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CONTENTS

ABSTRACT

Precambrian rocks of an area in the northeastern part of the province of Småland, southeastern Sweden have been investigated by the writer. The volcanic rocks, sedimentary rocks and subsequent intrusives (including the Småland granites) have previously been thought to belong to a separate orogenic cycle, the so-called Gothian. The acid volcanics and subsequent plutonics are considered by some authors to be post-orogenic Svecofennian, on the evidence of radiometric age determinations (Welin 1966). According to Åberg (1972) the Rb/Sr isochron age of the porphyries is 1695 ±20 m. y. Structures, textures and field relations (e. g. a large areal extent) suggest that the porphyries are ignimbrites, probably erupted along fissures. Intercalations of tuffs and agglomerates in the porphyries indicate rhythmic volcanic activity. A tuff, partly agglomeratic, shows beautiful pisoliths. It is probably the youngest extrusive rock type of the area, as it has porphyry fragments. Perlitic textures are evident in the well-preserved porphyry types, and an evolution towards a higher "glass" content seems probable. The volcanic rocks are strongly recrystallized under the influence of intrusive granites, showing wide transitional contact-zones to the latter. In the area investigated all the volcanic rocks are interpreted as older than the granites and of anatectic origin. Different types of dykes cut the volcanic and plutonic rocks. Two phases of deformation took place in the volcanic rocks, with fold axes and lineations in NNW—SSE and WNW—ESE directions, while the granites seem massive. The granites caused this deformation of the volcanics. Later the bedrock has been split along tectonic lines in two main directions also marked by dykes. Thus, the conditions imply a close connexion between volcanic rocks, plutonic rocks, tectonic activity and hypabyssal rocks, a normal development under post-orogenic conditions.

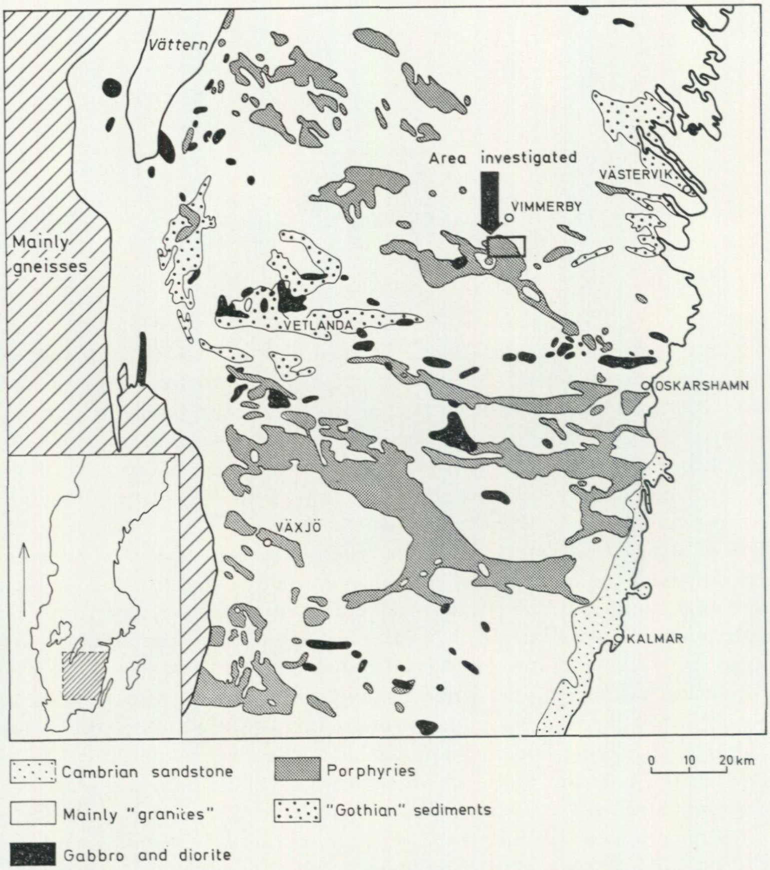


Fig. 1. Simplified geological map of eastern Småland from Magnusson et al. (1958) showing the area investigated. Algonkian rocks excluded together with Svecofennian rocks in the northeastern corner.

INTRODUCTION

The investigation concerns Precambrian rocks in the northeastern part of the province of Småland, about 10 km south of the centre of Vimmerby (Fig. 1), and covers an area of 50 sq. km. The area investigated coincides with the easternmost part of Nordenskjöld's Sjögelö porphyry area (Nordenskjöld 1894, p. 108). This paper deals with the description of the different rocks of the area and their geological evolution (cf. Persson 1973). 25 chemical analyses are presented (Tables 2a and 2b).

GENERAL GEOLOGY

The area comprises volcanic rocks with transitions to granitic rocks and is shown in the petrological map (Fig. 2). The volcanic rocks include tuffs, a grey porphyrite (originally a tuff), agglomerates (mostly lapilli tuffs) and, finally, different types of porphyries. The age relationships between these rocks are complex, but all volcanic rocks are older than the surrounding granites. Different phases of volcanic activity are shown by intercalations of tuffs and agglomerates in the porphyries. The properties of the latter suggest an interpretation as ignimbrites. Their relationship to the granites is very complex. Wide transitional zones are found, where strongly recrystallized porphyries separate the granites and the rather well-preserved volcanic rocks. However, thin granitic dykes with intrusive contacts occur in the porphyries. The granites are mainly red, felsic, medium- to coarse-grained rocks, which often have fine-grained contact facies in the vicinity of the porphyries. A gabbro massif with dioritic margins exists in the northeastern part of the area. Schlieren of hornblende-granite occur in the diorite. These rocks seem to be differentiation products of one magma. They are older than the salic granites. Different types of hypabyssals cut the volcanic and the plutonic rocks (cf. Fig. 2).

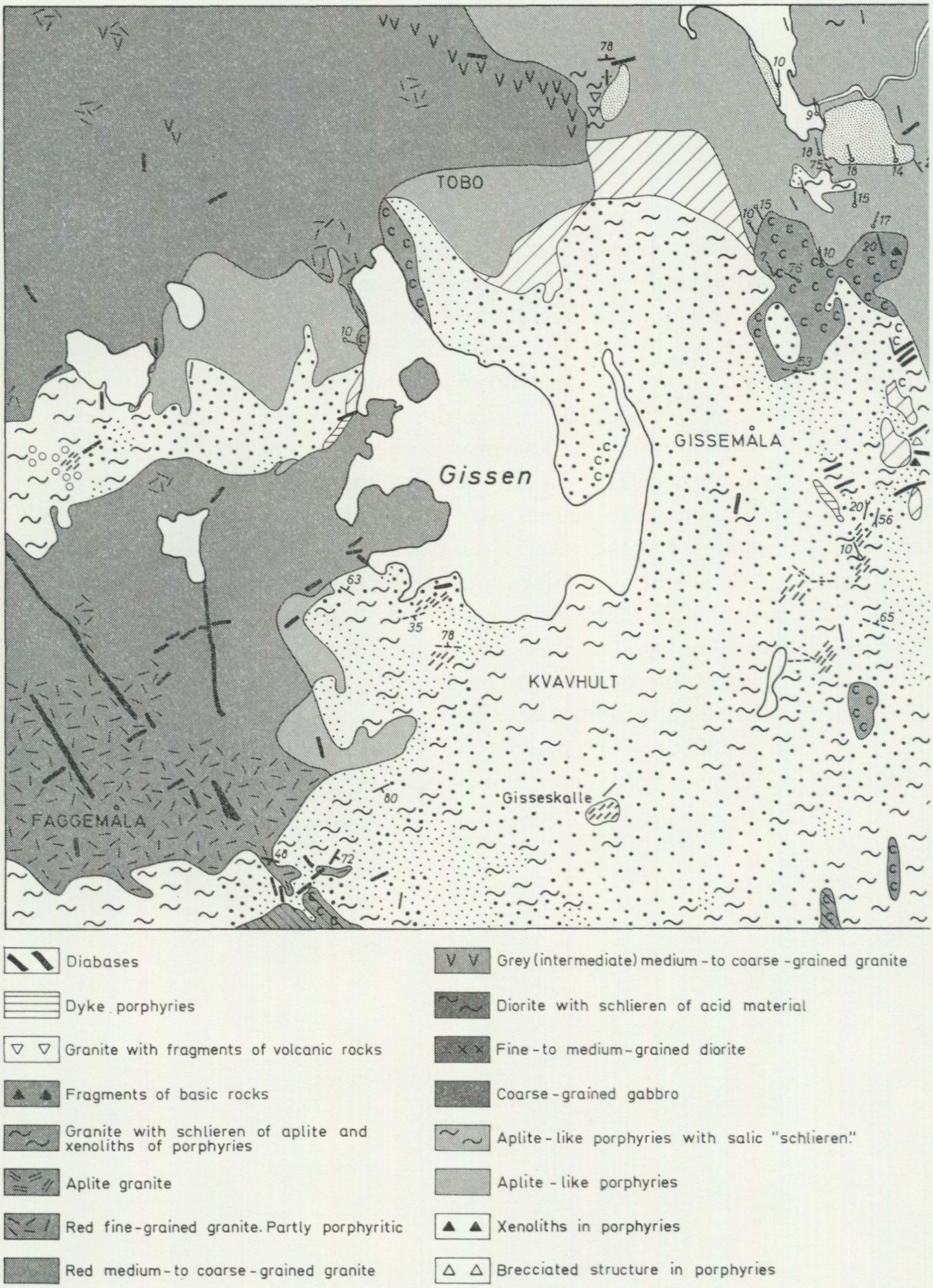
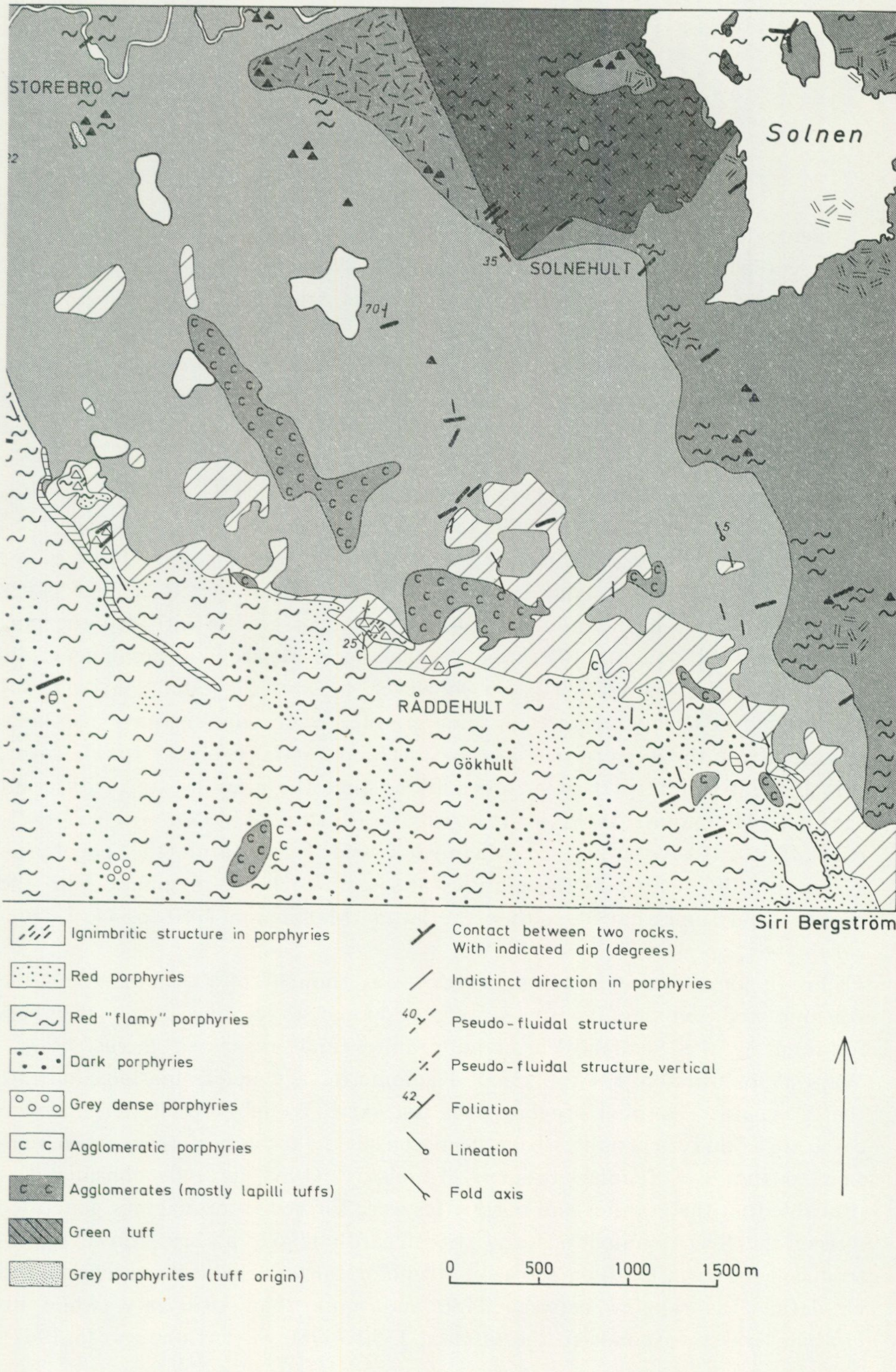


Fig. 2. Petrological map from the region south of Vimmerby, in the northeastern part of the Province of Småland. Lars Persson (1973).


STOREBRO
Solnen
SOLNEHULT
RÅDDEHULT
Gökhult
Siri Bergström
Ignimbritic structure in porphyries
Red porphyries
Red "flamy" porphyries
Dark porphyries
Grey dense porphyries
Agglomeratic porphyries
Agglomerates (mostly lapilli tuffs)
Green tuff
Grey porphyrites (tuff origin)
Contact between two rocks. With indicated dip (degrees)
Indistinct direction in porphyries
Pseudo-fluidal structure
Pseudo-fluidal structure, vertical
Foliation
Lineation
Fold axis
0 500 1000 1500 m

PREVIOUS WORK

Geological maps of this part of southeastern Sweden are obsolete and not very detailed (e.g. Holst 1885, Nordenskjöld 1894, p. 108). Here, volcanic and sedimentary rocks outcrop in narrow belts trending mainly in W—E, WNW—ESE, and, sometimes, NW—SE directions. It has often been noted that the volcanic rocks occur irregularly, have great compositional variations and show complex relations towards the granites. In the Sjögelö area Nordenskjöld (1894, pp. 121—124) interpreted the rocks as volcanic and produced evidence of an eruptive origin. Previously, a sedimentary origin (Hummel 1877), or participation in a crystalline schist formation (Holst 1885) had also been considered (cf. Nordenskjöld 1894, pp. 12—14). As regards the age relationships between the granites and the porphyries, Nordenskjöld (1896, p. 28) suggested the two rock types to be of about the same age. In a later paper (1900, pp. 7—15) he mentioned that thin dykes of granite intruded the porphyries, and subsequently the porphyries have been regarded as being generally older. In his last-mentioned paper, however, he also suggested that some of the porphyries were younger than some granites. Such relations have also been reported from the western part of the Sjögelö area (Hagström 1970). However, it is difficult to interpret such information, since the granites are of different ages (cf. Hjelmqvist 1969, p. 157; Elbers 1971, p. 47; Gorbatschev 1971; Röshoff 1973). According to Magnusson and Lundegårdh the porphyries are genetically related to the granites and seem to be co-magmatic with the granites, but somewhat older than the latter (Magnusson 1960, p. 44; Lundegårdh 1967, pp. 31—39).

For a long time a Gothian orogeny was thought to exist, in which the volcanic and sedimentary rocks were supposed to be the oldest members followed by the Småland-Värmland granites and associated intrusions (cf. Wahl 1936, Larsson 1947, p. 335). Radiometric age determinations indicate that a separate Gothian orogeny does not exist (Welin 1966). Later, the volcanic rocks and the granites have been considered to be post-orogenic in relation to the Svecofennian orogeny. Lundqvist (1968, p. 160) considered it probable that the granites and porphyries were formed from magmas generated during the Svecofennian orogeny. Lundegårdh (1967, p. 279), however, introduced the term Gothian era as a chronological term. The Svecofennian era he defined as ranging between 1780 and more than 1950 m.y. while his Gothian era corresponds to the interval 1350—1780 m.y. (Lundegårdh 1967).

AGE DETERMINATIONS

K/Ar age determinations on granites in southeastern Sweden have given ages between 1475 and 1759 m.y. (Magnusson 1960). Many age determinations on granites (K/Ar, Rb/Sr and also U/Pb on minerals) have given ages around 1740—1750 m.y. (cf. Welin and Blomqvist 1966, p. 16; Welin et al. 1966, pp. 20—27), but all these early datings were carried out on few samples and are inaccurate. Besides, it is certain that there are several generations of granites. For example, one granite near Virserum has been shown to be older than the "Gothian" effusive rocks (Hjelmqvist 1969, p. 157). The Rb/Sr isochron age of granodiorites from the Nömmen area, Småland, is 1839 ±58 m.y. (Röshoff 1973). New Rb/Sr whole-rock determinations have been made on porphyries in Småland, including some samples from the area investigated. The isochron age is 1695 ±20 m.y. (Åberg 1972). Rb/Sr age determinations on other volcanic rocks in Sweden have given ages ranging between 1725 and 1605 m.y. (Welin et al. 1971, pp. 23—32; Åberg 1972, cf. Lundegårdh 1971, p. 1399).

VOLCANIC ROCKS

Among the volcanic rocks two main groups can be distinguished, viz. one which is characterized by strong recrystallization and another, including porphyries, with rather well-preserved structures and textures. Among the recrystallized types there are aplite-like porphyries, a grey porphyrite (originally a tuff), crystalline transitional types (compositionally and in grain size between the aplite-like porphyries and the well-preserved porphyries) and agglomerates (mostly lapilli tuffs and coarse tuffs). Among the well-preserved porphyries there are red, red "flamy" (dark with irregular red parts), dark (brown to black) and grey types. Finally there are green, partly agglomeratic tuffs (Table 1). The transitional types of the porphyries (Fig. 2) are in some instances not easy to distinguish. The crystallinity and the red colour increase outwards from the well-preserved cores; situated in the southern parts of the volcanic belt. These transitions occur over distances of 0.5—3 km from the contacts with medium- to coarse-grained granites, which in some places have fine-grained

TABLE 1. The volcanics of the investigated area. Relatively younger rocks upwards.

"Basic" and intermediate volcanics	E.g. rhyodacite	
Tuffs — agglomerates	Quartz latite — rhyodacite	
Dark porphyry Red "flamy" porphyry Red porphyry	Rhyolite — alkali rhyolite	Ignimbrite facies Primary structures and textures
Tuffs — agglomerates	Quartz latite	Strongly recrystallized
Crystalline transitional type and aplite-like porphyry	Rhyolite — alkali rhyolite	Strongly recrystallized Probable ignimbrite facies

contact facies. The porphyritic structure is very distinct in the aplite-like porphyries, especially on weathered surfaces. Also the fine-grained granites are porphyritic in structure. The uniform mineralogy of all volcanic rocks and granites is evident. In the present paper Rittmann's terminology (1952) for volcanic rocks has been used.

GENERAL MODAL COMPOSITION

Phenocrysts of plagioclase, perthitic microcline, microcline, and quartz as a rule occur in the volcanic rocks. The porphyries usually contain between 5 and 25 % phenocrysts. Most dark porphyries have about 10 % phenocrysts, while the aplite-like porphyries generally carry about 20 %. The tuffs are most frequently characterized by 25—30 % phenocrysts, with as much as 45 % in exceptional cases. The plagioclase phenocrysts are usually lath-shaped (idiomorphic), albitized, sericitized, epidotized, corroded, and zoned. The zoning and the euhedrality of the crystals suggest that they were formed by crystallization from a melt (cf. Peterson and Roberts 1963, pp. 120—121, Lipman et al. 1966, p. F30). The corrosion of the feldspar phenocrysts suggests that high temperatures were maintained for a long time during the crystallization of these special rocks (cf. Rast 1962, pp. 103—108 cf. Smith 1960 b, Vlodavetz 1961). The maximum An content is about 30—34 % (i.e. the plagioclase is an acid andesine), as determined from the extinction of albite twins in the symmetrical zone. Epidote minerals, micas, sphene, ore minerals, apatite and quartz might be aggregated and these aggregates may form a distinct parallel texture, to some extent fluidally deviating around the phenocrysts. The main part of the groundmass consists of quartz and feldspars. Subordinate minerals are sericite, sphene, biotite, ore minerals (often magnetite, pyrite and titanium-iron oxide), chlorite (also penninite), muscovite, zoisite, clinozoisite, apatite, zircon, calcite, fluorite as well as, in some cases, allanite and garnet.

APLITE-LIKE PORPHYRIES

These rocks are fine-grained, red, with white feldspar phenocrysts which stand out distinctly on weathered surfaces. In some places there exist somewhat coarser, felsic schlieren. These rocks are generally very poor in dark minerals, but close to the tuffs and the agglomerates the colour may be darker. This is due to the occurrence of micas, epidote minerals, ore minerals, chlorites, and sphene. Lineations or foliations can also be seen. In composition, these rocks are rhyolites and alkali rhyolites. The groundmass is hypidiomorphic (Fig. 3). The rocks generally seem to be homogeneous, but in spite of strong recrystallization, darker, denser "fragments" can be seen in some places. These fragments are probably similar to those found in the crystalline transitional types. The aplite-like porphyries have been assimilated by the granites, and large xenoliths exist in the latter (cf. Fig. 4).

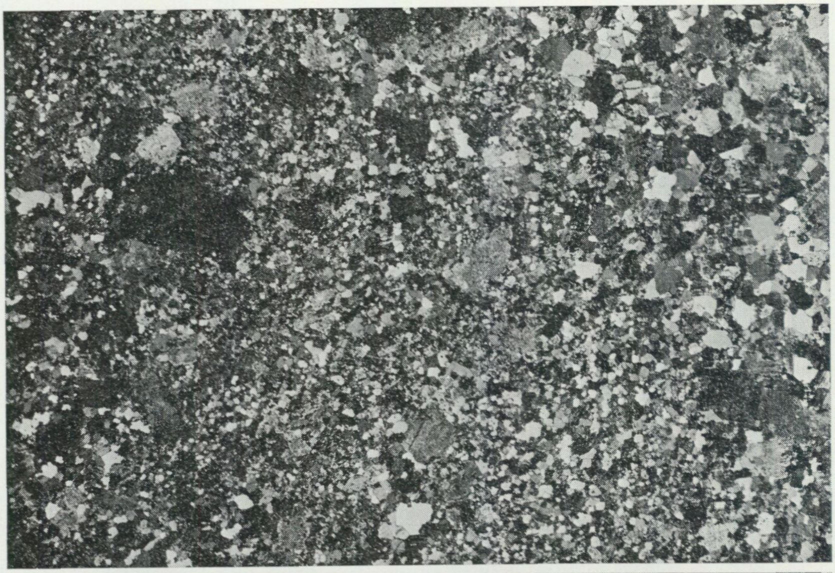


Fig. 3. Aplite-like porphyry. Storebro. Nic. crossed x7.
Fig. 4. Red, medium- to coarse-grained, salic granite. 4.3 km ESE of Storebro. Nic. crossed x7.

GREY PORPHYRITES

This rock type mainly occurs immediately south of Storebro, in some small massifs (Fig. 2). It is called grey gneiss by Holst (1885). In hand specimen the rocks are grey, fine-grained to finely medium-grained. The grey porphyrite has a distinctly inhomogeneous groundmass. This rock type generally carries dark lenses of varying size (from some mm to five cm, Fig. 5), consisting of fragments in a tuff matrix (Fig. 6). The lenses form a lineation, which is rather constant (average plunge 10—15°N, but varying between 5—25° N25°W—N15°E). North of the area investigated near Kvillehult the plunge is gently towards the south (10—20°). A foliation has also been developed: strike N40°W, dip 20—25°NE. This direction is subparallel to a compositional banding of small intercalations of a red rock similar to the aplite-like porphyry which occurs in this foliation plane. There are successive transitions to the normal grey and grey-red agglomerates, but in the latter the lenses are scattered. The grey porphyrite has a quartz-latitic groundmass.

Under the microscope the grey porphyrite has a quite crystalline, but inhomogeneous groundmass (Fig. 6). Normally it is fine-grained to microcrystalline. The phenocrysts usually constitute about 40 % of the rock. The red, salic, medium-grained granite 1.5 km WSW of Storebro (alkali granite according to Streckeisen's terminology 1967) cuts the grey porphyrite, and the granite contains xenoliths of the porphyrite measuring 4—5 cm in length. The colour of the porphyrite xenoliths is almost red.

CRYSTALLINE TRANSITIONAL TYPES

The crystalline transitional types are a group of rocks which, with regard to crystallinity, are intermediate between the aplite-like and the rather well-preserved porphyries. This rock type very often contains fragments which are strongly elongated and often autobrecciated. In hand specimen this rock is red and very dense, but under the microscope completely crystalline. The chemical analysis of the rock shows an alkali rhyolite. Phenocrysts constitute only 5 % of the rock. There are elongated quartz aggregates and "veinlets", which may correspond to recrystallized spherulite aggregates in an original volcanic glass. Garnet has been found in this rock type.

TUFFS AND AGGLOMERATES

Airborne tuffs have been developed by a more explosive vulcanicity than ignimbrites (Rittmann 1960). The term agglomerate is used for a consolidated volcanic rock of pyroclastic origin, which consists of rounded or angular fragments lying in a matrix of tuff (Carozzi 1960, pp. 94—96 cf. Fisher 1966, pp.

291—297). In special cases some sedimentary material might be involved (cf. Török 1962, pp. 351—354).

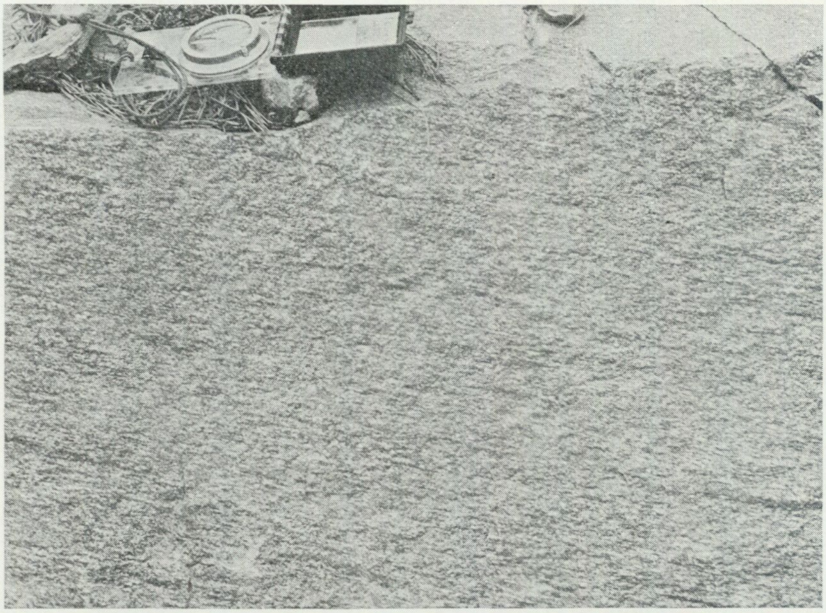
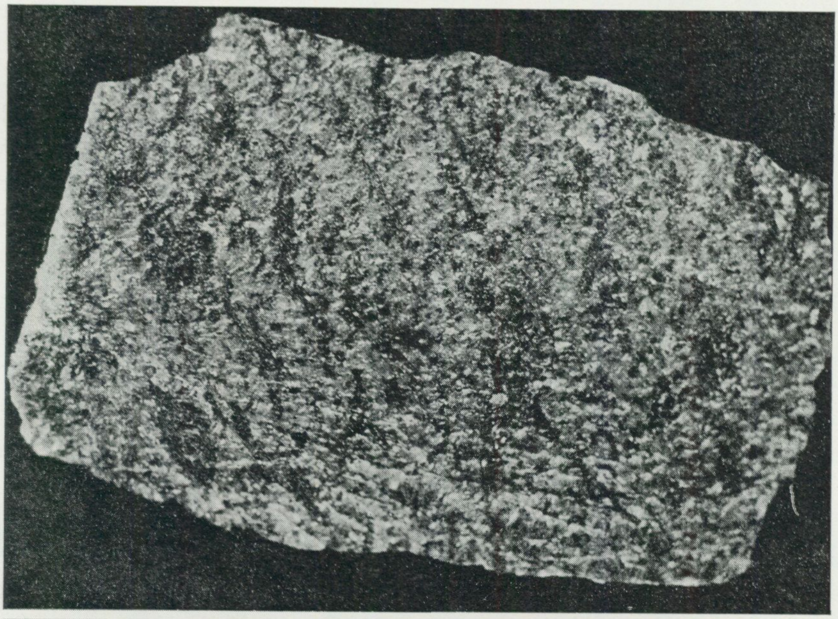


Fig. 5. Grey porphyrite (tuff) with a distinct lineation. Road-cutting 0.6—0.7 km SSE of Storebro.

Fig. 6. Thin section of the rock type of Fig. 5. Strongly transformed phenocrysts in a completely recrystallized groundmass. Nic. crossed x7.

In the area occur both strongly recrystallized and rather well-preserved agglomerates. The strongly recrystallized types are similar to the aplite-like



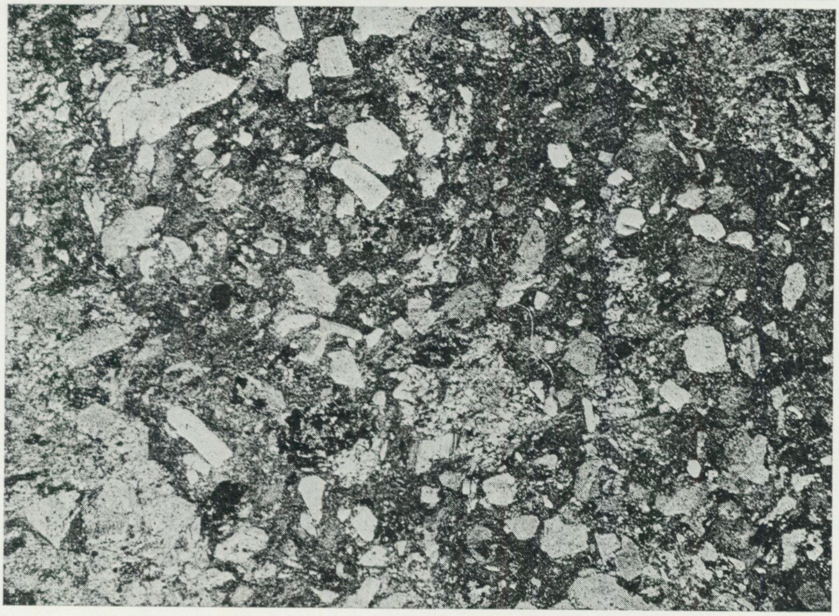


Fig. 7. Yellow to light red agglomerate. 1.6 km SW of Råddehult. Scale 1:1.3.
Fig. 8. Thin section of the rock type of Fig. 7. A large number of phenocrysts occur in a dense, well-preserved, mostly cryptocrystalline groundmass. Nic. crossed x7.

porphyries and the grey porphyrites found in the topographically low parts of the area. The massifs generally have a northwesterly orientation. Usually the rocks have grey to greyish red colours. The groundmass is normally microcrystalline, but transitions to fine-grained types occur. These rocks have a very inhomogeneous groundmass, and phenocrysts constitute between 25 and 40% of the rock. Transitions to /lapilli/tuffs normally occur.

A well-preserved agglomerate is found 1.5 km ESE of Gisseskalle and 1.6 km SW of Råddehult. This rock type has a yellow to light red colour with elongated, dark lenses measuring 2—3 cm in length (Fig. 7). The groundmass varies between crypto- and microcrystalline. Phenocrysts constitute about 25% of the rock (Fig. 8).

RED PORPHYRIES AND RED "FLAMY" PORPHYRIES

The red porphyries sometimes carry fragments. These fragments are described below among the special structural forms. Even the red "flamy" porphyries may carry fragments, but usually they are rather homogeneous.

In hand specimen these porphyries are red and dense, while the red "flamy" porphyries are dark with red, irregular parts. These rocks are called "flamy" owing to this change in colour. They are usually better preserved than the red porphyries. Both rock types contain about 10% phenocrysts (sometimes less than 10%). Chemically the rocks correspond to rhyolites, or, rarely, alkali rhyolites. Under the microscope the groundmasses are inhomogeneous and microcrystalline, rarely cryptocrystalline.

DARK PORPHYRIES

The dark porphyries are the best preserved of the area. As is the case in all old volcanic rocks, devitrification has destroyed the original vitreous character. But in these devitrified rocks there is often still a distinct fluidal character (cf. Ross and Smith 1961, pp. 26—36). The dark porphyries form the highest hills in the area investigated, e.g. Gisseskalle 234.8 m and Gökhult 214.6 m, whereas the topographically lowest parts are situated at levels of about 100—120 m and occupied by granites.

The dark porphyry at Gisseskalle is a well-preserved, brown, rather dense rock type with darker, denser, elongated, somewhat rounded fragments. The size of these fragments varies between 1 and 10 cm (Fig. 9). They consist of spherulites, i.e. devitrified volcanic glass. The dark porphyry at Gökhult is of the same type as the one at Gisseskalle, although it is as a rule black in colour and its fragmental character is not so distinct. At close quarters this brown or black porphyry changes to red "flamy" and red types. The rocks now described correspond to rhyolites.

Under the microscope the rocks show a cryptocrystalline groundmass,

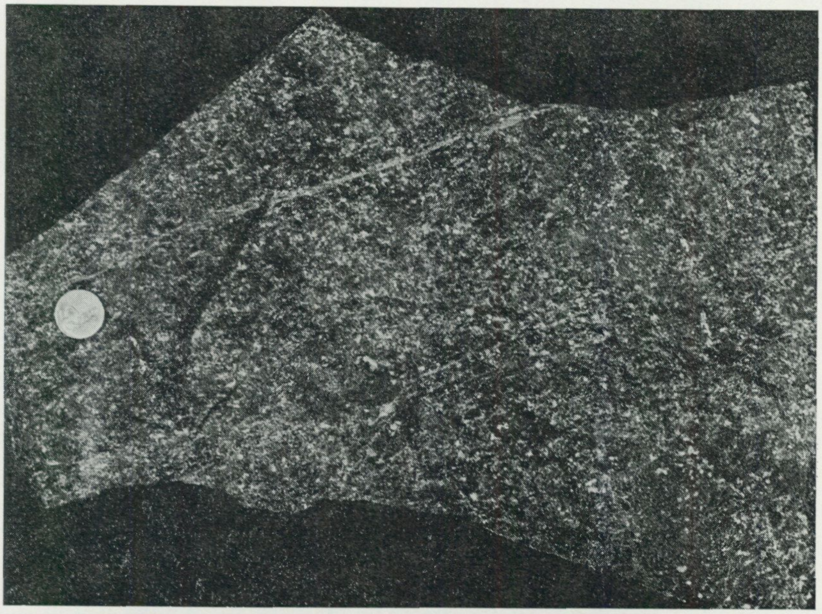


Fig. 9. Dark porphyry with rounded to angular spherulite aggregates. Gisseskalle. The diameter of the coin is 17 mm.

Fig. 10. Thin section of the rock type of Fig. 9. Well-preserved, cryptocrystalline, sericite-rich groundmass with spherulite aggregates. "Pseudo"fluidal texture. Nic. crossed x7.

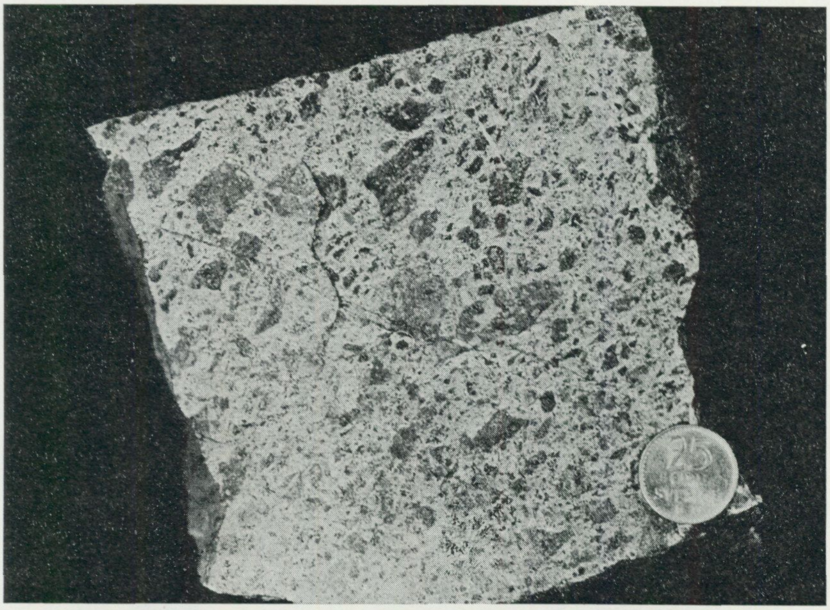
which is stained by ore minerals and sericite. The sericite usually defines a fluidal texture around the phenocrysts (Fig. 10). Veinlets of quartz often have the shape of semi-circles possibly revealing an original perlitic texture. Aggregates of spherulites occur (Fig. 10) and mark an obvious eutaxitic texture (cf. Smith 1960 a, p. 515). Phenocrysts in these two rock types constitute 12 and 11 % respectively (point counter analyses; 700 points).

The grey porphyry is a special rock type, which is exposed, for example, at Gåskullen 2 km N—NNE of Faggemåla. It is a grey rock type with dense fragments, which may be subrounded, subangular or angular. The size of these fragments varies between 1 and 20 cm (Fig. 12). The groundmass is rich in sericite, whereas the rock matrix seems to be sericite-poor. The fragments may be of glass origin. Phenocrysts are estimated to constitute 20 % of the rock.

INTERCALATIONS OF "GLASS" IN THE WELL-PRESERVED VOLCANIC ROCKS

In the red, red "flamy" and dark porphyries occur dense, green, partly "schist"-like fragments (Fig. 13) of different sizes (1 dm to 1 m). These are of perlitic origin. In the central parts of the area the fragments are elongated mainly in a NNW—NNE direction. In the southernmost parts of the area, most fragments are oriented WNW—ESE, the dip generally being about 70° to the south. The frequency of these fragments seems to increase towards the southern parts of the area, thus, in the direction of the better preserved porphyries. Small "massifs" (several m^2) of felsitic rocks can be found. These are similar to the types of the above-mentioned fragments showing stronger alteration. All fragments now mentioned display more or less blurred contacts with the surrounding porphyries. The fragments have a cryptocrystalline groundmass rich in sericite showing a beautiful fluidal texture. Sericite and lepidoblastic, undulose quartz reflect a beautiful perlitic texture (Fig. 14), where quartz aggregates often form the centres. The next stage of alteration is probably a very sericite-rich groundmass with a large number of rounded quartz grains. This rock type occurs near Granberg (1.5 km NNW of Faggemåla). It has been called a felsite.

The groundmasses of the porphyries are cryptocrystalline with much sericite showing a fluidal texture. Spherulites exist. Under the microscope appear some fragments, which are rounded, cryptocrystalline and lacking sericite. Similar fragments exist in the green tuff (described below) and in the agglomerate at the road-cutting in Lönneberga (cf. Fig. 11), where a grey felsitic rock type is represented. These types of fragments are special and cannot be correlated with aggregates of spherulites or of perlitic texture. They may have been formed as aggregates of volcanic ash. The two mentioned felsites (at Granberg and Lönneberga) have high Niggli si and al values, while the content of alk, especially Na_2O, is low. The content of mafic constituents is low. Thus, q and c (CIPW norm) are high, whereas the content of or is normal or low and ab and an (CIPW norm) are low (Table 4).



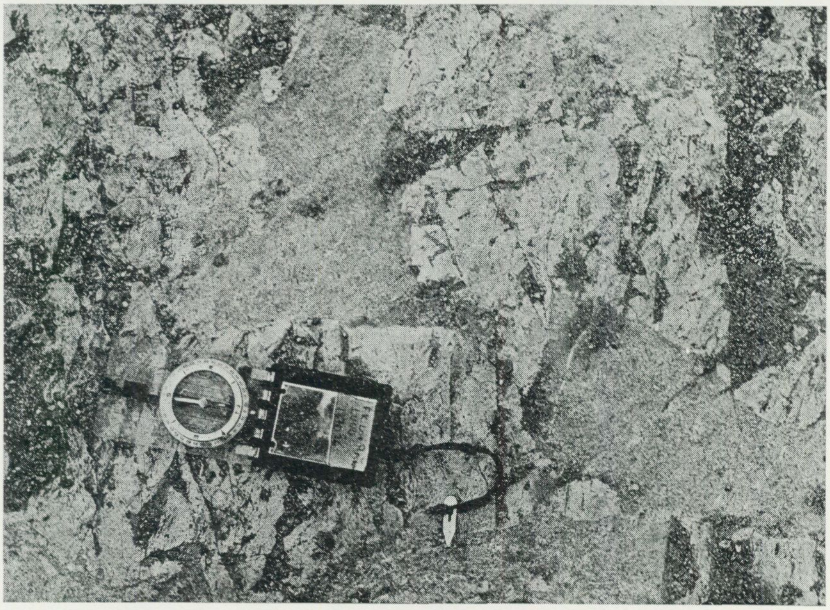
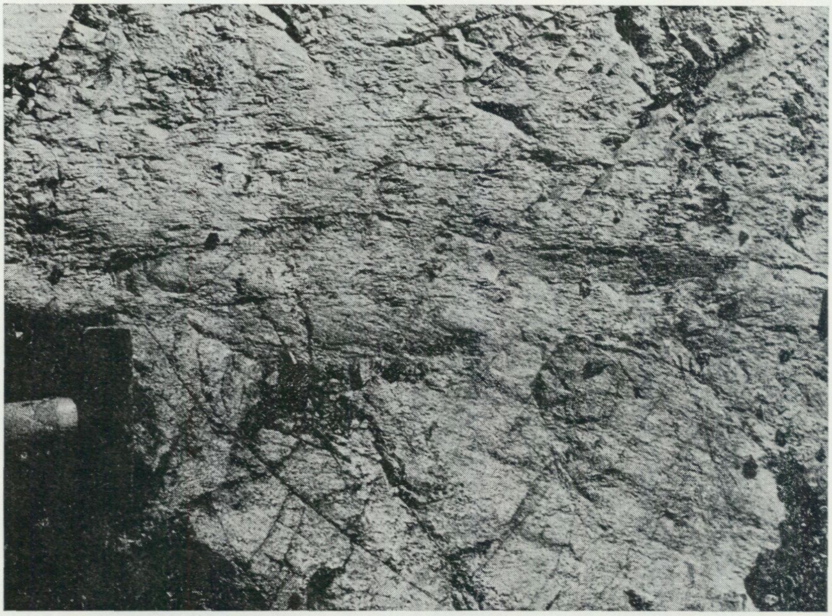


Fig. 11. Tuff with large number of fragments. Road-cutting, Lönneberga. The diameter of the coin is 17 mm.

Fig. 12. Grey porphyry with subrounded to angular fragments. Gåskullen.

Apart from the "normal" groundmass, these volcanic rocks consistently contain aggregates corresponding to volcanic ash and glass of earlier formation. Both spherulites and aggregates with perlitic textures are formed by devitri-



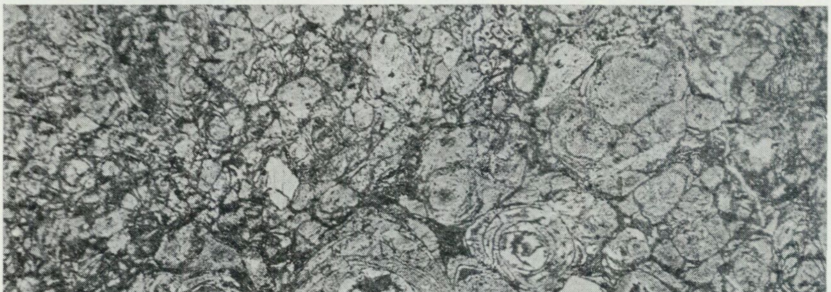


Fig. 13. "Perlite" fragments in red porphyry. 2.9 km S of Storebro.
Fig. 14. Perlitic texture. Thin section. 1.8—1.9 km ESE of Gisseskalle. 1 nic. x40.

fication of volcanic glass. Two types of glass have been reported in many rhyolitic rocks (e.g. Steiner 1960, pp. 7—11, cf. Hjelmqvist 1961; Martin and Lewis 1963). According to Ross and Smith both obsidian and perlite are present. The perlite was formed as a result of a secondary process (Ross and Smith 1955, pp. 1072—1080 cf. Pantó 1962, p. 322).

GREEN, IN PART AGGLOMERATIC TUFF

The green tuff crops out in a small area 1.4—1.8 km ESE of Faggemåla. Similar rock types are found 5 km WSW of Vena (about 10 km SE of Storebro), in Lönneberga (about 8 km SW—WSW of Storebro) and north of Karlstorp (22 km SW—WSW of Storebro). Obviously it is thus abundant in the southern parts of the volcanic area. The main outcrop is oriented WNW—ESE. In the northern marginal parts of the outcrop, agglomerates are well represented and contain rounded, subrounded to subangular fragments of normal porphyries (i.e. red, red "flamy", and dark porphyries). The size of the fragments ranges from some cm to 2—3 dm, rarely 1 m. Some are elongated in a WNW direction of foliation. This rock type is called conglomerate-like *hälleflinta* by Holst (1885) and agglomerate-lava by Nordenskjöld (1894). As the fragments are made up of one rock type only, the rock can be called a pyroclastic breccia (cf. Fisher 1958, p. 1072, 1961, p. 1412, 1966; Wright and Bowes 1963, pp. 83—85, 1968, p. 15; Parsons 1969, pp. 270—277).

The green tuff is associated with a grey-green-brown rock containing up to 40 % phenocrysts. This rock is in part similar to the green tuff. The phenocrysts of this rock type are small. In hand specimen the rock looks felsitic, and there are parts with only about 5 % phenocrysts. The "felsitic" rock type corresponds to a rhyolite, while the green tuff is a quartz latite. An average chemical analysis of the Lönneberga eodacite (Nordenskjöld 1894) shows a rhyodacite.

The phenocrysts of these two rocks are usually lath-shaped, but often bent and crushed. According to Cook (1968, pp. 114—147), this crushing can occur (1) in the magma chamber, (2) during the deposition, and (3) *in situ* owing to welding and compaction. Different types of "groundmass" exist in the green tuff (Fig. 15), viz. (1) cryptocrystalline, very sericite-rich, with a large number of phenocrysts and a distinct fluidal texture, (2) rounded and elongated "fragments" of a cryptocrystalline groundmass without phenocrysts and sericite, but sometimes with spherulites (this might be an ash aggregate), and (3) lenses and "veins" of spherulites (originally volcanic glass), partly fluidally arranged. Both in the green tuff and the felsite-like rock occur 5—10 mm rounded, white- and red-coloured augen. Some red augen have been found to consist of spherulites. Others consist of quartz, and, in the cores, of epidote minerals.

sphene, allanite, leucoxene, ore minerals and chlorite. Some of these augen may be interpreted as subsequently filled original lithophysal cavities, but mainly they display spherulite aggregates. Open cavities have been reported from the

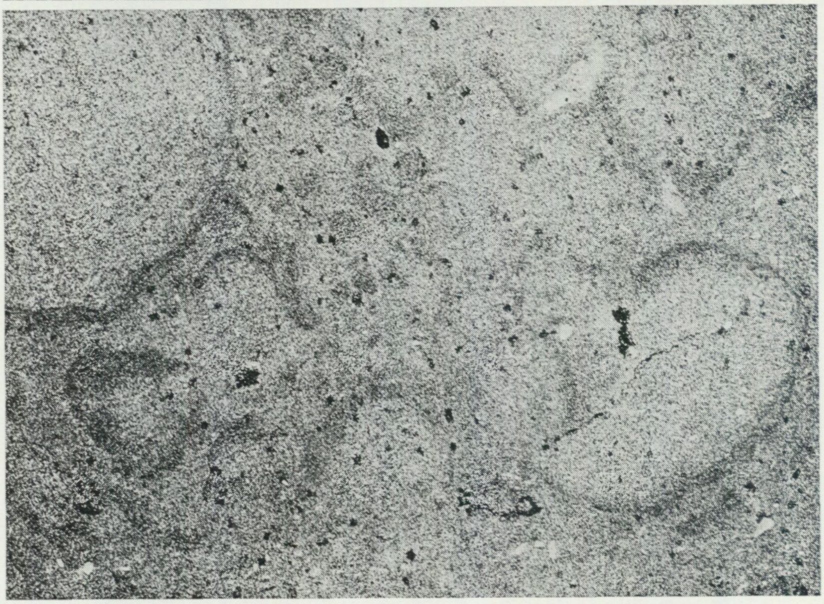


Fig. 15. Green tuff. Sericite-rich, cryptocrystalline groundmass with a streaky texture. Spherulite aggregates. 1.6—1.7 km ESE of Faggemåla. Nic. crossed x7.

Fig. 16. Pisoliths in the greyish to greenish brown tuff. 1.6—1.7 km ESE of Faggemåla. Nic. crossed x7.

green tuff (Högbom et al. 1910, p. 1031). Lithophysal zones have been reported in welded tuffs from, for instance, southern Nevada (Lipman et al. 1966, p. F5, cf. Smith 1960 a, pp. 831—835).

In the dense felsite-like rock type small elliptic rings (5—7 mm in diameter) have been found. Under the microscope they appear as rounded, dark rings. The inner parts are more crystalline (Fig. 16). These are pisoliths. According to Rittmann (1960, p. 85, cf. Lundqvist 1968, p. 113) pisoliths are small compact balls, developed during eruption rains owing to the fact that fresh glass-ash has a strong cementation tendency. They are typical of subaerial eruptions.

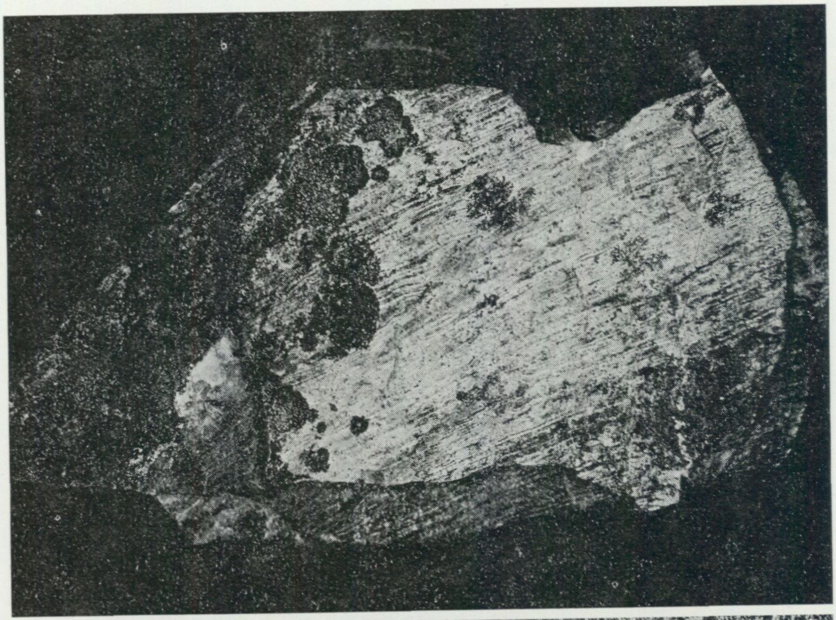
The green tuff seems to be the youngest extrusive volcanic rock in the area investigated. The intermediate (i.e. more basic) so-called Nymåla granophyre (Nordenskjöld 1894, p. 108) about 11 km WSW of the area investigated appears to contain large xenoliths of the green tuff. Consequently, a stage of more basic eruptions may have occurred after the acid vulcanism, but before the formation of the plutonics.

SPECIAL STRUCTURAL AND TEXTURAL FEATURES OF THE PORPHYRIES

South of Fårudden (about 1.5 km NW of Gisseskalle), 2—2.1 km NE of Gisseskalle, and at some other localities occur strongly elongated, "elliptic" quartz-spherulite aggregates, which sometimes are only 1 mm in width (Fig. 17). Occasionally an autobrecciation of these aggregates is also visible (Fig. 19). The aggregates define a foliation, which has highly variable dips. Small folds have also been developed. Similar rock types have been found in the western parts of the Sjögelö area and in the neighbourhood of Nybro (southeastern Småland). The aggregates may have a length of 5 cm. Quartz and spherulites are the main constituents of these band or veins. The quartz is undulose and lepidoblastic. It is often oriented perpendicular to the band direction. The bands are beautifully bent around the phenocrysts (Fig. 18). This parataxitic structure mainly occurs in the red porphyries, but occurs also in the red "flamy" porphyries. Probably similar structures occur among the transitional types, even if strongly transformed. The fragments or aggregates were originally glass fragments, in which the glass has been transformed to spherulites and, later, to quartz. Quartz alone may occur in such lenses and fragments. Glass shards have been observed in the groundmass of one red porphyry containing the above-mentioned fragments.

The orientation of these fragments is similar throughout the whole district. The trends are NNW—SSE, WNW—ESE and E—W. Fold axes are found in NNW—SSE directions and indicate tectonic deformation. However, a primary flow structure may have existed. This phenomenon is known in welded tuffs

(Schmincke and Swanson 1967 b, pp. 656—659 and p. 641, cf. Ross and Smith 1961, pp. 18—26 after Kuno 1941; Hoover 1964, p. 83; Noble 1968, pp. 721—



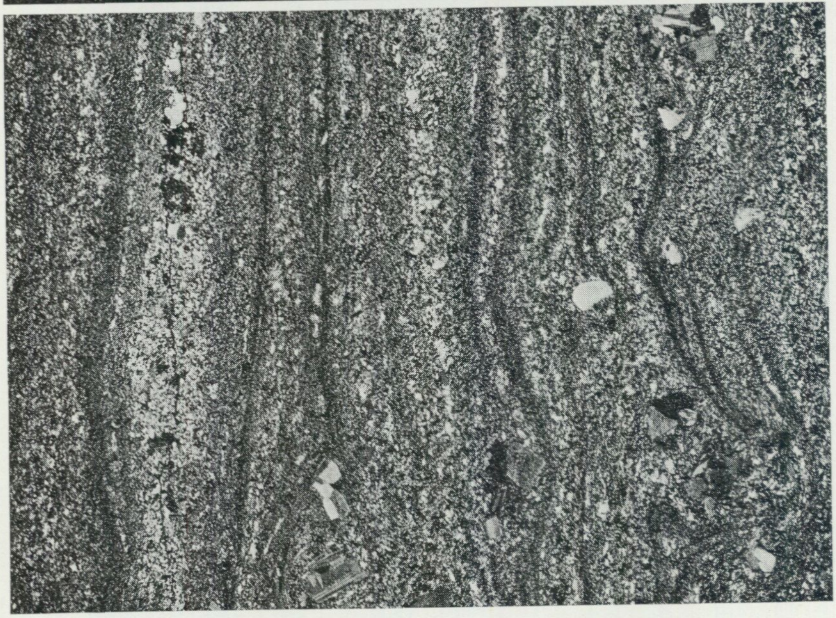


Fig. 17. Banded, parataxitic, red porphyry with strongly elongated spherulite aggregates. Scale 1:1.6. Fårudden, 1.5 km NW of Gisseskalle.
Fig. 18. Thin section of the rock type of Fig. 17. Nic. crossed x7.

724; Smith and Elston 1968, p. 207; Walker and Swanson 1968, p. B47; Elston and Smith 1970, p. 3393; Almond 1971, p. 172). According to Tazieff (1970,

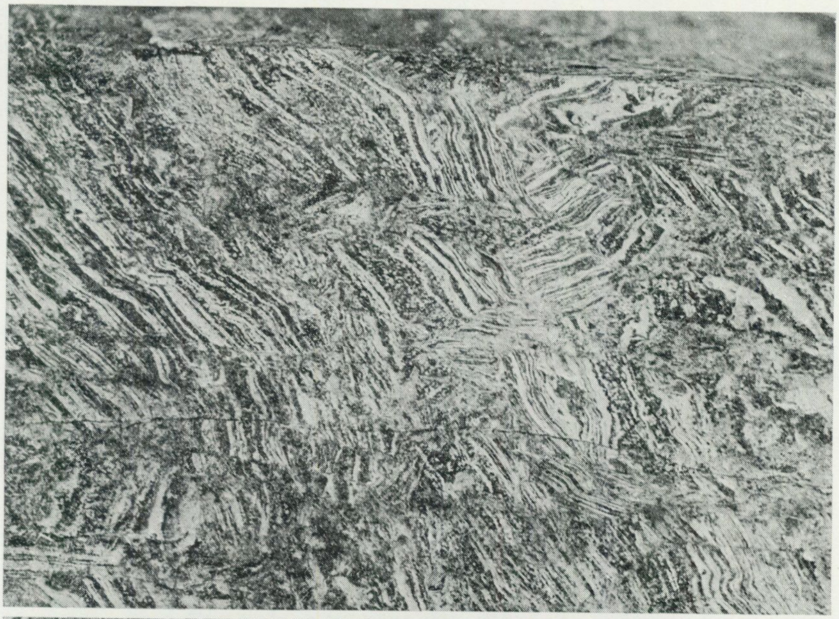


Fig. 19. Banded, parataxitic red porphyry. Autobrecciated. Scale 1:0.6. Fårudden, 1.5 km NW of Gisseskalle.

Fig. 20. Gabbro with big hornblende crystals. 3.2—3.3 km E—ENE of Storebro. Nic. crossed x7.

pp. 162—164) the large areal extent of ignimbrites and the conservation of heat can be explained by the high contents of heavy carbon dioxide in the gas phase.

From the investigation of different zones in an ash flow unit in the Canary Islands, Schmincke and Swanson (1967 b, pp. 646—648) found that the fragments in the basal part were paper-thin and elongated, while they were equidimensional in the upper parts and similar to the ramp structure (cf. Gilbert 1938, pp. 1831—1837; Beavon et al. 1961, p. 604; Fitch 1967, p. 203). Folds owing to flow developed in the pressure shadows of these fragments. Thus, the parataxitic rocks of the area investigated were probably formed by a primary flattening. In some places they possibly show a primary flow structure. Later, a tectonic deformation has affected the rocks.

Quartz and/or epidote minerals often occur as spots or veins in all the volcanic rocks. Because these minerals also occur in thin joints, they seem to have formed at a late stage. Around these spots or veins reaction zones are common, ranging in colour from, for example, in the aplite-like porphyries light red and in the green tuff black. The spots may mark former cavities in the rocks.

In some outcrops 0.4 km WNW of Råddehult occur fragmental rocks. These rocks belong to the transitional porphyry types. In a light red, recrystallized rock there is an occurrence of darker and denser fragments, which are subangular to angular. They are also oriented in bands or ”veins”. Autobrecciation has certainly caused the formation of the angular fragments. Similar structural forms have been found at other places in the area. A comparison can be made with the above-mentioned structural forms, but the recrystallization is too strong to allow an exact interpretation.

In the transitional porphyry types 1.2—1.3 km E—ENE of Råddehult, the rock has a distinct parallel structure formed by quartz bands and the parallel arrangement of aggregates of quartz. On weathered surfaces these aggregates are seen as lenses of light red colour, normally 6×2 mm in size. The strike is NNW—SSE, and the dip vertical. Under the microscope the quartz is lepidoblastic and undulose. In these aggregates also occur muscovite, garnet, ore minerals, and small plagioclase laths. Some of the aggregates are beautifully bent around the phenocrysts. Their origin is difficult to state, because recrystallization has been strong, but they resemble very much the spherulite aggregates of the better preserved porphyries, which mainly consist of quartz when altered.

A compositional banding owing to chemical and mineralogical differences in the material is visible in the aplite-like porphyries south of Storebro. The orientation of this banding is about N 50° W, 45° NE, and is thus identical with the foliation of the grey porphyrite. It may be subparallel to the ”bedding”. This ”bedding” is cut by a NNW foliation, which dips 60—85° E.

SUMMARY OF IDEAS ABOUT THE VOLCANIC ROCKS

Recrystallization and tectonic deformation have destroyed many primary features of the rocks. In some of the porphyries ignimbrite textures and structures occur (cf. Hjelmqvist 1956; Lundqvist 1968), and even if such structures and textures are lacking in most of the porphyries, they are all interpreted as belonging to an ignimbrite sequence with intercalations of tuffs, lapilli tuffs, and agglomerates. Structural and textural criteria are not enough to prove an ignimbrite origin (cf. Hentschel 1955, p. 142; Pichler 1963, p. 288; Schmincke and Swanson 1967 a, p. 702). However, the porphyries showing ignimbrite structures and textures have a large regional extent. This is an important support of an ignimbrite origin. Ignimbrites are considered to be the acid equivalents of plateau basalts (Steiner 1960, pp. 34—36, cf. Rittmann 1962). The difference between lavas, ignimbrites and tuffs can be difficult to define in metamorphic rocks (cf. Gaedeke 1962; Cook 1966, p. 161) and, besides, these rock types very often occur together (cf. Schmincke 1970, p. 1215; Pichler and Zeil 1972, p. 428). The rocks called tuffs and agglomerates are different from the porphyries. The differences are in chemical composition, structure and texture. Chemically, the grey porphyrite and green tuff have a quartz-latitic groundmass. In comparison with the porphyries they are richer in Al_2O_3, CaO, MgO, total Fe, and poorer in SiO_2. Besides, phenocrysts constitute a much greater proportion of the rock than in the porphyries. Thus, an intercalation of tuffs in the porphyries seems obvious. A possible increase in the contents of aggregates with perlitic texture and of spherulites in the direction of the well-preserved porphyries (particularly the dark porphyries) is described above. Possibly there is an evolution towards a lower volatile and water content and a higher viscosity (cf. Kennedy 1955, pp. 494—496; Pichler 1959, pp. 114 and 130; Hrdličková 1966, p. 198). The comparatively quiet ignimbrite emission has been interrupted by the formation of explosive, subaerial tuffs and agglomerates (cf. Tazieff 1970, p. 158; Rittmann 1967).

PLUTONIC ROCKS

Different types of granites and basic plutonics have traditionally been distinguished in the Småland region owing to, for example, differences in colour and grain size (Holst 1885, pp. 24—33, and pp. 32—37, cf. Eichstädt 1887, p. 7). Examples are the red Växjö granite, grey Växjö granite, and intermediate Filipstad augen granite. The commonly held view is that the plutonics are co-magmatic (cf. Lundegårdh 1950 a, 1950 b). The basic massifs often have a core of gabbro, while the borders are of diorite (Svedmark 1904, p. 26). The basic rocks are considered to be older than the acid ones (e.g. Munthe and Hedström 1904, p. 19; Hjelmqvist 1934, p. 171; Geijer et al. 1951, pp. 18—21). The large mass of Småland granites is inhomogeneous, and several granite generations certainly occur (cf. Hjelmqvist 1969; Elbers 1971; Gorbatschev 1971; Röshoff 1973). Elbers (1971, p. 47) considered some massive Småland granites to be serorogenic, while Gorbatschev (1971, p. 51) expressed the view that other Småland granites are mainly post-orogenic or extra-orogenic. Elbers (1971) considered the porphyritic granites of Loftahammar type to be primorogenic and prekinematic. Röshoff (1973) investigated a differentiated sequence of plutonics (gabbro to granodiorite) in the province of Småland. The Rb/Sr isochron age of the granodiorites is 1839 ± 58 m.y., and these rocks are younger than the sediments and the volcanics of the related area. Thus, there seem to exist syn-, ser- and postorogenic Svecofennian plutonics in Småland.

A basic massif is situated in the northeastern part of the area investigated (Fig. 2). Its centre is made up of a hornblende gabbro (Fig. 20), whereas the margins are of dioritic composition (nomenclature according to Moorhouse 1959). Fine- and medium-grained diorites can be distinguished. Schlieren of hornblende granite occur in the diorite (cf. Eichstädt 1887, pp. 16—18), and a differentiation sequence gabbro→diorite→quartz diorite to hornblende granite seems probable. A granodioritic massif is situated about 1.6 km WSW of Storebro (Fig. 2). This granodiorite contains 40—45 % plagioclase, while quartz and alkali feldspar (mostly perthitic) constitute 15—20 % (1000 points). The red, salic granite has a large areal extent (Fig. 2). It may exhibit a fine-grained contact facies towards the volcanic rocks. The porphyritic structure (visible in all granites) is then particularly distinct. The red, salic granite has in places assimilated rather large masses of porphyritic material. The granites also contain xenoliths of diorite and, more rarely, quartzite.

The basic rocks carry hornblende which is secondary after pyroxene. The hornblende in the gabbro constitutes about 35—40 % and in the fine-grained diorite c. 5—10 % (800 and 411 points, cf. Table 3). Diffuse pyroxene remnants can occasionally be seen. The optical character and the extinction suggest that these remnants indicate a clinopyroxene, probably augite. The hornblendes normally show the pleochroism X light yellow, Y yellow green and Z yellow green, while the greatest value of birefringence is 0.021 in the gabbro and 0.018 in the diorite. 2 $V\alpha$ of the hornblendes of the gabbro varies between 72 and 88° (the mean value 80° gives 82 % Mg according to Tröger 1956). The corresponding values of the hornblendes of the granodiorite are 56—68°. A mean value of 63° gives 25 % Mg (Tröger 1956). The maximum An contents of the plagioclases correspond to intermediate labradorite in the gabbro, acid labradorite in the fine-grained diorite and acid andesine in the granodiorite. The corresponding plagioclase contents are about 40 %, 65 % and 40—45 %. In addition the following minerals have been observed in the basic rocks, viz. sericite, biotite, light green chlorite, penninite, muscovite, sphene, epidote, zoisite, clinozoisite, ore minerals (magnetite, titanium-iron oxide, pyrite and chalcopyrite), quartz, apatite, zircon, calcite, K-feldspar (perthitic), and leucoxene.

Three of these rocks (gabbro, fine- and medium-grained diorite) have been chemically analysed. The marginal parts of the diorite have been affected by the granite. Thus, this diorite is high in q and or, and poor in an (CIPW norm). In comparison with the diorite the gabbro is poor in SiO_2, Na_2O, K_2O, TiO_2, P_2O_5, Fe_2O_3 and BaO. The variations from the central gabbro to the fine-grained diorite involve a decrease in FeO and MgO. As regards trace elements, the gabbro is rich in Co, Ni, Cr and poor in V in comparison with the diorites (cf. Taylor 1965, pp. 168—176). These facts are evidence of differentiation, but the analyses are too few to permit definite conclusions.

The granites of the area are always massive and mostly hypidiomorphic (Fig. 4). The minerals are the same as in the volcanic rocks. Hornblende is quite rare in the red, salic granites. The maximum An contents correspond to intermediate and acid andesine. The granites are very rich in perthite, film, string, braid and patch perthites being most common. In the patch perthites 2 $V\alpha$ of the alkali feldspar ranges between 77 and 81°, corresponding to microcline according to Kerr (1959). The granites as well as the aplite-like porphyries vary between monzo- and syenogranites according to Streckeisen (1967). Planimetric analyses show that the medium- to coarse-grained granites contain 20—30 % quartz, 25—65 % alkali feldspar (mostly 50—55 %), and 15—30 % plagioclase. The corresponding values for the aplite-like porphyries are 40 %, 35—40 %, and 20—25 % (point counter analyses with 800—1000 points). According to the terminology of Rittmann (1952), most granites correspond to "quartz latites".

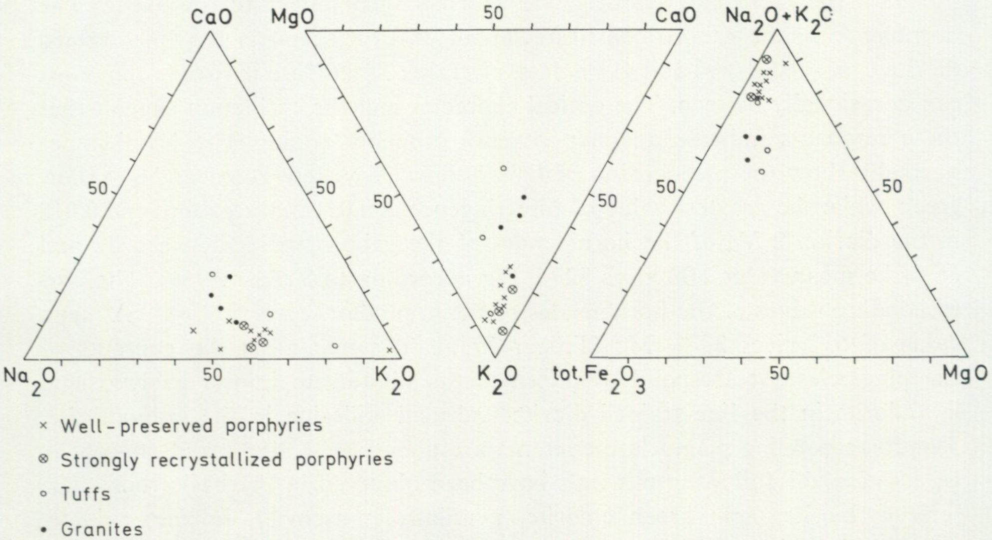


Fig. 21. CaO—Na_2O—K_2O, MgO—CaO—K_2O and (Na_2O+K_2O)—tot.Fe_2O_3—MgO diagrams of volcanic rocks and granites.

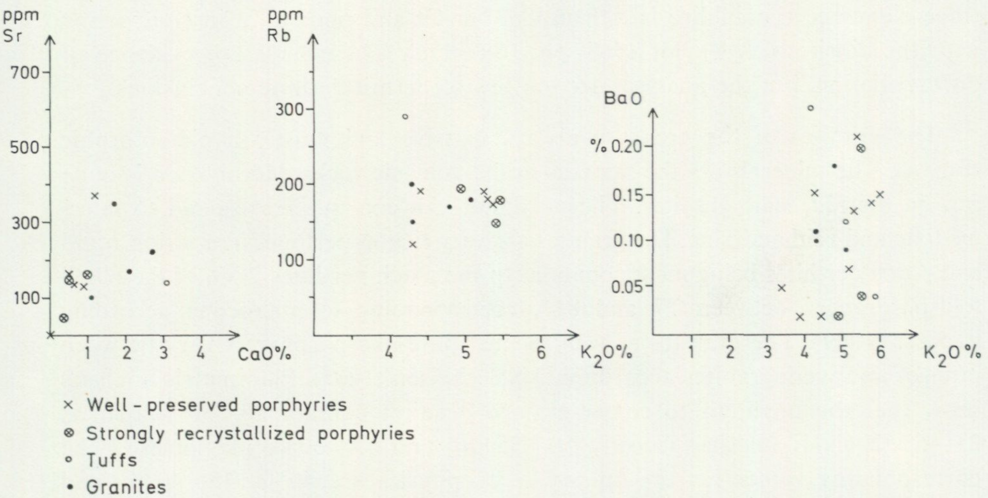


Fig. 22. Plots of Rb and BaO against K_2O, and Sr against CaO for volcanic rocks and granites.

Chemically the granites and the agglomerate—tuffs show great similarities (cf. Fig. 21). The close compositional relationship between volcanic rocks and granites is also demonstrated by variation diagrams of the different oxides in relation to SiO_2. There is a continuous decrease in these from low to high SiO_2-values (cf. Persson 1973, pp. 66—68). In comparison with the porphyries, the granites have lower contents of Na_2O+K_2O and higher contents of total Fe_2O_3 and MgO (Fig. 21). Generally the porphyries are higher in K_2O, especially the strongly recrystallized types (Fig. 21). The contents of K_2O vary, possibly depending on secondary alterations (cf. Fig. 22).

A red, medium-grained granite (1.5 km WSW of Storebro) is an alkali granite according to the terminology of Streckeisen (1967). The K-feldspar (perthitic) content of this granite is about 60 %. The plagioclase content is very low (about 5 %), while the quartz content is between 25 and 30 % (800 points). Both myrmekitic and granophyric intergrowths exist in this rock type as well as in the other types.

Available data (e.g. field relations, chemical evidence) support the concept of a differentiation among the basic plutonic rocks of the area investigated (from gabbro to diorite and quartz diorite). The contacts of the basic massif with the aplite-like porphyries possibly dip gently to the west, whereas the contacts with the red, salic, medium- to coarse-grained granites seem to be more or less vertical. The basic rocks, like the volcanic rocks, are affected by the granites. The granites contain xenoliths of both basic plutonic and volcanic rocks. The volcanic rocks were recrystallized during the intrusion of the granites, this recrystallization affecting particularly their marginal parts. Much porphyritic material has obviously been assimilated.

TABLE 2 a. Chemical analyses of volcanics from northeastern Småland. Contents of trace elements in ppm, major elements in weight percent. (Concerning the exact positions of the outcrops for chemical analyses see Persson 1973.)

Analysis	1	2	3	4	6	7	8
SiO_2	69.8	76.1	77.9	76.1	62.9	77.5	73.1
TiO_2	0.40	0.23	0.13	0.21	0.65	0.15	0.31
Al_2O_3	15.0	12.7	11.7	12.8	17.5	12.3	13.8
Fe_2O_3	0.81	0.76	0.39	0.74	2.97	0.33	0.75
FeO	1.00	0.36	0.32	0.35	0.94	0.51	0.70
MnO	0.09	0.04	0.04	0.02	0.09	0.05	0.06
CaO	1.18	0.54	0.35	0.52	3.10	0.23	0.67
MgO	0.73	0.44	0.10	0.36	2.67	0.27	0.44
Na_2O	4.43	3.21	3.21	3.19	4.24	3.61	3.59
K_2O	5.40	5.24	4.93	5.46	4.19	3.91	6.03
Loı	0.31	0.40	0.16	0.32	0.41	0.40	0.22
$H_2O>105°$	—	—	—	—	—	—	—
$H_2O<105°$	—	—	—	—	—	—	—
BaO	0.21	0.07	0.02	0.04	0.24	0.02	0.15
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sum	99.5	100.1	99.3	100.2	100.0	99.3	99.9
U	<30	<30	<30	<30	<30	<30	<30
Th	<30	<30	<30	<30	<30	<30	<30
Rb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d	n.d.
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Suite index	3.6	2.2	1.9	2.3	3.6	1.6	3.1
Suite type	weak Pacific	average Pacific	average Pacific	average Pacific	weak Pacific	strong Pacific	weak Pacific
Nomenclature Rittmann -52	Rhyolite	Rhyolite	Alkali rhyolite	Rhyolite	Quartz latite	Rhyolite	Alkali rhyolite

1. Dark porphyry
2, 7, 10, 17. Red porphyries
3. Crystalline transitional type
4, 16. Aplite-like porphyries
6. Grey porphyrite

Analysis	9	10	11	12	16	17	18	19
SiO_2	72.5	75.4	73.7	66.4	70.8	71.5	77.6	76.7
TiO_2	0.36	0.26	0.25	0.44	0.37	0.28	0.19	0.13
Al_2O_3	14.0	13.1	15.4	17.4	15.0	15.5	13.0	14.3
Fe_2O_3	1.07	0.97	0.91	1.25	1.6	1.3	0.6	0.8
FeO	0.60	0.36	0.42	0.95	0.4	0.3	0.2	<0.1
MnO	0.06	0.05	0.07	0.10	0.08	0.03	0.04	0.06
CaO	0.90	0.79	0.34	1.21	1.0	0.9	0.6	0.1
MgO	0.73	0.50	0.56	1.74	0.44	0.32	0.32	0.1
Na_2O	3.15	4.28	1.13	2.42	3.8	3.5	2.2	<0.1
K_2O	5.81	3.43	5.88	5.13	5.4	5.3	4.3	4.4
Loi	0.31	0.30	1.29	1.49	—	—	—	—
$H_2O>105°$	—	—	—	—	0.3	0.6	0.6	1.5
$H_2O<105°$	—	—	—	—	0.3	0.1	0.1	0.3
BaO	0.14	0.05	0.04	0.12	0.20	0.13	0.15	0.02
P_2O_5	n.d.	n.d.	n.d.	n.d.	0.04	0.02	<0.01	<0.01
Sum	99.7	99.5	100.0	99.0	99.7	99.8	99.9	98.6
U	<30	<30	<30	<30	<20	<20	<20	<20
Th	<30	<30	≤30	<30	<30	<30	<30	<30
Rb	n.d.	n.d.	n.d.	n.d.	150	180	120	190
Sr	n.d.	n.d.	n.d.	n.d.	160	130	140	<10
Suite index	2.7	1.8	1.6	2.4	3.0	2.7	1.2	0.6
Suite type	average Pacific	average Pacific	strong Pacific	average Pacific	weak Pacific	average Pacific	strong Pacific	extreme Pacific
Nomenclature Rittmann -52	Rhyolite	Rhyolite	Rhyolite	Quartz latite	Rhyolite	Rhyolite	Rhyolite	Quartz latite

8, 9. Red "flamy" porphyries
11, 12. Tuffs
18, 19. Felsites
n.d. = not determined
loi = loss of ignition

TABLE 2 b. Chemical analyses of granites and basic rocks from northeastern Småland. Contents of trace elements in ppm, major elements in weight percent.

Analysis	5	13	14	15	20	21	22	23	24	25
SiO_2	65.8	68.9	66.6	66.1	44.5	49.3	47.0	49.5	46.3	47.3
TiO_2	0.58	0.34	0.46	0.51	0.92	1.1	1.2	0.89	0.96	3.9
Al_2O_3	16.6	16.6	17.6	16.3	19.9	18.7	20.0	18.2	20.4	17.8
Fe_2O_3	1.02	1.2	1.8	2.1	3.9	4.3	5.9	5.8	2.5	3.6
FeO	1.50	0.7	1.3	1.7	6.3	5.0	5.1	4.2	6.7	8.9
MnO	0.10	0.08	0.11	0.10	0.15	0.14	0.19	0.20	0.15	0.15
CaO	1.71	1.1	2.1	2.7	9.1	7.2	9.6	7.9	9.7	7.0
MgO	1.52	0.54	1.1	1.4	7.9	5.5	4.6	5.3	6.2	4.8
Na_2O	4.28	4.0	4.1	3.5	2.5	2.8	3.4	2.5	2.3	3.3
K_2O	4.80	5.1	4.3	4.3	1.0	2.3	1.7	1.2	1.0	1.5
Loi	0.50	—	—	—	—	—	—	—	—	—
$H_2O>105°$	—	0.4	0.4	0.7	2.4	2.1	1.4	2.9	2.3	0.8
$H_2O<105°$	—	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.2	0.4
BaO	0.18	0.09	0.10	0.11	0.06	0.13	0.12	0.07	0.05	0.08
P_2O_5	n.d.	0.05	0.13	0.19	0.23	0.4	0.42	0.29	0.20	1.1
Sum	99.1	99.3	100.4	100.0	99.2	99.3	100.9	99.4	99.0	100.6
U	<30	<20	<20	<20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Th	<30	<30	<30	<30	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Rb	n.d.	180	200	150	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sr	n.d.	100	170	220	1500	1100	1500	920	750	760
V	n.d.	n.d.	n.d.	n.d	140	170	190	180	130	150
Cr	n.d.	n.d.	n.d.	n.d.	25	30	10	40	45	25
Co	n.d.	n.d.	n.d.	n.d.	65	45	35	80	50	55
Ni	n.d.	n.d.	n.d.	n.d.	50	30	5	25	40	35

5, 13, 14, 15. Red, salic, medium- to coarse-grained granites
20. Gabbro
21. Medium-grained diorite
22. Fine-grained diorite
23. Uralite diabase
24. Diabase porphyrite
25. Black diabase

TABLE 3. Modal (volume percent) analyses of rocks from northeastern Småland. + = accessory minerals <0.5 %; — = the mineral has not been observed. Numbers correspond to those of table 2 a and 2 b.

Analysis	5	6	14	16	20	22
Quartz	21	16	29	38	2	5
K-feldspar (perthitic)	56	27	27	39	1	3
Plagioclase	16	14	33	19	41	65
Hornblende	—	—	—	—	38	6
Micas	5	13	4	1	2	7
Epidote minerals	+	1	2	1	5	7
Sphene	+	1	1	+	+	+
Ore minerals	1	2	3	1	3	3
Chlorite	+	+	1	+	7	4
Apatite	+	+	+	+	1	+
Zircon	+	+	+	+	+	+
Calcite	+	—	+	—	+	—
Undefined groundmass	—	26	—	—	—	—
Sum	99	100	100	99	100	100
Numbers of points counted	1100	825	818	815	800	411

TRANSITIONS BETWEEN VOLCANIC AND PLUTONIC ROCKS

Successive transitions between volcanic rocks and granites in Småland have been noted by many authors (e. g. Hummel 1877, p. 9; Svedmark 1904, p. 18, 1913, p. 13; Munthe and Hedström 1904, p. 24; Gavelin and Munthe 1907, pp. 43—52; Gavelin 1912, pp. 18—24; Geijer et al. 1951, pp. 12—13, cf. Magnusson et al. 1924, pp. 14—23; Marmo 1962, pp. 140—142). Earlier these rocks of transitional character were called hälleflint gneisses, granulites, eurites and felsites (Nordenskjöld 1894, pp. 7—14). According to Branch the metamorphic effects around a granite area are silicification and recrystallization (Branch 1963, pp. 54—56, cf. Ham et al. 1964, pp. 47—50; Souther 1967, pp. 171—176; Taylor et al. 1968, p. 185). As the rhyolites generally have higher contents of SiO_2 than the granites (cf. Moorhouse 1959, p. 201; Eskola 1962, pp. 137—139), a desilicification would be expected (Härme 1958, pp. 56—60, 1959, pp. 44—54). Epidote is described to have been enriched near the eruptive contacts during thermal and contact metamorphism (Firman 1957, pp. 44—47, Clark 1964, pp. 349—351). All the rocks in the area investigated have a rather high content of epidote. Experimentally, different stages of recrystallization of volcanic glass have been shown, which correspond to the above-mentioned transitions. A final stage would possibly correspond to granophyres and granites (Lofgren 1971, p. 121). According to Nordenskjöld (1894, p. 100) the outer margins of the ”basic” (the mineralogy suggests an intermediate composition) volcanic rock-massif near Karlstorp (22 km WSW of the area investigated) have been altered to diorite-like rocks. Thus, rocks resembling plutonites may be of volcanic origin (cf. Palivcová 1966, p. 71; Palivcová and Šťovíčková 1966, p. 245; Hanuš and Palivcová 1969, pp. 163—165).

CHARACTER OF THE PORPHYRY — GRANITE TRANSITION. A CASE STUDY

A profile from Gökhult in a northeasterly direction has been examined. It passes from dark porphyry via red porphyry, crystalline transitional type, and aplite-like porphyry to red, salic, medium-grained to coarse-grained granite (at Gökhult as well as 700—750 m NE, 1100—1150 m NE, 1900 m NE and 2300 m NE of Gökhult). The groundmasses of the dark porphyries are mainly cryptocrystalline, those of the red porphyries crypto- to microcrystalline, those of the crystalline transitional types microcrystalline, and those of the aplite-like porphyries fine-grained and hypidiomorphic.

The dark porphyry at Gökhult contains 10 % phenocrysts, 70 % groundmass, and 20 % quartz aggregates, the red porphyry 10 %, 50 %, and 40 % of the same components. The crystalline transitional type contains 5 % phenocrysts, 45 % groundmass, and about 50 % quartz aggregates (point counter analyses with 700 points). In the aplite-like porphyry the content of phenocrysts amounts to about 30 % of the rock (300 points). In the strongly recrystallized porphyry types it can be difficult to determine the proportions between groundmass and aggregates, as the groundmass also becomes finely crystalline.

The grain-sizes of the components of the groundmass increase successively from the well-preserved porphyries to the granites (quartz in the crystalline transitional type c. 0.02 mm and in the aplite-like porphyry 0.03—0.1 mm). The size of the phenocrysts in the well-preserved porphyries is smaller than in the red porphyries (0.8 and 0.9 mm respectively; mean values of 50 measurements). The size of the phenocrysts in the crystalline transitional type is very small, i.e. 0.4 mm, whereas it is 0.7 mm in the aplite-like porphyries (mean values of 50 measurements).

In all the well-preserved volcanic rocks the percentage of phenocrysts is lower than in the aplite-like porphyries. The percentage of well-preserved groundmass decreases in the same way towards the strongly recrystallized types. The maximum size of the phenocrysts also decreases from the well-preserved types to the crystalline transitional types but is greatest in the aplite-like porphyries. There is a noticeable decrease concerning size and percentage of phenocrysts in the crystalline transitional types compared to all other porphyries. The crystal size of quartz increases from the well-preserved porphyries to the granites, owing to recrystallization effects.

Typical petrographic zoning exists in ignimbrite deposits (cf. Smith 1960 a, pp. 798—800; Shirinian 1963, p. 16; Vlodavetz 1966, pp. 142—146). These transitions involve certain petrographic and chemical changes. In such a deposit of uniform mineralogy, an increase in the phenocryst content and a decrease of SiO_2 upwards is reported (Lipman et al. 1966, p. F41, cf. e.g. Ewart 1965, pp. 618—620; Lipman 1966, pp. 818—820; Noble et al. 1969, p. 605; Gibson 1970, p. 108; Noble 1970, pp. 2678—2680). According to Hrdličková intercalated tuffs may have smaller contents of Al_2O_3 and greater contents of alkalies and mafic minerals (Hrdličková 1966, pp. 196—198). In the area investigated the rocks characterized as tuffs are comparatively richer in mafic minerals but also richer in Al_2O_3. At the Wildcat section, Nevada, increase of Fe_2O_3 and CaO is reported upwards within an ignimbrite cooling unit (Scott 1966, pp. 278—282). Hrdličková (1966, pp. 196—198) reported an upward increase in Al_2O_3.

It may be suggested that the following age relationships exist among the volcanic rocks (beginning with the oldest): aplite-like porphyries, grey porphyrites, crystalline transitional types, red, red "flamy" and dark porphyries, and finally the green tuff (cf. Table 1). In the porphyries K_2O and SiO_2 have a tendency to decrease towards "the younger rocks". According to Lipman (1965, pp. D5—D22, partly after Simons 1962, pp. 881—882) the crystallized types of volcanic rocks have higher contents of SiO_2 and lower contents of Al_2O_3 as compared to vitrophyres. The strongly recrystallized porphyries generally have higher K_2O-contents than the well-preserved porphyries (cf. Fig. 21), and the latter a still higher content than the granites. The other oxides show a slight tendency to increase towards "the younger rocks". The crystalline transitional type has a high content of SiO_2, while the other oxides show low values. Thus, the crystalline transitional type is very special owing to its high content of SiO_2, low content of other oxides, low content of phenocrysts, and small size of the phenocrysts. These special properties must be primary, possibly suggesting an original basal position for this rock, a fact which is supported by petrographic observations. The similarity between the above-mentioned common features and the related facts in the investigated area is striking, i.e. a possible decrease of SiO_2 and perhaps a growth of alkalies, Al_2O_3 and total Fe_2O_3 towards "the younger rocks". Besides, the phenocryst content is lower in the dark porphyries as compared with for example the aplite-like porphyries.

It is, indeed, difficult to form any definite conclusions concerning the reasons for the variations between the rocks. These differences are mainly primary, but there are many factors that cannot be controlled, such as the primary crystallization of the rocks and the recrystallization, factors depending on the intrusion of the plutonic rocks and the two phases of deformation.

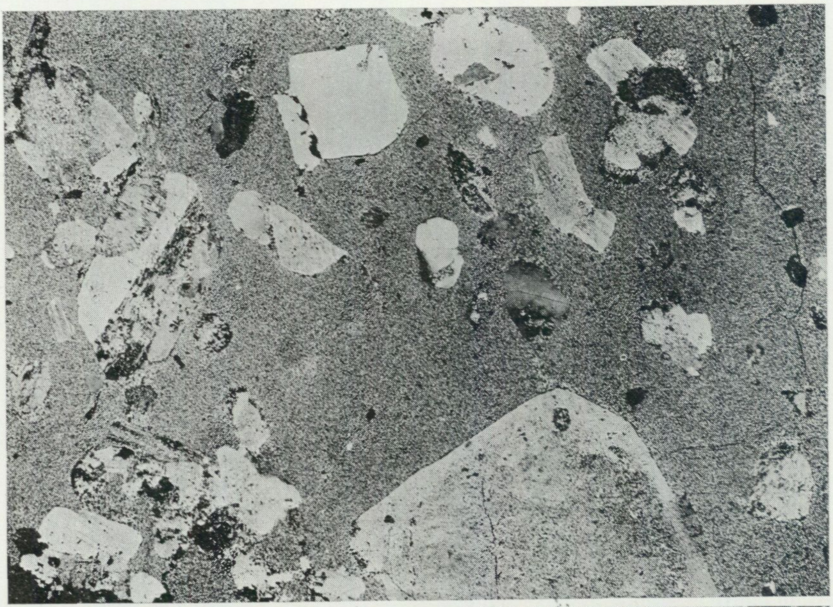
DYKE ROCKS

The dyke rocks comprise granite porphyries (or "dyke porphyries"; max. width c. 50 m), diabase porphyrites (max. width c. 50 m), uralite diabases (max. width c. 5 m) and black diabases (max. width c. 10 m). Most dykes of uralite diabase measure 0.5—1 m across. All dykes are probably younger than the volcanic and plutonic rocks. The granite porphyries have never been seen cutting the plutonics. The orientation of the granite porphyry and diabase porphyrite dykes is generally NNW—NW. Most uralite diabases have ENE—NE and NNW—NW orientations, but other directions are also represented. Some of the black diabases strike in N—S. The granite porphyries also occur as stocks (5—50 m in diameter). All the dykes mentioned are as a rule irregular and end abruptly. The diabase porphyrites have a tendency to widen to the south (cf. Fig. 2). Composite dykes with granite porphyries and uralite diabases occur (cf. Eichstädt 1884, pp. 710—712). The latter seem to cut the granite porphyries. In turn the uralite diabases are cut by the black diabases.

The granite porphyries have been strongly recrystallized, while others, i.e. the dyke porphyries, show many primary textures. Spherulites can be observed in the latter. The rocks are generally grey to red, but also green or brown, with abundant feldspar crystals measuring 1—3 cm in length. The maximum An content corresponds to an acid andesine. Hornblende may appear in these rocks. The minerals present are the same as those reported from the volcanic rocks and the granites (cf. Fig. 23).

The diabase porphyrites are black rocks with grey to light green plagiclase crystals (2—3 cm in length; Fig. 25) and rounded, anorthositic aggregates (20—30 cm across), probably gravitational accumulations in the magma chamber (cf. Gorbatschev 1961, pp. 17—23). The maximum An contents of the plagioclase indicate a basic labradorite. Pseudomorphs of olivine are found. The alteration products are serpentine, talc, tremolite, iddingsite, and ore minerals. Only one pyroxene, clinopyroxene, has been identified, and has $2V\gamma$ values between 36—38° and 44—50°. Thus, this pyroxene is probably subcalcic (cf. Kuno 1968). The pyroxene has altered to uralite and chlorite (probably prochlorite). In addition, sericite, epidote, sphene, hornblende, clinozoisite, muscovite, penninite, calcite, leucoxene, zircon, apatite, and quartz have been observed.

The uralite diabases are strongly changed. They display usually fine-grained, green or grey rocks. The groundmass mainly consists of plagioclase laths (usually andesine), epidote and ore minerals, chlorite, and uralite (Fig. 24). The plagioclase crystals are sometimes strongly zoned (up to 15 successive



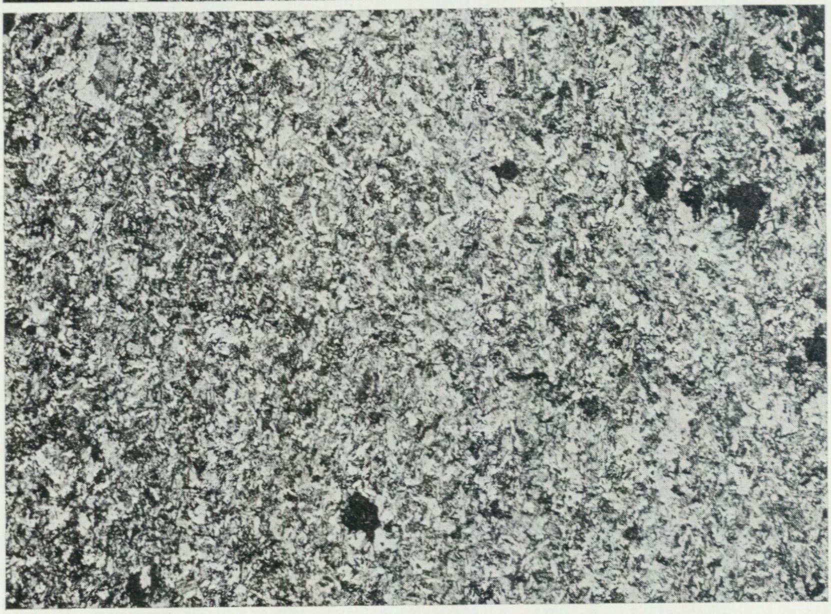


Fig. 23. Dyke porphyry with a well-preserved groundmass. 2.7—2.8 km ENE of Gisseskalle. Nic. crossed x7.

Fig. 24. Uralite diabase. Fine-grained groundmass with plagioclase laths, epidote and ore minerals, chlorite and uralite. 1.7—1.8 km S of Storebro. Nic. crossed x7.

zones have been observed). The epidote minerals and the uralite sometimes form aggregates. Light red augen, 2—5 mm across, have been observed,

Fig. 25. Diabase porphyrite. Phenocrysts of transformed plagioclase laths. 0.9 km NE of Faggemåla. Nic. crossed x7.
Fig. 26. Black diabase. 1.5—1.6 km NE of Faggemåla. Nic. crossed x7.

TABLE 4. Niggli values and CIPW norm (%). Numbers correspond to those of tables 2 a and 2 b.

Analysis	1	14	18	19	20	21	22	23	24	25
si	341	283	540	622	100	127	111	129	110	119
qz	90	69	304	428	—28	—16	—30	— 4	—17	—23
al	43	44	53	68	26	28	28	28	29	26
fm	13	18	8	7	45	41	37	42	40	44
c	6	10	5	1	22	20	24	22	25	19
alk	38	29	34	24	7	11	10	8	7	10
mg	0.41	0.39	0.42	0.16	0.58	0.52	0.43	0.49	0.54	0.41
k	0.44	0.40	0.56	0.96	0.20	0.35	0.24	0.24	0.22	0.23
ti	1.47	1.46	0.99	0.79	1.54	2.13	2.13	1.74	1.71	7.40
q	19.78	20.27	46.58	59.94	—	0.12	—	6.08	—	—
c	—	2.63	3.57	9.36	—	—	—	—	—	0.60
or	32.18	25.38	25.46	26.45	5.98	13.73	9.98	7.17	5.98	8.84
ab	37.81	34.66	18.65	0.86	21.40	23.94	24.96	21.38	19.71	27.86
an	5.14	9.74	3.19	0.48	40.59	32.00	34.07	35.26	42.92	27.62

especially near the contacts of the dyke. The minerals of these augen are epidote and sphene (often in the cores), and perthitic microcline, microcline, quartz, zoisite, clinozoisite, and apatite. In addition, pyrite, penninite, hornblende, zircon, fluorite, allanite, and leucoxene have been observed in the rocks mentioned.

The black diabases seem to be better preserved than the other dyke rocks (Fig. 26). The maximum An contents correspond to intermediate labradorite. Olivine occurs. It is euhedral and surrounded by clinopyroxene. 2 $V\alpha$ values of c. 82° correspond to 33—35 % fayalite, according to Tröger (1956). The olivine is frequently altered, and pseudomorphs of serpentine, talc, iddingsite, and ore minerals occur. Both ortho- and clinopyroxene have been observed. The 2 $V\alpha$ values of the orthopyroxene range between 68 and 70°, corresponding to 25 % Fe (Tröger 1956). The 2 $V\gamma$ values of the clinopyroxene mainly vary between 51 and 53°, but 49 and 41° have also been found. Thus, a trend towards a subcalcic augite occurs in these rocks. In addition, the rocks contain uralite, sericite, chlorite, epidote, sphene, clinozoisite, hornblende, biotite, muscovite, antigorite, apatite, zircon, quartz, calcite, and myrmekite.

Only one chemical analysis of each rock type has been made. These analyses show a gradation from the diabase porphyrite via uralite diabase to black diabase. There is an increase in the Niggli values fm, ti and alk, and a decrease in mg, al and c towards the last rock type. Concerning the trace elements the diabase porphyrite has, in comparison with the other rock types, high values of Cr and Ni, whereas the uralite diabase has high values of V, Co and Sr.

In comparison (on Al_2O_3—Na_2O+K_2O—SiO_2-diagrams) with rocks from Japan, Korea, and Sakhalin the diabase porphyrite and the uralite diabase (also the gabbro) are high-alumina basalts, while the black diabase (and the diorites) are alkali-basalts. The first-mentioned rocks are close to the tholeiitic rocks (cf. Kuno 1968). On MFA-diagrams from the Izu-Hakone-area, the basic rocks from the area investigated should belong to the hypersthenic rock series (Kuno 1968, p. 643). Thus, some of the rocks are close to the tholeiitic rocks, which are characterized by a reaction relation between Mg-olivine and Ca-poor pyroxenes, viz. orthopyroxene and pigeonite. In addition, free quartz generally occurs in the diabases of the area. As already mentioned subcalcic pyroxene and an olivine with 30—35 % fayalite (i.e. relatively Mg-rich) occur in the black diabases.

MAIN FEATURES OF THE TECTONIC STRUCTURES

As regards the tectonic evolution, the WNW—ESE to E—W, the NW—SE to NNW—SSE, and possibly the NE—SW to ENE—WSW directions (distribution of supracrustals) are very old, as both the sedimentary and volcanic rocks in Småland show these general directions (cf. Fig. 1). The ignimbrites probably erupted along fissures. As is well known volcanic centres generally lie along or at the intersections of important tectonic lines (cf. Palivcová and Šťovíčková 1968, p. 184).

The oldest volcanic rocks display lineations (and a few fold axes), mainly in a NNW direction with low plunges either to the north or to the south. The youngest volcanic rocks (i.e. the green tuff) have lineations mainly trending towards WNW, with low plunges to the west (easterly dips have also been observed). Thus, there seem to be two directions of deformations, which may have caused the topographically faintly undulating dome and basin terrain. The granites of the area are generally massive. The influence of the granites on the deformation of the volcanic rocks is hard to assess. Parallel structures have been reported in granites from other parts of Småland (e.g. Gavelin and Munthe 1907). Elbers (1971) considered some Småland granites of the Västervik area to be serorogenic. These granites intruded prior to, synchronously with and subsequent to F_2 deformation (compression in NE—SW). According to Elbers (1971), some Småland and Loftahammar granites are prekinematic and became later subjected to strong deformation resulting in folds with horizontal axial planes (F_1 has fold axes trending NNE—SSW). Röshoff (1973, pp. 122—127) considered the supracrustals of the Nömmen area (Småland) to have been affected by two phases of deformation before the intrusion of the plutonics. A third phase of deformation caused a foliation (S_3) in the granodiorite, probably in connexion with the intrusion (S_2 subparallel S_3 WNW—ESE to NW—SE). A fourth deformation is reported to have a cataclastic character. This WNW—ESE cataclastic deformation is probably the same that which affected rocks especially in the southern parts of the area investigated, e.g. the green tuff.

According to several authors there is a general rise of areas in connexion with vulcanism (cf. van Bemmelen 1963; Speranskaia 1967). Two sets of tension joints can appear in rocks exposed to subsidence, compression and uplift (Price

1959). Measurements of about 4300 joints in the area show a predominance of the directions NNW—NW and ENE—NE, which are parallel to the dykes. The NNW—NW dykes are long and broad, while the ENE—NE are short and narrow. Slickensides indicate mainly horizontal movements in both directions (cf. Persson 1973, pp. 107—116).

The same directions of lineaments have been measured on aerial photographs (totally about 1300 measurements, cf. Persson 1973, pp. 111—122). Thus, the domes may, owing to uplift, have been split up mainly along and at right angles to the main direction of NNW—NW. Formerly these two directions were suggested to have been formed under compression from NW to SE in Subjotnian time (cf. Asklund 1923, 1927; Nordenskjöld 1944). Thus, the dykes were also considered to be Subjotnian. Owing to this theory the NE—ENE fault system was put under compression and should have no dykes, but as mentioned before there are a lot of dykes especially in this direction. A NNW—NW fault system was interpreted as Svecofennian by Gorbatschev (1969, pp. 488—490, cf. 1961; Martin 1939), renewed in post-Svecofennian time. There is no obvious reason to place the hypabyssal rocks of the area in a period considerably younger than the granites.

SUMMARY

The volcanic and plutonic rocks in Småland are considered to belong to a post-orogenic stage of the Svecofennian orogeny. This stage is considered to be "a stage of completed folding" according to Sheinmann (1958) or "a quasi-cratonic stage" according to Stille (1950; Ustiyev 1970, p. 11). Obviously there are several generations of granite (cf. Hjelmqvist 1969; Elbers 1971; Gorbatschev 1971; Röshoff 1973). In the Nömmen area the sediments and volcanics are considered to be early Svecofennian and intruded by plutonics (1839 ± 58 m.y., Röshoff 1973). The volcanics of the area investigated (1695 ± 20 m.y., Åberg 1972) have another character than the Nömmen volcanics, and the accompanying granites are completely massive. The Nömmen granodiorites are usually foliated. Today no parallel can be drawn between these two areas, and a post-orogenic origin of the rocks of the area investigated seems to be most probable in spite of the traces of deformation in the volcanics. This deformation has evidently been caused by the granites. Most ignimbrites have been developed during the late stages after geosynclinal evolution (Maleyev 1963, pp. 44—45) and generally belong to a post-orogenic period (cf. Rittmann 1959, 1960; van Bemmelen 1963; Lundqvist 1968, p. 159) characterized by tectonic uplift (van Bemmelen 1963, pp. 158—172; Speranskaia 1967, pp. 105—110), owing to the fact that the parental magma has a high mechanical activity (Rittmann 1960, p. 235; Zeil and Pichler 1968, p. 78; Pichler 1970, cf. Winkler 1962, pp. 356—358). All the volcanic rocks are of Pacific type (cf. Table 2 a). The formation of large amounts of Pacific magma is claimed to be only possible as a result of anatexis of sialic rocks (Pichler 1968). This origin is suggested by, for example, (1) the Pacific suite type; (2) the eutectic (Q-Or-Ab) composition and the granitic chemistry of the rocks; (3) an excess of Al (the normative c values according to the CIPW norm being high) and (4) high Niggli k values (mostly 0.4—0.5; cf. Marinelli and Mittempergher 1966; Marinelli 1968, pp. 127—140; Pichler 1968, pp. 117—126, 1970, pp. 20—41; Zeil and Pichler 1968, pp. 74—80, cf. Winkler 1962; Winkler and Platen 1958, 1961). In addition, the K/Rb ratios for volcanics and granites (Fig. 22) are quite normal, possibly also suggesting anatexis. Besides the initial Sr^{87}/Sr^{86} ratio (0.7065) for Småland porphyries (isochron age 1695 ± 20 m. y., Åberg 1972) is low, as is normal for anatectic rocks. A close connexion

prevails between vulcanism, plutonism and intrusion of hypabyssal rocks (cf. Bederke 1948, pp. 127—131; Hoenes 1949, pp. 197—199; Oen 1960, p. 291; Westerveld 1963, pp. 77—78; Pantó 1964, 1967). In the area investigated the different hypabyssal rocks are younger than the plutonics, but the time interval separating them from the latter is not known. There is no obvious reason to ascribe the hypabyssal rocks to a period considerably younger than the plutonics. Thus, the evolution seems to be a normal one under post-orogenic conditions with a close relation between volcanic (ignimbrites with intercalated tuffs and agglomerates), plutonic, and hypabyssal rocks.

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