The Iddefjord granite: geology and age

SVEND PEDERSEN & SVEN MAALØE

Pedersen, S. & Maaløe, S. 1990: The Iddefjord granite: geology and age. *Nor. geol. unders. Bull. 417*, 55-64.

The Iddefjord granite forms part of the Swedish Bohus batholith and ranges in composition from diorite to granite. The granite consists of 13 individual plutons, and the mechanism of intrusion is related to block subsidence rather than forceful intrusion. There is no evidence of marginal chill, and the temperature of the host gneiss must have been similar to that of the granites. This suggests that the intrusion took place in a regionally pre-heated rock complex under plutonic conditions. The major element trends of the granites are similar to those of recent granite batholiths.

Rb/Sr age determinations carried out on two of the granites yield a common isochron age of 918 ± 7 Ma with an initial Sr isotope ratio of 0.7063 ± 0.0008 suggesting contributions from older crustal components. Mineral analyses from one of the investigated granite samples indicate a Rb/Sr mineral age in the order of 835 Ma, reflecting either a slow cooling of the pluton or a younger thermal effect causing resetting of the mineral system.

Svend Pedersen, Institut for almen Geologi, Øster Voldgade 10, DK-1350 København K, Denmark
Sven Maaløe, Institutt for geologi, Avd. A, Allégt. 41, N-5007 Bergen, Norway

Introduction

The Iddefjord granite forms the northern extension of the Swedish Bohus batholith, which was mapped by Asklund (1947). Recently, the Swedish part of the batholith has been investigated by Eliasson (1987) and Eliasson et al. (1988). The Bohus batholith is undeformed and formed in post-Sveconorwegian time. Rb/Sr whole-rock age determinations demonstrate that surrounding gneisses were affected by metamorphism and deformation in Sveconorwegian time, but that they also have a pre-Sveconorwegian history (e.g. Pedersen et al. 1978, Hageskov & Pedersen 1981, Åhäll & Daly in press). The Bohus batholith marks the end of the Sveconorwegian Orogeny in southeastern Norway-southwestern Sweden.

Post-Sveconorwegian granites are abundant in southern Norway, especially west of Oslofjorden, where a number of granites have been dated during the last ten years and yielded post-Sveconorwegian ages (e.g. Priem et al. 1973, Killeen & Heier 1975a, Pedersen & Falkum 1975, Wilson et al. 1977, Petersen & Pedersen 1978, Pedersen 1981). The Bohus batholith is the largest of these post-orogenic granites.

Both the Norwegian and the Swedish part of the batholith consists of several plutons, which range in composition from diorite to granite. The exposed part of the Swedish and the Norwegian part of the batholith are not similar; the Swedish part contains large areas where the gneissic roof is exposed, while remnants of the roof are rare in the interior of the Norwegian part of the batholith. Remnants of the roof in the Norwegian part are only present east of Sarpsborg where the dip of the contact zone is about 12° (Fig. 1). The difference is due to different levels of exposure in the northern and southern parts of the batholith. A major NW-SE trending fault zone about 300 m wide occurs in the Iddefjord area at Halden, and Iddefjorden itself formed in the fault zone during the last ice age. Extensively developed slickensides are present within the fault zone, plunging at about 45° towards the north. The prevalence of roof pendants in the south suggests that the batholith is downfaulted south of Iddefjorden. There is no lateral movement along the fault zone even though the map picture may suggest a lateral movement (Fig. 1). A few pegmatites intrude the rocks of the fault zone. As pegmatites were not formed in the area after the intrusive event related to the batholith, the faulting most probably occurred soon after the intrusion of the batholith.

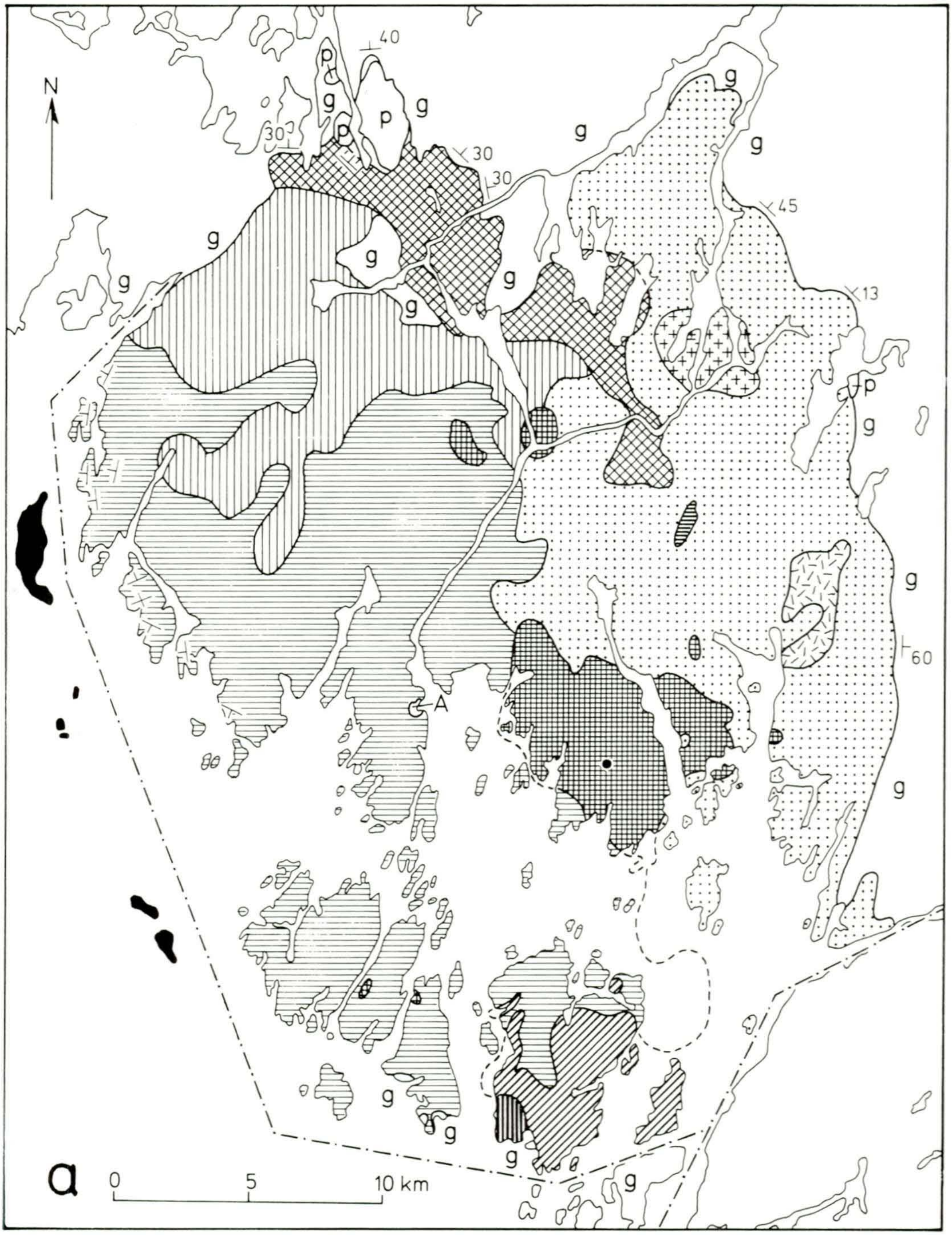
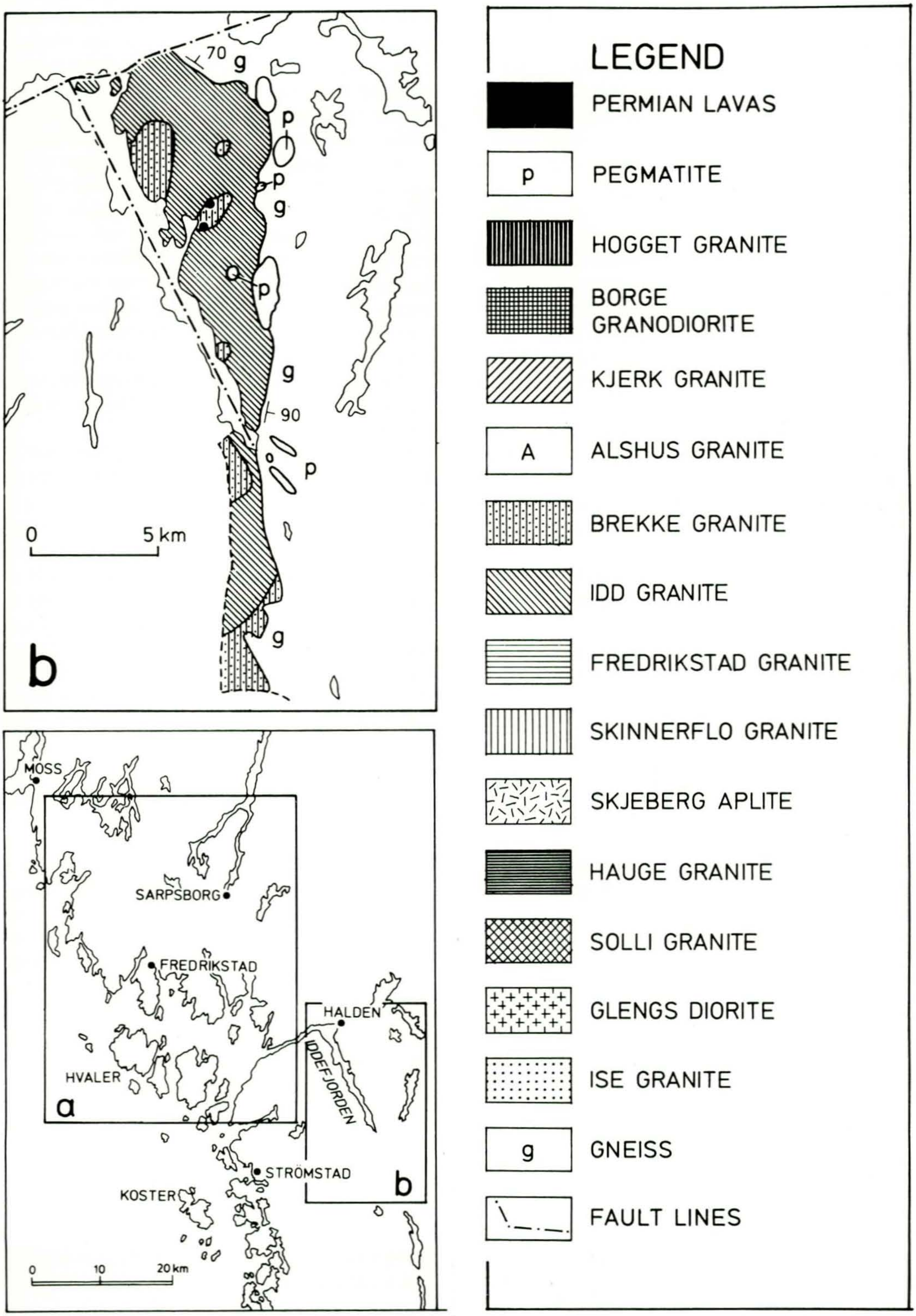


Fig. 1: Field map of the plutons within the Iddefjord granite.
(a) The main part of the granite and the Hvaler islands.
(b) The Iddefjord area. Localities for age determination samples are indicated by dots.


70
g
p
p
g
p
g
90
p
0 5 km
g
b
MOSS
SARPSBORG
FREDRIKSTAD
HALDEN
HVALER
IDDEFJORDEN
a
STRÖMSTAD
KOSTER
b
0 10 20 km
LEGEND
PERMIAN LAVAS
p PEGMATITE
HOGGET GRANITE
BORGE GRANODIORITE
KJERK GRANITE
A ALSHUS GRANITE
BREKKE GRANITE
IDD GRANITE
FREDRIKSTAD GRANITE
SKINNERFLO GRANITE
SKJEBERG APLITE
HAUGE GRANITE
SOLLI GRANITE
GLENGS DIORITE
ISE GRANITE
g GNEISS
FAULT LINES

Rb/Sr whole-rock age determinations on the batholith were published by Killeen & Heier (1975b) and Skiöld (1976) for the Norwegian and the Swedish part, respectively, yielding similar results of 881 ± 34 Ma and 891 ± 34 Ma and with initial Sr isotope ratios of 0.7098 and 0.711 ± 0.003, respectively. Skiöld mentioned that there seems to be some spread of data in the isochron diagram which may be due to a systematic variation, as samples with low $^{87}Rb/^{86}Sr$ ratios were collected from the eastern part of the batholith. He also mentioned that it is possible that instead of one isochron, two or perhaps even more, probably parallel isochrons should be drawn with small differences in initial Sr isotope ratios. In Killeen & Heier (1975b) no comments were made concerning the scatter of points in the isochron diagram, but on comparing the geographical position of the sample sites (Killeen & Heier 1975c) with the map presented in this paper, it appears that their samples used for the Rb/Sr work were collected within different granite bodies.

The aim of the Rb/Sr age determinations presented here is to eliminate the effect of the above-mentioned sampling errors. To avoid this, samples were collected from two well defined intrusions within the batholith.

Field relations

The Iddefjord granite consists of 13 separate plutons (Fig. 1), most of which are of granitic composition; the least fractionated pluton, however, has a dioritic composition, using the nomenclature of Streckeisen (1967) (Fig. 4). The contacts between the different plutons may be sharp or transitional, with a zone of xenoliths of the earlier granite near the contact. Features indicating a remelting of the host pluton by a younger granite have been observed.

The contacts between the granites and the country rock gneiss are generally sharp with no deformation of the structures in the gneiss and with no chill zone developed. The dip of the contact varies from vertical to subhorizontal, a typical dip being about 45° outwards with the granites extending beneath the gneiss.

There is not much evidence in the plutons within the Iddefjord granite for 'granite tectonics', and only two plutons, the Fredrikstad granite and the Brekke granite, display internal structures. The Fredrikstad granite contains 5-20 cm broad bands consisting of concentrations of biotite situated a metre apart. These bands dip nearly vertically in the western part of the pluton. Further to the east a westerly dip becomes prevalent, and thereafter the bands become horizontal. As the dip gradually becomes less steep the biotite bands decrease in frequency, and they are absent in the middle of the pluton. From the map (Fig. 1) it appears that the Fredrikstad granite forms intrusive tongues extending to the east and north. The orientation of the biotite bands may be explained if it as assumed that the magma moved in a vertical direction in the western part of the body and thereafter moved horizontally in easterly to northerly directions.

The Brekke granite forms several intrusions south of Halden (Fig. 1) and contains parallel-arranged plagioclase crystals.

Apart from these fabrics the granite plutons appear to be without significant flow structures. The general absence of internal structures may be ascribed to the granite magmas being in a completely fluid state during their intrusion. The granite structures described by Balk (1937) will only appear if the intruding granite is partly crystallized. In the absence of phenocrysts no fabric will develop during the emplacement of the intrusion. It is therefore considered likely that most of the Iddefjord granites intruded in a completely molten state. The only evidence for the direction of flow may be obtained from the orientation of minor basic clots, but these are not common, except in the Borge granite.

Domes of pegmatites occur along the eastern and northern contact zones to the gneiss, and the pegmatites have intruded both gneiss and granite. These domes, which reach kilometre size, have not been observed in the western part of the batholith. There is no evidence for any extensive fractionation within the pegmatites; they are all of the simple type, without exotic minerals. There are hardly any pegmatites in the interior parts of the batholith, those observed being restricted to a few metre-size lensoid pockets.

The youngest pluton, the Borge granodiorite, intruded into the central part of the batholith and formed several small dyke swarms. A similar type of late-stage granite is present in the Swedish part of the batholith where it also formed dykes (Asklund 1947). Apparently the entire batholith was intruded by this late granite.

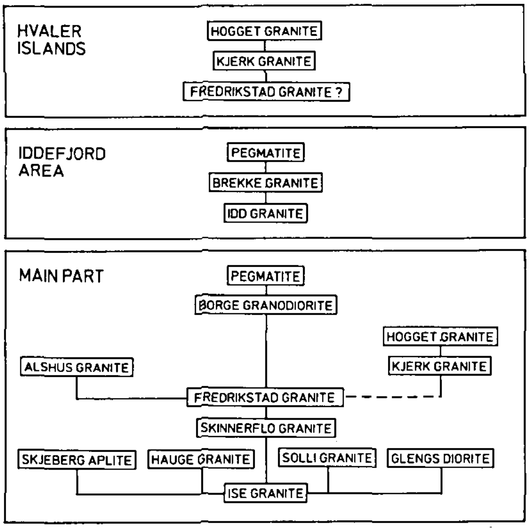


Fig. 2: The relative age relations of the granite plutons in three separate areas. In each part the oldest pluton is at the base.

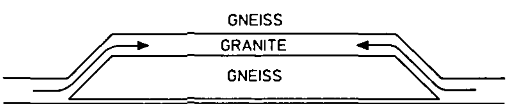


Fig. 3: The mechanism of intrusion by block subsidence suggested by the field relations.

Age relations

The relative ages of the plutons are shown in Fig. 2. The age relationships between the faulted segments, that is, the section east of Iddefjord, the Swedish part of the batholith, and the part north of Iddefjord, cannot be determined in the field.

The largest plutons were emplaced in the beginning of the intrusive phase, while the smaller ones are comparatively late. Two of the youngest plutons, the Brekke granite and the Borge granodiorite, have been dated in connection with this work.

The contacts between the plutons are only rarely exposed, but two types have been observed. Most are sharp with no chill zone developed, so that age relations are based on the occurrence of cross-cutting dykes. Others are of an intermixed type, where contorted fragments of both types of granite occur. This type does not allow a determination of the age relations. The intermixed contact relationship suggests that the host granite was in a partially fluid condition when the younger granite intruded. An intermixed contact is particularly well exposed between the Fredrikstad and Skinnerflo granites at Krokstadfjorden.

Mechanism of intrusion

The tabular shape of the batholith (Lind 1967) and the orientation of the biotite bands in the Fredrikstad granite, as well as the marginal occurrence of pegmatite domes, suggest that the intrusion of magma initially took place in the marginal parts of the batholith. Furthermore, the dip of the contacts and the absence of deformation of the gneiss suggest that the intrusive space was gained by block subsidence (Fig. 3). The presence of a large batch of magma beneath or deep in the crust may have caused this subsidence, whereafter the magma moved into the fracture formed during the subsidence.

Petrography

The plutons are fine- to medium-grained and vary in colour from grey to reddish-grey, the red colour due to microcline. Most of the plutons are even-grained, but the Fredrikstad granite and the Brekke granite are slightly porphyric. The Borge granodiorite is fine-grained and the Skjeberg aplite has local occurrences of pegmatite. The only pluton that deviates markedly in texture is the Glengs diorite

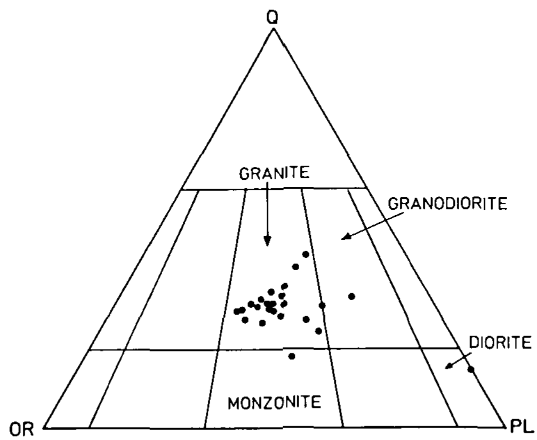


Fig. 4: Modal proportions of plagioclase, microcline and quartz for the Iddefjord granits plotted in the Streckeisen classification diagram.

that contains glomerophyric clusters of amphibole. The plutons are generally without flow structures, but the large plagioclase phenocrysts of the Fredrikstad granite may display a subparallel orientation due to flow. Another indication of flow is that of the basic clots which have an ellipsoidal shape, from 5 to 20 cm in length. Where present they have a parallel orientation, but their occurrence is too sporadic to define a regional flow pattern within the granites.

The plutons consist mainly of plagioclase, microcline and quartz, the plagioclase cores having the composition of oligoclase and the zoning being normal. The accessory minerals are biotite, hornblende, muscovite, Fe-oxides, chlorite, apatite, titanite and zircon. In most granites there is less than 1 % hornblende, but the Glengs diorite contains up to 22 %. Biotite constitutes between 2 and 13 % of the mode of the granites, with the exception of the Glengs diorite that may contain up to 28 %. The modal proportions of plagioclase, microcline and quartz are shown in Fig. 4. Individual plutons display some variation in mineral proportions, and the granites therefore cannot be separated on the basis of mineralogical composition alone. The granites were distinguished by their colour and texture, but since these features also display some variation the separation between individual plutons has in some places been difficult.

The texture of the granites is mostly interlobate, and the crystallization sequence could not be determined for most of the granites. The Brekke granite is an exception, and this granite was therefore chosen for an experimental determination of the water content (Maaløe & Wyllie 1975).

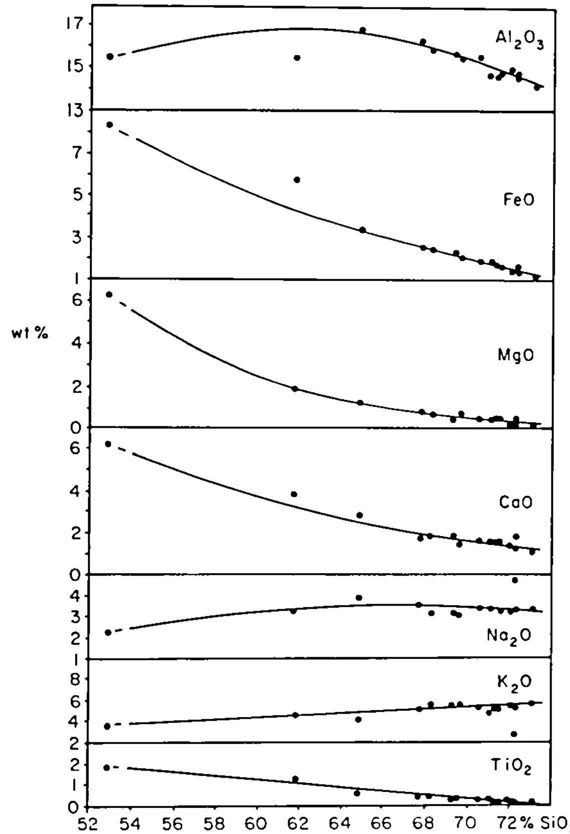


Fig. 5: Major element trends for the Iddefjord granite.

Chemical composition

The major element trends for the granite are shown in Fig. 5, and the analyses in Table 1. The curvatures of the trends shown are evidently based on extensive extrapolation but are probably justified, since the trends are similar to the those of Tertiary and Cretaceous granites (Maaløe & Petersen 1981). Apparently, the Iddefjord granites have similar compositions of some of the more recent granites and were probably generated in a similar manner. The range of composition from diorite to granite might suggest that the granites are I-type granites, and the absence of cordierite and sillimanite as well as the presence of basic clots also suggest I-type rather than S-type granites. However, the classification scheme between these types is rather vague and the suggested I-type character is only tentative (White & Chappell 1977).

The presence of flow-oriented basic clots in some of the plutons shows that no fractionation occurred after the granites where intruded. However, fractionation of the magma might have occurred before their intrusion. The trends are not so well defined to enable an evaluation of the formation of the granites by fractionation or anatexis, and therefore the origin of the granite magmas will not be considered further.

Table 1
Chemical analyses of samples from the Iddefjord granites

	21335[1]	55[1]	16622[1]	16617[1]	21219[1]	313[2]	319[3]	317[4]	21229[5]	320[6]	321[6]	328[6]	322[6]	16620[7]	327[7]	MG-1[8]
SiO_2	71.22	71.38	71.61	72.39	73.21	64.87	68.31	72.39	52.86	67.75	69.65	70.55	72.04	61.76	69.42	71.30
TiO_2	.33	.21	.21	.16	.12	.62	.47	.23	1.88	.47	.37	.28	.20	1.35	.34	.40
Al_2O_3	14.63	14.57	14.74	14.62	14.13	16.77	15.80	14.75	15.45	16.36	15.46	15.50	14.95	15.44	15.61	14.44
Fe_2O_3	.63	.51	.68	.66	.51	.67	.49	.32	2.33	.58	.34	.97	.24	2.95	.80	1.00
FeO	1.39	1.29	.99	.80	.78	2.84	2.00	1.39	6.26	2.09	1.80	1.08	1.25	3.10	1.65	1.41
MnO	.06	.08	.09	.09	.05	.09	.07	.07	.14	.08	.08	.06	.03	.09	.06	.03
MgO	.39	.46	.41	.22	.20	1.20	.67	.49	6.23	.73	.63	.44	.23	1.87	.46	.40
CaO	1.64	1.55	1.59	1.32	1.09	2.85	1.82	1.84	6.04	1.74	1.50	1.62	1.42	3.84	1.87	1.69
Na_2O	3.44	3.45	3.37	3.42	3.31	3.92	3.16	4.67	2.30	3.57	3.04	3.46	3.29	3.34	3.25	3.44
K_2O	4.86	5.22	5.12	5.26	5.62	4.12	5.65	2.95	3.51	5.08	5.56	5.22	5.44	4.38	5.45	5.45
H_2O^-	.00	.06	.06	.03	.02	.04	.03	.02	.26	.07	.10	.04	.14	.08	.05	.06
H_2O^+	1.10	.80	.76	.77	.80	.94	.99	.83	1.90	.97	.86	.56	.63	.84	.62	.45
CO_2	.13	.04	.06	.09	.06	.04	.25	.08	.07	.10	.05	.17	.12	.09	.11	
P_2O_5	.06	.04	.09	.03	.02	.13	.08	.04	.39	.10	.04	.05	.02	.34	.06	.10
sum	99.88	99.66	99.78	99.85	99.92	99.10	99.79	100.11	99.62	99.69	99.48	100.00	100.00	99.40	99.75	100.17

1: Ise granite 2: Hauge granite 3: Skinnerflo granite 4: Solli granite 5: Glengs diorite 6: Fredrikstad granite
7: Borge granodiorite 8: Brekke granite
Analyst: Per-Reidar Graff, Norges Geologiske Undersøkelse.

Rb/Sr age determinations

Sampling and analytical techniques

In this contribution to the geology and the Rb/Sr systematics of the Iddefjord granite, samples from two plutons were investigated. From the Brekke granite, 8 samples from two quarries were collected, and from the Borge granodiorite 5 samples were taken. The analytical techniques used during the work have been described by Hageskov & Pedersen (1981).

Results

Table 2 shows the data from the whole-rock samples analysed in this investigation. Ages and initial Sr isotope ratios have been calculated by means of the programme by Williamson (1968) using a $\lambda^{87}Rb$ of $1.42 \times 10^{-11} \times a^{-1}$. To make the results obtained during this study comparable to those of Skiöld (1976) and Killeen & Heier (1975b), their data have been recalculated using the same programme (in the case of Skiöld to obtain information on the MSWD parameter, as Skiöld (1976) had already used the Williamson programme). Table 3 shows the isochrons calculated and recalculated.

The Brekke granite yields an age of 918 ± 36 Ma with an initial Sr isotope ratio of 0.7063 ± 0.0029 and a MSWD of 0.37 (Fig. 6). No individual age has been calculated for the Borge granodiorite due to only a very little spread in the $^{87}Rb/^{86}Sr$ ratio. Calculating a common age for the two types yields an age identical to that for the Brekke granite, 918 ± 7 Ma,

Table 2. Analytical data from the Iddefjord batholith.

Brekke granite Sample no.	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
25018	5.13 ± 4	0.7736 ± 3
25019	4.99 ± 3	0.7723 ± 3
25020	5.04 ± 4	0.7721 ± 3
25021	5.18 ± 4	0.7739 ± 3
25022	5.28 ± 4	0.7752 ± 3
25023	6.25 ± 4	0.7883 ± 3
25024	6.11 ± 4	0.7864 ± 3
25025	5.95 ± 4	0.7845 ± 3
loc. 1: 25018—25022		
loc. 2: 25023—25025		
Borge granodiorite		
MAAL 1	8.98 ± 4	0.8247 ± 2
MAAL 2	9.17 ± 5	0.8261 ± 2
MAAL 3	8.82 ± 4	0.8228 ± 2
MAAL 4	9.13 ± 5	0.8256 ± 2
MAAL 5	9.21 ± 5	0.8262 ± 2

Table 3. Rb/Sr age data from the Bohus—Iddefjord batholith

Reference	Age	$(^{87}Sr/^{86}Sr)_o$	MSWD
Killeen & Heier*) (1975b)	881 ± 31 Ma	0.7098 ± 0.0028	6.56
Skiöld (1976)	*890 ± 35 Ma*	*0.7110 ± 0.0034*	1.10
This work Brekke	918 ± 36 Ma	0.7063 ± 0.0029	0.37
This work Brekke + Borge	918 ± 7 Ma	0.7063 ± 0.0008	0.74

*): 1% error is assigned to the $^{87}Rb/^{86}Sr$ ratio and 0.15 ‰ to the $^{87}Sr/^{86}Sr$ ratio.

$\lambda^{87}Rb$: 1.42×10^{-11}/year

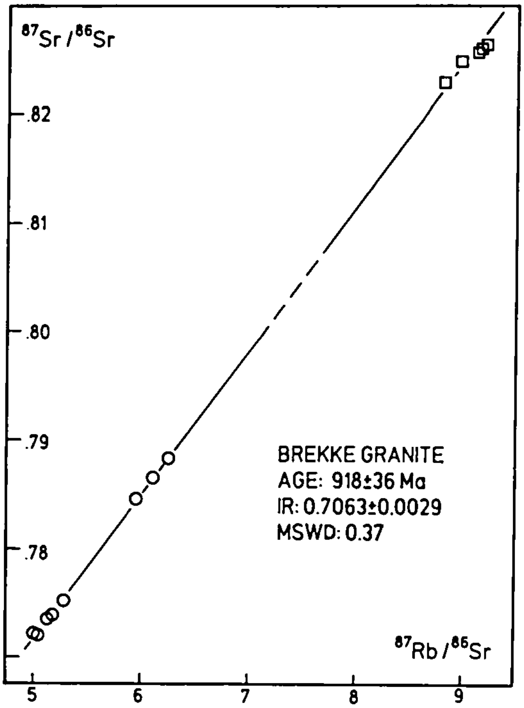


Fig. 6: Rb/Sr whole-rock isochron diagram for the Brekke granite (circles) and the Borge granodiorite (squares).

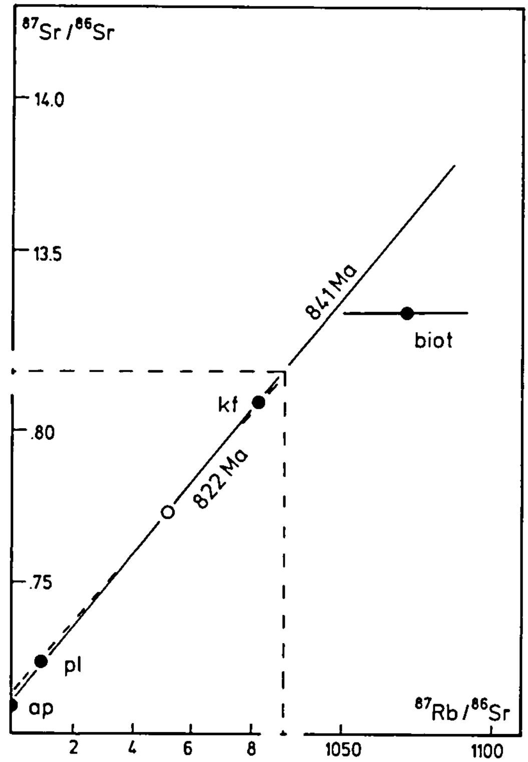


Fig. 7: Rb/Sr isochron diagram for minerals from the Brekke granite. Minerals filled circles; whole-rock open circles. The horizontal bar indicates the error of the Rb/Sr ratio for the biotite analysis.

and an initial Sr isotope ratio of 0.7063 ± 0.0008 with a MSWD of 0.74.

To investigate the mineral system within the Brekke granite, apatite, K-feldspar, plagioclase and biotite were separated from sample no. 25021. The whole-rock/mineral system yields an age of 841 ± 10 Ma (except apatite, which falls clearly below the isochron) while the whole-rock/biotite system gives 822 Ma (Fig. 7), which from a statistical point of view is similar to the age for the whole-rock/total mineral system (Table 4). The mineral age is significantly lower than the whole-rock age for the Brekke granite. Skiöld (1976) obtained similar low ages on micas by the K/Ar method whereas coarse-grained muscovite gave a higher age.

Table 4. Mineral separate results

Sample no.	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
25021/apatite	0.014 ± 3	0.7097 ± 2
25021/plagioclase	1.064 ± 5	0.7243 ± 2
25021/K-feldspar	8.23 ± 4	0.8106 ± 2
25021/biotite	1071 ± 21	13.295 ± 30

Age, Minerals — WR*)
841 ± 10 Ma, $(^{87}Sr/^{86}Sr)_o$: 0.7115 ± 0.0009, MSWD: 0.72
Age, biotite — WR:
822 Ma

*) apatite omitted from the calculations

Discussion

The present investigation indicates that some of the youngest plutons within the Iddefjord granite have a higher age than that shown by earlier published studies. This may be due to the fact that the plutons have a systematic variation in $^{87}Rb/^{86}Sr$ ratio together with a variation in initial Sr isotope ratios. The initial Sr isotope ratio for some of the plutons may be lower than earlier reported. This has implications for genetical considerations and the classification of the batholith. Wilson (1982) and

Wilson & Åkerblom (1982) classified the Bohus batholith as representative of an S-type granite based on the initial Sr isotope ratio. The present investigation does not unequivocally support this classification, either from a petrological or from a Sr isotope ratio point of view, as the initial Sr isotope ratio falls close to the line separating the I-type granites from the S-type granites.

The low mineral age is of interest and this may be caused by slow cooling or alternatively by a younger thermal effect on parts of the batholith resulting in resetting of the mineral system.

Conclusions

The Iddefjord granite, which forms part of the Bohus batholith, is among the abundant granites formed in post-Sveconorwegian times in southern Norway and southwestern Sweden. It exhibits an age comparable to many of the granites west of Oslofjorden, demonstrating an important period of magmatism after the Sveconorwegian orogeny. The Iddefjord granite consists of 13 individual plutons, some of the youngest of which yield a common age of 918 ± 7 Ma and an initial Sr isotope ratio of 0.7063 ± 0.0008. In some ways the plutons are different from many of the granites west of Oslofjorden, e.g. in having a slightly higher initial Sr isotope ratio.

The mineral system yields an age in the order of 820-840 Ma which is suprisingly much lower than the whole-rock age, indicating a prolonged cooling history of the granite. Alternatively, a resetting of the mineral system due to a younger heating of the granite may be considered.

Acknowledgements

We would like to thank Professor D. Bridgewater for constructive criticism of the manuscript and for improving the English.

References

Asklund, B. 1947: Svenska steindustriomraaden. *Sver. geol. unders. Ser. C 479.*

Balk, R. 1937: Structural behaviour of igneous rocks. *Geol. Soc. Amer. Mem. 5.*

Eliasson, T.M. 1987: Trace element fractionation in the late Proterozoic Bohus granite, SW Sweden. *Int. Symp. on Granites and Associated Mineralizations, Salvador, Brasil, Jan. 1987,* 211-214.

Eliasson, T., Sundquist, V. & Wallroth, T. 1988: Rock mass characteristics at the HDR geothermal research site in the Bohus granite, SW Sweden. *HDR Geothermal Energy project. Dept. Geol. Chalmers Univ. Technology and Univ. Göteborg. Publ. Fj-5.*

Hageskov, B. & Pedersen, S. 1981: Rb/Sr whole rock age determinations from the western part of the Østfold basement complex, SE Norway. *Bull. Geol. Soc. Denmark 29,* 119-128.

Killeen, P.G. & Heier, K.S. 1975a: Th, U, K and heat production measurements in ten Precambrian granites of the Telemark area, Norway. *Nor. geol. unders. 319,* 59-83.

Killeen, P.G. & Heier, K.S. 1975b: A uranium and thorium enriched province of the Fennoscandian shield in southern Norway. *Geochim. Cosmochim. Acta 39,* 1515-1524.

Killeen, P.G. & Heier, K.S. 1975c: Radioelement distribution and heat production in Precambrian granitic rocks, Southern Norway. *Vid. -Akad. Skr. I Mat-Naturv. Klasse Ny Serie no. 35.*

Lind, G. 1967: Gravity measurements over the Bohus granite in Sweden. *Geol. Fören. Stockh. Förh. 88,* 542-548.

Maaløe, S. & Wyllie, P.J. 1975: Water content of a granite magma deduced from the sequence of crystallization determined experimentally with water-undersaturateed conditions. *Contrib. Mineral. Petrol. 52,* 175-191.

Maaløe, S. & Petersen, T.S. 1981: Petrogenesis of oceanic andesites. *J. Geophys. Res. 86,* 10273-10286.

Pedersen, S. 1981: Rb/Sr whole rock age determinations on late Proterozoic granitoids from the Evje area, Central Aust-Agder, SE Norway. *Bull. Geol. Soc. Denmark 29,* 129-143.

Pedersen, S. & Falkum, T. 1975: Rb-Sr isochrons for the granitic plutons around Farsund, Southern Norway. *Chem. Geol. 15,* 97-101.

Pedersen, S., Berthelsen, A., Falkum, T., Graversen, O., Hageskov, B., Maaløe, S., Petersen, J.S., Skjernaa, L. & Wilson, J.R. 1978: Rb-Sr dating of the plutonic and tectonic evolution of the Sveconorwegian Province (extended abstract). *In* Zartman, R.E. (ed.) *Short papers of the fourth international conference, geochronology, cosmochronology isotope geology 1978.* U.S. Geol. Surv. Open-file report 78-701, 329-331.

Petersen, J.S. & Pedersen, S. 1978: Strontium-isotope study of the Kleivan granite, Farsund area, South Norway. *Nor. Geol. Tidsskr. 58,* 97-102.

Priem, H.N.A., Boelrijk, N.A.I.M., Hebeda, E.H., Verdurmen, E.A. Th. & Verschure, R.H. 1973: Rb-Sr investigations on Precambrian granites, granitic gneisses and acidic metavolcanics in Central Telemark: metamorphic resetting of Rb-Sr whole rock systems. *Nor. geol. unders. 327,* 35-39.

Skiöld, T. 1976: the interpretation of the Rb-Sr and K-Ar ages of late Precambrian rocks in southwestern Sweden. *Geol. Fören. Stockh. Förh. 98,* 3-29.

Streckeisen, A. 1967: Classification and nomenclature of igneous rocks. *N. Jb. Miner. Abh. 107,* 144-214.

White, A.J.R. & Chappell, B.W. 1977: Ultrametamorphism and granitoid genesis. *Tectonophysics 43,* 7-22.
Williamson, J.H. 1968: Least-squares fitting of a straight line. *Can. J. Phys. 45,* 1845-1847.
Wilson, J.R., Pedersen, S., Berthelsen, C.R. & Jacobsen, B.M. 1977: New light on the Precambrian Holum granite, South Norway. *Nor. Geol. Tidsskr. 57,* 347-360.
Wilson, M.R. 1982: Magma types and tectonic evolution of the Swedish Proterozoic. *Geol. Rundsch. 71,* 120-129.
Wilson, M.R. & Åkerblom, G.V. 1982: Uranium-enriched granites in Sweden. *In* Evans, A.M. (ed.) *Metallization Associated with Acid Magmatism.* John Wiley and Sons Ltd.
Åhäll, K.I. & Daly, J.S. in press: Age, tectonic setting and provenance of Östfold-Marstrand belt supracrustals: westward crustal growth of the Baltic Shield at 1760 Ma. Precambrian Res.

Manuscript received November 1988; revised typescript May 1989; accepted July 1989.