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By PER H. LUNDEGÅRDH

ABSTRACT

The Proterozoic bedrock of central and northwestern Värmland, between the great Mylonite Zone in the west and the extensive intrusions of variform Filipstad and Hagfors granites in the east, is dominated by gneissic granites and granodiorites which in Sweden are also called gneiss-granites. These have been divided into three groups, viz. old granite, middle granite grading into granodiorite, and late granite. The middle granite and granodiorite contain granulated microcline augen. The old and middle rocks have been tectonized on, at least, three occasions, the late rock only twice. The age of the middle granite and granodiorite has been determined by means of the Rb-Sr and U-Pb zircon methods. (See the second part of this paper.)

The gneissic granites and granodiorites contain numerous conformable sills and dikes of a black, in part uralitized, dolerite which has long been termed hyperite. Bodies of three metasedimentary and metavolcanic formations occur, viz. the Hammarö Formation in the south, the Östmark Formation in a central zone in east-west, and the Gräsmark Formation in the west, occur isolated in the gneissic granitoids. The Proterozoic rock evolution in central and northwestern Värmland is outlined below. The second and third phases of folding are reversed compared with earlier reports. This revision is founded on detailed studies of the Hammarö Formation in southern Värmland and the great Mylonite Zone in northern Västergötland.

TECTONIC EVENTS	AGE Ma	ROCKS
	891	The Bohus granite and pegmatite. Migmatization incl. a wide-spread formation of small magnetite crystals
F 3. Folding of highly variable intensity around axes trending E–W to NE–SW and in most cases flat-lying		
F 2. Folding around axes striking N–NW with low or moderate plunges, thrusting along isoclinical fold limbs implying the development of mylonite zones, probably initiated by the approach of two crustal plates		The Gräsmark Formation (mainly metavolcanics)
	1550	The hyperite (black dolerite)
Foliation in zones striking N–NNW and dipping towards the west caused by the approach of two crustal plates	1655	The Hagfors granite
	1665	The Filipstad granite
		Monzodiorite, diorite, gabbro
		Old granite, most frequently gneissic
F 1. Folding around flat-lying axes striking N–NW. Thrusting along isoclinal fold limbs still visible as zones of red fine-grained gneiss		*(Continued.)*

1777 Old granite and granodiorite with granulated augen, Oldest granite, gneissic

The Östmark and Hammarö Formations (metasediments, metavolcanics)

Lundegårdh, Per H., 1980-07-12: The gneissic granitoids and allied rocks in central and northwestern Värmland, western Sweden. Sveriges geologiska undersökning, Ser. C, No. 777, pp. 3–23. Uppsala.

Värmland County in western Sweden lies in the western part of the Fennoscandian Shield and is dominated by granitoids which most frequently have altered to gneissic rocks. These rocks have been cut into slices by thrusting along shear zones trending south to northwest–southeast. The greatest shear zone is the 'Mylonite Zone' which separates southwestern Värmland from the rest of the county (N. H. Magnusson 1937, A. Lindh 1974).

In central and northwestern Värmland the granitoids comprise gneissic granites and granodiorites which in Sweden are also named gneiss-granites (Plate 1). These rocks belong to the great complex of 'Pregothian gneisses', or 'iron gneisses', of southwestern Sweden. (See Lundegårdh 1964–1978.) They have been distinguished as the eastern Pregothian mega-unit by R. Gorbatschev (1975).

In eastern Värmland the principal granitoids are a variform, in part rather basic rock (quartz-syenite to granodiorite) with microcline augen known as Filipstad granite, and a rather coarse, felsic rock named Hagfors granite.

Fig. 1. Dyke of postorogenic granodiorite in recrystallized gneissic granite tectonized and granulated by the oldest folding observed in Värmland (F 1). Top. map TORSBY SV, coordinates in the Swedish national grid 66718/13195. Photo P. H. Lundegårdh 1977.

The gneissic granites and granodiorites are older. Mostly they have been granulated and recrystallized throughout, and show both lineation and foliation of variable strength and orientation. (See Plate 1.) The Filipstad and Hagfors granites are younger, and show strong tectonization only in thrust zones.

Three generations of gneissic granites and granodiorites have been distinguished, viz. a red or grey red granite of early formation, a somewhat younger, reddish grey to grey red granodiorite grading into granite which has granulated, frequently laminated microcline augen (porphyritic gneiss-granite), and a grey red to red granite showing weaker metamorphism. The latter was found and defined by Björn Lagerblad in Lund (personal communication 1977). It cuts and brecciates the porphyritic rock east to southeast of Sunne city.

A number of chemical and modal analyses of gneissic granites and granodiorites are given in Tables 1–4. The contents of alkalies are high, Na_2O = 4.1 % and K_2O = 5.1 % in the earlier gneiss-granites (N = 17), Na_2O = 4.1 % and K_2O = 4.5 % in the granite found by Lagerblad (N = 2).

The magmas of the oldest granitoids rose and spread through formations of sedimentary and volcanic rocks, which remain as enveloped bodies of various sizes. The greatest of these in gneissic granitoids is known as the Hammarö Formation (originally described by Magnusson 1933) and trends towards the east from Hammarön island south of Karlstad city. Other included bodies of considerable size occur in central Värmland and have been described as the Östmark Formation (Lundegårdh 1980). Like the granitoids, the rocks of the Hammarö and Östmark Formations have been tectonically rearranged and strongly metamorphosed.

The oldest granites and granodiorites have been involved in two periods of Proterozoic folding, whereas the granite found by Lagerblad missed the first tectonic activity, F 1, in the scheme above. This early tectonization caused strong folding around flat-lying axes striking north-south, which is reflected in mineral lineation in various parts of Värmland and, possibly, also other deformations. The final manifestation of the early tectonization was thrusting along isoclinal fold limbs. The strongly tectonized granitoids have recrystallized and now appear as fine-grained gneisses, most frequently red granitic gneisses but also grey to red grey, in part granodioritic gneisses.

After formation of the granite at first observed by Lagerblad, which should be interpreted as late- or post-kinematic in relation to the first folding, ultrabasic and basic magmas intruded along the eastern boundary of the complex of gneissic granites and granodiorites to form ultrabasic gabbro (Magnusson 1925), normal gabbro, diorite and monzodiorite. Later, the huge body of the Filipstad and Hagfors granites appeared in the boundary zone. These rocks belong to a broad belt of post-Svecokarelian granitoids through south and west Sweden. Granite porphyries are common at contacts with the Svecokarelian rocks in the east, and extensive volcanism resulted from the

Fig. 2. Narrow sills of schistose uralite-hyperite in reddish gneissic granite of early formation, dip 40°W. Top. map TORSBY SO, coordinates in the Swedish national grid 66549/13451. Photo P. H. Lundegårdh 1976.

intrusions. The volcanics, known as sub-Jotnian porphyries and porphyrites, are concentrated in areas north and south of the iron ore- and marble-bearing *'Bergslagen'* kernel of the southern Swedish Svecokarelides, viz. eastern Småland, southern Östergötland, northern Dalarna (Dalecarlia) and southern Härjedalen. Further, the belt of post-orogenic granitoids widens in the neighbourhood of the volcanic rocks, and the granitoids have been less tectonized there. Probably, strong east-west pressure prevented volcanic activity around the intrusions of the Filipstad and Hagfors granites, to the west of the *'Bergslagen'* kernel, and kept most of the granitoid magma under the solid crust. It is thus by no means astonishing that the Filipstad and Hagfors granites contain numerous zones of strong synmagmatic foliation that strike N-NNW and dip west. Nor it is remarkable that geophysical investigations (Sven Aaro and Mats Lagmanson, personal communication originally published in Lundegårdh 1977) indicate continuation of the Filipstad and Hagfors granites towards the west, at moderate depths beneath the gneissic granites and granodiorites, and probably along low-dipping, early thrust planes. Indeed, minor bodies of Filipstad granite and allied rocks penetrate the gneissic granitoids, for instance, southwest of Munkfors city (Plate 1). In westernmost Värmland and the neighbouring Hedmark Fylke in Norway granites similar to the Filipstad and Hagfors (here called 'tricolor') granites appear as masses of considerable extent, and rare dykes of a similar granite occur in the adjacent gneissic granite (Fig. 1).

As stated by Gorbatschev (1971), no distinct boundary has been found separating the Filipstad and Hagfors granites from the complex of gneissic granites and granodiorites, although there are altered inclusions of the latter rocks especially in southeastern Värmland. Even minor masses of Filipstad and allied granites such as the one southwest of Munkfors city, grade into the surrounding gneissic granite. Obviously heat and compounds emitted from the giant intrusions of granitoid magmas have profoundly altered neighbouring parts of the older bedrock. Gneissic granites and granodiorites situated near intrusions of Filipstad granite may thus contain microcline porphyroblasts showing the same oligoclase mantling that characterizes many Filipstad granite augen.

For comparison with the gneissic granites and granodiorites a number of chemical and approximate modal analyses of Filipstad and Hagfors granites are given in Tables 5–6. High contents of alkalies characterize all these rocks. The Filipstad granite shows Na_2O = 4.2 % and K_2O = 4.4 % (N = 10), the Hagfors granite Na_2O = 3.9 % and K_2O = 5.2 % (N = 9).

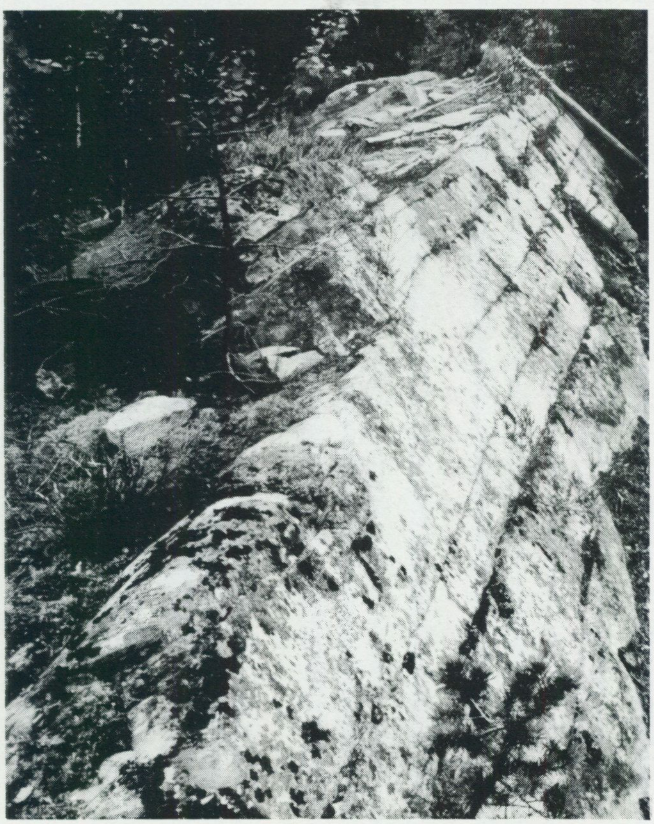

Fig. 3.
Schistose granite of early formation in so-called mylonite zone, dip 40°W. Top. map TORSBY NV, coordinates in the Swedish national grid 66808/13238. Photo P. H. Lundegårdh 1977.

After the consolidation of the Filipstad-Hagfors granites and the conclusion of the associated volcanism there are no signs of further deformation until the intrusion of a differentiated basaltic magma rather rich in iron along high-dipping tensional fissures striking north-south. The basaltic magma rose nearly exclusively through the complex of gneissic granite rocks and also spread along some of the flat-lying thrust planes, pushing the strongly tectonized rocks – frequently red granitic gneisses – aside and congealing as sills (Fig. 2). Single dykes have been found in the neighbouring Filipstad and Hagfors granites. The basaltic magma crystallized as a black dolerite which has long been termed hyperite (A. E. Törnebohm 1881). At least two generations of this rock have been observed (compare Gorbatschev 1971), and an early anorthositic phase locally appears as swarms of small xenoliths. The hyperite contains 45.6–49.8 % SiO_2 and 6.3–12.2 % Fe, the quotient Mg:Fe is 0.24–0.63 (N = 27). The hyperite is thus comparatively strongly differentiated with regard to its Mg:Fe ratio and crystallized during a quiet period of considerable length. (Compare Lundegårdh 1949.)

Heat and compounds emitted from the magma of the hyperite have altered the wall rock in various places and have developed hybrid rocks as well as granitoid products of remelting (rheomorphic rocks). The latter locally appear as back-veining and eruptive breccias in marginal parts of the hyperite. Like the Filipstad granite they are characterized by mantled microcline augen.

A metaspilite in the volcanic Gräsmark Formation, western central Värmland (Lundegårdh 1977), bears witness of submarine basaltic eruptions at a later stage of the crustal evolution. This rock is richer in calcium and magnesium compared with the hyperite and shows Mg:Fe = 1.0. Its magma thus seems to have risen more directly from great depth than the magma of the hyperite, probably at the beginning of the second Proterozoic period of tectonization, viz. the Dalslandian (Sveconorwegian).

During this period the oldest gneissic granites and granodiorites became tectonized again, and the younger granitoids as well as the other rocks now described attained their present stages of metamorphism. Two entirely different sets of structures developed by the second orogeny have been distinguished in the field, viz. folding around axes striking north to northwest – F 2, and cross-folding around axes trending east-west to northeast-southwest – F 3. The former should at least in part have been isoclinal, implying final thrusting along fold limbs to produce zones of strong disintegration known as mylonite zones (Magnusson 1937) although most of the rocks involved have not been mylonitized but appear as schists (Fig. 3). Simultaneously the hyperite dykes and sills were divided into boudins. The latest folding was most frequently plastic and developed the winding structural pattern of the hyperite boudins displayed in Plate 1. It also affected considerably the older parallel structures and the mylonite zones. F 3 grew extraordinarily strong in the area of the Hammarö Formation, S–ESE of Karlstad city. This mainly sedimentary for-

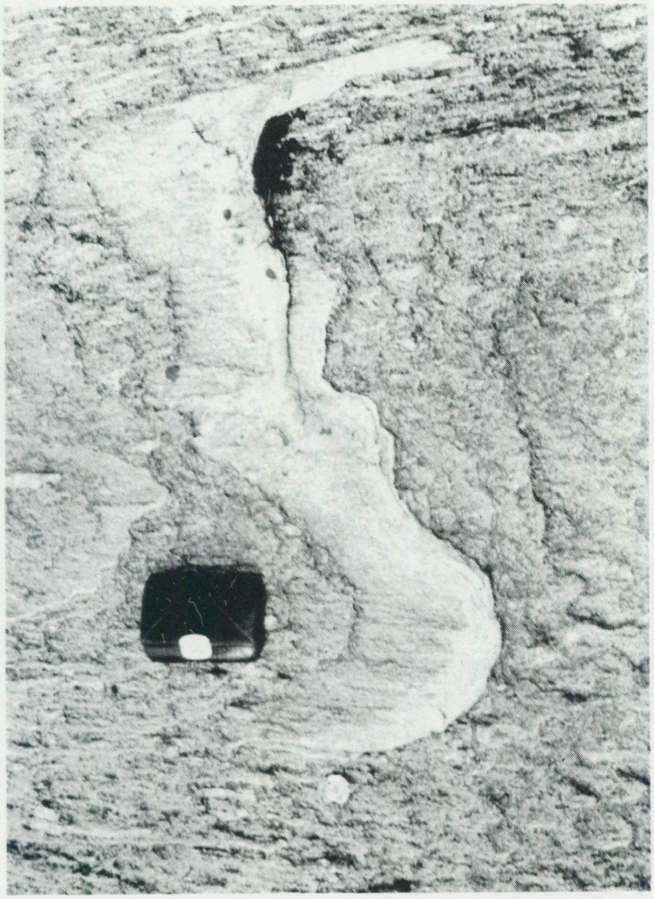

Fig. 4.
Quartzite xenolith cross-folded during the second Dalslandian (Sveconorwegian) tectonic phase (F 3), fold axis 10°N 75°E, in schistose porphyritic granodiorite of early formation. Top. map KARLSTAD NO, coordinates in the Swedish national grid 66585/13833. Photo P. H. Lundegårdh 1976.

mation, as well as the neighbouring and in part intrusive gneissic granite, has already been folded twice, first by F 1, later by F 2, and became thus cross-folded (Fig. 4). This implies that the orientation of the members of the formation changed from approximately north-south to ENE–WSW. The hyperite dykes intrusive in the formation were involved in the cross-folding and now appear as conformable sheets of mottled metabasite in part resembling metaspilite. However, not far to the north and south of the Hammarö Formation the hyperite dykes retain their original doleritic character and strike more or less north–south.

A gneissic granite at Munkfors, which is referred to the second generation of gneissic granitoids, has been dated. (See the second part of this paper.) The U-Pb zircon age is 1 777 Ma. A Rb-Sr reference line from six samples of gneissic granite and granodiorite (Plate 1) gives an age of 1 770 Ma.

The complex of gneissic granites and granodiorites not only bears signs of alteration caused by the Filipstad and Hagfors granite magmas (see below) but also of late Dalslandian migmatization involving wide-spread formation of single crystals (0.5–1.5 mm) or aggregated (≤ 1 cm, seldom more) of magnetite surrounded by leucosomes which have grown through the structures of the host rocks. (Compare Gorbatschev 1971.) In some areas hastingsitic hornblende has developed instead of magnetite. In rare cases, both minerals occur together. However, the zircon crystals in the dated gneissic granite at Munkfors have not been affected by secondary alterations.

The Rb-Sr whole rock age of the older Filipstad granite is 1 665 Ma and of the younger, penetrating Hagfors granite 1 655 Ma. The initial $^{87}Sr/^{86}Sr$ ratio of the former is 0.7068 and of the latter 0.7021 (Welin et al. 1977, Welin 1980).

Zircon crystals extracted from a sample of coarse (pegmatoid) hyperite to the north of Torsby city in west central Värmland have given a U-Pb age of 1 550 Ma (Welin et al. 1980).

According to the quoted radiometric dating, the first Proterozoic folding (F 1) in Värmland could tentatively be correlated with the final manifestations of the Svecokarelian orogeny. There exist, however, great structural and chemical differences between Värmland and the established Svecokarelian areas in Sweden. Thus the strike of F 1 is in Värmland NW-SE to N-S, whereas the strike of the youngest Svecokarelian folds is in central Sweden E-W (Lundegårdh 1967). Furthermore the oldest granitoids of Värmland are on the whole more calcic and richer in alkalies than the Svecokarelian granitoids. This has also been observed by Lundqvist, who recently (1979) published a plate-tectonic hypothesis implying subduction in southwestern Sweden both in Svecokarelian and post-Svecokarelian times. A consequence should have been the development and intrusion of older magmas of calc-alkaline character and younger magmas of alkaline compositions. The former should have produced the parent rocks of the gneissic granites and granodiorites, the latter the Filipstad and Hagfors granites. (Compare Tables 1–3 and 5–6.)

Obviously, the petrological and tectonic evolution of Värmland and the established Svecokarelian of central Sweden have been quite different. The complex of gneissic granites and granodiorites in Värmland seems to have been at some distance from the bedrock of central Sweden during the Svecokarelian orogeny and should then have approached the latter in post-Svecokarelian time. The broad zone of post-Svecokarelian Filipstad, Hagfors and related granitoids, many of which are characterized by very low ratios $^{87}Sr/^{86}Sr$, numerous inclusions of basic magmatic rocks and extensive beds of associated volcanics suggests a rise of mantle derivatives between two plates of crust which should have approached each other.

Especially the post-Svecokarelian basic magmatic rocks of eastern Värmland have given important information regarding the evolution of the crust in this part of Sweden. The gabbro, diorite and monzodiorite associated with, but older than, much of the Filipstad and Hagfors granites display undifferentiated and well-preserved mantle derivatives with high values of the quotient Mg:Fe, about 1.5, and high contents of chromium, 500 p.p.m. or more, (ultrabasic olivine gabbro from the Eriksberg massif south of Filipstad city in eastern Värmland). The magma of such a rock ought to have risen rapidly from great depths.

The hyperite of Värmland forms part of a broad belt of black diabases stretching from northeast Skåne (Scania) into northwest Värmland and adjacent areas in Norway. There are two principal kinds of this rock, viz. a noritic hyperite in the south (Skåne and Småland) and an olivine-bearing hyperite or black dolerite in the north (Värmland and Västergötland). From various geological points of view, including petrographical and geochemical considerations, I have regarded the former as younger (Lundegårdh 1964–1978). The idea that the two groups are unrelated has been strongly supported by Lindh et al. (1981), who have made a thorough analytical and statistical investigation of the Swedish hyperites. 61 doleritic, most frequently olivine-bearing hyperites on an average show $K_2O = 0.95$, $TiO_2 = 1.92$, and $P_2O_5 = 0.35$ per cent by weight; Mg:Fe = 0.41. In comparison, 29 noritic hyperites show $K_2O = 1.53$, $TiO_2 = 3.72$, and $P_2O_5 = 1.20$ per cent by weight; Mg:Fe = 0.35. Moreover, t-test statistics have revealed that the means for TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, and P_2O_5 are different at the 0.999 significance level. However, both groups of hyperite are anorogenic and could possibly have similar ages (I. Klingspor 1976, Welin et al. 1980). In such a case they might originate from a common parent magma divided into portions of entirely different composition, one of earlier formation solidifying as dolerite and one later crystallizing as noritic hyperite.

The low chromium content of the Värmland hyperite, 75 p.p.m. (N = 22), is characteristic also of many other olivine-bearing products of anorogenic basic magmatism (cf. Lundegårdh 1949), whereas the high concentration met with in the Gräsmark metaspilite, 500 p.p.m., points at orogenic conditions. As I have suggested earlier (p. 8), the latter rock seems to have been formed at the beginning of the Dalslandian orogeny, 1 100–1 200 Ma ago. (Compare Lundqvist 1979.)

The Dalslandian orogeny not only implies thorough structural reworking but also extensive mineral alterations of the pre-Dalslandian rocks of Värmland, such as the above-mentioned growth of magnetite surrounded by leucosomes. Migmatization is especially common in the gneissic granites and granodiorites. Final intrusions of palingenic magmas (Bohus and Blomskog granites, pegmatites locally with cleavelandite and amazonite) should also be reported. The later manifestations of the Dalslandian orogeny in the great Mylonite Zone have been dated by Lindh and Kähr 1977 (recalculation by Welin 1980). The K-Ar ages obtained are 968, 926 and 878 Ma. According to T. Skiöld (1976, recalculation by Welin 1980), the Rb-Sr whole rock age of the Bohus granite is 891 Ma. Skiöld (op. cit.) has also determined K-Ar ages of micas from the end of the Dalslandian orogeny and of later formation. Figures between 880 and 678 Ma have been reported.

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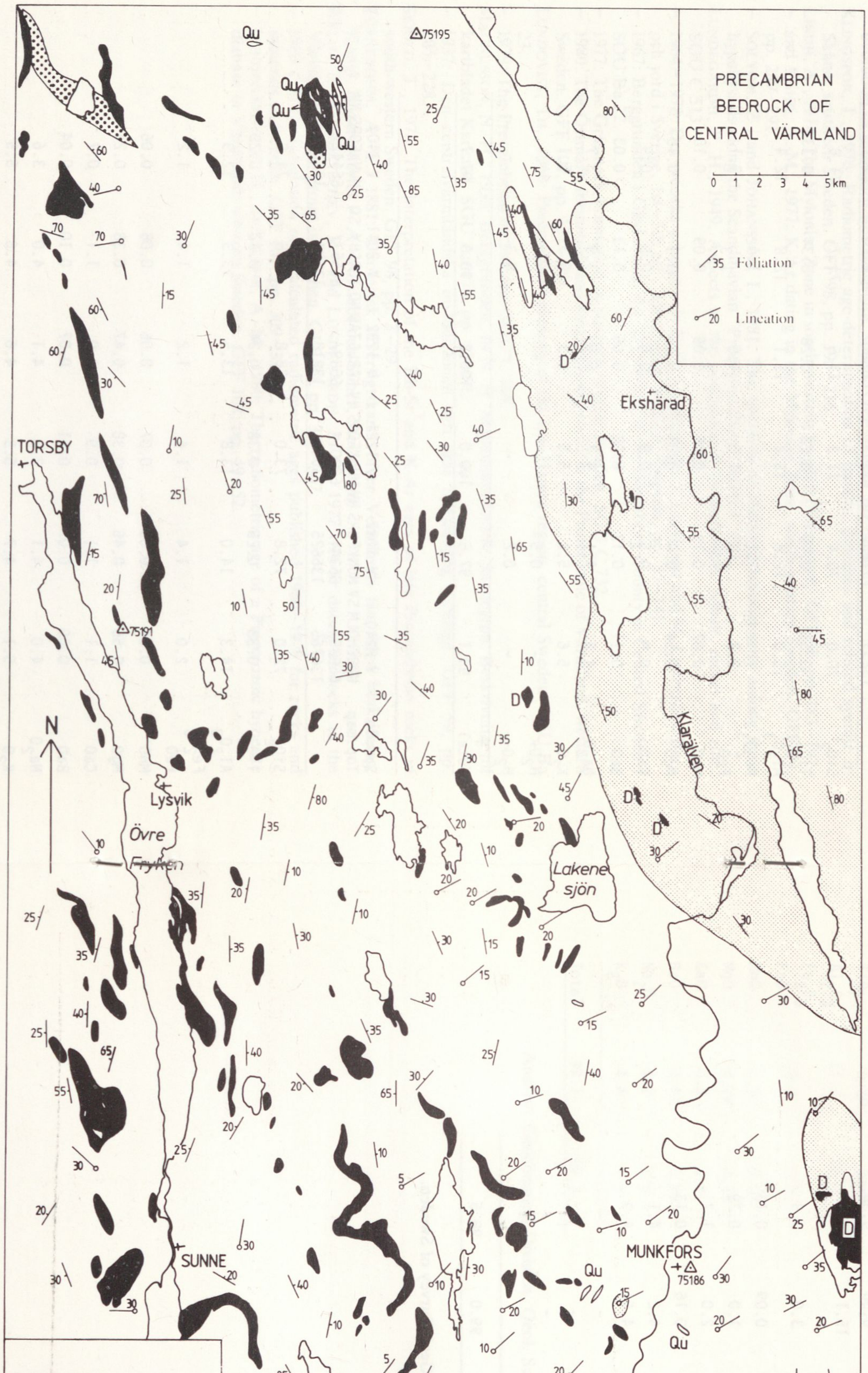
TABLE 1. Chemical analyses of oldest granite, grey red to red, gneissic, southern and central Värmland, per cent by weight. As regards Tables 1–3 and 5–6, the total contents of di- and trivalent iron in most samples have been determined as Fe_2O_3 (figures placed in the gap between Fe_2O_3 and FeO). All coordinates in Tables 1–8 are given in the Swedish national grid.

Sample Top.map	V 2793 TORSBY SO 66711/ 13259	V 3040 TORSBY NV 66930/ 131955	V 231 KARLSTAD NO 65971/ 13969	V 207 KARLSTAD NO 65855/ 13932	V 3195 TORSBY NV 669155/ 131875	V 79 KARLSTAD NO 658615/ 13981
SiO_2	70.0	70.4	71.3	71.5	71.7	71.8
TiO_2	0.53	0.40	0.28	0.28	0.34	0.33
Al_2O_3	15.0	12.8	15.4	15.1	12.8	12.4
Fe_2O_3		1.1			1.4	
	2.2		1.5	1.6		3.1
FeO		1.7			1.3	
MnO	0.07	0.13	0.05	0.09	0.09	0.10
MgO	0.54	0.4	0.31	0.25	0.3	0.19
CaO	0.8	0.5	0.9	0.6	0.6	0.9
BaO	0.11	0.13	0.08	0.05	0.13	0.03
Na_2O	4.2	4.1	4.7	5.5	3.9	3.7
K_2O	5.6	5.2	5.5	5.3	5.3	5.1
H_2O+	-	0.5	-	-	0.7	-
H_2O-	-	0.2	-	-	0.3	-
Total	99.1	97.6	100.0	100.3	98.9	97.7

Sample Top.map	V 2240 UDDEHOLM SV 66585/ 136765	V 1087 MUNKFORS NV 66344/ 136625	V 1221 MUNKFORS NV 66301/ 13659	V 1232 KARLSTAD NO 6589/ 13818	V 2041 TORSBY SO 66557/ 13397	V 1404 MUNKFORS NV 66442/ 13527
SiO_2	72.0	72.8	73.0	73.8	73.8	74.0
TiO_2	0.38	0.26	0.38	0.24	0.32	0.29
Al_2O_3	14.3	14.0	13.8	13.5	13.3	12.9
Fe_2O_3 / FeO	2.0	1.4	1.4	1.2	1.4	1.2
MnO	0.04	0.09	0.07	0.06	0.08	0.06
MgO	0.56	0.46	0.38	0.47	0.38	0.24
CaO	1.1	1.1	0.9	1.0	1.1	0.7
BaO	0.09	0.07	0.11	0.07	0.10	0.04
Na_2O	4.0	4.1	3.8	4.1	4.0	3.6
K_2O	5.1	4.7	5.3	4.6	4.6	5.5
Total	99.6	99.0	99.1	99.0	99.1	98.5

Analyst: Geochemical Division, Geol. Survey of Sweden.

PLATE 1



PRECAMBRIAN BEDROCK OF CENTRAL VÄRMLAND
0 1 2 3 4 5 km
35 Foliation
20 Lineation
Hyperite (black dolerite), in part uralitized and foliated
Postorogenic granitoids
Gabbro, diorite, metabasite (D)
Early granitoids, metamorphosed (gneiss-granites)
Volcanics, metamorphosed
Qu Quartzite
75195 Age determination
TORSBY
Ekshärad
Klarälven
Lysvik
Övre Fryken
Lakenesjön
SUNNE
MUNKFORS
Ransäter
Ö. Ämtervik
Visten
Öv. Ullerud
Älvsbacka
N
PER H LUNDEGÅRDH 1979

TABLE 2. Chemical analyses of old granodiorite, red to red grey, with granulated microcline augen, gneissic, southern and central Värmland, per cent by weight.

Sample Top.map	V 2361 UDDEHOLM SV 667205/ 135285	V 1252 MUNKFORS NV 66331/ 136205	V 3321 DALBY SO 670805/ 13386	V 515 MUNKFORS SO 66225/ 13763	V 1674 MUNKFORS SV 66112/ 13696
SiO_2	66.0	66.8	68.0	68.3	68.4
TiO_2	0.77	0.59	0.43	0.56	0.56
Al_2O_3	15.6	16.0	15.1	15.1	14.5
Fe_2O_3	1.5		1.4		
FeO	2.8	3.0	1.2	3.0	3.3
MnO	0.13	0.10	0.07	0.09	0.13
MgO	1.31	1.0	1.04	1.0	0.79
CaO	2.8	1.8	2.1	2.0	1.7
BaO	0.16	0.17	0.14	0.16	0.13
Na_2O	4.2	4.2	3.9	4.2	4.1
K_2O	4.2	5.4	5.1	4.6	4.9
P_2O_5	0.29	-	0.12	-	-
F	0.09	-	-	-	-
H_2O+	0.6	-	0.6	-	-
H_2O-	0.1	-	0.2	-	-
Total	100.55	99.1	99.4	99.0	98.5

Analyst: Geochemical Division, Geol. Survey of Sweden.

TABLE 3. Chemical analyses of old granite, red, in part gneissic, western central Värmland, per cent by weight.

Sample Top.map	V 2110 TORSBY SO 66715/ 13399	V 2117 TORSBY SO 66549/ 13491
SiO_2	77.0	77.5
TiO_2	0.20	0.19
Al_2O_3	11.7	11.7
Fe_2O_3 FeO	0.7	0.8
MnO	0.07	0.08
MgO	0.18	0.10
CaO	0.6	0.4
BaO	0.03	0.03
Na_2O	4.2	3.9
K_2O	4.4	4.5
Total	99.1	99.2

Analyst: Geochemical Division, Geol. Survey of Sweden.

TABLE 4. Point count analyses of oldest granite, gneissic (EW 75188), old granodiorite and granite with granulated microcline augen, gneissic, and, finally, old granite, gneissic (EW 75187, 75192, 75183), per cent by volume.

Sample	EW 75188 (V 777)	EW 75180 (B 358)	EW 75132 (V 515)	EW 75184 (V 504)	EW 75186 (V 256)
Topogr. map-sheet	MUNK-FORS NV 6640/ 13673	MUNK-FORS SO 66089/ 13797	MUNK-FORS SO 662225/ 13763	MUNK-FORS SO 66268/ 13785	MUNK-FORS NV 66372/ 137345
Quartz	34	19	25	20	33
Microcline (in part perthitic)	34	20	25	22	28
Plagioclase (in part sericitized)	28	45	35	38	24
Biotite	3	13	12	15	10
Muscovite	< 1	< 1	0	< 1	< 1
Titanite	< 1	< 1	1	1	< 1
Zircon	< 1	< 1	< 1	< 1	< 1
Apatite	< 1	< 1	< 1	1	< 1
Ore	1	< 1	< 1	< 1	0
Fluorite	0	0	0	0	0
Calcite	0	0	0	0	0
Allanite	0	0	0	< 1	< 1
Garnet	< 1	0	0	0	0
Epidote	0	4	3	4	5
Chlorite	0	< 1	< 1	< 1	0
Total	100	101	101	101	100

TABLE 4. *Continued.*

Sample	EW 75195 (V 866)	EW 75191 (V 2008)	EW 75187 (V 774)	EW 75192 (V 1397)	EW 75183 (V 506)
Topogr. map-sheet	UDDE-HOLM NV 66897/ 13608	TORSBY SO 66649/ 13492	MUNK-FORS NV 66394/ 13689	UDDE-HOLM SV 66552/ 13605	MUNK-FORS NO 66282/ 137285
Quartz	29	20	24	36	41
Microcline (in part perthitic)	31	35	41	30	35
Plagioclase (in part sericitized)	33	32	30	29	21
Biotite	6	7	4	3	3
Muscovite	<1	0	<1	1	<1
Titanite	<1	2	1	1	0
Zircon	<1	<1	<1	<1	<1
Apatite	<1	1	<1	<1	<1
Ore	1	<1	<1	1	<1
Fluorite	<1	0	<1	0	0
Calcite	<1	0	0	0	0
Allanite	<1	<1	<1	<1	0
Garnet	0	0	0	0	<1
Epidote	1	2	<1	<1	<1
Chlorite	<1	1	<1	<1	<1
Total	101	100	100	101	100

TABLE 5. Chemical analyses of granodiorite to granite, dark reddish grey to grey red, with microcline augen (Filipstad granite), mainly eastern Värmland, per cent by weight.

Sample	V 1408	V 1417	V 545	V 992	V 3255
Top.map	MALUNG SV	MALUNG SV	MUNK- FORS NO	UDDE- HOLM SO	TORSBY SO
	67045/ 13519	670125/ 13508	66314/ 13821	66534/ 13829	66572/ 13288
SiO_2	58.3	59.1	59.7	60.5	63.5
TiO_2	0.86	0.91	0.71	0.81	0.54
Al_2O_3	18.6	18.2	18.8	18.1	17.5
Fe_2O_3 FeO	6.0	5.6	4.9	4.7	1.5 2.4
MnO	0.14	0.14	0.13	0.11	0.09
MgO	2.0	1.9	1.9	1.4	1.57
CaO	4.4	4.2	4.1	2.8	4.3
BaO	0.23	0.24	0.26	0.22	0.19
Na_2O	4.6	4.4	4.7	4.5	4.1
K_2O	3.5	3.9	3.8	5.7	3.8
P_2O_5	-	-	-	-	0.17
Total	98.6	98.6	99.0	98.8	99.7

Sample	V 1030	V 1017	V 1380	V 1608	V 931
Top.map	MUNK- FORS NO	MUNK- FORS NO	UDDE- HOLM SO	UDDE- HOLM SO	KARL- SKOGA NV
Swed.net	66311/ 13997	66268/ 139695	667275/ 13803	665485/ 139985	659335/ 141635
SiO_2	64.3	65.6	66.7	67.8	69.6
TiO_2	0.55	0.54	0.48	0.52	0.36
Al_2O_3	16.8	15.8	15.7	15.0	14.7
Fe_2O_3 FeO	4.0	3.9	3.1	3.4	2.8
MnO	0.09	0.09	0.10	0.09	0.06
MgO	1.6	1.7	1.0	1.0	0.50
CaO	3.6	3.4	2.3	2.2	1.5
BaO	0.15	0.10	0.14	0.08	0.08
Na_2O	4.1	3.7	4.2	3.9	3.4
K_2O	3.7	4.1	4.7	4.5	6.0
Total	98.9	98.9	98.4	98.5	99.0

Analyst: Geochemical Division, Geol. Survey of Sweden.

TABLE 6. Chemical analyses of granite, grey to red, mostly coarse (Hagfors granite), eastern Värmland, per cent by weight.

Sample Top.map	V 1995 UDDE- HOLM NV 6691/ 136955	V 1552 UDDE- HOLM SO 665605/ 139235	V 1645 UDDE- HOLM SO 665905/ 139545	V 1864 UDDE- HOLM NO 669435/ 13848	V 1480 UDDE- HOLM NO 6680/ 13822
SiO_2	64.2	67.4	68.1	69.5	69.7
TiO_2	0.78	0.45	0.46	0.49	0.43
Al_2O_3	16.6	15.7	15.4	14.5	14.7
Fe_2O_3 FeO	3.4	2.9	2.5	2.8	2.3
MnO	0.10	0.08	0.07	0.08	0.07
MgO	1.1	0.84	0.79	0.83	0.68
CaO	2.3	1.8	1.7	1.8	1.6
BaO	0.24	0.11	0.12	0.08	0.10
Na_2O	4.2	4.1	3.7	3.6	3.8
K_2O	5.6	5.1	5.6	4.9	5.1
Total	98.5	98.5	98.4	98.6	98.5

Sample Top.map Swed.net	V 1491 UDDE- HOLM NO 66835/ 138385	V 1894 UDDE- HOLM NO 668935/ 13736	V 3362 MALUNG SV 661615/ 136375	V 3343 DALBY NO 674415/ 13389
SiO_2	69.9	71.2	71.3	73.4
TiO_2	0.45	0.35	0.35	0.28
Al_2O_3	14.3	14.3	15.0	13.4
Fe_2O_3 FeO	2.2	1.7	1.4 0.8	0.8 0.9
MnO	0.07	0.07	0.08	0.06
MgO	0.65	0.51	0.60	0.86
CaO	1.8	1.2	1.5	1.2
BaO	0.10	0.07	0.09	0.07
Na_2O	3.8	4.0	4.3	3.6
K_2O	5.0	5.1	5.1	5.0
P_2O_5	-	-	0.08	0.07
Total	98.3	98.5	100.6	99.6

Analyst: Geochemical Division, Geol. Survey of Sweden.

TABLE 7. Average mineral composition of granodiorite to granite, dark reddish to grey red (Filipstad granite), per cent by volume.

Sample Top. map-sheet	V 1380 UDDE- HOLM SO 66728/ 13803	V 1408 MALUNG SV 67045/ 13519	V 1417 MALUNG SV 67013/ 13508	V 1608 UDDE- HOLM SO 66549/ 13999
Quartz	20 - 30	10 - 20	10 - 20	20 - 30
Microcline (in part perthitic)	20 - 30	10 - 20	10 - 20	20 - 30
Plagioclase	30 - 50	30 - 50	30 - 50	30 - 50
Biotite	1 - 10	10 - 20	10 - 20	10 - 20
Hornblende	0	10 - 20	10 - 20	<1
Titanite	1 - 5	1 - 5	<1	≤1
Apatite	<1	≤1	<1	<1
Ore	<1	<1	<1	<1
Zircon	<1	<1	0	<1
Garnet	<1	0	0	0
Epidote	<1	1 - 5	1 - 5	<1
Muscovite	<1	0	0	0
Calcite	0	0	<1	0

TABLE 8. Average mineral composition of granite, grey red to red, mostly coarse (Hagfors granite), per cent by volume.

Sample Top.map	V 1480 UDDE- HOLM NO 6678/ 13823	V 1491 UDDE- HOLM NO 66835/ 13839	V 1522 UDDE- HOLM SO 66561/ 13924	V 1645 UDDE- HOLM SO 66591/ 13955	V 1864 UDDE- HOLM NO 66943/ 13848	V 1893 UDDE- HOLM NV 66894/ 13736	V 1995 UDDE- HOLM NV 6691/ 13696
Quartz	20 - 30	20 - 30	20 - 30	20 - 30	20 - 30	20 - 30	10 - 20
Microcline (in part perthitic)	30 - 50	30 - 50	20 - 40	30 - 50	30 - 50	30 - 50	30 - 50
Plagioclase	30 - 50	30 - 50	20 - 40	30 - 50	30 - 50	30 - 50	30 - 50
Biotite	1 - 5	1 - 5	10 - 20	1 - 5	1 - 5	1 - 5	5 - 10
Muscovite	0	0	0	1 - 5	0	1 - 5	<1
Titanite	<1	<1	≤1	≤1	≤1	≤1	1 - 5
Zircon	<1	<1	<1	<1	<1	<1	<1
Apatite	<1	<1	<1	<1	<1	<1	<1
Ore	<1	<1	<1	<1	<1	<1	<1
Fluorite	<1	0	0	0	<1	<1	<1
Epidote	≤1	<1	<1	≤1	<1	≤1	<1
Chlorite	<1	<1	<1	<1	<1	<1	<1
Calcite	0	0	<1	0	0	0	0

THE RB-SR AND U-PB AGES OF PROTEROZOIC GNEISSIC GRANITOIDS IN CENTRAL VÄRMLAND, WESTERN SWEDEN

By ERIC WELIN AND ANN-MARIE KÄHR

ABSTRACT

The major part of the bedrock of central Värmland consists of various Proterozoic granitoid rocks. At Munkfors a gneissic granite has a U-Pb zircon age of 1 777^{+19}_{-11} (1 σ) Ma. The Rb-Sr isotopic system of this granite has been profoundly disturbed, and only a reference line, corresponding to an age of 1 770 Ma, can be calculated.

Welin, Eric, and Kähr, Ann-Marie, 1980-07-12: The Rb-Sr and U-Pb ages of Proterozoic gneissic granitoids in central Värmland, western Sweden. Sveriges geologiska undersökning, Ser. C, No. 777, pp. 24–28. Uppsala.

Early studies of the gneiss complex of southwestern Sweden divided the bedrock into areas dominated by red and grey gneisses. The former occur in the east whereas the latter predominate in the west. The bedrock of central Värmland is part of the red gneiss complex. Recent mapping of this area has contributed much to a more detailed and diversified knowledge of the geology, and a summary is given in the first part of this volume. The granitoids sampled for age determinations represent the second generation of granites and granodiorites. (See Plate 1 and Table 4 in the first part of this volume.) Three samples (75180, 75182 and 75184) are granodiorites. The others are of granitic composition. All samples represent fine- to medium-grained gneissic rocks with microcline augen which are granulated. In addition to quartz, plagioclase and microcline, the rock contains biotite and some epidote. The granitoids have been tectonized by at least two, possibly three deformation phases and are thoroughly recrystallized. In general, the gneissic granitoid complex shows evidence of alteration caused by the Filipstad–Hagfors granite magmas and the late Proterozoic Dalslandian event. All the samples are free from visible signs of these alterations.

A concentrate of zircons from sample 75186 was used for U-Pb dating. The concentrate was split into three size fractions which are all non-magnetic at 1.6 A in the Frantz isodynamic separator. The zircon crystals are transparent, euhedral and have a prismatic habit with few pyramid faces. No zoning has been observed. Scanning electron microscope studies show that the crystals have slightly rounded edges, irregular surfaces with visible pits and, in particular, rough pyramid faces. All these features indicate a metamorphism of primary magmatic zircons which, however, has not resulted in a total recrystallization of the mineral.

The age dating was made at the Laboratory for Isotope Geology in Stockholm employing conventional analytical techniques (Welin et al. 1980). The

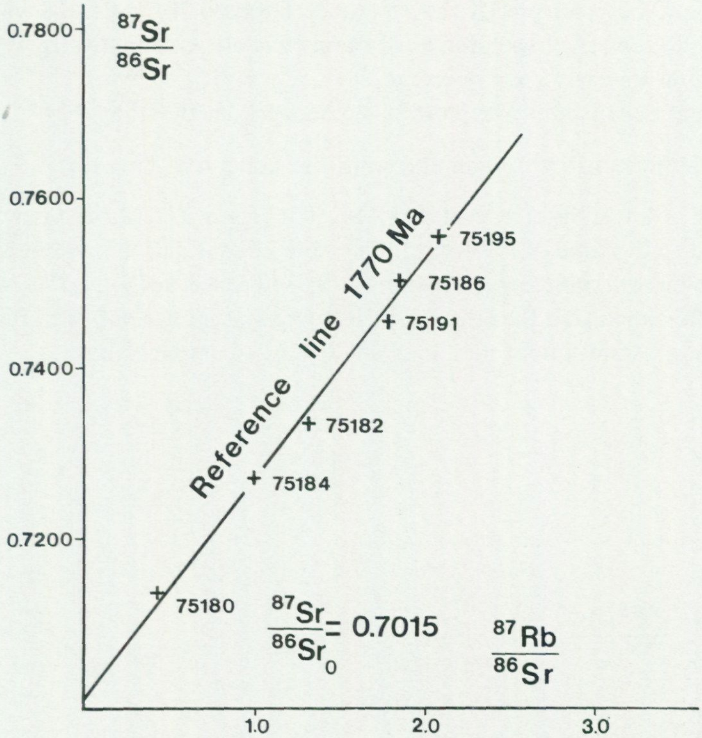


Fig. 1. Rb-Sr whole rock isochron diagram for gneissic granite and granodiorite, central Värmland.

accuracy of the XRF measurements of the $^{87}Rb/^{86}Sr$ ratio is 0.6 % (1 σ) and 0.03 % of the isotopic measurements of the $^{87}Sr/^{86}Sr$ ratio. The strontium isotopic ratios were normalized to $^{88}Sr/^{86}Sr = 0.1194$. The Rb-Sr isochrons were calculated following the procedure described by Williamson (1968).

The error in the $^{207}Pb/^{235}U$ ratio was estimated to 0.03 (1 σ) and in the $^{206}Pb/^{238}U$ ratio to 0.001. No correction for fractionation was made. The measured $^{207}Pb/^{206}Pb$ ratio of the NBS reference lead SRM 981 is 0.91780 as compared to the reported value of 0.91464. For the common lead corrections the following ratios were used $^{206}Pb/^{204}Pb = 15.8$, $^{207}Pb/^{204}Pb = 15.3$ and $^{208}Pb/^{204}Pb = 35.6$. The calculation of the age according to the episodic-loss model was made following Pankhurst and Pidgeon (1976).

In the calculations of the Rb-Sr and U-Pb age data the decay constants recommended by Steiger and Jäger (1977) have been employed. The analytical data are given in Tables 1–2. The results are presented graphically in Figs. 1 and 2.

All six samples plotted in the Rb-Sr diagram (Fig. 1) yield an age-reference line of 1 770 Ma. The MSWD is 15.6 and the reference line does not qualify as an isochron. The intercept of the reference line is 0.7015±0.0018 which indicates that the scatter of the analytical points has not systematically rotated the reference line towards a younger age.

The U-Pb zircon data are plotted in a concordia diagram (Fig. 2); the six fractions define an isochron intersecting the concordia curve at $1\,777^{+19}_{-11}$ Ma (1 σ), with a lower intercept at 495 Ma. The age 1 777 Ma is interpreted to correspond to the time of crystallization of the zircons and the parent rock. The age of the zircon coincides with the Rb-Sr reference age of 1 770 Ma which supports the conclusion that the Rb-Sr isotopic system has not been rearranged to indicate any subsequent metamorphic event. (Compare above.)

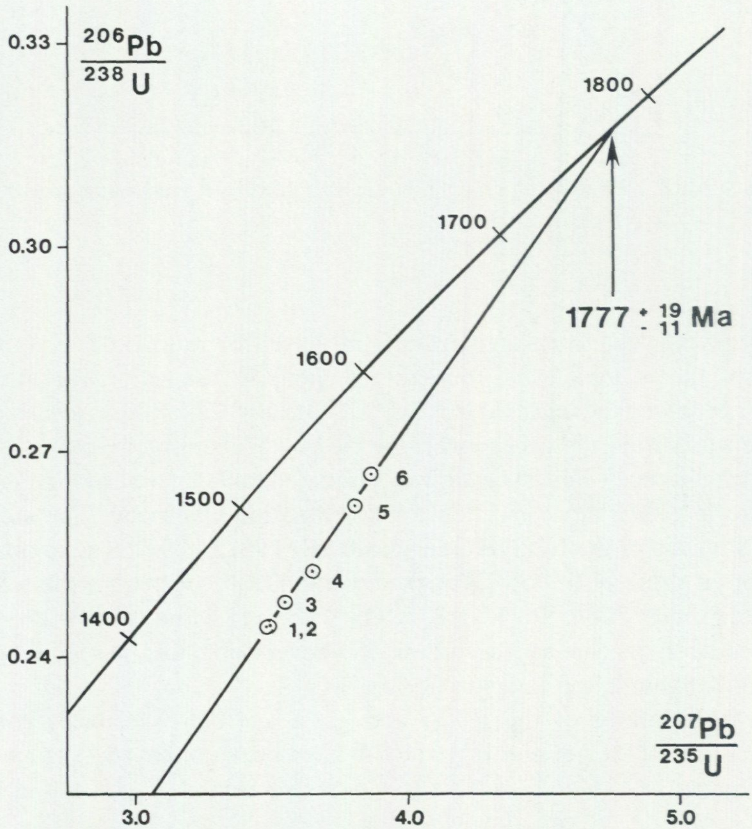


Fig. 2. Concordia diagram with data points of zircon fractions separated from a gneissic granite (Sample No. 75186), Munkfors, central Värmland.

Toward the east the gneissic granitoids of central Värmland are intruded by the Värmland granitoids which have Rb-Sr whole-rock ages of 1 655 and 1 665 Ma (Welin et al. 1977). The contacts are usually diffuse but xenoliths of altered gneissic granite have been observed in Värmland granite. Rare dikes of the Värmland granites intersect the gneissic granitoids (cf. first part of this volume). A lower limit on the age of the gneissic granitoids is therefore given by the Värmland granitoids.

This investigation is a part of a large geochronological study of western Sweden. A more complete discussion of the implications of the geochronological results will be made by one of the authors (Welin) in a separate paper and only a few comments will be made. The age of the gneissic granite at Munkfors shows that this rock conforms with the general geological pattern in the Precambrian of the Baltic Shield – the oldest rocks appearing in the north in Karelia and the Kola peninsula, the units further south and southwest being progressively younger. Obviously the gneissic granitoid complex of central Värmland does not constitute a pre-Svecofennian basement as suggested by Magnusson (1963). The granitoid complex is of approximately same age (1 750–1 800 Ma) as the ser- and post-orogenic Svecokarelian granites to the east of the huge belt of Värmland granitoids (approximately 1 660 Ma old). These Svecokarelian granites, however, are massive and differ from the gneissic granitoids in chemical composition and petrography. The deformations which affected the gneissic granitoids at the margin of the Baltic Shield were thus effectively absorbed by the Värmland granitoids and never penetrated the Svecokarelian rocks.

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TABLE 1. Analytical data for gneissic granite and granodiorite, central Värmland.

Sample	Rb [1] ppm	Sr [1] ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
75180	105	715	0.428	0.7137
75184	135	395	0.987	0.7270
75182	145	325	1.320	0.7326
75191	170	280	1.786	0.7454
75186	205	320	1.855	0.7502
75195	205	290	2.084	0.7545

[1] Approximative contents

TABLE 2. Analytical data for zircon from gneissic granite (Sample No. 75186), Munkfors, central Värmland.

No.	Fraction	Concentration in ppm		Isotopic composition		
		U	Pb_{rad}	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
1	74-106 µm	826	212	730	0.12311	0.16180
2	105-150 µm	758	194	746	0.12307	0.15756
3	45-74 µm	983	256	1923	0.11232	0.13402
4	150 µm	649	170	2326	0.11197	0.11551
5	45-74 µm	783	216	2564	0.11175	0.12871
6	45-74 µm	748	210	2222	0.11261	0.13050

No.	Age in Ma		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1	1410	1522	1705
2	1410	1525	1710
3	1429	1537	1713
4	1452	1560	1734
5	1501	1594	1742
6	1525	1606	1737

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