

ROLAND GORBATSCHEV

AGE RELATIONS AND ROCKS  
OF THE SVECOFENNIAN -  
GOTHIAN BOUNDARY,  
LINKÖPING, SOUTH  
CENTRAL SWEDEN



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## CONTENTS

Preview summary .....	3
Introduction .....	4
Principal geological units of the Linköping area .....	6
Early Svecofennian development: supracrustal rocks .....	8
Svecofennian development: plutonics and hypabyssals .....	12
"Gothian" development: plutonics .....	23
The Linghem schistosity belt .....	46
Discussion .....	50

## ABSTRACT

The chronology and some of the petrological and tectonical traits of the Linköping area are considered. Three principal groups of plutonics are distinguished: (1) an early differentiated complex comprising several, mostly sodic subunits, (2) migmatizing granites, and (3) late granitoids associated with local migmatization only. Groups (1) and (2) have been affected by the development of regional gneissosity. Peculiar of the Svecofennian-Gothian boundary area is the occurrence of belts occupied by granites which are chemically related to the late plutonics, but subjected to strong crushing and foliation.

## PREVIEW SUMMARY

Geological relations at the boundary between the traditional Svecofennian and Gothian megacomplexes are reviewed. Early Svecofennian supracrustal rocks comprising predominantly quartzites and dacitic to basaltic volcanics are followed by diversified suites of plutonics. The oldest plutonic successions range from metagabbro to granitoids and can on tectonical and compositional grounds be subdivided into several subunits. Most of these are distinctly sodic, but there are reversals of acidity and color index development. The relation of the early plutonics to a first period of migmatization is considered. As different from conditions prevailing in the core areas of the Svecofennian, the main group of migmatites and associated acid alkaline granites and pegmatites is commonly overridden by regional schistosity. Peculiar to the whole Linköping-Norrköping region is the development of NNW to WNW-striking comparatively narrow belts occupied by foliated, but otherwise homogeneous granites. These zones appear to be independent of the trend of the earlier migmatization and suggest granite emplacement into zones of mechanical failure which were later subjected to renewed shearing movements. More restricted mig-

matization and metamorphism is associated with the emplacement of masses of "Gothian" granitoid plutonics associated with granitic porphyries. Fine-grained granites comprise several groups, some of which are older and others younger than the main bodies of coarse-grained "Gothian" granite. Giant breccias of older rocks in the "Gothian" are common. In relation to regional folding the intrusion tectonics of the "Gothian" are essentially postdeformational. Comparison is made between the geological development in the Linköping area and conditions in the Västervik area farther southeast which have been considered in a number of recent publications. It is concluded that the Gothian Småland granites cannot be parallelized with Early Svecofennian plutonics. Coarse augen-granitoids make their appearance throughout the Svecofennian-Gothian, but in the Linköping area most "Gothian" plutonics are clearly "postorogenic" in relation to the "Svecofennian" development.

## INTRODUCTION

This paper summarizes and discusses the chronological results of an investigation of the Linköping area, Östergötland, south central Sweden and in addition gives short summaries of the petrography of the most important rock types. The Linköping area was studied 1967–1971 as part of the Geological Survey routine mapping programme. It extends across the alleged boundary between the Svecofennian "orogenic belt" in the north and east, and the "Gothian" complex in the southwest. Its chronological features merit attention in the context of recent discussions of the absolute and relative age of the Svecofennian and "Gothian" magacomplexes (Magnusson 1960, Polkanov and Gerling 1960, Welin 1966, Welin et al. 1966, Priem et al. 1969). Petrological differences between these two greater units attracted interest early in the course of geological work in Sweden. As orogeny concepts were applied to the geology of Fennoscandia these differences were employed to define two orogenic belts, the Svecofennian and the Gothian or Gothokarelian (Wahl 1936, Backlund 1936, 1937, Magnusson 1936). The Svecofennian of central Sweden is a composite megaunit comprising a supracrustal volcanic-sedimentary sequence, three principal groups of plutonics: the syn-, late-, and postkinematic "granites", and several groups of intraorogenic basic rocks, mainly metabasite dikes. In contrast, the predominant rocks in the Gothian of southeastern Sweden are plutonics known as the Småland granites, further a complex of porphyries – the Småland porphyries, subordinate units of sediments, and, in the far south, a late group of granites. Even reckoning with the possibly related rocks of southwestern Sweden (Magnusson 1962, Gorbatshev 1971), the lithofacies of the "Gothian" is difficult to reconcile with a consistent traditional orogeny model. Attempts to force the "Gothian" plutonics into a strict synkinematic-latekinematic classification have not been immediately successful. Tectonically and chemically many of the Småland granites rather compare with what are considered to be early postorogenic granitoid plutonics of the Svecofennian, e. g. the Rätan granite of north central Sweden. Conspicuous is also the pau-

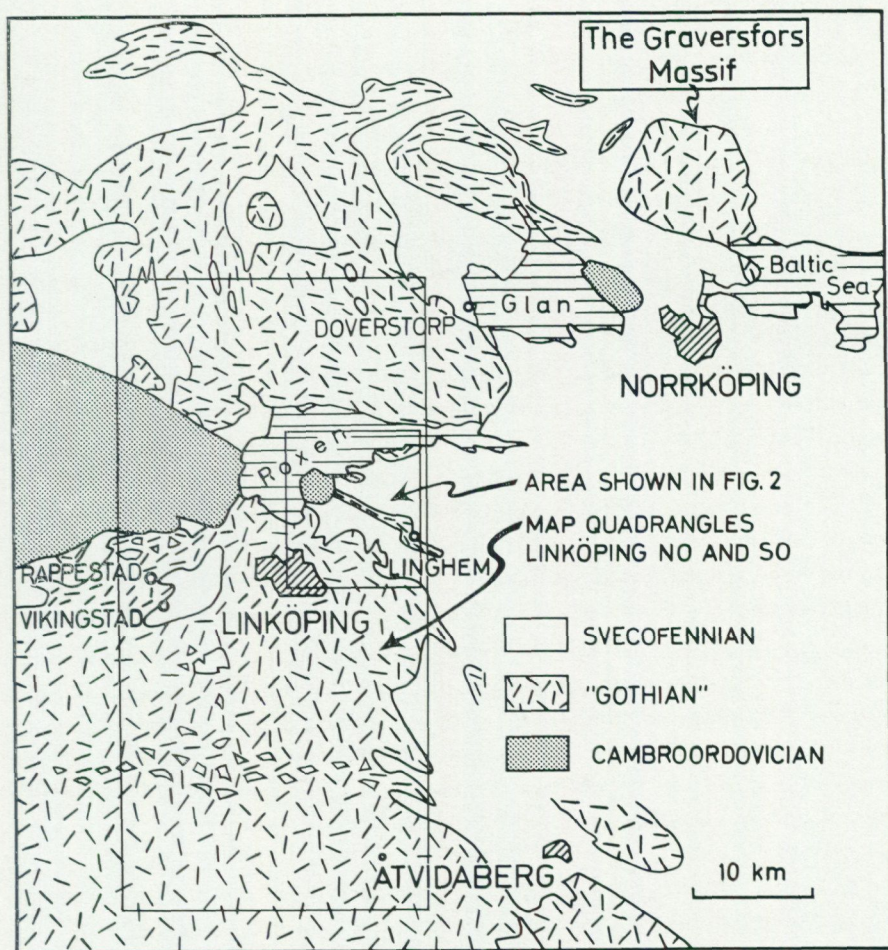


Fig. 1. The Linköping area is situated on the boundary between the Svecofennian orogenic region and the "Gothian" Småland granite complex. Somewhat modified from Geijer and Magnusson (1944).

city of the Swedish "Gothian" in rocks which may be equated to geosynclinal sedimentary-volcanic sequences. Whereas early K/Ar datings (Polkanov and Gerling 1960, Magnusson 1960) appeared to support the geographical subdivision into chronologically different Svecofennian and Gothic complexes, recent work rendered a. o. a Rb/Sr dating of 1740 m.y.s. for a characteristic Småland granite (Welin et al. 1966). This is clearly within the time limits of the Svecofennian development and moves the Småland granites into parity with other (early-) postorogenic Svecofennian rocks (Welin 1970).

## PRINCIPAL GEOLOGICAL UNITS OF THE LINKÖPING AREA

In the vicinity of Linköping predominantly coarse-grained "Gothian" granites come into contact with a complex terrain of "Svecofennian" character. The Linköping area which is essentially covered by the geological quadrangles Linköping NO and SO, is bipartitioned by an east-west trending depression filled by Cambrosilurian sediments and the waters of Lake Roxen (Fig. 1). The Precambrian area to the north of this depression contains coarse-grained granitoid rocks of "Gothian" classification (Magnusson 1962). Older sources sometimes describe these rocks by the one-time terminological counterparts of the current terms "Gothian" and "Svecofennian". A characteristic member of the suite is the Graversfors granite massif which crops out just to the north of Norrköping, approximately 40 km NE of Linköping. In the coarse-grained "Gothian" plutonics north of Roxen there are rather subordinate intercalations of older (Early Svecofennian) supracrustals and plutonics. To the south of the Roxen-Cambrosilurian belt coarse granitoid rocks which in many respects are similar to the "Gothian" rocks north of Lake Roxen coalesce to form the huge semicoherent Småland-Östergötland granite area. The frequency of large relics of "Svecofennian" rocks rapidly decreases southwards.

Traditionally, the "Gothian" granites of the Linköping and adjoining areas have been subdivided into augen-granites of Filipstad type, usually coarse-grained semiequigranular acid Red Våxjö granites, and some additional varieties of lesser quantitative importance (Magnusson 1922, 1924). The term "Red Våxjö" is of old standing in Swedish geology (Hummel 1877a, 1877b). Originally it was applied to medium-grained rocks, whereas coarse varieties received other names ("Järeda", "Grinderum"; Holst 1879, 1885, 1893). The locality terms "Örebro" and "Filipstad" have variously been applied to coarse-grained augen-granitoids throughout central and southern Sweden. Following the outcome of a discussion in the nineteen-thirties (Holmquist 1934a and b, Landergren 1934, Magnusson 1934a and b), the Örebro granite is now regarded as part of the Late Svecofennian group of plutonics, while the Filipstad granite is referred to the Gothian. Both in the Filipstad and the Linköping areas there is some diversity of coarse augen-granite types and a. o. the terms "Filipstad", "Kristinehamn", "Nykil", and "Graversfors" have been used. An essential contemporaneousness of all these units appears probable from their geological relations and distribution pattern. Nevertheless, there is some vagueness and even contradiction in the definitions employed hitherto: for instance, just to dwell on a detail, Filipstad granite is described as a rock with plagioclase-mantled K-feldspar megacrysts which never contain myrmekite (Holmquist 1906). In the Filipstad granite area of Linköping (Magnusson 1922) mantled augen are either absent or rather inconspicuous and myrmekite is quite well-developed, while in the granites to the north of L. Roxen thick mantles around the megacrysts or other grains of K-feldspar are almost always present and

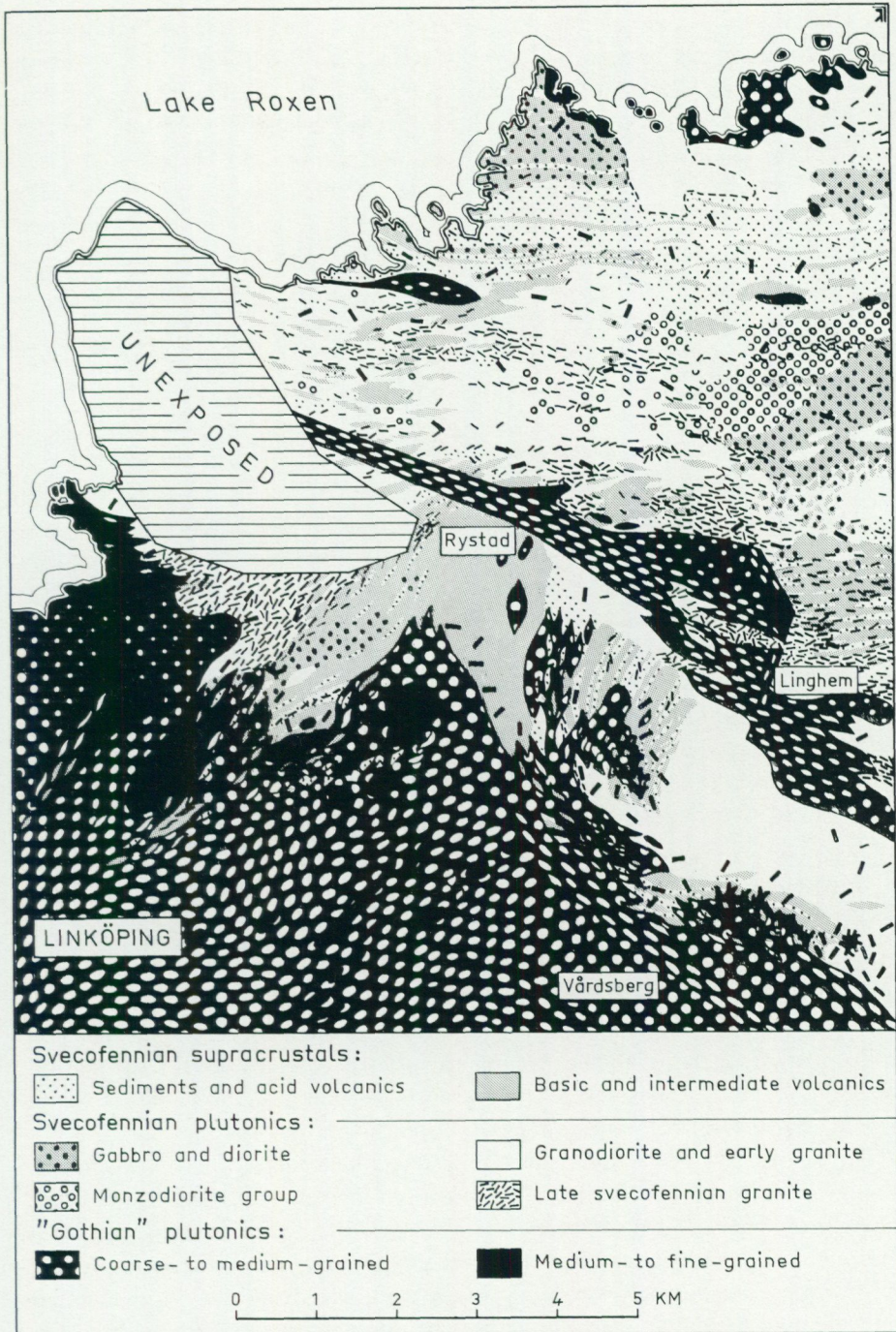


Fig. 2. The Svecofennian - "Gothian" boundary to the northeast of Linköping. Somewhat simplified from the Geological Survey quadrangle map Linköping NO (Gorbatshev, in preparation).

the rock exhibits some of the most magnificent examples of myrmekite development seen by this writer. Because the accident of myrmekite in the "Gothian" granites of Linköping is roughly related to the Ca-contents of plagioclase, the rocks which in this particular respect best meet Holmquist's description of Filipstad granite are coarse, red, alkaline granites of Magnusson's (1922) Växjö classification. Of course they are often much more acid and alkaline than the classical "Filipstad" (Törnebohm 1880a, Holmquist 1906). Some regional chemical differences between various units of Filipstad classification have been pointed out by Sundius (1921b). The Graversfors granite massif (cf. Holmquist 1906, Asklund 1925) comprises two different principal varieties – a red nearly equigranular to augen-bearing type and a brownish-blackish-violet augen rock. The term "Graversfors" thus has a geographical-chronological rather than typological significance. The description of Graversfors rocks by Holmquist (1906) fits well the part of the Linköping area which is situated to the north of Lake Roxen and this similarity also extends to the chemical parameters. The essential similarity of the dark Graversfors variety and a rock described by Törnebohm (1880b) from the area north of L. Roxen has been pointed out by Holmquist (1906).

To the northeast and southeast of Linköping the Småland-Östergötland granites meet a terrain of older rocks of great complexity and basically different tectonic blueprint. Geological relations in the area NE of Linköping (Fig. 2) will be in the focus of attention throughout the present paper. In contrast to relics of "Svecofennian" type to the north of L. Roxen, the rocks on the southern shores of the lake are characterized by the abundance of different types of plutonics and by complicated interrelations between these units.

#### EARLY SVECOFENNIAN DEVELOPMENT: SUPRACRUSTAL ROCKS

Throughout the Linköping area the oldest rocks are supracrustal gneisses which in areal distribution and petrological development exhibit close liason with metavolcanics and metasediments of adjoining classical Svecofennian localities. In the northern parts of the Linköping area the Doverstorp ore field (described by Asklund in Tegengren 1924) represents the common Svecofennian association of leptites, ores, limestone, and amphibolite. The rest of the supracrustals to the north of L. Roxen are disconnected, commonly hornfels-transformed fragments enclosed in "Gothian" granites. Alongside with fine-grained feldspar-quartz gneisses (leptites) and stratified micaceous-quartzitic gneisses of obvious sedimentary descent, pyroxene-garnet-plagioclase and amphibole-pyroxene-garnet hornfeldes and skarns are locally prominent and associate with positive magnetic anomalies or even minor prospects of iron ore (Trehörningsjö mine, etc). Semicohesent areas of supracrustal gneiss are important to the south of Lake Roxen and in the central part of the Linköping SO quad-



Fig. 3. Interstratification between quartzitic metaarenite and intermediate to basic laminae of volcanic and essentially volcanic provenance. The rock association shown in the photograph is typical of the layered sedimentary sequence to the south of Lake Roxen, 4 km NE of Rystad.

range with other interrupted occurrences of supracrustals linking them to the Åtvidaberg mining district farther southeast. In addition, considerable parts of the Linköping SO quadrangle, which are shown as granite areas in older maps, can be described as giant breccias of older supracrustals enclosed in coarse "Gothian" granites. Peculiar of the supracrustal rocks in the Linköping area is the almost complete absence of metaargillites and metagraywackes which are well developed around Norrköping, close to Åtvidaberg and, of course, in the central part of the Svecofennian Sörmland gneiss belt to the north of the Linköping-Norrköping region. Instead, the Linköping rocks are characterized by the association of metaarenites ("quartzites") with metabasalts, metadacites, metalatites, trachyandesites and quartz-feldspar gneisses (leptites) of approximately granitic composition and commonly controversial original genesis. Limestones occur to the east of Linköping somewhat outside of the area shown in Fig. 2.

Immediately to the south of Lake Roxen supracrustals build up a broad belt which in its northern part is dominated by quartzites and impure quartzites locally intercalated with gray laminated feldspar-quartz-biotite rocks of sedimentary or tuffitic derivation (Fig. 3). Toward the south, leptitic feldspar-

**Table 1. Principal minerals of some supracrustal rocks (vol. p. c.)**

Quartz .....	40	36	33	33	25	24	21	19
Plagioclase .....	53	27	26	46	33	31	60	49
Potassium feldspar .....	6	29	29	-	21	34	9	7
Biotite and chlorite .....	1	7	9	4	11	10	7	21
Amphibole .....	-	-	-	7	-	+	-	-
Epidote .....	-	-	-	1	4	+	+	-
Muscovite .....	-	1	1	-	2	+	1	-
Quartz .....	15	9	9	9	6	6	4	3
Plagioclase .....	53	41	39	37	60	58	55	39
Potassium feldspar .....	7	9	4	-	-	+	+	+
Biotite and chlorite .....	16	24	18	26	15	30	23	18
Amphibole .....	3	-	14	23	15	-	16	34
Epidote .....	4	9	5	1	1	-	-	-

quartz (-mica-amphibole) gneisses gradually increase in importance. Hornblende-rich gneisses with or without quartz occur throughout the supracrustal complex and are not restricted to any particular stratigraphical position. Characteristical of the Svecofennian supracrustals in the entire central part of the Linköping area is the lack of cleancut demarcations between sequences of quartzites and rocks of decidedly or probably volcanic origin. Indeed we find that details of the mineral composition of quartzites often depend on the character of associated metavolcanics. Thus metaarenites interbedded with amphibolites often contain hornblende, whereas quartzites occurring together with acid leptites may pass into varieties which are rich in alkali feldspar and consequently in composition transitional between quartzite and leptite. Similarly, laminae rich in quartz grains often occur in laminated amphibolites while some compositionally outright granitoid leptites may exhibit textural relics interpretable as sedimentary lamination and carry rounded placered zircon grains. In numerous cases the very definition of leptite as a rock of recrystallized metamorphic texture (Geijer 1944) precludes more precise statements as to originally volcanic, redeposited volcanic, or orthosedimentary provenance. Altogether, compositional and some preserved textural characteristics of the Linköping supracrustals demonstrate that volcanic and sedimentary deposition processes were operating simultaneously. Conditions of formation thus resembled those in the Örebro area (Gorbatshev 1969) in precluding the formation of sharp divisions between predominantly sedimentary and exclusively acid volcanic stratigraphical successions which are claimed to characterize large regions of the Central Swedish Svecofennian (Geijer 1963). It will also be remembered that the local stratigraphy of the adjoining Ätvidaberg area, which from descriptions by Sundius (1921a, 1924, 1926) can be interpreted as a syncline with amphibolites at the bottom, schists in intermediate position, and leptites at the top, is very much different from the usual Svecofennian dual-

**Table 2. Principal minerals of Rystad metabasalts (vol. p. c.)**

Sample:	919	920	1144a	1144b	1145
Plagioclase	36	32	39	41	41
Amphibole	52	65	36	45	58
Pyroxene	10	—	15	4	—
Biotite, chlorite	2	—	+	1	—
Epidote	—	—	4	6	—
Calcite	—	2	5	3	—

ism of lower leptites and upper sediments. By and large the metavolcanics or probable metavolcanics of the Linköping area are clearly dominated by intermediate and basic rocks, whereas leptites of rhyolitic composition while being omnipresent, are quantitatively comparatively subordinate. According to Sundius (1968) this may indicate a rather high stratigraphical position in the Svecofennian, but the disrupted character of the Linköping supracrustals allows only a very rudimentary stratigraphical reconstruction. Hitherto these rocks provided no clear indications of stratigraphical top-bottom relations. Table 1 gives a general idea of the mineral composition of Linköping supracrustals of volcanic or probably essentially volcanic provenience, arranged in order of decreasing quartz contents.

A coherent and well-preserved segment of supracrustal rocks is the metabasalt to the south of Rystad (Fig. 2). This is an area of between 2 and 3 square kilometers occupied by bluish-black and greenish-black submassive to moderately foliated rock exhibiting a multitude of primary structures and textural traits. There are relics of ophitic and flow textures, recrystallized calcite-, chlorite-, epidote-, and feldspar (formerly zeolite?) -filled amygdules, abundant agglomerates plus rocks carrying fragments of leptite (Fig. 4). Part of the rock is feldspar-porphyrific. In contrast to most other mafic supracrustals of the Linköping area, the Rystad metabasalt does not contain quartz (Table 2).

Among the supracrustals in the vicinity of Linköping the metabasalt in the Rystad area is unique in the homogeneity of its comparatively extensive occurrence. The Rystad rock is cut by dikes and penetrated by small massifs of coarse "Gothian" granite and associated fine-grained or pegmatite dikes, but is conspicuously devoid of intrusions of Early Svecofennian plutonics. Neither are there signs of the main migmatite formation episode in this area. Rocks in the vicinity which are affected by Early Svecofennian or synmigmatization intrusions may be strongly foliated equivalents of the metabasalt, but differ from the central parts of the Rystad area in being intercalated with more silicious metavolcanics and with metasediments. This raises the question of whether the Rystad metabasalt may actually be younger than the "Early Svecofennian" development and intermediate between that period and the "Gothian". Still there is no positive proof of such a chronological position and the good state of preservation and lack of Early Svecofennian dikes may

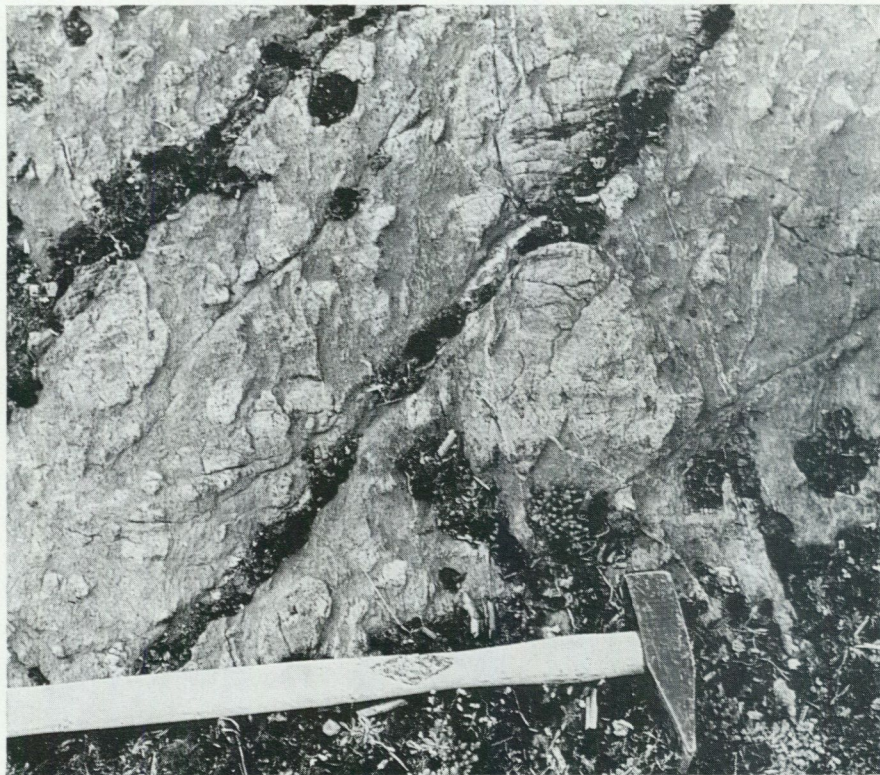


Fig. 4. Agglomeratoid breccia of leptonite and quartzite fragments in amygdaloidal Rystad metabasalt. 2 km SSE of Rystad.

be due to the tectonical position of the well-conserved metabasalt at the apex of a major fold (Fig. 2). Indeed, this location in combination with foliation strongly suggests that the metabasalt has been involved in Early Svecofennian folding. Regrettably the poorly exposed peripheral parts of the Rystad area allow no good observations of contact relations between metabasalt and surrounding rocks.

#### SVECOFENNIAN DEVELOPMENT: PLUTONICS AND HYPABYSSALS EARLY PLUTONICS

Throughout large areas to the north of Lake Roxen (Fig. 1) the oldest plutonics have a rather uniform development. Typically, these rocks are even- and medium-grained, light to medium gray to reddish and macroscopically sub-

massive to moderately gneissic in texture. Constituting approximately half of the rock's volume oligoclase is in the commonest type of oldest plutonics always very predominant over microcline which usually ranges between 3 and 15 p. c. by volume. Dark minerals (biotite, chlorite, epidote) are consistently around or just above 10 p. c., quartz occupies between 25 and 30 p. c. of the volume. The overall chemical composition is thus pronouncedly sodic. Transitions toward more alkali-intermediate varieties where plagioclase contents exceed but slightly those of microcline occur at quartz percentages of approximately 30 to 35. Simultaneously the content of dark minerals drops to or below 5 p. c. Nevertheless, not even pronouncedly red specimens of granite were found to have microcline volumes exceeding those of albite-oligoclase. A common proportion is here approximately 25 p. c. microcline versus 35 p. c. plagioclase. In the field the contacts between the predominant sodic and the more subordinate alkali-intermediate reddish types are either clean-cut, or, which indeed appears to be much more common, blurred by a gamut of transitional rock varieties occupying large areas.

In contrast to these comparatively uncomplicated relations the early plutonics to the south of Lake Roxen abound in chemical and chronological intricacies. Compositional variability is pronounced and differences in age are demonstrated by numerous intrusive crosscutting contacts. Indeed there is reason to subdivide the gneissose plutonics of that sector into several different age groups extending from "Early Svecofennian" over migmatizing acid granitoids of "Late Svecofennian" classification to early members of the "Gothian" suite. Among rocks of "Early Svecofennian" classification differences of tectonization and intrusion tectonics suggest the existence of several distinct subgroupings, an aspect which presently will be developed in some detail.

Apart from some minor occurrences of medium-grained granitoid gneisses formed by in situ recrystallization of supracrustal rocks of suitable bulk composition, the oldest Early Svecofennian plutonics are hornblende-gabbros (metagabbros) transitional into occasionally potassium-feldspar-bearing diorites.

A distinctive, but chronologically controversial rock is a coarsely medium-grained normally pronouncedly gneissic monzodiorite (the terminology used is that of Streckeisen 1967) usually studded with closely-spaced homogeneously distributed pink or white mantled feldspar megacrysts which may reach between 1 and 2 cm in longest diameter and thus are somewhat larger than the coarsest grains of the intervening matrix. The central potassium feldspar parts of the megacrysts are markedly perthitic and usually surrounded by thick mantles of myrmekitic plagioclase. Matrix plagioclase is a sodic to intermediate andesine which forms tabular subhedral grains which are somewhat altered to sericite and saussurite and subjected to marginal recrystallization as well as reformation of the decomposition products into clear grains of muscovite and clinozoisite. The principal dark minerals are biotite and amphibole in variable pro-

**Table 3. Mineral composition of five samples of monzodiorite (vol. p. c.)**

Quartz .....	6	8	8	10	14
Microcline .....	15	13	10	12	14
Andesine and sericite .....	45	36	38	36	42
Hornblende .....	12	17	12	1	3
Biotite .....	17	11	22	26	10
Epidote, prehnite .....	2	4	4	8	13
Chlorite .....	-	4	1	-	2
Sphene .....	1.6	5.6	3.8	1.0	1.2
Apatite .....	0.6	0.7	1.2	0.6	0.4
Magnetite .....	+	0.2	0.5	0.2	0.2
Calcite .....	-	-	+	5	+

portions and often intergrown with considerable amounts of sphene which is largely formed by unmixing from Fe-Mg silicates. Also chlorite and magnetite appear to be essentially secondary metamorphic products. Quartz is always present, but the contents of this mineral are rather low except in subordinate granitoid rock varieties where concomittant changes of composition also imply a slight increase of the K/Na ratio and a lowering of the biotite-amphibole total. Representative monzodiorite modes are given in Table 3. The monzodiorite has a chemical composition which in some respects relates it to the "Gothian" granitoid plutonics. Nevertheless it is involved in the development of E-W trending regional schistosity which connects it to the Svecofennian plutonics and contrasts with the tectonics of the "Gothian" granitoids. The monzodiorite is further cut by a. o. dikes of gray sodic granite and to some extent involved in migmatization which although in individual localities not clearly attributable to the "Gothian" or "Late Svecofennian" appears to be of a regional character and conforms with the Svecofennian tectonical pattern. The monzodiorite is therefore tentatively attributed to the Early Svecofennian development. If still related to the "Gothian" as an early member of that suite it must imply a very close liason and even partial overlapping of the Late Svecofennian and early phases of the "Gothian" plutonic activity. The monzodiorite is clearly older than the granites of the Linghem belt which are described below (p. 46-49).

Because megacryst-bearing fragments of basic and intermediate plutonics are enclosed in different kinds of later intrusives and because there are dikes of monzodiorite in metagabbro, the formation of mantled potassium feldspar megacrysts cannot be related to any of the subsequent processes of migmatization and regional metamorphism. The good development of perthite and the width of myrmekitic plagioclase mantles suggest formation from originally homogeneous high-temperature feldspars. As just mentioned the monzodiorite is older than some sodic granites-granodiorites but nevertheless a few inclusions of gray and reddish-gray gneissic medium-grained Early Svecofennian granitoid rocks in megacryst-bearing monzodiorite have been observed. In con-

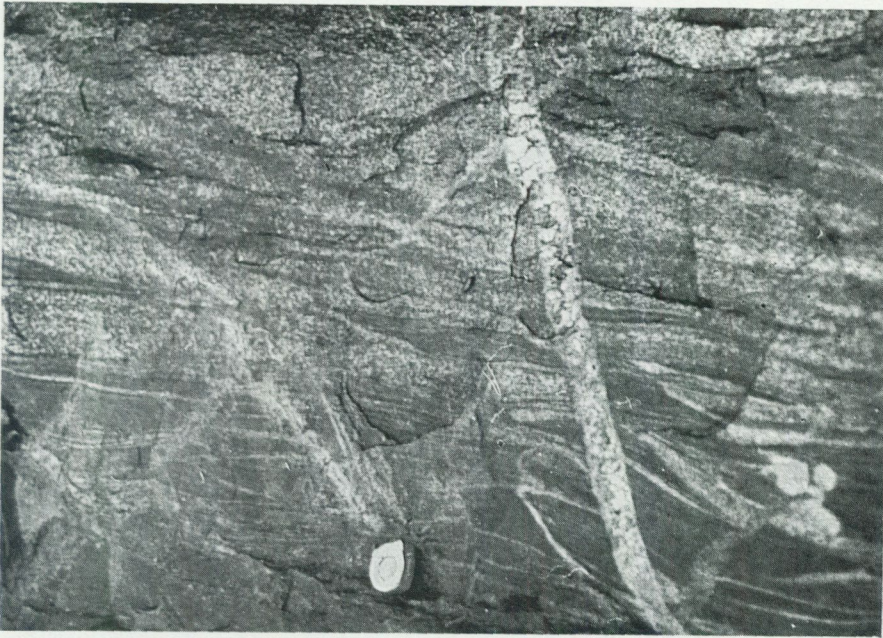


Fig. 5. Migmatitoid veining of supracrustal amphibolite by synorogenic granodiorite-granite. The traversing pegmatite vein may be late Svecofennian or "Gothian". Southern shore of Lake Roxen 4 km NNW of Rystad.

trast, dike intrusions or intrusive crosscutting contacts of monzodiorite have only been noted in metagabbro.

The principal group of Early Svecofennian plutonics in the Linköping area are medium-grained gray to reddish rocks belonging to a differentiated suite ranging from quartz-diorites to granites with a predominance of granodiorites. These rocks are generally regionally schistose and/or lineated and because it may thus be concluded that they were emplaced during of before orogenic events, they are in Scandinavian geological literature described as primorogenic or synkinematic. Their contacts with the Early Svecofennian supracrustals are generally subconcordant, but details of the contact lines clearly testify to the intrusive nature of most of these plutonics. Inclusions of supracrustals are exceedingly common. The locality name "Risten" has been applied to a gray granodioritic rock occurring to the southeast of Linköping. Because the rock belongs to a type of Early Svecofennian plutonics which is common throughout central Sweden, the term is not really indispensable and what is worse, it is somewhat ambiguous since it has previously also been applied to a pale red throughbreaking granite (Törnebohm 1885, Blomberg 1909).

Similar to the equivalent plutonics to the north of Lake Roxen, the synkinematic Svecofennian granitoids of the Linköping area are distinctly sodic, the

Na/K atomic ratio most frequently appearing to be between 2 and 4. Simultaneously, however, the rocks are commonly not very rich in dark minerals and rather high in quartz. As different from conditions in numerous nearby areas rock types with K/Na ratios approaching or exceeding 1 are rather uncommon. Generally their color is red.

In an overwhelming majority of synkinematic granitoids in the Linköping area plagioclase compositions fall into the interval between  $An_{10}$  and  $An_{30}$ . Normal zoning is fairly common in larger crystals as are thin lamellae of antiperthitic K-feldspar and cloudy alteration products sometimes recrystallized to larger muscovite and clinozoisite grains. The usually subordinate microcline is well-twinned, commonly perthitic and/or surrounded by thin rims of clear plagioclase. Myrmekites are reasonably common. Microcline-porphyrific rock varieties sometimes occur, but generally augen rocks are rather inconspicuous in this group. Dark minerals are hornblende and/or biotite, biotite being decidedly the predominant species. It is sometimes transformed into chlorite, contains lenses of prehnite and exsolves sphene and/or magnetite. Small amounts of epidote occur in almost all of the examined twenty-odd thin-sections and are often intergrown with amphibole. Relics of pyroxene enclosed in amphibole grains with epidote and quartz suggests that pyroxene may once have been more common.

The plutonics considered here form a consistent differentiation series where color index falls and quartz contents as well as the Na/Ca ratios increase in the younger members. With the exception of the monzodiorite and its diorite and granite associates which represent a trend of their own and where the relative age classification is somewhat tentative, variations of similar consistency also apply to the Na/K ratio. The contacts between different rocks of the early plutonic complex are commonly crosscutting.

In analogy with these rocks a group of predominantly fine-grained or finely medium-grained granitoids occurring to the east of Linköping was found to be older than the main migmatization episode in the area. The grain size of these rocks is similar to that of dikes or the contact facies of common granodioritic-granitic medium-grained varieties, but in contrast to the principal members of that group the fine-grained granitoids are often associated with pegmatite dikes and schlieren which appear to be absent in the dike and contact facies of the medium-grained plutonics. This is similar to the pegmatite association of some early plutonics described by Sundius (1924) from the Åtvidaberg area. It is interesting to recall here that pegmatites connected with synkinematic plutonics of the Svecofennian core areas are extremely rare and in most regions altogether nonexistent. In the Linköping area association between the "fine-grain-size" early plutonics and minor schlieren of pegmatite is actually the normal case. Still these rocks are never observed to associate with areal migmatization. Another difference in comparison with the "medium-

Table 4. Characteristical volume modes of Svecofennian granitoids in the Linköping area

	Late Svecofennian				Early Svecofennian													
					North of L. Roxen				South of Lake Roxen									
Quartz .....	27	28	31	33	24	27	27 <sup>1/2</sup>	30 <sup>1/2</sup>	12	19	19	21 <sup>1/2</sup>	22 <sup>1/2</sup>	26	27	29 <sup>1/2</sup>	33 <sup>1/2</sup>	34 <sup>1/2</sup>
Plagioclase and fine-grained alter- ation products	32	32	29	24	52	48	54	35	39	48	55	37	53 <sup>1/2</sup>	50	42	39 <sup>1/2</sup>	41 <sup>1/2</sup>	36 <sup>1/2</sup>
Microcline .....	34	30	29	32	13	1	4 <sup>1/2</sup>	26	18 <sup>1/2</sup>	9 <sup>1/2</sup>	4 <sup>1/2</sup>	21 <sup>1/2</sup>	1 <sup>1/2</sup>	6 <sup>1/2</sup>	21	23 <sup>1/2</sup>	14 <sup>1/2</sup>	22 <sup>1/2</sup>
Amphibole .....													0.2	+				
Biotite .....	4	4	2 <sup>1/2</sup>	5	2	7	8	2	24 <sup>1/2</sup>	+	15	12 <sup>1/2</sup>	3	10	7	1 <sup>1/2</sup>	10	
Chlorite .....					6	14	1	2	<sup>1/2</sup>	12 <sup>1/2</sup>	<sup>1/2</sup>	3 <sup>1/2</sup>	11	1	<sup>1/2</sup>	1 <sup>1/2</sup>	+	5 <sup>1/2</sup>
Epidote .....	1		1		1 <sup>1/2</sup>	+	2	1	1	1	1	1	3 <sup>1/2</sup>	4	+	1	+	+
Muscovite .....	<sup>1/2</sup>	5	5	5	<sup>1/2</sup>	<sup>1/2</sup>	<sup>1/2</sup>	1				<sup>1/2</sup>	<sup>1/2</sup>	2	+	3 <sup>1/2</sup>	<sup>1/2</sup>	<sup>1/2</sup>
Apatite .....	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.1	1.0	0.8	0.6	0.6	0.4	0.6	0.6	+	0.3	+
Sphene .....	0.3	0.2	0.4	0.2	0.6	0.1	1.6	0.1	0.6	1.6	1.4	0.8	0.8	1.0	0.4	0.6	0.3	+
Opauques .....	0.4	0.4	0.8	0.4	1.0	1.7	0.5	0.7	3.2	3.8	2.0	1.0	0.8	0.4	1.2	0.2	+	0.6
Carbonates .....	0.3		0.1	0.2						3.7	0.9	0.2	0.2					+
Zircon etc .....	+		0.1	+		+	0.1	0.1		0.2	0.2	+			0.1	+	+	+

grained" group of early plutonics is the considerably weaker development of schistosity and lineation. While these textures are by no means absent, some varieties of the rock are macroscopically massive and there are a few observations of brecciating contacts or dikes with inclusions of dislocated gneissic fragments of medium-grained granitoids. The observed differences of tectonization can thus not be attributed solely to the well-known tendency for medium-grained granites to show up macroscopical deformation textures more clearly than their finegrained equivalents. The typical mode of occurrence of the younger group of pre-migmatization plutonics is as dike networks and small lensoid massifs commonly rich in inclusions of older rocks. However, there also exist a few comparatively large bodies, though it must be conceded that in the absence of observable crosscutting contacts it may be difficult or impossible to distinguish in the field between different members of the early plutonics complex. When contacts can be observed the fine-grain-size group is consistently found to be younger than the medium-grained group of early plutonics. Although this normally conforms with a development toward younger rocks richer in silica, a reversal of color index and acidity is sometimes involved. To the northeast of Linköping there are three localities where oldest Svecofennian granodiorite or granite is cut by finely medium-grained to medium-grained diorite or quartz-diorite which in turn is older than dikes of light gray sodic granite. Similarly, to the west of Linköping, in the Rappestad area, fragments of intermediate gray granite-granodiorite are included in a dioritic rock which in turn is older than amphibolite dikes and the regional migmatization in the area. Other basic bodies of some areal extent, particularly between Linköping and Rystad (Fig. 2) may or may not be chronologically intermediate between the two principal groups of older plutonics. There is a considerable difference in fabric isotropy in comparison with the surrounding rocks, although this may possibly in some cases be due either to the normally better preservation state of basic plutonics or to the regenerating effect of huge neighboring bodies of "Gothian" granites. In general there is basis to suggest that the development within the early plutonics around Linköping implies a repeated recurrence of basic magmatism as is also suggested by Elbers (1970) for the Västervik area.

The younger group of early plutonics is chemically very similar to the main medium-grained members of the complex in being predominantly sodic (Fig. 15), only the latest red varieties showing a tendency to assume compositions close to that of residual melts in the silica-feldspars system. The rocks are usually equigranular, although there are sometimes somewhat porphyritic varieties which carry small feldspar augen ( $\sim 5$  mm across). The rock color is normally a mixture of gray and red, purely gray or, particularly, red varieties being quite subordinate. The minerals are similar to those of the main granodiorite-granite group of older plutonics, but hornblende is less common.



Fig. 6. Svecofennian dioritic rock with relic schlieren of supracrustal amphibolite (upper right part of the photograph) and crosscutting porphyrite dike. The dike which probably is younger than the Late Svecofennian migmatization is slightly offset and deformed. It strikes approximately north-south.

#### BASIC DIKES

In most of central Sweden and southern Finland an intraorogenic period separating the synkinematic plutonics from potassic granites associated with migmatization is defined by basic dikes which usually have been transformed into amphibolites of more or less orientated texture. In the Linköping area manifestations of this hypabyssal basic activity are extremely scarce, and only a few dike localities can more or less confidently be attributed to this period. In addition to these, and apart from the dioritic bodies mentioned above and referred to the complex or early plutonics, there are some small fine-grained either massive or slightly schistose sometimes porphyritic basic dikes. They cut either the supracrustals or the granodiorite, but strike obliquely across the regional schistosity. All except one of these observations stem from areas where there are no products of Late Svecofennian magmatic or migmatizing activity and thus little evidence is found to indicate whether the rocks are actually part of the Svecofennian development. Layers and large lenticular bodies of medi-

um- to fine-grained metabasites are common in the supracrustals to the south of Lake Roxen, but since they are never found in the early plutonics, their introduction probably preceded most of the synkinematic development. Similarly, a few dikes of granitoid feldspar-porphyrines in the quartzites belong to the early volcanic-sedimentary evolution because they are cut by apophyses of synkinematic plutonics.

#### LATE PLUTONICS

In central Sweden regional Svecofennian migmatization is closely tied up with the formation of eutectoid and potassic granites. The gamut of grain-size and textural variations ranges from fine-grained equigranular (the Stockholm type) to coarse more or less porphyritic (the Fellingsbro-Örebro type). The coarse rocks usually tend to form well-defined homogeneous massifs, whereas the Stockholm type normally enters extensive networks of dikes and small massifs.

The areal distribution of migmatization and late Svecofennian granites in the Linköping area is very uneven and late granites generally belong to a fine-grained to medium-grained reddish variety. In the area investigated to the north of Lake Roxen there are almost no traces of Late Svecofennian igneous or metasomatic activity. To the south of the lake, areas rich in Late Svecofennian material alternate with others which are virtually free from late granite and migmatite. Typically, the areal distribution is one of approximately east-westerly belts and lentoid units which means that the general pattern of Late Svecofennian plutonics conforms well with the regional direction of schistosity and bedding strike and with the trend of the contacts between supracrustals and early plutonics. The late granites of the Linköping area seldom form coherent bodies more than a few hundred of meters across and even in these cases the granite is studded with slices and relic schlieren of country rock. Intimate migmatitoid mixtures between granitic-pegmatitic veins and older rocks are always closely associated with small aggregated granite bodies, i. e. as different from conditions prevailing in many nearby areas there is no general development of veining or other types of migmatization in the supracrustals and older plutonics. Off the granite-migmatite belts Late Svecofennian rocks are restricted to single pegmatite veins.

The mineral association of the supracrustals south of Lake Roxen includes biotite and epidote. Biotite is quite commonly more or less completely altered to chlorite which is also one of the trends of mineral alterations in the older plutonics where recrystallized sericite-muscovite, epidote, and clinozoisite grains develop at the expense of the original igneous paragenesis. Garnet is restricted to limestone skarns which are poor or moderate in aluminium and occur to the east of the Linköping area proper, and to sporadic occurrence in a few metabasite and sedimentary units where check-ups of its composition show



Fig. 7. Primorogenic Svecofennian granodiorite with intraorogenic Svecofennian amphibolite dikes and fragments of metasediments has been folded, foliated and slightly veined during the regional migmatization. The crosscutting dike is a "Gothian" granite-pegmatite. Vikingstad, 12 km WSW of Linköping.

high contents of manganese and calcium. The combination of temperature, water fugacity, and Mg/Fe ratios was thus usually not favorable for the replacement of the biotite/chlorite – clinozoisite – muscovite paragenesis by almandine-grossular garnet. Similarly, aluminosilicates were not stable in association with potassium feldspar. In the Late Svecofennian granites of the Linköping area muscovite coexists with biotite/chlorite which considering the necessarily elevated temperatures of granite formation indicates high water fugacity. Similar parageneses in association with the absence of general migmatitic veining outside of areas immediately associated with granite suggests that in general temperatures of regional metamorphism were not high enough to allow this factor to induce the segregation of veins and the development of migmatites.

The mineral composition of the Late Svecofennian granites is characterized by approximative parity of the volumes of quartz, microcline, and albite-oligoclase or by slight predominance of K- over Na-feldspar. Thus there is a very substantial difference in comparison with older plutonics of similar quartz contents. The combined percentages of biotite, chlorite, opaques, and sphene are at or just above 5, muscovite is regularly a minor constituent as are small

secondary grains of epidote. The available chemical analyses indicate that apart from differences in the Na/K ratio there may possibly also be a consistent difference of Mg vs. Fe between the younger synkinematic and the Late Svecofennian granite groups. In rocks with similar Si contents Mg/Fe is higher in the synkinematic group. Still, so far the analyses are neither numerous nor systematic enough to allow definite conclusions.

In striking contrast with conditions in the Svecofennian core areas of central Sweden, the Late Svecofennian granites around Linköping are quite often overriden by regional, but unevenly developed weak to moderate schistosity which in general approximately conforms with the WNW- to ENE-trending textures of the older rocks. In addition, in some localities of late Svecofennian rocks we find more marked zones of crushing which even affect coarse pegmatites and migmatites, but terminate against the contacts of dikes and other intrusions of still younger rock referable to the "Gothian" development. The investigated area around Linköping is too limited to permit conclusions concerning the spatial relation between these tectonization phenomena and the general shape of the area occupied by Småland granites. Disregarding ruptures and deformation on a purely local contact scale, there seems to be no relation between the direction of late deformations of the kind considered here and local protrusions and recessions of the contact line of "Gothian" Småland granites. In consequence of the above observations it must be emphasized that the macroscopical isotropy of Late Svecofennian granites which is used as a diagnostic feature in the geological mapping of the classical Svecofennian areas in Central Sweden is not necessarily always preserved along the "Svecofennian-Gothian boundary" in County Östergötland. Indeed there is often no great difference in the intensity of gneissic fabric development between Late Svecofennian (late kinematic) granites and the young sodic group of predominantly fine- to finely medium-grained granites referred to the synkinematic complex. In areas where the synkinematic complex includes late potassic members associated with pegmatite, which for instance appears to apply to the Åtvidaberg area described by Sundius (1924), there may thus arise considerable difficulties of classification and risks of misinterpretation due to the unwarranted application of diagnostic features based on observations of geological relations in the classical Svecofennian areas farther to the north. The ensuing confusion is clearly perceptible in descriptions of the geological quadrangles to the southeast of Linköping (Sundius 1924, 1926, etc.) where granites referred to the early gneissic group are said to be associated with migmatization and veining on a regional scale. Reconnaissance in these areas gives the writer reason to suggest that age and rock development relations are not basically different from those described in the present paper. It should also be stressed here that conditions in Östergötland are further complicated by the existence of at least two still later ("Gothian") generations of fine- to medium-

grained red granites. In the Linköping area there is a difference of K/Na ratios and type variability between the late synkinematic and late-kinematic groups of plutonics and in spite of some similarities there is no compelling reason to assume that synkinematic sodic granites associated with minor pegmatite veins grade directly into rocks of the first generation of migmatizing intrusions which by analogy with conditions in other Svecofennian areas have here been classified as Late Svecofennian (late orogenic, late kinematic).

### "GOTHIAN" DEVELOPMENT: PLUTONICS

The intricate pattern of Svecofennian rock distribution is abruptly terminated at the contacts of granite massifs belonging to the "Gothian" development. The Linköping area is at the northeastern tip of the huge coherent Småland-Östergötland granite region and also embraces part of the granite massif to the north of Lake Roxen (Fig. 1). Most of the "Gothian" granites are coarse to coarsely medium-grained, but there is considerable variation in textural development and composition, and the "Gothian" complex includes large amounts of medium-grained, fine-grained, and pegmatitic rocks. The area to the north of Lake Roxen is occupied by coarsely porphyritic rocks varying in color between red and blackish-violet or blackish-brown. Characteristical of the whole massif is the good development of perthitic potash-feldspar megacrysts enclosed in thick shells of generally pronouncedly myrmekitic plagioclase. The potash feldspar is well-twinned (microcline grating) to almost untwinned, developing, microcline grating only in the vicinity of perthite lamellae. The megacrysts are anhedral rounded to subhedral, but the shape appears often to have been modified by the process of perthite and myrmekite unmixing and mantle formation with attendant penetration of thus developed plagioclase along intergranular boundaries of the surrounding matrix. The megacrysts may be orientated to form more or less clearly recognizable patterns of preferred elongation conforming with the long-axis alignment of fragments or resorbed relic schlieren of older Svecofennian country rock. In many instances, however, the rock lacks recognizable texture anisotropies. Variations in rock color and composition are either very gradual, particular color varieties dominating more or less coherent large areas, or assume the shape of more or less well-defined parallel schlieren distribution. Whenever recognizable and definable at all, intramassif contacts between different rock types are never really sharp or brecciating except in the case of fine- to medium-grained equigranular aplitic and granitic or pegmatitic dikes and other small aggregate intrusive bodies. Still, when the distribution of different rock schlieren can be studied in detail in well-exposed outcrops, for instance in road cuttings, quartz-rich red varieties trending towards an orthogranitic composition are from the shape of the schlieren always found to be slightly later

**Table 5. Chemical analyses of coarse-grained "Gothian" granites from the Roxen (LN-samples) and Graversfors massifs (GR-samples)**

	LN 594	LN 155	LN 598	LN 55	LN 128	LN 148	LN 389	LN 536	LN 611	GR 1	GR 2
SiO <sub>2</sub> .....	63.8	64.1	63.8	63.4	63.2	64.6	66.2	65.2	75.0	65.0	66.3
TiO <sub>2</sub> .....	0.95	0.70	0.79	1.24	1.20	0.72	0.64	1.07	0.34	0.72	0.58
Al <sub>2</sub> O <sub>3</sub> .....	16.7	17.4	17.2	14.9	15.6	16.7	16.2	14.3	12.8	16.9	15.7
Fe <sub>2</sub> O <sub>3</sub> .....	1.6	4.3 <sup>1)</sup>	1.7	2.2	7.5 <sup>1)</sup>	1.3	4.1 <sup>1)</sup>	6.0 <sup>1)</sup>	1.7 <sup>1)</sup>	1.3	1.1
FeO .....	3.9		3.3	4.9		3.9				3.2	2.3
MnO .....	0.08	0.08	0.07	0.11	0.13	0.10	0.07	0.11	0.03	0.08	0.07
MgO .....	1.4	1.2	1.3	1.7	1.8	1.2	1.0	1.5	0.51	0.98	0.75
CaO .....	3.2	2.9	3.2	3.8	3.8	2.5	2.7	3.0	0.8	2.9	2.6
Na <sub>2</sub> O .....	3.3	3.5	3.3	3.3	3.2	3.5	3.5	2.5	2.5	3.1	3.0
K <sub>2</sub> O .....	4.8	4.9	4.8	4.2	3.7	4.4	4.8	4.6	5.5	5.0	4.9

<sup>1)</sup> Total iron as Fe<sub>2</sub>O<sub>3</sub>

Table 6. Chemical analyses of granitoids from the Linköping "Filipstad" and "Red Växjö" (Rappestad area) massifs

	"Filipstad" granite							"Red Växjö" granite						
	Marginal		Dark		Normal									
	LN 211a	LN 211b	LN 909	LN 217	LN 1171	LN 1119	LN 1472	LN 734	LS 17	LN 728	LN 668	LN 687	LN 676	LN 669
SiO <sub>2</sub> .....	63.8	62.0	61.0	61.8	67.0	67.5	69.9	63.8	69.1	69.3	71.6	71.7	71.7	73.6
TiO <sub>2</sub> .....	0.72	0.74	0.82	0.87	0.47	0.62	0.36	0.68	0.44	0.46	0.26	0.28	0.34	0.25
Al <sub>2</sub> O <sub>3</sub> .....	16.6	17.0	19.2	17.0	16.5	16.0	15.0	16.2	15.1	13.8	14.3	13.8	13.4	13.5
Fe <sub>2</sub> O <sub>3</sub> .....	5.6 <sup>1)</sup>	2.0	1.6	6.9 <sup>1)</sup>	1.1	1.6	2.5 <sup>1)</sup>	5.4 <sup>1)</sup>	1.0	3.2 <sup>1)</sup>	0.6	0.6	2.4 <sup>1)</sup>	2.8 <sup>1)</sup>
FeO .....		3.6	3.7		1.8	2.0			2.5		2.1	2.1		
MnO .....	0.10	0.09	0.08	0.16	0.07	0.06	0.06	0.11	0.06	0.06	0.02	0.05	0.06	0.04
MgO .....	1.3	1.3	1.3	1.4	0.87	0.87	0.74	1.3	0.75	0.63	0.52	0.44	0.55	0.52
CaO .....	2.8	2.8	2.1	3.3	2.1	2.1	1.7	1.2	1.8	1.4	1.1	1.1	1.3	1.1
Na <sub>2</sub> O .....	2.7	2.7	4.2	3.7	3.9	3.6	3.4	2.0	3.4	2.7	3.1	2.8	2.9	2.9
K <sub>2</sub> O .....	4.5	5.0	4.5	3.8	4.8	4.2	5.1	5.4	3.9	5.0	4.8	5.3	4.4	4.3

<sup>1)</sup> Total iron as Fe<sub>2</sub>O<sub>3</sub>



Fig. 8. Characteristically, the porphyritic texture of the Filipstad-type granite in the Linköping area is not very marked and the size of the megacrysts grades down to the grain-size of the matrix. Linköping town.

than darker monzonitic, monzodioritic, and granodioritic types. Even in these instances the transition is usually gradual over a distance of a few centimeters or so, and there is never any truncation of crystals, and very seldom textural orientation effects, such as biotite flake alignment to conform with schlieren boundaries. Dark minerals are predominantly hornblende and biotite, hornblende naturally being more prominent in calcic rock varieties. Biotite and amphibole are often intimately intergrown and there may occur amphibole rims between biotite and plagioclase. Some of these minerals from the area to the north of Lake Roxen have previously been considered in another context (Gorbatshev 1969a). Hornblende is often, but not necessarily always, somewhat zoned. The cores are slightly richer in Mg than the rims. A zoning of much steeper compositional gradient is found around cores of calcic or subcalcic Mg-Fe pyroxene and/or actinolite which are characteristic of numerous specimens of "Gothian" granites to the north of Roxen and have also been found in the Graversfors massif. These core crystals are sometimes pseudomorphosed by aggregate mixtures of amphibole, chlorite, and calcite. The core crystals are almost always sharply delimited, subhedral, and homogeneous, while mantle hornblende shows color zoning from darker, occasionally bluish green in the rims to lighter green in the inner parts of the mantles. Characteristical compositional differences between core and mantle amphibole vary about:



Fig. 9. Porphyritic texture in the Filipstad-granite of Linköping is better developed in rocks close to the outer contacts of the massif. This type is rather potassic. The texture reminds of that in the Roxen and Graversfors massifs, but the megacrysts are usually unmantled or nearly so. 2.5 km WSW of Linghem.

Core:  $\text{Ca}_2\text{Mg}_3\text{Fe}_2\text{Si}_8\text{O}_{22}(\text{OH})_2$  with Ti, K, Na  $< 0.1$ , Al  $\leq 0.2$ ,

Mantle average:  $(\text{K}, \text{Na})_{0.5}\text{Ca}_2\text{Mg}_{1.6}\text{Fe}_{2.8}\text{Ti}_{0.2}\text{Al}_{0.4}\text{Si}_{6.7}\text{Al}_{1.3}\text{O}_{22}(\text{OH})_2$

Under any circumstances this implies considerable departures from chemical equilibrium which, however, are somewhat mitigated by the probability that core amphibole replaces original pigeonitic pyroxene of early crystallization which accounts for low Al, Ti, and alkalis in the core.

Normal zoning is pronounced in many large grains of andesine. The cores of these crystals are sometimes antiperthitic. Accessory and minor minerals are magnetite, sphene, allanite, zircon, apatite, and sometimes calcite and fluorite. Sphene either forms large reddish euhedral crystals or more grayish unmixed aggregates in ferromagnesian minerals, particularly amphibole. Sausuritization, sericitization, and chloritization of the original mineral assemblage is normally rather weak to moderate. Occasional late recrystallization is in some specimens accompanied by the development of intramineral cracks particularly frequent in large microcline megacrysts and filled with quartz, chlorite, epidote, and calcite. The cracks postdate the unmixing of perthite lamellae. Myrmekite may form two sets of mutually sharply delimited rims and there are sometimes late divergently orientated rosettes of biotite flakes. Opaque dusting in the feldspars may be prominent.

A number of mineral features suggests high temperature of original crystal-

**Table 7. Chemical analyses of fine- to medium-grained "Gothian" granites, tectonized "Filipstad" granite, and granites from the Linghem belt.**

	LN 251	LN 980	LN 73	LN 1471	LN 313	LN 1223	LN 208	LN 173
SiO <sub>2</sub> .....	69.2	73.1	74.0	77.4	64.5	66.6	68.6	70.8
TiO <sub>2</sub> .....	0.30	0.02	0.21	0.06	0.60	0.53	0.50	0.56
Al <sub>2</sub> O <sub>3</sub> .....	14.5	15.6	14.3	11.6	16.5	14.9	14.1	13.8
Fe <sub>2</sub> O <sub>3</sub> .....	0.1	0.5 <sup>1)</sup>	0.5	0.9 <sup>1)</sup>	1.4	4.0 <sup>1)</sup>	0.7	3.5 <sup>1)</sup>
FeO .....	1.3		1.3		3.1		2.5	
MnO .....	0.05	0.02	0.01	0.02	0.08	0.06	0.05	0.05
MgO .....	0.53	0.10	0.48	0.34	1.2	0.74	0.79	0.70
CaO .....	1.4	0.6	0.6	0.07	2.1	2.2	1.6	1.3
Na <sub>2</sub> O .....	3.7	3.9	2.6	2.2	3.1	3.3	3.1	2.4
K <sub>2</sub> O .....	4.7	5.2	5.7	5.2	4.8	5.0	4.9	5.9

<sup>1)</sup> Total Fe as Fe<sub>2</sub>O<sub>3</sub>

Code: LN 251 and LN 980: medium-grained granites, LN 73 fine-grained granite younger than the Linköping "Filipstad", LN 1471 medium-grained granite from inclusion in the Linköping "Filipstad", affiliation uncertain – probably "Gothian", LN 313 zone of crushing in the Linköping "Filipstad", LN 173, 208, and 1223 are granites from the Linghem tectonical belt.

lization. Here belong the strong development of perthite and antiperthite, exceptionally prominent myrmekite rims, mineral zoning, and high contents of titanium in amphibole and biotite (Gorbatshev 1969a) in addition to large amounts of sphene which obviously have been unmixed from these minerals. The development of microcline megacrysts with inclusions of differently orientated small microcline grains and the existence of microcline porphyroblast aureoles along some segments of the contact line of the Graversfors and Roxen granite massifs demonstrate high mobility of potassium and its late redistribution within the rock itself.

A characteristic feature of whole-rock mineral and chemical composition is the concentration of most analyses around quartz - K-feldspar - plagioclase proportions 20-30-50 with extensions of compositional variation towards 35-35-30 (Fig. 12). Except in the latter rather subordinate, usually red, quartz-rich varieties, quartz contents are between 15 and 20 p. c. by volume, dark minerals are around 15 p. c., the Ca/Ca+Na ratio usually around 0.35, oxidation degree of iron about 0.25-0.30 and Mg/Mg+Fe consistently between 0.29 and 0.35 even in quartz-rich, K- and Na-rich varieties. Normative composition mostly includes a slight content of cor. A more extensive consideration of the chemical parameters of the "Gothian" Småland granites of the Linköping area is planned in another context. The chemical data quoted here are based on analyses prepared for that study. For the Roxen massif and the immediate vicinity of Linköping chemical data are given in Tables 5-8.

Altogether the similarities of composition, mineral development and field occurrence between the Roxen and Graversfors massifs of granitoid rocks are so pronounced as to suggest that speculations along lines attributing one of them to the "Gothian" and the other to the "Svecofennian" development are not warranted (cf. Geijer and Magnusson 1944, Pl. 50 vs. Magnusson 1962).

Most parts of the granite massif to the north of Lake Roxen are infested with dikes and small stocks of grayish-reddish granite and pegmatite. These dikes usually do not show marked preferred orientation, they are mostly equigranular and massive and contain approximately equal amounts of quartz, microcline, and albite-oligoclase. As will be considered below there is in spite of compositional and other similarities no reason to equate these dikes with the Late Svecofennian granites of the Stockholm type. The Roxen massif further contains a couple of small lamprophyric dikes.

To the south of L. Roxen, the Linköping area of "Gothian" granites essentially comprises two more or less well individualized granite types which have been called "Filipstad" and "Red Växjö" granites by Magnusson (1922, 1924) and Sundius (1924). The area around Linköping is predominantly occupied by rock of Magnusson-Sundius' "Filipstad" classification. Chemically the compositional range of this rock is rather similar to that of the principal Graversfors-Roxen granitoid (Figs. 12 and 16), but quantitatively emphasis is



Fig. 10. Dikes of pegmatite, aplite and fine-grained granite are common in the Filipstad-type granite of Linköping. Eastern outskirts of Linköping town.

on types slightly poorer in dark minerals and relatively – i. e. versus biotite – poorer in amphibole. Myrmekite rims are normally considerably less prominent than in the Roxen massif as is mantling which is either absent or restricted to thin rims of both plagioclase around microcline and microcline around plagioclase. Chemically this corresponds to  $K/K+Na$  and  $Mg/Mg+Fe$  which are virtually identical with these ratios in the Roxen and Graversfors massifs, but  $Ca/Ca+Na$  tends to be rather below than above 0.3. Macrotexturally the most obvious difference is in the development of potassium feldspar megacrysts. In the "Filipstad" granitoid around Linköping they are on the whole much less closely spaced than in the Roxen massif and instead of being all approximately of the same size within the area of one or a few outcrops, the megacrysts in the Linköping "Filipstad" typically range through a gamut of sizes, the smallest being only slightly larger than grains of the coarsely medium-grained matrix. The distribution of potassium feldspar between matrix and megacrysts is considerably more even in the Linköping than in the Roxen massif which suggests that late alkali redistribution has been more important in the latter case. Megacryst shapes are more angular in the Linköping "Filipstad". Rock color varies from red to reddish-brown and further to brownish-medium gray, but cannot be correlated with hitherto recognized variations of rock composition. Similarly to the Roxen massif, the "Filipstad" around Linköping comprises a number of compositional varieties, but the commonest

variety appears to be rather more predominant than in the northern massif, i. e. the Linköping "Filipstad" is on the whole more homogeneous.

Intramassif contacts and the age sequence of different compositional types are the same as described above from the area to the north of Roxen. The rock is either massive or has a faint tendency for megacryst and biotite alignment essentially parallel with the outer contacts of the granite body. The northern parts of the "Filipstad" massif around Linköping are rich in veins and dikes of fine- to medium-grained granite and pegmatite, but the frequency of these rocks decreases southwards.

Peculiar of the Linköping massif is the regular occurrence within the principal rock of rather large (50–500 m) elongated bodies of equigranular medium grained red granite. The compositional variation is between rocks not very much different from the main porphyritic type and alkaline leucogranites. The boundaries toward the surrounding "Filipstad" variety are sharp and sometimes intricately cornered, but there are usually no fragments or dikes of one rock type in the other. The general shape of the medium-grained equigranular bodies may sometimes be bent and curving in conformity with preferred megacryst orientation in the surrounding rock. Because the occurrence of this medium-grained variety is restricted to the Linköping "Filipstad" massif it appears to be indigenous and an integrating component of the Linköping "Filipstad" development. From megacryst immigration into the even-grained rock and from some rare unequivocal contact age relations the medium-grained equigranular rock must be older than the main variety in the massif, but younger than a granodioritic-monzodioritic type with closely spaced, perceptibly mantled megacrysts. In some parts of the "Filipstad" granite area the rock gradually becomes more orthogranitic and is in mineral composition indistinguishable from the principal rock of the "Red Växjö" massifs. This confirms further the impression of compositional overlap between the differently denominated components of the Småland granite region. Allowing for this the composition of the "Red Växjö" is more alkali- and quartz-rich than that of the "Filipstad".

The term "Red Växjö" has been applied to several units of Småland granite in the Linköping area. The largest is situated to the southwest of the town whence it extends westward beyond the limits of the area represented in Fig. 1. As we just mentioned, the predominant rock variety is still more leucocratic and alkaline than the average "Filipstad".  $Ca/Ca + Na$  varies within rather wide limits (0.1–0.3),  $K/K + Na$  is rather above than below 0.5 and normative quartz exceeds 30–35 p. c. The sum volume of dark minerals is between 5 and 10, and biotite plus chlorite dominate over hornblende. The feldspars are perthitic/antiperthitic and there are narrow exsolution rims around many grains. The development of myrmekite is marked, but nevertheless far weaker than in the other Småland granite varieties of the Linköping region. Granophyric textures

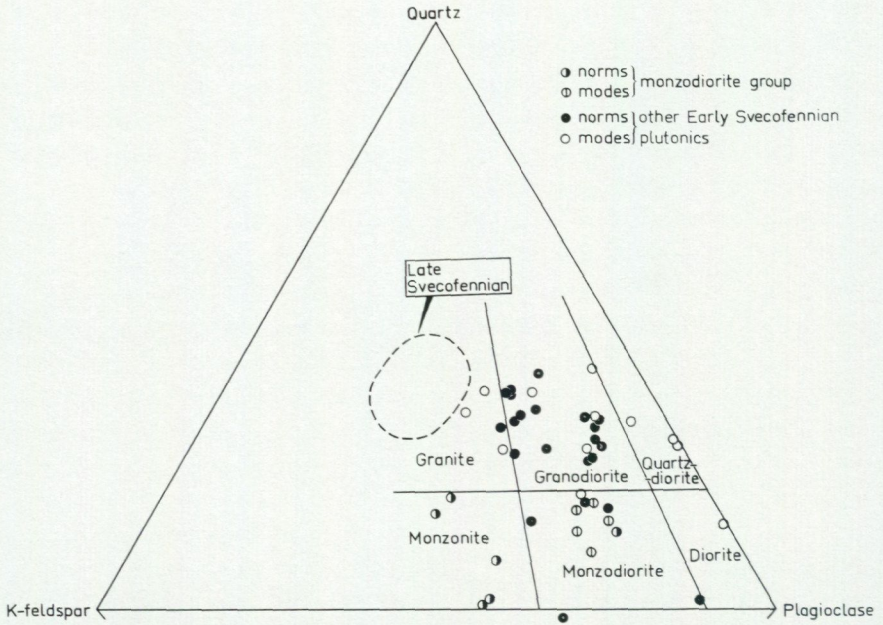


Fig. 11. Modal and normative plagioclase-alkali feldspar-quartz compositions of Svecofennian plutonics and the monzodiorite group. Terminology according to Streckeisen (1967).

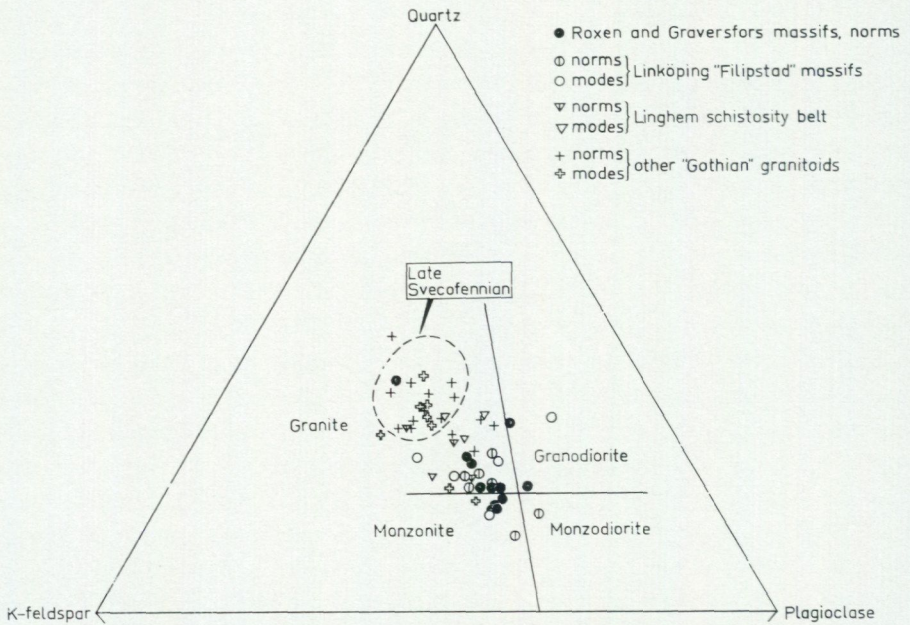


Fig. 12. Modes and norms of "Gothian" plutonics plotted in the K-feldspar-plagioclase-quartz diagram. Terminology acc. to Streckeisen (1967). The field of late Svecofennian granites entered for comparison demonstrates the compositional convergence of Late Svecofennian and acid "Gothian" granitoids.

Table 8. Summary of some chemical parameters of "Gothian" granites

	Roxen massif									Graversfors massif	
	LN 594	LN 155	LN 598	LN 55	LN 128	LN 148	LN 389	LN 536	LN 611	GR 1	GR 2
Weight norm:											
quartz .....	15.3	15.5	15.9	16.2	17.1	17.5	18.6	22.2	36.6	18.3	22.3
orthoclase .....	28.4	28.9	28.4	25.0	21.7	26.1	28.4	27.2	32.3	29.5	28.9
albite .....	27.8	29.3	27.8	27.8	27.3	29.9	29.3	21.0	21.0	26.2	25.2
anorthite .....	16.1	14.7	16.1	13.3	17.2	12.8	13.6	14.2	4.2	14.8	13.1
corundum .....	0.2	1.0	0.7	-	-	1.4	0.3	-	1.3	1.0	0.7
Atomic ratios:											
Ca/Ca+Na .....	0.35	0.31	0.35	0.39	0.40	0.29	0.30	0.40	0.15	0.35	0.33
K/K+Na .....	0.49	0.48	0.49	0.46	0.43	0.45	0.47	0.55	0.59	0.52	0.52
Mg/Mg+Fe .....	0.32	0.36	0.32	0.31	0.32	0.30	0.33	0.33	0.37	0.29	0.29
Fe <sup>3+</sup> /Fe <sup>3+</sup> +Fe <sup>2+</sup> ..	0.27		0.32	0.29		0.23				0.27	0.30
Ba/Ba+K .....	0.011	0.011	0.011	0.011	0.011	0.010	0.009	0.008	0.003	0.013	0.013
Ti/Ti+Fe .....	0.138	0.141	0.129	0.139	0.138	0.113	0.135	0.151	0.169	0.129	0.137
Mn/Mn+Fe .....	0.015	0.021	0.015	0.016	0.019	0.019	0.019	0.020	0.019	0.018	0.021
Weight ratios:											
K/Rb .....	660		560			260				520	
Ba/Rb .....	27		22			9				24	

Table 8. — Continued —

	"Filipstad" granite of Linköping								Linghem belt		
	LN 211a	LN 211b	LN 909	LN 217	LN 1171	LN 313	LN 1119	LN 1472	LN 1223	LN 208	LN 173
Weight norm:											
quartz .....	20.1	17.2	10.6	14.1	19.3	20.0	23.8	24.7	20.8	25.6	28.8
orthoclase .....	26.7	29.5	26.7	22.2	28.4	28.4	25.0	30.0	29.5	28.9	35.0
albite .....	23.1	23.1	35.6	31.4	33.0	26.2	30.4	28.8	27.8	26.2	20.4
anorthite .....	14.2	14.2	10.8	16.4	10.6	10.8	10.6	8.6	11.2	8.1	6.7
corundum .....	2.0	1.9	3.3	0.8	1.0	2.2	1.6	0.7	—	0.7	0.9
Atomic ratios:											
Ca/Ca+Na .....	0.36	0.36	0.22	0.33	0.23	0.28	0.25	0.21	0.27	0.22	0.24
K/K+Na .....	0.52	0.55	0.41	0.40	0.45	0.50	0.43	0.50	0.50	0.51	0.62
Mg/Mg+Fe .....	0.31	0.30	0.31	0.29	0.36	0.33	0.31	0.37	0.26	0.31	0.28
Fe <sup>3+</sup> /Fe <sup>3+</sup> +Fe <sup>2+</sup> ..		0.33	0.28		0.35	0.29	0.42			0.20	
Ba/Ba+K .....	0.015	0.013	0.013	0.012	0.008	0.011	0.006	0.007	0.006	0.006	0.005
Ti/Ti+Fe .....	0.114	0.110	0.126	0.112	0.132	0.110	0.140	0.125	0.116	0.126	0.138
Mn/Mn+Fe .....	0.020	0.017	0.016	0.025	0.025	0.018	0.017	0.026	0.017	0.016	0.016
Weight ratios:											
K/Rb .....		700	380		300	560	260			320	
Ba/Rb .....		31	18		8	23	5.5			6.3	

Table 8. — Continued —

	"Red Växjö" massif, Rappestad area							Fine- to medium-grained rocks			
	LN 734	LS 17	LN 728	LN 668	LN 687	LN 676	LN 669	LN 251	LN 980	LN 73	LN 1471
Weight norm:											
quartz .....	24.7	28.0	28.9	30.7	30.9	33.0	35.6	24.9	28.9	34.1	43.8
orthoclase .....	31.7	22.8	29.5	28.4	31.1	26.1	25.6	27.8	30.6	33.9	30.6
albite .....	16.8	28.8	23.1	26.2	23.6	24.6	24.6	31.4	33.0	22.0	18.3
anorthite .....	6.1	9.2	7.2	5.6	5.6	6.7	5.6	7.0	3.1	3.1	0.6
corundum .....	4.8	1.9	1.2	1.9	1.4	1.4	1.9	0.7	2.4	3.6	2.2
Atomic ratios:											
Ca/Ca+Na .....	0.25	0.23	0.22	0.16	0.18	0.20	0.17	0.17	0.08	0.12	0.02
K/K+Na .....	0.64	0.43	0.55	0.50	0.55	0.50	0.49	0.46	0.47	0.59	0.61
Mg/Mg+Fe .....	0.32	0.28	0.29	0.26	0.23	0.32	0.27	0.40	0.29	0.33	0.43
Fe <sup>3+</sup> /Fe <sup>3+</sup> +Fe <sup>2+</sup> ..		0.27		0.21	0.21			0.07		0.26	
Ba/Ba+K .....	0.010	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.002	0.004	0.008
Ti/Ti+Fe .....	0.112	0.104	0.127	0.082	0.087	0.125	0.081	0.165	0.038	0.097	0.062
Mn/Mn+Fe .....	0.022	0.018	0.021	0.008	0.019	0.028	0.016	0.035	0.043	0.006	0.024
Weight ratios:											
K/Rb .....		320		280	620		320	240		200	
Ba/Rb .....		6.3		4.5	12		5.7	4.4		2.7	

occur occasionally, but are not typical of a majority of the investigated specimens. Syenitoid varieties have been mentioned by Magnusson (1922, 1924) and have also been found in the present survey, but usually in association with breccias of amphibolite or other basic rocks in which cases the An contents of plagioclase increase to above 30, the Mg/Mg+Fe ratio rises beyond 0.35 (as compared to 0.25–0.30 in the most common Red Våxjö), but the rocks commonly still have more K than Na. Contamination and chemical interaction with the wall-rock is in these cases suggested both by composition and by the spatial-textural relations of mineral distribution. Normally the "Red Våxjö" granite in the area is an equigranular to slightly porphyritic medium- or coarse-grained massive red rock, but variations in textural development and composition are common and sharp contacts between somewhat different types have been observed. Thus, for instance, around Rappestad the rock develops a kind of pavement-texture with 0.5–1 cm large perthitic-antiperthitic feldspars embedded in subordinate quartz-biotite-feldspar matrix. Here the grain shapes display pronounced east-westerly elongation alignment. This rock is more or less sharply set off against somewhat porphyritic and against extremely leucocratic types.

As has been found by Magnusson (1922), the "Red Våxjö" massifs are younger than the "Filipstad" of the area, and sometimes even develop fine-grained marginal facies. However, all occurrences of leucocratic fine- to medium-grained red granite inside the other types of Småland granite are not necessarily equatable with Red Våxjö granite. Even discounting the commonly schistose, possibly hybridic fine-grained granites of the area (Magnusson 1922, 1924, Sundius 1924, 1926), detailed mapping of the "Filipstad" terrains around Linköping demonstrates that some leucogranitic rocks are obviously older than the principal kinds of "Filipstad" granite since they occur as fragments in, or are traversed by dikes of coarse porphyritic "Filipstad". The rest, which cut the Filipstad type, belong to at least two different melt surges, some of which may be late differentiates of the Filipstad massif itself while others possibly are independent or actually may form dike aureoles around the local Red Våxjö bodies. Thus the employment of the term "Red Våxjö" for all these rocks would lead to certain ambivalence since its strict application appears to require the coincidence of a geographical-chronological aspect with the petrographical function of describing leucocratic acid granites tied up with Småland granite areas. Red leucogranites are not necessarily always the latest members in the "Gothian" group, although in general rock units dominated by them do indeed have that age position and the term "Red Våxjö" thus retains its obvious justification.

Notwithstanding differences in age position in relation to the Red Våxjö and Filipstad types, the fine- and most medium-grained "Gothian" granites tend to have chemical compositions which project close to the eutectoid in the quartz-

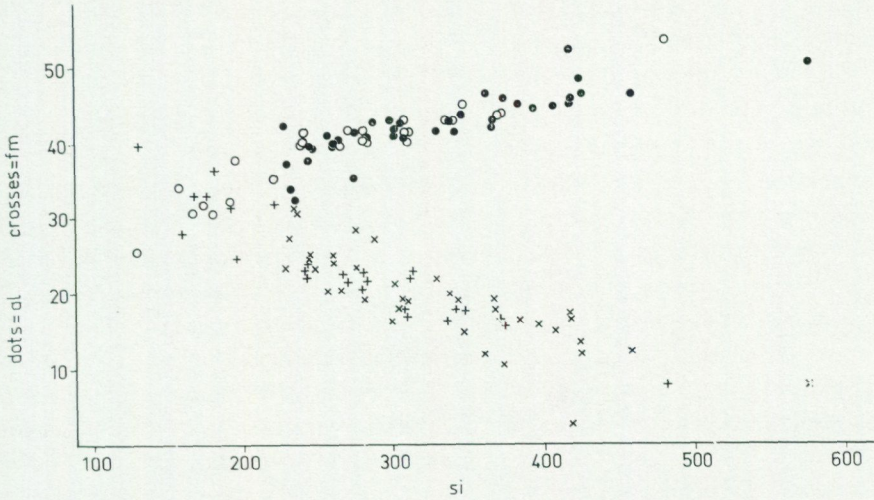


Fig. 13. Plot of Niggli *si* versus *al* and *fm*. These parameters fail to discriminate between the Svecofennian and "Gothian" plutonics. Black signs and inclined crosses - "Gothian"; open signs and upright crosses - Svecofennian.

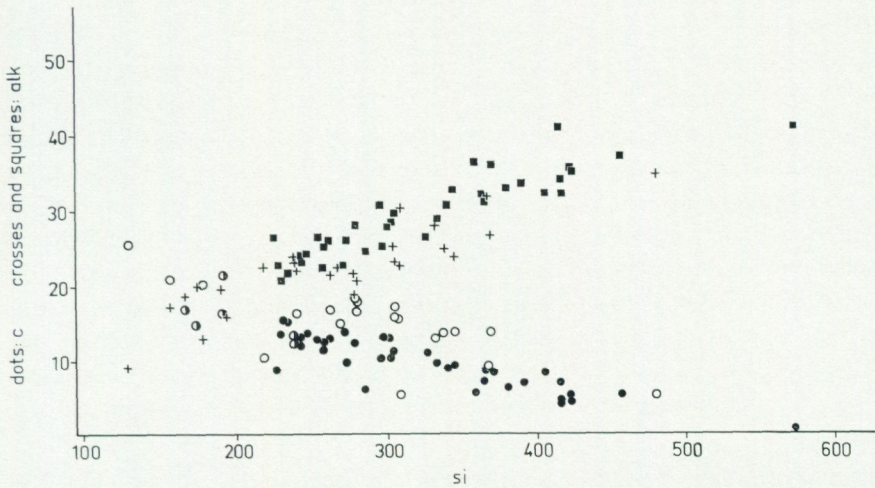


Fig. 14. Plot of Niggli *si* versus *alk* and *c*. Open circles and upright crosses: Svecofennian, far right entry: late Svecofennian granite, others: early Svecofennian plutonics. Half-filled circles: monzodiorite group. Filled circles and squares: "Gothian". The diagram shows that the "Gothian" rocks of the Linköping area are slightly more alkalic than the predominant local Svecofennian plutonics. The alignment of the monzodiorite group with the "Gothian" is due to high *K* in that group (cf. Fig. 15-16).

albite-potassium feldspar system. There is thus obvious convergence in the main-elements-composition of the fine-grained "Gothian", the fine-grained "Late Svecofennian" and even the late synkinematic plutonics of the Östergötland area. The distinction between these varieties must consequently be based on other factors than main-element chemical composition.

The development of feldspar crystals defines different textural types of "Gothian" fine- to medium-grained red granites. One of these has perthitic and antiperthitic, but still well individualized grains of microcline and albite-oligoclase. In another type both feldspars are intergrown to form intricate perthitic mixtures suggesting the original existence of anorthoclase. Transitional are varieties with thick mantles of one feldspar around the other. Granophyric textures and myrmekites may occur. Dark minerals are biotite, chlorite, and opaques. Muscovite is usually an essential constituent. Minor and accessory minerals comprise zircon, allanite, sphene, carbonates, fluorite, and apatite. Secondary alterations are common and include sericitization, saussuritization, calcitification, and chloritization of plagioclase and biotite and probably also of originally present hornblende.

Besides occurring in areas of "Gothian" plutonics, fine-grained granites associating with pegmatites also form extensive dike aureoles in the environment of the "Gothian" granites. Localities of younger generations of "Gothian" granite dikes cutting the earlier sometimes gneissic migmatizing granites are very common. In these cases it is easy enough to distinguish between different generations of red granite. In other instances, however, the attribution of singly occurring granite-pegmatite intrusions to one of the two principal chronological groups must be very tentative. Regions of "Gothian" plutonics also contain numerous areas of schistose equigranular red granite. Obviously some of these belong to the "Gothian" and very frequently associate with fragment trains and other relics of Svecofennian rocks. The gneissic Nykil granite of Magnusson (1922) is one of the members of this group. There are nevertheless occasions when it appears impossible to decide in the field whether gneissic fine-grained red acid granites enclosed in or occurring in conjunction with coarse Småland granite belong to the Svecofennian or Gothian development. However, containing in extreme cases less than one p. c. of opaques and Fe-Mg-minerals, many of the "Gothian" fine- or medium-grained red granites tend to be highly leucocratic. Such compositions are not characteristic of non-pegmatitic Svecofennian igneous rocks in this area.

Porphyroid red granites with feldspar and quartz phenocrysts in a fine-grained matrix occupy small disconnected areas inside the Red Väjö and Filipstad massifs. Others form more coherent areas and have been interpreted as marginal facies developments of the Linköping "Filipstad" (Magnusson 1922) which is confirmed by our observations of gradual transitions into coar-

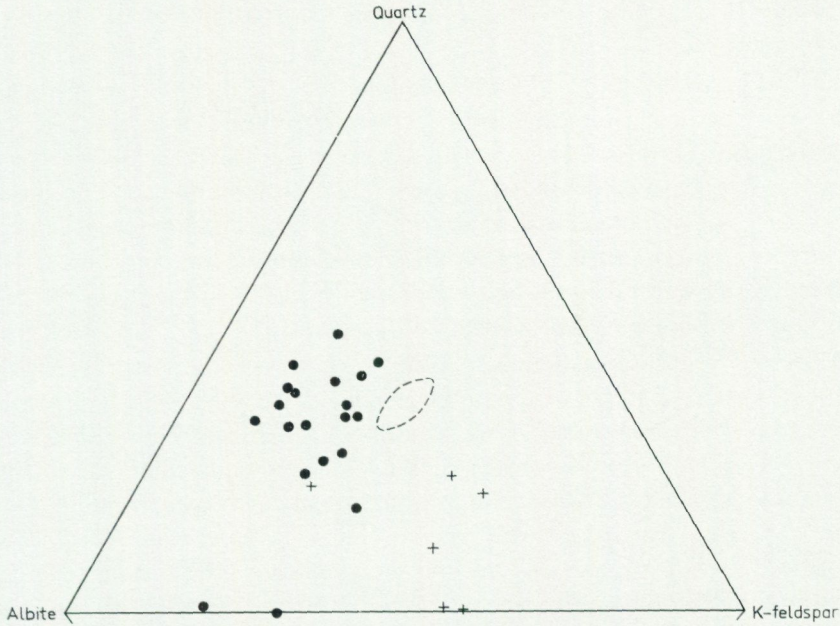


Fig. 15. Projection of normative compositions of Svecofennian plutonics into the albite - K-feldspar - quartz system (weight proportions). The diagram illustrates the sodic character of most early Svecofennian granitoids and the deviating compositional characteristics of the monzodiorite group. Broken line shows the maximum of granite analyses acc. to Tuttle and Bowen (1958). Crosses: monzodiorites, dots: Early Svecofennian plutonics.

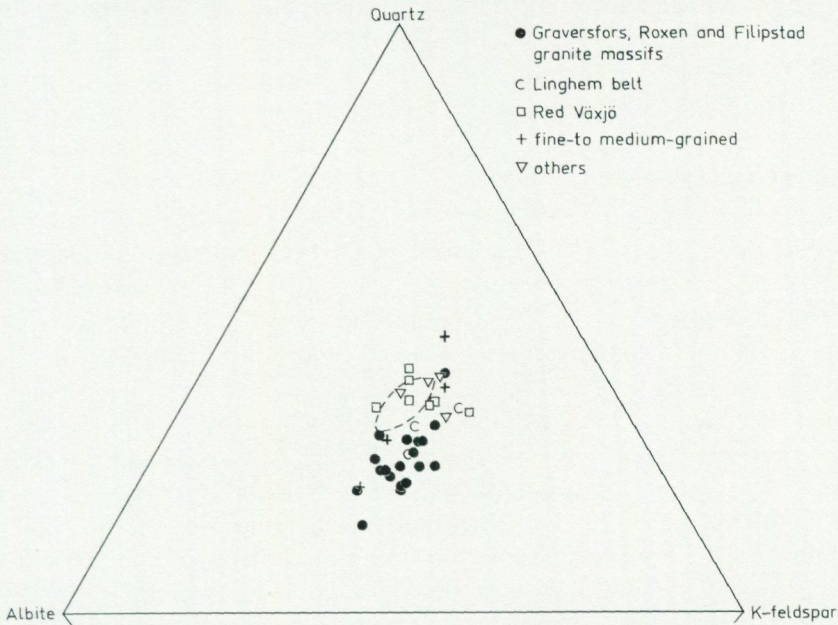


Fig. 16. Normative compositions of "Gothian" granitoids projected into the albite - K-feldspar - quartz triangle. Broken line delimits the granite maximum of Tuttle and Bowen (1958).

ser granite. Supracrustal Småland porphyries s. s. have not been found in the Linköping area.

The diagrams Fig. 11 to 20 serve to summarize and illustrate some chemical parameters of the "Gothian" and Svecofennian plutonics in the Linköping area. For the "Gothian" granites the diagrams are based on the analyses in Tables 5-7, plus some others of granites from the Linköping SO quadrangle which have not yet been classified according to massif appurtenance. The data concerning plutonics of the Svecofennian development are based on analyses of rocks from the Linköping NO quadrangle which will be published in the quadrangle description (Gorbatshev, in preparation).

As should be expected in an essentially orogenic - early postorogenic chronological and calc-alkaline geographical milieu, the main Niggli parameters fail to provide clear distinction between the different age groups. A tendency for the "Gothian" plutonics to be slightly more alkaline than the analyzed common Svecofennian gneissic granitoids of the area emerges from Fig. 14, but there is overlap with porphyritic gneissic Early Svecofennian plutonics (the two low  $c$  - high alk entries) and the monzodiorite group tentatively attributed to the Svecofennian tectonical development aligns well with the "Gothian" rocks. This simply illustrates that related processes produce related rocks and that similar compositions correspond to textural similarities and, in view of the overwhelming field evidence of age differences, does in no way indicate chronological equivalence or any other sort of "cosanguinity" except that of an origin in a common continental-orogenic environment. In comparison with the Late Svecofennian granites both the Early Svecofennian and the "Gothian" clans have a wider composition range which has long been recognized by geologists working in the Svecofennian shield and is evident from comparisons e. g. with the compilations by Stålhös (1962, diagram 12). It tends to invalidate the type of reasoning applied by Westra et al. (1969) to deduct the conditions of origin and solidification depth of "Gothian" granites.

Within the limited scope of the investigated rocks and areas consistent chemical differences are brought out by the plots in Fig. 15 to 19, which visualize the aforementioned sodic character of most Early Svecofennian gneissic plutonics in the Linköping area except the deviating monzodiorite group probably belonging to the syenite-diorite-norite clan of the Östergötland development which has been distinguished by Sundius (1927). A consistent difference between the "Gothian" groups and the Late Svecofennian granites appears to be the statistically speaking relatively higher  $Mg/Mg+Fe$  ratio in the "Gothian", which has also been noted in investigations by this writer of the Filipstad and associated granites in County Värmland and the Rätan granite in Jämtland (unpublished data shortly referred to in Gorbatshev 1969a and 1970). It remains, however, to investigate to what extent this parameter in the Late Svecofennian granites is a function of their occurrence in terrains

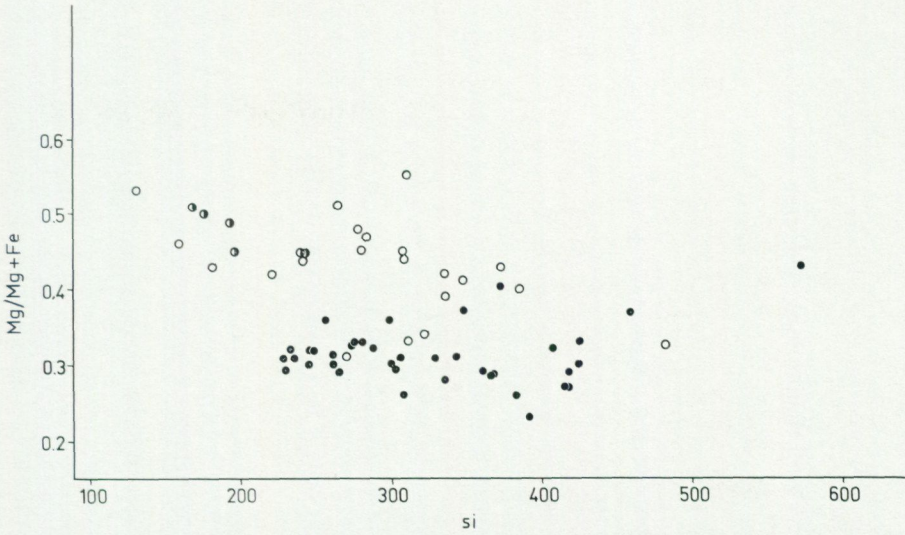


Fig. 17. Plot of Niggli  $si$  versus the atomic ratio  $Mg/Mg+Fe$ . Open circles – Svecofennian gneissic granitoids, half-filled circles – monzodiorite group, filled circles – "Gothian" plutonics. Note the similarity of  $Mg/Mg+Fe$  proportions in "Gothian" plutonics of different  $si$ .

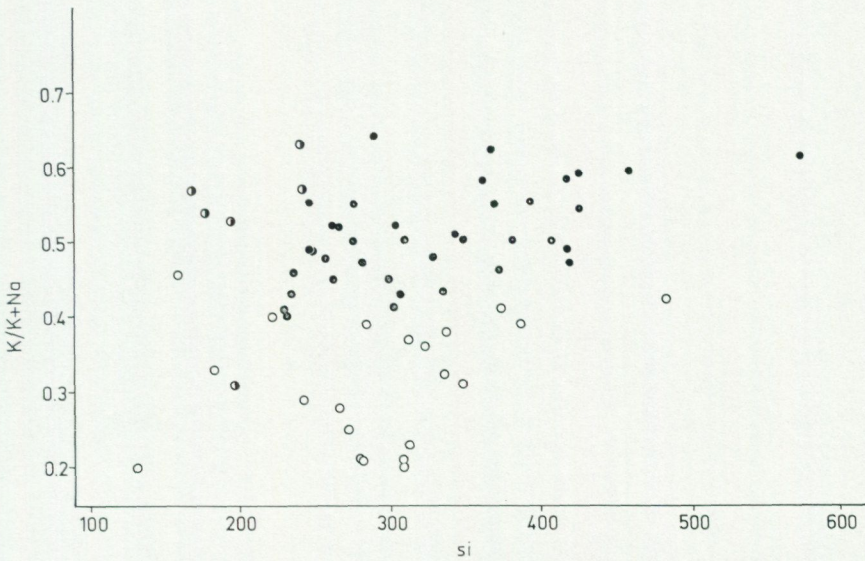


Fig. 18. Plot of Niggli  $si$  versus the atomic ratio  $K/(K+Na)$ . Open circles – Svecofennian gneissic plutonics, half-filled circles – gneissic monzodiorite group, filled circles – "Gothian" plutonics.

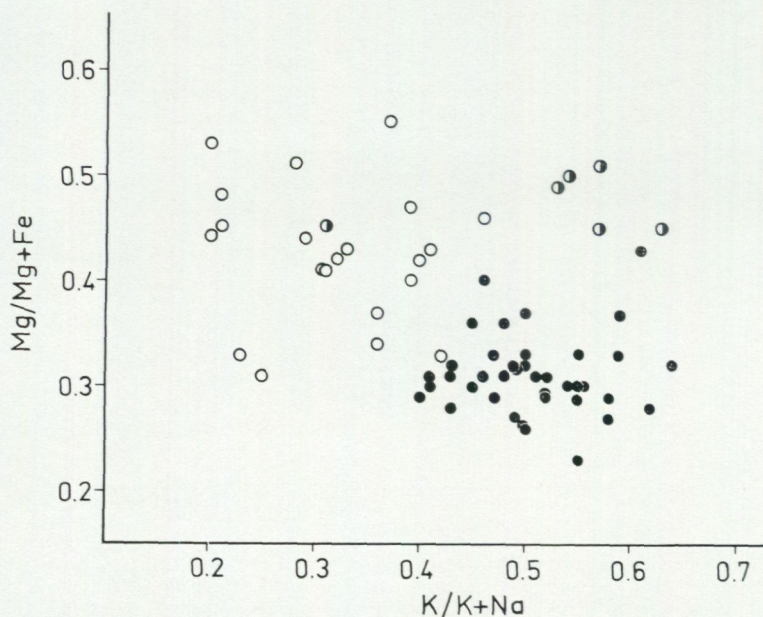


Fig. 19. Mg/Mg+Fe vs K/K+Na plot defines different fields for Svecofennian gneissic granitoids (open circles), monzodiorites (half-filled circles) and "Gothian" granitoids (filled circles).

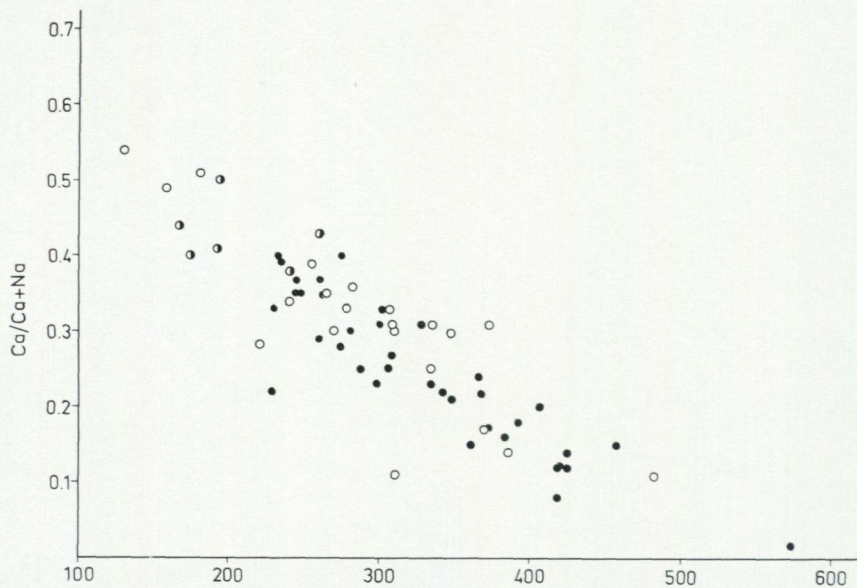


Fig. 20. Ca/Ca+Na ratio plotted versus Niggli si. Signs as in Fig. 19. This diagram shows a regular decrease of Ca/Ca+Na with increasing si throughout all rock groupings and in conjunction with Fig. 18 demonstrates that the slightly more alkalic character of the "Gothian" plutonics (Fig. 14) is due predominantly to relatively higher contents of potassium.

of different Mg/Mg+Fe proportions. In comparison with all plutonics of the Early Svecofennian complexes which display a normal relation of Mg/Mg+Fe versus Niggli si, here used as a differentiation index, the "Gothian" plutonics of the area have remarkably constant Mg vs Fe proportions, a slight relative increase in iron occurring only in some members of the "Red Våxjö" group. The genetical implications of this and some other geochemical characteristics must await further control in other rocks of the Småland-Värmland "Gothian" to establish whether they are a local feature of the Linköping area or characterize this group of plutonics on a regional scale.

Preliminary probes of the trace elements contents of the "Gothian" granitoids indicate a throughout rather high K/Rb ratio. More elaborate development of this aspect which at present is under investigation, is deferred until additional data from this and other areas become accessible. For the sake of reference, however, the presently available ratios are included in Table 8.

#### CONTACT RELATIONS OF THE "GOTHIAN" GRANITES

The contacts of "Gothian" granites with rocks of the Svecofennian development are predominantly crosscutting and sharp. Decreasing grain-size often characterizes the contact facies and fine- to medium-grained varieties of "Gothian" granites tend to concentrate towards the peripheral parts of the "Gothian" area. Nevertheless there are numerous instances of well-defined dikes of coarsely porphyritic Roxen-Graversfors and Filipstad type granites in the Rystad metabasalt, in synkinematic Svecofennian plutonics, and in the supracrustals of the Doverstorp area. Giant breccias of older rocks in "Gothian" granites occur e. g. in the area to the west of Linköping (medium-grained basic rock in Red Våxjö granite) and throughout substantial sections of the Linköping SO quadrangle (predominantly supracrustal rocks in Filipstad type granite). Considerable chemical exchange is signalled by the local increase of Mg versus Fe and Ca versus Na in greenstone breccia varieties of the Red Våxjö. In spite of depletion in quartz, thin-sections and chemical analyses of these rocks show that K is often enriched vs. Na or that the K/Na ratios are kept similar to those of the central area of the Red Våxjö massif. In conjunction with local aureoles of microcline porphyroblasts along the contacts of "Gothian" granites this indicates the redistribution of K towards the peripheral parts of some "Gothian" granite bodies and the emigration of predominantly potassium from the granite. Occasionally the contact line may be entirely blurred by such metasomatic and absorption action, but nevertheless gradual contacts of "Gothian" granites are very subordinate in the Linköping area and the typical case is clean brecciation of the older rocks. Immediately to the northeast of Linköping a rather sodic, medium-grained, reddish-grayish granite with scattered characteristically perthite-zoned microcline megacrysts

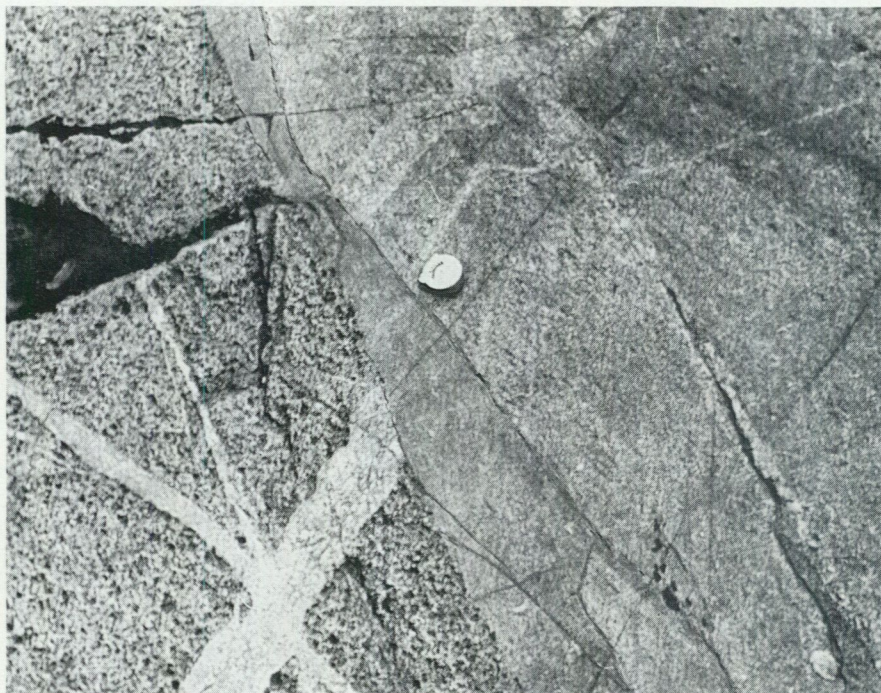


Fig. 21. Dislocation and mylonitization zone along the boundary between older granodioritic (left) and younger sodic-granitic (right) Early Svecofennian plutonics offsets Late Svecofennian pegmatite vein. Bjursby, 2 km N of Rystad.

may be a hybrid between synkinematic Svecofennian and Filipstad-type "Gothian" granites. It appears to terminate a more complex Svecofennian terrain, but is in turn cut by dikes of Filipstad granite and in spite of subisotropic fabric carries diffuse schlieren of varying dark minerals content. Irregularly dissolved slices of older rocks are common in the southern part of the Linköping SO quadrangle and along the northern margin of the Linköping NO area. In these instances the surrounding "Gothian" granites transmute into atypical varieties with generally finer grain-size, irregular megacryst distribution and agmatitic-migmatitic schlieren of rapidly varying chemical composition.

Fine- and medium-grained kinds of "Gothian" granite often develop extensive networks of dikes. Dikes of porphyritic granite are in comparison rather subordinate. Similarly, notwithstanding the areas of hybridization described above, a great majority of older relics in the coarse-grained "Gothian" rocks are angular and sharply delimited and although often recrystallized into hornfelses, without macroscopical indications of extensive resorbing action.

Migmatization of Svecofennian rocks occurs in trains of Svecofennian inclusions inside and in between the different "Gothian" granite massifs and

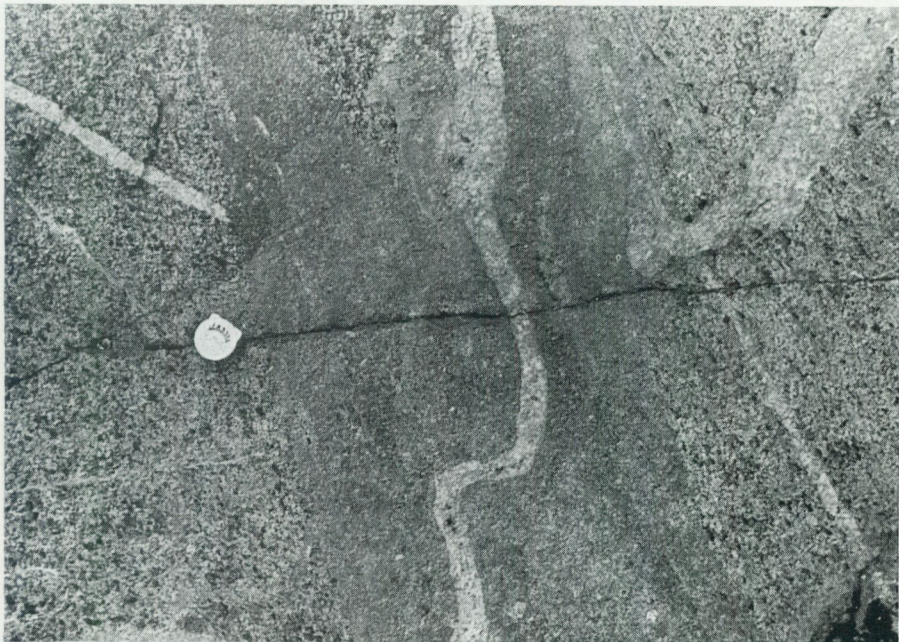


Fig. 22. Dislocation zone similar to that in Fig. 21 is intruded by dark "Gothian" early basic rock which truncates Svecofennian pegmatite dike. Youngest is the "Gothian" granite vein in the centre of the photograph. Bjursby, 2 km N of Rystad.

also in the northern and northeastern outskirts of Linköping where there is lit-par-lit veining and schlieren migmatization of the older supracrustals and plutonics. In larger coherent patches the "Gothian" granite is here a finely medium-grained red rather leucocratic variety, but in the migmatite outcrops mixing of material leads to rapidly varying textures and compositions. The migmatites and associated granites appear to be somewhat older than the adjoining Filipstad-type granite which intrudes it to form irregularly dissipating dikes. Except for a few lenticular small areas conforming with the general regional strike of the older schistosity, migmatization which is "Gothian" in the sense of being allied with massifs of Småland granite, appears in the Linköping area to be more or less restricted to within a few kilometers from large granite bodies. Nevertheless, here it is prominent enough to be reckoned with as a second ("Gothian") period of migmatization. According to earlier descriptions summarized by Magnusson (1962) and Geijer and Magnusson (1944), the northern periphery of the "Gothian" granite area and the Västervik-Valdemarsvik region on the Baltic are characterized by the appearance of belts of gneissic augen rock occurring in association with, and sometimes passing into massifs of "Gothian" granite. Some of these belts are depicted in the upper – the northern – part of Fig. 1. According to Magnusson

they grade into rocks characterized by the development of porphyroblasts in older (Svecofennian) matrix material. Magnusson's interpretation is that the augen rock belts are feeder channels of the "Gothian" granite bodies and occur in the substratum of the granites of which he thinks as essentially flat-lying intrusions. In most cases and with the exception of schistosity belts similar to that described in the next section, this explanation is rather too general if one considers that much of the material in zones of augen gneiss appears to be, and according to Magnusson actually is derived from older Svecofennian rocks. If anything, feeder channels should have been cleared of older rocks. Instead the polymict provenience of the components suggests that apart from features similar to the Linghem schistosity belt the augen gneiss zones of the north are extramassif metasomatic developments controlled by the availability and synintrusion enhancement of preexisting gneissic structures. It may also be noted that they tend to occur in an area which on the basis of mineral associations and regional thorough migmatization has been suggested to be a Late Svecofennian high temperature belt (Gorbatshev 1969b) and disappear or are less well developed in areas where the Svecofennian metamorphic facies is lower and e. g. andalusite joins or replaces sillimanite as the stable form of  $Al_2SiO_5$ . Nevertheless these suggestions are not based on more than superficial examination and since remapping of the concerned areas by the Geological Survey is in progress we would be well advised to await its results before proposing a definite opinion.

### THE LINGHEM SCHISTOSITY BELT

To the northeast of Linköping between Linghem and Rystad the Svecofennian terrain is traversed obliquely by a very prominent belt of strong schistosity and cataclastic crushing which is predominantly occupied by medium- to coarse-grained porphyritic red granite (Fig. 2). Zones of cataclastic breakdown and foliation development are known to occur within both the "Svecofennian" and the "Gothian" granites of Östergötland, but the belt to the east of Linköping differs from most of them in being not only a tectonical zone, but also a feature deviating from its environment in pre-foliation petrology. The strike of this schistosity belt, which will here be referred to as the Linghem belt, is about N 60–65°W as contrasted with the east-westerly to northeast-southwesterly strikes of its immediate Svecofennian surrounding (Fig. 2). In its northern part the boundaries of the Linghem belt are singularly sharp and rectilinear, whereas in the south the diversity of rocks is greater, the crushing somewhat weaker and more unevenly distributed, and the limits not quite as well-defined as in the north. Here the schistosity zone also involves some slices of crushed wall-rock. To the southeast of Linghem (Fig. 2) the schistosity belt attains a width of more than one kilometer – as compared to 200–250 meters in the north – and

appears to dissipate, the strike of its ingredient rocks simultaneously assuming a more east-westerly direction. Nevertheless, farther off Lingham the extrapolated continuation of the schistosity belt coincides with a major fault line running through lakes Hövern, Lången, Taggen, and Yxningen to the Baltic Sea.

The coarse to medium-grained brightly red granite which is the principal rock of the Lingham belt has a composition which is well within the variation limits of the neighboring "Gothian" massifs (table 8, and Fig. 12 and 16). It deviates somewhat from that of the common types of Linköping granitoids belonging to the Svecofennian development, the Late Svecofennian granite being more eutectoid and the Early Svecofennian plutonics generally more sodic. The texture of the rock is dominated by prominent, rather closely spaced megacrysts of red feldspar set in a strongly foliated matrix. The commonest size of the megacrysts is between one and two centimeters. Under the microscope the megacrysts, which are predominantly, but not exclusively made up of perthitic microcline, are seen to be broken and contained in a streaky, cataclastic, strongly schistose matrix composed of quartz, feldspars, chlorite, muscovite, epidote, allanite, opaques, and sphene. Analytical checkups reveal that in spite of the brightly red rock color, the oxidation degree of iron is approximately the same as in the Gothian granite massifs in the area. The differences in coloring are probably due to differences in the distribution of oxide iron, which in the Lingham belt develops prominent ore dusting of the feldspars. The matrix includes disconnected fragments of broken megacrysts. The peripheral parts of the megacrysts may be somewhat granulated. There are usually myrmekite rims around the potassium feldspar megacrysts and granulation of these rims may develop a kind of poikilitic quartz-oligoclase texture. In the northern and central parts of the Lingham belt the porphyritic coarse red granite is the only rock of quantitative importance, occurrences of fine-grained and pegmatitic facies being few and small. About a score of narrow pegmatite dikelets have been recorded during the mapping, all but two of them being cataclastically deformed approximately as intensely as the surrounding rock. In the southern and south central parts of the Lingham belt small bodies of fine-grained red granite make their appearance. Within the Lingham schistosity belt proper they are strongly foliated, but massive rather leucocratic red granite appears just outside of the schistosity area where it forms rims of small intrusive bodies. The wallrock contacts of some of these intrusions are unexposed and thus do not offer basis for their attribution to either of the main granite groups in the area. Other red granites are seen to cut the adjoining Svecofennian plutonics and migmatites. Similarly, in the south central and southern parts of the Lingham belt, coarsely medium-grained red granite extends beyond the limits of the schistosity belt proper, and while still pronouncedly gneissic, has a more east-westerly strike of this texture than the bulk of the foliated rocks. Still the

differently tectonized coarsely medium-grained granites are continuous and thus obviously belong to the same intrusion. In the southernmost extreme of the Linghem belt slices and splinters of Svecofennian country rock are involved in the belt and can be seen to represent both original inclusions in the principal porphyritic granite and tectonically annexed slices which have had their original external contacts destroyed by tectonization. To the southeast of Linghem a relatively large area of reddish-grayish crushed fine-grained rock involved in the schistosity belt appears to be continuous with migmatizing Late Svecofennian granites of the environment. As mentioned above, the Linghem belt widens in this sector and becomes less pronouncedly developed and finally appears to finger out into an area distinguished by alternating zones of strong and moderate foliation, and very inhomogeneous composite Svecofennian-*"Gothian"* petrology.

The regional importance of the Linghem belt derives from the fact that coarse-grained porphyritic to fine-grained equigranular red granites are intruded into a planar dislocation structure which unambiguously cuts across all rocks belonging to the Svecofennian development, including even the granite-associated late migmatites. There is thus a distinct hiatus between the cessation of the Late Svecofennian *s. s.* plutonic activity and the emplacement of the Linghem belt granites which consequently compare chronologically with the *"Gothian"* development – an age classification which is supported by the pronounced similarities of compositional and textural development variations. The surrounding country rock obviously could not respond to the imposed strain by plastic deformation, instead it fractured to develop a zone of tectonization and intrusion, the ultimate origins of which may be syn- or preintrusive in relation to the *"Gothian"* granitoid plutonics. Once the belt of compositional and tectonical discontinuity had arisen, subsequent movements led to the development of postintrusive foliation and crushing, and eventually, in Postordovician times, to the utilization of the northwestern continuation of the Linghem belt in the generation of fault escarpments which delimit the Cambroordovician area of Östergötland in the north. To the south of Lake Roxen, however, the Linghem belt appears to have been free from major Postordovician vertical movements – at least there is nothing in the topography and the distribution of Cambroordovician rocks to suggest such a late tectonical activity. Instead the complex major Postordovician fault in the area which outlines the high ground to the north of Lake Roxen turns northwards at the western extreme of the lake and then continues eastwards partly utilizing preexisting NNW- and EW-striking Precambrian dislocations along the northern shores of lakes Roxen and Glan (Fig. 1).

A minor granite-occupied schistosity zone reminding of the Linghem belt has been found a few kilometers to the north of Rystad (Fig. 2). In analogy with conditions prevailing in the Linghem belt the granite is partly strongly

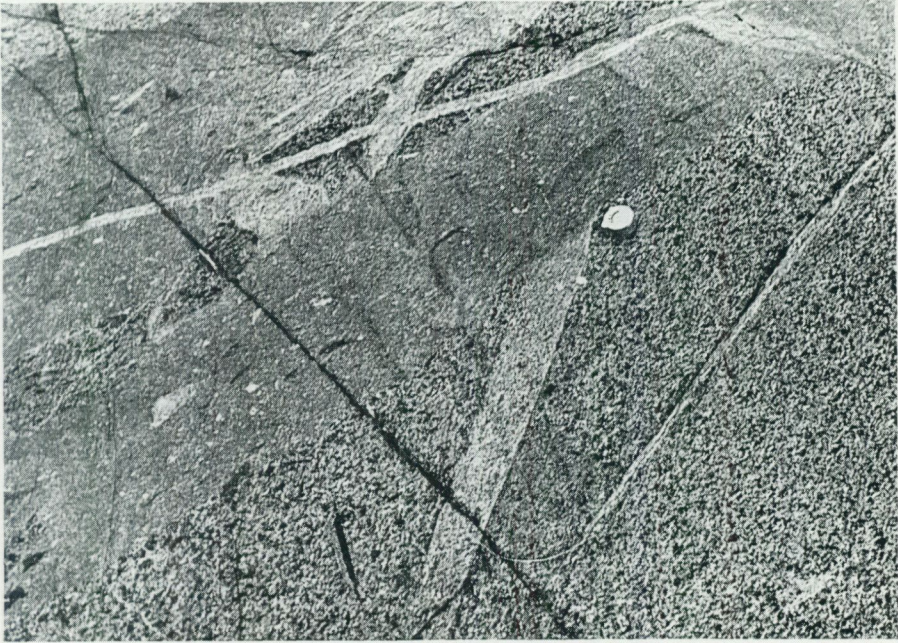


Fig. 23. Small dislocation-intrusion zone helps distinguish between different generations of granite and pegmatite dikes. Svecofennian rocks are truncated, "Gothian" vein passes through. Bjursby, 2.3 km N of Rystad.

foliated, the strike direction deviating from that of the surrounding Svecofennian rocks. The granite of the foliation belt is here acid, red and medium-grained, comparing closely with the Red Väjö in the area. Whenever exposed, the contacts toward Early and Late Svecofennian plutonics are clearly cross-cutting. Related features have also been observed farther east, towards Norrköping, where the rock of one deviating belt is a fine- to medium-grained granite. Because of the compositional convergence of acid members of the "Gothian" granitoid clan and the migmatizing granites a definite age classification may prove difficult in such cases. Because the Lingham belt cuts across Late Svecofennian granite and migmatite terrains its rocks must be younger than the regional migmatization which sets a lower age limit. They do not come into contact with outliers of the Linköping massif of Filipstad granite and thus the relative age of these two rock groupings remains unsettled. Microscopically observable sequences of crushing-recrystallization-renewed crushing and the presence of a few apparently unfoliated pegmatite dikelets suggests that the general foliation in the Lingham belt precedes the final cessation of acid igneous activity in the area, but it is of course not imperative to regard the pegmatite dikelets as related to the Småland granites. In contrast with these infrequent exceptions a fine-grained lamprophyre dike in the Lingham belt has also been foliated.

To the northwest of Lake Roxen the continuation of the Lingham belt is a zone of strong foliation, which from the scarce available outcrops appears to affect equally the Svecofennian and the "Gothian" Roxen massif rocks. The latter do not appear to penetrate and send tongues into the schistosity belt to give it a deviating petrographical character similar to that in the southeast. This may indicate that the dislocation was not there when the Roxen massif was emplaced. However, due to spatial coincidence with the large Postordovician zone of stepwise faulting, the degree of exposure is very low. The strong foliation and cataclastic crushing affecting the whole length of the Lingham belt and its northwestern continuation is of course later than the "Gothian" rocks northwest of L. Roxen and because parallel foliation zones occur in the Filipstad-type granite massif of Linköping, also younger than that rock. Since it affects all granites of the Lingham belt there is no implicit indication that these rocks are younger than the rest of the "Gothian" granitoids in the area. This deformation belongs to the second period of tectonical activity in and along the Lingham belt, the first recognizable one being the development of a planar structure admitting access to the quasi-"Gothian" granite filling the belt. After the general foliation there followed local development of quartz-healed breccias. In these features we find support for Asklund's (1923) idea that the original generation of tectonical dislocation belts in the Precambrian of Östergötland is very early. The Lingham belt suggests that it is even earlier than the cessation of "Gothian" plutonic activity. As has been demonstrated by Asklund the northwesterly zones of fracturing coincide with the strikes of diabase dikes which by him were classified as "Subjotnian". The development of foliation in the dislocation belts precedes the intrusion of another Jotnian or Postjotnian generation of diabase dikes (Asklund 1927, p. 545). Similarly a faulted, but not crushed diabase dike has been observed to cut across the mylonitized rock of the northwestern extension of the Lingham belt just to the southeast of Ljungsjön, map quadrangle Linköping NO. The dike appears to strike NNW.

Dikes of the Hällefors-Breven swarm enter the large WNW- to NW-trending dislocation zones (Gorbatshev 1961, 1969b), but nevertheless these continued subsequently to be tectonically active (Krokström 1936, p. 255 and Gorbatshev 1961, p. 33) and were eventually utilized in the block subsidence of the Cambrosilurian area in Östergötland.

#### DISCUSSION

The relative chronology at the Svecofennian-"Gothian" boundary in the Linköping area can be tabulated as follows:

Early Svecofennian supracrustal development	{ Metaarenites, limestone, (metaargillites), metavolcanics, hypabyssals
Early Svecofennian plutonic complexes (synorogenic or primorogenic)	{ Gabbro-granodiorite-granite { (Gabbro)-diorite-monzonite-monzodiorite-granodiorite-granite-(syenite?) { Diorite-granodiorite-predominantly sodic granite-minor pegmatite
Hypabyssal	{ Amphibolite cutting the oldest Early Svecofennian plutonics. The relations with the other rock groups attributed to the Early Svecofennian are not positively established due to lack of observations
Regional migmatization (late orogenic or serorogenic)	{ Migmatites { Granite, aplite, and pegmatite
"Gothian" development (essentially postorogenic or extraorogenic)	{ (Gabbro, norite, diorite), basic dikes { Granite, local migmatites, pegmatite { Granodiorite-monzodiorite-monzonite-granites-aplite-pegmatite { Lamprophyres, amphibolites

The rocks indicated in brackets are not represented or could not be unequivocally identified in the Linköping area as outlined in Fig. 1, but are according to literature reference or reconnaissance observations present in its surroundings.

This sequence of relative age agrees basically with the chronology developed by previous investigators and codified for instance in Magnusson's compilation of 1962. It is especially important to emphasize once more the break between the Svecofennian and the "Gothian" developments in the rocks of the presently exposed surface. This break implies the transition from orogenic folding-metasomatic-palingenic conditions to the emplacement of large differentiated plutonic granitoid masses essentially foreign to the preceding tectonical development. Observations in the Linköping area very clearly demonstrate that under no circumstances is a chronological parallelization possible between the Svecofennian primorogenic plutonics and the "Gothian" Småland granites, which suggestion can be deduced from a group of recent publications dealing with the geology of the Västervik area (Westra et al. 1969, Priem et al. 1969, Elbers 1970, 1971). It is feasible, indeed probable, that rocks previously referred to the Småland granites include some older units, but because the term "Smålandsgranit" and later on "Gothian" have for a long time

been used with a genetical-chronological intention rather than as a geographical description, such mixing-up is certainly unsought for and has been due to the very incomplete knowledge of the geological contexts in large parts of southern Sweden. The inhomogeneousness of, geographically speaking, Småland granites is also justly emphasized by some of the above writers (Westra et al. 1969, p. 530). Rocks equivalent with the Early Svecofennian should then definitely not be regarded as members of the Småland-Värmland granite clan or the "Gothian", however defined, and should when recognized receive other group denominations. Notwithstanding this difference it may very well be that the main regional migmatization which has here been termed "Late Svecofennian" and the "Gothian" development as described above are continuous in space and time representing different aspects of a single late-orogenic – early postorogenic evolution.

Porphyritic granites and other augen rocks have in the past played an important part in the establishment and correlation of different groups of plutonics in the eastern Östergötland-Småland region. Petrographical similarities have repeatedly been advanced as basis for the parallelization of one or other of the augen gneiss/granite massifs with the Småland granites and thus with what we here consider the younger – the "Gothian" – development in the area. Even when there may be potentially characteristic chemical differences, analytical data have usually not been available, at least not in numbers sufficiently great to make them acceptable as basis for definite decisions. We must thus conclude that mostly the petrological similarity cited to support age correlation refers to macroscopical plus at best microscopical appearance, unless field observations of contact relations can actually be quoted to offer firmer basis for chronological classification.

Long before the Gothian and the Svecofennian were thought of as two different orogenic cycles, a distinction was attempted between rocks of two chronological groupings. In the Västervik area A. Gavelin in a number of publications (1910 and others) distinguished between the porphyritic Småland granites and the similarly augen-bearing gneissic Loftahammar granite. The Småland granites were considered as comprised in a younger grouping to which also belonged the migmatizing-palingenic processes along the coast of the Baltic Sea. The Loftahammar granite is intruded by basic rocks which thus eventually came to be considered as forerunners of the Småland granites, and because similar rocks were found to be associated with other noritic-syenitic-porphyritic gneissic bodies this whole group was later referred to the Gothian orogeny. In 1927 Sundius voiced objections against the views which tied up the augen gneiss of Östergötland with the Småland granites and instead attempted to allocate the augen gneisses to his "gneiss series", i. e. a group comprising also what we now call synorogenic Svecofennian plutonics. In the synopsis given by Sundius most rocks which are older than the Småland gran-



Fig. 24. Around Vikingstad synorogenic rocks have been subjected to late orogenic Svecofennian migmatization and late Svecofennian and "Gothian" pegmatite-granite intrusions. Tip of pencil points at contact between two different Svecofennian granite varieties.

ites were referred to two large "series": one comprising gneissic granitoids and the other diverse rocks such as peridotite, amphibolite, mica-gneiss, and aplite-pegmatite. All rocks of the latter "amphibolite series" were thought of as formed by crystallization from a giant differentiating magma and the layering was said to have been caused by movements in this melt. Details of Sundius' description such as the statement that salic gneissic granitoids are intimately related and pass diffusely into the aplite-pegmatite material in the "amphibolite series", suggest that Late Svecofennian - "Gothian" migmatites were lumped together as parts of the giant melt, which of course makes it cumbersome to recognize these rocks from quadrangle maps and descriptions compiled under such extremely plutonistic assumptions. The schistose character of many of the Late Svecofennian rocks which has been pointed out in one of the foregoing sections probably contributed to the confusion. Still, there is reason to hold that Sundius is right in attributing some of the "augen gneisses" in Östergötland to developments preceding what is now known as the "Gothian". A balanced, pluralistic view on the "augen rocks" had been adopted by Gavelin (1910) and Asklund (1928 and other papers). It appears obvious from the mapping in the Linköping area and reconnaissance in its surroundings that the augen gneisses comprise several distinct groups of which we can list

- (1) members of the Svecofennian development
- (2) metasomatic rocks with microcline porphyroblasts developed in the Svecofennian terrain concomittantly with the emplacement of Småland granites
- (3) schistose augen-granitoids in tectonical belts of which the Lingham belt is a representative. The affiliation with planar features need of course not be as marked as in the described case. To this group also belong early "Gothian" plutonics which have been deformed under the influence of subsequent intrusions.

An age difference between the Loftahammar and the Småland granite groups is as already stated, part of the prevailing concept of Svecofennian-Gothian age relations developed by Gavelin. There is thus no reason to consider the feldspar-megacryst bearing rocks as an entity and automatically extend conclusions obtained in one locality to the rocks of others. The age relations of the monzodiorite group of gneissic plutonics and the rocks occupying the Lingham belt are very illustrative in this respect. The rocks of the Lingham belt are clearly younger than all other plutonics with which they come into contact, whereas the monzodiorites and the basic rocks associated with them are brecciated by somewhat gneissic granitoids which appear to belong to the Svecofennian tectonical development. Other augen-bearing granitoids are unambiguously members of the synkinematic Svecofennian suite. It has already been noted that the Svecofennian plutonics in the Östergötland area have a development which is somewhat different and more diversified than that which is found in most other Svecofennian regions in central Sweden. Very different opinions have been expressed on the relations between the Loftahammar granite, basic rocks, sediments, and the regional migmatization (Holmquist 1905, Gavelin 1910, Sundius 1927 etc.). As long as the "Gothian" was considered to be an independent orogenic cycle segregated from the Svecofennian by a long interval of time, the "older Gothian" plutonics similar to the Loftahammar granite defined the onset of "Gothian" times (Magnusson 1962, cf. however Lundegårdh 1964, 1970).

Substantial difficulties for the existence of the "Gothian" as an independent cycle have been brought about by Rb/Sr datings of "Gothian" granites in the Östergötland region. The Rb/Sr age obtained by Welin et al. (1966) for "Gothian" granites is 1740 m. ys. The dated specimens are from an area to the southwest of Linköping and although representing two somewhat different types of rock, they all belong to the kind of more or less massive "Gothian" Småland granites which have been considered in this paper. The Rb/Sr age obtained by Welin is in excellent agreement with the Pb/U age of pegmatite-aplite minerals from the Västervik area. These minerals which are genetically related to the Småland granites have an age of 1745 m.ys. (Welin and Blomqvist 1966).

The Rb/Sr age of Småland granite from the Linköping area is further of the same order of magnitude as single-specimen Rb/Sr datings of Västervik rocks, which were made employing a higher Rb decay constant, but instead preassumed a probably slightly too low  $^{87}\text{Sr}_0/^{86}\text{Sr}_0$  ratio (Priem et al. 1969). The quoted isotopic ages suggest that the "Gothian" development as represented by the Småland granites is in immediate continuation of the Late Svecofennian, the difference of age being no more than 60–70 m.y.s. (Welin 1966). Consequently it appears very improbable that the "Gothian" Småland granites belong to an independent separate cycle of orogenic development. "Older Gothian" rocks to which the Loftahammar granite is referred by Magnusson (1962), are accordingly moved right into the Svecofennian where they are also placed by Lundegårdh (1970).

In agreement with the isotopic age data available at that time Th. Lundqvist (1968) suggested that anatectic melts generated in the depths of the Svecofennian geosynclinal region were moved up to extrude and intrude forming a sequence of predominantly acid volcanics (largely ignimbrites) and associated postorogenic plutonics. Volcanics of this period are frequent in marginal Svecofennian areas in northern and north central Sweden. In congruence with the geological observation that volcanics of the Dala porphyry complex are younger than the "Gothian" granites (Hjelmqvist 1966), the obtained Rb/Sr ages range between 1605 and 1725 m.y.s (Welin 1970), the Dala porphyries proper having a Rb/Sr age of about 1670 m.y.s. (Weiln et al. 1966, Welin and Lundqvist 1970). The Småland porphyries differ from the Dala porphyries in being older than the "Gothian" Småland granites, but still they probably belong to the same general period of geological evolution which by Welin (1970) has been called the period of intrusion and deposition. The sediments of this period appear to be essentially arenitic and a number of quartzite deposits along the margins of the Svecofennian core area have previously been referred to the "Gothian". In some cases they carry balls of Late Svecofennian granite (Hjelmqvist 1966), whereas in others some of them have been demonstrated to be part of the early Svecofennian supracrustal development (Lundqvist 1968). In regions close to the Linköping area these arenites are represented by the sediments of Västervik and Vetlanda which predominantly comprise arenites sometimes intercalated with mostly basic volcanics. The quartzites of the Västervik area have traditionally been considered as belonging to a Gothian supracrustal sequence (Gavelin and Lundegårdh 1960, Magnusson 1962). They are intruded by "Gothian" granites, but the age relations with the Loftahammar granite have not yet been settled beyond dispute. Most investigators agree that the Loftahammar granite has either intrusive or gradational contacts towards the quartzite which by itself would indicate that the granite is the younger rock, but nevertheless it is sometimes thought to form the substratum of the quartzite (Gavelin 1910) and the observed contact relations are dismissed as

being due to remobilization (Magnusson 1962). Geological investigation of the Loftahammar granite is consequently of critical importance in determining the local chronology of the Västervik area and if it be accepted that the granite is Svecofennian and younger than the quartzites, then the Västervik quartzites must belong to the Svecofennian supracrustal development. This has been suggested by Elbers (1971) and Westra et al. (1969) who moreover consider that the Loftahammar and the local Småland granites are both prekinematic-primorogenic Svecofennian and have Rb/Sr ages around 1700 m.y. As has already been emphasized, contact relations in the Linköping area demonstrate that the correlation of "Gothian" Småland granites with primorogenic Svecofennian plutonics is untenable which also emerges along most of the long contact line between the Svecofennian and the Småland-Östergötland-Värmland granite complexes. The Småland granites of the Linköping and Västervik areas moreover appear to have similar Rb/Sr ages and consequently, and because both rocks are the youngest plutonics of any areal extent in their respective areas, there is no reason to assume that the Småland granites to the west and southwest of Västervik belong to a different generation of Småland plutonics. The similarity of Rb/Sr ages obtained for the Loftahammar and Småland granites of course confirms that the Loftahammar granite is not the younger rock; nevertheless it can be older which certainly applies to the adjoining Västervik sediments subjected to the same metamorphic influences and rendering a similar one-specimen Rb/Sr age ( $1644 \pm 40$  vs.  $1651 \pm 50$  acc. to Priem et al. 1969, which considering the employed  $^{87}\text{Rb}$  decay constant must be increased somewhat when comparing to the Rb/Sr ages given by Welin. As represented by the "Gothian" Småland granites the "Gothian" plutonic events move closer to the Svecofennian, but are still distinctly younger than the main deformation stages of the Svecofennian development in the Linköping area. In the Västervik area and in the Lower Dala series metamorphism during Welin's intrusion-deposition period led to intensive deformation and to the development of parageneses comprising high-temperature minerals (Hjelmqvist 1966), but in general the plutonic massifs pertaining to his period can be regarded as postorogenic or extraorogenic in relation to the Svecofennian orogenic development. This is clearly the case in the Linköping area and also in the Los-Hamra area described in great detail by Lundqvist (1968). In this context it would be important to know the relations between the Småland-Värmland granites and the Svecofennian in areas where the "Gothian" plutonics come closest to high-temperature centres of the Late Svecofennian. In this regard the best prospects are probably in the border area between the counties Östergötland and Sörmland. Regrettably no modern investigations are available for most of that sector, but in view of the isotopic ages it would not be entirely surprising if the segregation into Late Svecofennian and "Gothian" developments would prove to be indistinct there, even trending towards still

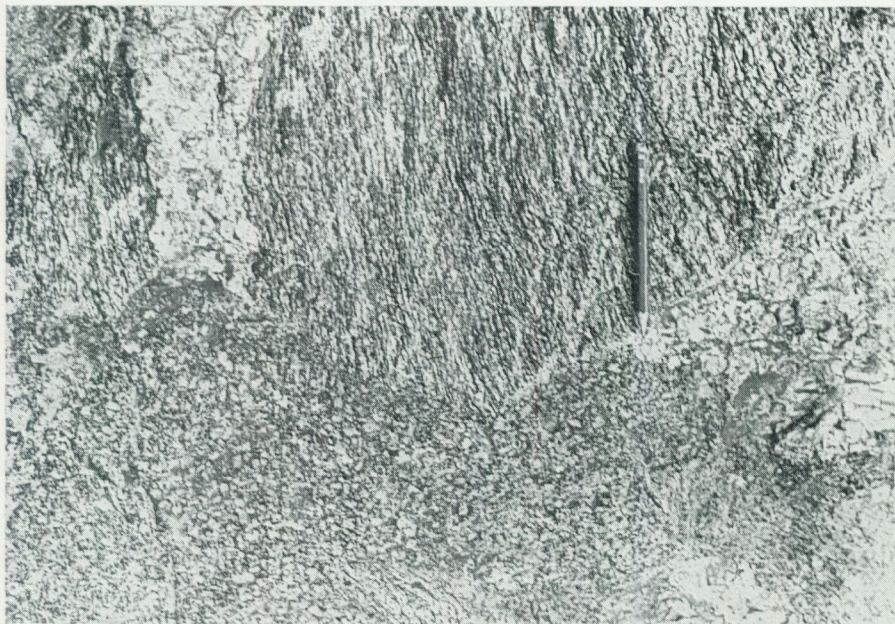


Fig. 25. Foliated synorogenic Svecofennian granite is subjected to intrusion and migmatization by late orogenic Svecofennian granite and pegmatite. The complex Svecofennian rocks terminate sharply against "Gothian" augen granite related to the Filipstad type. The "Gothian" granite contains rotated fragments of the Svecofennian rocks (lower margin of the picture). The photograph demonstrates the chronological and tectonical hiatus between the "Gothian" and the synorogenic Svecofennian granitoids. Vikingstad, 12 km WSW of Linköping.

more gradational transitions than in the area considered in this paper. The work by Elbers (1971) and Asklund (1925, 1928) suggests that this is the case along the coast of the Baltic.

Whatever the details of age relations in the Västervik area – and the writer has here of course no reason or basis to voice own opinions – the Småland region undoubtedly contains sediments which are older than the Småland granites, but younger than an exposed granitic basement. Very clear primary depositional contacts of the Vetlanda supracrustals have recently been demonstrated by Hjelmqvist (1969). The granitic basement in that area has previously been described as "older Gothian" by Magnusson (1962). The critical problem, and one which is of paramount importance for our concept of the geology of southern Sweden, is whether the basement granites can be parallelized with the Svecofennian or whether they represent some other and older kind of "Pre-gothian". Obviously, and in view particularly of the isolated geographical setting of these rocks amid "Gothian" terrains, the best way to arrive at a wholly satisfactory solution is by isotopic dating employing different methods of age determination.

A feature which is characteristic of southeastern Sweden is the incongruence of datings obtained by the K/A and Rb/Sr methods. K/A datings in the late fifties (Polkanov and Gerling 1960, Magnusson 1960) were with one exception between 1420 and 1560 m.y.s. and thus appeared to substantiate the geologically established concept of two independent orogenic cycles – a notion which was later collapsed by forthcoming Pb/U and whole-rock Rb/Sr ages. The only rocks for which coincidence of Pb/U and K/A ages at approximately 1450 m.y.s. has been demonstrated are the Karlshamn-Spinkamåla granites in the southern extreme of the Småland region. This granite group intrudes into the Småland granites and is considered to be palingenic (Norin 1936, 1959, Magnusson 1962). One explanation of the divergence of isotopic ages in southeastern Sweden may be by loss of radiogenic argon in connection with the so-called Sveconorwegian regeneration which appears to have affected all of southwestern Sweden where the K/A ages throughout a region of diversified and complex geology all are between 920 and 1130 m.y.s. (Magnusson 1960). Outside of the geological boundary of southwestern Sweden as it is defined by the eastern limit of coherent foliated gneisses, there extends a belt of regeneration in older unfoliated rocks where the K/A ages successively decrease westwards. In the northern part, to the north of Lake Vättern, the width of this belt can be estimated to be somewhat above 50 kilometers which contrasts with a width of over 150 km for the area in Småland which renders incongruent K/A ages. In the western part of the Småland granite area superposed arenitic sediments of the Almesåkra complex have suffered folding and thrust-faulting (Gavelin 1931) possibly contemporaneous with the Sveconorwegian regeneration (= Dalslandian tectonization, Lundegårdh 1964, 1970) of southwestern Sweden. Nevertheless the great areal extent of K/A ages around 1400–1500 m.y.s. and the presence of the Karlshamn-Spinkamåla granites and of pegmatites in the Västervik area which according to a Rb/Sr dating (Priem et al. 1969) are roughly contemporaneous with these granites, suggests that throughout much of the "Gothian" region in Småland regeneration has not been due to partial loss of radiogenic argon during the Dalslandian episode, but rather to events approximately 1400–1500 m.y.s. ago (cf. Welin 1966, p. 16). There are at present no further isotopic age data to demonstrate the nature, products and extent of these processes in southeastern and southwestern Sweden.

The acceptance of the term Gothian for an alleged orogenic cycle came in the wake of Sederholm's and Wahl's proposal of cyclical evolution in the Precambrian of Fennoscandia. Each cycle was thought to comprise primorogenic, serorogenic, and postorogenic granite suites, Wahl's model has been fruitful in systematizing and rationalizing the treatment of the Precambrian and committantly emphasized actualistic aspects and the idea of periodical recurrence of analogical events and products. Nevertheless the ensuing cycliza-

tion of the Precambrian geological processes in certain cases led to oversystematization and obscured differences in the actual regional geological evolution. Its unfitnes as a basis of systematical terminology has been pointed out by Welin (1966). The cycle term Gothic was by Wahl (1936) intended to cover the rocks of southeastern and southwestern Sweden and the granites in that region were accordingly grouped together to be assigned either primorogenic or serorogenic positions. Subsequently most of the foliated gneissic rocks were expelled from the Gothic to form the "Pregothian" and similarly the rocks of the Stora Le-Marstrandserie and the Dalslandian were assigned to other than Gothic contexts. This left the Gothic with the granites of the Småland-Värmland complex and the Åmål-Kroppefjäll granites in western Sweden, plus some sedimentary and volcanic rocks, e. g. the Västervik quartzite and the Åmål supracrustals. The Karlshamn granites still played the role of a (quasi-)serorogenic complex in the Gothic (Magnusson 1962, Lundegårdh 1964). Gradually, reasoning in terms of regular complete orogenic cycles started to be supplanted by the definition of mountain building periods sometimes thought to correspond to geological eras. Lundegårdh (1964) thus speaks of the era "Gothium" corresponding to the Gothic tectonization, commencing at 1600 m.y.s. and situated between the Svecofennian-Karelian and Dalslandian eras and orogenies. Within this era the Småland granites are considered to be a group of early plutonics succeeding the Gothic supracrustals. This classification basically agrees with the notion that boundaries of Precambrian eras should in some way delimit periods of igneous activity and regional metamorphism, although the use of the same terms for time units and poorly dated or undated rock complexes and geological events contains the prerequisites of conflict.

As additional isotopic datings moved substantial parts of the Gothic and the Subjotnian into immediate vicinity of the Svecofennian, the term "Gothian" has been employed in a purely chronological sense in the form of "Gothian era" which according to Lundegårdh (1967) covers the time between ca 1350 and 1780 m.y.s. A similar use of "Gothian" is also made in the legend of the new edition of the international tectonical map where "on distingue huit régions plissées d'âge divers" among them "Gothien (1750 ± -1200)". In these terminologies the limits of the Gothic era/folding period separate the bulk of the Svecofennian orogenic activity from rocks and events which have been argued to be anatectic postorogenic products (Lundqvist 1968) or seem to be tectonical stragglers of the Svecofennian geosynclinal evolution. Similarly, an upper limit of about 1200 m.y.s. risks to wind up in the mid of some major tectonical event in southwestern Sweden where the K/A, and consequently final cooling ages are between 950 and 1150 m.y.s. Though delimiting the Svecofennian orogenic activity, the boundaries of the "Gothian" era thus do not entirely answer the demand of coinciding in some way with intervals or at least minima of igneous and mountain-building activity. It is evident that the term Gothic

has here been following the Småland-Värmland granites whereas the rocks and events of southwestern Sweden exercised less influence on its destinies for the simple reason that none but K/A ages are as yet available in that region. In the region rendering Dalslandian K/A ages the term "Svecofennian" has been applied to the Stora Le-Marstandsserie and the Glava "mica-schists", but this age is not founded on any determinations of absolute age. Again it would not be surprising if some of the "Pregothian" turned out to be Svecofennian. The "Gothian" Åmål-Kroppefjäll granites appear to be rather inhomogeneous and the necessity of further subdivision into tectonically and chronologically diverse units which has been indicated for the Göteborg area in an important analysis of some field relations (Brotzen 1961) has been fully substantiated on a regional scale (Gorbatshev 1971). Some of these rocks are definitely orogenic and thus differ from the Småland "Gothian". It is not known at present whether the "Gothian" or "Pregothian" periods of migmatization, folding, and igneous activity in western Sweden all represent events which can be parallelized with orogenic periods in Scandinavia bearing other names, but in this area we must still reckon with the possibility of a major independent orogenic evolution intervening between the Svecofennian mountain building and the Dalslandian igneous events. If this proves to be the case then there would be an obvious successor to the term "Gothian" and we could let the Småland granites pass off into the postorogenic Svecofennian. These aspects indicate the present necessity of conservatism when using "Gothian" in the rigid definition of events or time subdivisions, lest the term becomes useless by shifting meaning too frequently. Preferably, time and event nomenclature should be kept apart. The past and present transmutations of "Gothian" are a bit confusing and we may as well admit that at present we lack the factual basis to give the term a definite scope. In a decennary or so we shall probably know. There is thus good reason to agree with Lundegårdh's (1971) statement that the terms Svecofennokarelian and Gothian in their present sense should be regarded as provisional.

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