U-Pb and Rb-Sr geochronology of the eastern part of the south Rogaland igneous complex, southern Norway

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The successive intrusive events in the eastern part of the south Rogaland anorthosito-mangeritic complex have been dated by the U-Pb method applied to zircon, sphene, monazite, uraninite and accessorily by the Rb-Sr whole rock isochron method. The whole magmatic activity in that part of the complex takes place in a short time interval: between 955 m.y., the intrusion age of the Bjerkrem-Sogndal layered norites, and 910 m.y., the emplacement age of a pegmatite in the Lyngdal granodiorite. The U-Pb geochronological data are consistent with field and petrological data on origin and mutual relations of the intrusives. The Rb-Sr data give incoherent results probably due to open system behaviour in some cases.

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The south Rogaland igneous complex has been studied from both field and petrological points of view by P. Michot and J. Michot and their co-workers (see Michot & Michot 1969; De Waard et al. 1974). With the exception of the Bjerkrem-Sogndal lopolith, the eastern part has been mapped in detail only these last few years.

The southeastern tip of the complex consists of two acidic intrusions – the Farsund charnockite and the Lyngdal granodiorite – long considered to be a single unit (the so-called farsundite – Barth 1960). The genetic relationship between these rocks is presently being reconsidered, as well as their possible relations with the anorthosites outcropping to the west (Egersund-Ogna body and Bjerkrem-Sogndal lopolith, Fig. 1).

According to P. Michot (1960, 1965), the Bjerkrem-Sogndal lopolith consists of three units emplaced after each other and corresponding to three stages of a gravity-differentiation process; the anorthositic-noritic phase, here called layered norites, the monzonoritic phase (monzonorite is equivalent to jotunite [hypersthene monzodiorite] in the Streckeisen's [1974] nomenclature of charnockitic rocks), and the mangeritic and quartz mangeritic phase.

This lopolith is separated from the easternmost intrusives by a thin septum of gneisses. These intrusives, the Hidra and Garsaknatt anorthositic bodies appear clearly as late tectonic intrusions slightly discordant on the N-S regional gneissic textures.

The previous geochronological data throw little light on the problem of the timing of emplacement and thus possible genetic relations of these rocks either because of their imprecision and insufficient number or because of the usual drawbacks of the radiometric methods: open system behaviour, inherited material, etc. In this study, therefore, it was attempted, using improved techniques and taking carefully into account all other information at hand, to clarify the intricate picture of the successive intrusions.

Geological setting

The part of the igneous complex, lying east of the Hidra anorthosite has been called 'farsundite' (Barth 1960), but recent studies have shown that it consists of several intrusions separated, locally at least, by gneiss septa (Beelen 1971; Falkum et al. 1972). Only the two most important intrusions will be considered here –

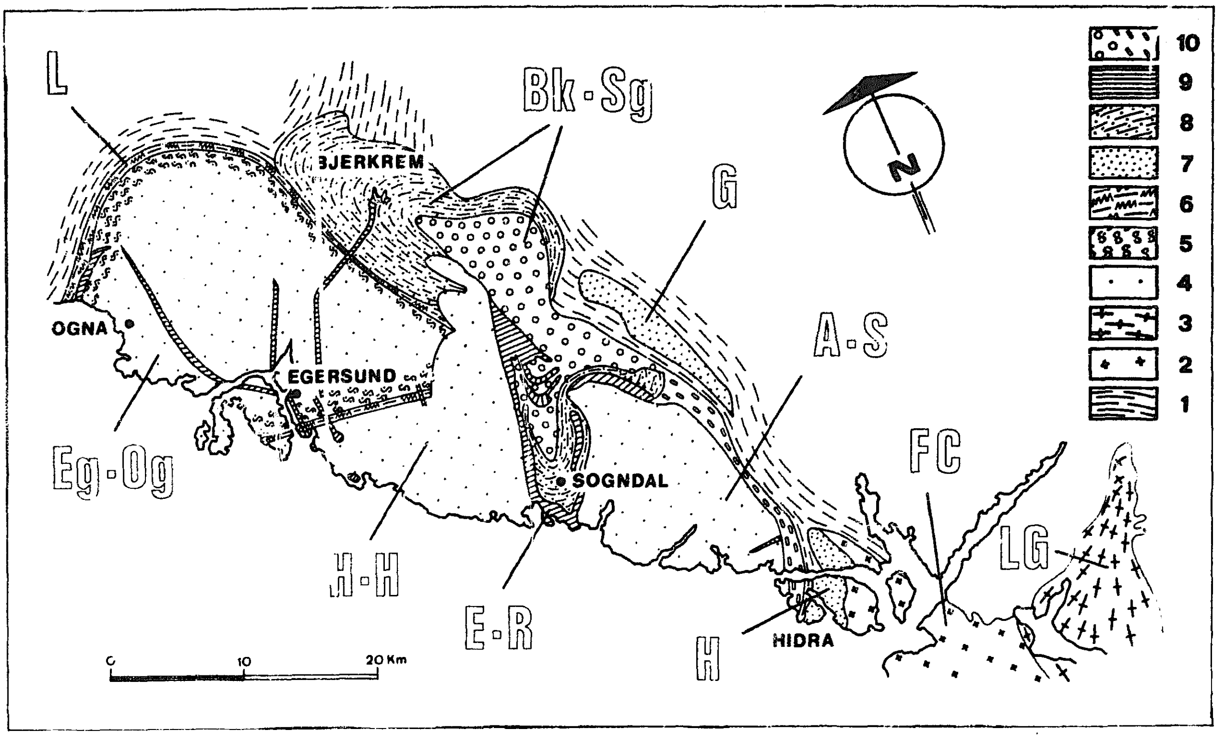

Fig. 1. General geological map of the south Rogaland igneous complex (from J. & P. Michot 1969; slightly modified). (a) *Western part of the complex:* Egersund-Ogna (Eg-Og) body; Lakssevelefjeld (L) noritic intrusion; Haaland-Helleren (H-H) massif. (b) *Bjerkrem-Sogndal (Bk-Sg) lopolith* and Eia-Rekefjord (E-R) monzonoritic intrusion. (c) *Eastern part of the complex:* Aana-Sira (A-S) massif; Hidra (H) and Carsaknatt (G) bodies; Farsund charnockite (FC) and Lyngdal granodiorite (LG). 1: Surrounding gneisses; 2: Farsund charnockite; 3: Lyngdal hornblende granodiorite; 4: anorthosite; 5: leuconoritic gneiss; 6: norite; 7: leuconorite (with accessory anorthosite); 8: layered norites; 9: quartz monzonorite; 10: mangerite and quartz mangerite.

the Farsund charnockite and the Lyngdal hornblende granodiorite. An intrusive contact of the former into the latter is mentioned by Falkum & Petersen (1974). Moreover, these rocks are too dissimilar from a chemical point of view to be considered as co-magmatic (Falkum et al. 1972).

Subsequent REE investigations have shown that the granodiorite with negative Eu anomaly may be co-magmatic with the anorthosito-noritic rocks outcropping to the west, while the charnockite, without Eu anomaly, is probably anatectic (Demaiffe et al. 1978). The relations of these two units to the Bjerkrem-Sogndal lopolith, more especially to one or the other of its distinct intrusive phases, are uncertain.

Geochemical investigations have confirmed that the quartz mangeritic phase in the Bjerkrem-Sogndal lopolith represents the liquid left after the crystallization of the layered norites: this is mainly based on a quantitative modelling of the Sr, Ca, Rb and K contents in the lopolith (Duchesne 1978; Duchesne & Demaiffe 1978) and on the REE geochemistry (Demaiffe et al. 1978). The possibility of some crustal contamination of the quartz mangerites has also been invoked. The monzonorites, on the other hand, would correspond to undifferentiated magma (Duchesne et al. 1974; Duchesne & Demaiffe 1978) and for this reason may have been emplaced at several different times.

The succession observed in the main part of the Bjerkrem-Sogndal massif is also observed in its southeast extension or apophyse (Demaiffe 1972). Mangerite samples of this apophyse have been included in the Rb-Sr whole rock isochron.

The Hidra massif consists of anorthosite and leuconorite surrounded by a fine-grained monzonoritic border rock interpreted as a chilled margin (Demaiffe et al. 1973; Duchesne et al. 1974; Demaiffe 1977). Charnockitic dykes and pegmatitic lenses representing residual liquid of anorthosite differentiation (Demaiffe et al. 1978) crosscut the anorthosite. Leuconoritic dykes originating from the main Hidra body intrude the Farsund charnockite.

Previous geochronological investigations

All geochronological data have been calculated or recalculated with the decay constants recommended by the IGCP-IUGS Subcommission for Geochronology (Steiger & Jäger 1977) which are thought to yield agreement between Rb-Sr and U-Pb ages for closed systems.

The uranium-lead method has been applied to the Bjerkrem-Sogndal mangerite (zircon) and the Lyngdal granodiorite (zircon, sphene) by Pasteels et al. (1970). A probable age of 951 ± 12 m.y. is proposed for the first rock; 977 ± 18 m.y. for the second. An electron multiplier has been used as a collector for these earlier measurements and the 207/206 ages tend to be slightly too high because of instrumental bias. For the Bjerkrem-Sogndal mangerites and quartz mangerites, Versteeve (1975) has established a Rb-Sr whole rock isochron (25 points) which gives an age of 842 ± 29 m.y. with $(^{87}Sr/^{86}Sr)_0 = 0.7121 \pm 0.0012$. Some scatter of the experimental points exceeding errors is observed. This Rb-Sr age is hard to reconcile with the U-Pb age mentioned above.

Pedersen & Falkum (1975) obtain 834 ± 39 m.y. and 912 ± 36 m.y. respectively for the Farsund charnockite and the Lyngdal granodiorite, also with the Rb-Sr isochron method. The corresponding initial ratios are 0.7128 ± 0.0009 and 0.7054 ± 0.0005. These isochrons are based on five and six rather clustered points respectively, which may be too little for a firm age assessment. Let us mention finally that a large pegmatite body occurring within the Lyngdal granodiorite, at Rymteland, contains uraninite crystals dated at 905 m.y. by Kulp & Eckelman (1957).

Results and discussion

Analytical methods

Rb and Sr concentrations were determined either by X-ray fluorescence (Delvigne and Durez - M.R.A.C. - Tervuren, Belgium) or by isotope dilution.

Comparison of both methods allows a precise assessment of the accuracy of the technique (cf. Table 2).

The isotopic composition of Sr separated on an ion-exchange column has been measured by thermoionization on single Re filament using the TH5 VARIAN MAT mass spectrometer of the 'Belgian Centre for Geochronology'. Ten determinations of the $^{87}Sr/^{86}Sr$ isotopic ratio for the E. and A. standard yield as a mean 0.70804 ± 0.00007 (1σ).

All zircons were dissolved under high pressure in a mixture of hydrofluoric and nitric acids (Krogh 1973). The other minerals (uraninite, sphene, monazite) were dissolved in nitric or in a hydrofluoric-nitric (or hydrofluoric-perchloric) acid mixture at atmospheric pressure.

A combined spike $^{208}Pb + ^{233}U$ has been used in most cases. The reproducibility of the concentration measurements has been checked in one case (Table 1). The common lead contamination has been estimated by two different methods: blank experiment and common lead actually observed in non-magnetic zircon considered as containing no common lead at all (Krogh 1973). From both methods, it would appear that this contamination does not exceed 10 ng.

Lead has been extracted on ion-exchange columns, though, in a few cases, an additional purification with dithizone appeared necessary.

Rb-Sr data

Two new isochrons have been established on rocks sampled in the upper acidic phase of the Bjerkrem-Sogndal lopolith on the one hand and in the charnockitic dykes and pegmatitic lenses of the Hidra body on the other. The analytical data are given in Table 1 and illustrated in Fig. 2.

In a $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ diagram (Fig. 2), twelve whole rock *mangerites and quartz mangerites of Bjerkrem-Sogndal* define a straight line which corresponds to an age of 857 ± 21 m.y. with $(^{87}Sr/^{86}Sr)_0 = 0.7107 \pm 0.0004$.

Table 1. Rb-Sr analytical data.

Sample number	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$
(A) *Bjerkrem-Sogndal mangerites and quartz mangerites*				
QM 64120	199	71	9.95	0.8306 ± 0.0003
QM 101/73	160–166*	88.3–91*	5.77	0.7814 ± 0.0002
QM 6687	138	88.4	4.55	0.7664 ± 0.00025
QM 66261	113	98.4	3.33	0.7515 ± 0.0004
QM Pa66N	100*	142*	2.05	0.7368 ± 0.0004
QM Pa66M	81*	208*	1.14	0.7238 ± 0.00015
QM 73776	78	207	1.09	0.7222 ± 0.0002
M Pa66Q	72*	214*	0.97	0.7230 ± 0.0004
M Pa66P	62*	281*	0.64	0.7192 ± 0.0003
M 15B/72	33*	390*	0.25	0.7157 ± 0.0003
M 133/72	43*	329*	0.37	0.7146 ± 0.0002
M 130/72	39	313	0.36	0.7131 ± 0.0003
(B) *Hidra charnockitic dykes and pegmatites*				
P0501-1	1050*	34*	100.4	2.0154 ± 0.0005
0298-2/1	282*	238*	3.45	0.7523 ± 0.0002
0377-2/1	197*	201*	2.85	0.7454 ± 0.0003
P0501-2	115*	151*	2.21	0.7352 ± 0.0002
0238-2/2	148*	299*	1.44	0.7267 ± 0.0003
0443-4/1	84.8–88*	420–418*	0.585	0.7164 ± 0.0003

QM = Quartz mangerite; M = Mangerite; P = Pegmatite; D = Dyke.

* Concentrations measured by X-ray fluorescence (Delvigne & Durez - M.R.A.C. - Tervuren, Belgium); the others by isotope dilution.

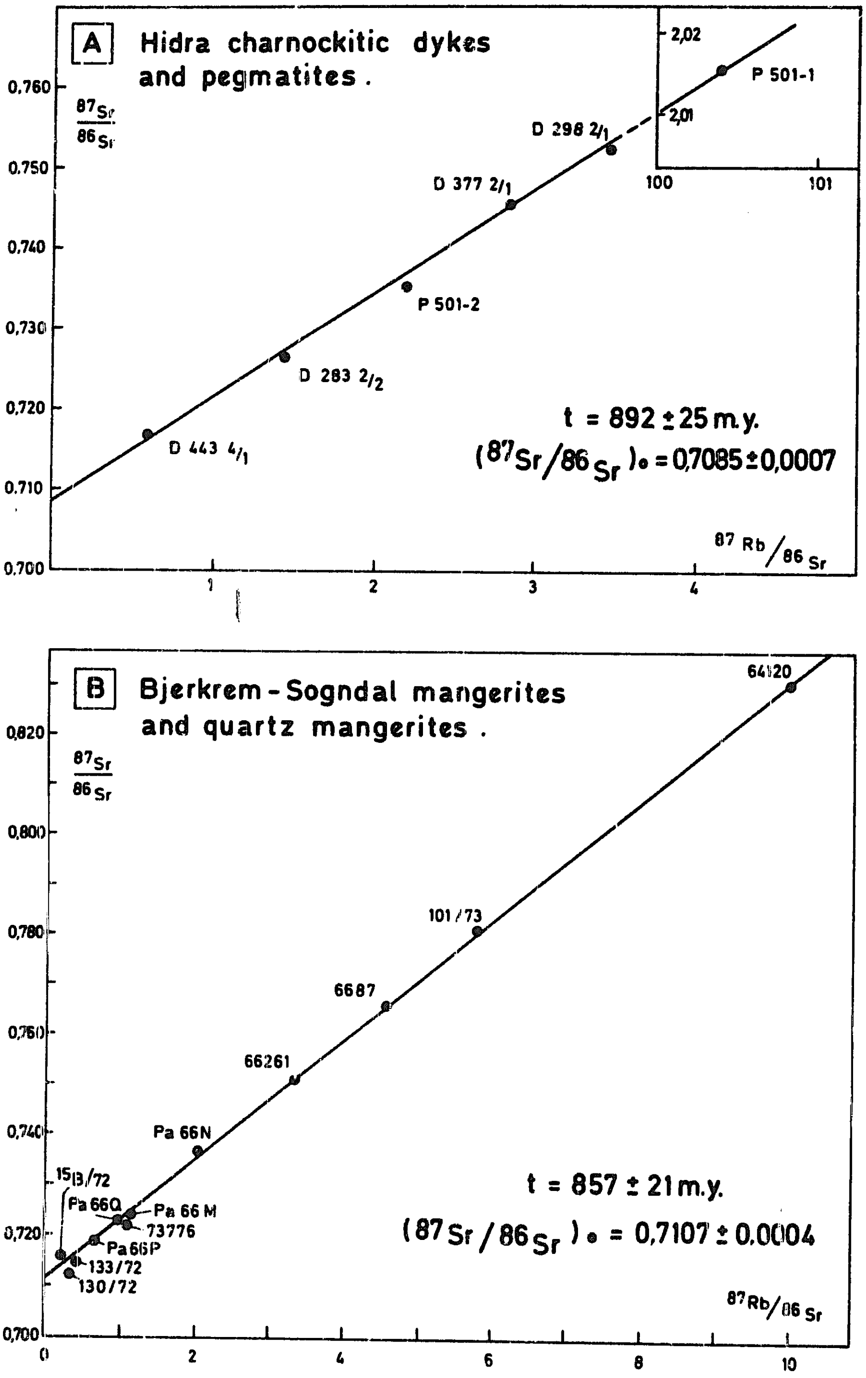

Fig. 2. Rb-Sr whole rock isochrons. A: Hidra charnockitic dykes and pegmatites. B: Bjerkrem-Sogndal mangerites and quartz mangerites.

In the *Hidra body*, a six points whole rock isochron (four charnockitic dykes and two pegmatites), with a good spread of the Rb/Sr ratios, gives an age of 892 ± 25 m.y. with $(^{87}Sr/^{86}Sr)_0 = 0.7085 \pm 0.0007$. The geochemical features of these charnockites, namely their K/Rb evolution, high REE content and large negative Eu anomaly (Eu/Eu* ≃ 0.50) (Demaiffe et al. 1978), have demonstrated that they belong to the Hidra differentiation sequence as residual liquid, although a slight crustal contamination of this liquid cannot be entirely ruled out. The relatively high value of the Sr isotopic initial ratio of the charnockites (0.7085) in comparison with the ratios measured on the Hidra anorthosites and leuconorites (the mean of thirteen values is 0.7055 ± 0.0004; Demaiffe et al. 1974; Demaiffe 1977) confirms this interpretation.

As far as the Rb-Sr data are concerned, some conclusions may already be put forward:

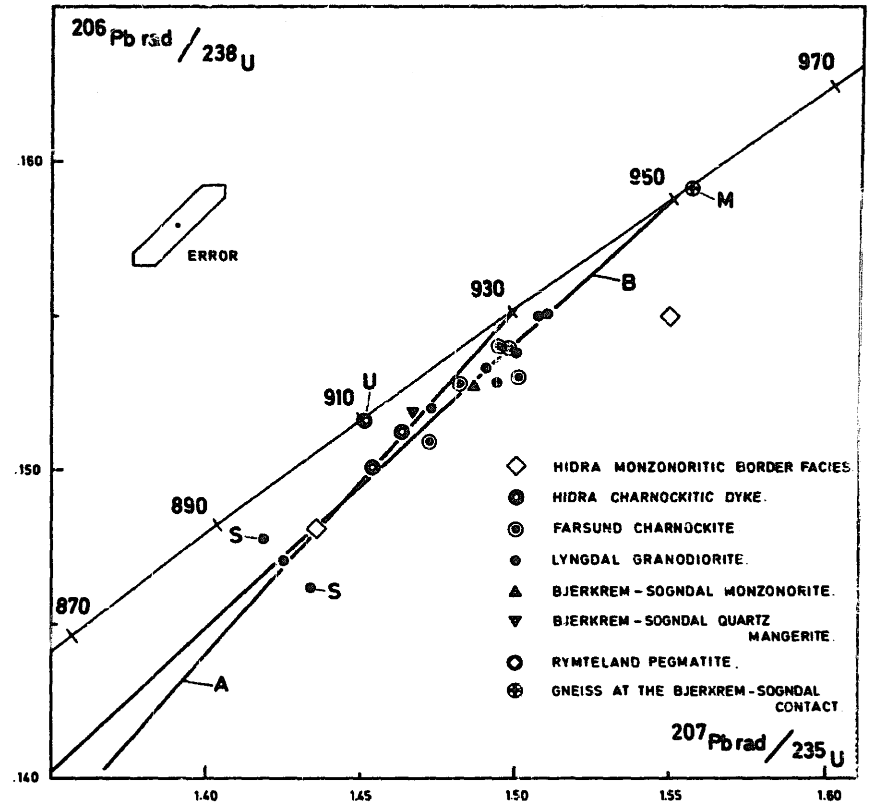

Fig. 3. Concordia diagram showing the data points for the uraniferous accessories of the magmatic rocks of the eastern part of the south Rogaland igneous complex. S: Sphene; M: monazite; U: uraninite; the others: zircon. A: chord drawn through the Hidra data points. B: chord drawn through the size fractions of the Lyngdal granodiorite. For A and B, see text for explanations.

(1) For the Bk-Sg mangerites and quartz mangerites, two different laboratories obtain similar apparent ages and initial ratios on the basis of different sample collections. Nevertheless, these ages are probably too low in comparison with the Hidra age because the essentially synkinematic nature of the Bk-Sg lopolith (Michot 1960, 1965) and the gneissic texture of the mangerites of the SE apophyse (Demaiffe 1972) implies that these rocks were emplaced slightly before or during the last tectonic phase, while in the Hidra body, the preservation of primary orthocumulate textures, the absence of oriented structure and the existence of leuconoritic dykes crosscutting the surrounding gneisses are, without doubt, characteristic of late to post-tectonic intrusion.

One possible explanation for the inconsistency between the Rb-Sr ages is the following. The linear array of points for the mangerites and quartz mangerites is characterized by a MSWD value of 8.7, which is higher than the maximum expected value (around 3.5; Brooks et al. 1972) for a twelve points isochron if the dispersion of the data points is only due to experimental error. This means, following Brooks et al. (1972), that the straight line corresponds to an errorchron and not to an isochron and that the exact meaning of the deduced age (and also of the initial ratio) is not at all obvious. For the Hidra charnockitic dykes, the MSWD value is close to 2, so the straight line corresponds to a true isochron.

(2) Although the Rb-Sr age of the Hidra charnockite dykes and pegmatites (892 ± 25 m.y.) is lower than the zircon U-Pb age (upper intercept of Concordia curve: 931 ± 10 m.y.; see below), the two values are nearly in agreement within the experimental error limits.

(3) The lower Rb-Sr age obtained by Pedersen & Falkum (1975) for the Farsund charnockite is thus not consistent with other data. Indeed field relations (Hidra leuconoritic dykes intruding the charnockite) definitively show that this rock is older than the Hidra anorthosite.

The Rb-Sr radiometric approach to determine the magmatic intrusive sequence in the investigated area is thus not conclusive. A careful U-Pb investigation may represent the only hope left to solve the problem, at least by means of geochronology.

U-Pb data

The analytical data are given in Table 2 and Fig. 3 (Concordia diagram). Only two samples yield

Table 2. Isotopic data and apparent U-Pb ages.

Sample	Mineral, size fraction	Concentrations U ppm	Concentrations Pbrad ppm	Lead isotopic composition 204	206	207	208	Apparent ages (m.y.) $t\frac{206}{238}$	$t\frac{207}{235}$	$t\frac{207}{206}\pm2\sigma$
Pa 66K, gneiss	Monazite	3035	3391	0.0296	100	7.519	697.3	951	953	957±8
Pegmatite	Uraninite	n.d.	n.d.	0.0025	100	6.984	4.125	909	910	914±6
Hidra monzonoritic 'chilled' facies										
259	Zircon	324	53.1	0.01067	100	7.401	16.090	928	950	1001±6
72–31	Zircon	367	61.0	0.01640	100	7.263	23.958	891	904	937±4
Hidra charnockitic dyke										
443-4/1	Zircon R200	509	94.1	0.0299	100	7.455	37.073	901	911	935±6
	Zircon P200	554	105.4	0.01807	100	7.273	39.624	908	915	932±4
Lyngdal granodiorite										
La 68/A Farsund	Sphene	77.3	30.4	0.4589	100	13.614	203.18	879	903	953±10
				0.4518	100	13.474	206.47	–	–	941±27
	Zircon	166.9	28.2	0.0270	100	7.436	22.074	919	926	944±8
				0.0584	100	7.860	23.129	–	–	936±6
Pa 69/K Rymteland	Sphene	71.0	15.69	0.3917	100	12.550	76.09	389	897	915±11
	Zircon-Bulk	132.4 133.3	21.65 21.79	0.0949	100	8.442	20.388	916 916	928 928	956±7
	Zircon R150	123.8	20.59	0.0655	100	7.994	19.759	929	934	948±5
	Zircon 150–200	138.7	22.94	0.0255	100	7.420	17.96	928	933	945±7
	Zircon 200–270	145.0	23.98	0.0844	100	8.271	20.747	922	930	950±9
	Zircon 270–400	138.3	23.18	0.1958	100	9.812	27.965	912	919	936±11
	Zircon P400	115.7	19.21	0.3051	100	11.373	33.998	884	899	937±15
Farsund charnockite										
Pa 70A	Zircon bulk	154.1	23.13	0.0413	100	7.624	12.681	923	928	939±8
	Zircon R150	140.3	22.04	0.0050	100	7.411	13.399	923	929	945±5
	Zircon 150–200	147	22.8	0.0267	100	7.418	12.157	916	923	940±3
	Zircon 200–270	178.5	27.38	0.0099	100	7.216	11.508	906	919	950±4
				0.00605	100	7.139	11.330	–	–	945±4
	Zircon P270	197.4	30.70	0.0254	100	7.475	11.987	917	930	962±8
				0.0256	100	7.486	12.053	–	–	963±8
Bjerkrem-Sogndal monzonorite										
Pa 66G	Zircon	31.2	5.28	0.2352	100	10.440	30.212	916	925	946±14
Bjerkrem-Sogndal quartz mangerite										
Pa 66N	Zircon	158.1	24.29	0.0673	100	7.976	13.068	911	917	932±5

concordant ages: the uraninite separated from the Rymteland granitic pegmatite and the monazite from a granitic gneiss collected close to the contact with the Bjerkrem-Sogndal layered norites.

The geological situation of these two rocks allows one to fix, quite precisely, the time interval during which the late-magmatic activity of this part of the Rogaland complex took place.

The *Rymteland uraninite* (made available by B. Nilsen of the Mineralogisk-Geologisk Museum, Oslo) yields 910 m.y., which is practically identical to the earlier reported result (905 m.y.) of Kulp & Eckelman (1957).

An *accessory monazite separated from a granitic gneiss* outcropping at 5 metres of the contact of the Bjerkrem-Sogndal layered norites yields 955 m.y. This figure corresponds probably to the emplacement time of the norites representing the first phase of the differentiation of the Bk-Sg lopolith. It has indeed been shown (Pasteels & Silver 1965; Köppel 1974) that monazite may be useful for dating metamorphism when zircon still holds an isotopic record of its pre-metamorphic history. In this particular case, however, the zircon of the same granitic gneiss gives the same age (by extrapolation on the Concordia diagram), which is also the lowest age recorded by uraniferous accessories in the gneissic cover (Pasteels & Michot 1975).

If the Rymteland pegmatite occurring in the Lyngdal granodiorite is considered as representing the ultimate phase of igneous activity and if the 955 m.y. figure really dates the emplacement time of the Bjerkrem-Sogndal layered norites, then on the basis of the U-Pb system the late tectonic magmatism in that area occurred in the time interval 955–910 m.y.

The other samples consist of bulk zircon concentrates from the Bjerkrem-Sogndal mangerite, the Bjerkrem-Sogndal and Hidra monzonorite, the Hidra charnockitic dyke, the Lyngdal granodiorite and the Farsund charnockite.

All the zircons have a slightly discordant age pattern as is generally the case for U-poor and consequently weakly metamict zircons. Such patterns can theoretically be explained in one of two ways: lead loss (or another type of disturbance having the same effect, as uranium gain), or inheritance of older zircons.

The only obvious case of inheritance is that of sample 259 of the *Hidra monzonoritic chilled margin*, which is the most discordant of all zircons measured: the 1001 m.y. age corresponding to t-207/206 is improbable. Indeed, the climax of the deformation and of the metamorphism in the country rocks has been dated at 975 m.y. (Pasteels & Michot 1975), while it has been previously shown that the Hidra massif is clearly a late to post-tectonic intrusion necessarily younger than 975 m.y. Moreover, the presence of fine grained, xenomorphic, sometimes dark zircon crystals with occasionally concave outlines suggesting corrosion does not preclude an inherited origin. Rapid cooling of the monzonorite has probably prevented the erasure of the 'isotopic memory' of zircon presumably inherited from the gneissic cover.

In the other sample of the *Hidra monzonorite* (72–31) big and clear zircons (probably of magmatic origin) plot closer to Concordia and yield a t-207/206 of 937 m.y.

The two size fractions extracted from the *charnockitic dyke* crosscutting the Hidra massif yield, within error limits, the same apparent ages. It is allowed to consider these dykes as contemporaneous with the chilled margin and draw a chord (line A, Fig. 3) through the three points 72–31 (chilled margin), 443-4/1-R200 and 443-4/1-P 200 (charnockitic dyke). This yields an extrapolated upper intercept of 931 m.y., but since this chord cuts the negative side of the ordinate axis, a slightly higher age (935 m.y.) may be preferred. Considering the probable origin of the dykes and the excellent agreement of the 207/206 apparent ages, an inherited origin for part of the zircon is not considered likely. The 935 m.y. figure may thus be considered as the age of the intrusion.

The bulk concentrates of the other slightly discordant zircon populations from the Farsund charnockite and the Lyngdal granodiorite have been subdivided into size fractions. In *the Lyngdal granodiorite*, which is a truly magmatic rock probably genetically related to anorthosite, the amount of disturbance of the different size fractions varies regularly as a function of grain size, which is the case generally encountered. The fact that the U concentrations do not follow the same regularity is due to a small amount of impurities (sphene, feldspar, quartz) in the finest fractions.

The 207/206 apparent ages of these fractions remain similar, which allows one to conclude the probable absence of inherited zircon. The age obtained by extrapolation on the Concordia diagram (upper intercept) is 950 m.y. (line B in Fig. 3). Two sphenes have been separated from two samples of the Lyngdal granodiorite. In the interpretation of the U-Pb data on sphene, it must be taken into account that t-206/238 is generally too low, t-207/206 approximately correct and that sphene age is more easily reset to zero than zircon age (Tilton & Gruenenfelder 1968). Sphene La68A yields a 207/206 age of 953 m.y., which confirms the U-Pb zircon age and which coincides with the oldest event previously recognized.

Sphene Pa/69K, collected at Rymteland, close to the mineralized pegmatite, gives an age of 915 m.y. A thermally or hydrothermally induced recrystallization or resetting of this sphene sample by the pegmatite intrusion could explain this lower age.

In *the Farsund charnockite*, which is presumably anatectic, the regular variation observed between the amount of disturbance and the grain size of the different zircon fractions is no longer apparent. The finest one (P270 mesh) exhibits a higher t-206/238 than the intermediate 200–270 mesh fraction, while t-207/206 is distinctly on the high side (which has been confirmed by repeating the analysis on another split). Since country rock zircons are generally much finer than those of the late tectonic intrusives, an inherited component in the fine size fraction is not at all unexpected. Geochemical arguments (no Eu anomaly, high $^{87}Sr/^{86}Sr$ initial ratios: Demaiffe et al. 1978) plead for an anatectic origin of the considered rock. The spread of apparent ages for the least discordant fractions, however, gives the range of possibilities from 920 to 940 m.y. for the emplacement time of the Farsund charnockite, which is also in the time span defined earlier for the late magmatic activity. Moreover, this age is younger than that of the Lyngdal granodiorite, which agrees with the geological observation (Falkum & Petersen 1974).

Only a bulk zircon concentrate has been analysed from a quartz mangerite and from a monzonorite of Bjerkrem-Sogndal. The *mangerites and quartz mangerites* of that lopolith are magmatic rocks related to the anorthositic-noritic phase (see geochemical arguments before) but possibly contaminated. Examination of polished sections of large zircon crystals from these rocks coupled with fission-track mapping has allowed the identification of U-rich, presumably inherited cores (Duchesne & Pierlot, pers. comm.). Considering thus the possible influence of those cores on the 207/206 apparent age, one is allowed to conclude that emplacement occurred between 910 and 930 m.y. ago for these mangerites and quartz mangerites. This figure, which corresponds to the last stages of the Bjerkrem-Sogndal differentiation, is compatible with that of 950 m.y. obtained for its first stage.

There is insufficient data (only a point yielding a t-207/206 of 946 m.y.) to argue whether or not the *monzonorites* are (slightly) older or younger than the mangerites. This rock type, corresponding to undifferentiated magma (Duchesne et al. 1974; Duchesne & Demaiffe 1978), presents itself mostly in thick and continuous dykes and is thus undoubtedly among the last intrusive phases in the considered area, although these dykes have never been seen crosscutting the mangerites.

Conclusions

From the comparison of Rb-Sr and U-Pb ages, for both earlier and new results, the following conclusions can be drawn. Compared to the U-Pb, the Rb-Sr ages are systematically on the low side. Nevertheless, the isochrons for the Lyngdal granodiorite (912 ± 36 m.y.) and for the charnockitic dykes and pegmatitic lenses at Hidra (892 ± 25 m.y.) are reconcilable with the U-Pb data (950 ± 5 and 931 ± 10 m.y. respectively). The isochron for the Farsund charnockite is poorly established, and is based on five rather clustered points yielding an age of 834 ± 39 m.y., which is definitively lower than the U-Pb zircon age (range of possibilities: 920 to 940 m.y.). The Rb-Sr investigation of the Bjerkrem-Sogndal mangerites and quartz mangerites carried out independently in two different laboratories leads to the establishment of quite similar linear arrays of points which for our determinations at least, have been interpreted as errorchrons instead of isochrons on the basis of high MSWD value. The age deduced from this errorchron is probably meaningless. The U-Pb age, which is more reliable, is fixed at 910–930 m.y.

Only tentative explanations can be put forward to account for these discrepancies. A possible cause is a pervasive, or only local, reopening of the Rb-Sr total rock systems, which assumes, as the geological observations show, that the U-Pb ages are correct.

The Caledonian orogeny has no visible influence on the investigated rocks. On the other hand, a swarm of WNW trending dolerite dykes crosscuts all above described rocks and, according to palaeomagnetic (Storetvedt & Gidskehaug 1968) and K-Ar (Versteeve 1975) data, may be of Upper Precambrian age (around 660 m.y.). But that dyke emplacement may have caused considerable strontium migration in adjacent rocks (through a fluid phase) is, at least, questionable. Nevertheless, it is to be noted that the oxygen isotopic composition of some quartz mangerites (Demaiffe et al. 1978; Demaiffe & Javoy 1976 and in prep.) is abnormal ($\delta^{18}O = 4‰$), while other quartz mangerites, the Lyngdal granodiorite and the Hidra charnockitic dykes, have normal $\delta^{18}O$ values around 6–7‰. These low values are probably the result of an oxygen isotopic exchange between the rocks and a fluid phase at high temperatures. This fluid phase may have caused some Sr migration in the quartz mangerites. An interaction of the rocks with a fluid phase is evident in the Bk-Sg lopolith since Duchesne (1972) has shown that the Fe-Ti oxides have, in most cases, suffered a deuteric readjustment. In the adjacent garnet gneisses, symplectitic intergrowths of cordierite and K-feldspar have been interpreted by Henry (1974) as a late event corresponding to garnet destabilization.

On the basis of the most significant geochronological data, Table 3 presents a consistent picture of the succession of igneous events: this table has been separated into two areas – Bjerkrem-Sogndal and Farsund.

The whole late magmatic activity in the east-

Table 3. Timing of the late tectonic intrusive phases.

m.y.	Bjerkrem-Sogndal (Bk-Sg) area	Farsund area
–900		
	– (Bk-Sg monzonorites?)	– Dyke emplacement: pegmatites, charnockites at Hidra (residual magma); mineralized pegmatite at Rymteland
–925		
	– Crystallization and cooling of the Bk-Sg mangerites and quartz mangerites	– Post tectonic emplacement, along décollement zone, of the Hidra mass
	– Bk-Sg monzonorites?	– Emplacement and cooling of the anatectic Farsund charnockite
–950		
	– Emplacement of the Bk-Sg cumulate layered norites	– Emplacement of the Lyngdal granodiorite
–975		
	Granulite facies metamorphism	– Emplacement of the porphyroblastic syntectonic granites (Liland and Feda augengneisses; Pasteels & Michot 1975, Falkum, pers. comm. 1975)
–1000		

ern part of the Rogaland igneous complex took place during a short time span, not exceeding 50 m.y. (from 955 to 910 m.y.). This magmatic activity gave rise to important anorthosito-noritic bodies (lower part of the Bjerkrem-Sogndal lopolith, Hidra and Garsaknatt outliers) and to more acidic rocks, either of charnockitic type (Bjerkrem-Sogndal mangerite and quartz mangerites, Farsund charnockite) or of the normal type (Lyngdal granodiorite) dependent upon the level of their initial emplacement in the crust.

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