# 6. The Relation between Diabase, Granite, and Porphyry at Bullberget in Dalarna, Central Sweden

## A Proof of Magmatic Granite Formation

By

**Sven Hjelmqvist**

## Introduction

The Bullberget hill in the parish of Lima in western Dalarna rises about 100 m above its surroundings. The ridge strikes NNW-SSE and has a length of about 2 km. The top of the hill is 626.6 m above sea-level. Bullberget is situated in the centre of a 5 km wide belt of effusive Öje diabase which is surrounded on both sides by Jotnian sandstones. The Öje diabase at Bullberget is intersected by an intrusive diabase belonging to the same age group as the Jotnian Åsby and Särna diabases of Dalarna. By revision of the geological mapping of Dalarna in 1954 the author found at the top of Bullberget a gradual transition upwards of the intrusive diabase into a syenite-like rock and quartz-porphyry, the whole series covered by Öje diabase. TÖRNEBOHM, in his description of the diabase and gabbro types of Sweden (1877, p. 28), mentions the diabase of Bullberget and points out its difference from the common Öje diabase. In a later paper (1896, p. 15) TÖRNEBOHM supposes that Bullberget represents a volcanic centre for the Öje diabase. GEIJER, referring to TÖRNEBOHM, also mentions the peculiar diabase of Bullberget (1922, p. 417). He has examined a specimen in the collections of the Geological Survey of Sweden and characterizes this as a granophyre composed of albitic plagioclase, potash feldspar, quartz, and pseudomorphs after a mafic mineral. This is the granophyric granite described below.

The author, on seeing the acid rocks of Bullberget, at first thought that these possibly derived from a previous layer of sandstone in the Öje diabase. Jotnian sandstone indeed forms an intercalation in Öje diabase 2.5 km ENE of Bullberget. This hypothesis, however, had to be abandoned as the investigation proceeded.

Owing to the general petrological interest of the Bullberget rock sequence Mr. C.-A. Larsson was instructed in 1957 to make a detailed geological survey of Bullberget on the scale 1:2000. In 1960 this map was slightly added to by the author. Topographic contour-lines with 5 m equidistance were drawn after

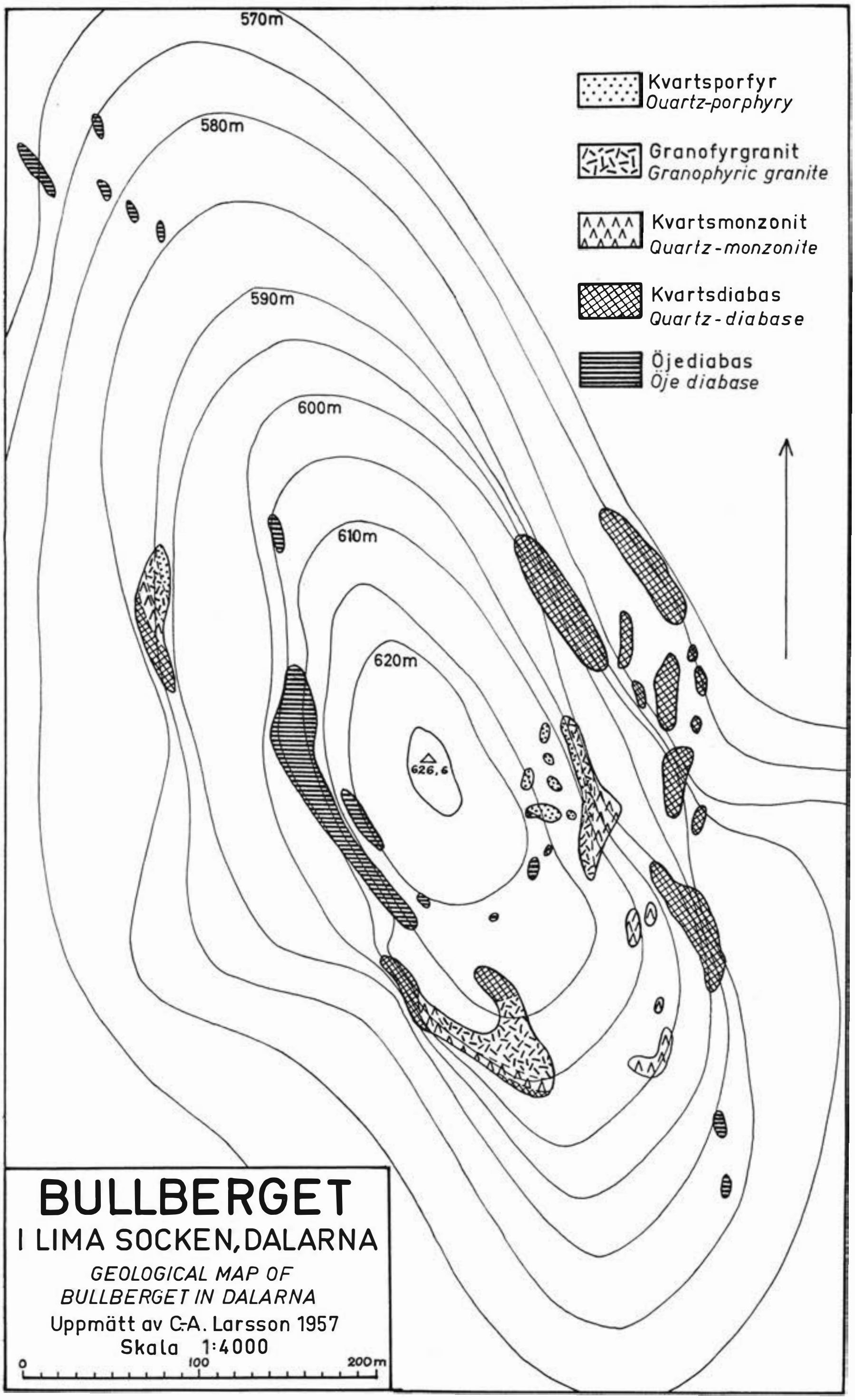
570m
580m
590m
600m
610m
620m
626,6
Kvartsporfyr
Quartz-porphyry
Granofyrgranit
Granophyric granite
Kvartsmonzonit
Quartz-monzonite
Kvartsdiabas
Quartz-diabase
Öjediabas
Öje diabase
BULLBERGET
I LIMA SOCKEN, DALARNA
GEOLOGICAL MAP OF
BULLBERGET IN DALARNA
Uppmätt av C-A. Larsson 1957
Skala 1:4000
0
100
200m

Fig. 1.

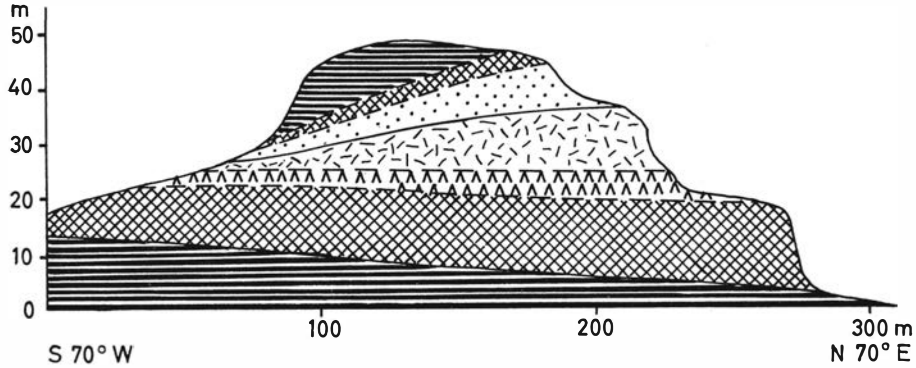


Fig. 2. Section of Bullberget. Concerning the signs, see Fig. 1. Scale of height is twice that of length.

hand-levelling. In the northern and southern parts of the map the heights were determined photogrammetrically. Mr Larsson has also determined the optic axial angles of the pyroxenes here communicated.

As the map (Fig. 1) shows, the rocks building up Bullberget are effusive Öje diabase, intrusive quartz-diabase, quartz-monzonite, granophyric granite, and quartz-porphyry. These latter rocks form a continuous series with transitions between all the different rock types. The effusive diabase occurs both under and over the intrusive series. The vertical distribution of the rocks is evident from the schematic section (Fig. 2). According to this, there is a thin layer of fine-grained quartz-diabase over the porphyry next to the Öje diabase. South of the summit the fine-grained diabase follows directly on the granite without any transition belt of porphyry. There is, however, no sharp boundary between the two rock types. In the direction of the diabase the granite gradually becomes more greyish. ESE of the summit the reddish quartz-porphyry grades into a dark-grey quartz-porphyrite next to the overlying quartz-diabase.

The whole series of quartz-diabase to porphyry has a maximum thickness of about 50 m. On the eastern slope of the hill the quartz-diabase is 30 m thick, on the north-western side less than 10 m. The quartz-monzonite is 3–7 m thick, the granite has a maximum thickness of 10 m, and the quartz-porphyry of about the same.

## Description of the Rocks

### *Öje Diabase*

This rock is part of a huge composite lava bed in the Jotnian Dala sandstone extending about 70 km in a NW–SE direction and reaching a maximum thickness of more than 100 m.

The Öje diabase of Bullberget is fine-grained, greyish black with isolated plagioclase phenocrysts more than 1 cm large. Sometimes an amygdaloidal

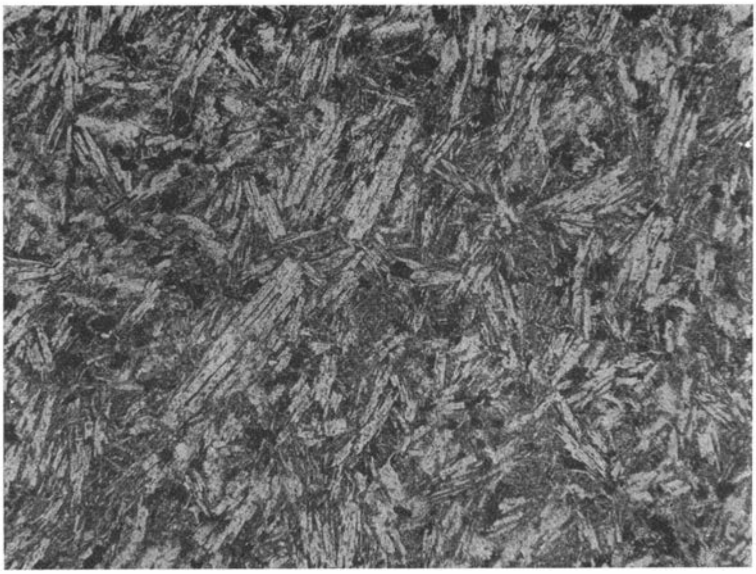

Fig. 3. Öje diabase. Ord. light. × 50.

structure is developed. The texture of the groundmass is subophitic to subdoleritic with small fields or short prisms of pyroxene and lath-shaped plagioclases sometimes lying almost parallel (Fig. 3).

The plagioclase phenocrysts are fractured and rather strongly sericitized, and consist of basic labradorite with 67–68% An. The groundmass is composed of andesine, diopsidic augite with $2\ V_\gamma = 60°$, and ore minerals. The pyroxene is partly or entirely transformed into chlorite. Biotite forms small flakes which are likewise partially replaced by chlorite. Epidote and prehnite also occur as secondary products, the latter as veinlets and lens-shaped aggregates. In addition, there occur apatite needles, zircon and comparatively richly irregular grains of ores. Quartz is found as insignificant filling mass between some plagioclase laths, sometimes together with a little potassic feldspar.

### *Quartz-diabase*

The quartz-diabase can be studied in several outcrops to the east and south of the top. It is a medium-grained, greyish black rock with sometimes a faint inclination to greyish green. On the fresh surface appear black pyroxene prisms up to 1 cm long. Immediately below the Öje diabase at the top of Bullberget a fine-grained modification of the quartz-diabase constitutes the contact zone of the intrusive series upwards.

Under the microscope the quartz-diabase shows a doleritic texture characterized by plagioclase tables and long-prismatic pyroxenes (Fig. 4). The latter mineral also occurs as drop-shaped inclusions in plagioclase in a sort of symplec-

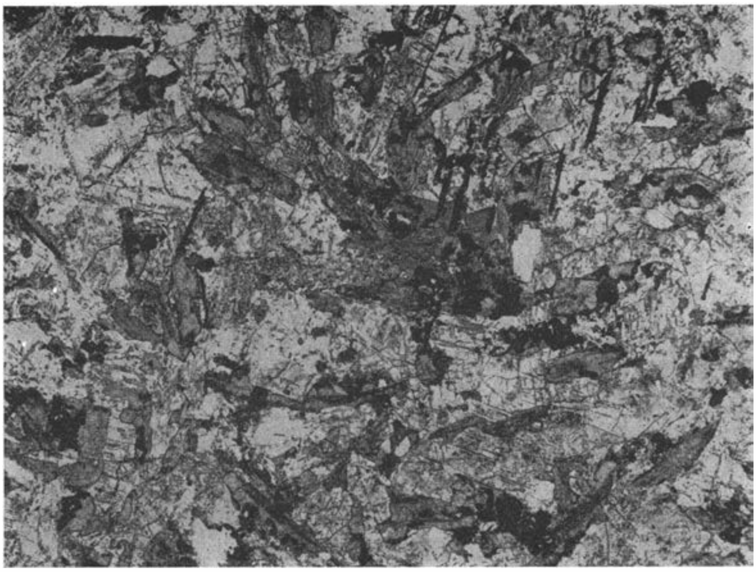

Fig. 4. Quartz-diabase. Ord. light. ×20. Essentially plagioclase, clinopyroxene, and ilmenite.

titic intergrowth (Fig. 5). The filling mass between the plagioclase tables is made up of granophyre passing into coarser intergrowths of quartz and alkali feldspar and of homogeneous quartz fields.

The main minerals are plagioclase, alkali feldspar, and clinopyroxene. Minor constituents are hornblende, chlorite, quartz, ore minerals, and apatite. The plagioclase is a basic andesine to labradorite. Sometimes the whole individual but generally only the core is strongly sericitized, often showing a spotted appearance. The central plagioclase passes into a form considerably poorer in lime (oligoclase). This in its turn is surrounded by clear alkali feldspar which occasionally makes a uniform rim round the plagioclase table showing an idiomorphic boundary against the quartz outside. The granophyric alkali feldspar is clear or faintly brownish.

The clinopyroxene forms heavy prisms, often with a weak curving (Fig. 5). The colour is greyish brown. It is a pigeonite, the positive axial angle being about 47°. It is partially transformed into brownish green hornblende. Chlorite, calcite, and dirty epidote are also found as seondary minerals. The apatite occurs as long, idiomorphic prisms or thin needles. Among the frequently occurring ore minerals a generally columnar ilmenite predominates. In addition, there are magnetite and pyrite.

### *Quartz-monzonite*

The upper part of the quartz-diabase gradually passes into quartz-monzonite which megascopically differs from the diabase through greyish-red colour

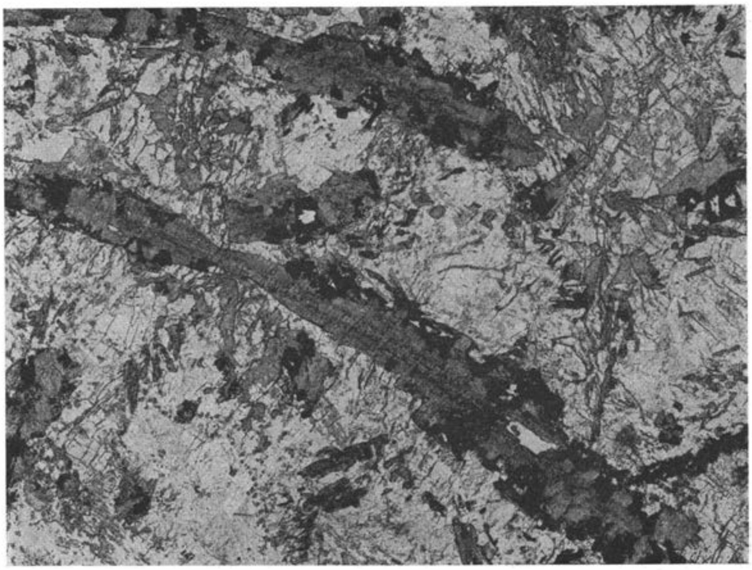

Fig. 5. Quartz-diabase. Ord. light. × 20. Two long prisms of clinopyroxene and between them symplectitic intergrowths of plagioclase and clinopyroxene.

and smaller grains. The transition can be followed in the large outcrop south of the top.

The quartz-monzonite is fine- to medium-grained and like the diabase shows dark prisms up to 1 cm large of pyroxene or pseudomorphs after this mineral. Microscopically the rock is characterized by a doleritic texture with broad rectangular feldspars and prisms or more irregular grains of clinopyroxene (Fig. 6). The interstices between the feldspar tables are filled up by frequently occurring granophyre and quartz.

The essential minerals of the quartz-monzonite are broadly speaking the same as those of the quartz-diabase, namely plagioclase, alkali feldspar, and clinopyroxene (including pseudomorphs after this mineral), although they occur in other proportions. Quartz is a more important constituent in the quartz-monzonite. The idiomorphic feldspars are made up of a generally somewhat sericitized core of andesine to oligoclase which is surrounded by a strongly pigmented rim of alkali feldspar. This latter often shows an idiomorphic boundary against granophyre, the feldspar component of which is likewise strongly brownish pigmented. Farther away from the plagioclase grain the granophyric texture grows coarser and the interstices are occasionally occupied by homogeneous quartz fields. The alkali feldspar, too, is sometimes found as somewhat larger independent individuals.

The clinopyroxene is the same greyish brown pigeonite as in the diabase with $2 V_\gamma$ about 46°. It is more frequently transformed into chlorite, to a less degree into brownish green hornblende. Other secondary minerals are epidote,

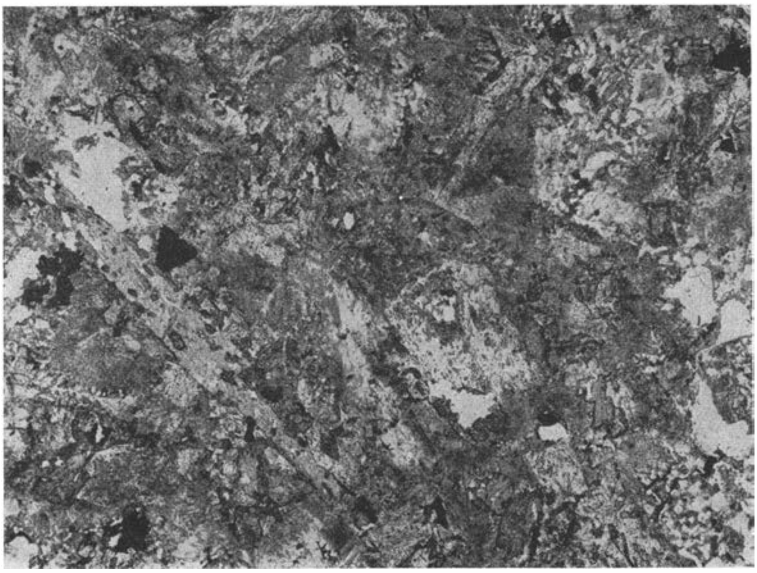

Fig. 6. Quartz-monzonite. Ord. light. × 20. To the left a long prism of clinopyroxene. White fields are quartz.

calcite, and prehnite. There are also found magnetite, ilmenite, and titanite together with long columns of apatite.

### *Granophyric Granite*

Without any visible boundary the quartz-monzonite grades into granophyric granite. The transition can be observed in outcrops to the east, south, and northwest of the summit. It implies that the colour changes to reddish or brownish red, the grain size at the same time diminishing to fine-grained. The megascopic appearance is syenite-like with lath-shaped feldspars and sparse dark columns of chlorite.

The microscopic texture is hypidiomorphic and is characterized by comparatively thin, divergent feldspar tables, the spaces between them being occupied by granophyre and quartz (Figs. 7, 8). The texture can be derived from that of the monzonite and diabase.

The essential minerals of the granite are alkali feldspar, plagioclase, and quartz. In small amounts chlorite, hornblende, apatite, and ore minerals are found. The feldspars frequently have an idiomorphic core with rectangular cross-section and consisting of light grey oligoclase to albite, which is surrounded by a wide rim of strongly brownish-pigmented alkali feldspar. Next to the plagioclase, this is homogeneous or very finely quartz-striped but it grades into an ever coarser granophyre which sometimes forms a spongy aggregate round the plagioclase table. More seldom the plagioclase core is surrounded by a

Fig. 7. Granophyric granite. Ord. light. × 50. Laths of light grey plagioclase surrounded by strongly pigmented alkali feldspar.

distinct edge of clear alkali feldspar bordering on granophyre. The quartz occurs both as granophyric intergrowths with alkali feldspar and as larger homogeneous fields.

Fig. 8. Granophyric granite. Nic. crossed. × 50.

Among the dark minerals may be mentioned small prisms of light brownish green hornblende which is usually transformed into chlorite; epidote, titanite, and calcite are also found. Thin needles or narrow prisms of apatite occur in small quantities. More abundant are ore minerals, principally rounded magnetite grains but also ilmenite and small rods of hematite.

### *Quartz-porphyry*

The granite passes into quartz-porphyry and in this case also the change is completely gradual with intermediate forms. The transition can be seen in outcrops to the east and northwest of the summit. In the upper part of the granite there occur a few rounded quartz grains about 1 or 2 mm large as well as isolated feldspar phenocrysts.

The quartz-porphyry is fine-grained, to the naked eye almost compact. Its colour is red or reddish brown. Isolated feldspar phenocrysts up to 5 mm large and small spherical quartz grains of grey or greyish black colour and 1–2 mm in size appear in the groundmass. The quartz balls apparently constitute original amygdules. Calcite amygdules of the same size also occur.

Under the microscope the groundmass shows a hypidiomorphic texture with comparatively short lath-shaped feldspars which to some degree display a diverging arrangement (Fig. 9). Between them there are small quartz grains, very fine-grained granophyre and chlorite. In this mineral are seen insignificant relics of a light brownish green amphibole. Other minerals are epidote, magnetite, hematite, and fine needles of apatite.

Fig. 9. Quartz-porphyry. Nic. crossed. × 50. In the centre a phenocryst of acid oligoclase.

Fig. 10. Porphyrite. Ord. light. × 50. Small phenocrysts of oligoclase in a very fine-grained groundmass.

The feldspar is partly a light grey, somewhat sericite-spotted oligoclase-albite with pronounced rectangular cross-sections, partly and predominantly a strongly brownish-pigmented alkali feldspar, the lath shape of which is visible only between crossed nicols. The feldspar phenocrysts consist of acid oligoclase.

In the outcrops to the southeast of the summit the red porphyry grades into brown and nearer to the top into grey porphyry, which in its turn passes into a dark grey porphyrite without marked boundary against the overlying fine-grained quartz-diabase. This porphyrite has isolated plagioclase phenocrysts up to 5 mm long as well as small quartz balls about 1 mm large. Microscopically the porphyrite is characterized by narrow, sharply outstanding oligoclase laths in a very fine-grained groundmass spotted in brownish and greyish (Fig. 10). In addition, there occur alkali feldspar, quartz, fairly abundant chlorite, epidote, and hornblende. In the groundmass there are also seen narrow strings of ore dust, sometimes faintly curved, as well as compact ore grains.

## Chemical Composition and Origin of Rocks

According to spectrographic and flame-photometric determinations which have been made by the Boliden Central Laboratory at Rönnskär, the chemical composition of the main rocks of the intrusive series of Bullberget is as follows.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 56.0 | 64.0 | 70.0 | 70.0 |
| $TiO_2$ | 1.7 | 1.5 | 0.8 | 0.7 |
| $Al_2O_3$ | 14.0 | 13.0 | 13.5 | 13.0 |
| Fe | 9.6 | 6.0 | 4.1 | 4.5 |
| MnO | 0.2 | 0.2 | 0.1 | 0.2 |
| MgO | 2.9 | 2.5 | 1.1 | 0.8 |
| CaO | 6.7 | 3.8 | 1.9 | 1.6 |
| $Na_2O$ | 2.7 | 2.8 | 2.8 | 3.0 |
| $K_2O$ | 2.7 | 3.6 | 4.3 | 4.2 |

1 = quartz-diabase, 120 m SSW of the top of Bullberget.
2 = quartz-monzonite, 150 m SE of the top of Bullberget.
3 = granophyric granite, 170 m SSE of the top of Bullberget.
4 = quartz-porphyry, 70 m ESE of the top of Bullberget.

The most striking feature of these analyses is the high Fe percentage. In this respect they correspond to silicic differentiates of lopoliths (HAMILTON 1960, p. 59). The comparatively low $Al_2O_3$-content of the basic members points in the same direction.

The Niggli values have been calculated and are plotted in the diagram (Fig. 11). The figures for the quartz-porphyry have not been inserted. They lie close to the points for the granophyric granite. The diagram indicates a fairly regular development, the *c*- and *alk*-curves being practically straight lines. This is what might be expected in the case of fractional crystallization. As the preceding description has shown, there is a completely gradual transition from the basic to

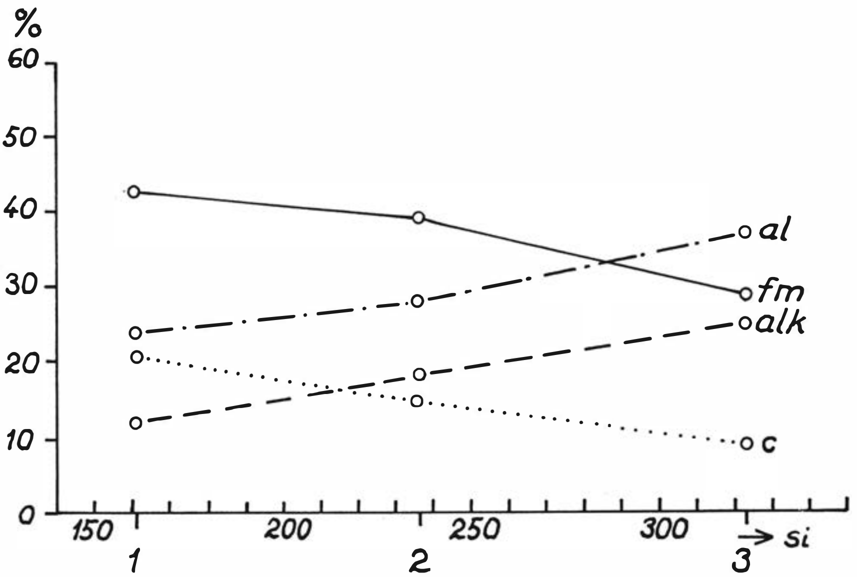


Fig. 11. Niggli diagram of the Bullberget rocks. The figures 1, 2, 3 refer to the number of the analysis.

the acid members, the heavy constituents being enriched in the lower parts and the lighter components in the upper parts of the series.

At the beginning of this paper it was mentioned that the author at first considered the possibility that the acid rocks of Bullberget had replaced a previous layer of sandstone in the effusive Öje diabase and that the granite was consequently a sediment granitized *in situ*. Among the facts which argue against this hypothesis is the quite homogeneous transition from basic to acid rocks, accompanied by the simultaneously decreasing grain-size, together with the fact that the quartz-porphyry is the close-grained marginal zone of the granophyric granite with the same mineralogical and chemical composition as the latter. To this can be added the hypidiomorphic texture of both the granite and the quartz-porphyry, as well as the presence of the upper basic contact zone of the intrusive series. No sandstone has been observed in the proper neighbourhood of Bullberget. If the granite had replaced an older sandstone layer, relics of this rock ought to have been found as ghost-like remnants in the former. After much searching a few quite small fragments of sandstone have, indeed, been found in the granite and the quartz-porphyry. In these cases, however, there is no continuous transition but a sharp boundary between the rocks, although the sandstone has obviously been influenced. This argues against the probability of the granite's being a completely melted sandstone layer which has maintained its original position. Palingenetic phenomena at the contacts of similar diabases are reported from several places, *inter alia* from Finland. They show, however, quite another appearance.

The observed data consequently indicate a magmatic formation of the granite as well as of the whole series, the granite being a hypabyssal solidification product of the magma. Nothing is implied by this as to the primary origin and history of the magma. It seems quite possible that the basic melt on its way upwards has incorporated and assimilated acid rocks such as granite and sandstone, which have affected its composition. The essential matter in this connection is that the granite of Bullberget has crystallized out of a magma. To most petrologists, this probably seems to be self-evident. The reason why it is emphasized here is the fact that there exist, in other parts of Dalarna, other granites which are in many respects similar to the granite of Bullberget but which appear in much larger masses.

## References

GEIJER, P., 1922: Problems suggested by the igneous rocks of Jotnian and sub-Jotnian age. *Geol. Fören. Förh.* Bd 44. Stockholm.

HAMILTON, W., 1960: Silicic differentiates of lopoliths. *Int. Geol. Congr. Rept., XXI. Sess.*, Part XIII. Copenhagen.

TÖRNEBOHM, A. E., 1877: Om Sveriges vigtigare diabas- och gabbro-arter. *Kgl. Sv. Vet.-Akad. Handl.* Bd 14. Stockholm.

— 1896: Grunddragen af det centrala Skandinaviens bergbyggnad. *Ibid.* Bd 28.