SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 722 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 70 NR 4

LARS PERSSON

PETROLOGY OF THE JÄRNVÄGSFORSEN TUNNEL, WESTERN MEDELPAD, CENTRAL SWEDEN

STOCKHOLM 1976

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 722 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 70 NR 4

LARS PERSSON

PETROLOGY OF THE JÄRNVÄGSFORSEN TUNNEL, WESTERN MEDELPAD, CENTRAL SWEDEN

STOCKHOLM 1976

ISBN 91-7158-100-6

Fig. 1. på s. 4 är ur sekretessynpunkt godkänd för spridning. Statens Lantmäteriverk 1976-04-26.

Schmidts Boktryckeri AB
Helsingborg 1976

CONTENTS

ABSTRACT

A petrological profile is presented of the 11 km long tunnel of the Järnvägsforsen power plant in the river Ljungan. The tunnel is situated in the western part of the Province of Medelpad, central Sweden. The rocks belong to the Svecofennian orogenic complex and comprise supracrustals, syn- and serorogenic granitoids. The first two groups of rocks have been migmatized. Numerous dolerites intersect the older rocks. A summary of the tectonic features is given.

INTRODUCTION

The work on the tunnel of the Järnvägsforsen power plant (owner AB Skandinaviska Elverk) was started in April 1973 and finished in November 1976. The tunnel is located in the western parts of the Province of Medelpad (topographic maps 17 F Ånge SO and NO). The tunnel starts at Holmsjön 1.5 km west of Östavall (Figs. 1 and 3) and its outlet is near Ovansjö (Fig.1) at the small island called Ön in Ångesjön, about 4.5 km southwest of Ånge. The river Ljungan in this area flows through Holmsjön and in a wide swing to Ångesjön. The direction of the tunnel is northeast—southwest and its length about 11 km. The area of cross section of the tunnel is about 98 m^2. The height of fall is 87 m.

The tunnel was mapped in order to get information for the work in progress on the petrological map of Västernorrland County (directed by Dr. Thomas Lundqvist, Geological Survey of Sweden).

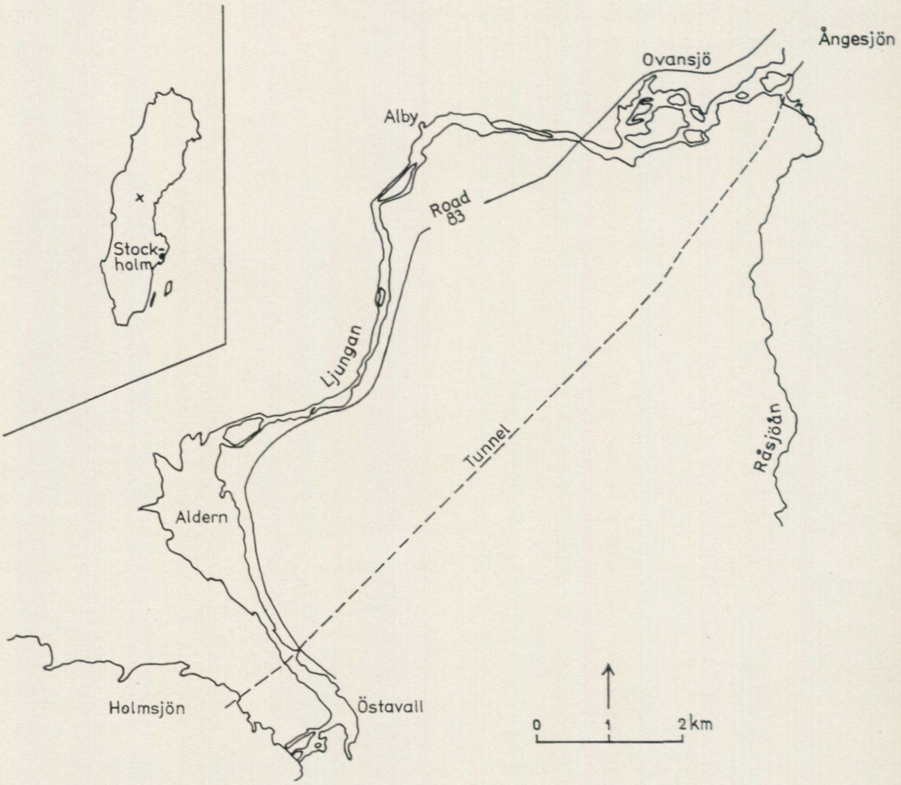


Fig. 1. Outline map.

Fig. 2. Entrance to the tunnel near Alberget.

The tunnel gives an excellent profile across the bedrock of the area and this is of special importance, as outcrops are very few in this region.

Some power plants have earlier been built in the river Ljungan and its tributaries. A tunnel near Torpshammar has been described by Hjelmqvist (1944) and another tunnel near Parteboda by Lundegårdh (1962; with a petrological profile by E. Åhman).

ROCKS OF THE TUNNEL REGION

The tunnel is excavated in rocks belonging to the Svecofennian orogenic complex. Only the numerous intersecting irregular sheets and dykes of dolerite are younger. These dolerites are considered to be of Jotnian or post-Jotnian age, their specific texture corresponding to that of Åsby dolerites as defined by Krokström (1936).

The oldest Svecofennian rocks of the area are so-called greywackes, i.e. rather well-preserved, sedimentary rocks interbedded with unknown quantities of volcanic material. These greywackes are very often metamorphosed to coarser sedimentary gneisses, which in turn have been migmatized to varying degrees. Thus, veined gneisses and different types of migmatites belonging to a more advanced

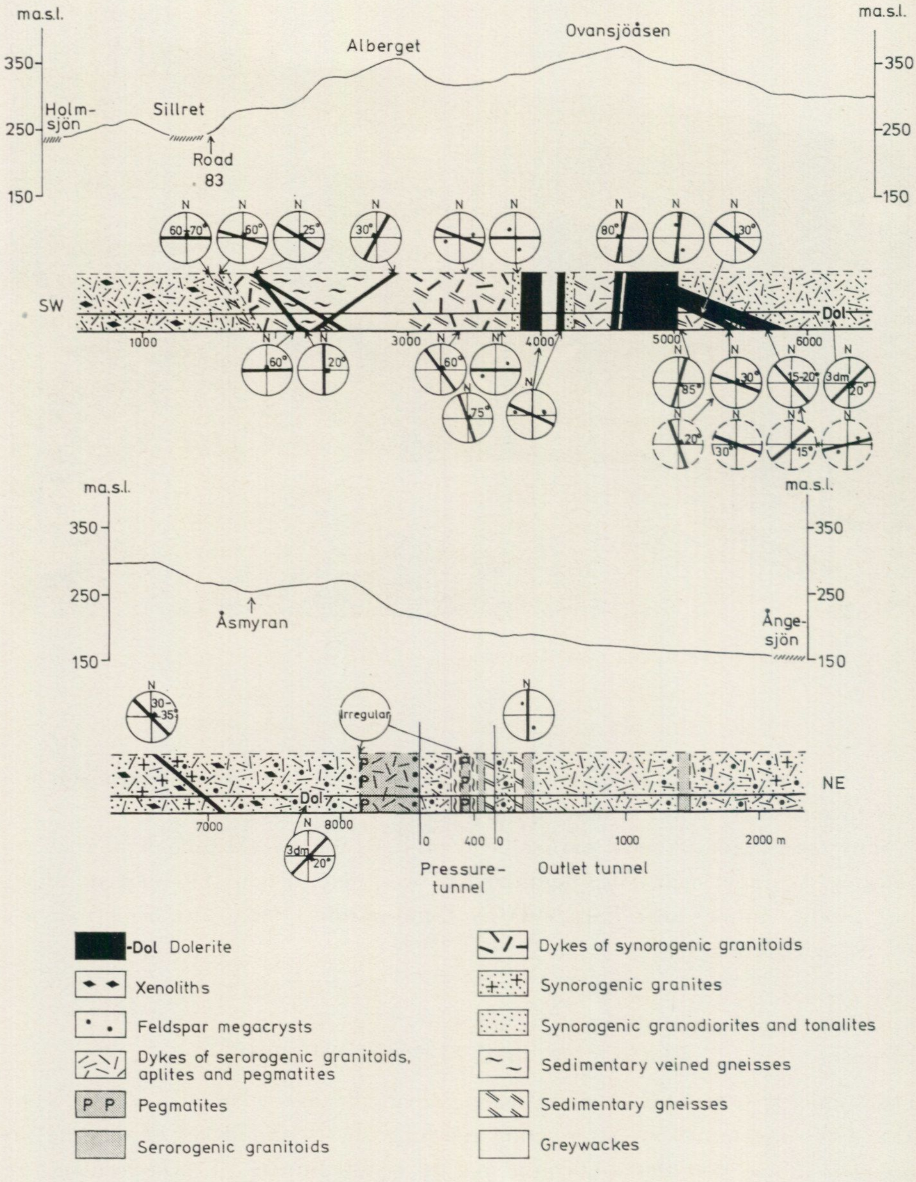


Fig. 3. Petrological profile of the tunnel of the Järnvägsforsen power plant. Stereograms show strike and dip of the contacts.

stage of mobilization have been formed. In extreme cases occur migmatites with pieces of sedimentary gneiss (raft migmatites, Mehnert 1968, p. 10) and migmatites with ghost-like remnants of sedimentary rocks (nebulitic migmatites, Mehnert 1968, p. 11). The age of the supracrustals is probably about 2 000 m.y. These pre-orogenic rocks have been intruded by synorogenic plutonics, which are considered to constitute a differentiation suite from gabbros via diorites and granodiorites to granites. Normally they have a distinct foliation, and the quartz-bearing rocks are therefore called gneiss-granites. The synorogenic intrusions have also been affected by migmatization. The age of the synorogenic rocks is c. 1 950–1 850 m.y. (Magnusson 1960, Welin et al. 1970). A number of serorogenic intrusions, the so-called Härnö granites, intruded after the migmatization, and are in turn followed by aplitic granites and pegmatites. The age of the Härnö granites is c. 1 800 m.y. (Magnusson 1960, Welin and Blomqvist 1964).

The Åsby dolerites and other Jotnian or post-Jotnian dolerites of these parts of Sweden have been dealt with in several contexts (e.g. von Eckermann 1936, Hjelmqvist 1944, Lundegårdh 1962, Larson 1973, Lundqvist and Samuelsson 1973). In some cases a monzonitic differentiation has been observed (e.g. von Eckermann 1936, Hjelmqvist 1944 and 1966, Lundqvist 1968). A Rb/Sr determination of an olivine dolerite from the Nordingrå area has given a very approximate age of 1 300—1 400 m.y. (Welin 1966, Welin et al. 1966). A K/Ar isochron calculation of the age of Jotnian or post-Jotnian olivine dolerites from the Nordingrå area has given 1 245 m.y. (Welin and Lundqvist 1975). Åsby dolerites very often appear in eastern Ångermanland and the western and central parts of Medelpad (cf. Lundbohm 1899), in Gävleborg County (Lundegårdh 1967, Lundqvist 1968) and Kopparberg County (Hjelmqvist 1966). They generally form thick sheets and sills but also occur as narrow, steep dykes.

SUPRACRUSTAL ROCKS

The supracrustal rocks are represented by greywackes of varying metamorphic grade. They mostly occur in the neighbourhood of Alberget (1 800–4 600 m, Fig. 3). The greywackes are well-preserved, fine-grained, dark grey rocks which sometimes have a distinct planar or linear fabric. Alternating quartz-feldspar-rich and mica-rich layers exist. Dominant strikes of the schistosity planes are from N 45°W to N 85°W with vertical or high northerly dips. Also NNW and NNE directions are represented. The explanation of the varying directions may be that the supracrustals have been brecciated into blocks and rotated by the synorogenic intrusions. It is also possible that the supracrustals were deformed before the intrusion of the granitoids.

The greywackes are quartz-mica-feldspar rocks. In some places there are layers rich in mica, probably representing original argillaceous beds. Graphite together with sulphides occur in 1–3 dm large, elliptic, schistose aggregates, e.g. in section 2 011. Some centimetre-wide calcite-filled veinlets occur at Alberget (Fig. 4).

Fig. 4. Calcite-filled joint in greywacke. Diameter of coin is 15 mm. Alberget.

Frequently the greywackes have been altered to coarse and gneissose rocks. White, salic, finely medium-grained granitic veins may then also appear subparallel with the primary schistosity planes. Regularly occurring veins produce veined gneisses, e.g. sections 2 200, 2 300 and in the pressure tunnel (Fig. 3). A large number of synorogenic granitoid dykes intersect the supracrustals, e.g. from 2 800 to 3 800 m. Metre-wide sheets of greywacke occur as xenoliths in these granitoids, e.g. near section 830. In some places numerous, irregular dykes of pegmatite have intruded the supracrustals both concordantly and discordantly. The width of these dykes varies from one decimetre to some tens of metres. Irregular pegmatitic schlieren very often occur as well.

The texture of the greywackes is massive because of randomly oriented biotite crystals. The matrix constituents range between 0.04 and 0.15 mm in size. The mica is about 0.1 mm. Some granulated quartz grains of about 0.8 mm diameter occur. A point-count analysis (1 091 points) showed the following: quartz 37 % (undulose, relatively straight boundaries), biotite 32 % (X yellowish brown Y=Z reddish brown), plagioclase 30 % (sericitized, An contents corresponding to oligoclase) and finally 1 % potassic feldspar (perthitic). Accessories are chlorite (light green), zircon, apatite, prehnite, ore minerals and tourmaline. Another, more tectonized sample shows a very strong chloritization and sericitization. Thin veinlets of epidote minerals and/or quartz and potassic feldspar intersect the rock. This rock type has a distinct parallel texture. The content of potassic feldspar is much higher in this rock type as compared to the former sample (partly in the form of antiperthite).

SYNOROGENIC INTRUSIONS

The synorogenic intrusions constitute the main part of the tunnel. They have a varying appearance and generally cannot be considered to be typical for the Västernorrland County. The are usually grey or greyish white, rather salic or intermediate, finely medium-grained to medium-grained, granitic to granodioritic rocks with a weak parallel structure (e.g. near Holmsjön, Fig. 5). Tonalites

Fig. 5. Synorogenic, medium-grained, foliated granodiorite. Diameter of coin is 15 mm. Holmsjön.

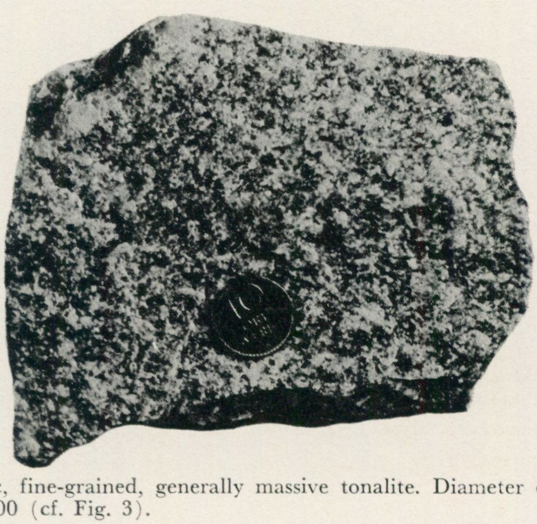


Fig. 6. Synorogenic, fine-grained, generally massive tonalite. Diameter of coin is 15 mm. Section 3 300 (cf. Fig. 3).

also occur frequently (Fig. 6). Other types are grey, intermediate and with a distinct parallel structure (section 795). Grey—white, elongated feldspar megacrysts (length 0.5—1.5 cm) occur in the sections 7 600—8 200 and in the outlet tunnel. Near Ångesjön there is a greyish white, rather salic, relatively massive, finely medium-grained granitic to granodioritic rock type with few and rather small megacrysts (0.5×0.5 and 1×0.5 cm). In their massiveness, light colour and small grain size, the synorogenic granitoids in the tunnel partly resemble younger granites of serorogenic age. They have very often been regenerated and their synorogenic character is indicated by the numerous intrusions of salic granites, aplitic granites and pegmatites, e.g. in the sections 1 525—2 196 in the outlet tunnel. The synorogenic intrusions contain xenoliths of supracrustal rocks. These xenoliths are centimetre- or decimetre-large pieces but may also attain sizes of 1 m to 20 m (e.g. sections 500—1 800 and 6 500—8 000). Garnet can be found sporadically in the intrusions. In general the latter have been intersected by pegmatitic material. In some sections, e.g. near Ångesjön, salic veins occur concordantly with the gneissosity plane, i.e. a migmatization has occurred.

In the quartz — potassic feldspar — plagioclase triangle (Fig. 8) the composition of the synorogenic intrusions corresponds to monzogranites, granodiorites, and tonalites according to Streckeisen's terminology (1967). This rock trend is typical of synorogenic intrusions in the Svecofennides.

TABLE 1. Modal (volume percent) analyses of synorogenic intrusions

Sample	LP74:7 6946[2]	TL73: 126a Ångesjön	Holmsjön	Drill-core 9 Ångesjön	LP74:2 1140	LP74:3 1305	3300
Quartz	30	28	30	33	30	28	31
Potassic feldspar	29	33	13	16	4	4	4
Plagioclase[1]	34	32	41	40	53	52	57
Amphibole	—[3]	—	1	—	—	—	—
Biotite	+[4]	3	13	10	+	14	7
Chlorite	4	3	+	+	9	+	+
Muscovite	1	+	+	+	+	+	+
Ore minerals	+	+	+	+	+	+	+
Sphene	+	+	+	—	1	+	+
Apatite	+	+	+	+	+	+	+
Epidote minerals	1	+	—	+	+	+	+
Zircon	+	+	+	+	+	+	+
Calcite	+	+	+	+	+	+	+
Fluorite	+	—	—	—	—	—	—
Prehnite	+	+	+	+	+	+	+
Number of points	1 049	877	895	980	1 243	996	1 055
Nomenclature Streckeisen -67	Monzogranite	Monzogranite	Granodiorite	Granodiorite	Tonalite	Tonalite	Tonalite

[1] including secondary sericite
[2] figure marks section in the tunnel (Fig. 3)
[3] — = not observed
[4] + = less than 1 %

The synorogenic intrusions have an anhedral, uneven-grained texture. Usually they are strongly tectonized. The plagioclase laths have been crushed and kink bands exist in the biotites. Modal compositions are given in Table 1. The plagioclase is usually strongly sericitized. It is normally zoned. Myrmekitic intergrowths with quartz are common. The An content is generally around 30 % (sligthly lower in the granites), which corresponds to calcic oligoclase — sodic andesine. The cores may correspond to intermediate andesine (36 %). Microcline with a distinct cross-hatching occurs and is often perthitic. Film, string, vein, plume and interpenetrant perthites (cf. Spry 1969, p. 182) exist. The potassic feldspar tends to gather around the plagioclase laths. Existing biotites have the pleochroism: X yellowish brown, Y=Z dark brown or reddish brown. A chloritization and prehnitization (cf. Hjelmqvist 1937, Phillips and Rickwood 1975) is common. In one sample near Holmsjön amphibole has been observed. Besides, muscovite, epidote minerals, opaque minerals, sphene, apatite, zircon, calcite and fluorite exist (cf. Table 1).

SERorOGENIC INTRUSIONS

The serorogenic intrusions (the so-called Härnö granites) occur especially in the lower part of the tunnel (the end of the main tunnel, the pressure and the outlet tunnel, Fig. 3). Most typical is a grey—white, salic, massive, fine-grained to finely medium-grained granite. Sometimes a parallel structure can be observed (Fig. 7). Red, fine-grained, salic types also exist, e.g. in the pressure tunnel, at the end

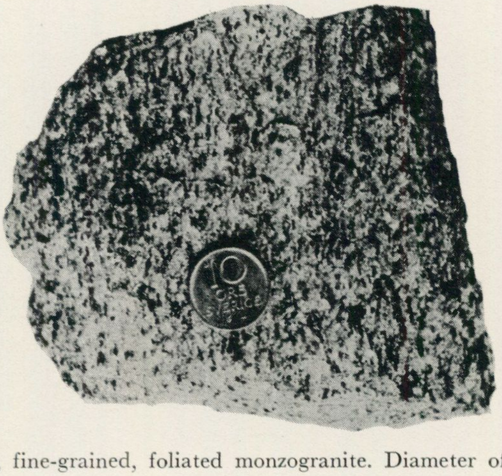


Fig. 7. Serorogenic, fine-grained, foliated monzogranite. Diameter of coin is 15 mm. Alberget.

of the outlet tunnel and at section 8 540. Near the section mentioned a local porphyritic structure can be seen in the grey granitoid. Late-magmatic solutions are represented by aplitic granites, pegmatites and a red microcline-dominant granitoid. Pegmatites are numerous in all the older rocks along the whole tunnel. Most often these pegmatites are white, but red types also occur, especially in the lower third of the tunnel.

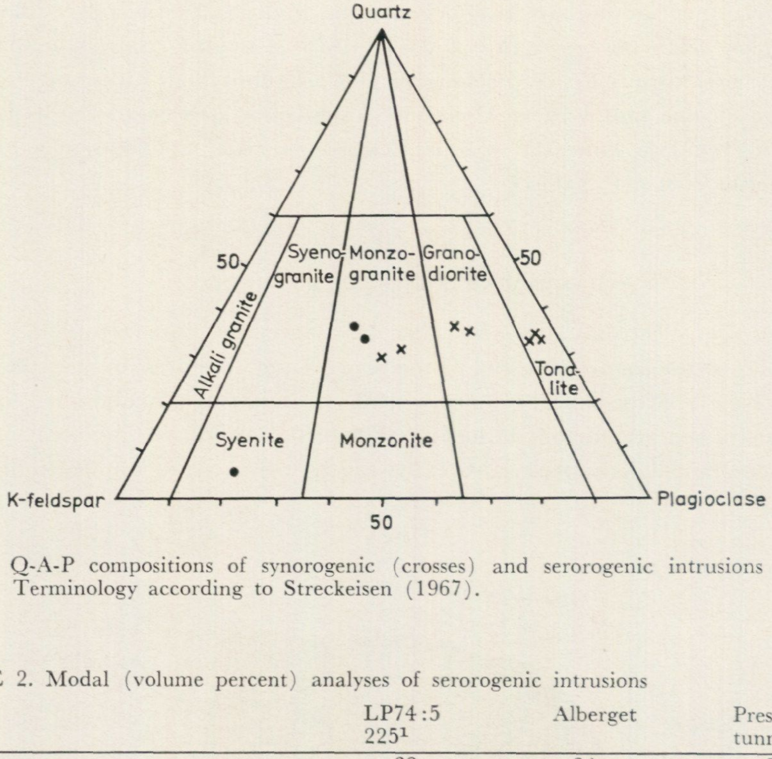


Fig. 8. Q-A-P compositions of synorogenic (crosses) and serorogenic intrusions (dots). Terminology according to Streckeisen (1967).

TABLE 2. Modal (volume percent) analyses of serorogenic intrusions

Sample	LP74:5 225[1]	Alberget	Pressure tunnel
Quartz	32	34	6
Potassic feldspar	34	34	73
Plagioclase	27	23	18
Biotite	—	6	—
Chlorite	+	2	+
Muscovite	+	+	+
Ore minerals	+	+	2
Sphene	+	+	+
Apatite	+	+	—
Epidote minerals	5	—	+
Zircon	+	+	+
Number of points	1 099	605	550
Nomenclature Streckeisen -67	Monzo-granite	Monzo-granite	Syenite

[1] Pressure tunnel

Some thin sections have been examined through the microscope (cf. Table 2). The composition is generally monzogranitic (Fig. 8) according to Streckeisen's terminology (1967). The monzogranites are fine-grained, grey and greyish white rocks with a tendency towards porphyritic texture (feldspar megacrysts often smaller than 2—3 mm). The rocks are generally tectonized and the quartz is highly undulose. The potassic feldspar is a perthitic microcline. The plagioclase is sericitized and often pigmented. It may occur as megacrysts and is then normally zoned. The An contents of the monzogranites correspond to calcic oligoclase — sodic andesine (22—24 %, cores 32—36 %). The plagioclase laths are usually crushed and bent. The biotite shows the following pleochroism: X light brown, Y=Z reddish brown. It is more or less completely chloritized. The chlorite is most often yellowish green and yellowish brown. Other constituents are muscovite, ore minerals, sphene, epidote minerals, apatite and zircon.

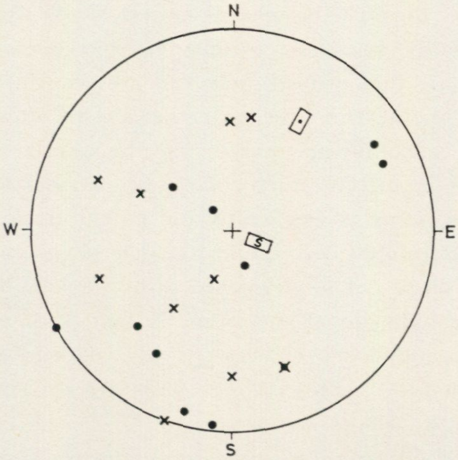
The red microcline-dominant granitoid occurring sporadically in the pressure tunnel is a syenite (Fig. 8) according to Streckeisen's terminology (1967). The feldspars are highly pigmented. Other constitutents are opaque minerals, chlorite, muscovite, sphene, epidote minerals and zircon (cf. Table 2). Biotite was not observed.

DOLERITES

The dolerite sheets of Åsby type (cf. Krokström 1936) are of relatively large dimensions, but dolerite also appears as narrow, more or less vertical dykes. All the latter seem to be of rather small dimensions (cf. Lundegårdh 1962, p. 13). In one case, in the Torpshammar tunnel, a narrow vertical dyke has been seen intruding a sill (Hjelmqvist 1944, p. 278). As can be seen from Fig. 3, numerous dolerites of varying sizes intersect the older rocks.

The dolerites are greyish black or greenish black, medium-grained rocks with radially arranged plagioclase laths (2—6 mm). Fine-grained types appear, especially near the contacts, where cooling has been more rapid. Also in fine-grained types the plagioclase is radially arranged. Usually the narrow dolerite dykes are highly irregular, and they can be seen to thin out at one locality. Tectonic movements have affected the dolerites severely and have produced chlorite- and serpentine-rich schistose zones.

The dolerite in the Järnvägsforsen tunnel generally has a subdoleritic texture (cf. Krokström 1932). Lath-shaped plagioclase crystals are radially arranged. They have been sericitized and have a normal zoning. The observed An contents vary from 33 to 63 %, i.e. the plagioclase is a sodic andesine to calcic labradorite. According to a point-count analysis (525 points) the plagioclase content is about 58 %, while that of pyroxene is 18 %. The clinopyroxene has a characteristic reddish brown colour, indicating a titaniferous augitic composition.



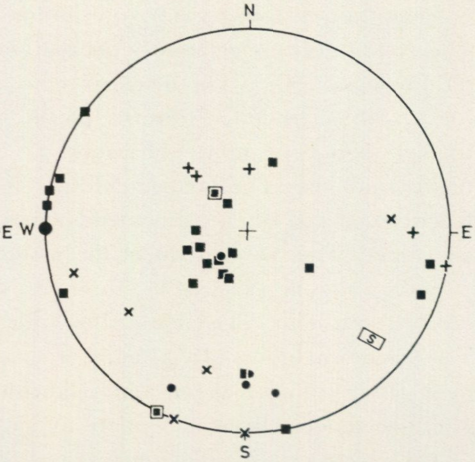


Fig. 9. Stereographic projection (Schmidt's net, lower hemisphere) of poles to schistosity planes in synorogenic intrusions (crosses) and supracrustal rocks (dots). The rectangle with a dot or a letter 's' mark lineation in the synorogenic intrusions and supracrustal rocks, respectively.

Fig. 10. Stereographic projection (Schmidt's net, lower hemisphere) of poles to contacts between different rock types. Supracrustal rocks (dots), synorogenic intrusions (crosses), serorogenic intrusions (big dots), pegmatites (upright crosses) and dolerites (squares).

Olivine makes up 9 % of the sum. Most of it has been pseudomorphosed by chlorite, serpentine and ore minerals. In addition there are 8 % ore minerals, 3 % quartz and 2 % chlorite. Accessories are sphene, potassic feldspar, apatite, amphibole (brownish green), biotite (X yellowish brown, Y=Z brown), muscovite and calcite. Granophyric intergrowths of quartz and potassic feldspar are very common. The mineralogy of similar dolerites has been described by Hjelmqvist (1944), Lundegårdh (1962), Lundqvist (1968), Lundqvist and Samuelsson (1973).

TECTONIC FEATURES

Structures such as schistosity planes (banding, orientation of micas) and in some cases lineations in the supracrustals and synorogenic plutonics have been compiled on a stereogram (Fig. 9). The directions of the structures mentioned for all these rock types are rather scattered but seem to be subparallel. The schistosity planes have W—WNW—NW strikes with high or rather high dips mainly towards NE, or NNE directions with dips of 30—60° towards E and SE.

Contacts between the different rock types have in the same way been compiled on a stereogram (Fig. 10). Three main directions occur, namely WNW—ESE to E—W with dips towards N, NE with low dips towards SE and finally NNE

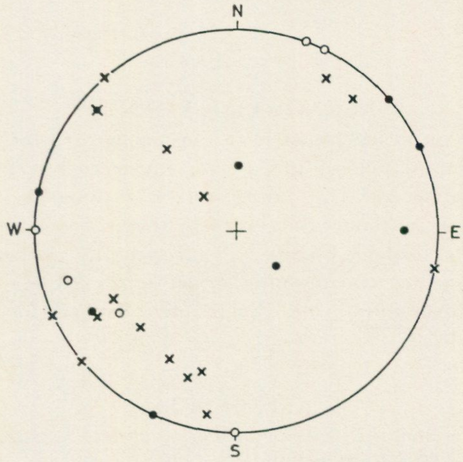


Fig. 11. Stereographic projection (Schmidt's net, lower hemisphere) of poles to tectonic zones (crosses), zones with a leaking of water (circles) and zones with clay (dots).

with more or less vertical dips. Several dolerites show northwesterly strikes with low dips towards NE.

Wide tectonic zones and zones or joints with water or clay are presented in Fig. 11. The directions of these zones show good correlation with the strikes of the contacts (Fig. 10). The tectonic zones may have used older fabrics (i.e. schistosity and contact planes) and have been formed preferably along planes of mechanical weakness. Similar observations with a regeneration (cf. Bergher and Pitcher 1970, p. 456) were reported by Persson (1974) from the Province of Småland.

There is often a pressure of water and a presence of clay in connection with the contacts between the different rock types and especially between thin tectonized pegmatite or dolerite dykes and the surrounding bedrock. During the construction of the tunnel problems arose owing to the numerous small irregular dolerite dykes as well as at those places where there are a lot of intrusions of pegmatite, aplitic granites and where the synorogenic intrusions have been remobilised and intruded by pegmatites, e.g. northeast of Åsmyran. The tectonization was severe at these places. On the contrary the wide northeasterly valley, in which the river Ljungan flows (Sillret, see Fig. 3) consists of a bedrock which is relatively poor in joints. Otherwise most valleys on topographical map-sheets mainly have NW—SE but also E—W, WNW—ESE and N—S directions (cf. Fig. 11).

ACKNOWLEDGEMENTS

The author wants to express his gratitude to the management of AB Skandinaviska Elverk for the permission to publish this paper, engineers Edvin Persson and Torsten Brännmark for information and help during work in the tunnel, Dr. Thomas Lundqvist for making it possible to introduce this work in the frame of the geological mapping of the bedrock in Västernorrland County and for critically reading the manuscript, Dr. P. H. Lundegårdh for giving valuable information on the geology of the tunnel and for critically reading the manuscript, and Dr. Kennert Röshoff for critically reading the manuscript.

REFERENCES

GFF = Geologiska Föreningens i Stockholm Förhandlingar
SGU = Sveriges geologiska undersökning

BERGHER, A. R., and PITCHER, W. S., 1970: Structures in granitic rocks: a commentary and a critique on granite tectonics. — Proc. of the geologists' ass. Vol. 81, 441—461.

ECKERMANN, H. VON, 1936: The Loos-Hamra region. — GFF 58, 129—343.

HJELMQVIST, S., 1937: über Prehnit als Neubildung in Biotit-Chlorit. — GFF 59, 234—236.

— 1944: Diabasintrusioner och algonkisk tektonik i Medelpad. — GFF 66, 277—282.

— 1966: Beskrivning till berggrundskarta över Kopparbergs län. — SGU Ca 40.

KROKSTRÖM, T., 1932: On the ophitic texture and the order of crystallization in basaltic magmas. — Bull. Geol. Inst. Upsala Vol. 24, 197—216. Upsala 1932—1933.

— 1936: Diabas och dolerit — en nomenklaturfråga. — GFF 58, 419—424.

LARSON, S. Å., 1973: Igneous layering in the Ulvö dolerite, Ångermanland, central Sweden. — GFF 95, 407—409.

LUNDBOHM, H., 1899: Praktiskt geologiska undersökningar inom Vesternorrlands län. II Berggrunden. — SGU C 177.

LUNDEGÅRDH, P. H., 1962: The petrology of the Parteboda tunnel east of Ånge, central Sweden. — SGU C 582.

— 1967: Berggrunden i Gävleborgs län. — SGU Ba 22.

LUNDQVIST, Th., 1968: Precambrian geology of the Los-Hamra region central Sweden. — SGU Ba 23.

LUNDQVIST, Th., and SAMUELSSON, L 1973: The differentiation of a dolerite at Nordingrå, central Sweden. — SGU C 692.

MAGNUSSON, N. H., 1960: Age determinations of Swedish Precambrian rocks. — GFF 82, 407—432.

MEHNERT, K. R., 1968: Migmatites and the origin of granitic rocks. — Elsevier, Amsterdam.

PERSSON, L., 1974: Precambrian rocks and tectonic structures of an area in northeastern Småland, southern Sweden. — SGU C 703.

PHILLIPS, E. R., and RICKWOOD, P. C., 1975: The biotite-prehnite association. — Lithos 8, 275—281.

SPRY, A., 1969: Metamorphic textures. — Pergamon Press, Oxford.

STRECKEISEN, A. L., 1967: Classification and nomenclature of igneous rocks. — N. Jb. Miner. Abh. 107, 2, 144—214.

WELIN, E., 1966: The absolute time scale and the classification of Precambrian rocks in Sweden. — GFF 88, 29—33.

WELIN, E., and BLOMQVIST, G., 1964: Age measurements on radioactive minerals from Sweden. — GFF 86, 33—50.

WELIN, E., and LUNDQVIST, Th., 1975: K-Ar ages of Jotnian dolerites in Västernorrland County, central Sweden. — GFF 97, 83—88.

WELIN, E., BLOMQVIST, G. and PARWEL, A., 1966: Rb/Sr whole rock age data on some Swedish Precambrian rocks. — GFF 88, 19—28.

WELIN, E., CHRISTIANSSON, K., and NILSSON, Ö., 1970: Rb-Sr age dating of intrusive rocks of the Haparanda suite. — GFF 92, 336—346.

PRISKLASS B

Distribueras genom

LiberKartor

162 89 VÄLLINGBY

Schmidts Boktryckeri AB
Helsingborg 1976

ISBN 91-7158-100-6