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THE MIOGEOSYNCLINAL ROCKS OF EASTERN CENTRAL SWEDEN

BY

PER H. LUNDEGÅRDH

WITH 12 PETROFABRIC DIAGRAMS

BY THOMAS LUNDQVIST

AND ONE PLATE

STOCKHOLM 1960

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Abstract: Scheme of the Petrological Sequence in Eastern Central Sweden (Maps, see Figs. 1—2 and Plate 1)

	Late faults, in part Tertiary
	Algonkian (Proterozoic) dolerite referred to the Jotnian
	Great hiatus
Bothnian cycle	**IV. Serorogenic Bothnian evolution** 3. Crystallization of palingenic magma to granite (*Hernö granite*) and pegmatite 2. Granitization *in situ,* mainly regeneration of granodiorite and alteration of schists (development of porphyroblastic *Revsund granite*) 1. Migmatization, mainly formation of pegmatitic veins in older rocks
Bothnian cycle	**III. Intraorogenic period**
Bothnian cycle	**II. Primorogenic Bothnian evolution** 6. Thrusts 5. Development of tonalite, granodiorite, granite, granite gneiss, and mica gneiss, either *in situ* or by mobilization of older rocks 4. Imbrications 3. Cross-folding and shearing 2. Development of ultrabasic and basic plutonic rocks (rare) 1. Initial folding **I. Bothnian sedimentation** B. Eugeosynclinal facies: Schists (metamorphic graywackes and clayey slates) with intercalations and intermixing of rudaceous-arenaceous and basic volcanic rocks A. Miogeosynclinal facies in S.W.: Arkose, arkosic quartzite, subgraywacke, mica schist very rich in silica, and rare volcanics (mainly basic)
	Substratum: Svecofennian

The miogeosynclinal sedimentary rocks (I A above) have been analysed chemically and mineralogically (Table 2, p. 28). Most of these rocks are composed of immature gravelly-sandy-silty drift rich in feldspar and deposited by swift currents (Figs. 5—6, pp. 14—15). They resemble very much part of the sparagmites of the Caledonian range and also some Quaternary glacifluvial deposits. They originate from an anticlinorium of Svecofennian rocks in the S. W. (Fig. 2, p. 6).

Conglomerates are lacking in the miogeosyncline, but the largest gravel grains of the arkose, which are composed of quartz, show diameters amounting to 7 mm. They correspond to the sizes of the largest quartz grains of the predominant rocks in the anticlinorium, which are granodiorite and granite. Most of the gravel grains are rounded, but angular grains (grits) also occur.

These data indicate frost weathering and rapid transportations.

The main feldspar mineral of the miogeosynclinal sedimentary rocks is microcline, and the K_2O content of the low-metamorphic arkosic quartzite amounts to about 4.5 %. The rocks are hence well fitted for the development of secondary granitic rocks, little or no addition of potassium being necessary. Great masses of granite gneisses and granites originating from immature sediments have also been found in the miogeosyncline. Owing to strong intermixing with argillaceous matter during the primorogenic cross-folding (II: 3 above) garnet, cordierite, and sillimanite have frequently been formed in large quantities (Fig. 26, p. 45, Fig. 27, p. 47, Fig. 28, p. 49).

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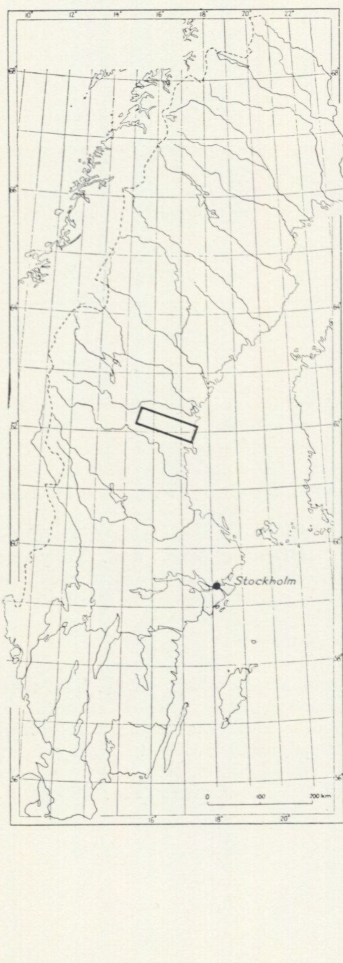


Fig. 1. Location of the Ramsjö—Gnarp region (Plate 1) in Central Sweden.

Preface

In 1953 I started to investigate for the Geological Survey of Sweden the solid rocks of the Gevleborg (Gävleborg) county. I should like to express my greatest thanks to the former Director of the Survey, Professor N. H. Magnusson, for this inspiring task and for several discussions.

In 1953 little was known about the petrology and tectonic deformation of great parts of the Gevleborg county. Available maps covered only the southern and westernmost parts of the county (in the south the Geol. Survey map-sheets Aa 176, 178, 185, 186, 190 by B. Asklund and Aa 191 by P. H. Lundegårdh; in the west the Los-Hamra map by H. von Eckermann, 1936). Special interest was paid at first to the supracrustal rocks of the Hamrånge syncline to the north of Gevle (Lundegårdh 1956 a). Later the hyperitic ore-bearing norite and associated rocks in central and northern Helsingland (Hälsingland) were investigated (Lundegårdh 1957 a), as well as the rudaceous-arenaceous rocks and neighbouring rocks in northern and northeastern Helsingland. The results of the last-mentioned work will be described in the present paper. (Compare Plate 1 and Figs. 1—2.)

The mapping of the region covered by Plate 1 has been carried out during the years 1956—59 by the writer assisted by Hans W. Lindholm, Fil. lic., in the coastal eastern area and by Thomas Lundqvist, Fil. kand., in the western area. The microscopical data have been produced in 1959 by Mr Lundqvist and the writer. The petrofabric analyses on quartz and mica have been performed with great skill by Mr Lundqvist. A special grant for this purpose has been received from Statens Naturvetenskapliga Forskningsråd (Swedish Natural Science Research Council). The chemical, x-ray, and spectrographic analyses have been carried out in the Chemical (head at that time G. Assarsson, Ph. D.) and Geochemical (head at that time K. Fredriksson, Fil. lic.) sections of the Geological Survey. The x-ray data have been calculated from GUINIER photograms.

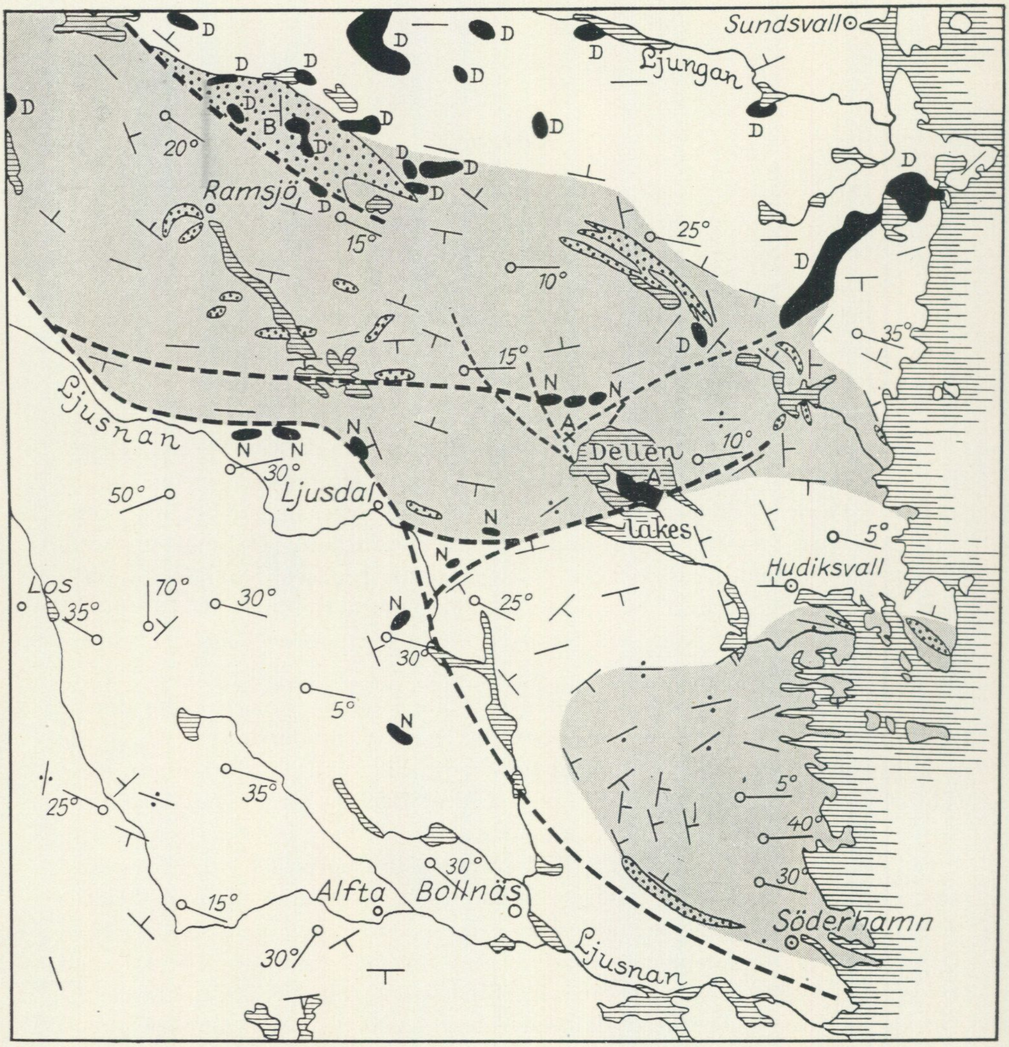


Fig. 2. Part of the southwestern Bothnian miogeosyncline. (Compare Plate 1.) The fold arcs are gray, the preserved rudaceous-arenaceous sedimentary rocks have been dotted. N means titaniferous ore-bearing gabbro, in part norite, D dolerite, and A andesite. Thick broken lines are zones of thrust planes, thin broken lines zones of fault planes. In the S. W., the Alfta anticlinorium is seen, and, in the N.E., part of the Bothnian eugeosyncline. Scale 1 : 1,000,000. The vertical margins are orientated N.—S. Map sketched by the writer and drawn by E. Björk.

Introduction and Survey of Earlier Researches in the Archean of Central Fennoscandia

In the centre of Sweden lie the provinces of Helsingland (S.E.), Herjedalen (Härjedalen, S.W.), Medelpad (E.), Ångermanland (N.E.), and Jemtland (Jämtland, N.W.). Together with part of northern Dalecarlia (Dalarna) these, from a purely geographical point of view, comprise most of Central Sweden. The mapped region is shown in Fig. 1 (location map) and Plate 1 (petrological map). It has been called the *Ramsjö—Gnarp region* and includes a large part of northern Helsingland as well as adjacent areas in Medelpad.

The new Geological Survey map, series Ba, No 16 (Stockholm 1958), in scale 1 : 1,000,000, gives a good picture of the solid rocks of Central Sweden. To the west we there observe the complicated pattern of the Central Swedish Caledonides, both autochthonous rocks and nappes. Outside the Caledonian range and its marginal deposits, Precambrian supracrustal rocks (sedimentary rocks frequently intermixed with volcanics) and granites predominate. The former have mostly been altered to a rather high degree, displaying then feldspathized and in part granitized arenites as well as various kinds of metamorphic lutites, such as schists, mica gneisses, and garnetiferous veined gneisses. The granites comprise three porphyritic varieties and a number of fine- or medium-grained rocks including both granodiorite and tonalite. Furthermore sills of dolerite are common, and these have proved to be the youngest Precambrian rocks encountered in the region to the east of the Caledonides. A west-southwestern postkinematic porphyritic granite known as Rätan granite (Rätan is a village situated in eastern Jemtland) has been considered as late Precambrian, too, though not so young as the dolerite, and the same applies to the masses of rapakivi granites occurring in the northern part of Central Sweden (Ångermanland and northern Jemtland). The dolerite has been referred to the Jotnian, viz. the middle Algonkian (Proterozoic), the Rätan and rapakivi granites to the final Archean and the early Algonkian (the Subjotnian). The remaining Precambrian rocks outside the eastern margin of the Caledonides are all of Archean age (> 1,000 millions of years).

The Precambrian supracrustal rocks have their widest areal distribution in the coast region of Central Sweden, in 1910 designated by A. G. Högbom as the Bottnian (= Bothnian) gneiss district (Högbom 1910, pp. 62—63). Högbom's petrological survey of this region, and the adjacent granite areas (op. cit., pp. 63—64), is still remarkably well applicable, being in part founded, indeed, upon the map and description of the Vesternorrland (Västernorrland) county by Hj. Lundbohm (1899).

In southwestern Finland J. J. Sederholm had at that time (1910) already finished his famous investigations of the basic volcanics (in the first instance uralite-porphyrites) and sedimentary rocks (Sederholm 1891 and 1897), especially the Tampere (Tammerfors) schist belt (Sederholm 1897). Sederholm (1893) classed these rocks as *Bothnian* and considered them to be younger than the Finnish supracrustal rocks corresponding to the leptites, hälleflints, marble (oldest Archean limestone and dolomite), and iron ores of the Swedish Bergslagen.[1] The latter he eventually called *Svionian* (Sederholm 1920).

Granitic rocks intrusive into the Svionian supracrustal series but assumed to be older than the Bothnian — viz. granodiorites and tonalites more or less schistose ('gray gneiss-granites') — were grouped by Sederholm into a *first group of granites,* viz. the oldest Archean granites, whereas the true granites — red or reddish massive microcline-rich rocks — intrusive into both the Svionian and the Bothnian series were grouped into a *second group of granites.* Sederholm thought that the Svionian and the first group of granites were separated from the Bothnian by a great unconformity. (Compare Sederholm 1932.) The Bothnian and Svionian series should thus have developed independently, the former on an eroded basement composed of the Svionian rocks and the granites of the first group.

This hypothesis has been critizised by many Finnish and Swedish geologists, especially as Sederholm included in the Bothnian not only the Skellefte schists in Northern Sweden but also the Saxå and Grythytte schists and slates in the Western Swedish Bergslagen. N. Sundius (1923), who has investigated the Grythytte field in detail, could not find any noteworthy unconformity separating the lower leptites and hälleflints of Svionian age from the upper slates supposed by Sederholm to belong to the Bothnian.

In Finland the critizism was started in 1915 by E. Mäkinen and eventually resulted in a new scheme of the Archean petrological sequence by A. Simonen (1953, p. 15). Simonen used the term *Svecofennides,* introduced in 1909 by W. Ramsay for the belt of marble- and ore-bearing rocks stretching towards E.N.E. from eastern Vermland in Western Sweden (Bergslagen, cp. above) to Southern Finland W. of the Viipuri (Viborg) rapakivi granite and in 1936 applied by W. Wahl as a name for the supposed earliest Archean orogenesis in Fennoscandia (the *Svecofennian folding*). Simonen places the Svionian and Bothnian series, and some other supracrustal rocks, too, in the bottom of the 'first (= oldest Archean) orogenic cycle', viz. the Svecofennian (Svecofennidic) one. The basic granitic (and associated) rocks, such as granodiorites, being usually tectonized, he calls *synkinematic* (= primorogenic) rocks, because they ought to have been formed during the strongest phase of the orogenesis. The less tectonized microcline-granites, viz. common granites (in part migmatite-granites), of somewhat younger formation Simonen finds to be *late-kinematic* (= serorogenic). In Finland there seems to exist no great *hiatus* between the synkinematic and the late-kinematic rocks, and much common granite (microcline granite) in Sweden defined as synkinematic = primorogenic has in Finland been classed as late-kinematic.

Turning to Northern Sweden, G. Kautsky (1957) has stated as his opinion that the supracrustal rocks of this district, earlier supposed to be entirely Svecofennian (cp. S. Gavelin 1955), could be divided into two groups separated by a great hiatus including the formation of a series of differentiated granodiorites and granites. These plutonic rocks (Jörn and Arvidsjaur granites) have

[1] The iron-ore-rich district stretching eastwards from eastern Vermland (Värmland).

Table 1. The Svecofennian petrological sequence in Bergslagen and adjacent parts of Sweden

Svecofennian	Serorogenic[2] phase	Pegmatite Granites Migmatization
	Intraorogenic period	Basic eruptive dikes Vätö granite } Eastern Uppland Ultrabasic gabbro } Eastern Uppland
	Primorogenic[1] phase	Granites, development of gneisses Granodiorite Tonalite Gabbros, lherzolite etc.
		Mälar-Grythytte series (quartzites, slates and schists, graywackes, basic volcanics)
	Preorogenic period	Leptite-hälleflint series (volcanics with iron ores, marble = limestone and dolomite, and sedimentary rocks)

[1] Primorogenic, of Lat. *primus*, the first orogenic activity in a geological cycle. Corresponds to synkinematic.
[2] Serorogenic, of Lat. *serus*, a late orogenic activity in a geological cycle. Corresponds to late-kinematic.

always been regarded as equivalents of the primorogenic (synkinematic) Svecofennian granites of Bergslagen, southwestern Finland, and adjacent regions. N. H. Magnusson (1957) has arrived at the same opinion as Kautsky.

The younger supracrustal rocks thus distinguished have been designated by Kautsky as the Elvabergs series, and they have been in part involved in the development of the migmatitic Revsund granite (pp. 14 and 59), earlier interpreted as a northerly Svecofennian serorogenic (late-kinematic) granite.

P. H. Lundegårdh (1957 b) has suggested that the Swedish sedimentary rocks situated in the same belt as the Tampere schists in Finland, viz. the Hernö (Härnö, N. H. Magnusson 1949, p. 60) and Elvaberg (G. Kautsky 1957) series, are post-Svecofennian and thus form the earliest rocks of a *Bothnian cycle* in part in the sense of Sederholm (cp. above) though not containing the Grythytte and allied series of sediments accompanied by volcanics. Magnusson (1957) also considers the Hernö and Elvaberg series as younger than these rocks.

In Bergslagen and adjacent regions, a detailed scheme of the Svecofennian petrological sequence has eventually appeared as a result of the efforts of many geologists. (See, *inter alia,* A. E. Törnebohm 1880—82, N. Sundius 1923, S. Hjelmqvist 1938, P. Geijer—N. H. Magnusson 1944, P. H. Lundegårdh 1946, 1956 b, and N. H. Magnusson 1957.) An abbreviated scheme of this sequence has been given in Table 1.

Instead of Svecofennian many Swedish geologists have used the name Svionian proposed by Magnusson (1936) for the whole cycle, viz. in a much wider sense than was originally intended by Sederholm. (Compare above. See also Magnusson 1957 and Lundegårdh 1956 b.) In 1959 the term Svecofennian was, however, chosen for the second edition of the petrographic map of Europe in the scale 1: 1,500,000 (Meeting of the Scandinavian sub-committee in Hanover, Nov. 2d, 1959). And of course it seems quite convenient to use the terms Svionian and Svecofennian in the same way in both Finland and Sweden.

The Ramsjö—Gnarp Region and Its Relations to Neighbouring Parts of the Crust

GENERAL SURVEY

The Ramsjö—Gnarp region (Fig. 1 and Plate 1) stretches eastward from the western part of the parish of Ramsjö to the Bothnian coast in the parishes of Harmånger (S.), Jättendal (centre), and Gnarp (N.). It forms part of a southwestern miogeosyncline (Fig. 2) bordering upon the eugeosyncline of Medelpad—Ångermanland assumed to have developed and become folded during the Bothnian cycle (cp. above and Lundegårdh 1957 b). S.W. of the miogeosyncline we find an anticlinorium (Fig. 2) which I should like to call the *Alfta*[1] *anticlinorium*. In N.W., near Los, this anticlinorium displays pre-Bothnian terrestrial sediments which are still easily recognizable (Losberget, Lillskog).

Petrological comparisons show that the southwestern Bothnian miogeosyncline reappears in southwestern Finland in the Turku (Åbo) and Kalanti regions, which have been described by Anna Hietanen (1943, 1947). The eugeosyncline has been found to include the Tampere schist belt. (See Simonen 1953.)

The northern shore of the ancient sea containing the Bothnian geosyncline has been shown by G. Kautsky (1959, p. 564) to stretch from Central Swedish Lappland (Sorsele) in the west to the southeastern part of the Norrbotten county in the east. Kautsky (op. cit.) states that the tectonic activity has been moderate in the northern coastal region. To the north of the shore-line lies an anticlinorium, first mentioned by J. Eklund (1923) and named by Kautsky (op. cit.) 'Arvidsjaur land'.

In the south the shore-line is marked by the lower limit of a thick and persistent strip of arenaceous and rudaceous[2] rocks, chiefly quartzite and arkose, which have, however, been strongly folded and sheared and to a very great extent transformed to secondary gneissic and granitic rocks. (See Fig. 2 and Plate 1.) In spite of the great difference in degree of tectonic deformation between Helsingland and the northern part of the Vesterbotten (Västerbotten) county (G. Kautsky 1959), we may be allowed to assume the southern shore of the ancient sea to have stretched from southern Jemtland through northwestern Helsingland to southeastern Helsingland (Fig. 2), viz. along the northeastern border of the Alfta anticlinorium.

THE SVECOFENNIAN ROCKS IN THE SOUTH

The oldest preserved rocks of the Alfta anticlinorium are: 1. members of the leptite-hälleflint series (Table 1), 2. sedimentary rocks and basic volcanics

[1] Alfta is a parish in the centre of the anticlinorium (Fig. 2).
[2] Arenaceous = sandy, rudaceous = gravelly. (See F. J. Pettijohn 1957, p. 17.)

(chiefly spilites and pyroclasts) belonging to the Hamrånge—sub-Los—Lower Los series (H. von Eckermann 1936, P. H. Lundegårdh 1956 a and 1957 a), which are probably equivalents of the Mälar-Grythytte series in Table 1. The members of the leptite-hälleflint series are found in the anticlines and the Hamrånge—sub-Los—Lower Los series in the synclines of the anticlinorium. The former seem to have developed on land and in shallow water, whereas the latter appear to be mainly marine (tourmaline-bearing quartzite and thick beds of argillaceous sedimentary rocks, intraformational volcanic conglomerates, spilites).

The deposition of the supracrustal rocks was followed by strong folding and magmatic activity (the primorogenic or synkinematic phase of the Svecofennian orogenesis). The magmas were mostly palingenic, which means that they were composed of older rocks completely mobilized and strongly homogeneized. The magmatic activity was associated with the formation *in situ* of gneisses and granites to a large extent composed of the supracrustal complexes.

The serorogenic or late-kinematic phase of the Svecofennian cycle implied granitizations and regenerations[1] of part of the gneissic and granitic primorogenic rocks as well as mobilizations of acid silicate matter eventually developing intrusions of granite and pegmatite. The regeneration involved also a widespread formation of pegmatitic veins in the gneisses of the metamorphic supracrustal complexes.

THE BOTHNIAN ROCKS AND THE EVOLUTION OF THE CENTRAL SWEDISH MIOGEOSYNCLINE

During the first period of the Bothnian cycle the Upper Los series (quartzite, schists, volcanics; cp. H. von Eckermann 1936) seems to have been deposited, followed in the petrological sequence by folding. The folding caused the intrusion of titaniferous ore-bearing gabbro of central and northern Helsingland intrude (P. H. Lundegårdh 1957 a) and started afterwards a regeneration of the Svecofennian granodiorites and granites involving also some further alteration of the Svecofennian supracrustal rocks. The regeneration has implied in the first instance the growth of microcline porphyroblasts in the older rocks.

The miogeosynclinal rocks can be divided into: 1. regenerated rocks of the Svecofennian basement, and 2. Bothnian rocks. The basal rocks comprise granodiorites especially, and granites, most frequently with porphyroblasts of microcline and sometimes mylonitized along thrust planes. The bulk of the mylonites have changed to gneisses by recrystallization. No identifiable Svecofennian supracrustal rocks occur in the Helsingland part of the miogeosyncline, but in westernmost Medelpad (parish of Haverö) and southeastern Jemtland (the parishes of Hackås, Bodsjö and Lockne) several remnants of such rocks are found. These remnants are situated in the same anticline which is seen in Plate 1 and the upper part of Fig. 2, viz. the Ramsjö—Harmånger fold arc,

[1] Regeneration corresponds to *Metablastese* in German and means here a partial or total recrystallization of an older granitic rock.

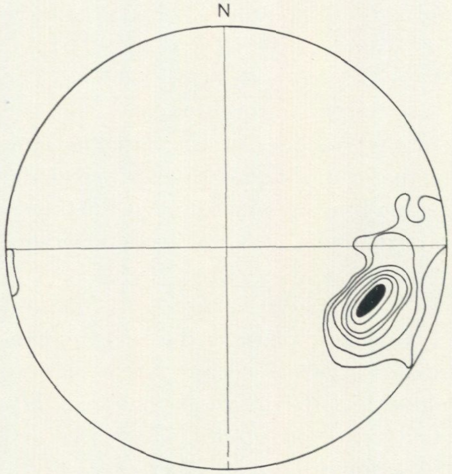


Fig. 3. Projection of 100 observations of lineation in the Ramsjö—Gnarp region (lower hemisphere, SCHMIDT's net). Contours 0—3—6—9—12—15—18—21 %, maximum 23 %.

the axis of which dips gently towards the S.E. (Ramsjö)—E.S.E. (Harmånger). As the oldest rocks of this fold arc appear in the N.W., it ought to represent an anticline, which is also in agreement with most observations of planar schistosity. Most dips of the schistosity point N.N.E.—N.E. in the northern limb and S.S.W.—S.W. in the southern limb (Fig. 2 and Plate 1).

Most of the core of the anticline has been occupied by granodiorites and granites, part of which are supposed to be regenerated Svecofennian rocks and part of which represent strongly metamorphic Bothnian supracrustal rocks.

The northern limb of the anticline contains the arenaceous and rudaceous rocks already touched upon and interpreted as the basal sediments of the Hernö series. They have been distinguished as the *Naggen group,* after the lakes Lillnaggen and Stornaggen 17—20 km N.E.—E.N.E. of Ramsjö. (See Plate 1.) The Naggen group comprises arkoses and quartzites (mainly arkosic quartzites) grading into subgraywackes (terminology in accordance with F. J. Pettijohn 1957). Intercalations of metamorphic lutaceous (clayey; Pettijohn 1957, p. 17) sediments are common in part of the arenites, and these are also overlain by metamorphic lutites. Volcanics are not very common. In Plate 1 only a few boudins of metamorphosed layers (metabasite) can be seen.

In the Bothnian eugeosyncline graywacke schists often admixed with basic volcanic matter (pyroclasts) predominate. Both there and in the Naggen group primary bedding has been observed (in part graded bedding; see Plate 1, the westnorthwestern part, and Figs. 4—6). The strike of the bedding is N.N.E.—N.—W.N.W., with variable dips even in neighbouring outcrops indicating an early folding around axes striking in the same direction as the bedding, viz. on an average N.—N.N.W. The main planar structure of the geosynclinal rocks is, however, an often strong and often shearing schistosity striking W.—N.W. (Plate 1 and Fig. 4). This schistosity has developed during later cross-folding about axes directed to E.—S.E. and with moderate dips (Plate 1, Figs. 2 and 3).

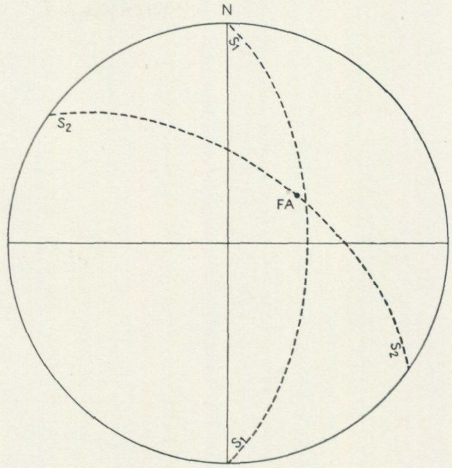


Fig. 4. Projection of bedding (S_1), schistosity (S_2), and axis of shear-folding (FA) in arkosic subgraywacke with lutaceous intercalations (lower hemisphere, SCHMIDT's net). 18 km N.E. of Ramsjö. (See Plate 1.)

Imbrications owing to glidings along shear planes have produced huge flakes of sedimentary rocks, which have become afterwards in part strongly altered and displaced by intrusions of magma. (See below.) The flakes have approximately glided in the directions of the minimum pressure, viz. the fold axes, and these have thus been preserved as a lineation frequently very strong (Plate 1, Figs. 3, 16, and 18).

During the primorogenic Bothnian folding, palingenic (secondary) magma developed in and around the roots of the folds and rose to higher levels of the crust, there attacking, brecciating, and in part assimilating older rocks and eventually congealing as primorogenic (synkinematic) Bothnian granodiorite (grading now and then into tonalite). The rising granodiorite in the first instance occupied the cores of the anticlines, there forming domes, and then penetrated the country rocks along the planes of schistosity already used when the sedimentary rocks became imbricated. The imbricated bodies were thus separated, and we got the distribution of sedimentary rocks as displayed in the present level of erosion (Plate 1, in the first instance the quartzite-arkose bodies N.—E. of Ramsjö and in the neighbourhood of Hassela).

Heat and compounds emitted from the intruding magma, viz. so-called emanations, regenerated (foot-note p. 11) the remaining older Svecofennian granodiorite and granite, and altered a great part of the Bothnian sedimentary country rocks to mica gneisses, garnet gneisses, granite gneisses, and secondary granites. In and around the crest of the Ramsjö—Harmånger anticline (see the right part of Plate 1), the magmatic solutions met with arenaceous and lutaceous sedimentary rocks frequently strongly intermixed (Figs. 19 and 20), owing to flowage and drag-folding. Certainly the rocks in the crest were in late primorogenic Bothnian time in part plastical. Highly variable pressure conditions and the intermixing of the various rock compounds made possible the formation of garnetiferous rocks with or without cordierite and sillimanite, garnet-free rocks rich in sillimanite and cordierite, as well as locally char-

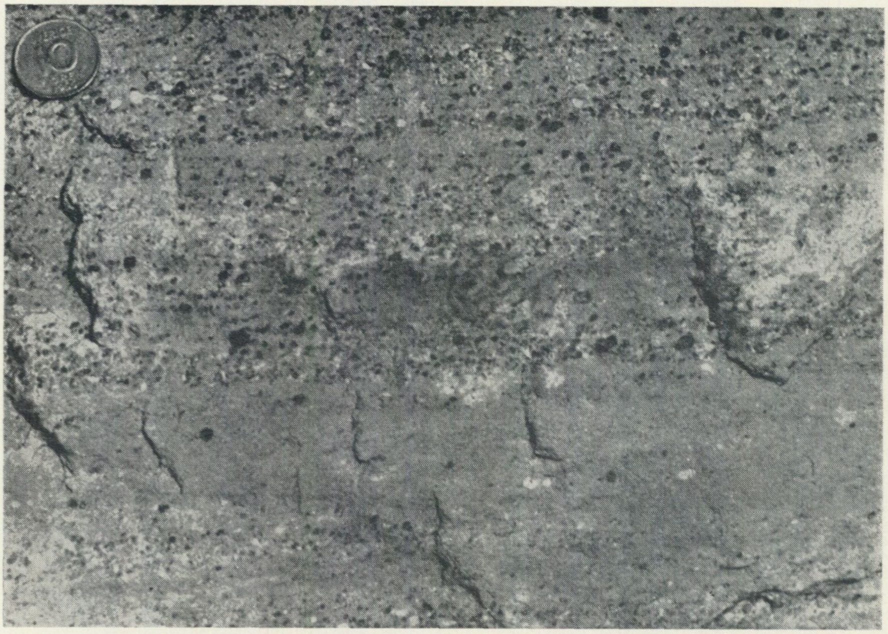


Photo: P. H. LUNDEGÅRDH.

Fig. 5. Arkose with sandy-silty intercalations. Lenticular cross-bedding is visible in the central and lower parts of the photo. 0.8 × nat. size. 16.5 km N.E. of Ramsjö, to the north of the western part of Lake Lillnaggen (near loc. No 865 in Plate 1.)

nockitic rocks and andalusite- or spinel-bearing rocks. The Harmånger—Gnarp area thus offers a very good opportunity for studying various stages of alteration of sedimentary rocks to igneous-appearing rocks under variable conditions, including what has to be called incomplete and complete granitizations (partial and total alterations *in situ* of various supracrustal rocks to granite gneisses and granites).

The primorogenic granodiorite and granite of the miogeosyncline most frequently contain microcline prophyroblasts, which are as a rule red or reddish in the southwestern part of the miogeosyncline (as well as in the Alfta anticlinorium), and often in the northeastern part of the miogeosyncline, too. In the central and northwestern parts of the Ramsjö—Gnarp region the augen are, however, mostly gray white, and the same holds for all porphyritic tonalites, granodiorites, and granites of the eugeosyncline, the degree of oxidation being lower there.

Two generations of porphyroblasts have been formed in the miogeosynclinal granodiorite and granite, viz. an older tectonized one (Figs. 22—24) and a younger undeformed one (Figs. 32—34). Younger porphyroblasts have also been encountered in incompletely granitized parts of the lutaceous sedimentary rocks (granitic mica gneisses). The various granitic rocks containing non-deformed porphyroblasts have been summed up as *Revsund granite* (after Revsund in eastern Jemtland). (The still younger, porphyritic Rätan granite does not occur in the mapped region.)

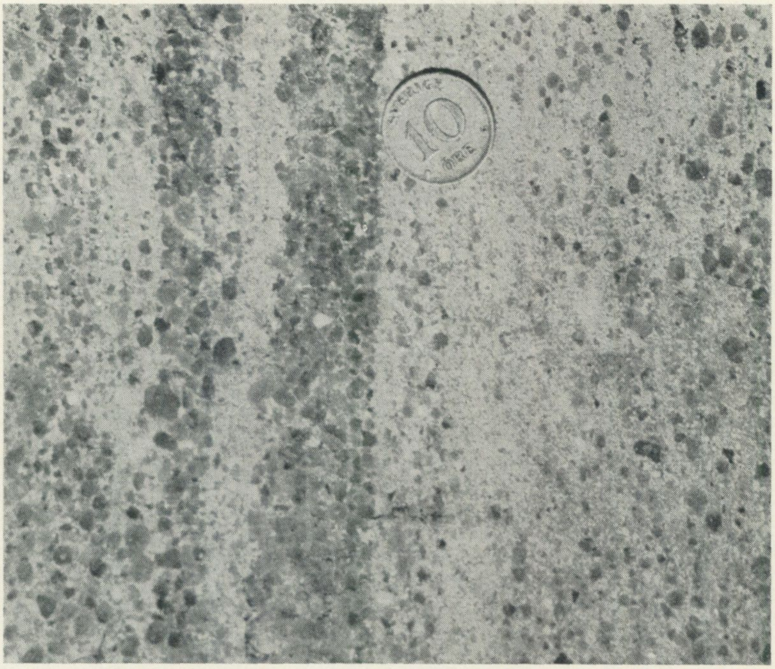


Photo: P. H. Lundegårdh.

Fig. 6. Lenticular gravelly beds in arkose rich in sand and silt. Nat. size. Locality, see Fig. 5.

In the Ramsjö—Gnarp region the Revsund granite appears as zones and small areas of more or less schistose granodiorite (sometimes tonalite) rich in undeformed porphyroblasts. These have been marked with sparsely distributed Y-signs on the petrological map (Plate 1: the left part). Further towards the N.W., the schistosity frequently vanishes, the Revsund granite — there gray to red gray — having obviously developed deeper in the crust, at hydrostatic pressure. This accords with its position in the core of an anticline the axis of which is dipping S.E. (See pp. 11—12.)

The granodiorites and granites that developed during the primorogenic (synkinematic) phase of the Bothnian cycle, as well as their older microcline porphyroblasts, became deformed towards the end of this phase so that they now appear as *gneiss-granites.* Thrust zones with mylonites and mylonite gneisses and sometimes friction breccias also developed, for example in the northwestern part of Plate 1, along the southwestern border of the quartzite-arkose body N.—E. of Ramsjö.

The greatest of these zones is the *Ljusnan thrust zone* (Fig. 2; see also P. H. Lundegårdh 1957 a, p. 6), which follows with some deviations the river Ljusnan from Ljusne south of Söderhamn in the S.E. to Ljusdal and south-eastern Jemtland in the N.W. Two branches stretch from this thrust zone E. and E.N.E. They meet and continue as one thrust zone to the Dellen lakes and from there towards the Bergsjö—Harmånger area. Though the last-mentioned

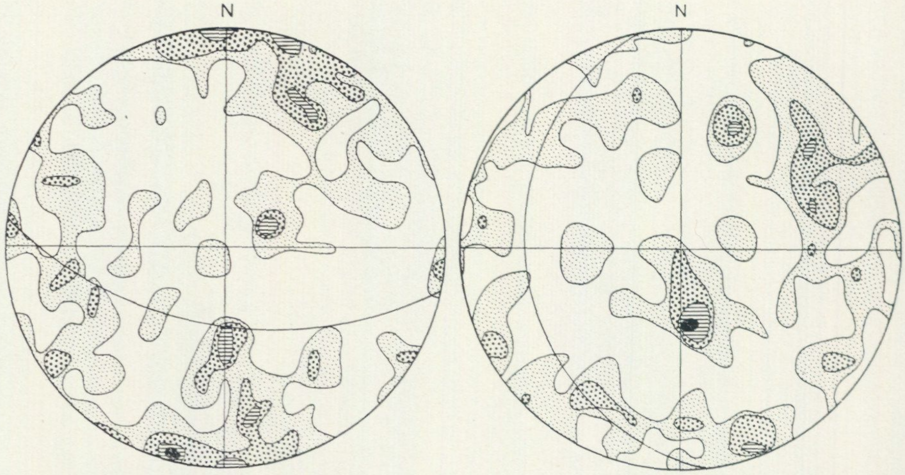


Fig. 7. Orientations of optic axes of quartz (projection on SCHMIDT's net: lower hemisphere). To the left subgraywacke from loc. No 436 in Plate 1, 20 km E. N. E. of Ramsjö. N = 200, contours 0—1—2—3—4 %. To the right arkose from loc. No 865 in Plate 1, 16.5 km N.E. of Ramsjö. (Compare Figs. 5—6.) N = 200, contours 0—1—2—3—4 %. The *s*-plane of diagram No 436 marks the schistosity of the rock, whereas the *s*-plane of diagram No 865 shows the bedding.
Analyst: TH. LUNDQVIST.

thrust zone has been located in outcrops immediately to the south of the region mapped in Plate 1, no mylonite and only one late friction breccia cemented by quartz has been seen inside the boundaries of this region. The thrust zone may be covered there with Quaternary deposits (till, gravels, sand, and silt) because it ought from, a tectonic point of view, continue at least to the area between Bergsjö and Jättendal. Another thrust zone runs parallel to the northwestern part of the Ljusnan zone, to the north of this (Fig. 2).

The primorogenic tectonization with its final thrusts was followed by a serorogenic (late-kinematic) migmatization characterized by mobilizations within the sedimentary rocks (the lutites especially) that had already been altered to gneisses, and very locally in the primorogenic granodiorite and granite, too. The mobilized compounds crystallized as granite *(Hernö granite),* aplite, and pegmatite, or as porphyroblasts of microcline (second, undeformed generation of Bothnian porphyroblasts) in pre-existing rocks (development of Revsund granite). The greater part of the Revsund granite represents granodiorite with primorogenic augen only completely recrystallized in serorogenic time, however.

During the Jotnian period, basic magma was intruded in the northern part of the miogeosyncline as well as in the outer parts of the eugeosyncline (Fig. 2). The basic magma congealed there as sills, dikes, and masses of olivine-bearing dolerite (*Åsby dolerite,* after Åsbyn in northern Dalecarlia). This rock has been locally fractured along thrust or fault zones (cp. S. Hjelmqvist 1944), indicating movements probably to be ascribed to late Algonkian (Proterozoic), and/or

Caledonian, and/or Tertiary tectonic activity. In the Dellen area, in the southern vicinity of the Ramsjö—Gnarp region (Fig. 2), both tectonic and volcanic activity occurred during the Tertiary, probably owing to the Tertiary upheaval of the Caledonides. Late shear zones developed and were used by faults, especially in and around the Dellen lakes. One of these zones can be seen stretching N.N.E. along the river Svågan from the southern boundary of Plate 1. A late zone of fault planes is also stretching E.—E.N.E. to the southern end of the great dolerite intrusion N.—W. of Gnarp, having there affected this comparatively young rock.

The positions of the late fault zones established up to date in northern Helsingland are found in Fig. 2. We there observe a minor intrusion of Dellen andesite immediately to the N.W. of the major occurrence, which has proved to be a twin volcano. (See L. Redaelli 1957, p. 13.)

The Rudaceous and Arenaceous Rocks

TECTONIC DATA

The rudaceous and arenaceous rocks of northeastern Helsingland have been interpreted as the earliest sediments deposited during the Bothnian cycle. This means that they represent the basal sediments of the Hernö series and together with some lutaceous intercalations form the Naggen group. Their areal distribution has been sketched in Fig. 2. High-metamorphic derivatives of the Naggen group, viz. granite gneisses and secondary granites, have not been specially marked in the sketch-map, however. The total amount of rudites and arenites originally deposited in the southwestern Bothnian miogeosyncline ought thus to have been much greater than the amount still easily recognizable in the bedrock. Plate 1 makes obvious that granite gneisses and granites to be later interpreted (p. 43 ff) as granitized arenites are abundant in the southern and eastern parts of the Ramsjö—Gnarp region.

The preserved rudaceous and arenaceous rocks form huge flakes and sheets in the gneisses and granites of the region. Primary structures are common only in the quartzite-arkose body N.—E. of Ramsjö, which is also the largest encountered in the miogeosyncline. The original grains of the sediments are still visible in the coarser arkosic varieties in the core of this body (Figs. 5 and 6), and the bedding is there often very good (Figs. 4—6; see also the 'B' signs and loc. No 953 in Plate 1). The strike of the bedding lies between N.N.E. and N.W., on an average pointing straight to the north. The dips are, however, highly variable (cp. Plate 1), indicating rather strong folding around axes also oriented N.—S.

The beds thus folded have been afterwards cross-folded and cut by shear planes striking N.W.—W., often with rather high dips. The shear planes are sometimes parallel to the bedding planes, such as at loc. No 953 in Plate 1. During the cross-folding, which has worked about axes dipping slowly towards E.S.E. (Figs. 2—3 and Plate 1), imbrications have also occurred along certain shear zones (Plate 1, the upper part). These zones show the strongest planar

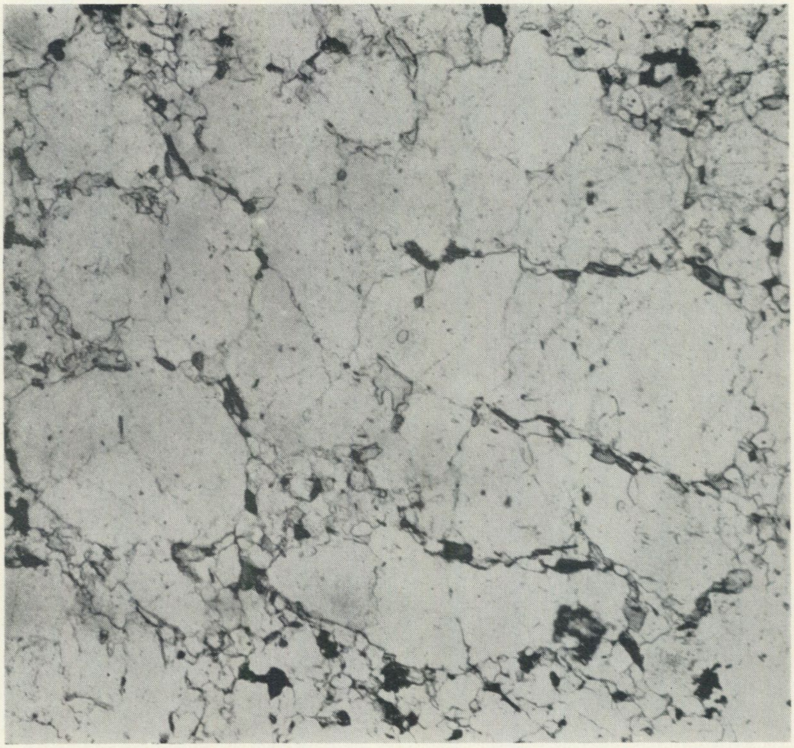


Photo: P. H. LUNDEGÅRDH.

Fig. 8. Arkosic quartzite with rounded quartz grains. Thin section, 45 × nat. size. Loc. No 953 in Plate 1, 16.5 km N.N.E. of Ramsjö.

schistosity encountered in the Ramsjö—Gnarp region, disregarding the younger zones of thrust and fault planes marked with broken lines in Fig. 2 and Plate 1. They also show the strongest lineation met with in the sedimentary rocks of the region. The lineation is in the first instance marked by needles and fibres of sillimanite (Figs. 16 and 26).

The fold axes constructed from the fold arcs as shown in Fig. 2 have the same bulk orientations as the lineations of the rocks of the arcs (Plate 1, Fig. 3). The strong lineations of the rocks of the imbrication zones should thus be parallel to the B-axes and ought to represent simultaneously the directions of the glidings of the imbricated masses of sedimentary rocks in the limbs of the arcs. In the crest of the Ramsjö—Harmånger anticline, viz. in the present level of erosion of the Harmånger—Jättendal area, the incompetency of the lutaceous rocks of the sedimentary series have led up to a contemporaneous development of drag-folds (Plate 1, to the right).

In Figs. 7, 10, 12—14, and 17 are given a number of fabric diagrams of arkosic quartzite, arkose, and subgraywacke[1] in the Ramsjö—Harmånger anticline, which will serve to illustrate to some extent the tectonic history and style

[1] Terms in accordance with F. J. Pettijohn 1957.

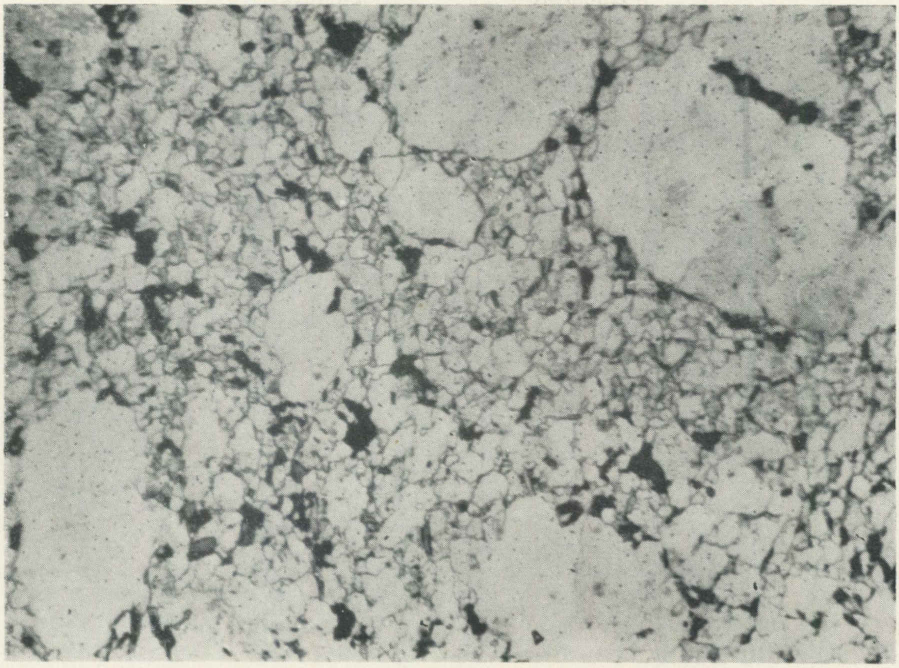


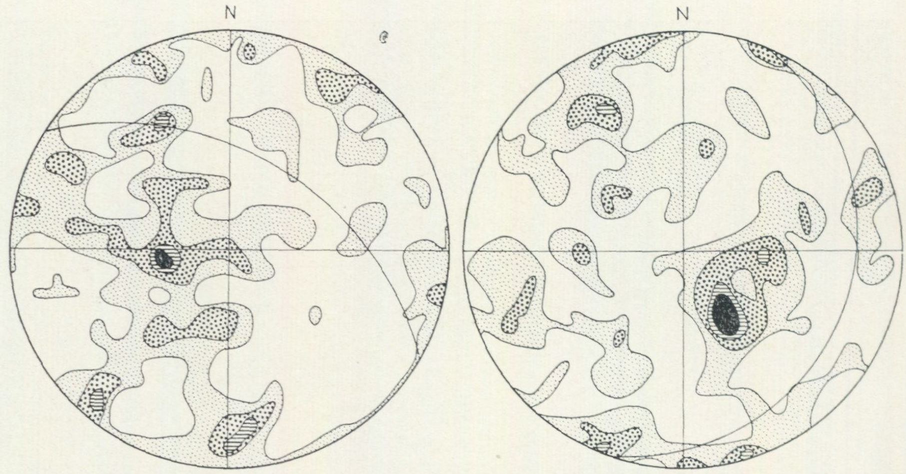
Photo: P. H. Lundegårdh.

Fig. 9. The same quartzite as in Fig. 8. Along the planes of schistosity the quartz grains have been strongly fractured. Thin section, 40 × nat. size.

of the region mapped. Before starting to interpret these diagrams we shall, however, throw a glance upon the textural development of the rocks analysed and discuss some problems concerning the quartz fabric in deformed rocks.

The best preserved rudaceous and arenaceous rocks are found in the core of the great lenticular body N.—E. of Ramsjö. The shear has there been very weak and has often developed no more than joints. In Figs. 8—9 are shown two microphotos of a quartzite from the low-metamorphic core of the quartzite-arkose body. The quartzite shows good bedding and only weak, in part shearing schistosity. Dominance of primarily rounded quartz grains is seen in Fig. 8; fracturing of most rounded grains is displayed by Fig. 9. The fracturing seems to have been caused by the primorogenic shear, the same shear that has made possible the imbrications of the beds of the Naggen rocks (Plate 1).

In 1930 B. Sander applied among other hypotheses what has been called in English the fracture hypothesis in order to explain the quartz orientation in deformed rocks. This hypothesis implies a reduction by tectonization of the primary quartz grains of the rocks to fragments more or less needle-like. The axes of most fragments should have been orientated parallel to the crystal axes of quartz. D. Griggs and J. Bell (1938) have confirmed Sander's hypothesis regarding the formation of quartz needles by fracture. They found, however, that the axes of the fragmentary needle-shaped individuals were oriented paral-



935 **953**

Fig. 10. Orientations of optic axes of quartz (projection on SCHMIDT's net: lower hemisphere). To the left subgraywacke from loc. No 935 in Plate 1, 13.5 km E.N.E. of Ramsjö. N = 200, contours 0—1—2—3—4 %. To the right arkosic quartzite from loc. No 953 in Plate 1, 16.5 km N.N.E. of Ramsjö. N = 200, contours 0—1—2—3—4 %, max. 5 %. The *s*-plane of diagram No 935 marks the schistosity of the rock, whereas the *s*-plane of diagram No 953 shows the bedding.
Analyst: TH. LUNDQVIST.

lel to the rhombohedral and horizontal as well as to the vertical edges of the fractured crystals.

During tectonizations, the quartz fragments have very often become rotated so as to form girdles after projection of their optic axes on a SCHMIDT net. Several girdles, all displaying rotation around the tectonic *b*-axis, may develop theoretically. These have been known as *ac*-girdles. H. W. Fairbairn (1939 b) has shown, however, that in several quartzite samples from Quebec most *ac*-girdle maxima can be correlated with the assumption of most fractured and rotated, needle-shaped quartz individuals having their axes parallel to $[(10\bar{1}1):(01\bar{1}1)]$ and displaying $(10\bar{1}1)$ and $(01\bar{1}1)$ as bounding planes in *ab*. These faces should also represent the best cleavages of the individuals (Fairbairn 1939 a).

In quartzites only *ac*-girdles are met with as a rule. The origin of these girdles seems to be best explained by means of the fracture hypothesis (cp. Sander 1930 and Fairbairn 1939 b), but their further development has been discussed by several authors. Sander (1930) considers the *ac*-girdles to be due to an orientation of the axes of the fractured grains (needles etc.) parallel to *a*, combined with a rotation around *b*. This process often seems to be the result of microfolding. The *s*-planes ought then to undulate, and cleavage poles of mica when present ought to form girdles (Figs. 14 and 17), the more complete the stronger the folding. Such undulations are visible in Fig. 15, which is a microphoto of a strongly deformed quartzite.

We shall first examine four samples from the quartzite-arkose body N.—E. of Ramsjö, viz. Nos 436, 865, 935, and 953 (Figs. 7 and 10). These rocks

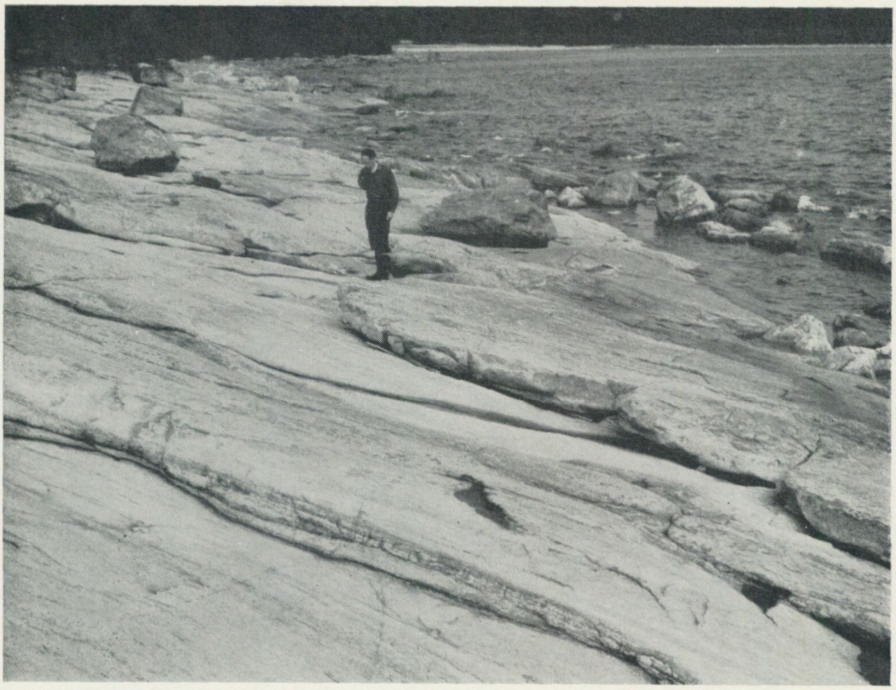


Photo: P. H. LUNDEGÅRDH.

Fig. 11. Coarse quartzite and subgraywacke with strong planar schistosity and containing large porphyroblasts of either cordierite (Fig. 27) or microcline. Loc. No 843 in Plate 1, 7 km E.S.E. of Jättendal.

frequently show good primary bedding, especially No 865, which is an arkose (Figs. 5 and 6). In this sedimentary rock the bedding is the main structure. The compressional primorogenic stress has only produced joints dipping 70° to N. 30° E.

In the remaining samples, which are all arenaceous sedimentary rocks, the shear planes are visible as planar schistosity, however, and part of the quartz grains has been crushed. (Compare Figs. 8 and 9.) In the subgraywacke No 935 and quartzite No 953, the schistosity planes are oriented parallel to the bedding. The subgraywacke No 436 shows intercalations of mica gneiss.

The fabric diagrams now examined have failed to reveal any data indicating deformation of considerable strength. This is in harmony with the low-metamorphic character of the rocks analysed. Only in sample No 935 can perhaps be traced a slight tendency for the optic quartz axes to assemble in the western part of the diagram so as to suggest a fold axis dipping gently to the east. (The macroscopic lineation is on an average 5° E.S.E.)

Of the next four diagrams (Figs. 12 and 13), three — Nos 843, 645, and 660, belong to metamorphic arenites from the crest of the Ramsjö—Harmånger anticline. All three show distinct tectonic S-planes, especially No. 843 (Fig. 11). Bedding has been observed only in No 660, where it coincides with the schistosity.

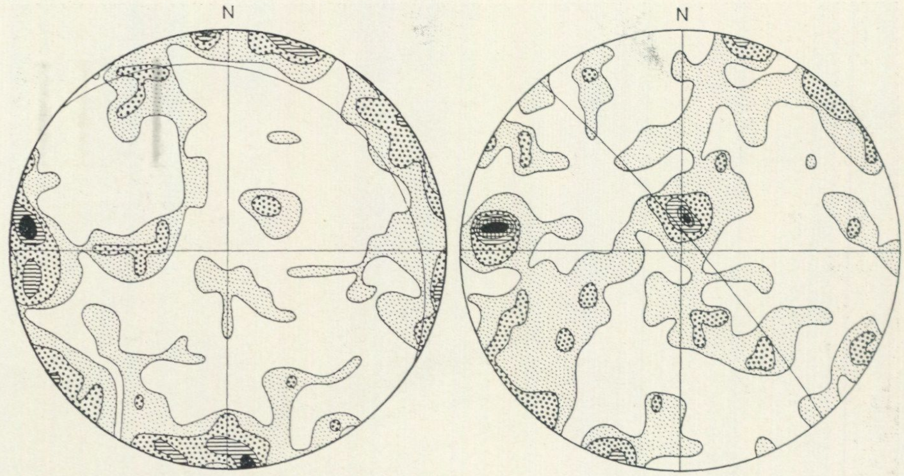


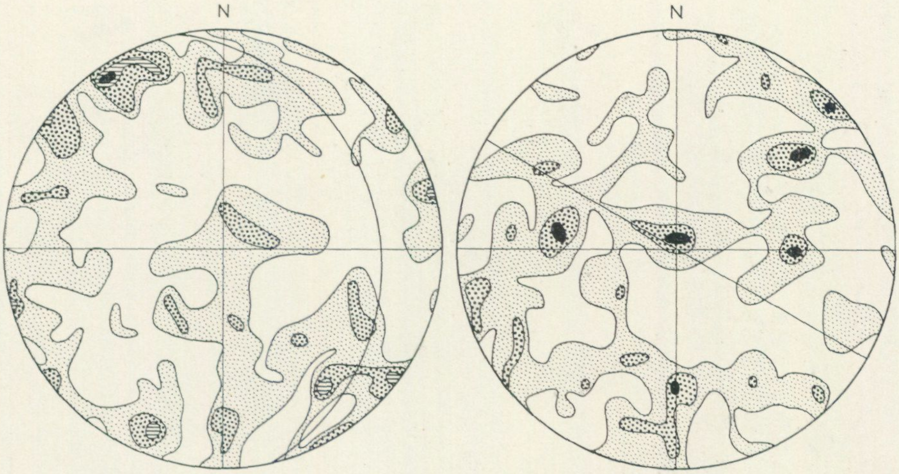
Fig. 12. Orientations of optic axes of quartz (projection on SCHMIDT's net: lower hemisphere). To the left subgraywacke from loc. No 843 in Plate 1, 7 km E.S.E. of Jättendal. (Compare Fig. 11.) To the right arkosic quartzite from loc. No 645 in Plate 1, 11 km E.S.E. of Hassela. N = 200, contours 0—1—2—3—4—5 %.
The *s*-planes of the diagrams mark the schistosity of the rocks.
Analyst: TH. LUNDQVIST.

The distributions of the optic quartz axes of Nos 645 and 660 are wholly devoid of significant trends, whereas No 843 displays an almost horizontal girdle nearly parallel to the low-dipping strong schistosity of the rock. (Compare Fig. 11.)

Sample No 932 (Fig. 13) has been taken from a marginal part of the quartzite-arkose body N.—E. of Ramsjö. It also lacks interpretable data regarding the orientations of the optic quartz axes, which is most interesting in respect of its position near the southwestern border of the quartzite-arkose body. As a matter of fact this border bears evidence of being a late thrust zone, displaying strong deformation of the neighbouring intrusive granodiorite (and tonalite), too. The tectonization of the granodiorite (and tonalite) is, however, restricted to a narrow zone, and the same apparently holds for the arenite, according to the diagram No 932 and to the investigations in the field.

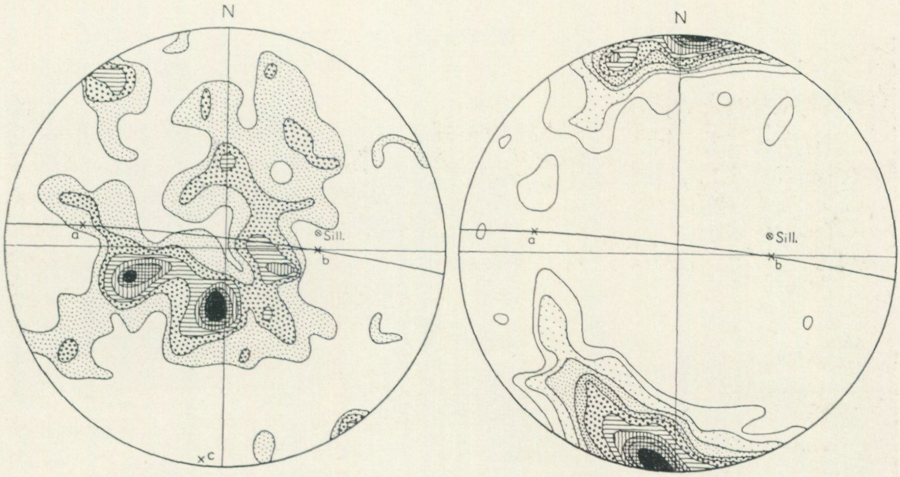
We shall now turn to an area displaying in part strongly metamorphosed arenite sheets with intercalations of mica schist and separated by zones of mica gneisses and intrusions of granodiorite. The area is situated in the northern limb of the Ramsjö—Harmånger anticline, at Hassela in the western vicinity of the crest. The arenites are in part strongly schistose, showing both tectonic S-planes and lineation. In part, however, they appear in the field to have been but little deformed. One arkosic quartzite and one subgraywacke[1] from this area have been subjected to fabric analysis. One of the samples, viz. No 411 in Fig. 14, has been taken in an outcrop showing only weak macroscopic schistosity. The other sample, viz. No 633 in Figs. 15—17, originates from an outcrop

[1] Terms in accordance with F. J. Pettijohn 1957.



660 **932**

Fig. 13. Orientations of optic axes of quartz (projection on SCHMIDT's net: lower hemisphere). To the left subgraywacke from loc. No. 660 in Plate 1, 5.5 km S.E. of Bergsjö. N = 200, contours 0—1—2—3—4 %. To the right arkosic quartzite from loc. No 932 in Plate 1, 12 km N.E. of Ramsjö. N = 200, contours 0—1—2—3 %.
The *s*-planes of the diagrams mark the schistosity of the rocks.
Analyst: TH. LUNDQVIST.



quartz **411** biotite

Fig. 14. Orientations of optic axes of quartz and cleavage poles of biotite (projections on SCHMIDT's net: lower hemisphere).
Arkosic quartzite from loc. No 411 in Plate 1, 2.5 km E.N.E. of Hassela. To the left quartz. N = 200, contours 0—1—2—3—4—5—6 %, max. 7 %. To the left biotite. N = 200, contours 0—1—2—3—4—5—6—7—8—9—10 %, max. 13 %. Sill. = c-axes of sillimanite (M, arrangement of measured needles, see Fig. 26).
The *ab*-planes of the diagrams mark the schistosity of the rock.
Analyst: TH. LUNDQVIST.

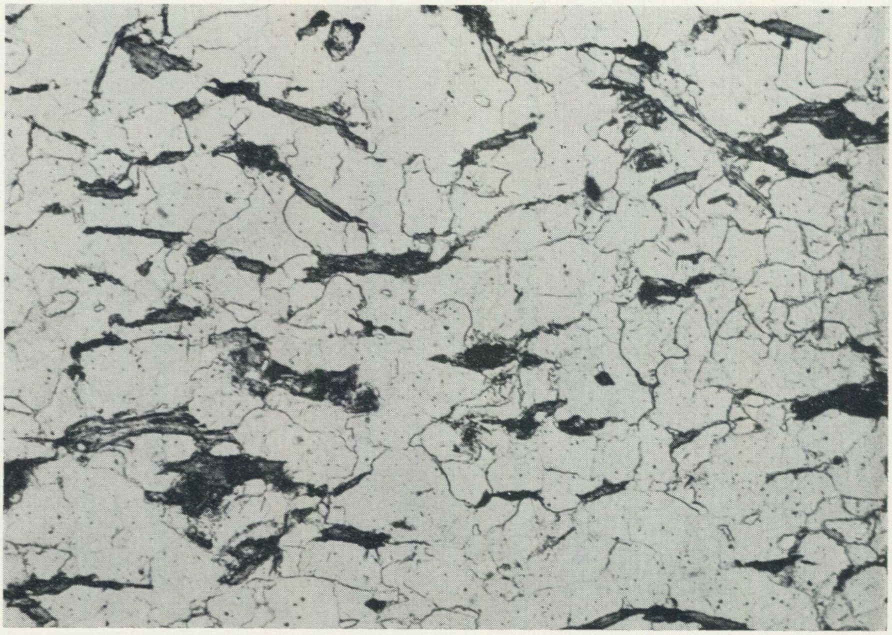


Photo: P. H. LUNDEGÅRDH 1959.

Fig. 15. Biotite flakes in tectonized and recrystallized subgraywacke. Thin section, 50 × nat. size. Loc. No. 633 in Plate 1, 2.5 km W.N.W. of Hassela.

Photo: P. H. LUNDEGÅRDH 1959.

Fig. 16. Sillimanite parallel to the tectonic *b* axis (cp. Fig. 17). The same rock as in Fig. 15.

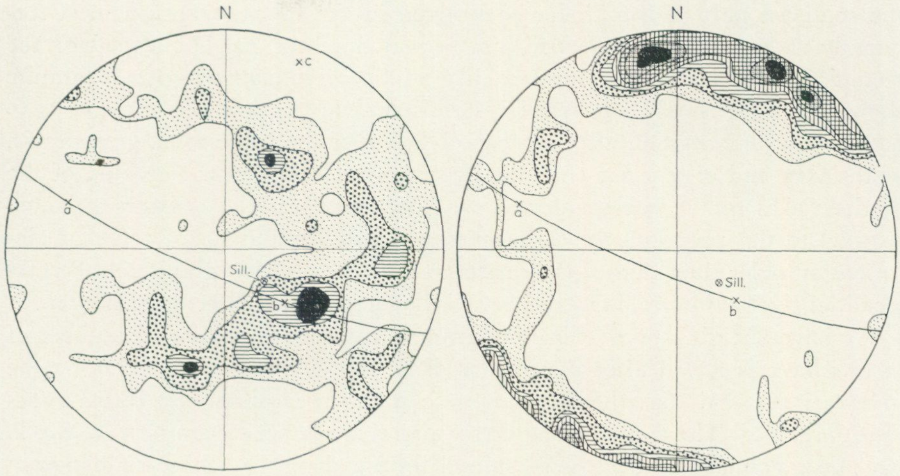


Fig. 17. Orientations of optic axes of quartz and cleavage poles of biotite (projection on SCHMIDT's net: lower hemisphere).
Subgraywacke from loc. No 633 in Plate 1, 2.5 km W.N.W. of Hassela. To the left quartz. N = 300, contours 0—1—2—3—4 %, max. 5 %. To the right biotite. N = 201, contours 0—1—2—3—4—5—6—7 %, max. 9 %. Sill. = *c*-axes of sillimanite (M, arrangement of measured needles, see Fig. 16).
The *ab*-planes of the diagrams mark the schistosity of the rock.
Analyst: TH. LUNDQVIST.

of strongly schistose rock. In both samples the original arenaceous sediment is seen to have been intermixed with lutaceous matter, in the first instance now visible as biotite and sillimanite but to some extent also often as muscovite and cordierite. (For details, see p. 48 ff.)

In spite of its weak macroscopic schistosity, the rock No 411 shows very decisive fabrics of both sillimanite and biotite when analysed on the universal stage. The data found in the microscope are as follows: 1. c-axes of sillimanite approximately parallel to the tectonic *b*-axes (= B; see above); 2. one strong and one weak maximum of the biotite cleavage poles, which on the whole tend to form an incomplete *ac*-girdle; 3. two distinct maxima of the optic quartz axes.

The biotite diagram reveals two statistical *s*-planes intersecting at a small angle near the *b*-axis of the diagram and joining into the macroscopic S-planes of the rock (= the *ab*-plane drawn in Fig. 14). The flattening has thus been strong, as is also evident from the incompleteness of the girdle.

The quartz diagram is interesting inasmuch as the maxima are the highest encountered in the rudaceous and arenaceous rocks investigated, viz. 6—7 %. These maxima cannot be correlated with the biotite maxima, however, and, owing to the sensitivity to crystallographic rearrangement displayed by quartz, they ought to be due to some younger deformation, during or after (cp. p. 16) the serorogenic migmatization at the end of the Bothnian orogenesis. Recent analyses by B. Loberg (1959) of early Svecofennian sedimentary gneisses from the southern part of Stockholm have given in the fabric diagrams most frequently rather distinct quartz maxima situated in the neighbourhood of the tectonic *a*-axes. A sample from a dike of Svecofennian serorogenic granite shows the same trend. The quartz fabric found in the samples ought thus to be due to a deformation after the consolidation of the serorogenic granite, viz. at the very end of or even after the Svecofennian orogenesis. The bulk of the biotite flakes of the rocks analysed by Loberg are on the contrary oriented parallel to the primorogenic Svecofennian schistosity and hence reflect a deformation older than that of the quartz and the serorogenic granite. At certain localities the biotite has, however, been influenced by the later deformation.

We have already seen that in northern and eastern Helsingland a number of thrusts have occurred after the primorogenic Bothnian folding (including the imbrications) and that the Ljusnan zone is the greatest of the thrust zones thus developed. The thrusts along these 'major' zones, which are seen in Fig. 2, have been contemporaneous with 'minor' thrusts along the schistosity planes in other parts of the bedrock, such as in the Hassela area. The rearrangement of the quartz in No 411 seems to be due to glidings along such a minor zone.

The second sample from the environs of Hassela is No 633, and it shows the following trends: 1. *c*-axes of sillimanite approximately parallel to the tectonic *b*-axes (= B; see also Fig. 16); 2. three maxima of the biotite cleavage poles assembled into an incomplete *ac*-girdle; 3. one major maximum and four submaxima of the optic quartz axes.

The biotite diagram shows the presence of three statistical *s*-planes intersecting near the *ab*-plane to the left of *b*. The *ab*-plane, which corresponds to the macroscopic S-plane of the rock, represents an average of the statistical *s*-planes. These are reflected by the varying orientations of the biotite flakes in Fig. 15. It would seem probable that the varying orientations are due to the resistance against total flattening of the biotite flakes as effected by the quartz grains of the rock. They may, however, as well be due to shear-folding. Such folding is common in the mica gneiss intercalating the arenaceous rocks to the south of loc. No 633. (See Fig. 18.)

Shear-folding has, indeed, produced a similar biotite fabric in an arenaceous layer in the cordierite gneiss (kinzigite) of the Kalanti region in the Finnish part of the miogeosyncline, according to Anna Hietanen (1943, p. 83 and Plate VII: D 9).

The optic quartz axes fall on two girdles intersecting near the maximum of the macroscopic lineations measured in the Ramsjö—Gnarp region. (Compare Fig. 3.) None of these girdles can be interpreted as homotactic with the biotite fabric and ought thus to reflect younger deformations, owing to the strong disposition for crystallographic rearrangement of quartz grains when being stressed. The major quartz maximum, however, coincides approximately with the macroscopic lineation of the specimen analysed (*b* of the diagram = B in the field), and in the outcrop the B axis seems to represent not only the fold axis but also the transport direction of the thrust mentioned in the above text — a minor equivalent of the great Ljusnan thrust (p. 15).

As mentioned, neither rock No 411 nor rock No 633 show orientations of the optic quartz axes which can be interpreted as homotactic to the biotite fabric. Homotaxis in these rocks ought to require quartz girdles around the tectonic *b*-axes, according to the experiences mentioned earlier in this chapter (p. 20; see also F. J. Turner 1948). Lack of homotaxis has also been found by Anna Hietanen (1943) in arenaceous rocks from the Kalanti region in the Finnish part of the miogeosyncline. Hietanen's quartz diagrams are, however, almost devoid of statistical trends, whereas in the Hassela area evidence of a younger deformation has been found.

PETROGRAPHY

The sedimentary rocks of the Naggen group are reddish or gray or gray white rocks showing great variations regarding both original petrographic character and degree of metamorphism. In the quartzite-arkose body N.—E. of Ramsjö low-metamorphic arkose, arkosic quartzite, and subgraywacke[1] have thus been encountered, whereas in and to the north of the crest of the anticline granite gneiss and secondary granite originating from arenaceous and rudaceous sediments are abundant. (See Plate 1.) The preserved arenaceous and rudaceous rocks will be described now and their high-metamorphic derivatives in a later chapter.

The preserved arenaceous and rudaceous rocks are found to the north and to the north-west of Lake Lillnaggen, which is in Plate 1 situated 16—17 km N.E. of Ramsjö. The arkoses — gray or slightly reddish brownish gray — show lenticular cross-bedding (Fig. 5) which is locally graded (Fig. 6). The grain size of the beds varies very much and possesses all the characteristics of river deposits. Some layers are sandy or silty, others are composed of gravel intermixed with sand and silt (Figs. 5—6). The whole sediment resembles very much some kinds of glacifluvial matter and has obviously been deposited by swift currents.

The gravelly layers contain grains measuring up to 7 mm in length. The grains are mostly rounded, but angular grains also occurs, as in grits. The leading gravel mineral is quartz. Further fine-grained mica gneiss and microcline occur, and the rock might thus also be defined as a *gravelly conglomerate*. Plagioclase is rare. In the eastern vicinity of loc. No 865, to the north of Lake Lillnaggen, the frequency of grains with diameters between 1 and 7 mm has been examined in a rectangle parallel to the bedding and measuring 50 cm^2:

Quartz	78
Mica gneiss	13
Microcline (pink)	4
Total	95

The finer fractions of the arkose have recrystallized and for the most part display granoblastic texture. Quartz and microcline are here the main minerals.

[1] Terms in accordance with F. J. Pettijohn 1957.

Table 2. Chemical and mineralogical analyses of sedimentary rocks from the northwestern part of the Ramsjö—Gnarp region

Analysts (when nothing else is stated): B. Rajandi (spectral analyses) and P. H. Lundegårdh (mineralogical analyses). Numbers of localities refer to Plate 1

	Arkosic quartzite, 3 km W.N.W. of loc. No 436, E. of Lake Lillnaggen	*Arkosic quartzite*, 3.5 km W.S.W. of loc. No 436, W. end of Lake Stornaggen	*Arkosic quartzite*, 14 km N.N.E. of Ramsjö	*Arkosic quartzite*, Loc. No 436, N. of Lake Stornaggen	*Arkose*, 1 km E. of loc. No 865, 16.5 km N.E. of Ramsjö	*Subgraywacke*, Loc. No 436, N. of Lake Stornaggen	*Schist*, at the railway, 22.5 km N.N.W. of Ramsjö
SiO_2	89.5	88.0	87.5	87.0	[2]86.7	84.0	71.0
TiO_2	< 0.2	< 0.2	< 0.2	< 0.2	0.16	0.2	0.46
Al_2O_3	4.9	5.8	5.7	5.9	[2]6.8	8.4	13.5
Fe_2O_3	0.13	0.23	0.39	0.30	[2]1.5	0.52	0.69
FeO	[1]0.23	[1]0.24	[1]0.41	[1]0.27	[2]0.31	[1]0.34	[1]4.26
MnO	—	—	—	—	0.02	—	0.20
MgO	0.38	0.33	0.44	0.48	0.40	0.65	2.4
CaO	0.20	0.25	0.30	0.25	0.10	1.1	1.4
Na_2O	0.70	0.20	0.30	0.40	0.76	1.16	3.02
K_2O	4.12	4.56	4.50	4.06	3.13	[3]3.95	1.76
Loss on ign.	0.3	0.3	0.6	0.8	0.4	0.5	2.2
Total	100.7	100.1	100.3	99.7	100.3	100.8	100.9
Major minerals	Quartz > microcline > muscovite > oligoclase	Quartz > microcline > biotite > muscovite	Quartz > microcline	Quartz > microcline > muscovite	Quartz > microcline > muscovite	Quartz > microcline > muscovite > biotite > plagioclase	Oligoclase-andesine ≈ quartz > biotite > muscovite
Minor minerals	Hematite, limonite, leucoxene, zircon, tourmaline, chlorite, apatite	Iron oxide ore, epidote, zircon, apatite, (tourmaline)	Muscovite, iron oxide ore, leucoxene, epidote, zircon, apatite	Plagioclase, chlorite, limonite, iron oxide ore, zircon, epidote, tourmaline	Biotite, epidote, apatite, iron oxide ore, tourmaline, chlorite, zircon	Chlorite, iron oxide ore, tourmaline. zircon, cordierite, apatite	Microcline, iron oxide ore, apatite, leucoxene, titanite, zircon (tourmaline)

[1] Analyst: V. Grundulis (chemical analyses)

[2] Analyst: A. Aaremäe (chemical analyses)

Table 3. The B_2O_3 contents of sedimentary rocks from the northwestern part of the Ramsjö—Gnarp region

Spectral analyses by B. RAJANDI. Numbers of localities refer to Plate 1

	parts per million
Arkosic quartzite, 3 km W.N.W. of loc. No 436, E. of Lake Lillnaggen	$\leq$ 30
Arkosic quartzite, 3.5 km W.S.W. of loc. No 436, W. end of Lake Stornaggen .	30 $\pm$ 10
Arkosic quartzite, 14 km N.N.E. of Ramsjö	$\leq$ 30
Arkosic quartzite, loc. No 436, N. of Lake Stornaggen	30 $\pm$ 10
Arkose, 1 km E. of loc. No 865, 16.5 km N.E. of Ramsjö	100 $\pm$ 10
Subgraywacke, loc. No 436, N of Lake Stornaggen	190 $\pm$ 10
Schist, at the railway, 22.5 km N.N.W. of Ramsjö	$\leq$ 30

Mica, both muscovite and biotite, are also always present. In some beds muscovite is more common than biotite, in other beds it is, however, only an accessory component. Biotite is always abundant. Part of it has changed to chlorite.

Minor constituents are epidote, iron oxide ore, further most often tourmaline (schorlite), apatite, and zircon.

A chemical analysis will be found in Table 2, a determination of the boron content of the rock in Table 3. The degree of oxidation is high, the concentrations of calcium and sodium are very low. As will be shown later, most of the Naggen quartzites are also poor in these elements and accordingly in plagioclase, too. (Compare Table 2.)

The boron content of the arkose analysed is remarkably high, especially when compared with the figures obtained in low-metamorphic parts of the adjacent quartzite. (See Table 3.)

Low-metamorphic arkosic quartzites (feldspar quartzites) — reddish or gray or gray white — are nearly exclusively encountered in the large quartzite-arkose body N.—E. of Ramsjö. Remnants are also found E.—E.S.E. of Hassela and in the Bergsjö—Harmånger area.

In the body N.—E. of Ramsjö we often observe quartz grains with preserved rounding (Fig. 8) and also angular, in part strongly fractured grains (along the planes of schistosity; Fig. 9). Quartz recrystallizes easily, however, and granoblastic grains thus predominate also in the low-metamorphic arenaceous rocks. Bedding is there often visible, in rare cases even cross-bedding. Many outcrops lack bedding, however. The schistosity is in the low-metamorphic rocks mostly weak or only marked by joints. It is either concordant to the bedding or shearing.

Quartz is of course the chief mineral, but microcline is also abundant in most samples investigated. At least part of this microcline ought to be a primary detrital mineral of the rocks, especially as larger grains incapable of interpretation as porphyroblasts have sometimes been found. (Compare the arkose.) Nearly all microcline occurs in the groundmass, however, where it shows a granoblastic or irregularly penetrative development indicating complete recrystallization. (Compare Fig. 31.)

Plagioclase appears in certain strata, for example at loc. No 932, 12 km N.E. of Ramsjö. The plagioclase, an oligoclase, is most probably primary and has been strongly altered to sericite. It shows in part a rather dense impregnation with minute grains of hematite, easily discernible as red colouring of the mineral.

Much of the quartzite originates from sediments intermixed with lutaceous matter and is now rich in mica, either biotite or muscovite or both. The biotite is frequently altered to chlorite.

Minor minerals always present are iron oxide and zircon. As a rule apatite also occurs and often epidote, leucoxene and tourmaline, but titanite is rare.

According to F. J. Pettijohn (1957), the arenaceous miogeosynclinal rocks have been classed as arkosic quartzite and subgraywacke. Both these and the arkose have mostly been changed to high-metamorphic rocks with cordierite, sillimanite, garnet, microcline poikiloblasts and sometimes still other secondary minerals. As already mentioned, these rocks will be described in a later chapter (p. 43 ff).

Tables 2 and 3 contain several chemical analyses of low-metamorphic rudaceous, arenaceous, and lutaceous rocks from the quartzite-arkose body N.—E. of Ramsjö and from the neighbouring eugeosyncline. When we compare two very low-metamorphic and evidently non-metasomatic rocks, viz. arkose from loc. No 865 (Figs. 5 and 6) and arkosic quartzite from a locality situated W.N.W. of loc. No 436 (similar to Fig. 8), with the other quartzites analysed in Table 2, we cannot deny the fact that also the latter ought to have been originally very rich in potassic feldspar. The uniformity of the K_2O values is very conspicuous when we consider the varying degrees of metamorphism of the rocks analysed. This uniformity speaks strongly in favour of the assumption of a high original potassium concentration in *all* arkosic and quartzitic rocks analysed. They should thus be designated as arkosic quartzites, and all rocks analysed in the quartzite-arkose body should represent immature sediments. (Compare Pettijohn 1957, pp. 323—24 and 328.) They resemble, indeed, very much the Caledonian sparagmitic sandstones. (See O. Kulling 1942, p. 82 ff.) The lenticular cross-bedding and the frequent interbedding of sediments of varying grain sizes encountered in some low-metamorphic parts of the quartzite-arkose body as well as the diffuse or even lacking bedding in other low-metamorphic parts accord with the observations by Kulling (loc. cit.) from the sparagmitic sandstones of the Vesterbotten county. Furthermore, as has been already mentioned, the most well-preserved arkose (Figs. 5 and 6) of the quartzite-arkose body shows the same appearance as parts of the Quaternary glacifluvial drift and differs decidedly from the petrographic development encountered in arid sandstones.

It seems therefore probable that high relief of the Alfta anticlinorium in combination with rapid mechanical weathering and swift transportations during a period of rather cold climate have been responsible for the immature composition of the arenaceous and rudaceous sediments of the miogeosyncline. This is also in harmony with the moderate degree of oxidation as shown by some of the arkosic quartzites, and the presence of fragments of mica gneiss in the arkose.

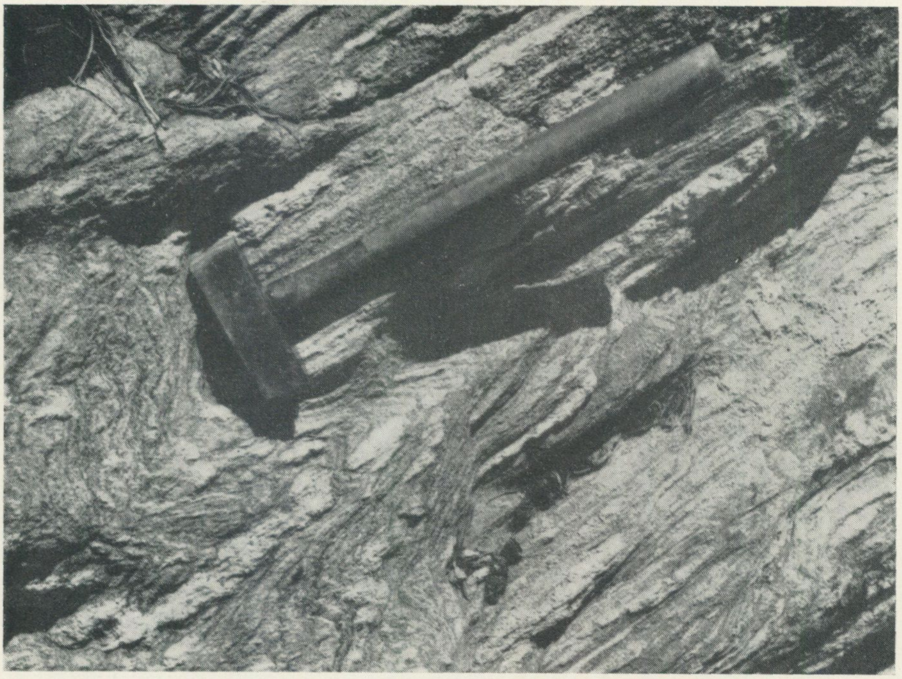


Photo: P. H. LUNDEGÅRDH.

Fig. 18. Shear-folding and strong lineation in migmatized subgraywacke. 3 km E.N.E. of Hassela. Length of hammer 40 cm.

The lack of conglomerate beds in the Naggen group indicates frost weathering of the parental rocks of the sediments. The largest quartz grains of the predominating rocks of the Alfta anticlinorium, which are granodiorite with microcline porphyroblasts and granite, have diameters amounting to 7 *à* 8 mm, and this value corresponds well to the sizes of the largest quartz grains in the arkose. (Compare above.)

The potassium feldspar has obviously as usual been more resistant against weathering than the plagioclase and the mafic silicate minerals of the eroded rocks and is hence far more common than the latter in the arenaceous-rudaceous sedimentary rocks. The components of the weathered minerals will be found in the lutaceous sediments, which ought, indeed, to be then very rich in divalent iron, magnesium, calcium, and sodium. The analysis given at the right end of Table 2 is not representative, as it refers to a rock from the eugeosynclinal margin and thus contains more SiO_2 and K_2O than the normal eugeosynclinal sediments. (Compare the still higher contents of these oxides shown by the lutaceous intercalations in the arenites and rudites; p. 34.) The chemical composition of the normal eugeosynclinal sediments has been testified, however, by the high contents of almanditic garnet, cordierite, sillimanite, and sodic (-calcic) feldspar (oligoclase or acid andesine) encountered in the high-metamorphic schists in the mapped region. (See p. 45.)

Photo: P. H. LUNDEGÅRDH.

Fig. 19. Sheared mica gneiss in coarse mobilized quartzite. Capsule opener (length 11 cm) orientated parallel to the shear. Near loc. No 843 in Plate 1, 7 km E.S.E. of Jättendal.

The Lutaceous and Volcanic Rocks

TECTONIC DATA

The layers of lutaceous sedimentary rocks have behaved incompetently during the foldings of the Bothnian cycle and have thus frequently been wholly put out of shape. Even in areas consisting of homogeneous gray, fine-grained mica gneisses with persistent and easily discernible planar structures, we cannot say whether these structures are primary or not. From the northeastern Bothnian miogeosyncline are known excellent examples of nearly isoclinal small-scale shear-folding of the lutaceous rocks (G. Kautsky 1957, pp. 21—22). A similar deformation is reported from petrographically well-preserved parts of the southwestern miogeosyncline, too. (See Fig. 4 and Anna Hietanen 1943, p. 83.) Even in high-metamorphic parts of the southwestern miogeosyncline we have been able to discern sometimes beautiful shear-folding (Fig. 18). As a rule this folding has eventually become isoclinal, and glidings have occurred along S-planes represented by the limbs of the isoclinal folds. Recrystallizations, and often also metasomatic alterations proceeding along the S-surfaces, have been able to produce afterwards structures that may very well be mistaken for original bedding. This in the first instance holds for sedimentary rocks that have been originally inhomogeneous, viz. graywackes. During orogenies these

Photo: P. H. Lundegårdh.

Fig. 20. The same rocks as in Fig. 19. The metamorphic lutaceous sedimentary rock, viz. the mica gneiss, has been highly incompetent, and in addition the quartzite has been mobilized. In the lower right corner a cordierite porphyroblast is seen. Scale 1 : 4.

mostly change to mica gneisses with felsic schlieren parallel to the S-planes. (Compare p. 44. See also P. H. Lundegårdh 1960.)

In the mapped region the incompetency of the lutaceous rocks can be studied at best in and around the crest of the Ramsjö—Harmånger anticline. The primorogenic cross-folding has produced there not only small and narrow shear-folds of the kind shown in Fig. 18 but also great drag-folds. During the primorogenic phase of tectonic deformation the temperature rose sufficiently high to make the lutaceous sediments plastic. The tectonic pattern hence became complicated by flowage (Figs. 19 and 20) which has facilitated metasomatic processes of various kinds (p. 47 ff), for example, the development of large cordierite porphyroblasts in quartzite (Fig. 27) and of wholly secondary rocks, in the first instance garnet- and cordierite-bearing granites (p. 53 ff).

PETROGRAPHY

No well-preserved lutaceous sedimentary rocks have been found in the Ramsjö—Gnarp region, but beds of lutaceous rocks in part showing moderate metamorphism (schists, meta-argillites) occur in and to the W.N.W. of the quartzite-arkose body N.—E. of Ramsjö. In this body the lutaceous rocks form several intercalations of varying thickness and admixed with arenaceous matter.

The intercalations are sheet-like or lenticular, and the greatest have been outlined in Plate 1. W.N.W. of the quartzite-arkose body N.—E. of Ramsjö the lutaceous rocks posess considerable width and from a regional point of view manifest the beginning of the eugeosynclinal facies. This is also in harmony with the petrographic and chemical character of the rocks. (See below.)

The lutaceous rocks of the quartzite-arkose body N.—E. of Ramsjö are mostly gray grano-lepidoblastic mica schists, or meta-argillites, grading to more or less metamorphosed subgraywackes. The schistosity is not very strong, and primary bedding of arenaceous-rudaceous rocks can sometimes be seen. The mica schists consist mainly of quartz, microcline, biotite, and muscovite. Quartz is as a rule the leading mineral, and the rocks are thus by no means purely lutaceous. The considerable contents of microcline most frequently observed indicate that the rocks originate from immature sediments, which also accords with the compositions of the surrounding arkosic-quartzitic rocks. (See p. 30 and Table 2.) The mica flakes have been oriented parallel to the tectonic S-planes.

Minor constituents include iron oxide ore, epidote, zircon, apatite, and tourmaline (schorlite).

In the northern part of the quartzite-arkose body, about 1 1/2 km to the north of loc. No 865 in Plate 1, occurs an interbedded sedimentary rock composed of arenaceous-rudaceous and lutaceous layers, viz. in part some kind of graywacke. The arenaceous-rudaceous beds are still rather well-preserved, with rounded quartz grains and rare mica gneiss grains measuring up to 4 mm in diameter, whereas the lutaceous beds have been changed to dark mica gneiss. The bedding and shear planes of this rock, which has in part been strongly shear-folded, are shown in Fig. 4.

The lutaceous rocks E.N.E. of the quartzite-arkose body N.—E. of Ramsjö are dark gray mica schists frequently grading to fine-grained mica gneiss. The textural development is grano-lepidoblastic. The main minerals are plagioclase (An about or a trifle more than 30 %), quartz, biotite (to some extent changed to chlorite), and muscovite. The frequency range is plagioclase $\approx$ quartz $>$ biotite $>$ muscovite. Minor constituents are microcline, apatite, zircon, iron oxide ore, and sometimes tourmaline (schorlite), leucoxene, and titanite. The micas show strong though *incomplete* flattening along the tectonic S-planes, which may hence very well have developed by isoclinal shear-folding. (Compare G. Kautsky 1957, pp. 20—22.) The plagioclase has been slightly sericitized.

A chemical analysis of schist from the eugeosynclinal margin in the northwestern corner of Plate 1 is found in Table 2, and a boron determination in Table 3. The degree of oxidation is as low as can be expected from a marine lutaceous sediment, but the boron content is also low, which is not in agreement with the general analytical experience gained on marine sediments. (Compare S. Landergren 1945 and H. Harder 1959.) The degree of metamorphism of the rock is, however, high enough to have made it possible for boron to leave the rock, especially under the conditions offered by strong shear-folding and resulting heating by friction. We have also met with evidence even in the neighbouring rather low-metamorphic quartzite of secondary migrations of boron as displayed by small tourmaline metablasts. — Some further aspects of the chemical composition of the schist in Table 2 are found on p. 31.

The lutites have in rare cases contained calcareous muds (calcilutites; F. J. Pettijohn 1957, p. 408), in the metamorphic rocks easily discernible as abnormal minerals such as bytownite, diopside, vesuvianite, and prehnite. (See p. 46.)

The lutaceous sedimentary rocks have been highly susceptible to alterations, and lutites showing moderate metamorphism are thus by far less common than low-metamorphic arenites and rudites. As a rule the lutaceous rocks have changed to mica gneiss (gray sedimentary gneiss) grading to schlieren gneiss and veined gneiss. These rocks will be described later on (p. 43 ff).

Volcanics are not very common in the Naggen group. Only two boudined beds of supracrustal metabasite in sedimentary rocks and neighbouring granodiorite have been outlined in Plate 1, viz. W.N.W. of Hassela and E.N.E. of Gnarp. Small sheets and spots of metabasite have also been met with locally in the primorogenic granodiorite and the mica gneiss but are on the whole rare. The normal development is a gray green black, fine medium- to fine-grained rock showing grano-lepido-nematoblastic texture. It is composed mainly of plagioclase (oligoclase or andesine; An = 20—40 %), amphibole (most often common green hornblende), and biotite (frequently altered in part to chlorite). Quartz is always present and may be abundant. Minor minerals are magnetite, titanite, apatite, and pyrite, with epidote, calcite, and zoisite in certain parts of the rock.

The oligoclase has developed secondarily by alteration of more calcic plagioclase and is therefore quite fresh, whereas the andesine is primary and very often shows strong sericitization. The amphibole has frequently grown in a porphyroblastic fashion.

The supracrustal metabasite now and then contains acid schlieren, such as in the knee of the folded metabasite sheet W.N.W. of Hassela. There, more felsic volcanics have also been encountered, viz. a dark greenish gray rock composed mainly of andesine (with sericite and some zoisite; An about 40 %), quartz, and chlorite. The quartz has been strongly fractured and arranged in winding zones of angular grains parallel to the S-planes. The chlorite has also clung together nematoblastically along the S-planes, whereas the andesine displays slightly rounded and probably sometimes rotated grains, the resistance of which against fracturing has forced the zones of quartz and chlorite to wind around them.

The felsic volcanic rock further contains considerable quantities of nematoblastic anthophyllite. It seems probable that the rock in question is a basic volcanic intermixed with clastic sediments, arenaceous matter especially. In other parts of the Ramsjö—Gnarp region, such as the area N.E. of Bergsjö, lutaceous sediments have sometimes been intermixed with basic volcanic ash and hence contain some hornblende, titanite, etc. (See p. 46.)

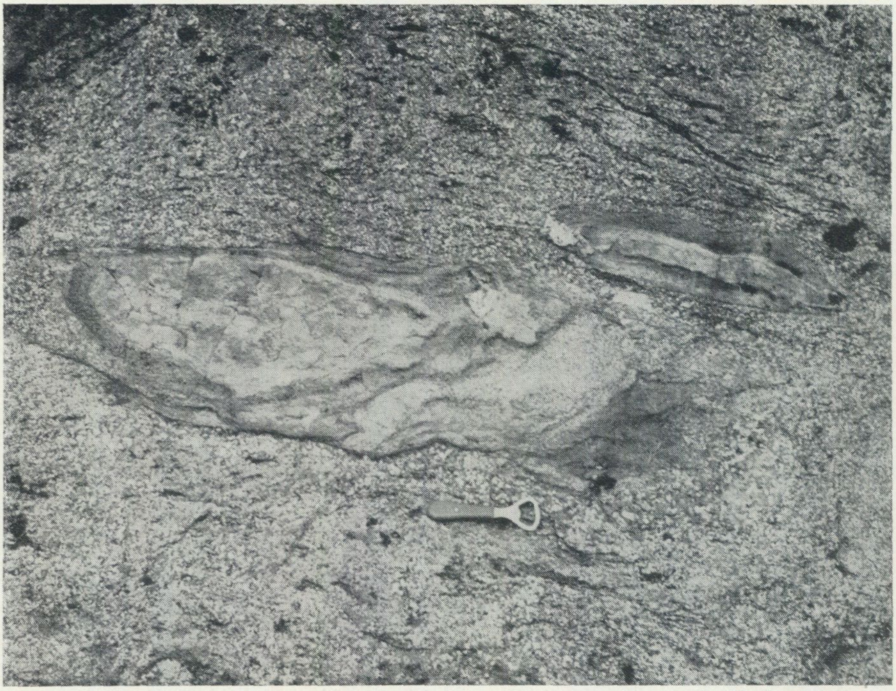


Photo: P. H. LUNDEGÅRDH.

Fig. 21. Xenoliths of quartzite and subgraywacke in granodiorite with biotite schlieren originating from assimilated mica gneiss. Length of capsule opener 11 cm. 16.5 km to the north of Ramsjö.

The Primorogenic (Synkinematic) Rocks

TECTONIC DATA

The primorogenic rocks of the Ramsjö—Gnarp region are those developed during and immediately after the cross-folding of the supracrustal rocks and their basement. The primorogenic rocks comprise in the first instance infracrustal ultrabasites and basites (davainite and metagabbro), granodiorite (now and then grading to tonalite), and granite, further a lot of secondary rocks still revealing their supracrustal origin.

The plutonic ultrabasites and basites have been described earlier (P. H. Lundegårdh 1957 a). They appear as several boudins composed chiefly of ore-bearing common gabbro grading to norite and frequently altered to metagabbro. One boudin consisting of metamorphic pyroxenite (davainite) has also been observed.

The boudins seem to originate from sheets of congealed magma once intruded along the S-planes of the bedrock during an early phase of the orogenesis. The relation of the basic boudins to the great thrust zones is apparent from a mere glance at Fig. 2, but the thrust zones in their turn are

Photo: P. H. LUNDEGÅRDH.

Fig. 22. Gneissic granodiorite rich in deformed microcline porphyroblasts (porphyritic gneiss-granite). Scale 1 : 4. 40 km S.E. of Ramsjö.

related to the mantles and the limbs of the fold arcs and have thus been controlled by the pre-existent tectonic style of the region. Besides, the thrusts occurred after the intrusion of the gabbroic magma and we can presume that they made use of the same zones of weakness which earlier permitted intrusion of the gabbroic magma.

We know little of the conditions prevailing during the intrusion of the gabbroic magma, but we may guess that it was intruded into those parts of the crust at that time subjected to a tensional stress. However, stress conditions changed later, and the gabbro became then boudined and in part altered to metagabbro. The boudination, too, is, from field experience, older than the regional thrusts.

Most gabbro boudins are found in granodiorite. The latter rock has attained its present character during and after the boudination. It seems, however, to be for the most part a mere regeneration[1] product of the rock once intruded by the gabbroic magma, viz. the Svecofennian granodiorite in the basement of the Bothnian miogeosyncline.

Other parts of the granodiorite of the Ramsjö—Gnarp region appear to have been intruded as magma after the deposition of the Bothnian sediments. Not only the sheet-like penetrative masses of granodiorite following the S-planes

[1] See the foot-note on p. 11.

Photo: P. H. LUNDEGÅRDH.

Fig. 23. The same granodiorite as in Fig. 22, though still stronger deformed and containing xenoliths of metabasite elongated parallel to the planar schistosity. Scale 1 : 3.

of the northeastern limb of the Ramsjö—Harmånger anticline but also local breccias of eruptive character (Fig. 21) support strongly this assumption. Outside the thrust zone forming the south-western border of the quartzite-arkose body N.—E. of Ramsjö the granodiorite (in part grading to tonalite) contains several xenoliths of sedimentary rocks (Fig. 21). Arenaceous rocks predominate, and these have been altered metasomatically in the marginal parts of the xenoliths. Schlieren of biotite (*e.g.* in the upper right part of Fig. 21) indicate that xenoliths emerging from lutaceous rocks have also been present, though they have become assimilated for the most part.

The primorogenic granite of the southern part of the mapped region shows no signs in the outcrops examined of a sedimentary origin. When the map Plate 1 was constructed, the granite, however, arranged itself in masses conformable with the lenticular bodies of gneissic rocks of clearly supracrustal origin still present in the area. Furthermore, the granodiorite has locally been seen to penetrate the granite along S-planes in the latter. In an ordinary magmatic sequence, the granite should be younger than the granodiorite. We are hence forced to interpret the granite as a granitization product, probably of arenaceous(-rudaceous) sedimentary rocks belonging to the miogeosynclinal deposits. As a consequence of this it has to be classed as a petrological equivalent of the secondary granite in the northeastern part of the Ramsjö—Gnarp region,

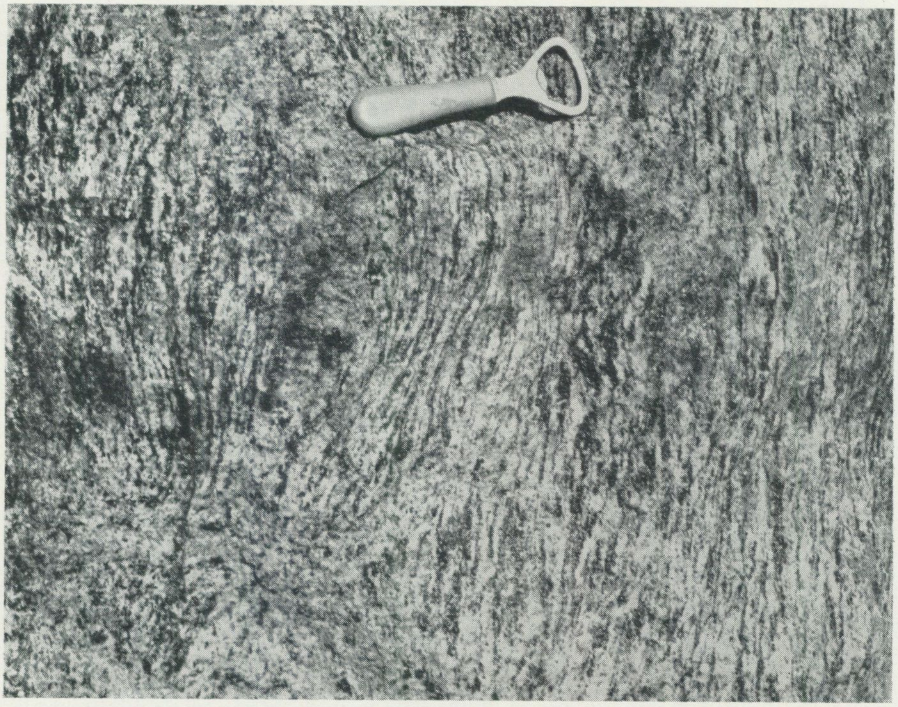


Photo: P. H. Lundegårdh.

Fig. 24. Strongly deformed granodiorite of the same mineral composition as the rock in Fig. 22. The microcline porphyroblasts have been completely fractured and flattened. They are now visible as numerous thin light schlieren. Scale 1 : 3.5. In the great thrust zone 32 km S.S.E. of Ramsjö. (See Fig. 2.)

which has, indeed, a similar textural development (though its mineral composition reveals a sedimentary origin; see p. 53 ff).

To sum up, we can say that the core of the Ramsjö—Harmånger anticline consists mainly of intrusive granodiorite with lenticular masses of completely and incompletely granitized arenites (and rudites) as well as sheets of better preserved sedimentary rocks. The granodiorite most probably originates from the Svecofennian basement of the miogeosynclinal sedimentary rocks and does not always seem to have moved as magma in Bothnian time, to judge from the occurrence of boudins of gabbroic rocks which ought to have once intruded along the S-planes of a pre-existent, Svecofennian granodiorite. In cases like this the granodiorite is of course a mere regeneration product in the sense of the foot-note on p. 11.

The cross-folding producing the great arcs in the southwestern Bothnian miogeosyncline has been followed by thrusts, the most important planes of which are found in Fig. 2. These thrusts have occurred along surfaces conformable with the primorogenic schistosity of the bedrock, and as earlier shown they have influenced the quartz fabric of a few of the arenaceous rocks of the Naggen group (in the neighbourhood of Hassela; see p. 26). The thrusting deformed the granodiorite strongly. In the central parts of the thrust zones we therefore find both mylonite gneiss and gneiss-granite with very well-developed glide-planes. The early, primorogenic, microcline porphyroblasts, which are indeed present in most granodiorite, have become fractured and in part completely disintegrated (Figs. 22—24). In the mylonitic gneiss-granite they are visible only as narrow lenticular schlieren (Fig. 24) parallel to the glide-planes.

The late, serorogenic, microcline porphyroblasts of the granodiorite have not been affected by the thrusts and are hence younger. The faults of the Ramsjö—Gnarp region are still younger, however, and glidings along fault planes have, as mentioned, occurred even after the intrusion and solidification of the doleritic magma, viz. in Algonkian time or later.

GABBROIC ROCKS

The gabbroic rocks have been described in detail in an earlier paper (P. H. Lundegårdh 1957 a). In the few boudins encountered in the Ramsjö—Gnarp region, two types of gabbroic rocks occur, viz. davainite and metagabbro.

The davainite is found 16.5 km to the east of Hassela, at Lake Annsjön. It is a metamorphic rock, a fine- to medium-grained green black metapyroxenite consisting essentially of hornblende and plagioclase pseudomorphs (saussurite and sericite), the former mineral being by far more common than the latter. Most hornblende individuals should be classed as normal uralite. They show $c:\gamma$ about 20°, $2V\gamma = 95°$, and pale pleochroism in bluish green to pure or olive green. Some hornblende individuals have been determined as actinolite, however.

The chromium content of the rock is high as compared with the other gabbroic rocks belonging to the same suite, viz. 700—1,000 p.p.m., and the nickel content amounts to 300 p.p.m., nearly nine times the cobalt concentration, which is 35 p.p.m. (op. cit., p. 26). The concentrations of titanium and vanadium are low. Accordingly the davainite has been classed as a magmatic first-differentiate (op. cit.).

The metagabbro forms two boudins at the southern boundary of the mapped region, a little east of the centre of Plate 1. It is green gray black to gray black and fine- to medium-grained. Major components are acid labradorite (An = 50—55 %), common hornblende with comparatively strong pleochroism, and titaniferous iron oxide ore. The alteration of the rock has apparently been quite strong, as it is now granoblastic throughout and contains no uralitic hornblende with weak pleochroism and remnants of pyroxene. Moreover the tectonic S-planes are often visible in thin sections of the rock (preferential orientations of the plagioclase laths and the accessory biotite).

The chromium content of a local general sample from one of the boudins is low, 40 p.p.m., and the titanium and vanadium concentrations high, 19,200 and 1,500 p.p.m. respectively. Nickel, however, still exceeds cobalt with 260 p.p.m. as against 150 p.p.m. The metagabbro has hence been classed from a geochemical point of view as an early middle differentiation product of the parental gabbro magma (op. cit.).

TONALITE

Tonalite occurs nearly exclusively in the area N.—E. of Ramsjö and always grades into granodiorite, which is the leading primorogenic rock of the area in question. The tonalite is a medium-grained gray rock with schistosity of variable strength, both planar and linear, hence the Swedish name *basic gneiss-granite*. Chief minerals are acid andesine (An = 30—35 %), frequently as rather large laths, quartz, and biotite. Common green hornblende with strong pleochroism and $2V\gamma = 120—130°$ is also often met with. Microcline, often perthitic, is as a rule present, and when the concentration exceeds about 10 % the rock is classed as granodiorite. The microcline is penetrative and most often forms poikiloblasts of varying dimensions. Adjacent parts of the plagioclase now and then contain myrmekite. Some poikiloblasts have grown very large, and the rock is then porphyritic (augen-granite).

The porphyroblasts — gray white or reddish (see granodiorite below) — are either tectonized — lenticular (Figs. 22 and 23), or undeformed — more or less idiomorphic (Fig. 32). In the first case the porphyroblasts are primorogenic — contemporaneous with the folding of the miogeosyncline. (See granodiorite below.) In the second case they are much younger, viz. serorogenic, and when frequent the rock containing them should be classed as Revsund granite. (See p. 59.)

The minor minerals of the tonalite are apatite, magnetite (titaniferous), titanite, and zircon. Calcite, epidote, allanite and pyrite or pyrrhotite are also often present in small amounts. Fluorite may appear as an accidental mineral.

GRANODIORITE

The granodiorite is the leading rock of the core of the Ramsjö—Harmånger anticline. Structurally and texturally it corresponds to the tonalite, but is richer in microcline and usually red gray in colour. The reddish tint is in the first instance due to the colour of the perthitic microcline porphyroblasts, which in most of the granodiorite are present in variable quantities and states of deformation (Figs. 22—24). A large part of the granodiorite is in fact nothing else than tonalite subjected to potassium metasomatism. The minerals are therefore the same, and in the altered tonalite we observe both a rather calcic plagioclase (An = 30—35 %) and often also columns of common hornblende. (Compare tonalite.)

In most part of the anticline core, the anorthite concentration in the plagioclase of the granodiorite is lower, however, actually corresponding to that of an oligoclase (An = 15—25 *à* 30 %). Owing to the schistosity of the rock, its Swedish designation is *intermediate to basic gneiss-granite*.

When describing the tonalite I mentioned that the microcline as a rule tended to form poikiloblasts even in the groundmass. This is not so often the case with the granodiorite, but the margins of plagioclase grains bordering upon microcline are frequently myrmekitic, and narrow rims of albite are in many cases seen at the contacts. Sometimes the plagioclase also contains diffuse spots of microcline. Great primorogenic porphyroblasts of microcline have in rare cases been surrounded by incomplete shells of oligoclase or albite, however, indicating an eventual lack of potassium during the metasomatism.

All microscopical data show that the microcline is the youngest mineral of the granodiorite even in positions where it has not recrystallized in serorogenic time. The mineral has certainly grown at the expense of the other minerals in the rock, especially the plagioclase. Moreover it seems probable that the potassium and other chemical compounds necessary for the primorogenic metasomatism thus established have been received from the magmas and solid rocks involved in the primorogenic development of the granodiorite, because all observations made on the non-affected and incompletely granitized sedimentary rocks of the region contradict the supposition of migrations of elements over great distances unless the transporting agents have been received from the primorogenic magmas and the eugeosynclinal lutaceous rocks. This accords also with the colour of the microcline porphyroblasts, which are as a rule gray white near and in the eugeosyncline in the north and reddish in the remaining, more extensive part of the miogeosyncline. The eugeosynclinal deposits have apparently been characterized from the very beginning by a lower degree of oxidation than the miogeosynclinal rocks.

In and around the crest of the Ramsjö—Harmånger anticline, in the eastern part of Plate 1, the granodiorite is mostly garnetiferous. It has obviously been influenced by the strongly variable pressure and chemical conditions ruling there in primorogenic Bothnian time. (See p. 50 ff.) In the parish of Jättendal has locally even charnockitic granodiorite been observed, with hypersthene (2Vγ about 110°) and almandite as the main minor minerals.

GRANITE

The primorogenic granite of the Ramsjö—Gnarp region is concentrated in the area S.—W. of Hassela, where it forms two great masses of approximately lenticular form (Plate 1). The primorogenic granite is red or gray red and fine medium- to medium-grained. It is more or less schistose and is given the Swedish name *acid gneiss-granite*.

The main minerals are quartz, microcline, and oligoclase (microcline > oligoclase). Biotite is also common. Minor minerals are zircon and frequently apatite, allanite, and iron oxide ore (magnetite, hematite).

The microcline is slightly impregnated with Fe_2O_3 and often also perthitic. Now and then it forms porphyroblasts, though not so often as in the granodiorite. The oligoclase is more or less sericitized and impregnated with Fe_2O_3. Myrmekite and thin margins of albite are common features wherever oligoclase borders microcline in the rock.

The eastern part of the mapped region, in and around the anticline crest, is characterized by great masses of granite and granite gneiss still bearing evidence of being sedimentary rock granitized *in situ* (p. 53 ff), but some garnetiferous primorogenic granite of obscure origin also occurs as lenticular bodies.

HIGH-METAMORPHIC SEDIMENTARY ROCKS

Most of the sedimentary rocks of the Southern Bothnian miogeosyncline have been strongly altered during the primorogenic folding. Two principal kinds of high-metamorphic sedimentary rocks can be distinguished:

A. Recrystallized rocks.
B. Metasomatic rocks.

The term metasomatic here only signifies the presence of minerals formed secondarily by reactions between ions received from different rocks. The gathering of these ions in the Ramsjö—Gnarp region seems to be due to tectonic transportations and migrations of solutions along the planes of schistosity. In the Ramsjö—Harmånger anticline the metasomatic rocks have been concentrated in its crest, which at the present level of erosion appears in the coastal part of the mapped region (Fig. 2 and Plate 1).

The recrystallized sedimentary rocks will be described first and the metasomatic rocks afterwards.

Recrystallized Rocks

The recrystallized sedimentary rocks are of two kinds, viz. A. granite gneiss, and B. mica gneiss. The former originates from arenites and is a red or reddish or, though less often, pale gray, fine- to medium-grained rock consisting mainly of quartz (leading mineral) and microcline (in part perthitic). Oligoclase (An = 10—25 %), biotite, and muscovite are also common. The oligoclase is often one of the main minerals. Much of it is strongly sericitized. Myrmekite is common near the contacts with microcline. Owing to slight impregnation with Fe_2O_3, both the microcline and the oligoclase are most frequently red or reddish.

Minor minerals are as a rule iron ore, zircon, tourmaline (schorlite), and leucoxene; often apatite, chlorite, calcite, and sometimes titanite, epidote etc. The fine-grained granite gneiss (also called acid sedimentary gneiss) is granoblastic, the medium-grained granite gneiss granitic and showing very weak schistosity.

The microcline content of the granite gneiss does not as a rule seem to have increased, but the mineral has often grown to expansive individuals fingering out along the intergranular film separating the other minerals of the rock (Fig. 31), and has also often assembled to poikiloblasts. The tourmaline content has often increased in the rocks thus altered, indicating serorogenic migmatization working by means of, *inter alia,* boron as a mineralizer. (See p. 63.) In some other recrystallized arenaceous-rudaceous rocks fluorite has been seen, bearing evidence of an addition of fluorine — also a mineralizer.

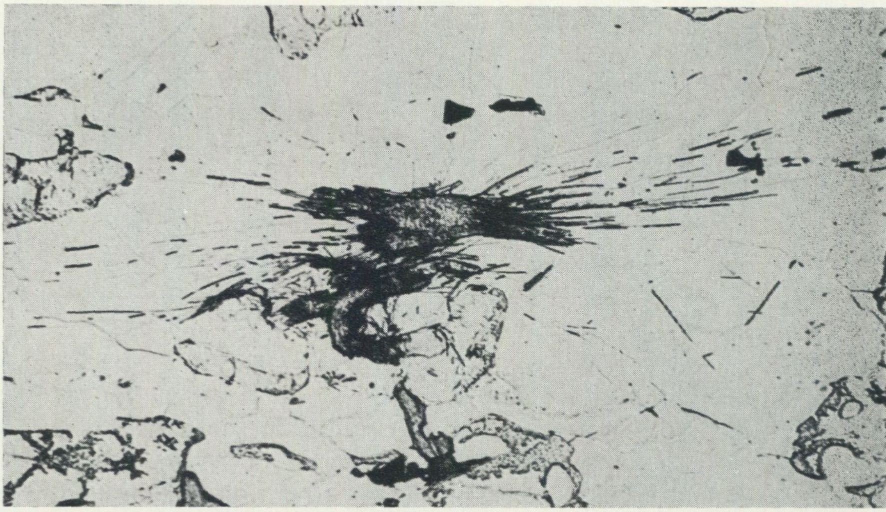


Photo: P. H. LUNDEGÅRDH.

Fig. 25. Sillimanite needles growing from compact kernel. Thin section, 60 × nat. size. Subgraywacke from loc. No 633 in Plate 1, 2.5 km W.N.W. of Hassela.

The mineral composition of the mica gneiss varies considerably, owing to the proportions between sandy, silty, and clayey matter in the original sediments. The mica gneiss originating from sediments rich in silt and admixed with sand is in the first instance met with as intercalations in the rudaceous-arenaceous rocks (cp. Fig. 19) and is most common in the areas N.N.E.—E. of Ramsjö and around Hassela. It is gray, fine-grained and composed chiefly of quartz, microcline, and mica. Plagioclase (An = 10—25 %) is also common. The mica is either biotite and muscovite or biotite only. Minor minerals are zircon, iron oxide ore, apatite, and often red violet garnet (almanditic). Iron sulfide ore is also sometimes present.

The texture is grano- to lepidoblastic, the mica flakes being approximately parallel to the tectonic S-planes. Felsic schlieren and pegmatitic veins are often met with (Plate 1), though they are on the whole not so frequent as in the gneiss to be described below. The felsic schlieren, nearly exclusively composed of quartz and feldspar, run parallel to the S-planes and may to some extent reflect primary inhomogeneities in the rock. (See p. 34.) The pegmatitic veins are less regular. (See below.) Potassium metasomatism has sometimes caused microcline porphyroblasts to grow.

In the northwestern corner of Plate 1, the eugeosynclinal clayey schists appear and can be followed from there to the eastern parts of the crest of the Ramsjö—Harmånger anticline, though they have been interrupted now and then by the primorogenic granodiorite. They have changed to gray or black gray, fine- to fine medium-grained mica gneiss all over the mapped region except for the northwestern corner, and this mica gneiss mostly contains felsic schlieren of coarser grain than the rest of the rock. The schlieren are parallel to the tectonic S-planes, which are as a rule winding.

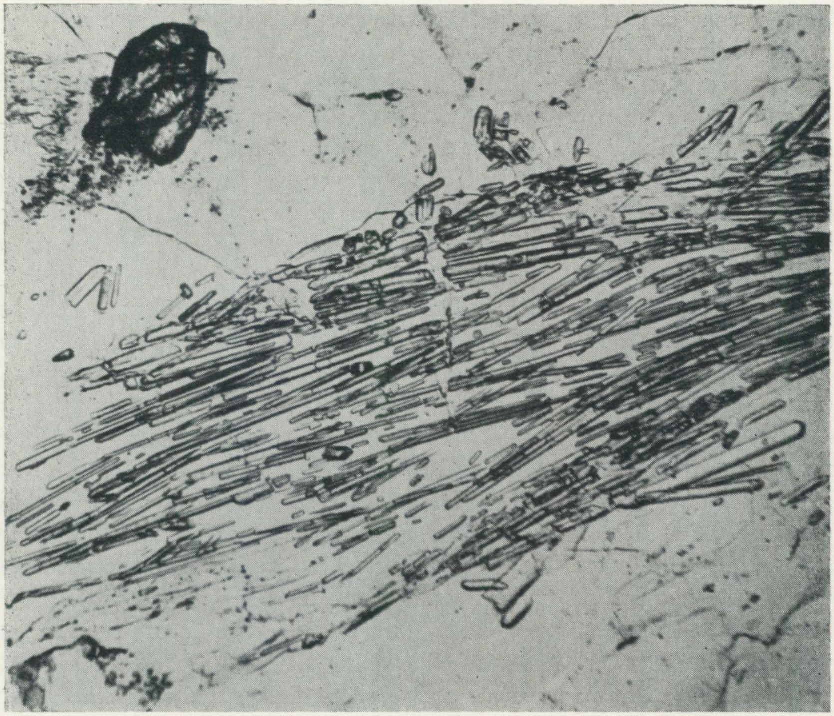


Photo: P. H. LUNDEGÅRDH.

Fig. 26. Sillimanite needles parallel to the tectonic *b*-axis (cp. Fig. 14), and late tourmaline (upper left corner). Thin section, 215 × nat. size. Arkosic quartzite from loc. No 411 in Plate 1, 2.5 km E.N.E. of Hassela.

Pegmatitic veins are also common, but these are not always conformable and apparently represent a later stage of alteration of the rock. They have been ascribed to the serorogenic migmatization. (See p. 59.) The schlieren are gray white or white, and the pegmatitic veins in most cases have the same colour. Near metamorphic arenaceous or rudaceous rocks, reddish veins indicating a higher degree of oxidation may be locally encountered, however.

The mica gneiss originating from the clayey schists differs from the mica gneiss earlier described not only in showing lower contents of quartz and usually higher concentrations of plagioclase and/or biotite but also in containing most frequently considerable amounts of Al—Mg—Fe minerals, often as large porphyroblasts, viz. red violet almanditic garnet (Table 4), gray — dark bluish cordierite (the same kind as has been analysed in Table 5), and dark brownish gray sillimanite. The plagioclase is frequently rather calcic (An = 20—35 %). The garnet is most often poikiloblastic, containing small grains of quartz (Table 4 and Fig. 28) and also often flakes of biotite, etc. Sometimes needles or fibres of sillimanite are seen (Fig. 28).

Further the mica gneiss in question often contains iron sulfides as minor minerals and sometimes graphite as an accidental constituent. (Compare p. 65.)

The presence of garnet, cordierite, and sillimanite in the mica gneiss originating from clayey schists does not indicate long migrations of certain elements. As a matter of fact the gneiss itself seems to have contained aluminum and femic compounds in quantities sufficient to develop in the metamorphosed rock these three minerals or at least one or two of them.

The mica gneiss associated with the arenaceous-rudaceous rocks is on the contrary devoid of all three Al—Mg—Fe minerals mentioned or contains only garnet, unless it has been subjected to aluminum-magnesium metasomatism. (Compare below.)

Sometimes the lutites contain volcanic ash, and the resulting mica gneiss is then extraordinarily rich in biotite and shows a plagioclase more calcic than the ordinary one, viz. an andesine (An = 35—40 %). The presence of titanite and often also hornblende, as well as increased concentrations of iron ore and apatite, are other characteristics of this kind of gneiss.

In rare cases the lutaceous sediments have originally been strongly calcareous (calcilutites) and have been altered to skarn rocks during the Bothnian orogenesis. The only calcic skarn occurrence of importance has been found 8 km to the north of Bergsjö and is interesting because of associated ore mineralization (pyrrhotite and pyrite sometimes accompanied by chalcopyrite, arsenopyrite, and scheelite; see p. 64). It is also to some extent contaminated by volcanic ash.

Part of the skarn forms irregular coarse to medium-grained masses, another part appears as winding narrow layers in mica gneiss with felsic schlieren. The irregular masses are intimately associated with the ore minerals mentioned, in the first instance pyrrhotite, and can be divided into two chief types composed as follows:

A. Vesuvianite (main mineral) > diopside > titanite. Minor minerals are prehnite and sulfides, especially pyrrhotite and pyrite, incidental minerals quartz, epidote, basic andesine, and apatite.
B. Quartz and basic andesine (main minerals; the latter in part strongly sericitized and showing An = 45 — 50 %). Minor minerals are prehnite and sulfides, especially pyrrhotite and pyrite, accidental minerals apatite, calcite, and zoisite.

The vesuvianite of skarn A is poikiloblastic and represents obviously a metasomatic mineral formed on the addition of mineralizers, in the first instance fluorine. The formation of vesuvianite seems to be one of the results of the ore mineralization of the area to be described later on (p. 64 ff).

The skarn layers in the mica gneiss consist essentially of basic andesine (often strongly sericitized; An = 45 %) and common green hornblende ($2V\gamma$ = 105—110°, $c:\gamma$ = 13°). Diopside, actinolite, and prehnite are also often important minerals. Minor constituents are sulfides, in the first instance pyrrhotite, iron oxide ore, chlorite, and zoisite, accidental minerals quartz, apatite, calcite, and titanite. These skarn layers may be interpreted as intercalations rich in or composed essentially of basic volcanics.

Part of the surrounding mica gneiss also shows high concentrations of calcium. A fine-grained gray, macroscopically normal mica gneiss composed

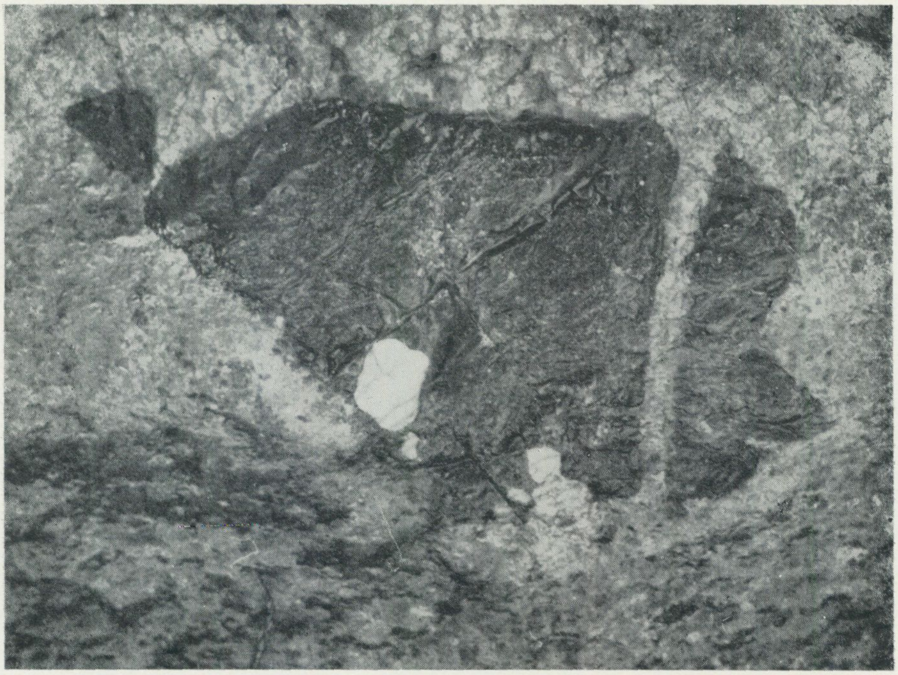


Photo: P. H. LUNDEGÅRDH.

Fig. 27. Porphyroblast of translucent cordierite with beautiful macroscopic pleochroism (p. 51). Chemical analysis in Table 5. 0.6 × nat. size. In coarse quartzite near loc. No 843 in Plate 1, 7 km E.S.E. of Jättendal.

mainly of quartz, plagioclase, and biotite thus shows An percentages in the plagioclase varying between 45 and 90. In spite of the high calcium content of part of the plagioclase it is comparatively well preserved.

The ordinary mica gneiss of the area to the north of Bergsjö consists chiefly of quartz, basic oligoclase (An c. 25 %), and biotite + chlorite (main minerals), further garnet (almanditic). Minor minerals are prehnite, apatite, zircon, and sulfides. Cordierite and sillimanite are lacking, whereas felsic schlieren indicating primary inhomogeneities in the rock are common.

The rocks of the area now studied in detail have to be interpreted as high-metamorphic graywackes. Not only their stratigraphic position in the anticline but also their inhomogeneities, their lack of cordierite and sillimanite, and their calcilutaceous intercalations support strongly this supposition. (Compare P. H. Lundegårdh 1960.)

Metasomatic Rocks

The metasomatic primorogenic rocks of the southwestern Bothnian miogeosyncline have been concentrated in

A. the rocks in and around the crests of the miogeosynclinal fold arcs,
B. the rocks bordering on the glide planes of the imbrications in the limbs of the fold arcs.

This is also applicable to the Finnish part of the miogeosyncline, though the ionic exchanges between the various rocks involved in the orogenesis have been on the whole more regional there. (See P. Eskola 1914, Anna Hietanen 1943 and 1947, H. V. Tuominen 1957.) The alteration products are, however, most frequently the same in the Swedish and Finnish parts of the miogeosyncline.

We shall study first the metasomatic minerals of the imbricated quartzites, subgraywackes, and arkoses. Starting in the northwestern part of the mapped region, we observe the presence of porphyroblasts of cordierite (rich in iron) and garnet only at the northeastern boundary of the quartzite-arkose body N.—E. of Ramsjö. This boundary has developed by imbrication. Both minerals seem to have received most of their chemical components excluding silica, as well as the heat necessary for their formation, by the glidings along the shear planes during the imbrication and the resulting intermixings of the interbedded arenaceous(-rudaceous) and lutaceous sediments. An additional supply of aluminum has been necessary, however, and might have been made possible by migrations of single or complex ions or solutions in the interstices and intergranular films or along the shear surfaces of the rocks.

The primorogenic mineral development thus sketched has been followed in the same part of the quartzite-arkose body by serorogenic mineral alterations. These are:

A. Migrations of chemical compounds such as potassium aluminate having caused microcline to assemble to non-deformed veins that have grown through the tectonic S-planes (migmatization).
B. Partial or total alteration of the cordierite to sericite, pinite (p. 53), magnetite, limonite and chlorite. (Compare Fig. 29.)
C. A marked increase of the content of tourmaline (schorlite) on addition of boron to the rock. (See Table 3: the subgraywacke.)

The serorogenic alterations will be more fully discussed later on (p. 61).

We shall now turn to the sheared interbedded arenaceous and lutaceous rocks of the Hassela area. As is seen from Fig. 18, the shear-folding and resulting intermixing has often been strong, and at least aluminum has been added metasomatically. Cordierite is common, and especially in the neighbourhood of the imbrication planes the frequence of swarms of sillimanite needles and fibres is high. These have crystallized parallel to the tectonic *b*-axes (Figs. 14, 16—17, and 25—26; discussion of the fabric data on p. 25). Contrary to the sillimanite, the cordierite does not show any preferential orientation. It often contains swarms of needles of sillimanite. The swarms wind considerably, indicating rotations during the crystallization of the cordierite. Although the presence of sillimanite in cordierite might be easily explained by the supposition of an excessive supply of alumina during the formation of the cordierite, the winding swarms indicate a more complicated development involving a reorganization of the original strong *b*-fabric of the sillimanite. The cordierite ought then to be decidedly younger than the sillimanite.

Parts of the sedimentary rocks in the environs of Hassela display beautiful intergrowths of microcline indicating migrations of potassium. (See Fig. 31 of

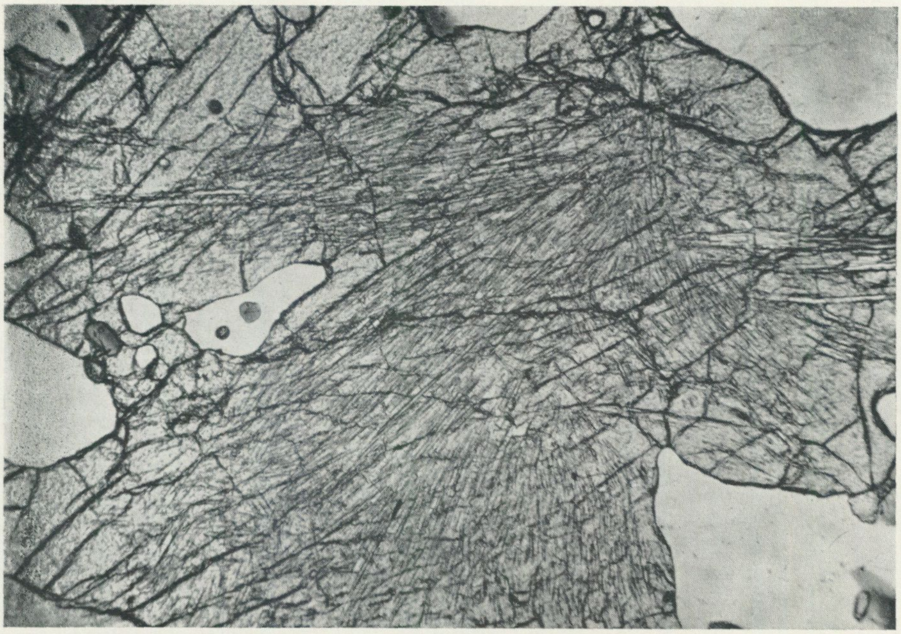


Photo: P. H. LUNDEGÅRDH.

Fig. 28. Almanditic garnet with needles and fibres of sillimanite. Thin section, 50 × nat. size. Inclusion of veined mica gneiss in secondary granite, 11 km E.S.E. of Gnarp.

Table 4. Garnet from veined mica gneiss near Bölan, parish of Enånger, half way between Hudiksvall and Söderhamn. (See Fig. 2.)

Analyst: A. AAREMÄE

	% by weight	Mol. prop. × 10 000	Calculated mineral composition	% by weight
SiO_2	42.90	7 143	Almandite	62.0
TiO_2	0.05	6	Pyrope	22.0
Al_2O_3	17.87	1 753	Spessartite	1.5
Fe_2O_3	4.70	294	[1]Quartz	10.5
FeO	26.92	3 747	Hematite (in cracks)	4.0
MnO	0.64	90	[2]$H_2O > 110°$	0.3
CaO	0.05	9	Total	100.3
MgO	6.60	1 637		
$H_2O > 110°$	0.27	150		
$H_2O < 110°$	0.02	—	[3] Unit cell size = 11.37 Å (M, N = 12)	
Total	100.02	—	[4] n_{Na} = 1.799 ± 0.003 G = 3.77	

[1] In part included in the garnet lattice, in part as minute grains in the garnet poikiloblasts.
[2] Forming limonite together with part of the Fe_2O_3.
[3] No quartz reflections observed. Analysts: A. AAREMÄE and V. GRUNDULIS. The cell size is rather small as compared with the data given by R. FRIETSCH (1957) but may be due to the inclusion of some silica in the garnet lattice. FRIETSCH's garnets originate, indeed, mostly from ore skarn rocks much lower in silica than the sedimentary gneisses of northeastern Helsingland.
[4] Determined by TH. LUNDQVIST.

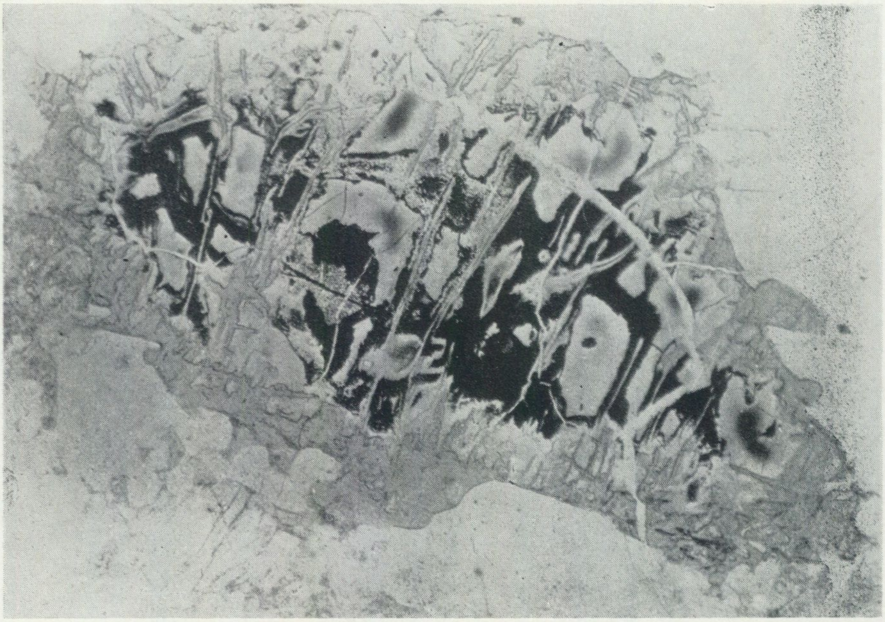


Photo: TH. LUNDQVIST.

Fig. 29. Iron-rich cordierite altered marginally to sericite and pinite and in the kernel to magnetite, limonite, chlorite and pinite. Thin section, 40 × nat. size. Chemical analysis of better preserved grains of this cordierite in Table 6. Secondary granite from the vicinity of Mt Västansjökullen, 11.5 km N.W. of Gnarp.

the rock at loc. No 645, E.S.E. of Hassela.) Simultaneously a little tourmaline (schorlite) is sometimes seen (Fig. 26), and the cordierite has frequently changed to sericite, pinite, and other secondary minerals. (Compare Fig. 29.) The alterations thus reported of may be serorogenic. (See above and p. 61.)

In and around the crest of the Ramsjö—Harmånger anticline, the intermixing of the interbedded rudaceous, arenaceous, and lutaceous rocks has been the most thorough of the whole Ramsjö—Gnarp region. (See Figs. 19 and 20.) This is due to the interactions of the various kinds of deformation there initiated by the position of the rocks in the crest of a regional cross-fold arch implying not only imbrications and shear-folding but also drag-folding and flowage. Disregarding the shear-folding, which is a small-scale kind of deformation (cp. Fig. 18), the tectonic alterations mentioned can all be seen in the coastal part of the map Plate 1.

The rudaceous and arenaceous rocks encountered in the coastal part of the Ramsjö—Gnarp region have recrystallized strongly and are now frequently coarse to medium-grained. Owing to imbrication they have been divided into several minor masses, which have in part been strongly admixed with lutaceous matter transported along the shear planes (Figs. 19 and 20) and have often been subjected to strong metasomatism as effected by this lutaceous matter and by neighbouring lutaceous rocks. Part of the rudaceous-arenaceous rocks have thus been invaded by aluminum, magnesium, and some divalent iron,

Table 5. Cordierite from coarse quartzite, loc. No 843 in Plate 1, 6.5 km E.S.E. of Jättendal

Analyst: A. Aaremäe

	% by weight	Mol. prop. × 10 000	Calculated mineral composition	% by weight
SiO_2	49.28	8 205	Magnesium-cordierite	79.8
TiO_2	0.02	3	[2]Iron-cordierite	15.9
Al_2O_3	34.40	3 375	Anorthite	0.6
Fe_2O_3	0.12	8	Albite	0.9
FeO	3.55	494	Sericite	0.4
MnO	0.06	9	Magnetite	0.2
MgO	11.02	2 733	[3]$H_2O > 110°$	1.3
CaO	0.12	21	[3]Al_2O_3 +	0.9
Na_2O	0.11	18	$H_2O < 110°$	0.1
K_2O	0.05	5		
$H_2O > 110°$	1.32	733	Total	100.1
$H_2O < 110°$	0.07	—		
Total	100.12	—	Cell dimensions	
[1] $n_{\alpha Na} = 1.537 \pm 0.002$			$a = 16.90$ Å $\pm$ 0.10	
[1] $n_{\gamma Na} = 1.546 \pm 0.002$			$b = 9.84$ Å $\pm$ 0.05	
$2V\gamma = 115°$			$c = 9.32$ Å $\pm$ 0.03	

[1] Determined by Th. Lundqvist. [2] Incl. MnO.
[3] Probably included in the cordierite.

Table 6. Cordierite from secondary granite, 11.5 km N.W. of Gnarp, near Mt Västansjökullen

Analyst: A. Aaremäe

	% by weight	Mol. prop. × 10 000	Calculated mineral composition	% by weight
SiO_2	48.82	8 129	Magnesium-cordierite	29.1
TiO_2	0.02	3	[1]Iron-cordierite	23.9
Al_2O_3	28.37	2 783	Anorthite	1.1
Fe_2O_3	2.60	163	Albite	3.1
FeO	6.44	896	Microcline	3.0
MnO	0.07	10	Sericite (incl. pinite)	24.0
MgO	4.04	1 002	Quartz	7.4
CaO	0.22	55	Magnetite	3.8
Na_2O	0.36	58	[2]$H_2O > 110°$	3.7
K_2O	3.36	357	$H_2O < 110°$	1.1
$H_2O > 110°$	4.80	2 664		
$H_2O < 110°$	1.12	—	Total	100.2
Total	100.22	—	Owing to alteration no cell dimensions available	

[1] Incl. MnO. [2] In part included in the cordierite.

and consists mainly of quartz and cordierite. Some biotite as well as small amounts of zircon, sillimanite, and muscovite also occur. The cordierite is fresh and macroscopically pleochroic (α = pale smoky or yellowish-brownish gray, β = violet blue, γ = blue). It often forms very large porphyroblasts

(Fig. 27). Though magnesium is the leading cation, it contains considerable amounts of divalent iron (Table 5). The cell dimensions correspond well to those given by B. Gossner and F. Mussgnug (1928, p. 216 ff), A. Byström (1941), and others. The values of the refractive indices and optic angle are the normal ones (Table 5). It has frequently been twinned and has not altered at all in rocks free from or comparatively poor in microcline. Sometimes it contains needles of sillimanite. These seem to have crystallized at places extremely rich in alumina and bear no evidence of being decidedly older than the cordierite, such as preferential orientation. (Compare the tendency as was described from the Hassela area in the above text.)

In great part of the rudaceous-arenaceous rocks migrations of potassium have afterwards occurred, and the rocks have become rich in large microcline porphyroblasts. When water was available, the cordierite was mostly or wholly altered to sericite, pinite, and other hydrous minerals, and much of the sillimanite has also changed to sericite. When the potassium metasomatism has operated under 'dry' conditions, most or all of the cordierite, and all sillimanite, have been preserved. (Compare Table 7.) Cordierite high in iron has been more easily altered than cordierite low in iron. (See the granite gneiss and secondary granite described below.)

An example will be given. At loc. No 843, E.S.E. of Jättendal, the cordierite is not so very high in iron (Table 5). Part of the quartzite has been there subjected to strong potassium metasomatism and is rich in large microcline porphyroblasts, whereas other parts are free from this mineral. Both the cordierite and the sillimanite are fresh even in the presence of the microcline, and at one locality a peculiar rock composed nearly exclusively of coarse microcline individuals and great swarms of sillimanite needles and fibres has been observed.

The source of the potassium of the microcline porphyroblasts in the quartzite in the first instance seems to be other parts of the arenaceous-rudaceous rocks themselves, in view of the high K_2O contents of low-metamorphic varieties of these. (See Table 2 and p. 30.) At some localities the porphyroblasts have, however, proved to be intimately associated with the development of the primorogenic microcline porphyroblasts in the granodiorite and ought then to have the same origin. (See p. 42.) The arenaceous and rudaceous rocks bearing evidences of migrations of potassium supposed to be primorogenic are mostly devoid of tourmaline, *e.g.* the neighbourhood of Hassela and the Harmånger —Gnarp area.

Some further migrations of potassium (as well as some recrystallization of primorogenic porphyroblasts of microcline) has, however, occurred in serorogenic time, as has already been described from the northeastern boundary of the quartzite-arkose body N.—E. of Ramsjö. This alteration implies a migmatization intimately associated with the development of tourmaline porphyroblasts in the altered rocks (Fig. 26), and the source of the boron of the tourmaline seems to be the marine lutaceous sedimentary rocks in the neighbouring part of the eugeosyncline. (See pp. 61 and 63.)

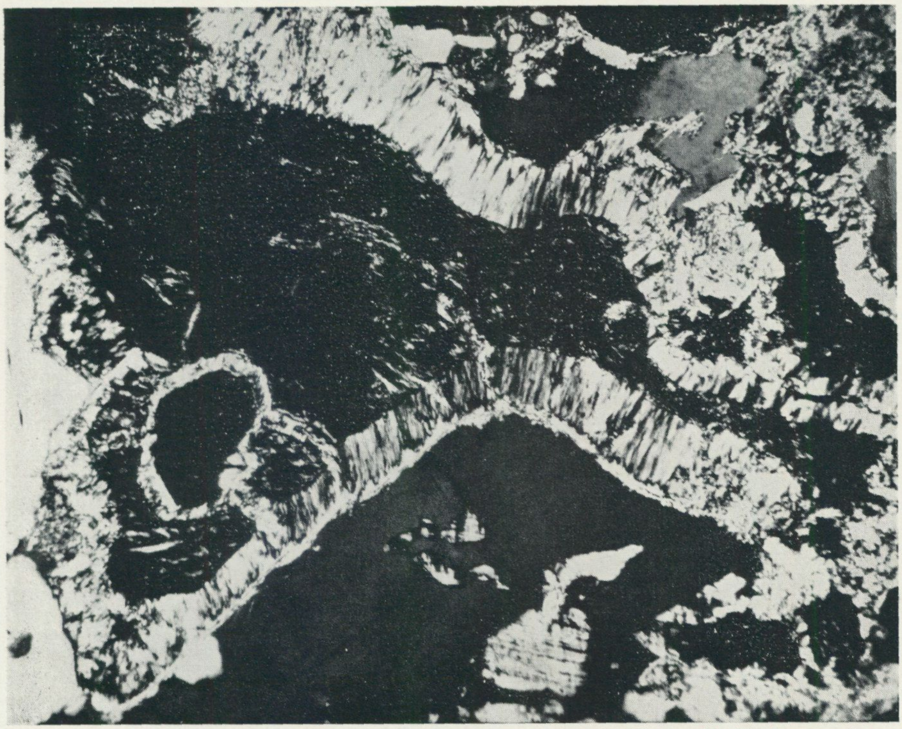


Photo: P. H. LUNDEGÅRDH.

Fig. 30. Andalusite with rims of radial flakes of sericite and in the central parts also strongly altered to this mineral. Thin section, crossed nicols, 55 × nat. size. The same secondary granite as in Fig. 29.

In the coastal part of the crest of the Ramsjö—Harmånger anticline and, especially, in the northern vicinity of the crest occurs a reddish or in some areas gray white, mostly medium-grained (sometimes fine medium-grained, sometimes coarse) granite gneiss or granite with poikiloblasts of red violet almanditic garnet and porphyroblasts or often poikiloblasts of black iron-rich cordierite. The garnet most frequently contains quartz grains and often also flakes of biotite. It is always fractured (Fig. 28), and the cracks have been filled with hematite, limonite, biotite, chlorite, etc. (Compare Table 4.) Large porphyroblasts are most often composed of several garnet grains. Now and then the garnet has grown under conditions implying an excess not only of silica (Table 4) but also of alumina. The garnet has then been filled with needles or fibres of sillimanite (Fig. 28).

The cordierite is not of the same sort as was described above. (Compare Table 5 and Fig. 27.) It is much richer in iron (Table 6) and corresponds closer with the cordierite encountered near the northeastern boundary of the quartzite-arkose body N.—E. of Ramsjö. It is mostly strongly or wholly altered (Fig. 29) to sericite and the related cryptocrystalline mineral pinite, as well as to chlorite, magnetite and limonite. Preserved kernels show strong pleochroism

Table 7. Metasomatic minerals in the high-metamorphic rudaceous and arenaceous sedimentary rocks of the Ramsjö—Gnarp region

Primorogenic addition of	Al	Al + Mg	Al + Fe	Al + Mg + Fe	Al + K
Hydrostatic pressure	Andalusite	Cordierite	Almandite Iron-cordierite	Iron-cordierite	Microcline
Stress	Sillimanite	Sillimanite Cordierite	Almandite	Almandite (+ pyrope) Cordierite Sillimanite	Microcline Sillimanite
Serorogenic addition of potassium only	Microcline (Sillimanite)	Cordierite Sillimanite Microcline	Almandite (Iron-cordierite) Microcline	Cordierite Almandite (+ pyrope) Microcline	Microcline
Serorogenic addition of potassium and water	Microcline Sericite	Sericite Microcline (Cordierite) (Sillimanite)	Almandite Sericite Iron ore Microcline	Sericite Iron ore Almandite (+ pyrope) Microcline	Microcline Sericite

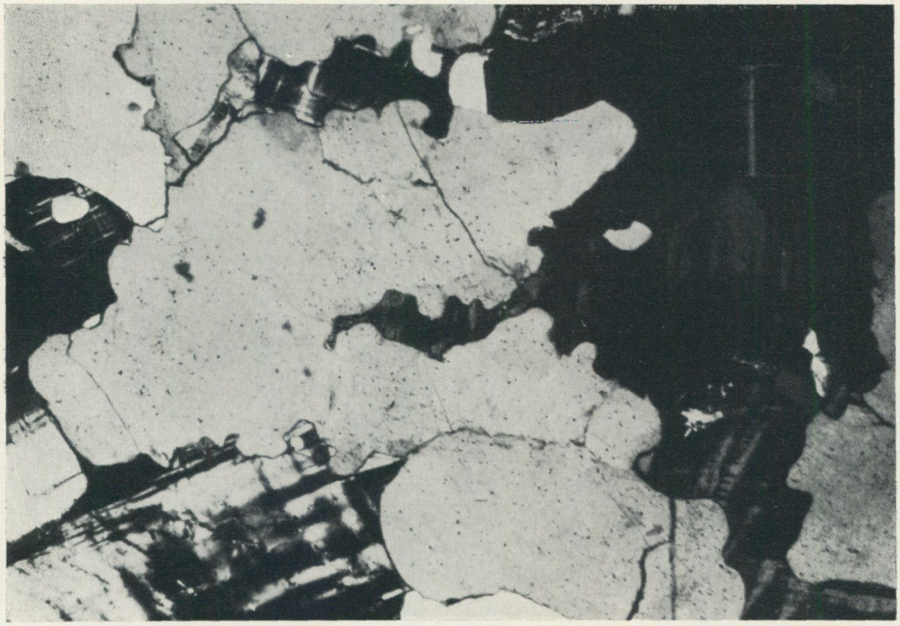


Photo: P. H. LUNDEGÅRDH.

Fig. 31. Microcline intergrowths in arkosic quartzite. Thin section, crossed nicols, 38 × nat. size. Loc. No 645 in Plate 1, 11 km E.S.E. of Hassela.

and sometimes beautiful twinning. Schistose granite gneiss and secondary granite most often show stronger alteration of the cordierite than undeformed.

Both cordierite and garnet are subordinate or minor minerals. When cordierite is common, garnet is most often quite rare or sometimes even lacking, and *vice versa*. (Compare Table 7.) The main minerals are quartz, perthitic microcline, and oligoclase (An most often about 20 % but sometimes lower). The proportions are either microcline > quartz > oligoclase, or quartz ≈ microcline > oligoclase, or quartz > microcline > oligoclase. Biotite is most frequently present as a subordinate mineral. In certain varieties muscovite is, however, more common. The list of minor minerals (most of which are not always present) runs as follows: sillimanite (sometimes sericitized), muscovite (incl. sericite and pinite, sometimes a subordinate mineral; see above), zircon (always present), leucoxene, rutile, apatite, chlorite, iron oxide ore, and limonite.

The microcline does not only form separate grains but now and then also occurs as diffuse spots in the plagioclase, which is sometimes myrmekitic and/or covered with a thin film of albite when bordering the microcline. This only means, however, that microcline has crystallized later than the plagioclase, and the crystallization may be very well a mere recrystallization. (See p. 57.)

A secondary granite very rich in cordierite has been found 11 *à* 12 km N.E. of Gnarp (Fig. 29 and Table 6). This granite is undeformed, in part coarse, and also contains some garnet and andalusite. The latter has in part changed to sericite arranged as rims of radial flakes (Fig. 30). In stressed schistose varieties of secondary granite showing the same composition, sillimanite appears instead of andalusite.

7 *à* 8 km S.S.W. of the granite now described another peculiar secondary granite has been observed. It displays intergrowths of sillimanite and green spinel and often also cordierite pseudomorphs. Moreover this granite contains some garnet.

Granite gneisses and secondary granites similar to those now described are rare in other parts of Sweden but common in the coastal western part of Southern Finland. They have been there concentrated to the southwestern Bothnian miogeosyncline and the adjacent parts of its Svecofennian basement. A typical example is the Kakola granite, or *kakolite,* from the Turku (Åbo) district, which has been described by Anna Hietanen (1947, p. 1073 ff). The kakolite is in part quite similar to the garnet-cordierite granite met with in and around the crest of the Ramsjö—Harmånger anticline. Part of it shows a different development, however, displaying regularly distributed spots composed of grains of garnet, cordierite, and biotite together. Such kakolite also occurs in Helsingland (*e.g.* to the south of the Dellen lakes) and has revealed there a serorogenic origin. Hietanen states that the Finnish kakolite is a secondary granite formed by thorough intermixing of cordierite-garnet gneiss (kinzigite) and granite material.

M. Härme (1958) has studied a series of granites in southwestern Finland from a chemical point of view and states that an increase of the potassium concentration and a decrease of the calcium content makes possible the formation of minerals rich in aluminum, such as almandite, cordierite, and sillimanite. He thinks that the granites containing these minerals have been originally for the most part primorogenic (synkinematic) Svecofennian tonalite, which has been subjected in serorogenic (late-kinematic) Svecofennian time to a regional potassium metasomatism. This hypothesis offers of course a very simple solution of the problem concerned, perhaps too simple, however, as it does not take into consideration the conception of a more complicated orogenic history of the actual region, including the regional alterations effected by a younger, Bothnian orogenesis.

At least Härme's hypothesis is not at all applicable to the Ramsjö—Harmånger anticline, because we have there a common primorogenic granite as rich in microcline and showing the same bulk mineral composition as the cordierite-garnet-bearing granite. The former granite is, however, situated in the core of the anticline, far away from the eugeosynclinal schists rich in aluminum, magnesium,[1] and divalent iron, whereas the latter granite is found in the outermost part of the mantle of the same anticline, there bordering upon high-metamorphic eugeosynclinal schists (veined garnet-cordierite-sillimanite gneiss).

Moreover, when we consider the composition of the most low-metamorphic

[1] According to investigations by, *i. a.,* K. Fredriksson (1959, pp. 114—115), lutaceous sediments easily take up magnesium shortly after their deposition and can thus become very rich in this metal.

Photo: P. H. Lundegårdh.

Fig. 32. Gneissic granodiorite with sparse late undeformed porphyroblasts of microcline. Scale 1 : 4.5. 5 km to the north of Ramsjö.

and evidently non-metasomatic arenaceous-rudaceous sedimentary rocks encountered in the Ramsjö—Gnarp region (Table 2, p. 30, and Figs. 5—6), and of course not forgetting their partial richness in large quartz grains (Figs. 5—6 and the text-table on p. 27), we cannot deny that the contents of potassium of the finer fractions are there sufficient to develop what has been called an ideal granite (P. Eskola 1950 and 1956). What we need in this special case is in the first instance not potassium but aluminum, some sodium, and femic components inclusive of the calcium necessary to develop plagioclase. All the components mentioned can be obtained from the eugeosynclinal schists, provided that these are situated near by and have occupied parts of the crust subjected to strong

Photo: P. H. LUNDEGÅRDH.

Fig. 33. Shear-folded xenolith of arkosic quartzite and subgraywacke (with strong marginal alteration) in granodiorite with late microcline porphyroblasts (Revsund granite). Scale 1 : 3.5. 27 km E.N.E. of Ramsjö.

tectonization implying also heating and the actions of solutions. But I still do not believe in such a strong granitization unless another condition exists, namely a primary lack of chemical balance in the rocks to be granitized, apt to initiate easy migrations of ions, especially in connection with shear. Such a sedimentary rock is in the first instance displayed by the interbedded graywacke showing well-developed arenaceous and lutaceous layers, a rock that has been found 18 km N.E. of Ramsjö, in the great quartzite-arkose body (p. 34). Moreover the graywacke has there a border position near the eugeosynclinal margin which indicates, that similar rocks may have been present all along the anticline mantle, such as N.E. of Hassela, where the greatest masses of cordierite-garnet-bearing granite occur. This is, indeed, the principal reason why I have designated the granite mentioned as secondary.

The Serorogenic (Late-Kinematic) Rocks

The rocks and minerals younger than the primorogenic schistosity and the glide planes of the great thrust zones of northeastern Helsingland (Fig. 2) have been classed as serorogenic. They have been referred to the Bothnian cycle, but we do not know the length of the intraorogenic period separating them from the primorogenic evolution. From the Ramsjö—Gnarp region no intra-orogenic rocks are in any case known.

The serorogenic evolution is in the mapped region characterized chiefly by:

A. Recrystallizations of older microcline and sometimes of other minerals (regeneration; see the footnote on p. 11). Migrations of potassium and formation of new microcline granoblasts, intergrowths (cp. Fig. 31), and porphyroblasts (Fig. 32 and 34), locally assembled to veins (migmatization).

B. Mobilizations in the first instance of silica and alkali-aluminum silicates, either as veins and small dikes of pegmatite and sometimes aplite, or masses, in part real intrusions, of pegmatite and fine medium- to fine-grained granite (serorogenic palingenic rocks; Figs. 35—37).

The recrystallizations and the appearance of new porphyroblasts are most often met with in the porphyritic granodiorite and are in the Ramsjö—Gnarp region concentrated to the western areas. They have in Plate 1 been marked with Y signs in the granodiorite pattern. (Remaining Y signs signify intrusive serorogenic rocks.) Granodiorite (or locally tonalite) with numerous microcline porphyroblasts and frequently also shown to have part or most of its groundmass either regenerated or altered by metasomatism, has been called *Revsund granite*.

Revsund granite is a group name for various gneissic and granitic Bothnian rocks with serorogenic microcline porphyroblasts. Not only granodiorite and tonalite but also schists (Fig. 34) have in serorogenic time been easily transformed to Revsund granite.

The colour of the Revsund granite depends on the degree of oxidation of the parental rock. Granodiorite (p. 41) regenerated or altered metasomatically to Revsund granite is thus either red gray or gray, whereas Revsund granite originating from eugeosynclinal schists is always gray. The diameter of the porphyroblasts ranges from a few to 10 cm (Figs. 32 and 34). Many porphyroblasts are poikiloblastic (Fig. 34). Complete or incomplete shells of albite or oligoclase may occur around large porphyroblasts, though they are on the whole rare.

The development of serorogenic porphyroblasts has been selective, as has been earlier shown by S. Gavelin for the coastal part of the Vesterbotten

Photo: P. H. LUNDEGÅRDH.

Fig. 34. High-metamorphic schist (mica gneiss), very rich in late undeformed porphyroblasts of microcline. Scale 1 : 3.3. Ånge in western Medelpad, about 40 km to the north of Ramsjö.

county (Gavelin 1955, p. 37 ff, with several photos). Rocks showing compositions facilitating metasomatic changes have thus been the first to develop in themselves microcline porphyroblasts, whereas many other rocks have remained intact in this respect even when they have been strongly recrystallized and also altered metasomatically. In the arenaceous-rudaceous and intercalated lutaceous sedimentary rocks near inside the northeastern boundary of the quartzite-arkose body N.—E. of Ramsjö, the serorogenic migrations of the original potassium of the rocks (cp. p. 48 and below) have developed numerous intergrowths (cp. Fig. 31) and veins of microcline but no porphyroblasts. An adjacent primorogenic medium-grained granite originating from arenite and/or rudite has also been locally regenerated in serorogenic time but is nevertheless devoid of porphyroblasts.

Even xenoliths of arenaceous-rudaceous rocks in Revsund granite have remained intact, as exemplified by Fig. 33.

In the Ramsjö—Gnarp region, nearly all Revsund granite originates from tonalite and granodiorite, and in the eugeosyncline in the north only the schists (Fig. 34) have been added to the group of parental Revsund rocks thus formed, whereas the basic volcanics have not been noteworthy altered. The Revsund granite developed by mere recrystallization of porphyritic tonalite and granodiorite has of course the same composition as its parental rocks, whereas the metasomatic Revsund granite is richer in microcline and on the whole more felsic.

Photo: P. H. Lundegårdh.

Fig. 35. Palingenic aplite granite in sedimentary gneiss with acid veins. Scale 1 : 7. 3 km E.N.E. of Hassela.

In the sedimentary rocks bearing only evidences of internal migrations of potassium, it is of course very difficult to distinguish between primorogenic and serorogenic alterations. In many cases nothing can be said of the age of the alterations met with in these rocks. Only when the migrations of chemical compounds have led up to the development of irregular veins cutting the tectonic S-planes of the primorogenic evolution, such as inside the northeastern boundary of the great quartzite-arkose body N.—E. of Ramsjö (cp. p. 48), the serorogenic age would seem obvious. Several tourmaline porphyroblasts (schorlite) have also grown in this rock, especially in and in the immediate vicinity of the microcline veins. The boron of the tourmaline has been supposed to originate from the eugeosynclinal schists in the north and to have served as a mineralizer during the alteration reported of. Similar alterations have been observed N.E. of Hassela and at some other places. The tourmaline porphyroblasts lack preferential crystal orientations although they form slenderly elongated prisms. (Fig. 26 shows a cross section through such a prism.)

The mobilized serorogenic rocks comprise as mentioned all kinds of masses ranging from minor veins to large intrusions. They are composed essentially of

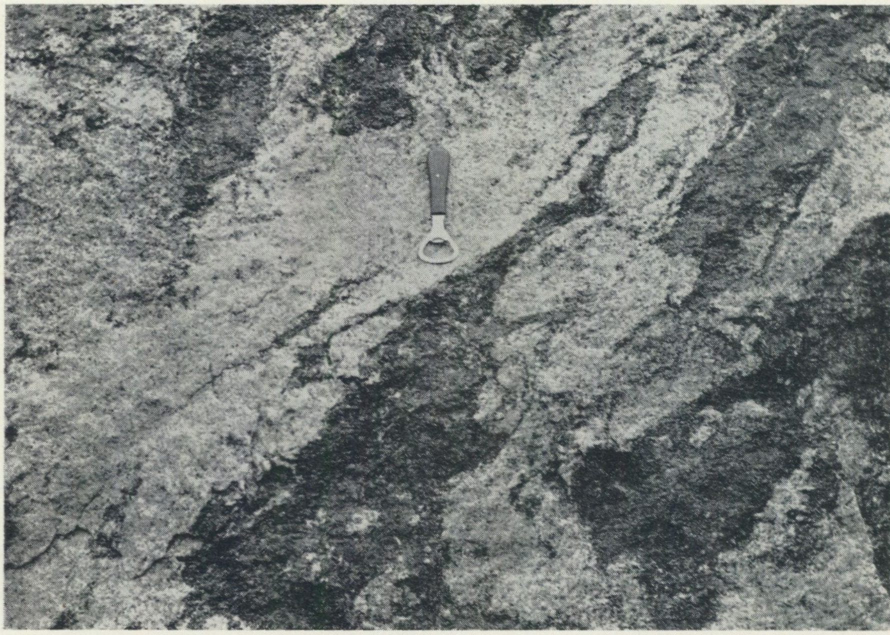


Photo: P. H. LUNDEGÅRDH.

Fig. 36. Palingenic granite (Hernö granite) in mica gneiss (high-metamorphic schist). Scale 1 : 7.5. 33 km to the west of the centre of Sundsvall (Fig. 2).

quartz and feldspar (Figs. 35—37). For the most part the mobilized compounds originate from the country rocks and have hence been called palingenic.

Serorogenic palingenic granite is quite rare in the Ramsjö—Gnarp region, whereas pegmatitic veins and small intrusions of pegmatite have been widely distributed, though they are abundant only in parts of the northern limb of the Ramsjö—Harmånger anticline and the neighbouring eugeosynclinal margin. The colours of both kinds of rocks are dependent of the colours of the parental rocks. As these in the mapped region mostly originate from lutaceous rocks and in the first instance from the eugeosynclinal schists, the main portion of palingenic rocks is pale gray to gray white. In the arenaceous-rudaceous rocks they are, however, as a rule reddish or red gray white, and in the primorogenic granitic rocks (granodiorite — cp. Fig. 37, granite, granite gneiss) the same colours predominate. The degree of oxidation of the parental rocks has thus even here determined the colour of the palingenic rocks.

The palingenic granite is fine medium- to fine-grained, as a rule pale gray and composed essentially of quartz, microcline (no or only small porphyroblasts), and oligoclase (myrmekite rare). Quartz is most and oligoclase less frequent. Subordinate minerals are biotite and most often muscovite, minor minerals zircon, hematite, magnetite, apatite, accidental minerals rutile, allanite, limonite, and tourmaline.

The presence of considerable amounts of muscovite is significant for this kind of granite, which has at several localities in the eugeosyncline in the

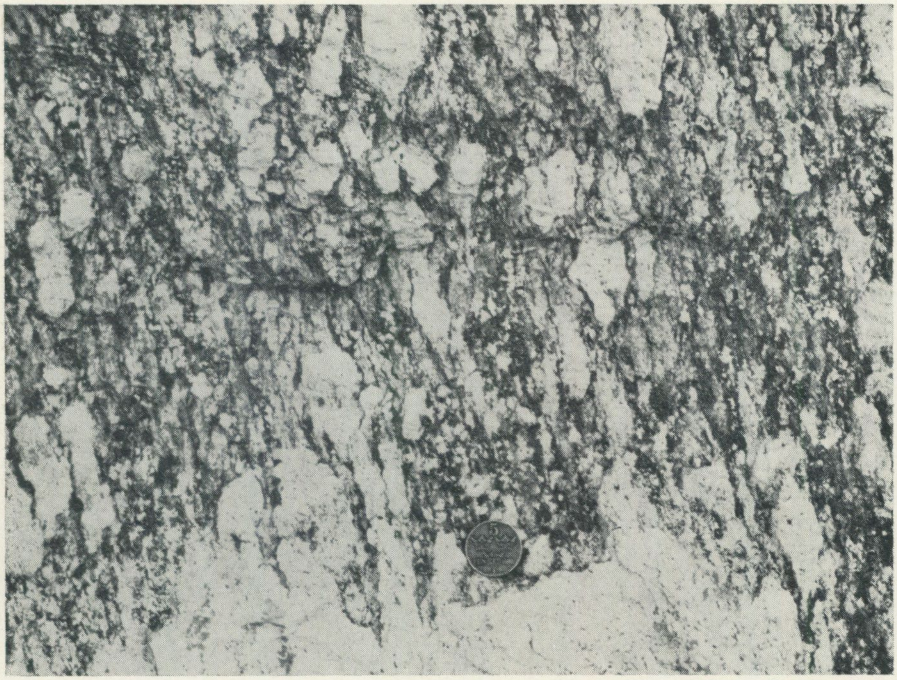


Photo: P. H. LUNDEGÅRDH.

Fig. 37. Palingenic pegmatite cutting granodiorite with deformed and recrystallized porphyroblasts of microcline. Scale 1 : 3.5. 39 km S.E. of Ramsjö.

north proved to be palingenic silica and silicic compounds originating from the schists (Fig. 36). The granite has been called *Hernö granite*. In the Ramsjö—Gnarp region the only intrusions of areal importance are found 6 km N.—N.N.W. of Bergsjö (Mt Baståsen) and in the eugeosynclinal schists in the northwestern corner.

The pegmatite is often accompanied by some aplitic granite and is either red gray white or gray white. It occurs as veins in many rocks of the Ramsjö—Gnarp region, especially the mica gneiss originating from the eugeosynclinal schists. Greater masses have also been found in a few cases, such as 7—9 km to the south of Bergsjö. The pegmatite is here red gray white and in addition to the main minerals, which are as usual quartz, microcline, oligoclase, and some mica, it contains small amounts of blue tourmaline.

As a matter of fact most pegmatite in the northern and eastern parts of the Ramsjö—Gnarp region contains tourmaline, which is always black (schorlite) in the gray white pegmatite originating from schists and has there sometimes grown to large elongated prisms ($\leq$ 2 cm in length). Even in veins and diffuse assemblages of serorogenic microcline in various rocks may tourmaline appear. As mentioned (pp. 48 and 61) it is quite common in the northeastern part of the quartzite-arkose body N.—E. of Ramsjö, where it forms porphyroblasts measuring up to 5 *à* 6 mm in length, but it also occurs occasionally N.E. of

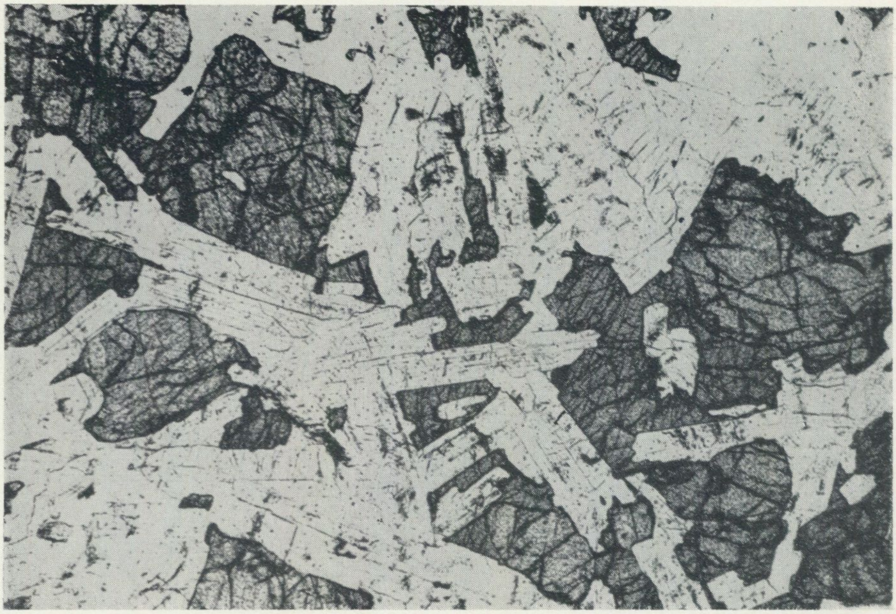


Photo: P. H. Lundegårdh.

Fig. 38. Olivine dolerite (Åsby dolerite). Thin section showing olivine and plagioclase laths. 35 × nat. size. 21 km E.N.E. of Ramsjö.

Hassela (Fig. 26) and farther eastwards. Its boron has obviously served as a mineralizer and seems to have facilitated the palingenesis. (Compare p. 61.)

The serorogenic palingenesis has also produced some ore mineralizations, which will be described in the next chapter.

The Ore Mineralizations

The Ramsjö—Gnarp region is poor in ores. Some titaniferous oxidic ore occurs in the metagabbro at the southern boundary of the region (p. 40), and small grains of both iron oxides and sulfides have been met with as minor or accidental constituents in many of the rocks of the region, but real ore mineralizations are rare.

During several years ore prospectors have worked in the environs of Mt Baståsen and Lake Grännsjön 6—8 km to the north of Bergsjö, and small amounts of copper, tin, and wolfram have been determined in many rocks and 'ore' samples collected by these prospectors. The veined mica gneiss of the Baståsen—Grännsjön area shows impregnations with pyrrhotite, pyrite, and other sulfides as well as of scheelite. These mineralizations have been strongest about 8 km to the north of Bergsjö. The original sediments, most probably graywackes (p. 47), have here been intercalated and intermixed with calcilutites and volcanics now in part easily visible as skarn (p. 46). The calcilutites have altered to vesuvianite, diopside, calcic plagioclase etc. The development of

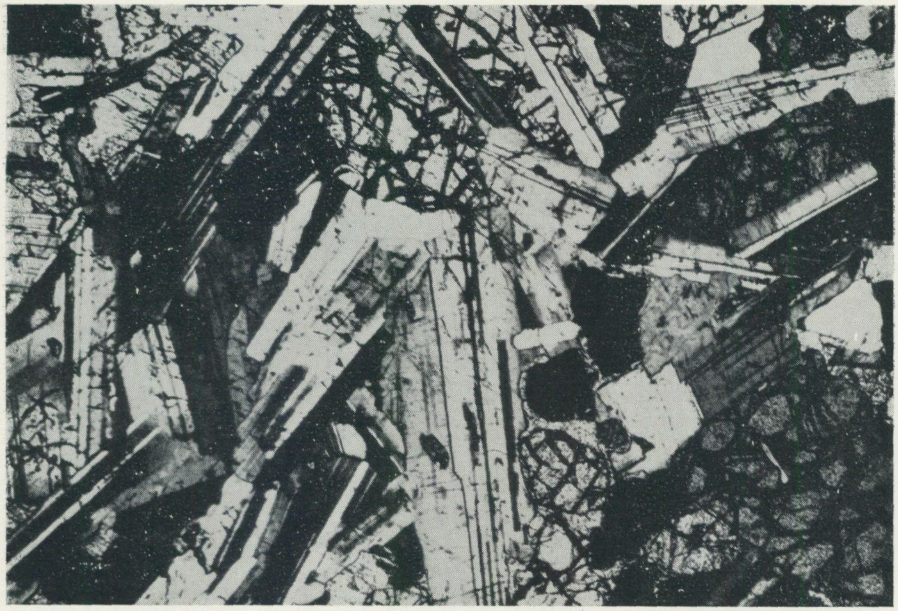


Photo: P. H. LUNDEGÅRDH.

Fig. 39. The same rock and minerals as in Fig. 38. Crossed nicols, 35 × nat. size. 7 km N.N.E. of Bergsjö.

vesuvianite bears evidence of an addition of fluorine, and it has been believed that at least part of the ore minerals have emerged simultaneously with the fluorine.

In the rest of the mapped region fluorine has only been observed as a component of the accidental fluorite met with in the primorogenic granodiorite, granite, and granite gneiss. The serorogenic rocks do not contain any fluorine minerals, boron and water there appearing to have been the principal mineralizers. (See the foregoing chapter.)

The leading ore mineral of the Baståsen—Grännsjön area is pyrrhotite. This sulfide has often assembled to veins and spots and is intimately associated with pyrite and a little chalcopyrite. It is seen to have been penetrated by scheelite and in rare cases also by arsenopyrite. The scheelite forms minor grains sparsely and irregularly distributed all over the actual area. The scheelite seems to have been developed by the serorogenic palingenic-magmatic granite visible as an intrusion in the southern part of Mt Baståsen (p. 63), and the tin traced in the area is probably of the same age.

The formation of the pyrrhotite as well as the associated pyrite and chalcopyrite might possibly be ascribed to the primorogenic activity. Pyrrhotite (often associated with pyrite) is quite common at several places in the Bothnian eugeosyncline, especially in Ångermanland, and has also locally assembled to ore in the coastal parts of the Ramsjö—Gnarp region. In the same areas distinguished by the presence of much pyrrhotite also graphite occurs as a minor or an accidental mineral, and hence it seems probable that the sulfide minerals originate from the graywackes and schists themselves, though they have afterwards moved from their original positions and assembled to veins or spots or irregular masses of ore.

The Dolerite

The dolerite is a variety of the Central Swedish *Åsby dolerite,* and according to several investigations it has been formed during the Jotnian period of the Algonkian (Proterozoic) era. It appears as smaller and larger intrusions in the northern limb of the Ramsjö—Harmånger anticline and in the southern part of the eugeosyncline. Studies in slopes of hills, in road-cuttings, and in tunnels from power stations have shown that the intrusions comprise normal dikes and sills (cp. S. Hjelmqvist 1944) as well as laccoliths.

The dolerite is black gray to gray black, as a rule fine- to medium-grained and most often beautifully ophitic (Figs. 38 and 39). Subophitic varieties have also been observed. The dolerite of the great intrusion N.N.E. of Bergsjö is in part coarse and has then been called *Galtström dolerite.* (Galtström is a village in southeastern Medelpad.)

Main minerals of the dolerite are labradorite (An = 55—70 %), olivine ($2V\gamma$ = 95—100°), and clinopyroxene (pigeonite or augite, frequently no more than subordinate minerals, see Figs. 38—39). Subordinate constituents are titaniferous magnetite and most often biotite, minor minerals apatite and as a rule serpentine (together with some iron oxide ore secondary after olivine and contained in the cracks of this mineral).

The plagioclase is mostly fresh (Figs. 38 and 39). It often shows zonal growth, with higher An percentage in the kernels than in the marginal parts. In the great intrusion N.N.E. of Bergsjö the doleritic magma has undergone some differentiation before its eventual solidification. Part of the dolerite shows there a zonal plagioclase with kernels composed of labrado-bytownite (An = 70 %), whereas another portion contains a plagioclase with only 55 % An. Hypersthene and iron sulfides (mostly pyrrhotite) belong to the minor minerals of the latter, which ought thus to represent the youngest dolerite variety in the intrusion.

As has been mentioned earlier, the dolerite has sometimes been influenced by late tectonic activity. Hjelmqvist (1944) has described tectonic deformations of some dolerite sills in Medelpad, and in the Ramsjö—Gnarp region deformations have been observed at the southern limit of the great intrusion N.N.E. of Bergsjö as well as in some of the intrusions in and near the marginal parts of the great quartzite-arkose body N.—E. of Ramsjö. The deformations have been produced by faults, and the principal kind of deformation is frictional brecciation including strong fracturing of the minerals of the rock. These have also been afterwards attacked and altered by aqueous solutions moving along the fault planes.

The brecciation at the southern limit of the dolerite N.N.E. of Bergsjö follows a zone of fault planes continuing to the Dellen lakes and probably developed simultaneously with the magmatic activity having produced the volcanoes there (andesitic lava and tuff referred to the Tertiary, cp. p. 17). Most of the brecciations in the northwestern part of the Ramsjö—Gnarp region have been produced by movements along the primorogenic Bothnian shear planes oriented E.N.E.—N.E. It is hence interesting to find that part of the contacts of the doleritic intrusions here follow other shear planes than the Bothnian ones. This mode of intrusion of the doleritic magma indicates some shearing fissuring during the Algonkian, and accords thus with the tectonizations closely associated with the doleritic intrusions in the north as earlier described by Hjelmqvist (1944).

The age of the brecciations of the dolerite will not be discussed in this paper. It can only be stated that we have to include in our computations at least three periods of movements in the crust, viz. the late Algonkian (cp. Hjelmqvist, op. cit.), the Caledonian, and the Tertiary.

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GFF = Geologiska Föreningens i Stockholm Förhandlingar
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PETROLOGICAL MAP OF THE RAMSJÖ– GNARP REGION IN CENTRAL SWEDEN By Per H. Lundegårdh

Location map see Fig. 1

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Mica gneiss (mainly altered lutites)

Granite gneiss, acid
Secondary granite } (mainly altered arenites)

Schist
Meta-argillite

Quartzite, arkose, subgraywacke

Primorogenic granodiorite (gneiss-granite, intermediate and basic)

Primorogenic granite (gneiss-granite, acid)

Metabasite, infracrustal (meta-norite, meta-pyroxenite)

Metabasite, supracrustal

Serorogenic granite and pegmatite

Acid palingenic veins and schlieren

Microcline porphyroblasts

Garnet

843 Petrofabric analysis

Horizontal lineation

Thrust and fault planes

Dolerite

B Bedding

Scale 1:300 000

0 2 4 6 8 10 km

För spridning godkänd i Rikets allmänna kartverk 31/12 1959

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