	—	1
Sphene	1	+	—	—	—	—	—	—	—	—
Apatite	+	+	+	+	+	+	+	+	+	+
Magnetite + ilmenite	+	+	1	1	+	2	1	—	1	1

Localities and numbers of the specimens: 1: G 18a/64 (Lindalen (Varden). 2: W1/64 (Breitjern (Varden). 3—4: W31/61 — Sv. 30/63, Skotterud. 5: T52/63, Holmsjøen. 6: T55/63, Kvernkroken. 7: T60/63, S of Mobekk. 8: K3/63, Bolfoss. 9: W2/64, Breitjern (Varden). 10: T53/63, Vangen (Holmsjøen).

Table II.

Chemical composition, CIPW norm and mode of typical grey gneiss, Vestmarka.

	Wt %	CIPW (mol) norm		Mode	
SiO_2	61,80	Q	14,6	Quartz	19
TiO_2	0,64	Or	10,5	Plagioclase	51
Al_2O_3	17,02	Ab	34,0	(% An)	(23)
Fe_2O_3	1,29	An	24,7		
FeO	3,86	(% An)	(42)	Biotite	13
MnO	0,17			Chlorite	+
MgO	2,83	Di	2,0	Hornblende	11
CaO	5,76	Hy	11,2	Epidote	2
Na_2O	3,76	Mt	1,5	Sericite	3
K_2O	1,79	Il	0,8	Apatite	+
H_2O+	0,56	Ap	0,3	Calcite	1
H_2O-	0,00	Cc	0,4	(Col. index)	(30)
CO_2	0,15	(Col. index)	(16,2)		
P_2O_5	0,11				
(Sum)	(99,74)				

Locality and number of anal. specimen: G1/64, 0,6 km W. of Ljøner, Vestmarka. Analyst: P.-R. Graff.

[1]) Sericite and antiperthitic K-feldspar inclusions are included.
[2]) In some cases slightly chloritized.

The red gneisses have mineral assemblages nearly identical with the grey ones and differ from these mostly in the relative proportions of the chief minerals. Characteristic is the high amounts of potash feldspar in most specimens. Somewhat higher quartz contents as compared with the grey gneisses is also fairly obvious. Table I, columns 9—10, shows modal analyses of two typical red gneisses.

Some mineralogical details of the gneisses deserve special mentioning, above all the presence of antiperthitic inclusions in the plagioclase in all the investigated thin sections (except one) of the gneisses.

The feldspars: In the grey gneisses the feldspar is chiefly *plagioclase*, composition varying between An_{23} and An_{40}, most frequently An_{30}—An_{40}. Inverse zoning has been observed, but is not very pronounced. Twinning according to the following twin laws has been observed, mentioned in the order of importance: Albite, pericline and Carlsbad. Post-crystalline deformation is indicated by the presence of pericline twins and by occasional bending of twin lamellae. The most conspicuous feature of the plagioclases is the presence of *antiperthitic inclusions of potash feldspar* (Pl. Ia). The inclusions have the form of rods or they are of more equidimensional, box-like types. Size of the inclusions is mostly in the range 0,01 to 0,05 millimetres while the plagioclase hosts are from 1 to 2 millimetres in general. Striking is the uneven distribution of the potash feldspar in many plagioclases: It may be abundant in one part and absent in another part of the same plagioclase individual. In some cases concentration of antiperthitic inclusions is observed along some albite twin lamellae, each inclusion being more or less parallel to the twin boundary. Deviating trends of the rods are, however, frequently observable. A Widmanstätten system of orientation is less common.

In larger potash feldspar inclusions microcline twinning can be detected, but as a rule, however, twinning is not obvious. Within each plagioclase grain all potash feldspar rods usually show contemporary extinction or nearly so.

Generally spoken, the antiperthitic feldspars possess the various characteristica described by several authors (see later) as typical of antiperthite formed by exsolution.

Also within the red gneisses are found the antiperthites described above, although not to the same extent.

Myrmekitic texture is commonly developed along the borders of plagioclase grains. Antiperthitic inclusions have nowhere been observed within the myrmekitic feldspar. In some cases the myrmekite is seen to occur where plagioclase border upon separate grains of potash feldspar, especially in the red gneisses; in the grey gneisses it is nearly equally as frequent where plagioclase borders upon quartz, hornblende or some other mineral grain.

In most thin sections the plagioclase can be seen to contain an unevenly distributed mass of sericite flakes. The sericitization never affects the potash feldspar rods. (As scapolite grains within some amphibolites are seen to have about the same birefringence as that of muscovite it might be suspected that some of the fine grained mass within the plagioclase in the gneiss also is scapolite, but as a rule, this seem not to be the case.)

Separate grains of *potash feldspar* are common, above all in the red gneisses, but also in small amounts in the grey ones (Table I). Microcline twinning is commonly present, but in many cases this twinning seems to be absent, the potash feldspar apparently being monoclinic. Measurements of 2V on the untwinned feldspars, however, give values which group around 60° and 80°, respectively, thus indicating that triclinic as well as monoclinic feldspars (lowest values) may be present. Microperthite is frequently observable in both types of potash feldspar.

The *amphibole* shows the same characteristic features in all specimens: Pleochroism, Z: Bluish green, $Y = X$: light brownish yellow or slightly greenish. Extinction c/Z about 15°. The highest refraction index: 1,695—1,700, the lowest about 1,680. (-)2V is large, nearly 90°. Inclined dispersion: distinct to weak, $r < v$. The hornblende is short prismatic or irregular in shape, no signs of transformation into pyroxene or vice versa have been observed. In a few cases it is seen that inclusions of garnet in the hornblende are surrounded by an intervening zone of plagioclase. *The garnets* are everywhere small and rarely visible in hand specimen. *The biotite* shows a strong red-brown colour in the Z direction. *Magnetite* and *ilmenite* are present among the ore minerals. It is of interest that *sphene* has been observed only in the easternmost area towards the mylonite zone where also retrograde chloritization and formation of epidote are prevalent.

Amphibolites and associated rocks.

Amphibolitic boudins and lenses are common in the gneisses. Some greater occurrences of amphibolite are also present (Fig. 1). The shape and extension of these are largely corresponding to the positive anomalies on the aeromagnetic maps.

Border relations are seldom observable, but the amphibolites are apparently concordant in the gneisses. Occasionally a diffuse boundary against gneiss has been detected with increasing plagioclase and decreasing hornblende contents outwards in the amphibolite. These observations mainly concerns small lenses and boudins. The boundaries of the larger amphibolites are so seldom exposed that no conclusions can be drawn safely. There is, however, little reason to believe that there exist any differences in age or genesis between the larger and smaller amphibolites of this area. From Swedish literature it is known that amphibolites in the comparable gneisses occasionally have retained a core of pyroxene-bearing gabbroid or noritic character (see Magnusson et. al. 1962 p. 11, for inst.). In the present area the greater amphibolites may partly show a more massive and coarse-grained texture in the central parts and might be termed hornblende gabbros. Remnants of pyroxene have not been detected but it should be born in mind that investigations are very limited. The only case where *pyroxene* has been observed is in an ultrabasic rock type from Myren, SW of Magnor. The rock is composed of diopsidic pyroxene and pale green amphibole. Lamellae of magnetite of exsolution type are abundant in the pyroxene (Pl. Ib) especially in the cores. They are mainly orientated parallel to the prismatic cleavages. The pyroxene is in a state of transformation into amphibole. The ore minerals are present also in the amphibole, but orientation is less regular and they are usually more irregular in shape than within the pyroxenes.

The normal amphibolites are, mineralogically, characterized by high contents of andesinic plagioclase and hornblende, less important amounts of biotite, calcite, sericite, apatite, occasional epidote and some ore mineral are present. *Scapolite* is significant in some specimens (Pl. II a). According to the optical properties it is a meionite, $3\ CaAl_2Si_2O_8 \cdot CaCO_3$. Birefringence and interference colours are about the same as for the muscovite (sericite). Secondary alteration of the scapolite into plagioclase (comp. unknown) and calcite along cracks has been observed in a few cases. *The plagioclase* is normally an andesine about An_{40} with inverse zonation pronounced in some cases. Usually there is a thin rim of more basic plagioclase, up to An_{52} has been measured. *The hornblende* is normally rather pale blue-green in the Z direction, axial angle 2 V_x nearly 90°, extinction angle c/Z varying, but high: 19—28° and the highest refraction index (determined in only 2 cases) between 1,690 and 1,700. The high Al content of the amphibolites taken into account (Table III) it seems probable that the hornblende, too, is high in Al_2O_3. Engel & Engel (1962) found in high grade metamorphism (amphibolite facies — granulite facies) the Al content of hornblende to be largely depending on the Al content of the rocks in question.

Other minerals of the amphibolites do not deserve special mention.

The chemistry of the common amphibolites is enlightened by two chemical analyses, listed in Table III. As shown by this table the amounts of Al_2O_3 are exceptionally high, especially in no. 2. The latter specimen is from the border facies of the amphibolite boss at Knutbro, N. of Vestmarka. *Some exchange of material with the adjoining gneiss* might be inferred from a comparison with no. 1, this specimen taken more centrally in a comparable amphibolite from Setskog (adjoining map sheet). Some supply of K, Na, Ti, Al and Si (?) and loss of Ca + Mg could be suggested.

Unfoliated red granite.

Red granite is relatively frequent within the gneisses. A fairly large area of granite is found close to the Swedish border at Aurbakk. Elsewhere red granite is mostly present as discordant or subconcordant veins, for instance in the western part of the map area by L. Skjervangen. It is supposed that the veins and the larger granite are comparable in time and genesis, though decisive proofs are lacking. Not seldom are the veins orientated parallel with the axial plane of asymmetric folds (see Fig. 2) or with slides (fold-faults). Inclusions of grey gneiss and hornblende-rich rocks in the granite have been observed in a number of localities, mainly within the veins. The inclusions in usual show the same orientation of foliation as the adjoining gneiss.

Texturally the red granites are frequently more fine-grained than the gneisses being fine-to medium-grained in the usual case. Pegmatitic variants are, however, by no means absent. With the present know-

Table III.

Chemical compositions, CIPW norms and modes of 2 amphibolites.

	Wt %			CIPW (mol) norms			Modes	
	1	2		1	2		1	2
SiO_2	48,57	49,23	Or	4,5	8,0	Plagioclase	31,0	42,0
TiO_2	0,43	1,16	Ab	25,7	36,5	(% An)	(40)	(40)
Al_2O_3	19,15	21,05	An	35,8	34,0			
Fe_2O_3	1,61	2,79	(% An)	(58)	(48)	Biotite	0,8	+
FeO	6,11	4,93	Ne	1,4	1,8	Chlorite	—	+
MnO	1,08	0,20				Hornblende	61,6	42,1
MgO	8,56	4,09	Ol	19,4	10,8	Epidote	0,8	—
CaO	10,10	8,34	Di	10,8	2,8	Sericite	5,6	10,5
Na_2O	3,14	4,38	Mt	1,6	3,0	Garnet	—	2,4
K_2O	0,76	1,34	Il	0,6	1,6	Magnetite	—	1,5
H_2O+	1,21	1,62	Ap	—	0,5	Apatite	—	1,0
H_2O-	0,00	0,02	Cc	0,2	1,0	Calcite	0,2	1,0
CO_2	0,05	0,40	(Col. index)	(32,6)	(19,7)	(Col. index)	(69,0)	(58,0)
P_2O_5	0,04	0,30						
(Sum)	(99,81)	(99,86)						

Localities and numbers of analysed specimens: 1. K4/63, Sotsjøen, Setskog. 2. G6/64, Knutbro, Vestmarka. Analyst P.-R. Graff.

ledge there is no reason to assume any differences in age or in genesis between the pegmatite veins and the granites.

Microscopic investigations of the granites are restricted to some few thin sections and powder preparates: The common red granite is composed of quartz, potash feldspar and plagioclase with small amounts of muscovite (mostly as sericite), biotite (frequently chloritized), apatite, epidote and ore minerals (pyrite etc.). *The potash feldspar* is in all cases microcline with the common twinning, and slightly microperthitic. *The plagioclase* is partly a sericitized oligoclase with scattered antiperthitic potash-feldspar rods. Surrounding the oligoclase is always a rim of clear albite, free of sericite inclusions (Pl. II b). The plagioclase with antiperthite is partly found as small inclusions within microcline, also in those cases with a rim of albite.

In the red pegmatite veins the oligoclase is replaced by (sericitized) albite and a higher amount of epidote than usually found in the granite.

The chemistry of a typical red granite vein is shown in Table IV. Attention is drawn to the high SiO_2 content.

Table IV.

Chemical composition, CIPW norm and mode of red, unfoliated granite vein.

	Wt %	CIPW (mol) norm		Mode	
SiO_2	78,58	Q	41,4	Quartz	46
TiO_2	0,08	Or	35,5	Microcline	37
Al_2O_3	11,10	Ab	17,0	Plagioclase	15
Fe_2O_3	0,56	An	4,0	(% An)	(25)
FeO	0,41	(% An)	(19)		
MnO	0,04	C	0,3	Biotite[1])	1
MgO	0,28			Muscovite	1
CaO	0,89	Hy	0,8	Ores	+
Na_2O	1,82	Mt	0,6	Apatite	+
K_2O	5,84	Il	0,2	(Col. index)	(2)
H_2O+	0,41	Cc	0,2		
H_2O-	0,00	(Col. index)	(1,8)		
CO_2	0,05				
P_2O_5	0,04				
(Sum)	(100,10)				

[1]) Including some chlorite.

Locality and number of anal. specimen: G2/64 Skjervangen. Analyst: P.-R. Graff.

Mineral facies.

As described in the petrographical part the following assemblage is generally characteristic of the gneisses: Quartz + plagioclase + biotite ± hornblende ± almandine ± potash feldspar ± epidote. According to Turner & Verhoogen (1960) this mineral association can be met with in most parts of the almandine–amphibolite facies. However, the petrographical description gives some further information: The frequent presence of plagioclase of andesine composition (up to An_{40}) and with only small amounts of, or no, epidote points to a metamorphism in the upper part of the almandine-amphibolite facies. At the same time the gneisses possess several features characteristic of, or common in rocks formed during granulite facies conditions:

a) Antiperthite of the exsolution type is commonly present.
b) The potash feldspars partly have a monoclinic appearance (absence of microcline twinning). Microperthitic texture is frequent.
c) Sphene is absent in the gneisses apart from those which are most strongly affected by retrograde metamorphism along the mylonite zone. Ilmenite is taking its place in some rocks.

Some comments on these features seem warranted:

a) Antiperthite, much resembling the type described in this paper, is interpreted as a result of exsolution processes by several authors, for instance Sen (1959), Hubbard (1965), Philpotts (1966) and Carstens (1967). Smithson (1963) described antiperthites much alike the present ones, from the Flå granite, Precambrian of S. Norway but interpreted them as replacement features. The antiperthites described by Smithson for instance show the same erratic distribution within single grains as in the present area. As arguments in favour of a replacement origin Smithson mentions the amounts of K-feldspar (some grains are mesoperthitic), the erratic occurrence and the preference for the K-feldspar patches to follow the plagioclase twin lamellae. In the Magnor area the amounts of antiperthitic inclusions are never as high as to exclude the possibility of exsolution. Concerning the erratic distribution and preference for plagioclase twin lamellae Carstens (1967) has shown both features to be matters of nucleation possibilities and no proof of replacement. Moreover, replacement ought to start in the outer parts of the pre-existing minerals coming in the best contact with introduced material. Antiperthitic potash feldspar is, however, in the present rocks no more common in the outer parts of the plagioclase hosts than in the cores. Other features, indicative of replacement, like K-feldspar veinlets in the plagioclase, for instance, have not been observed. The present writer, therefore, do not hesitate *to term the present antiperthites as most probably formed by exsolution processes.* As pointed out by the cited authors antiperthite of this type is typical of granulite facies rocks.

b) In the description of the pyroxene-granulite subfacies Turner & Verhoogen (1960, p. 555) express the following view: "Microperthitic structure is characteristic of the alkali feldspar and the plagioclase similarly tends to be antiperthitic". Microperthitic texture is not, however, restricted to rocks of the granulite facies and is no decisive feature in the discussion of facies.

Monoclinic potash feldspar occurs also in the uppermost part of the almandine-amphibolite facies (sillimanite-almandine-orthoclase subfacies) (see Heier, 1957).

c) The absence of sphene is striking and in accordance with the usual granulite facies assemblages. "Rutile is common in acid, and ilmenite in basic assemblages; sphene is invariably absent". (Turner & Verhoogen, 1960, p. 555). Ramberg (1952, pp. 72—73) considers sphene as stable in natural assemblages up to "the border field between amphibolite facies and granulite facies".

Although the gneisses thus show some features typical of granulite facies rocks, the mineral assemblage in general undoubtedly belongs to the almandine-amphibolite facies. Pyroxenes, always present in granulite facies rocks, are completely lacking in the gneisses. There is no indication, either, that the hornblende encountered was formed by transformation of pyroxenes. It is thus in best agreement with the observed facts to assume that the gneisses were formed during metamorphism in the upper almandine-amphibolite facies. The absence of a mineral like sillimanite, characteristic of the upper part of almandine-amphibolite facies, is readily explained by the chemistry of the gneisses (Table II): They were probably not high enough in Al content and/or too high in Ca to allow the formation of Al-silicates.

Observations in the basic rocks support the above conclusions of the metamorphic facies: The amphibolite assemblage plagioclase + hornblende ± biotite ± almandine belongs to the almandine — amphibolite facies. The presence of andesinic plagioclase, about An_{40} with inverse zoning and rims of composition up to An_{52}, indicates that the amphibolites were metamorphosed in the upper part of this facies. The association diopside + hornblende in an ultrabasic rock type points in the same direction. Also in these rocks, however, some features characteristic of the granulite facies have been detected: Abundant exsolution lamellae of magnetite in the pyroxene of the ultrabasic rock is a common observation in charnockitic rock types according to Carstens (personal communication). The scapolite encountered in some amphibolites is another feature frequently found in granulite facies areas. According to Turner & Verhoogen (1960): "Scapolite commonly accompanies or substitutes for plagioclase". However, as scapolite may occur also in rocks of a lower facies, the importance of its presence is doubtful.

The assemblage quartz + microcline + biotite (chloritized) + epidote ± muscovite of *the red, unfoliated granites belongs to the lower part of the almandine–amphibolite facies or even lower facies*'. The antiperthite occasionally found is looked upon as a remnant from the gneisses outside the granite veins (see petrographical description and following comments). It has not been observed in the pegmatitic variants. It is worthy of note that the potash feldspar is always microcline in the granitic rocks.

Discussion of some genetic problems.

Most rocks of the present area (gneisses, amphibolites) are evidently products of regional metamorphism in the upper part of almandine-amphibolite facies. Antiperthitic feldspar in the gneisses is supposed to have been formed by exsolution as a consequence of falling temperature. Its abundance in granulite facies rocks (literature cited in the preceding chapter) of other areas might be taken as an indication of a previously higher facies also in the present gneisses. However, the absence of any sign of pyroxenes having been a member of an earlier granulite facies assemblage makes such a suggestion less probable. Moreover, inverse zoning of the plagioclases testify to the formation of the rocks by *progressive regional metamorphism*. This is especially abundant in some amphibolites but is also fairly obvious in the gneisses. Most probably, therefore, the assemblages present reflect the peak of metamorphism in the area.

The red granites seem to be younger than the main metamorphism. This is shown by the mineral assemblages which point to a lower temperature of formation than for the gneisses, and by inclusions of antiperthitic feldspar in the granite microclines. The granites are also younger than the gneiss foliation which supposedly is contemporaneous with the high-grade metamorphism of the area. In some localities it has been observed that *a folding episode separates the formation of the gneiss foliation and emplacement of the granite veins:* While the foliation is folded, granite veins are located along axial planes (Fig. 2) or slides related to these folds.

Inclusions of grey gneiss and amphibolite in the red granites are not observed to have been rotated in relation to the foliation of the surrounding gneisses. The granites in this respect show no typical magmatic appearance. To the writer it seems probable that they were formed metasomatically. The antiperthitic inclusions in microcline could be taken as further evidence of metasomatism if they are considered as remnants of the gneiss assemblages only partially altered by the *granitization processes.* The clear albite rims, surrounding the sericitized oligoclase, are probably the Ca-Na-feldspar stable at the time of granitization. Thus the oligoclase remnants are to be looked upon as armored relics of the high-grade assemblages. In the pegmatitic rocks the transformation process is complete as albite and microcline are there the only feldspars. At the same time the amount of epidote is increased.

Turning now again to the gneisses, their original composition and nature are uncertain. The "banding" in most cases must be supposed to be of metamorphic origin. Frequently it occurs in the manner of schlieren or concordant/subconcordant veins. Magnusson (1962, p. 9), declares (in translation): "The formation of veined gneiss ("slirgnejs") constitutes a process of dissolution and reorientation with considerable transport of material". On the other side he also asserts: "The rapid alternations of bands of different rock types are difficult to explain, if sediments and volcanic rocks are not included in this rock mass".

From a chemical point of view the grey gneisses undoubtedly have their parallels among sedimentary as well as igneous rocks. This is demonstrated by Table V where a grey gneiss is compared with an andesite and the average greywacke composition. The similarities with both rock types are obvious. Judged from the chemistry, therefore, an igneous and a sedimentary origin are thus about equally probable. Other decisive criteria have not been found: Primary features are absent; the "banding" in some of the gneisses can hardly be interpreted as of sedimentary origin until the presence of obviously meta-sedimentary layers among these bands have been proven beyond doubt. However, as small occurrences of quartzite and calcite marble have been detected within comparable Swedish gneisses (Magnusson, 1962, p. 11) *it seems possible, or even probable, that the grey gneisses of the Magnor area are also of sedimentary parentage.* Whether the composition is the original one, or, for instance, changed by metasomatic supply of Na and Ca, is not possible to decide with the present data. In the case of relatively unchanged composition of the gneisses, it is obviously comparable to that of greywackes.

The red gneisses may be the products of regional metamorphism of more arkosic rocks (if the grey gneisses are meta-greywackes) or their composition was determined by metasomatic alteration of the grey gneisses before the main metamorphism. They might also originate from granitic rocks eventually intruded in pre-metamorphic time. With the present state of knowledge it is difficult to find strong arguments in favour of any of the hypotheses outlined above.

The amphibolites most probably are *metamorphosed gabbros or norites* intruded previous to the main regional metamorphism. This appears from their shape and extension, homogeneous composition and absence of banding or any other feature characteristic of supracrustal rocks. In comparable Swedish areas (Magnusson, 1962, p. 11) cores of gabbro and norite have been described from some amphibolites.

Table V.

Comparison of chemical composition of grey plagioclase gneiss (1), greywacke (2) and andesite (3).

Wt %	1	2	3
SiO_2	61,80	64,7	63,16
TiO_2	0,64	0,5	0,54
Al_2O_3	17,02	14,8	18,22
Fe_2O_3	1,29	1,5	1,36
FeO	3,86	3,9	3,33
MnO	0,17	0,1	tr.
MgO	2,83	2,2	2,30
CaO	5,76	3,1	5,24
Na_2O	3,76	3,1	4,06
K_2O	1,79	1,9	1,16
H_2O+	0,56	2,4	0,40
H_2O-	0,00	0,7	0,10
CO_2	0,15	1,3	—
P_2O_5	0,11	0,2	0,14
(Sum)	(99,74)	(100,4)	(100,01)

1. Grey gneiss (see Table II, this paper). 2. Average of 23 greywackes (—S, SO_3) after Pettijohn (1957, p. 307). 3. Pyroxene andesite (—BaO, SrO), Mt. St. Helens, Washington. Turner & Verhoogen (1960, p. 285).

Conclusions.

From the foregoing discussion and the petrographical description it can be concluded:

a) The gneisses of the area most probably represent metamorphosed (and metasomatized?) sediments.

b) The amphibolites are metamorphosed basic intrusives.

c) The regional metamorphism of gneisses and amphibolites took place under the conditions of the upper almandine-amphibolite facies.

d) Red granites were formed by granitization processes (K-metasomatism) subsequent to the main regional metamorphism.

e) A folding episode separates the formation of granites from the regional metamorphism.

f) Retrograde formation of chlorite, epidote and sphene is related areally to the mylonite zone and is probably the youngest event in the history of the area.

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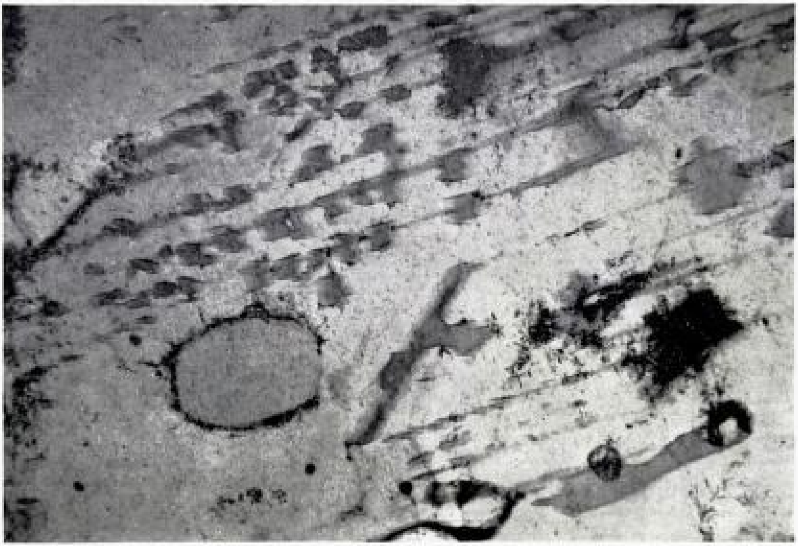
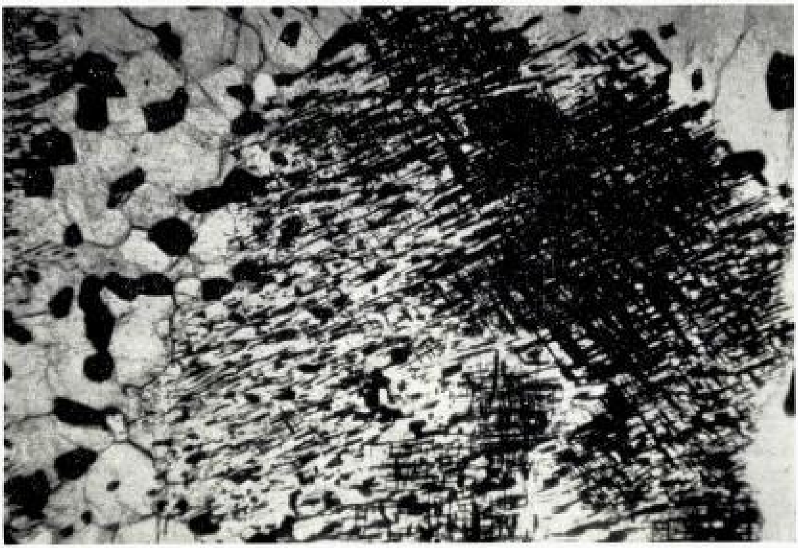
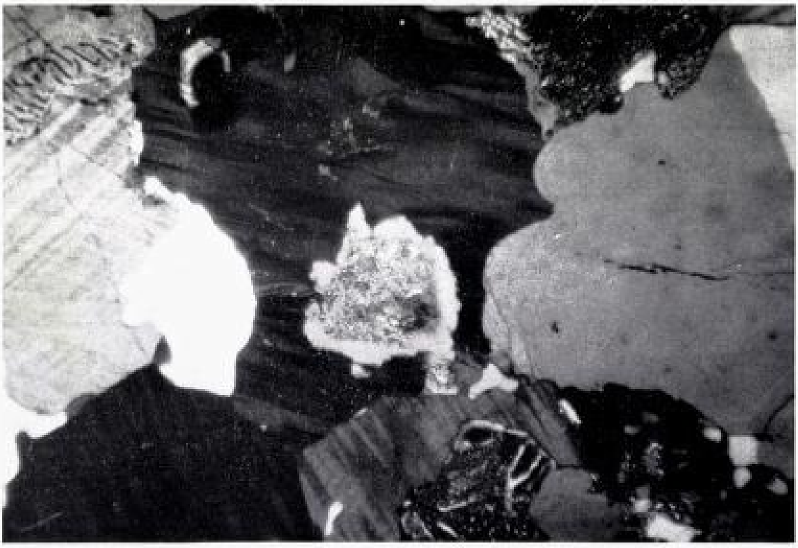


Pl. I a. Antipertbite (in grey gneiss) located along the albite twin lamellae. Deviating trend of one rod of potash feldspar (central in the picture). (+nic., 100x.)



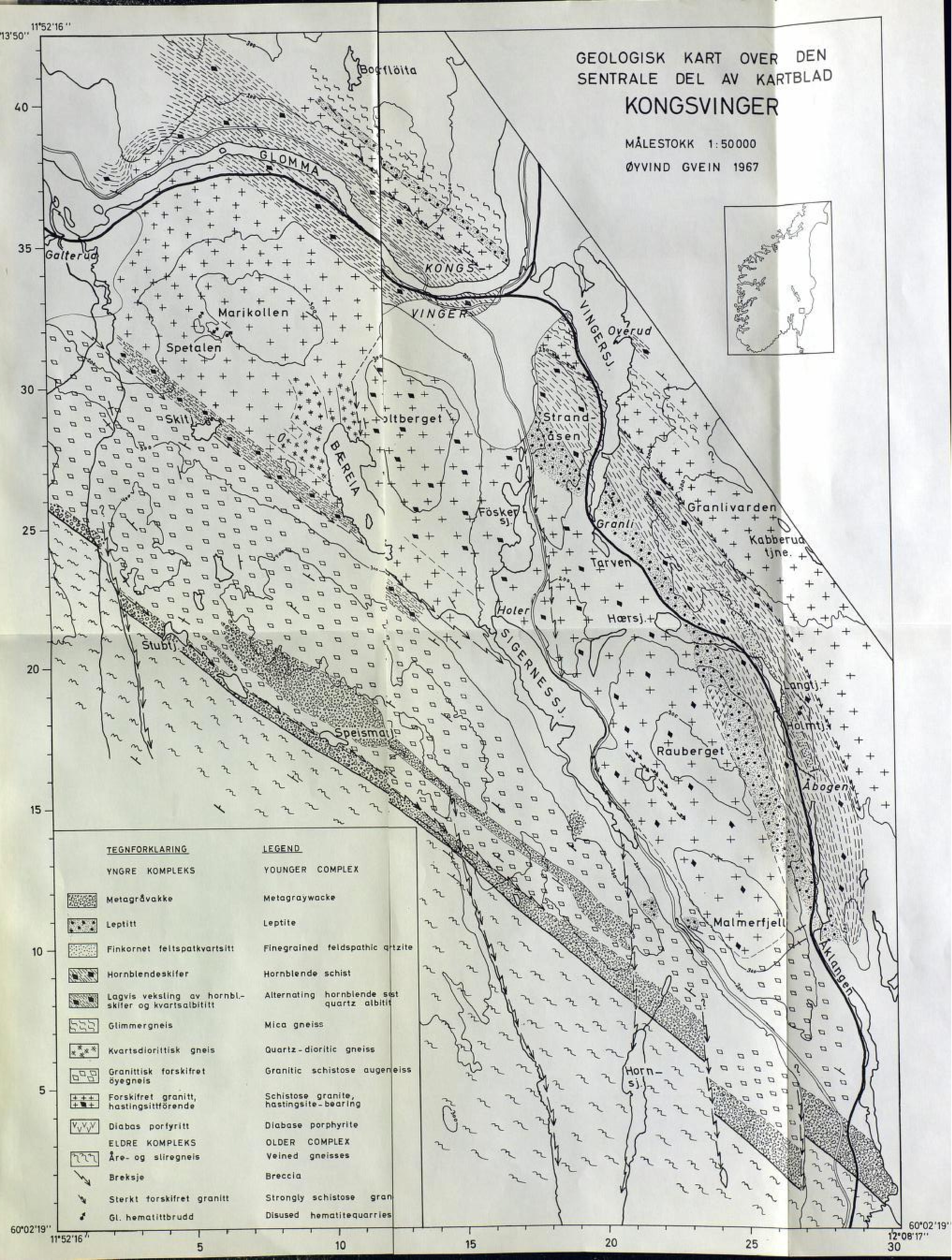
Pl. I b. Exsolution lamellae of ore minerals in two directions in diopside. The lamellae are more narrow than the impression is from picture. Hornblende and magnetite surrounds the pyroxene. (100x.)

Pl. II a. Scapolite (centre of picture) in amphibolite, intergrown with plagioclase. Albite + pericline twinning are discernible in the plagioclase. Other grains are hornblende. The cracks (running diagonally) are filled with plagioclase + calcite. (+nic. 35x.)



Pl. II b. Microcline, oligoclase and quartz in red, unfoliated granite. Note sericitized oligoclase surrounded by rim of clear albite. Antiperthitic potash feldspar inclusions are visible in the oligoclase. (+nic. 35x.)

Innholdsfortegnelse


GEOLOGISK KART OVER DEN SENTRALE DEL AV KARTBLAD
KONGSVINGER
MÅLESTOKK 1:50000
ØYVIND GVEIN 1967
TEGNFORKLARING
LEGEND
YNGRE KOMPLEKS
YOUNGER COMPLEX
Metagråvakke
Metagraywacke
Leptitt
Leptite
Finkornet feltspatkvartsitt
Finegrained feldspathic qrtzite
Hornblendeskifer
Hornblende schist
Lagvis veksling av hornbl.-skifer og kvartsalbititt
Alternating hornblende sst quartz albitit
Glimmergneis
Mica gneiss
Kvartsdiorittisk gneis
Quartz-dioritic gneiss
Granittisk forskifret öyegneis
Granitic schistose augeneiss
Forskifret granitt, hastingsittförende
Schistose granite, hastingsite-bearing
Diabas porfyritt
Diabase porphyrite
ELDRE KOMPLEKS
OLDER COMPLEX
Åre- og sliregneis
Veined gneisses
Breksje
Breccia
Sterkt forskifret granitt
Strongly schistose gran
Gl. hematittbrudd
Disused hematitequarries
GLOMMA
KONGS-
VINGER
VINGERSJ.
SIGERNESSJ.
BÆREIA
Bogflöita
Galterud
Marikollen
Spetalen
Skitj.
Stubtj.
Speismalj.
Strand-åsen
Överud
Granlivarden
Granli
Kabberud tjne.
Tarven
Hærsj.
Holer
Fösker sj.
Langtj.
Holmtj.
Åbogen
Rauberget
Malmerfjell
Åklangen
Horn-sj.
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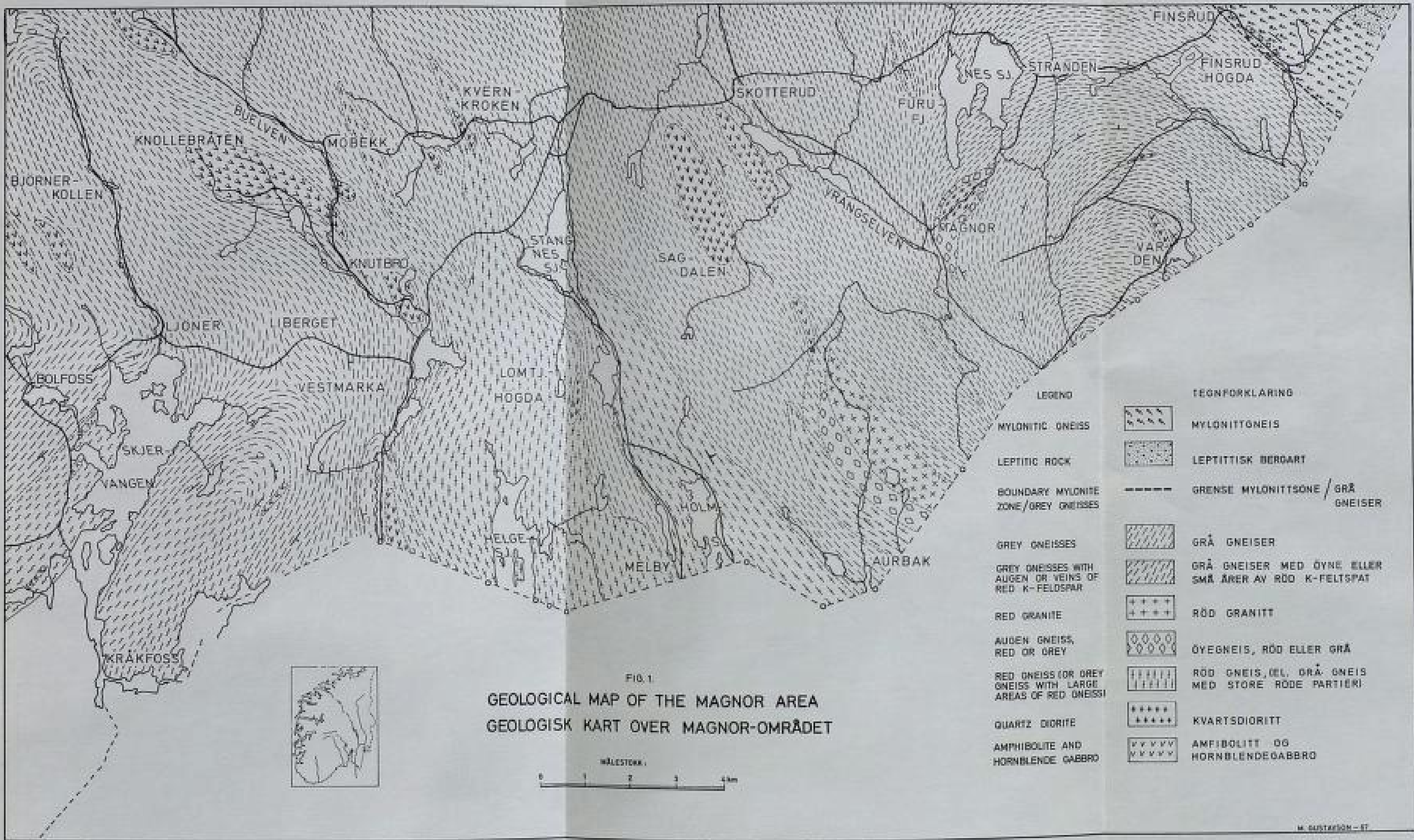

FIG. 1

GEOLOGICAL MAP OF THE MAGNOR AREA

GEOLOGISK KART OVER MAGNOR-OMRÅDET