8. On the Genesis of the Gabbroic Rock Bodies of the Norwegian Caledonides

By

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ABSTRACT.—The 180 by 50 km Jotunheimen massif of gabbroic rocks is in the current literature considered as an overthrust nappe of Precambrian rocks. However, some field observations as well as recent views on lopoliths merit a re-consideration of the views prevailing at the turn of the century, that the complex is of Caledonian age and is thrust only a moderate distance. It is suggested that the complex is of extrusive origin. The same origin is suggested for the typical "gabbro phacoliths" of the Caledonides.

Introduction

A number of large gabbroic bodies occur within the Caledonian mountain zone of Norway (see Fig. 1). In this article a new and uniform theory is suggested for their origin. This theory is based on observations described in the literature, on the author's very limited field knowledge of the different areas, and on new views from the latest literature. Only the shortest possible summaries of the key observations are presented. The new theory is advanced as a possible alternative to the current views on the origin of the gabbroic bodies of the Norwegian Caledonides (see T. STRAND, in HOLTEDAHL, 1960) and it is presented in the hope of stimulating detailed field work.

The largest gabbroic complex dealt with is that of the mountainous Jotunheimen area. This Jotunheimen complex is of anorthositic-charnockitic character. It is taken first, followed by the "phacoliths" containing ordinary gabbroic rocks.

The Jotunheimen Gabbroic Complex

The Jotunheimen gabbroic complex has a length along the axis of the mountain range of about 180 km. Its width is about 50 km and locally more. Petrographically the complex varies considerably, containing more monotonous gabbroic rocks, including smaller bodies of ultrabasics as well as complicated mixtures of gabbros, mangerites, syenites, and granites, all of charnockitic affinities. In the south-western half the intermediate and acid rocks predominate together with anorthosites (see Fig. 1). The geological shape of the complex is clearly that of a sheet overlying metamorphosed Cambro-Ordovician supra-

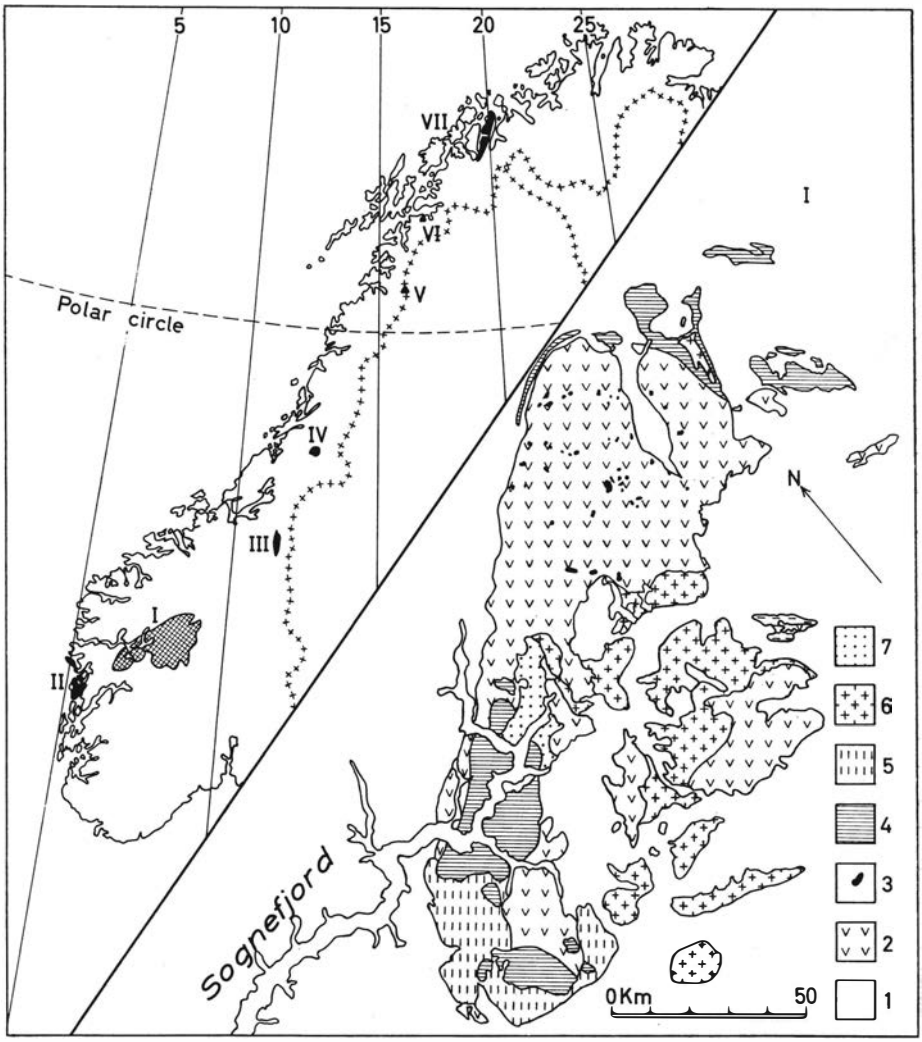

Fig. 1. Upper left: Map showing the location of most of the large bodies of gabbroic rocks in the Norwegian Caledonides. I — The Jotunheimen complex. II — The Bergen Arcs and the Strøno-Gullfjell massif. III — The Fongen, IV — the Heimdalshø, V — the Sulitelma, VI — the Råna, and VII — the Lyngen phacolithic massifs.

Lower right: Sketch map showing the rock types of the Jotunheimen complex. From the geological map of Norway by O. HOLTEDAHL and J. A. DONS 1960 (Holtedahl 1960).

1 — Precambrian gneisses and granites with surrounding Cambro-Ordovician. 2 — Gabbros. 3 — Ultrabasics. 4 — Anorthosite. 5 — Mangerites. 6 — Granites. 7 — Trondhjemite.

crustal rocks. Thus the complex presents two major problems. The first problem relates to the interior origin of the complex, including an explanation of the rock types and their distribution in three dimensions. The other problem, the exterior problem, considers the age and mise-en-place of the rock body. In this paper only the last problem will be considered.

The origin of what we for tectonic reasons may call the Jotunheimen sheet is a much discussed subject in Norwegian geological literature. One alternative was presented by BRØGGER (1893) in a comprehensive description and discussion, especially of the metamorphic beds below the sheet. Brøgger clearly favoured the assumption that the igneous rocks of the Jotunheimen complex form a laccolithic intrusion of Caledonian age. In 1896 TÖRNEBOHM presented a discussion of the central part of the Scandinavian Caledonides, where he assumed that large overthrusts occur at the eastern margin of the mountain range. He did not extend his overthrust nappes as far west as the Jotunheimen complex, but this was done in rather vague terms by REUSCH (1908). Later the discussion has oscillated back and forth between those two alternatives—Caledonian intrusion of phacolithic character, and the overthrust alternative where the gabbro complex could be of either Caledonian or Precambrian age, preferably the latter. During the period 1910–1930 the first alternative was preferred. Thus GOLDSCHMIDT (1916, p. 57) concluded after describing the rocks of the "Bergen–Jotun Kindred":

> Es scheint mir, dass die hier zusammengestellten Tatsachen mit grösserer Wahrscheinlichkeit auf ein frühkaledonisches als auf ein präkambrisches Alter des Bergen–Jotun-Stammes hindeuten .... Zu demselben Resultate kamen schon C. F. KOLDERUP für die Gesteine der Bergen-Bögen, J. REKSTAD für diejenigen von Indre Sogn, K. O. BJØRLYKKE für diejenigen von Jotunheimen. Bei der Annahme eines solchen, frühkaledonischen Alters dieser Gesteine wird man zu der Vorstellung geführt, dass die Bergen–Jotun-Gesteine auf den grossen Bewegungsflächen des Gebirges emporgedrungen wird. Während und nach ihrer Erstarrung wurden sie auf denselben Bewegungsflächen weiter verfrachtet.

Recently STRAND (HOLTEDAHL, 1960, p. 186–202) has summarized the geology of "the region with crystalline nappes in the central part of southern Norway" and in his introduction he reviews the development of the nappe theory. STRAND concludes by saying (p. 188) that "the nappe concept is regarded by all Scandinavian geologists to have wide application in the understanding of the structure of our Caledonides, being in a great number of cases an inescapable interpretation based on well-established facts". The present author agrees, but finds that it is still possible to explain all the proved thrusting as thrusting in the order of 10–30 km, perhaps as much as 50 km in an east-south-east direction. This means that the major thrust nappe of Bergen–Jotun rocks may not represent an overthrust unit, but may have retained its original stratigraphic position. STRAND does not explicitly discuss such problems (see STRAND, 1951, p. 35) but refers to the opinion of HOLTEDAHL (1936, p. 136) that the Jotunheimen sheet must have been thrust from west of its present position because it is "floating" on a thrust plane on the underlying sediments without anywhere showing signs of having roots in the present substratum.

The argument of HOLTEDAHL, however, may be confronted with a number of observations suggesting the contrary. Fig. 2 shows sections from the central

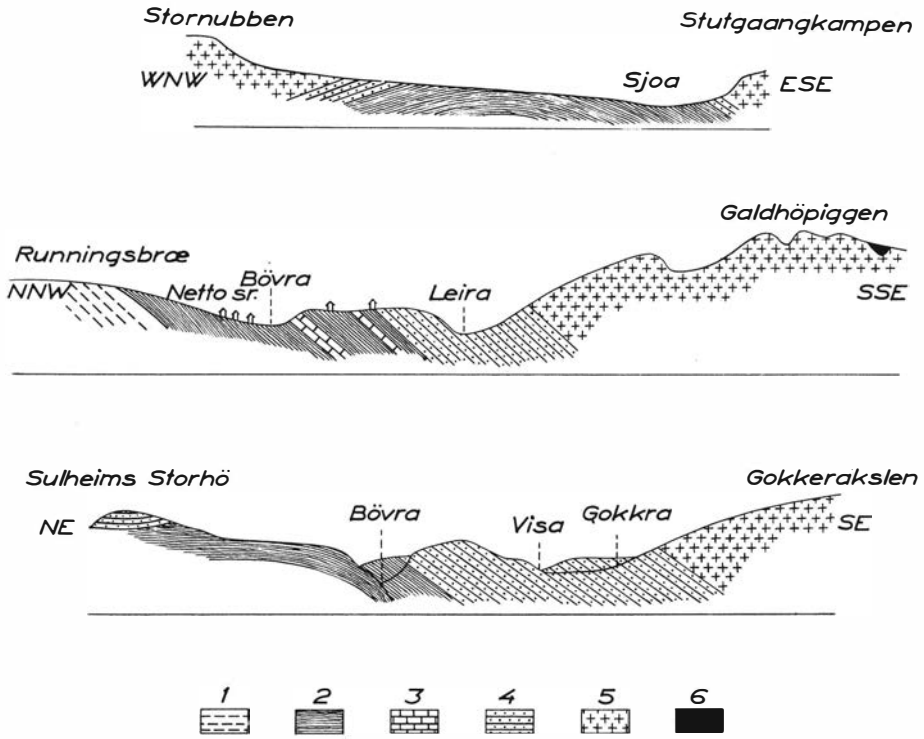

Fig. 2. Sections from the northeastern part of Jotunheimen. After J. REKSTAD (1904, p. 11). Precambrian: 1 — Gneisses. Cambro-Ordovician: 2 — Phyllite. 3 — Limestone. 4 — "Gneiss-quartzite" series. Uncertain age: 5 — Gabbro. 6 — Peridotite.

and north-eastern periphery of the Jotunheimen complex. Here Precambrian gneisses are overlain by the phyllite series, which is in turn conformably overlain by a rock series which REKSTAD (1904, 1905) called the gneiss–quartzite series. BJØRLYKKE (1905) called it the "Valdres sparagmite" series, because the less metamorphosed part in the east is mostly an arkose (= sparagmite). This series surrounds and underlies the Jotunheimen sheet nearly completely, and the lower contact of the igneous rocks is everywhere concordant with the gneissic sediments (REKSTAD, 1904, p. 12, for the north-eastern part of the areas). REKSTAD as well as BJÖRLYKKE (1905, p. 470, Bygdin area) specifically point out that it is difficult to find any contact between the gneissic sediments and the igneous Jotunheimen rocks.

Fig. 3 shows sections from the central and southern parts of the complex. In the valley of Lærdal beds of anorthosite are found in the phyllite series below the gneiss–quartzite series and the igneous rocks. At Langevadsvann, near the southern boundary of the complex, BRØGGER (1893, p. 112) found that the anorthosite body wedges out as a bed or a sheet in gneisses, which were later shown to be charnockitic (mangerites).

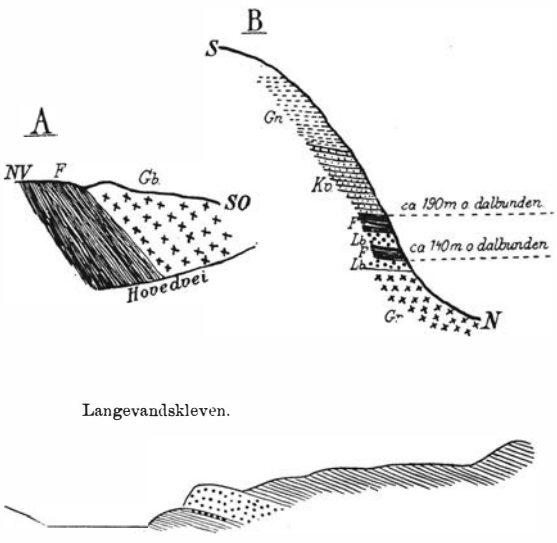

Fig. 3. Above: Sections from Lærdal. From J. REKSTAD (1905, p. 13). A — The contact between phyllite (F) and gabbro (Gb) at the main road ("Hovedvei") at Husum. B — Section at Kvamme from Precambrian granite (Gr) through anorthosite (Lb) and phyllite (F) zones to quartzite (Kv) and gneiss (Gn). "Ca. 140 m.o. dalbunnen" — Ca. 140 meters above the valley floor.
Below: Section from the southernmost part of the Jotunheimen complex, Lake Langevadsvann. From BRÖGGER (1893, p. 112). From below: Mangeritic gneisses, schistose anorthosite (3 m), white, massive anorthosite (20 m), mangeritic gneisses.

In short, there are so many features that link the certainly igneous rocks to acidic gneisses and sedimentary gneisses that a genetic relationship seems likely.

As a whole the Jotunheimen complex is an anorthosite–charnockite province, but, with its lense-shaped anorthosites, it has also affinity to the stratiform gabbro–anorthosite lopoliths (DIETRICHSON, 1958). Recently the old theory of DALY for the Bushveld lopolith has been applied to lopoliths in general (HAMILTON, 1960): lopoliths are essentially extrusive magmatic bodies differentiated to stratiform units in situ. It seems to me that this concept may also be applied to the Jotunheimen complex, whose origin would then be as follows.

In the Ordovician enormous quantities of basic magma poured out on the sea bottom in a deep trough of the main Caledonian geosyncline. Crystallization and differentiation was frequently interrupted by further upwelling of basic magma, thus producing the gneissic gabbro and their ultrabasics (see BATTEY, 1960). The intermediate and acidic rocks may have been produced by further differentiation. Possibly already during crystallization, but at least later, the whole complex was moved once or twice by rising anticlines to the west. Then the nappe structures developed along the south-eastern periphery. At the north-western boundary (e.g. in Sognefjord) the movements, or at least the last one, seem to be north-westwards (SKJERLIE, 1957).

One especially complicating feature is the existence of remnants of a "lower Jotun nappe" east of the Jotunheimen complex proper. According to STRAND (HOLTEDAHL, 1960, p. 192), the anorthositic–charnockitic rocks of this nappe are overlain by sediments and volcanics of a eugeosynclinal character. Instead of assuming the charnockitic rocks to be Precambrian, as STRAND does, the author prefers to consider them of Caledonian age (late Cambrian or very early Ordovician).

The Bergen Arcs

Rocks similar to the Jotunheimen complex occur in the so-called Bergen Arcs (II of Fig. 1) and in smaller areas further north along the western coast of Norway. These complexes are considered either to be remnants, preserved by down-folding, of one huge complex comprising these smaller areas as well as the Jotunheimen area, or remnants of a complex formed in a westerly situated syncline.

The Caledonian "gabbro phacoliths"

The situation of most of the larger and more well-known "gabbro phacoliths" are shown in Fig. 1.

South of the Bergen Arcs a concordant gabbroic body, 30 by 5 km occurs in the schists. KOLDERUP and KOLDERUP (1940, p. 25) describe the rocks as saussurite gabbro, but mention that earlier authors have in part described the rocks as greenschists.

The Fongen massif (III of Fig. 1) has not been described of late years. Norite, amphibolite, and greenschists are observed in the complex (CARSTENS, 1919).

The Heimdalshø massif in the Grong area (IV of Fig. 1) consists of normal gabbro and hornblende gabbro. The massif forms a typical "phacolith" in green schists. It will be described by the author in the near future.

The Sulitelma gabbro phacolith (V of Fig. 1) has been described in great detail by TH. VOGT (1927). The gabbro rests on amphibolites of volcanic origin.

The Råna norite (VI) has recently been described in great detail (FOSLIE, 1941). The norite body has a well-formed phacolithic shape. The lower half of the body is composed of ordinary norite containing small bodies of ultrabasics. The upper half consists of quartz norite.

The Lyngen gabbro massif (VII of Fig. 1) has been little studied. From what is known (see STRAND, in HOLTEDAHL, 1960, p. 267) it consists of a thick, platy body, 90 by 10 km, with steeply dipping contacts which are parallel to the enclosing sediments. The massif continues southward for some 20–30 km and wedges out as an amphibolite zone, appearing as a bed in the sedimentary sequence.[1]

[1] Personal communication of unpublished results by Dir. K. LANDMARK, Tromsø.

North-east of the Lyngen massif occurs a province of gabbroic rocks (the Kvænangen–Stjernöy–Seiland province), the geologic set-up of which is little known. The same is the case with the igneous province of the Lofoten islands.

All the gabbroic bodies mentioned are considered phacoliths, i.e. syntectonic intrusions along some bedding surface with pronounced movements. This mode of emplacement is, however, only a hypothesis which is an extrapolation from the laccolith concept, which has a far better foundation in geological observation. The author prefers another hypothesis for the Caledonian gabbro "phacoliths": they are formed by crystallization of a huge amount of basaltic magma extruded on the sea bottom of the geosyncline.

The idea of considering the gabbro phacoliths as syngenetic "mega-lavas" has recently been used for many such bodies in the Alpine orogene. One obstacle to this hypothesis will, to many geologists, be the making of a really "deep-seated" gabbro by crystallization on the surface. But it is known to the present author that coarse-grained plutonic rocks crystallized in the Oslo region under a roof of a few hundred meters. Strong support for assuming gabbros to have crystallized from thick lavas are also found in observations on Caledonian greenstones: not rarely the pillow lavas grade into patches of fine-grained to medium-grained gabbroic rocks. Finally, the theory presented for the formation of the Caledonian gabbro bodies finds support from the fact that gabbro formation from large-scale lava extrusions has really been observed in little-metamorphosed parts of the Alpine orogene, in northern Greece by J. H. BRUNN (1960), and in Syria by DUBERTRET (1943). BRUNN describes a concordant gabbro massif with ultrabasics at its base and transitional into pillow lavas in the upper part. It should not be impossible to find remnants of similar features, if they existed, in the metamorphic and tectonically deformed gabbro bodies of the Norwegian Caledonides. So far, stratigraphic position as concordant bodies and the abundance of green schists and similar rocks within many of the bodies are the best evidence for a supracrustal origin.

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