THE FIELD RELATIONS OF THE SULITJELMA GABBRO, NORDLAND

By

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Abstract. Recent field studies have shown that the rocks in NE Sulitjelma described by Th. Vogt in 1927 as parts of one large basic intrusion consist of a layered basic igneous complex which has been thrust over a series of metavolcanic rocks. This is in accord with the conclusions reached by Kautsky in 1953. However, the thrusting appears to be syn-metamorphic, rather than post-metamorphic, and not all the nappes described by Kautsky in Sweden can be recognized on the Norwegian side of the border.

Introduction

The Sulitjelma area of Nordland was the subject of a classic N.G.U. memoir by Th. Vogt in 1927. He described two sequences of metamorphic zones, one in calcareous schists, the other in basic igneous rocks, and explained the mineral assemblages of these zones in terms of the facies concept of Goldschmidt and Eskola. He emphasized that the sequences of metamorphic zones were metamorphic facies series representing varying pressure and temperature conditions.

Vogt thought that all the basic igneous rocks in NE Sulitjelma were part of one intrusion which he called the 'great Sulitjelma phacolite'. Within this phacolite he recognized four metamorphic zones representing different amounts of retrograde metamorphism of primary gabbroic assemblages (Fig. 1). The metamorphic grade of the rocks increased from chlorite-albite rocks in the sill-like offshoots of the phacolite to unaltered gabbros in the bulged upper portion. He considered that this sequence had arisen by repeated injections of magma while the surrounding country rocks were undergoing intense deformation and regional metamorphism.

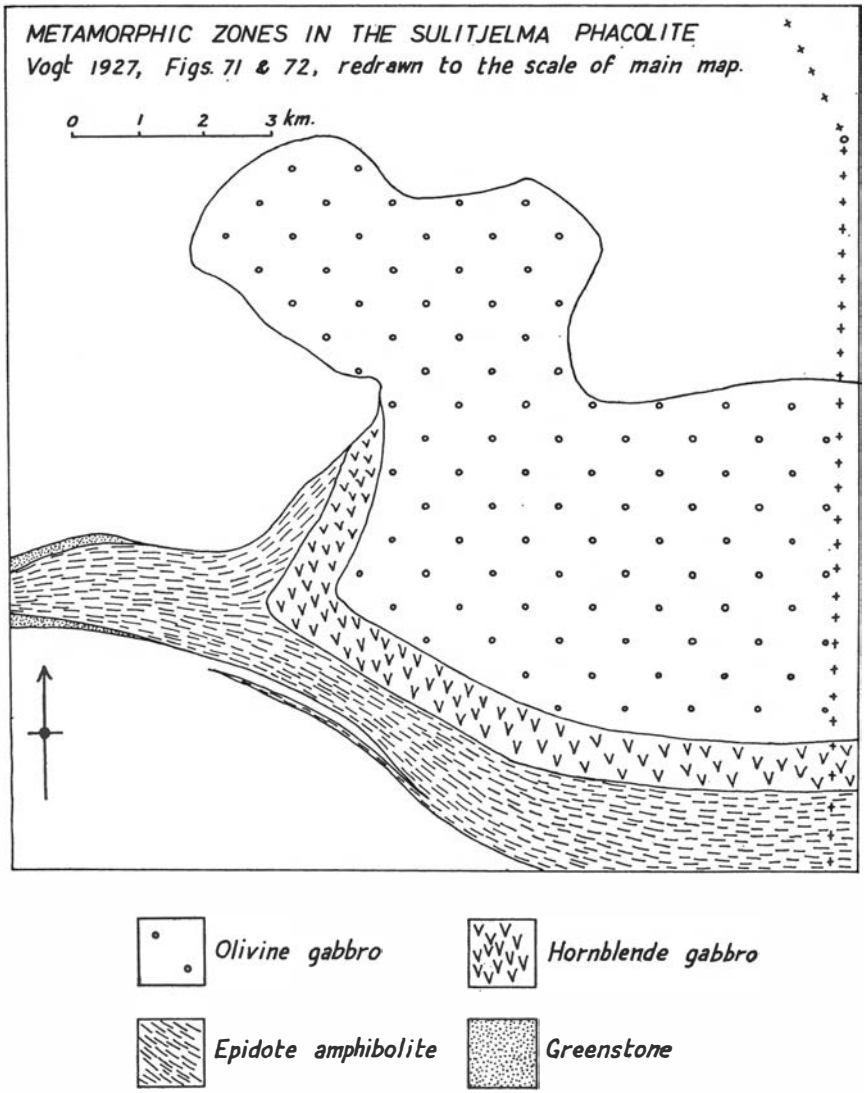

Figure 1.

In 1953 KAUTSKY published a structural study of the neighbouring Swedish part of Sulitjelma. In Sweden the metamorphic rocks of the Caledonides can be seen to be thrust over a basement of granitic Precambrian rocks and a thin layer of *Hyolithes* zone Cambrian sedi-

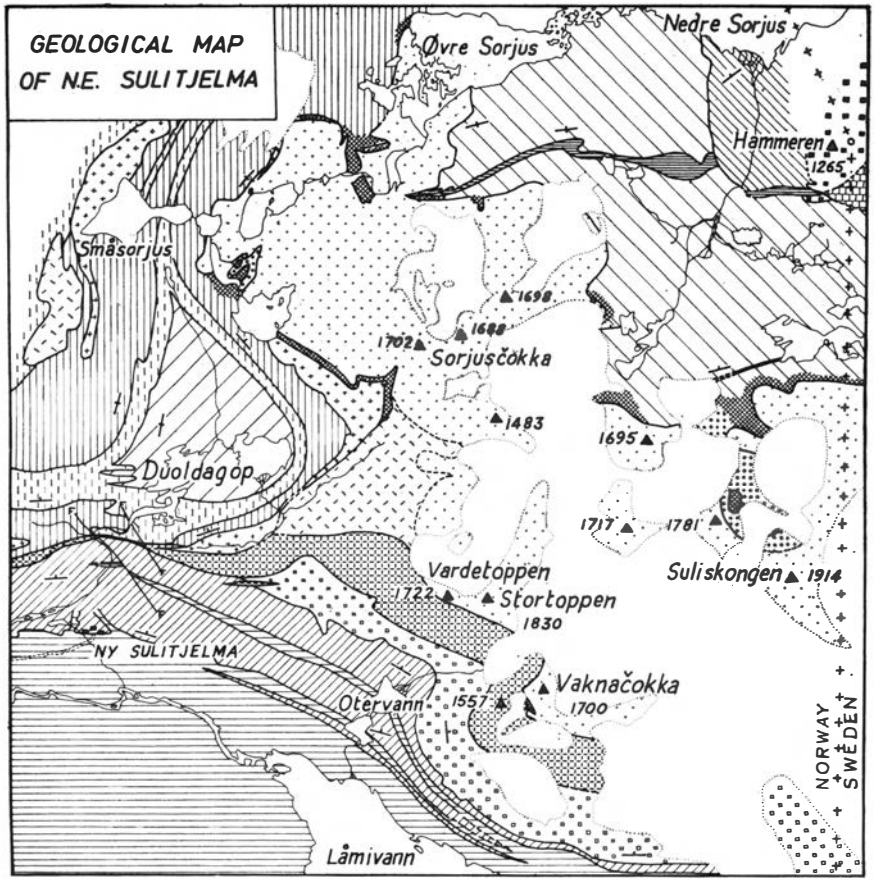
GEOLOGICAL MAP
OF N.E. SULITJELMA
Øvre Sorjus
Nedre Sorjus
Hammeren
1265
Småsorjus
1698
1688
1702
Sorjuščokka
1483
1695
Duoldagop
1717
1781
Vardetoppen
1722
Storttoppen
1830
Suliskongen
1914
NY SULITJELMA
Otervann
1557
Vaknačokka
1700
NORWAY
SWEDEN
Lamivann
PIESKE-VASTEN NAPPE
Metaporphyritic amphibolite
Schistose amphibolite
Furulund Schist
JUNCTION UNIT
Flaser gabbro
GASAK NAPPE
Calc-silicate schists
Quartzite band
Graphite schist
Kyanite schist
Micaceous psammite
Calc-silicate rocks
INTRUSIVES
Gabbro
Metagabbro
Granites
Igneous breccia
Ultramafics
UNCERTAIN
Amphibolite
Marble
Fault
Hornfels

Figure 2.

ments. The uppermost Caledonian thrust sheet is known as the Seve nappe. Kautsky suggested that in the Sulitjelma area the Seve nappe-complex is subdivided into three nappes called from the base upwards, the Pieske nappe, the Vasten nappe, and the Gasak nappe. The rocks which Vogt assigned to the Sulitjelma phacolite would fall into two of these nappes, the Gasak nappe and the Vasten nappe, while the Furulund schists immediately below the phacolite would lie in the Pieske nappe.

At the meeting of the Geologiska Föreningen at Stockholm in 1949, Kautsky discussed these opinions with Vogt. (An account of this discussion can be found in *Geol. Fören. Stockh. Förh.* 71, pp. 639–641.) Vogt admitted that small-scale thrusting might have occurred at Sulitjelma near the base of the phacolite, but thought it was very unlikely that the Sulitjelma gabbro had been thrust into place over a long distance.

The present writer has mapped the basic igneous rocks on the Norwegian side of the border on a scale of 1:15,000 (Fig. 2). This work has shed light on the controversy described above.

Thrusting in NE Sulitjelma

One major thrust horizon has been recognized in NE Sulitjelma. It divides Vogt's phacolite into two parts and is marked by a band of lineated flaser gabbro. This band varies in thickness, disappearing altogether in the west and reaching a thickness of 350 m south of the summit of Vaknačokka. It is characterized by:

(1) The presence of lenses of metagabbro or amphibolite composed of large crystals of hornblende and plagioclase.

(2) A preferred orientation of the prismatic hornblende crystals in the coarse-grained lenses and also in the fine-grained amphibolite between the lenses, giving rise to a distinct lineation.

The flaser gabbro lies on the extension of the contact between the Gasak and Vasten nappes mapped by Kautsky in Sweden. It dips northwards at about 30°. Above the flaser gabbro lies a layered basic igneous pluton, the Sulitjelma gabbro complex. Lenses of gabbro still containing primary olivine and pyroxene are occasionally found in the upper part of the flaser gabbro. The Sulitjelma gabbro complex and its envelope of metamorphic rocks correspond to Kautsky's Gasak

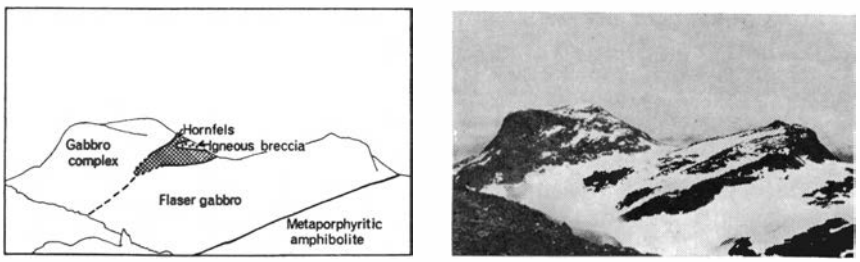

Figure 3. The summit ridge of Vaknačokka from the west. This shows the southern contact of the gabbro complex with a small area of hornfels and igneous breccia in the Gasak nappe (upper left) overlying the junction unit of flaser gabbro, which in turn overlies the metaporphyritic amphibolite in the Pieske-Vasten nappe (lower right).

nappe. The succession below the flaser gabbro corresponds to his Vasten nappe and the upper part of the Pieske nappe. The succession is:

(3) Metaporphyritic amphibolite
(2) Schistose amphibolite
(1) Furulund schist

Since no tectonic break in this succession has been detected in NE Sulitjelma, the writer prefers to assign these rocks to a lower unit called the 'Pieske-Vasten nappe'.

The reasons for regarding the flaser gabbro horizon as representing a thrust may be summarized as follows:

(1) The flaser gabbro is discordant with the lithological units above and below. From west to east the upper surface of the flaser gabbro is successively in contact with micaceous psammites and marbles of the envelope of the gabbro complex, deformed granite, the Sulitjelma gabbro complex, and near the summit of Vaknačokka a small area of hornfelses and igneous breccias which are part of the thermal aureole of the gabbro (Fig. 3). The lower surface is in contact with schistose amphibolite in the west and metaporphyritic amplibolite in the east.

(2) There is a particularly well-developed mineral lineation in the flaser gabbro. This is parallel to the lineation developed in the rocks below the flaser gabbro which runs E–W or WNW–ESE along the strike. The rocks above the flaser gabbro also display a lineation, but in the envelope of the gabbro complex this has changed in

direction and runs north down the dip of the rocks. There is no abrupt change in the direction of the lineation, but a gradual swing in direction over several kilometres. Lineation is rare in the gabbro complex, occurring only in those parts which have undergone deformation and metamorphism, but where it does occur it is concordant with the lineation of the flaser gabbro. The peculiarity of the flaser gabbro lies in the more intense development of the lineation in this horizon than in the rocks above and below. In a structural study of the Furulund schist, Henley (personal communication) has attributed the uniform lineation developed in this unit to homogeneous strain during a phase of intense deformation. But the lineation is not uniformly developed in the basic rocks lying above the Furulund schist. The flaser gabbro represents a horizon of particularly intense lineation, which suggests that it was a horizon of concentrated strain.

Thus the flaser gabbro band is a zone of concentrated deformation, dipping at a gentle angle and only slightly discordant with the surrounding rocks. Therefore, it is described here as a thrust horizon.

The meta-volcanic rocks below the flaser gabbro

The rocks below the flaser gabbro are varied, particularly the schistose amphibolites, which include chlorite schists, two conspicuous bands of garnet-mica schist (Fig. 2), bands of marble up to 1 m thick, and lenses of deformed conglomerate with a calcareous matrix. Some of the amphibolites and chlorite schists display a primary fragmental character, the original particles having been flattened and elongated, the elongation being parallel to the regional lineation described above. The metaporphyritic amphibolite is more uniform in character, with alternating bands of schistose amphibolite and more massive amphibolite. The massive bands vary in thickness from about 1 m to 10 m and have a coarse-grained porphyritic texture with phenocrysts of plagioclase or pseudomorphs of clinozoisite, oligoclase, and quartz after plagioclase, set in a fine-grained amphibolite matrix. This unit corresponds with rocks which Kautsky described as 'porphyrite amphibolite' and assigned to the Vasten nappe. Lenses of metaporphyrite amphibolite appear in the lower part of the flaser gabbro.

It therefore appears that the amphibolitic rocks below the flaser gabbro are to be regarded as a sequence of metamorphosed volcanic rocks with intercalations of meta-sedimentary material. The porphyritic appearance of some bands and the primary fragmental nature of others support this theory. There is no evidence for a thrust horizon at the base of the schistose amphibolite group, as Kautsky supposed. The resemblance between the schist intercalations in the amphibolites and the Furulund schist suggests on the contrary that the rocks below the flaser gabbro are a continuous sequence from sediments upwards into volcanics.

The Sulitjelma gabbro complex and its contact aureole

The Sulitjelma gabbro complex is a layered basic igneous pluton. It shows compositional banding and igneous lamination dipping at high angles or vertical. It has undergone a certain amount of differentiation, as Vogt observed, and a detailed account of its structure and petrology is in preparation. A few brief comments on its mineral composition and field appearance will be made here.

The complex consists predominantly of olivine gabbro with about 57% labradorite (An_{65-70}), 33% pyroxenes, 10% olivines and accessory pyrrhotite. Both clino- and orthopyroxenes are present, but there is nearly always more clinopyroxene than orthopyroxene. Bands in the gabbro complex are enriched either in labradorite, pyroxene, or olivine, but no rocks have been found with more than 80% by volume of any one of these phases. Thus, none of the rocks can strictly be called ultrabasic. The banding is thought to be due to crystal accumulation, and its present steep orientation to subsequent deformation. A narrow border facies of troctolite can be recognized in some places, but has often been obliterated by later deformation and metamorphism.

The gabbro complex is surrounded by a narrow aureole of massive hornfelses. This is up to about 30 m in width. There are also patches of igneous breccia at the contact, which consist of hornfels fragments in an igneous matrix. This matrix has a very varied composition but is most often granodioritic or dioritic. Recrystallized fragments of gabbro are occasionally found in the breccia.

The contacts of the gabbro complex are discordant with the stratigraphical units in its envelope and also with the internal banding of the

complex. They are locally discordant with the schistosity of the country rocks, although on a large scale the schistosity tends to run parallel to the contacts.

A discussion of Th. Vogt's facies sequence in the 'great Sulitjelma phacolite'

VOGT (1927, p. 383) divided his four zones into a series of metamorphic facies. He regarded the assemblages of this series as representing an approximation to chemical equilibrium, formed in response to varying pressure-temperature conditions during metamorphism. It is hoped that the account of the field relations of the Sulitjelma gabbro given above shows that his interpretation of the sequence is no longer valid. However, his observations of mineral assemblages and compositions still stand and if his theories are rejected it is necessary to explain these observations in some other way.

The area which Vogt mapped as unaltered gabbro agrees well with the more detailed mapping done by the present writer. The SW corner of the gabbro complex, however, has been metamorphosed and Vogt mapped most of this in the hornblende gabbro zone, although a small part of it falls into his epidote amphibolite zone (Compare Figs. 1 and 2). Thus Vogt regarded the metamorphism of the different rocks of the Sulitjelma gabbro complex as having occurred under different pressure and temperature conditions, corresponding to the gabbro, hornblende-gabbro, and epidote-amphibolite zones. The present writer considers the different assemblages of metamorphic minerals in the SW corner of the gabbro complex to have formed under relatively uniform pressure-temperature conditions, corresponding to the almandine-amphibolite facies. The equilibrium assemblage produced by the metamorphism is an amphibolite with plagioclase of composition about An_{30}, green hornblende, and clinozoisite, and rocks approximating to this composition are found in the SW corner of the Sulitjelma gabbro complex near the contact with the Furulund granite. The 'hornblende gabbros' (metagabbros) with and without clinozoisite and with plagioclase compositions between An_{30} and An_{60} are regarded as rocks which represent partial attainment of equilibrium, the particular assemblage which occurs being determined by the availability

of water during metamorphism and by the degree of cataclasis which occurred during deformation.

Most of the flaser gabbro band was mapped by Vogt in the hornblende gabbro zone although its western end falls into the epidote amphibolite zone. The greenstone zone and the zone of chlorite-albite rock are only found west of the area under consideration here.

There is a gradual decrease in metamorphic grade downwards in the metaporphyritic amphibolite and schistose amphibolite (see VOGT 1927, p. 377). This is indicated by the plagioclase compositions of the amphibolites, and also by the assemblages in the pelitic bands in the schistose amphibolites. This is an extension upwards of the progressive increase in metamorphic grade observed in the Furulund schist N of Lamivann, described by Vogt and confirmed by recent work by Henley (personal communication). Thus, the present writer agrees with Vogt's conclusion that the rocks overlying the Furulund schist in the Pieske-Vasten nappe are a series of amphibolites increasing in metamorphic grade upwards. The interpretations differ in that the evidence described in this account shows the rocks to be a series of metamorphosed volcanics, whereas Vogt thought they were the base of a large intrusion.

The chlorite-bearing rocks of the greenstone and chlorite-albite zones lie outside the scope of this paper, but it is possible that the local formation of large amounts of chlorite may have occurred at the same time as the late-stage formation of small amounts of retrograde chlorite in many rocks throughout the Sulitjelma area.

Conclusion

Although Vogt's Sulitjelma phacolite has been shown to consist of two unrelated groups of basic igneous rocks on either side of a thrust zone, it is possible to explain his observations of mineral assemblages and compositions. His idea that there is a continuous sequence of assemblages representing approximations to chemical equilibrium in an environment in which pressure and temperature varied must however be rejected. But KAUTSKY's (1952) interpretation of the structure of Sulitjelma is also not fully acceptable for two main reasons:

(1) There is no evidence in the area studied for a thrust corresponding to the base of the Vasten nappe.

(2) Kautsky regarded the nappes as essentially post-metamorphic. But the lineation of the flaser gabbro band marking the thrust between the Gasak and Pieske-Vasten nappes indicates that the rocks were undergoing metamorphic recrystallization at the time of deformation.

In defence of Vogt it is necessary to add that until Kautsky suggested otherwise, the basic rocks of NE Sulitjelma had always been regarded as parts of one intrusion. They had been studied by such distinguished geologists as J. H. L. VOGT (1895) and P. J. HOLMQUIST (1900). In the most accessible part of the Sulitjelma gabbro complex, its SW corner, only gradual transitions can be seen between schistose amphibolite and flaser gabbro, and metamorphosed, non-lineated gabbro. It was only visits to more remote areas such as the summit ridge of Vaknačokka that demonstrated to the present writer the difference between the Sulitjelma gabbro proper and the assorted amphibolites which lie structurally below it.

ACKNOWLEDGEMENTS

I thank Dr. R. Nicholson and Prof. R. W. R. Rutland for accompanying me in the field at Sulitjelma on several occasions. J. E. Larsen and M. R. Wilson have kindly allowed me to reproduce parts of their unpublished geological maps in Fig. 2. Dr. Nicholson and Dr. M. K. Wells read the manuscript of the paper and Dr. Wells helped me in the preparation of the illustrations. The work was carried out during the tenure of a National Environmental Research Council studentship in the Department of Mineralogy and Petrology, Cambridge University. A/S Sulitjelma Gruber provided free accommodation in Ny Sulitjelma.

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Manuscript received March 1967

Accepted for publication March 1967