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THE PETROLOGY OF THE PARTEBODA TUNNEL EAST OF ÅNGE, CENTRAL SWEDEN

BY

PER H. LUNDEGÅRDH

WITH ONE PROFILE BY ERIK ÅHMAN

STOCKHOLM 1962

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The Petrology of the Parteboda Tunnel East of Ånge, Central Sweden

By

PER H. LUNDEGÅRDH

ABSTRACT

The outlet tunnel of the Parteboda power plant E. of Ånge, in the southwestern corner of the Vesternorrland County (Figs. 1—3), has been mapped petrographically and tectonically (Fig. 4). Most of the rocks of the tunnel are of old Archean age and have been referred to the Bothnian cycle of the Svecofennian era. The earliest ones are grey sedimentary gneisses with distorted layers of amphibolite. Most of these rocks have originally been deposited as greywackes and basic volcanics in a geosyncline. They have been folded and now appear as remnants and larger inclusions in a grey gneissic granodiorite called grey gneiss-granite and developed during the primorogenic phase of the Bothnian orogenesis. The granodiorite sometimes passes into tonalite. During the serorogenic phase of the Bothnian orogenesis most of the granodiorite has recrystallized and a lot of grey-white microcline porphyroblasts have grown. The resulting augengranite has been called Revsund granite. Another product of the serorogenic period of alteration, or migmatization, is a grey non-porphyritic granite, the Hernö granite, which is intrusive and has been interpreted as palingenic sedimentary gneiss. A great number of dikes of grey-white pegmatite mark the fading of the serorogenic activity.

In post-Bothnian time, probably during the Algonkian, or Proterozoic, joint systems opened and basaltic magma intruded. This magma congealed as sills and dikes of dolerite (Åsby dolerite; Figs. 4, 6—7). The dolerite and the Bothnian rocks have suffered from tectonizations and have become in part fractured or schistose (Figs. 4—5). These tectonic activities seem to have occurred simultaneously with the foldings of the Caledonides and the Alps.

Introduction

Parteboda is the name of a village situated near Ånge, a market town and railway junction in the southwestern corner of the Vesternorrland County, W. N. W. of the Sundsvall district. The river Ljungan, having its rise in the Scandinavian Mountain Chain in the west, here runs in a broad east-west valley bordered to the north and south by hills and mountains of grey gneiss and granite (Fig. 1). The gneiss is mostly metamorphosed dark greywacke and schist with occasional basic volcanics occurring as separate layers frequently boudined or imbricated.

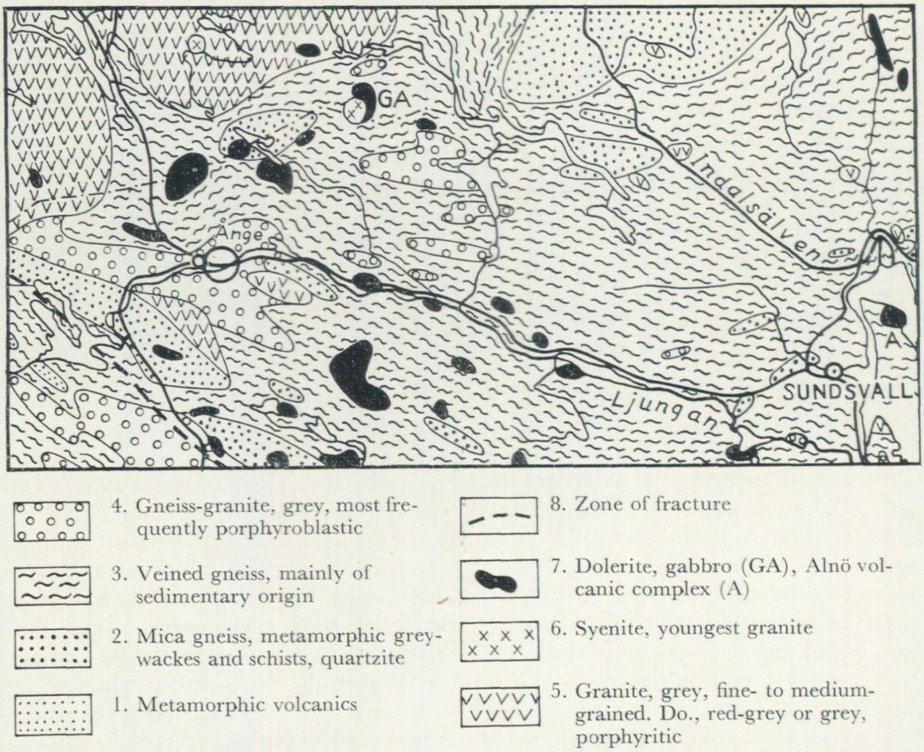


Fig. 1. Petrological sketch-map of the Ånge- Sundsvall region in Central Sweden, after Hj. Lundbohm (1899), A.G. Högbom (1920) and P.H. Lundegårdh (1960). The large circle immediately to the east of Ånge indicates the position of the Parteboda power plant. All serorogenic Svecofennian granites which lack parallel structures inherited from pre-existent rocks have been put together in group 5. — Scale 1: 1,000,000.

Pegmatite veins are common in the gneiss, and garnet as well as sillimanite sometimes appear as subordinate or accessory minerals. In strongly migmatized parts of the bedrock, the pegmatite of the veins occurs as large masses, and palingenic granite originating from the gneiss becomes an important rock.

The granites of the Ånge area are either gneissic granodiorite in part rather coarse-grained and called *grey gneiss-granite*, or the palingenic granite just mentioned. The gneiss-granite has been strongly recrystallized and has then frequently lost all or most of its parallel structures. It has simultaneously become porphyroblastic and now contains abundant grey-white microcline augen (rounded or rectangular) measuring up to 8 *à* 9 cm across. This rock has been known as *Revsund granite* (after Revsund, a church in Jemtland County), whereas the palingenic granite, which is frequently rather inhomogeneous though mostly fine medium-grained, has been called *Hernö granite* (after Hernö island about 50 km N. E. of Sundsvall). Some Revsund granite has also been developed by strong metasomatic alteration of greywacke gneiss.

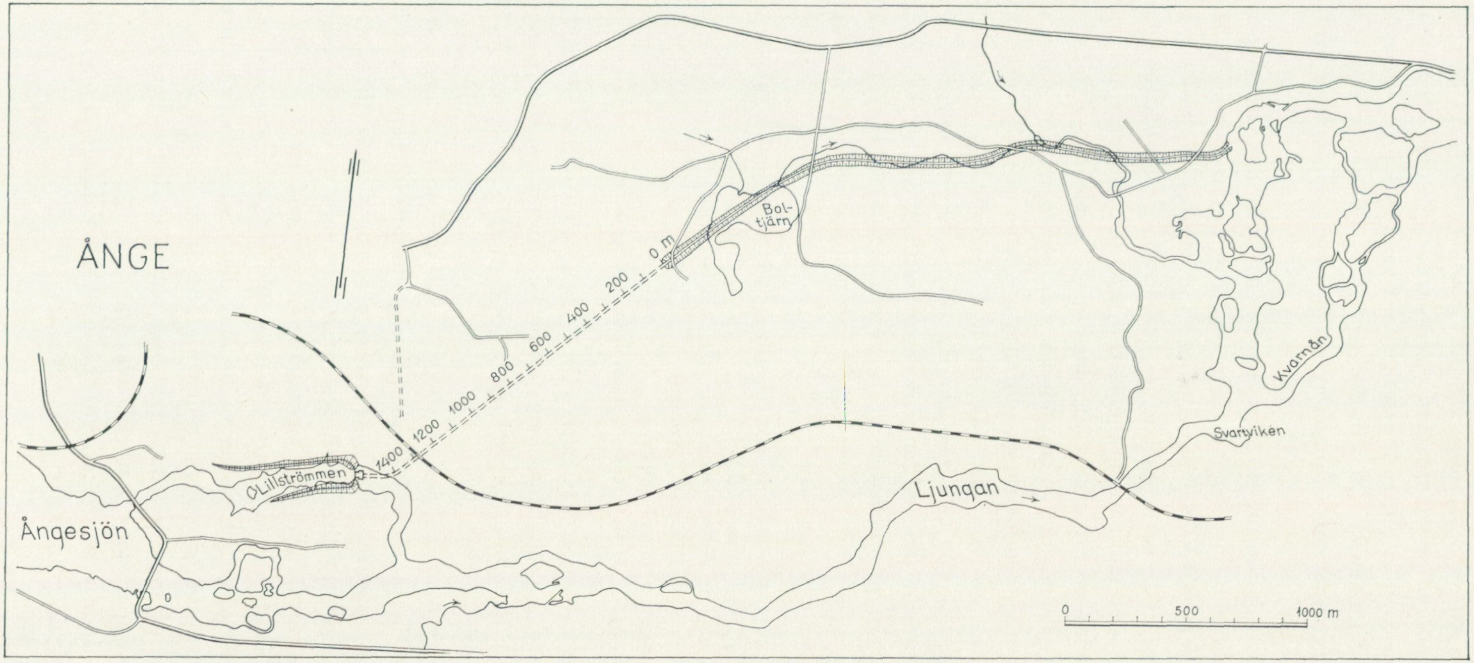


Fig. 2. The outlet tunnel (0—1400 m) and canal of the Parteboda power plant.

The ancient supracrustal rocks, viz. the metamorphosed greywackes and schists, have been deposited as sediments in a geosyncline stretching E. S. E. towards the Tampere schist belt in Finland, described especially by J. J. Sederholm in 1897, 1931, and A. Simonen in 1953. In Sweden, this geosyncline borders in the south on a miogeosyncline built up mainly of metamorphic arkoses and sandstones (the *Naggen group* described by the writer in 1960).

The granodiorite seems to originate chiefly from a homogenized migma of mobilized sedimentary rocks and basic, probably basaltic eruptions. The secondary magma thus developed has occupied the cores of the growing anticlines of the geosyncline at an early stage of its tectonization, whereas the migmatization including the development of the Hernö granite has been concentrated in the synclines and has occurred at a late stage of the orogenesis. Zones rich in Hernö granite are therefore poor in granodiorite, and *vice versa.* The acid residual solutions of the palingenic Hernö granite magmas have crystallized as dikes of pegmatite (Fig. 4), owing to the favourable P-T-conditions created by a stage of decreasing tectonic activity including the formation and opening of joints. The contents of boron of the marine geosynclinal sediments have been responsible for the crystallization of tourmaline in the outermost parts of the folded geosyncline.

The processes sketched above may be summarized as a cycle composed of the following stages:

Serorogenic stage	Migmatization including the development of pegmatite (veins, masses, dikes), Hernö granite, and Revsund granite.
Primorogenic stage:	Granodiorite.
Geosynclinal stage:	Greywackes, schists, basic volcanics.

The whole evolution has been called the *Bothnian cycle* (P. H. Lundegårdh 1960). This cycle probably belongs to the *Svecofennian era*, the youngest rocks of which seem to have been formed about 1750 million years ago (N. H. Magnusson 1960, E. Welin 1961).

During later Archean periods (900 — 1750 million years ago), the Bothnian rocks became in part cracked and disjointed and sometimes even intruded by magma. Thus appeared dikes and masses of younger rocks, the absolute ages of which are frequently difficult to determine especially as the sporadic magmatic activities continued during the Algonkian or Proterozoic (600 — 900 million years ago). In the southwestern corner of Vesternorrland County as well as in adjacent regions, numerous black dolerite sills and dikes have been produced by these activities. The grain size of the dolerite grades from fine-grained to coarse. The rock has been distinguished as *Åsby dolerite*, after the village *Åsens by* in the northern part of Kopparberg County (Dalecarlia).

Though quite a young rock, probably of Algonkian age, the dolerite has been influenced by still younger tectonic activities.

Fig. 3. Interior of the outlet tunnel of the Parteboda power plant (width about 10 m, maximum height about 9 m, area of cross section about 85 m^2). Photo from N. E. by P.H. Lundegårdh in 1960.©

In the vicinity of the river Ljungan, a series of power plants have been built during the last twenty years. Some of these power plants deliver their water to long outlet tunnels blasted through the bedrock. Such a tunnel has been described by S. Hjelmqvist (1944). It carries the water of the Gim rivulet to the river Ljungan through the bedrock N. E. of Torpshammar, a village situated between Ånge and Sundsvall. The Torpshammar tunnel exposes several sills and dikes of Åsby dolerite. Most of these have been affected by zones of tectonic brecciation. The Åsby dolerite of the Torpshammar tunnel is a normal olivine-dolerite which in one case has been seen to pass into monzonite. Monzonitic differentiation products of Åsby dolerite magma are by no means uncommon in Central Sweden. H. von Eckermann (1936) has described such rocks from the areas around the boundaries between the Kopparberg, Gevleborg and Jemtland Counties in West-

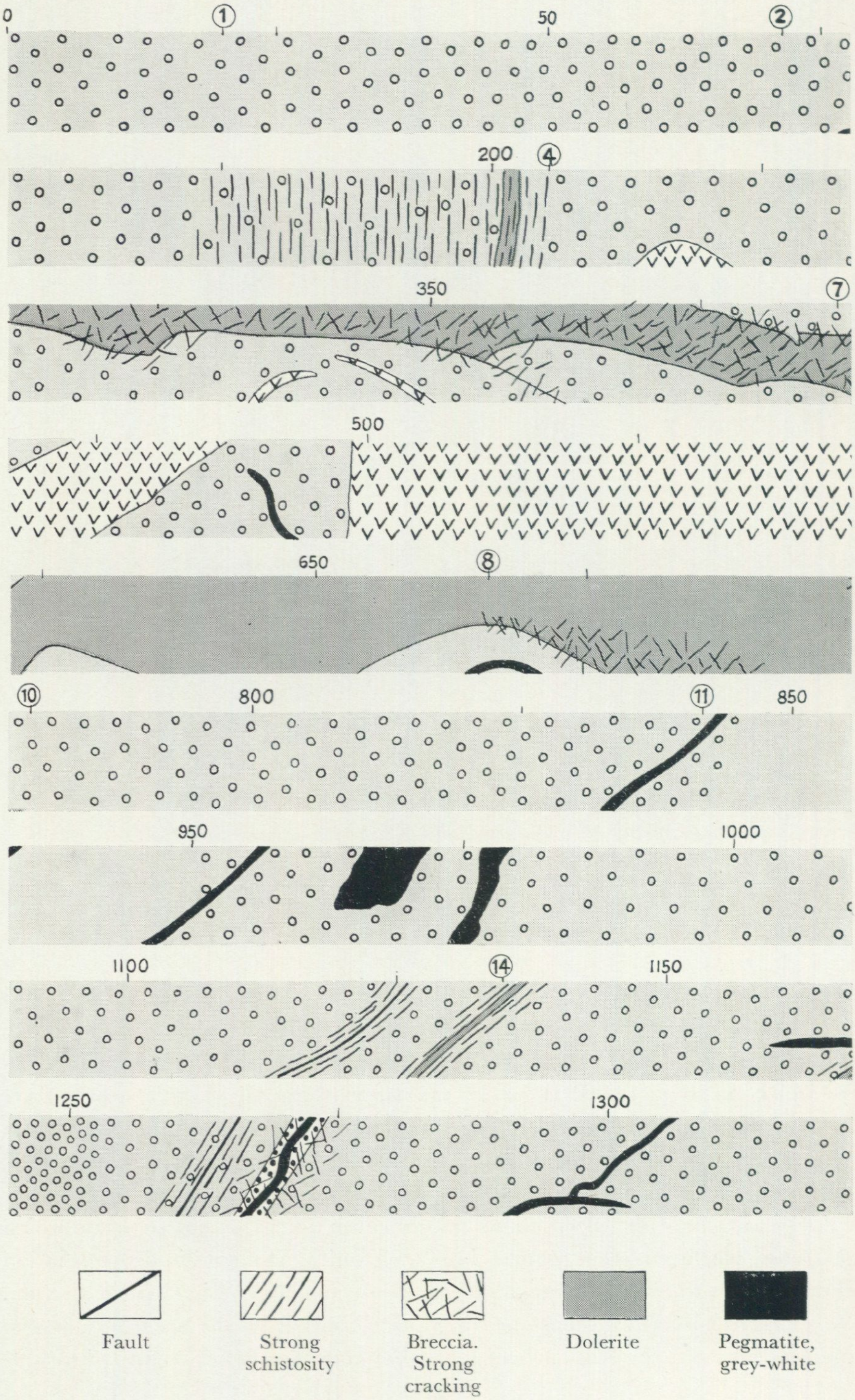
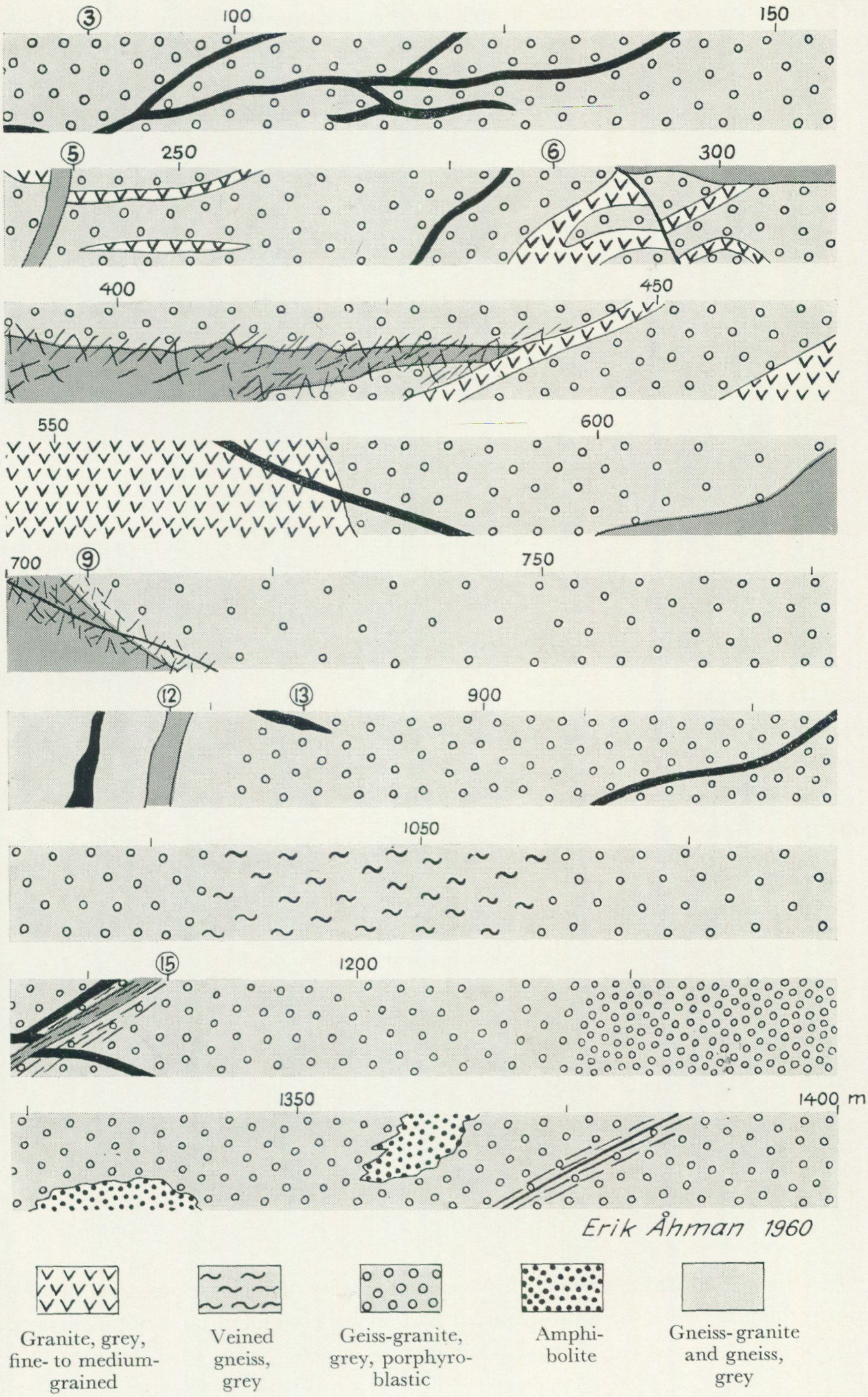


Fig. 4. Petrological profile along the southeastern wall of the outlet tunnel of the Parteboda power observations which have



plant, from NE (0 m) to SW (1400 m; compare Fig. 2). Numbers in circles indicate the structural
been recorded in Table 1.

ern Central Sweden. Even final stages of differentiation of Åsby dolerite magma consisting of granophyric granite have been met with in Central and Southern Sweden (S. Hjelmqvist 1961, T. Krokström 1932).

Petrography of the Parteboda Tunnel

The Parteboda power plant in the eastern vicinity of Ånge includes an outlet tunnel measuring a little more than 1 400 m in length (Fig. 2). The turbine-hall is situated in the bedrock immediately to the east of Lillströmmen in Fig. 2. The width of the tunnel is about 10 m and the maximum height amounts to 9 m (Fig. 3). A complete profile along the southeastern wall of the tunnel is given in Fig. 4. The mapping has been carried out with great skill by Dr. Erik Åhman of the Geological Survey.

PRE- AND PRIMOROGENIC BOTHNIAN ROCKS

The predominant rock of the Parteboda outlet tunnel is a grey medium-grained granodiorite composed mainly of oligoclase, microcline, quartz, and biotite. Microcline occurs mostly in the interstice and has thus crystallized at a late stage of the formation of the rock. Inferior or accessoric minerals include chlorite, iron sulfide ore, apatite, iron oxide ore, and zircon. The texture is hypidiomorphic to xenomorphic. Many of the plagioclase individuals seem to have developed originally as laths, but owing to secondary alterations their regular contours have been more or less spoilt.

Table 1. Structural observations in the outlet tunnel of the Parteboda power plant. The numbers refer to the profiles of Fig. 4. The observations have been made by Dr. Erik Åhman.

1. Porhyroblastic gneiss-granite, strike N55°W, dip 70° S.W.
2. *Do.*, strike N40°W, dip 5° S. W.
3. *Sköl* (schistose alteration zone rich in chlorite), strike N75°W, dip 85°S.
4. Dolerite dike, strike N80°W, dip 85°S.
5. *Do.*, strike N-S, dip 80°W.
6. Porphyroblastic gneiss-granite, strike N40°W, dip 40° S.W.
7. *Do.*, strike N60°W, dip 40° S.S.W.
8. Dolerite contact, strike N30°E, dip 25°E.S.E.
9. *Do.*, strike N20°W, dip 25° E.N.E.
10. Porphyroblastic gneiss-granite, strike N50°W.
11. Pegmatite dike, strike N30°W, dip 45° W.S.W.
12. Dolerite dike, strike E-W, dip 80°S.
13. Aplite dike, strike N70°E, dip 70° N.N.W.
14. Dolerite dike, strike N30°W, dip 40°W.S.W.
15. *Do.*, strike N50°W, dip 35° S.W.

The chief structural element is a planar schistosity of variable strength though most frequently weak or almost absent owing to post-tectonic recrystallization. Occasionally, a weak lineation (linear schistosity) is seen. (See p. 14.) The lineation,

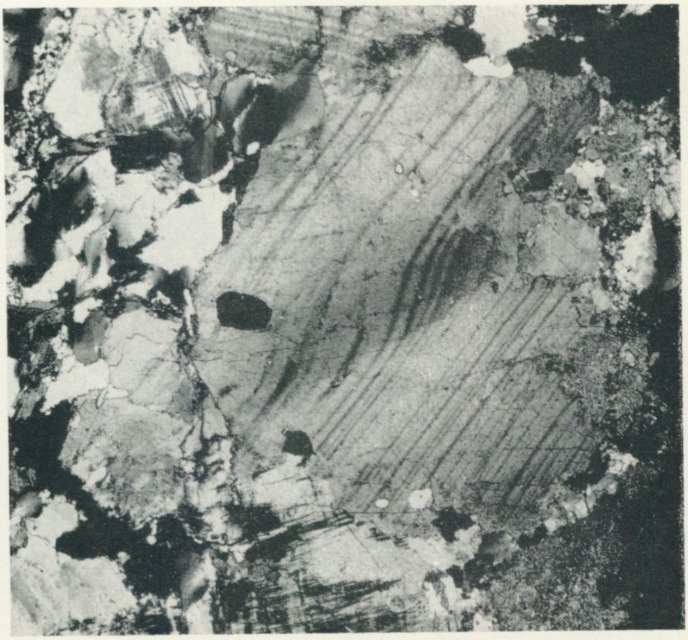


Fig. 5. Thin section of grey gneiss-granite with signs of late tectonization (crushing, bending of plagioclase individuals). Crossed nicols, magnification 20x. Near Lillströmmen (Fig. 2) in the upper end of the outlet tunnel of the Parteboda power plant. Photo by S. Hjelmqvist in 1961.

too, has been influenced by the post-tectonic recrystallization, the most conspicuous result of which has been the growth of a great number of grey-white microcline porphyroblasts, both rectangular and rounded. The maximum diameter of the augen amounts to 6 cm. The augen form intergrowths with scattered small remnants of pre-existent minerals, primarily oligoclase and biotite. Myrmekitic intergrowths appear to be intimately associated with the growth of secondary microcline. The myrmekite consists of minute threads of quartz aggregated in swarms in the marginal parts of some plagioclase individuals situated in the neighbourhood of the secondary microcline.

The *blastesis* indicates an increase of the bulk content of potassic feldspar in the granodiorite. The latter has a lower content of this mineral when non-porphyritic. In fact, part of the non-porphyritic granodiorite grades into tonalite.

Simultaneously with the *blastesis*, the granodiorite (and tonalite) has recrystallized nearly completely so that only sparse, small, strongly sericitized spots of older plagioclase are still visible in the oligoclase of the rock.

Because of its planar structure the granodiorite has been classed as a gneiss-granite (p. 4). It has been referred to the Bothnian cycle as a primorogenic rock, and its recrystallization including its *blastesis* has been interpreted as a serorogenic

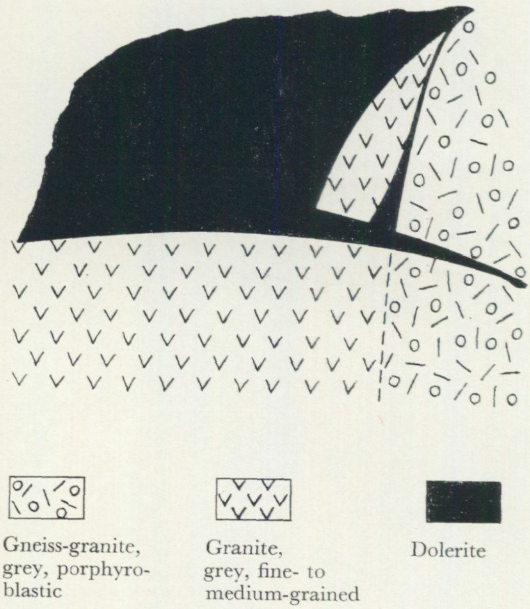


Fig. 6. Detail of margin of dolerite sil with apophyses. Scale 1: 25. On the opposite side of observation point no. 9 in the profile of Fig. 4.
P. H. Lundegårdh 1960.

alteration. As already mentioned, the porphyroblastic granodiorite has been called Revsund granite.

Part of the recrystallized granodiorite has been subjected to post-Bothnian tectonization involving the bending and crushing of certain mineral grains (Fig. 5) and the development of joints and zones of fracture (Fig. 4).

The granodiorite often contains remnants of grey fine-grained gneiss of sedimentary origin, most probably greywacke gneiss, and sometimes also of basic volcanics altered to amphibolite. The gneiss remnants are as a rule rather small and frequently show diffuse contours. For this reason only one inclusion has been marked in the profile of Fig. 4. Part of the gneiss remnants contain pegmatite veins (the veined gneiss of Fig. 4) which have been formed at an early stage of the serorogenic migmatization (see below), most probably by recrystallization of primorogenic acid veins.

One amphibolite dike has been found in the Parteboda tunnel. This amphibolite originates from basic magma intruded after the consolidation of the gneiss-granite but before the serorogenic migmatization. (See Fig. 4: between 1250 and 1300 m.)

Serorogenic Bothnian Rocks

The serorogenic phase of the Bothnian cycle was characterized by the rise of migmatite fronts in the synclines of the folded bedrock. The migmatization has always started with the growth of veins of pegmatite or sometimes of granite or syenite. The veins of the veined gneiss of the Parteboda outlet tunnel thus belong to the oldest serorogenic rocks. Somewhat later the blastesis has caused recrystallization of the granodiorite, or grey gneiss-granite, and growth of microcline porphyroblasts, viz. the development of a variety of the Revsund granite. (See above.)

The next step was the formation of a secondary magma by palingenesis of pre-existent rocks, mainly greywackes. Much of this magma became no more than migma and solidified to an inhomogeneous rock filled with remnants of greywacke gneiss and other metamorphic rocks of supracrustal origin. Other portions became rather homogeneous and intruded the metamorphic gneiss-granite, viz. the Revsund granite, congealing there as irregular masses and dikes of variable width (Fig. 4). Only the latter kind of intrusions have been met with in the Parteboda tunnel, but examples of the former occur not far to the east.

The serorogenic palingenic granite — the Hernö granite — is grey, fine- to medium-grained and composed mainly of quartz, microcline, oligoclase, and mica, both biotite and muscovite.

The fading tectonic and magmatic activity at the end of the Bothnian cycle is marked by the development of contraction joints in which palingenic rest solutions crystallized, viz. grey-white pegmatite showing a mineral composition similar to that of the Hernö granite. In a few cases, pale grey aplite has also been seen.

Åsby Dolerite

The Parteboda outlet tunnel contains several dolerite dikes with moderate to high dips. These dikes are quite narrow and consist of a black, dense, in part metamorphosed (uralitized or chloritized) rock. As is seen from Fig. 4, some of these dikes are situated in schistosity zones and have been strongly affected by late tectonic activities.

Furthermore two sills of dolerite have been encountered in the tunnel. The rock of the sills has also been altered in part and has been subjected to late tectonizations. It has thus become in part strongly cracked or even brecciated or faulted. The sills bear evidence of weak folding too, but this folding may have happened before the fissures opened and became filled with dolerite. The sills show chilled margins and locally extend into cross joints (Fig. 6).

The dolerite of the inner parts of the sills is grey black and fine to medium-grained. The rock shows a beautiful ophitic texture and, when preserved against mineral alterations, it contains both olivine, orthopyroxene ($2V\gamma$ about 95°), and clinopyroxene. (See Fig. 7.) The main components are, however, plagioclase (An about or a trifle less than 50%) and, in most cases, deuteric or secondary mafic minerals (uralite, serpentine, chlorite). In cases of strong mineral alteration, part or most of the plagioclase has been sericitized. Iron oxide ore, most probably titaniferous, is very common in the dolerite, whereas apatite is rare.

No magmatic differentiation products, such as monzonite, have been observed.

Fig. 7. Thin section of dolerite. 1 nic., magnification 21x. Northwestern side of cross section 730 m. (See Fig. 2.) Photo by S. Hjelmqvist in 1961.

Summary of Tectonic Events

The folding of the sedimentary and volcanic rocks deposited in the Bothnian geosyncline made possible the development and rise of a secondary magma of granodioritic composition. This process was the culmination of the first period of tectonic activity in the geosynclinal region, and the resulting new rocks — granodiorite in the first instance — have therefore been called primorogenic. The granodiorite is a high-pressure rock not accompanied by pegmatite. It has intruded into those parts of the bedrock characterized by decreasing pressure, viz. the anticlines. When pressure changed from hydrostatic to directed, the granodiorite became schistose. In the Parteboda outlet tunnel, its schistosity is as a rule planar (Table 1). Only one reliable observation of lineation has been made: at 675 m (Fig. 2) in the northwestern wall, where the dip of the structure is 30° towards S 50° E. This direction coincides well with the general lineation of middle and eastern Central Sweden, which is usually 5—40° E.—S.E. (E. in eastern, S.E. in middle Central Sweden). (Compare P.H. Lundegårdh, 1960.)

The folding of the Bothnian geosyncline was followed by a period of dilation characterized by further sinking of the synclines and the development of fissures. A few of these fissures have been filled with basic magma intruded before the serorogenic migmatization, and other fissures have been used by later intrusion of both migmatization products and Åsby dolerite. In the sinking synclines the sedimentary rocks were first veined by pegmatite, and later on palingenic matter assembled to secondary magma rising and crystallizing as Hernö granite and pegmatite. The youngest rock of the serorogenic period of migmatization is the pegmatite that has filled cracks and contraction joints in the bedrock.

The granodiorite became also affected by the migmatization. A regional *blastesis* occurred, the most conspicuous result of which has been the disappearance of fissures, and the growth of microcline porphyroblasts even in parts of the rock originally augen-free, such as the variety exposed in the Parteboda outlet tunnel.

The Archean geological periods following upon the Bothnian do not seem to have influenced the bedrock of the Parteboda power plant much. When the Åsby dolerite appeared, probably during the Algonkian or Proterozoic, only few joints and fissures had been added to the tectonic pattern already existing at the end of the Svecofennian era. In Fig. 4 one such fissure filled with dolerite can be seen at observation point no. 5. The Hernö granite sill faulted along this fissure is also interesting inasmuch as it gives evidence of the existence in late Svecofennian time of low-dipping or horizontal fissures of the same kind as have been used by the dolerite magma when intruding and solidifying as sills hundreds of millions of years afterwards.

Many fissures and joints, both low-dipping and high-dipping, were open or could be opened when the dolerite magma intruded. We thus obtained the numerous black dikes and sills of the present bedrock. The latter are as a rule much larger than the former in the Parteboda area. At least two generations of dolerite exist in middle and eastern Central Sweden, as displayed by a few observations of sills cut by dikes with high dips.

S. Hjelmqvist (1944, p. 280) has pointed out that some tectonization seems to have occurred simultaneously with the intrusion of the dolerite magma. Especially the growth of the thick sills should have caused some cracking and jointing and locally even crushing in the surrounding older rocks. In the Parteboda tunnel, the dolerite apophyses shown in Fig. 6 may have made use of such cracks.

As is seen in Fig. 4, the Åsby dolerite dikes and sills of the Parteboda tunnel have been affected by later tectonic activities. Cracking and brecciation are common features, as well as thrust zones marked by strong schistosity and faults (for example between 1150 and 1200 m in Fig. 4). The cracking has frequently been very strong and extensive, as shown in one of the sills in the Parteboda tunnel. The tectonizations now recorded seem to have to be ascribed chiefly to the Caledonian and Alpine orogenies, both of which have affected the bedrock in the west, the former by folding and thrusting, the latter by an upheaval of the land.

The dolerite sills undulate, but owing to the great age of the fissures followed by the intrusive dolerite, the undulations may be older than this rock. In other parts of Sweden, periods of folding have, indeed, occurred repeatedly between the Svecofennian migmatization and the intrusion of the Åsby dolerite.

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