ELSEVIER

Lithos 36 (1995) 51–66

LITHOS

The 1160 Ma Hidderskog meta-charnockite: implications of this A-type pluton for the Sveconorwegian belt in Vest Agder (SW Norway)

X.Q. Zhou [a], B. Bingen [a], D. Demaiffe [a,*], J.-P. Liégeois [b], J. Hertogen [c], D. Weis [a], J. Michot [a]

[a] *Laboratoire de Pétrologie et Géodynamique Chimique CP 160/02, Université Libre de Bruxelles, 50 av. Roosevelt, B-1050, Belgium*
[b] *Département de Géologie (Section de Géochronologie), Musée Royal de l'Afrique Centrale, B-3080 Tervuren, Belgium*
[c] *Afdeling Fysico-Chemische Geologie, Universiteit Leuven, B-3001 Leuven, Belgium*

Received 4 February 1994; accepted 13 March 1995

Abstract

The Hidderskog massif is a charnockitic intrusion located in the Rogaland–Vest Agder segment of the Sveconorwegian province of SW Norway. The U–Pb zircon age (1159 ± 5 Ma) and the Rb–Sr whole-rock isochron age (1153 ± 39 Ma) of this pluton are concordant. This age is interpreted as the magmatic emplacement age. The Hidderskog charnockitic intrusion is deformed and at a large scale concordant with amphibolite facies gneisses. It has been partially transformed to amphibole–biotite gneiss during the main Sveconorwegian orogeny (1040–980 Ma in Rogaland). Major and trace element composition as well as isotopic systems have been only weakly disturbed during this event. The Hidderskog intrusion displays A-type geochemical features. Most samples could correspond to mixing of a granitic liquid with feldspar crystals. It may be correlated in age with the Gloppurdi and Botnavatnet intrusions of Rogaland and tentatively to the Hovdefjell and Gjeving charnockites of the Bamble sector. This group of charnockitic intrusions defines an intraplate anorogenic geodynamic environment prior to the main Sveconorwegian orogenic phase. These anorogenic charnockites are distinct from the charnockitic magmas spatially related to the Rogaland anorthosite complex, which intruded after the main Sveconorwegian orogeny within a short period of time, from around 950 to 930 Ma.

---

1. Introduction

The Sveconorwegian province of SW Norway, west of the Oslo Graben, includes two granulite facies metamorphic domains (Fig. 1): one in the Bamble sector (Touret, 1971; Smalley and Field, 1985; Nijland and Senior, 1991; Starmer, 1991) and the other in the Rogaland–Vest Agder sector (Michot, 1960; Michot and Michot, 1969; Henry, 1974; Tobi et al., 1985). The Bamble sector is limited to the west by a mega-shear zone along which large horizontal movements occurred (Starmer, 1991). The Mandal–Ustaoset line (Sigmond, 1985) represents another tectonic limit of regional importance in the Rogaland–Vest Agder sector. These crustal segments delimited by shear zones could have had different early geological evolutions, and conclusions based on one segment would not be necessarily applicable to other segments. The discovery of narrow and long deformation zones separating crustal terranes (or segments) of distinct metamorphic

---

* Corresponding author.

0024-4937/95/$09.50 © 1995 Elsevier Science B.V. All rights reserved
SSDI 0024-4937(95)00005-4

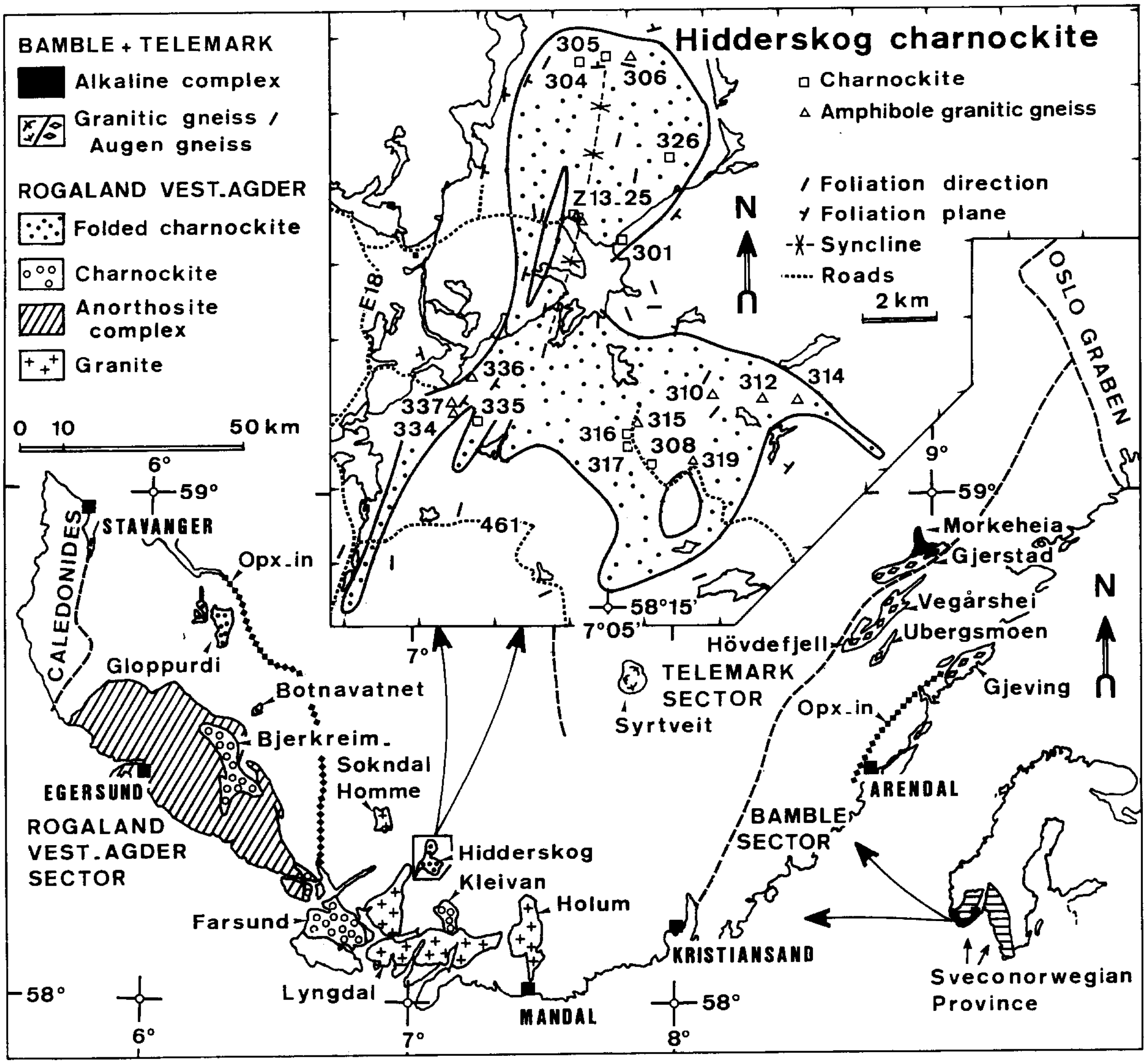

Fig. 1. Simplified geological map of S.W. Norway (modified after Falkum, 1982; Sigmond, 1985 and Starmer, 1991) with the positions of the magmatic units cited in the text. Inset: map of the Hidderskog charnockitic complex (after Falkum, 1982) with position of analysed samples.

grades and origins represents a major advance in the understanding of the tectonic and crustal accretion history: see Berthelsen (1980) for the eastern Sveconorwegian province; Rivers et al. (1989) for the Grenville province and Black et al. (1994) for the more recent Pan-African province of the Tuareg shield. Time markers are necessary in each domain to allow some correlations between the different crustal segments of a given orogenic belt. Within the Rogaland–Vest Agder metamorphic domain, the main Sveconorwegian phase, with its well known charnockitic and anorthositic intrusions, has been extensively studied (Michot and Michot, 1969; Pasteels et al., 1970; Demaiffe et al., 1979; Duchesne et al., 1985; Falkum, 1985). The age of this phase has been bracketed, in Rogaland, between 1040 and 980 Ma (Pasteels et al., 1979; Demaiffe and Michot, 1985; Bingen et al., 1993). However, some grey gneisses provide Nd model ages up to 1700 Ma (Menuge, 1988) and an early Sveconorwegian phase is likely to have affected Rogaland at c. 1250 Ma. Even older orogenic phases are not precluded (Demaiffe and Michot, 1985), though evidences of these are poorly preserved in the area. Well-preserved charnockites thought to be older than the main Sveconorwegian phase have been described (Hermans et al., 1975) and it is on one of these intrusions that this study focuses, the Hidderskog charnockitic intrusion (Hidderskog in short). Charnockite is the name used for hypersthene-bearing granite (Le Maitre et al., 1989) and for granitic metamorphic rocks containing orthopyroxene. Similarity of both mineralogy and texture does not allow to easily determine whether the charnockitic character of a rock is of primary (magmatic) or secondary origin (Bohlendre et al., 1992; Newton, 1992). This is particularly important in polymetamorphic domains such as the Rogaland–Vest Agder area. We will show that the Hidderskog protolith was a magmatic charnockite emplaced in an intraplate tectonic setting and that this intrusion has been relatively well protected during the subsequent regional metamorphism. This massif is thus a good candidate for constraining, in terms of plate tectonics, this poorly understood period prior to the main Sveconorwegian phase.

2. Geological setting

The Rogaland–Vest Agder sector is the westernmost segment of the Sveconorwegian province (Fig. 1). It is a crustal segment of Mesoproterozoic age, the average depleted mantle Nd model age on the oldest gneisses being 1670 Ma (Menuge, 1988; Lindh and Persson, 1990). Mainly composed of granitic, banded, migmatitic and augen gneisses (Michot and Michot, 1969; Falkum and Petersen, 1980; Falkum, 1982, 1985), this area has been affected by several metamorphic episodes. The most important belongs to the main Sveconorwegian orogenic phase and grades from upper amphibolite facies in the east to granulite facies in the west. The *P–T* conditions during this granulite facies metamorphism were estimated at 750–1000°C and 3–4 kbar (Jansen et al., 1985) or more than 7 kbar (Henry, 1974; Wilmart et al., 1991). Early to syn-kinematic porphyritic granodiorites metamorphosed to augen gneisses (Bingen et al., 1993) were emplaced at 1040 Ma (concordant Rb–Sr and U–Pb zircon ages). They represent a major magmatic episode with high-K calc-alkaline characteristics. They were metamorphosed in amphibolite and granulite facies and deformed to augen gneisses; their emplacement age thus represents an upper limit for the Sveconorwegian tectono-metamorphic event in the region (Bingen et al., 1993). Late- to post-kinematic intrusives (from 980 to 920 Ma) are quite abundant (Demaiffe and Michot, 1985; Verschure, 1985 and references therein).

By contrast, Hidderskog, which is located in the amphibolite facies domain to the east of the opx-in isograd (Fig. 1), is an intrusion of approximately 16 km^2 which preceded the main Sveconorwegian phase. It behaved as a rigid body during the regional tectono-metamorphic event and kept several magmatic features. Variably foliated, this massif shows an irregular shape (Fig. 1). It is in contact with (migmatized) banded gneisses to the west and to the south, and with homogeneous granitic gneiss to the east. Concordant on a regional scale, its foliation is locally oblique to the gneissic structure of the country rocks (angles of 5° to 30°) suggesting that Hidderskog behaved as a rigid body during the regional deformation. Large inclusions (up to 1500 m long) of banded gneisses and metabasic rocks occur within the intrusion; they are aligned along the major NNE–SSW tectonic trend of the area.

3. Petrography

Hidderskog is a magmatic charnockitic intrusion variably affected by a superimposed amphibolite facies tectono-metamorphic event. The petrographical types vary accordingly from a nearly pristine non-foliated charnockite to an amphibole bearing granitic gneiss having a structure similar to that of the country rocks, with all intermediate, more or less deformed and recrystallized stages. Although the amphibole granitic gneiss is more abundant close to the borders of the massif, there is no well defined spatial distribution of these gneissic rocks.

Preserved charnockite is a coarse-grained (2–5 mm) dark green rock which turns to sugar brown when weathered. It may contain > 1 cm K-feldspar megacrysts. Gneissic structure is absent or weakly developed. When present, it is marked by slightly elongated clino- and orthopyroxene-bearing mafic mineral clusters and stripes including also amphibole, oxides, minor biotite, zircon and apatite. These stripes occur along the boundaries of weakly oval shaped felsic aggregates

(5–7 cm in length) of granoblastic texture. K-feldspar is mainly orthoclase, but microperthite and mesoperthite can also occur. Fine strings of albite sometimes partly rim K-feldspar. Orthoclase and plagioclase form aggregates of polygonal grains exhibiting triple-point junctions similar to those described in the nearby Kleivan charnockite (Petersen, 1980a, b). Orthopyroxene locally contains small euhedral amphibole inclusions at its margin and coexists with larger anhedral amphibole grains. Inverted pigeonite has not been observed. Pyroxenes do not display amphibole coronas and rarely contain biotite relics. Biotite is dark brown, locally occurring as symplectitic intergrowths with quartz and K-feldspar, or as fine interfingering with quartz near the boundary of orthopyroxenes.

The amphibole granitic gneiss is often pink due to the presence of relatively large amount of microcline. Plagioclase is greenish grey or white. Quartz is smoky grey, colourless or greyish brown, it does not have the dark green colour characteristic of charnockites. Large grains of quartz are often granulated to form a mosaic structure. Mafic stripes consist mainly of amphibole (5–9% of the volume of the rock), biotite (< 8%), fine grained (0.5–1.5 mm) polygonal plagioclase (3–5%, An29–33), K-feldspar (orthoclase and microcline, 2–3%), ilmenite (2%), minor apatite (< 0.3%) and zircon (< 0.2%). They alternate with ellipsoidal clusters of felsic minerals which have larger grain size (generally 1–3 mm) giving the rock the appearance of an augen gneiss. One of the most conspicuous characters of the amphibole granitic gneiss is the development of microcline rim around the orthoclase, microcline sometimes replacing entirely this mineral. Well-developed biotite is reddish brown, which contrasts with the dark brown colour of the biotite in the charnockite. Intermediate facies between the charnockite and the amphibole granitic gneiss has been observed with sporadic large crystals of clinopyroxene (3–4 mm). Link between retrograde mineral assemblage and foliation together with the relic character of pyroxene indicate that the amphibole granitic gneiss results from the metamorphic overprinting and is not a primary magmatic feature.

In conclusion, the charnockite appears to have partly preserved its primary magmatic structure and mineralogy while, elsewhere, the tectono-metamorphic event has transformed it to the retrogressed (orthopyroxene disappearance) and deformed amphibole granitic gneiss. The most abundant facies in Hidderskog are these more or less transformed facies.

Numerous aplitic dykes and mafic inclusions have been observed throughout the intrusion.

4. U–Pb and Rb–Sr dating of Hidderskog metacharnockite

Zircon U–Pb age dating was carried out on a charnockite (sample BB308). The sample was taken from a fresh road cut showing an homogeneous outcrop (no lithological variations for more than 400 m). The rock is dark green and nearly undeformed. Four zircon fractions (average weight: 2 mg) in the size range from 63 to 106μm with different degrees of magnetic susceptibility were chosen; they were purified by hand picking.

A scanning electron microscope study (Savino, 1992) has shown several steps in the zircon growth (Fig. 2): a small inner core whose centre is rich in urano-thorite inclusions and metamict, a cracked homogeneous zone followed by an intensely zoned part and finally an homogeneous subautomorph to rounded external mantle. All these zones have developed a similar morphology and most are rich in inclusions, especially apatite. These characteristics point to a magmatic origin of this zircon population. Only the small metamict inner part could be inherited and the narrow outer mantle could be a metamorphic overgrowth (lack of inclusions and zoning, limpidity and rounded shape). Anyway, the largest part of the grain, at least 90% of volume is clearly of magmatic origin, which indicates that the amphibolite facies metamorphism had only weak effects on the zircon. Pyramid faces are poorly developed indicating a growth in a water-poor medium (Duchesne et al., 1987).

The four zircon fractions were analyzed following the analytical techniques described by Liégeois et al. (1991) which are modified from Krogh (1973) and Lancelot (1975). All errors are given at the 2 sigma level. The results are presented in Fig. 3 and Table 1. The zircon fractions define a discordia line intercepting the Concordia at 1159 ± 5 Ma (upper intercept) and at 169 ± 38 Ma (lower intercept). The evidence from zircon morphology and internal structures for only minor effects of metamorphism suggests that the 1159 ± 5 Ma figure corresponds to the magmatic crystallization age.

Fig. 2. Photomicrograph (back-scattered image) of zircon grain from sample BB308 used for U–Pb dating. Note the small inner metamict core rich in urano-thorite. inclusions, the cracked homogeneous zone, the intensely zoned part (all being of magmatic origin) and the subautomorphic homogeneous rounded external mantle probably of metamorphic origin.

Hidderskog is then clearly older than the main Sveconorwegian metamorphism of Rogaland (1040–980 Ma; Bingen et al., 1990, 1993). The meaning of the lower intercept is questionable, either it has no geological significance at all if it results from a continuous radiogenic Pb diffusion or it could correspond to an episodic Pb loss related to the opening of the Viking graben in the North Sea (Færseth et al., 1976).

Twelve of the least altered samples were selected for Rb–Sr isotopic composition measurement. The samples chosen have a large range of Rb/Sr ratios and cover all petrographic types. Analytical techniques are described in Demaiffe and Hertogen (1981) and the results are presented in Fig. 4 and Table 2. The 12 analyses define a line whose slope corresponds to a date of 1143 ± 36 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7053 ± 0.0007. Although the data points are not well

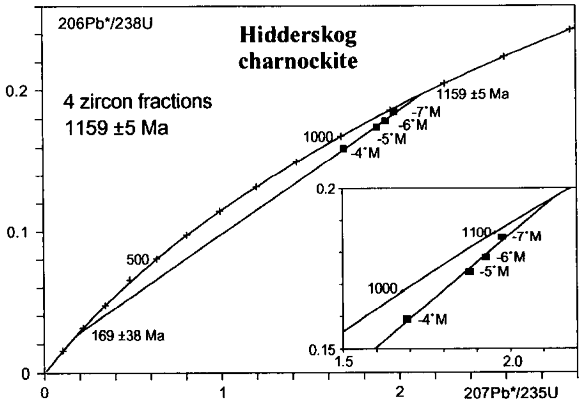

Fig. 3. U–Pb concordia diagram for four zircon fractions (sample BB308) with different magnetic susceptibility. Grain size (63–106 μm).

Table 1
Zircon U–Pb isotope data (sample BB308, charnockite)

Sample fraction	63–106 μm/ − 4°M	63–106 μm/ − 5°M	63–106 μm/ − 6°M	63–106 μm/ − 7°M
weight (μg)	1.95	1.96	0.8	2.57
U (ppm)	798.7	586.5	585.9	431.3
Pb* (ppm)	127	102.9	105.6	79.9
^{206}Pb/^{204}Pb ± 2σ	4128.5 ± 3.5	9886.8 ± 9.7	4960.9 ± 2.9	5428.6 ± 4.4
^{206}Pb*/^{238}U	0.159	0.174	0.1783	0.1847
^{207}Pb*/^{235}U	1.6917	1.8782	1.9276	1.9759
^{207}Pb*/^{206}Pb*	0.07718	0,0783	0.07839	0.07757
$t^{207}/^{206}$(Ma)	1126	1154	1157	1136

*radiogenic part

–M: magnetic susceptibility.

Error on ^{207}Pb/^{206}Pb is less than 0.1% and on Pb/U ratio less than 0.5%.

Corrected for common lead 208/207/206/204:36.429/15.473/16.756/1, corresponding to mixing of common lead at 1159 Ma (Stacey and Kramers, 1975) and 150 pg of contamination lead.

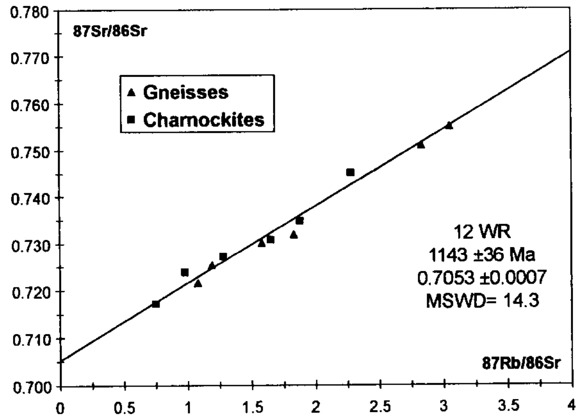

Fig. 4. Rb–Sr isochron plot for Hidderskog charnockitic complex: charnockites (square) and gneisses (triangle) (see text for explanation).

aligned (MSWD = 14.3), the age obtained is identical to the zircon age within error limits. The geochemical study (see below Fig. 6h) suggests that three samples, BB312, BB314 and Z24 which are amphibole granitic gneisses, have been more disturbed than the others. They plot distinctly below the reference line. Without these three samples, the regressed line gives 1153 ± 39 Ma, Sr$_i$: 0.7056 ± 0.0007, MSWD = 11.7. These computed Rb–Sr ages are in good agreement with the U–Pb upper intercept age. The high MSWD values indicate then either that samples had variable Sr$_i$ values (variable crustal contamination) or that the Sr isotopic system has been weakly disturbed after the crystallization. The perturbation event could be the main Sveconorwegian metamorphism or a later alteration.

5. Geochemistry: major and trace elements

Twenty-two whole-rock samples (weight 5–15 kg) were selected. They were analyzed for major and seven trace elements (Rb, Sr, Zr, Y, Nb, Ba, Pb) by X-ray fluorescence spectrometry (Bologne and Duchesne, 1991). Thirteen samples were further selected for REE,

Table 2
Rb–Sr isotopic data of whole rocks for charnockites and amphibole granitic gneisses

Sample	*	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	^{87}Sr/^{87}Sr ± 2σm
BB301**	ch	122	188	1.88	0.734813 ± 7
BB305	ch	101	178	1.65	0.73076 ± 13
BB308	gn	140	144	2.83	0.75102 ± 14
BB312	gn	145	230	1.83	0.73186 ± 15
BB314	gn	104	278	1.08	0.72158 ± 10
BB317	ch	128	163	2.28	0.74512 ± 13
BB319**	gn	154	147	3.05	0.754969 ± 6
BB326	ch	94	361	0.75	0.71718 ± 9
Z13**	ch	89	264	0.98	0.723686 ± 7
Z17b	gn	97	236	1.19	0.72526 ± 4
Z24**	gn	120	221	1.58	0.730055 ± 11
Z25	ch	97	224	1.28	0.72719 ± 6

*ch: charnockite; gn: amphibole granitic gneiss.

**measured on VG Sector 54 multicollector mass spectrometer. The others measured on Finnigan MAT 260 single collector mass spectrometer.

Table 3
Major (%) and trace element (ppm) compositions of the Hidderskog charnockitic complex samples

	charnockites										amphibole granitic gneisses											
	BB301	BB304	BB305	BB308	BB316	BB317	BB326	BB335	Z 13	Z 25	BB306	BB310	BB312	BB314	BB315	BB319	BB334	BB336	BB337	Z 17a	Z 17b	Z 24
SiO_2	65.90	69.99	70.57	68.79	68.10	68.20	69.33	71.36	68.76	69.47	70.51	65.04	66.63	66.66	68.53	67.72	72.37	71.15	69.27	74.75	69.43	70.56
TiO_2	0.69	0.29	0.48	0.58	0.54	0.55	0.35	0.48	0.44	0.39	0.33	0.53	0.58	0.40	0.61	0.65	0.32	0.38	0.36	0.29	0.35	0.41
Al_2O_3	14.18	15.2	12.59	14.04	14.01	15.01	14.93	12.51	14.69	14.19	14.10	15.31	15.29	15.91	13.99	14.02	13.38	13.02	14..34	12.24	14.72	14.03
Fe_2O_3	2.50	1.11	2.34	1.66	1.29	1.94	0.77	2.16	1.38	1.00	1.54	2.07	2.22	1.94	1.35	2.07	1.1	2.07	0.69	0.36	0.65	0.94
FeO	3.36	1.78	3.14	3.13	2.99	2.46	2.60	2.98	2.60	2.88	2.27	3.59	3.24	2.57	3.41	3.34	2.03	2.45	2.63	1.96	2.58	2.17
MnO	0.09	0.04	0.09	0.07	0.08	0.06	0.06	0.09	0.08	0.07	0.08	0.08	0.11	0.07	0.07	0.10	0.06	0.07	0.06	0.05	0.06	0.09
MgO	0.75	0.14	0.28	0.75	1.06	0.84	0.29	0.11	0.38	0.39	0.21	0.27	0.64	0.49	0.86	0.95	0.10	0.08	0.43	0.14	0.28	0.52
CaO	3.27	2.13	2.25	2.86	2.42	2.73	2.80	2.49	3.14	2.92	2.32	3.81	3.82	3.14	2.72	2.91	1.92	1.90	2.50	2.14	3.02	2.93
Na_2O	3.11	3.43	2.98	3.09	2.99	2.78	3.34	2.98	3.98	3.25	3.15	3.55	3.44	3.51	2.73	2.96	3.10	3.15	3.02	2.65	4.25	3.57
K_2O	4.37	5.19	4.21	4.46	4.88	5.08	4.46	3.91	3.95	4.35	5.04	3.72	3.50	4.05	5.00	4.33	4.64	5.10	4.94	4.30	4.23	4.33
P_2O_5	0.22	0.06	0.10	0.16	0.14	0.16	0.09	0.10	0.15	0.12	0.07	0.15	0.15	0.10	0.17	0.19	0.07	0.10	0.09	0.09	0.10	0.16
L.O.I.	0.94	0.67	0.77	0.95	0.98	0.68	0.81	0.78	0.77	0.84	0.73	0.88	0.93	0.75	0.95	0.94	0.68	0.64	1.00	0.92	0.89	0.79
Total	98.38	100.03	99.80	100.54	99.48	100.49	99.83	99.95	100.71	99.87	100.35	99.00	100.55	99.59	100.39	100.18	99.77	100.11	99.33	99.89	100.56	100.5
Zr	542	393	757	425	405	385	483	620	559	548	367	629	508	436	447	460	415	490	458	392	514	536
Hf	16.2		21.6	13.7		12.9	14.6		16.9	15.6			18.1	15.2		14.9				11.6	15.0	15.6
Y	72	52	83	92	62	86	52	87	63	88	96	66	71	33	84	101	60	67	72	48	72	42
Rb	122	86	101	140	126	128	94	90	89	99	149	106	145	104	136	154	117	100	97	77	97	120
Sr	188	225	178	144	148	163	361	176	246	224	178	265	230	278	145	147	179	173	234	175	236	221
Ba	1055	1723	1275	770	880	1010	1665	1150	1500	1580	1400	1650	1335	2095	820	740	1235	1325	1705	920	1550	1480
Th	8.0		13.8	9.5		9.0	6.6		9.5	6.4			4.8	2.5		12.2				8.0	9.5	7.8
U	1.0		1.00	1.7		1.30	0.81		0.81	0.80			1.20	0.73		2.00				0.58	0.91	0.83
Pb	16	15	16	16	19	18	15	16	12	14	23	20	18	19	15	18	15	20	16	16	19	18
Nb	25	18	29	24	21	22	16	28	18	22	25	23	23	12	21	26	18	20	21	15	21	18
Ta	1.01		1.37	1.12		0.96	0.78		1.61	1.71			1.23	0.65		1.23				1.90	1.97	3.10
Sc	12.1		10.0	11.1		10.0	6.2		8.8	8.6			12.3	8.5		12.2				5.5	7.3	11.5
Co	8.5		5.3	8.5		7.8	4.9		8.1	8.5			6.4	4.9		9.4				9.4	8.1	8.9
La	83.8		161.0	81.5		80.2	60.1		87.0	56.8			52.9	35.9		97.0				82.0	89.0	67.2
Ce	178		324	177		169	133		189	129			121	73		212				176	195	142
Nd	90		153	88		83	70		92	74			69	41		103				84	97	64
Sn	18.5		26.7	19.5		18.4	14.5		17.4	17.2			16.2	9.0		22.0				15.5	18.7	11.5
Eu	3.		5.24	2.79		2.95	5.40		5.34	5.02			5.10	6.75		2.72				4.21	5.39	4.24
Tb	2.66		3.23	3.15		2.88	1.86		2.28	2.69			2.49	1.22		3.34				1.88	2.51	1.46
Yb	6.9		8.4	8.9		7.6	4.8		6.1	6.7			7.8	3.4		9.6				4.0	6.5	4.3
Lu	0.95		1.14	1.20		1.04	0.69		0.84	0.92			1.05	0.52		1.25				0.57	0.90	0.63
ΣREE	384		683	382		365	290		400	292			276	171		451				368	415	295
La_N	247		474	240		236	176		256	167			156	106		285				241	262	198
$(La/Yb)_N$	8.0		12.7	6.1		7.0	8.3		9.4	5.6			4.5	7.0		6.7				13.6	9.1	10.3
Eu/Eu^*	0.58		0.67	0.44		0.50	1.26		1.02	0.89			0.99	2.50		0.39				0.94	0.95	1.26

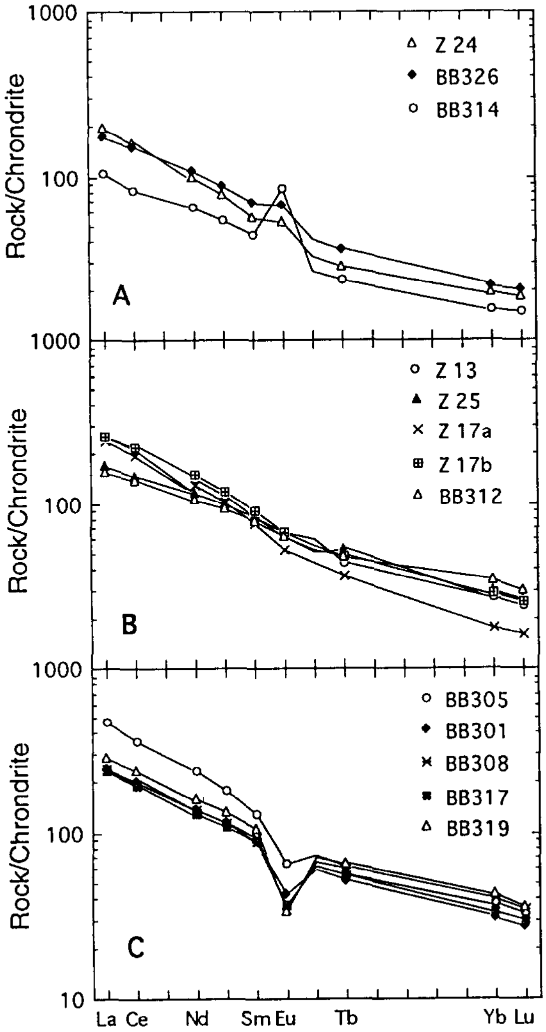

Fig. 5. Chondrite-normalized REE patterns of Hidderskog rocks with positive (A), no (B) and negative (C) Eu anomalies.

Sc, Co, Hf, Ta, Th and U by INAA (Demaiffe and Hertogen, 1981). FeO was measured by titration in Brussels. The results of major and trace elements are listed in Table 3.

5.1. Major elements

With SiO_2 in the range 65.0–74.8%, the Hidderskog intrusion is characterized by high K_2O (3.5–5.2%), K_2O+Na_2O (6.9–7.6%) and CaO (1.9–3.8%) contents and high $FeO_t/(FeO_t+MgO)$ ratios (0.74–0.96), indicating alkaline affinities (Anderson, 1983; Eby, 1990). In binary oxides vs. SiO_2 plots (not shown), there is a rough decrease of CaO, FeO, MgO, TiO_2, P_2O_5 and Al_2O_3 with increasing SiO_2, but the data points are scattered. The south-eastern part of the intrusion seems to be a little less differentiated than the north-western and northern parts. This is probably better explained by a primary magmatic trend than by a metamorphic effect. Indeed, the preserved charnockites and the amphibole granitic gneisses have roughly the same chemical compositions which suggest that the metamorphic overprinting has had only weak effects on the major element composition of whole rocks. Through the geochemical study of early-kinematic augen gneisses, Bingen (1988) also concluded that the main Sveconorwegian metamorphism in the Vest Agder area was an isochemical process.

5.2. Trace and rare earth elements: an A-type crystal mush

Despite a rather small SiO_2 range (65–70%, one sample at 74.8%), the rocks of the Hidderskog pluton show a wide range of rare earth contents (ΣREE = from 683 to 171 ppm) with both positive (up to 2.5) and negative (down to 0.39) Eu anomalies (Fig. 5). The most plausible way to interpret these distributions is to suggest a mixing between an already differentiated REE-enriched felsic liquid having a negative Eu anomaly with various proportions of feldspathic phase poorer in REE and with a positive Eu anomaly. There is indeed a negative correlation between the REE content and the Eu anomaly (Fig. 6a). Sample BB305 plots outside the trend, it is highly enriched in REE which is possibly due to the presence of REE-rich accessory minerals. The whole rock Eu anomaly is also negatively correlated with Mg# [$\equiv MgO/(MgO+FeO_t)$; Fig. 6b], TiO_2, Nb (not shown) and present day $^{87}Sr/^{86}Sr$ (Fig. 6h) while it is positively correlated with the Ba, Sr and Na_2O contents (Fig. 6c–e). By contrast, there is no correlation between the Eu anomaly and K_2O (Fig. 6f) and the correlation with CaO is poor (Fig. 6g): this seems to preclude the participation of K-feldspar as a mixing end member and suggests instead that a relatively acid plagioclase is the required phase. The correlation with CaO is probably blurred by the presence of this oxide in other minerals than plagioclase such as amphibole. As large samples were crushed (5–15 kg) and as megacrysts mainly consist of K-feldspar,

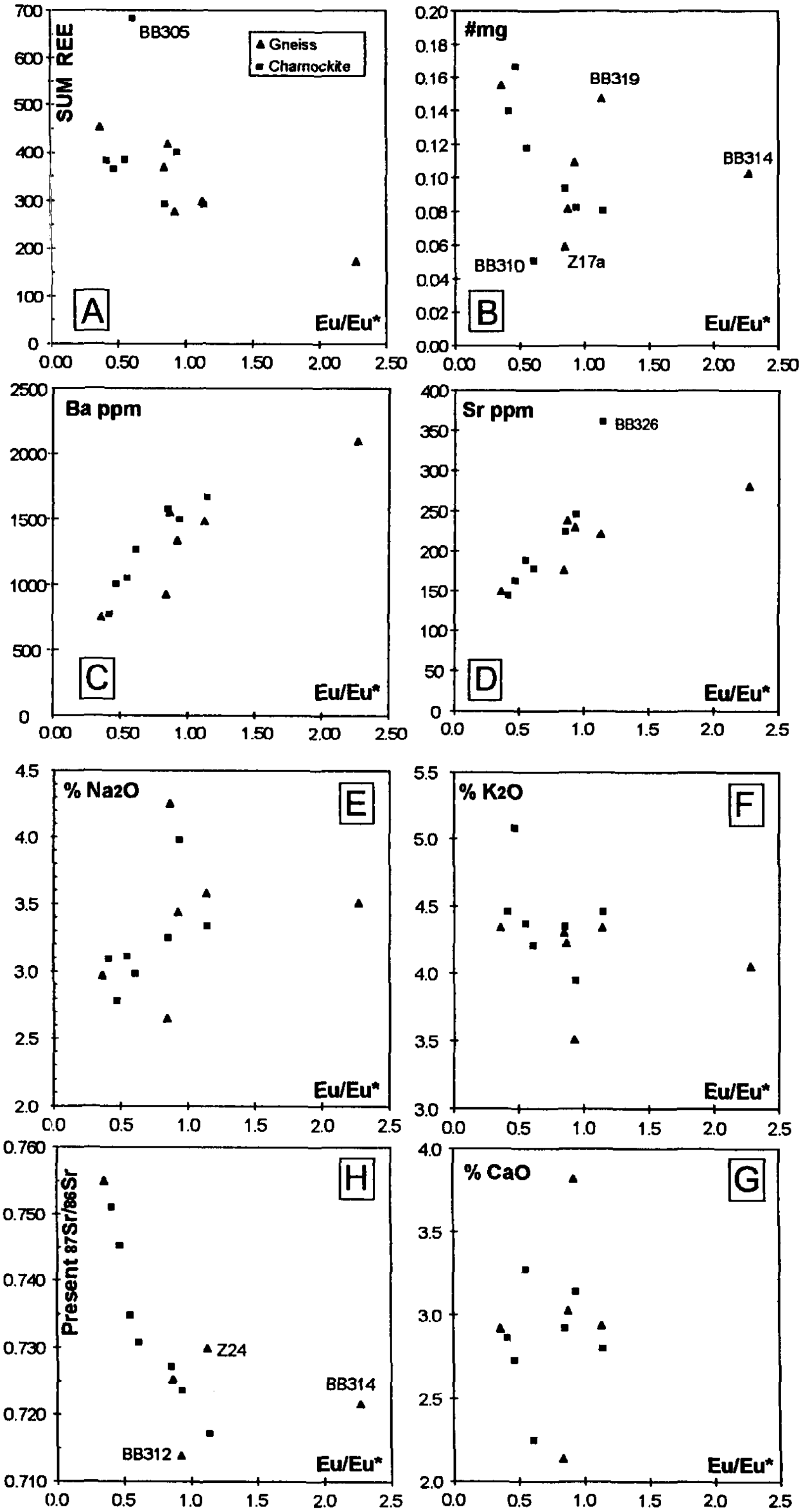

Fig. 6. Binary diagrams showing that the Eu anomaly (Eu/Eu*) is correlated with some elements or ratios (A, B, C, D, E, H) but not with other (F, G). These correlations are interpreted as mixing between a granitic magma and plagioclase crystals (crystal mush).

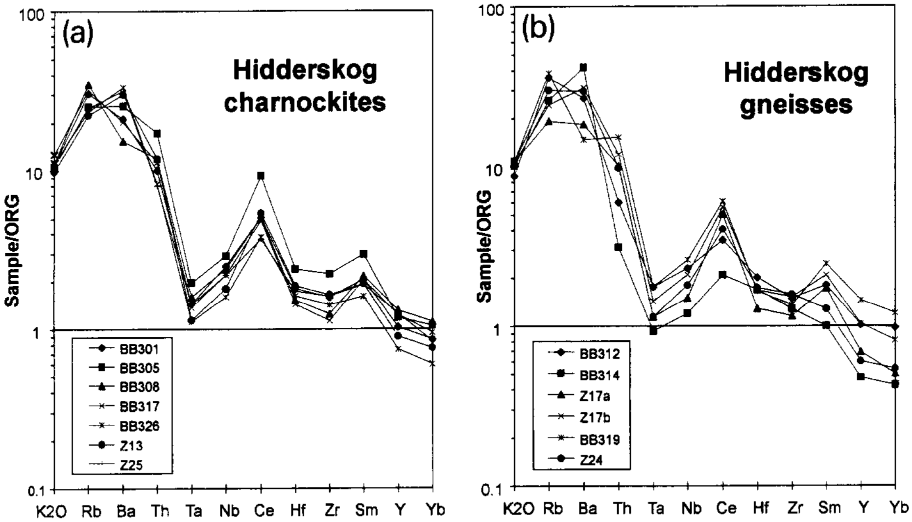

Fig. 7. Ocean ridge granite (ORG) normalized diagrams for charnockites (A) and gneisses (B). Normalizing values are from Pearce et al. (1984).

we can exclude a problem of non-representative samples ("augen effect") to explain the observed geochemical trend. The correlation between the Eu anomaly and the measured $^{87}Sr/^{86}Sr$ (Fig. 6h) shows three samples (BB312, BB314 and Z24) outside the trend which could mean that they have been more disturbed than the others. We can then consider the rocks of Hidderskog as crystal mushes with various amounts of early crystallized plagioclase in a granitic liquid.

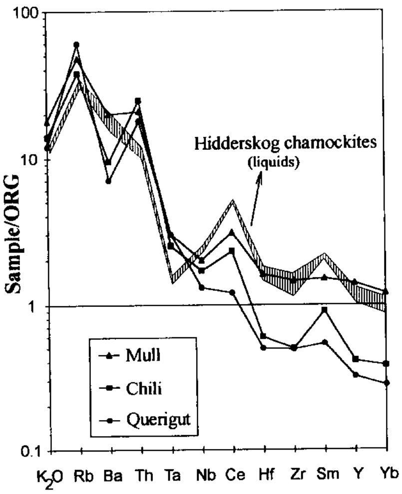

Fig. 8. Comparison between the average Hidderskog charnockitic liquids (based on sample BB301, BB308, BB317 and BB319) and reference granites (Pearce et al., 1984).

The ORG (ocean ridge granite) normalised spidergrams (Fig. 7a, b) show similar patterns for charnockites and gneisses but greater variations exist among the gneisses. The charnockites are more homogeneous in their trace element contents but sample BB305 is particularly rich in HFS elements (Figs. 6a and 7a) and in REE: as already noted, this may be due to a high content of accessory minerals. Moreover, charnockites with excess of plagioclase (positive or no Eu anomaly) have lower abundances in HREE and HFS elements. As shown by the major elements and Sr isotopes, the main Sveconorwegian metamorphism has only weakly affected the Hidderskog geochemistry, even in the most deformed rocks. However, for petrogenetic purposes, only the undeformed charnockites without plagioclase in excess will be used. For the same reason, sample BB305 has also been omitted in Fig. 8.

The charnockite spectra are characterized by important enrichments in alkalis (Rb, K), Ba, Th and LREE (Ce, Sm) and by two troughs corresponding to Nb–Ta and Zr–Hf (even if these elements are still above ORG). Y and Yb are close to or slightly below the ORG values. Compared to the granitic references of Pearce et al. (1984), the Hidderskog charnockites are comparable to the alkaline granites of the classical Scottish Mull ring-complex (Fig. 8). They are quite distinct from the Chilean subduction related granites and from the Querigut (Pyrénées, France) post-kine-

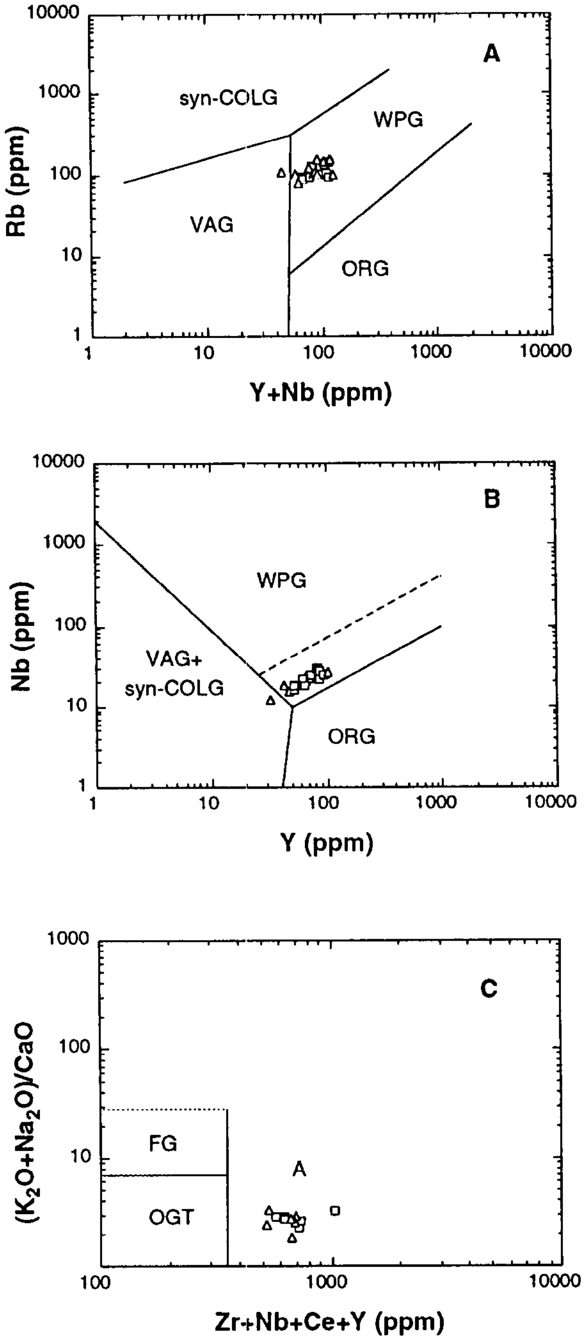

Fig. 9. Geochemical discrimination diagrams (a) Rb vs. Y + Nb (from Pearce et al., 1984), (b) Nb vs. Y (from Pearce et al., 1984), (c) ($K_2O + Na_2O$)/CaO vs. Zr + Nb + Ce + Y (from Whalen et al., 1987). Symbols as in Fig. 4. *syn-COLG* = syn-collision granites; *WPG* = within plate granites; *VAG* = volcanic arc granites; *A* = A-type granites; *ORG* = ocean rigde granites; *FG* = fractionated felsic granites; *OGT* = unfractionated M-, I- and S-type granites.

matic granites. In particular, Hidderskog samples do not have their typical Ba depletion and they do not show regularly decreasing enrichment factors from Th to Yb, with Y and Yb at half the ORG values. Hidderskog is roughly similar to Mull but is slightly higher in its REE contents. These features are characteristic of calc-alkaline magmas (Fig. 8). A small participation of a subduction-related material cannot be entirely excluded.

On bivariate discrimination diagrams, the alkaline anorogenic character of Hidderskog is confirmed: in the Rb vs. Y + Nb and Nb vs. Y diagrams (Pearce et al., 1984), Hidderskog samples plot into the "within

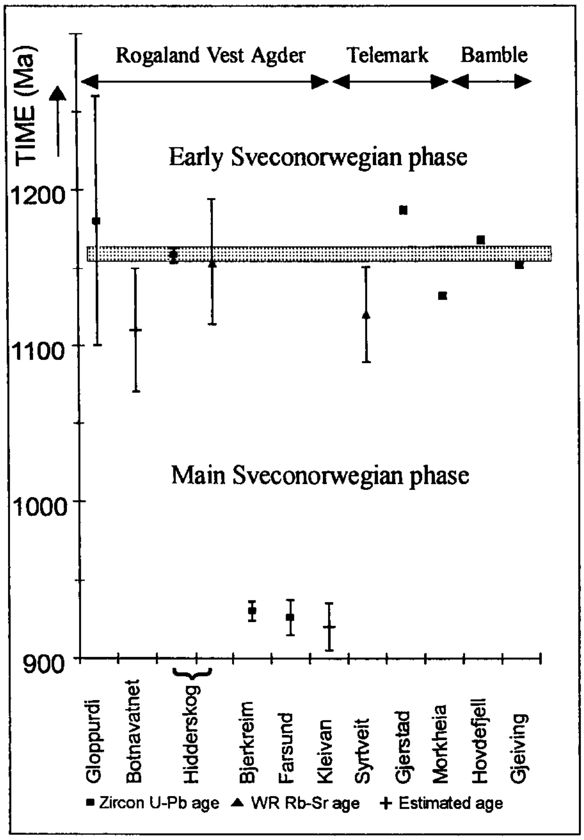

Fig. 10. Summary of the different ages known for the pre- and post-main Sveconorwegian granites with alkaline affinity in southern Norway (Gloppurdi and Botnavatnet: Versteeve 1975 and Wielens et al., 1981; Hidderskog: this study; Bjerkreim and Farsund: Pasteels et al., 1979; Kleivan: Petersen and Pedersen, 1978; Syrtveit: Pedersen 1980; Gjerstad and Morkheia: Heaman and Smalley, 1994; Hovdefjell: Smalley and Field, 1985; Gjeving: Kullerud and Machado, 1991).

plate granite'' area, more specifically in the ''attenuated continental crust'' area (Fig. 9a, b). In the Zr+Nb+Ce+Y vs. $(K_2O+Na_2O)/CaO$ (Fig. 9c) and vs. FeO_t/MgO (not shown) diagrams (Whalen et al., 1987), all Hidderskog samples fall within the A-type granite field (Fig. 9c). They cannot correspond to calc-alkaline differentiates. On the other hand, this diagram shows that the alkaline character of Hidderskog cannot be demonstrated on the basis of the $Na_2O + K_2O$ content alone: it has been shown (e.g. Liégeois and Black, 1987) that, even for alkaline rocks, the alkali content can strongly decrease during the late stages of differentiation. However, Hidderskog is always near the limits of the geotectonic fields, which can be correlated with the weak calc-alkaline characteristics found in the spidergrams.

Trace elements indicate that Hidderskog is an alkaline within-plate (A-type) granitic intrusion. Its origin is thus as controversial as that of other A-type rocks in general, i.e. lower crustal versus mantle origin. Its Sr isotopic initial ratio (0.7053 ± 7 or 0.7057 ± 7) cannot solve the problem especially as the crust in this area is relatively young (1680 ± 80 Ma).

The remelting of typical crustal material with calc-alkaline composition is not suitable, the calc-alkaline signature being small in Hidderskog. We need either an appropriate crustal source (Rogers and Greenberg, 1990; Creaser et al., 1991) or a mantle-derived (OIB type) magma slightly contaminated by a crustal material of calc-alkaline nature. This latter case is common in a post-collisional tectonic environment where chemical relics related to a former subduction process can be present in A-type granites (Liégeois and Black, 1987) while the former is postulated on a Pb isotope basis for the syn-tectonic charnockitic augen gneiss of Ubergsmoen (1120 Ma old) in the Bamble sector (Andersen et al., 1994). This will be constrained only when the early Sveconorwegian phase in Rogaland–Vest Agder (c. 1250 Ma, Demaiffe and Michot, 1985) becomes better understood.

6. Early Sveconorwegian (c. 1160 Ma) magmatism in south-western Norway

In the Rogaland–Vest Agder sector, the chronology of events prior to the main Sveconorwegian phase (older than 1100 Ma) is not well documented (Demaiffe and Michot, 1985; Verschure, 1985) and well-preserved rocks from this epoch are scarce. The knowledge of the geotectonic environment during Hidderskog emplacement is then of major importance. The nature and the geochemical affinity of magmatic rocks subcontemporaneous with Hidderskog are also important.

The Gloppurdi intrusion is a magmatic charnockite (Rietmeijer, 1979) situated in the granulite facies area of Rogaland, it has been dated at 1180 ± 80 Ma (Rb–Sr WR isochron; Versteeve, 1975). It is concordantly intercalated in granulite facies gneisses, and consists of quartz-monzonite (± orthopyroxene, ± fayalite) and charnockite. Geochemically, it has an alkaline affinity with high $FeO_t/(FeO_t+MgO)$ ratios (0.85–0.95) and K_2O contents (5.2–8.1%).

The Botnavatnet charnockite (also in the granulite facies domain of Rogaland) is lithologically and geochemically very similar to the Gloppurdi intrusion (Rietmeijer, 1979). Although the zircon fractions do not define good discordia chords (Wielens et al., 1981), age estimates are in the range of 1070–1150 Ma, a simultaneity of emplacement with Hidderskog and Gloppurdi is then possible. These three intrusions seem to have alkaline affinities and could have been formed in the same environment. This must however be confirmed.

In the Telemark sector, Smalley and Field (1985) have concluded that, during the 1.60–1.25 Ga period, the Proterozoic continental crust (Fig. 1) experienced an evolution from a primitive continental arc to mature continental arc and finally to anorogenic environment. The Gjerstad augen gneiss (1187 ± 2 Ma, U–Pb zircon; Heaman and Smalley, 1994) and the associated Morkheia complex (1132 ± 2 Ma; Heaman and Smalley, 1994), both of alkaline geochemical signature (Milne and Starmer, 1982), were emplaced in this post-collisional environment. In the Evje area, the Syrtveit leucogranitic gneisses ($SiO_2 > 70\%$), emplaced at 1120 ± 31 Ma (Rb–Sr WR isochron, Pedersen and Falkum, 1975), also have high $FeO_t/(FeO_t+MgO)$ ratios (0.87–0.90).

In the Bamble sector, Starmer (1991) has defined a ''Sveconorwegian anorogenic phase'' (between ~ 1175 and 1100 Ma) which follows the ''Early Sveconorwegian orogenic phase'' (~ 1250 Ma). Three augen gneiss complexes containing charnockitic units (Hovdefjell–Vegårshei, Ubergsmoen and Gjeving) of alkaline affinities have been reported. Although age determination of the augen gneisses is controversial (Smalley and Field, 1985; Starmer, 1991), the Hovdefjell charnockite (cited in Smalley and Field, 1985) and the Gjeving charnockite (Kullerud and Machado, 1991) give U–Pb zircon ages of 1168 ± 2 Ma and 1152 ± 2 Ma respectively. If these dates effectively represent emplacement ages, the charnockitic augen gneisses of the Bamble sector could be correlated with the Hidderskog and Gloppurdi charnockitic intrusions of the Rogaland–Vest Agder. A mean age, weighted by the errors, of all known c. 1160 Ma A-type magmatism can be calculated: it gives 1160 ± 4 Ma (Fig. 10).

On the other hand, paleomagnetic studies indicate that the pre-main-Sveconorwegian A-type charnockitic magmatism of southern Norway took place during a dextral shear zone dominated period preceding the 80° rotation of the Baltic shield which was followed by the main Sveconorwegian orogenic event (Park, 1992). This indicates that A-type magma could be linked either to a pure anorogenic period or more probably to the end of an older orogeny, as in the Telemark sector (Smalley and Field, 1985). Whichever is the case, they have no link with the main Sveconorwegian orogeny which occurred at c. 1100–950 Ma.

7. Two generations of charnockites in the Rogaland–Vest Agder segment

In the Rogaland–Vest Agder segment, large volumes of K-rich calc-alkaline granodiorites, later transformed to augen gneisses, were emplaced at 1040 Ma (Rb–Sr isochron and U–Pb zircon ages; Bingen et al., 1990), more than 100 Ma after the Hidderskog, Gloppurdi and Botnavatnet intrusions. These calc-alkaline augen gneisses belong to the main Sveconorwegian orogenic cycle; their nature points to a mature volcanic arc or active continental margin environment (Bingen et al., 1993). This main Sveconorwegian tectono-metamorphic event has been followed by the intrusion of many late- to post-kinematic granitoids (see age compilations by Demaiffe and Michot, 1985 and Verschure, 1985). Two groups of granitoids have been distinguished (Fig. 1):

- The biotite ± amphibole granites emplaced between 1000 and 950 Ma: the Homme granite (~ 1000 Ma; Rb–Sr WR isochron), the Holum granite which is the first undeformed granite (980 ± 34 Ma, Rb–Sr WR isochron) and the Lyngdal Hb-granodiorite (950 ± 5 Ma, U–Pb zircon and sphene ages);
- The charnockites emplaced between 950 and 930 Ma (U–Pb zircon ages): the Kleivan charnockite, the Farsund charnockite and the Bjerkreim–Sokndal quartz-mangerite. The two latter are spatially related to the Rogaland anorthosite complex. Emslie (1987, 1991) has convincingly shown that igneous charnockites and the classic rapakivi complexes often associated with anorthosites have many geochemical characteristics common to A-type granites.

In the Rogaland–Vest Agder segment, two generations of A-type charnockites are thus present; they were emplaced before and after the main Sveconorwegian orogenic phase at 200 to 250 Ma interval (Fig. 10). Only the second generation of charnockite (950–930 Ma) is spatially associated with anorthosites. They display initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.7053 for Kleivan (Petersen and Pedersen, 1978) to 0.7085–0.709 for the Bjerkreim–Sokndal qtz-mangerite and the Farsund charnockite (compilation of Weis, 1986). Hidderskog could then be compared to the least crustally contaminated charnockites of the second generation (Demaiffe et al., 1986).

8. Conclusions

(1) The Hidderskog massif was emplaced as a charnockitic intrusion, before the main Sveconorwegian metamorphic phase.

(2) The zircon U–Pb age (1159 ± 5 Ma) and the whole rock Rb–Sr isochron (1153 ± 39 Ma) age are concordant and interpreted as the primary magmatic emplacement age.

(3) The massif has been variably affected by the main Sveconorwegian amphibolite facies tectono-metamorphic event (1040–980 Ma) giving rise to amphibole granitic gneisses but large sections of the intrusion are still made up of nearly untransformed charnockite. Major and trace element composition of the intrusion has been only weakly affected by this metamorphism.

(4) Many trace elements are correlated with the Eu anomaly suggesting that the main geochemical variations of the Hidderskog rocks result from the mixing

in different proportions of an evolved felsic liquid and feldspar crystals.

(5) The Hidderskog intrusion has an A-type (alkaline–anorogenic–anhydrous) geochemical signature pointing to an intraplate anorogenic geodynamic environment, at c. 1160 Ma. This conclusion could perhaps also be applied to other intrusions with alkaline affinities in the Rogaland–Vest Agder segment such as Gloppurdi and Botnavatnet. A correlation between these charnockitic units and the alkaline Hovdefjell and Gjeving charnockitic augen gneisses of the Bamble sector and the Morkheia complex of Telemark is also proposed. Therefore the emplacement episode of these isolated charnockitic intrusions apparently took place in the different crustal segments of southern Norway.

(6) This regional anorogenic magmatic event preceded the 80° rotation of the Baltic Shield which led to the main Sveconorwegian orogeny. This would indicate an absence of a genetical link with the main Sveconorwegian orogeny. By contrast, these alkaline intrusions could have intruded not long after the early Sveconorwegian phase.

(7) Two generations of magmatic charnockites are present in the Rogaland–Vest Agder segment: one before (c. 1160 Ma) and the other after (950–930 Ma) the main Sveconorwegian orogenic phase. Only the second post-orogenic generation is spatially related to the Rogaland anorthosite complex.

Acknowledgements

XRF major and some trace elements analyses were obtained at the "Collectif Interinstitutionnel de Géochimie Instrumentale" (Université de Liége). G. Bologne is thanked for his help during the analyses of major and some trace elements. Financial support for the isotopic measurements was provided by the FNRS. This work was done as part of the International Geological Correlation Program, Project 290. The first author acknowledges financial support from State Education Commission of the People's Republic of China and the Service de Coopération de l'Université Libre de Bruxelles. B.B. benefits of a "Chargé de Recherches mandate" from the FNRS. Thanks are due to A. Bernard and J.M. Savino for help in the SEM photograph. J.C. Duchesne, J.L. Touret and P.C. Smalley are warmly thanked for their careful reviews.

References

Andersen, T., Hagelia, P. and Whitehouse, M.J., 1994. Precambrian multi-stage crustal evolution in the Bamble sector of south Norway: Pb isotopic evidence from a Sveconorwegian deep-seated granitic intrusion. Chem. Geol., 116: 327–343.

Anderson, J.L., 1983. Proterozoic anorogenic granite plutonism of north America. In: L.G. Medaris (Editor), Proterozoic Geology. Geol. Soc. Am. Mem., 161: 133–154.

Berthelsen, A., 1980. Towards a palinspatic tectonic analysis of the Baltic Shield. Mém. B.R.G.M. 6th Int. Geol. Cong., Paris, 108: 5–21.

Bingen, B., 1988. Origine Magmatique et Évolution Métamorphique de la Série des Gneiss Oeillés de Norvège Méridionale. Doctorate Thesis Univ. Libre de Bruxelles.

Bingen, B., Demaiffe, D. and Hertogen, J., 1990. Evolution of feldspars at the amphibolite–granulite-facies transition in augen gneisses (S.W. Norway): geochemistry and Sr isotopes. Contrib. Mineral. Petrol., 105: 275–288.

Bingen, B., Demaiffe, D., Hertogen, J., Weis, D. and Michot, J., 1993. K-rich calk-alkaline plutonism of Grenvillian age in S.W. Norway. J. Geol., 101: 763–778.

Black, R., Latouche, L., Liégeois, J.P., Caby, R. and Bertrand, J.M., 1994. Pan-African displaced terranes in the Tuareg shield (central Sahara). Geology, 22: 641–644.

Bohlendre, F., Van Reenen, D.D. and Barton, J.M. Jr., 1992. Evidence for metamorphic and igneous charnockites in the Southern Marginal Zone of the Limpopo Belt. Precambrian Res., 55: 429–449.

Bologne, G. and Duchesne, J., 1991. Analyse des roches silicatées par spectrométrie de fluorescence X: précision et exactitude. Serv. Géol. Belg. Prof. Pap., 249: 1–11.

Creaser, R.A., Price, R.C. and Wormald, R.J., 1991. A-type granites revisited: Assessment of a residual-source model. Geology, 19: 163–166.

Demaiffe, D., Duchesne, J.-C. and Hertogen, J., 1979. Trace element variations and isotopic composition of charnockitic acidic rocks related to anorthosites (Rogaland, S.W. Norway). In: L.H. Ahrens (Editor), Origin and Distribution of the Elements. Pergamon, Oxford, pp. 417–429.

Demaiffe, D. and Hertogen, J., 1981. Rare earth element geochemistry and strontium isotopic composition of a massif-type anorthositic–charnockitic body: the Hidra Massif (Rogaland, S.W. Norway). Geochim. Cosmochim. Acta, 45: 1545–1561.

Demaiffe, D. and Michot, J., 1985. Isotope geochronology of the Proterozoic crustal segment of southern Norway: a review. In: A.C. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 411–433.

Demaiffe, D., Weis, D., Michot, J. and Duchesne, J.C., 1986. Isotopic constraints on the genesis of the Rogaland anorthositic suite (Southwest Norway). Chem. Geol., 57: 167–179.

Duchesne, J.-C., Caruba, R. and Iacconi, P., 1987. Zircon in charnockitic rocks from Rogaland (southwest Norway): Petrogenetic implications. Lithos, 20: 357–368.

Duchesne, J.-C., Maquil, R. and Demaiffe, D., 1985. The Rogaland anorthosites: facts and speculations. In: A. Tobi and J.L.R. Touret

(Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 449–476.

Eby, G.N., 1990. The A-type granitoids: A review of their occurrence and chemical characteristics and speculation on their petrogenesis. Lithos, 26: 115–134.

Emslie, R.F., 1987. Rapakivi suites, igneous charnockites and A-type granite. Geol. Soc. Am. Abstract Program, 19: 655.

Emslie, R.F., 1991. Granitoids of rapakivi granite–anorthosite and related associations. Precambrian Res., 51: 173–192.

Færseth, R.B., MacIntyre, R.M. and Naterstad, J., 1976. Mesozoic alkaline dykes in the Sounnhordland region, western Norway: age, geochemistry and regional significance. Lithos, 9: 331–345.

Falkum, T., 1982. Geologisk kart over Norge, berggrunnskart Mandal 1:250000. Nor. Geol. Unders.

Falkum, T., 1985. Geotectonic evolution of southern Scandinavia in light of a late-Proterozoic plate-collision. In: A.C. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 309–322.

Falkum, T. and Petersen, J.S., 1980. The Sveconorwegian orogenic belt, a case of Late Proterozoic plate-collision. Geol. Rundsch., 69: 622–647.

Henry, J., 1974. Garnet–cordierite gneisses near the Egersund–Ogna anorthositic intrusion, South-Western Norway. Lithos, 7: 207–216.

Heaman, L.M. and Smalley, P.C., 1994. A U–Pb study of the Morkheia Complex and associated gneisses, southern Norway: Implications for disturbed Rb–Sr systems and for the temporal evolution of Mesoproterozoic magmatism in Laurentia. Geochim. Cosmochim. Acta, 58: 1899–1911.

Hermans, G.A.E.M., Tobi, A.C., Poorter, R.P.E. and Maijer, C., 1975. The high-grade metamorphic Precambrian of the Sirdal–Ørsdal area, Rogaland–Vest-Agder Southwest Norway. Nor. Geol. Unders., 318: 51–74.

Jansen, B., Blok, R., Bos, A. and Scheelings, M., 1985. Geothermometry and geobarometry in Rogaland and preliminary results from the Bamble area, South Norway. In: A. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 499–517.

Krogh, T.E., 1973. A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. Geochim. Cosmochim. Acta, 37: 485–494.

Kullerud, L. and Machado, N., 1991. End of a controversy: U–Pb geochronological evidence for significant Grenvillian activity in the Bamble area, Norway. Terra Abstracts, 3: 504.

Lancelot, J.R., 1975. Les Systèmes U–Pb Chronomètres et Traceurs de l'Évolution des Roches Terrestres. Doctorate Thesis Univ. Paris VII, 280 pp.

Le Maitre, R.W., Bateman, P., Dudek, A., Keller, J., Lameyre, J., Le Bas, M.J., Sabine, P.A., Schmid, R., Sorensen, H., Streckeisen, A., Woolley, A.R. and Zanettin, B., 1989. A Classification of Igneous Rocks and Glossary of Terms. Blackwell Scientific Publications, Oxford, 193 pp.

Liégeois, J.P. and Black, R., 1987. Alkaline magmatism subsequent to collision in the Pan-African belt of the Adrar des Iforas (Mali). In: J.G. Fitton and B.G.J. Upton (Editors), Alkaline Igneous Rocks. Geol. Soc. Spec. Publ., 30: 381–401.

Liégeois, J.P., Claessens, W., Camara, D. and Klerkx, J., 1991. Short-lived Eburnian orogeny in southern Mali. Geology, tectonics, U–Pb and Rb–Sr geochronology. Precambrian Res., 50: 111–136.

Lindh, A. and Persson, P.O., 1990. Proterozoic granitoid rocks of the Baltic shield-trends of development. In: C. Gower, T. Rivers and B. Ryan (Editors), Mid-Proterozoic Laurentia–Baltica. Geol. Assoc. Can., Spec. Pap., pp. 23–40.

Menuge, J.F., 1988. The petrogenesis of massif anorthosites: a Nd and Sr isotopic investigation of the Proterozoic of Rogaland/Vest-Agder, SW Norway. Contrib. Mineral. Petrol., 98: 363–373.

Michot, J. and Michot, P., 1969. The problem of anorthosites. The south Rogaland igneous complex (southwestern Norway). In: Y.W. Isachsen (Editor), Origin of Anorthosites and Related Rocks. New York State Mus. Sci. Serv., pp. 399–410.

Michot, P., 1960. La géologie de la catazone: le problème des anorthosites, la palingenèse basique et la tectonique catazonale dans le Rogaland méridional (Norvège mèridionale). Norg. Geol. Unders., 212a: 1–54.

Milne, K.P. and Starmer, I.C., 1982. Extreme differentiation in the Proterozoic Gjerstad–Morkeheia complex of South Norway. Contrib. Mineral. Petrol., 79: 381–393.

Newton, R.C., 1992. An overview of charnockite. Precambrian Res., 55: 399–405.

Nijland, T.G. and Senior, A., 1991. Sveconorvegian granulite facies metamorphism of polyphase migmatites and basic dikes, south Norway. J. Geol., 99: 515–526.

Park, R.G., 1992. Plate kinematic history of Baltica during the Middle to Late Proterozoic: A model. Geology, 20: 725–728.

Pasteels, P., Demaiffe, D. and Michot, J., 1979. U–Pb and Rb–Sr geochronology of the eastern part of the south Rogaland igneous complex, southern Norway. Lithos, 12: 199–208.

Pasteels, P., Michot, J. and Lavreau, J., 1970. Le complexe éruptif du Rogaland méridional (Norvège). Signification pétrogénétique de la farsundite et de la mangérite quartzique des unités orientales. Ann. Soc. Géol. Belg., 93: 453–476.

Pearce, J.A., Harris, N. and Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol., 25: 956–983.

Pedersen, S. and Falkum T., 1975. Rb–Sr isochrons for the granitic plutons around Farsund, southern Norway. Chem. Geol., 15: 97–101.

Pedersen, S., 1980. Rb/Sr age determination on late Proterozoic granitoids from the Evje area, South Norway. Bull. Geol. Soc. Den., 29: 129–143.

Petersen, J.S. and Pedersen, S., 1978. Strontium-isotope study of the Kleivan granite, southern Norway. Nor. Geol. Tidsskr., 58: 97–102.

Petersen, J.S., 1980a. The zoned Kleivan granite — an end member of the anorthosite suite in southwest Norway. Lithos, 13: 79–95.

Petersen, J.S., 1980b. Rare-earth element fractionation and petrogenetic modelling in charnockitic rocks, southwest Norway. Contrib. Mineral. Petrol., 73: 161–172.

Rietmeijer, F.J.M., 1979. Pyroxenes from Iron-rich Igneous Rocks in Rogaland SW. Norway. Thesis Geol. Inst. Rijksuniversiteit Utrecht, 341 pp.

Rivers, T., Martignole, J., Gower, C.F., Davidson, A., 1989. New tectonic divisions of the Grenville province, Southeast Canadian Shield. Tectonics, 8: 63–84.

Rogers, J.J.W. and Greenberg, J.K., 1990. Late-orogenic, post-orogenic, and anorogenic granites: Distinction by major element and trace-element chemistry and possible origins. J. Geol., 98: 291–309.

Savino, J.M., 1992. Morphologie et Structures Internes des Zircons des Granitoides et Gneiss de l'Aïr (Orogène panafricain, Niger). Implications Géodynamiques. Thesis licencié Univ. Libre Bruxelles, 140 pp.

Sigmond, E.M.O., 1985. The Mandal–Ustaoset line, a new discovered major fault zone in south Norway. In: A.C. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Province. Reidel, Dordrecht, pp. 323–330.

Smalley, P.C. and Field, D., 1985. Geochemical constraints on the evolution of the Proterozoic continental crust in southern Norway (Telemark Sector). In: A. Tobi and J.Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 551–566.

Stacey, J.S. and Kramers, J.D., 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Lett., 26: 207–221.

Starmer, I., 1991. The Proterozoic evolution of the Bamble Sector shear belt, southern Norway: correlations across southern Scandinavia and the Grenvillian controversy. Precambrian Res., 49: 107–139.

Tobi, A.C., Hermans, G., Maijer, C. and Jansen, B., 1985. Metamorphic zoning in the high-grade Proterozoic of Rogaland–Vest Agder, S.W. Norway. In: A.C. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 477–499.

Touret, J., 1971. Le faciès granulite en Norvège Méridionale. I. Les associations minéralogiques. Lithos, 4: 239–249.

Verschure, R.H., 1985. Geochronological framework for the late-Proterozoic evolution of the Baltic Shield in South Scandinavia. In: A.C. Tobi and J.L.R. Touret (Editors), The Deep Proterozoic Crust in the North Atlantic Provinces. Reidel, Dordrecht, pp. 381–410.

Versteeve, A., 1975. Isotope geochronology in high-grade metamorphic Precambrian of southwestern Norway. Nor. Geol. Uuders., 318: 1–50.

Weis, D., 1986. Genetic implications for Pb isotopic geochemistry in the Rogaland anorthositic complex (southwestern Norway). Chem. Geol., 57: 181–199.

Whalen, J.B., Currie, K.L. and Chappell, B.W., 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis. Contrib. Mineral. Petrol., 95: 407–419.

Wielens, J.B.W., Andriessen, P.A.M., Boelrijk, N.A.I.M., Hebeda, E.H., Verdurmen, E.A.T. and Verschure, R.H., 1981. Isotope geochronology in the high-grade metamorphic Precambrian of southwestern Norway: New data and reinterpretations. Norg. Geol. Unders., 359: 1–30.

Wilmart, E., Clocchiatti, R., Duchesne, J.C. and Touret, J.L.R., 1991. Fluid inclusions in charnockites from the Bjerkreim–Sokndal massif (Rogaland, southwestern Norway): fluid origin and in situ evolution. Contrib. Mineral. Petrol., 108: 453–462.