RENDICONTI DELLA SOCIETÀ ITALIANA DI MINERALOGIA E PETROLOGIA, 1988, Vol. 43-2, pp. 543-554

Basic intrusion, charnockite-rapakivi granite plutonism and crustal depletion, S.W. Sweden

FREDERIK H. HUBBARD
Department of Geology, Dundee University, Dundee, Scotland

ABSTRACT. — The southern segment of the South-West Swedish Province (SWSP) of the Precambrian of the Baltic Shield has features which distinguish it from the northern segment of the same province and the Svecofennian sequences to the east. Repeated cycles of syn and late-orogenic basic magma injection maintained high crustal temperatures and led to progressive depletion of the rocks at, and adjacent to, the conduits. This is shown by the development of local granulite facies zones in the general amphibolite facies terrain and the occurrence of plutonic charnockite masses.

The syn-orogenic basic magmas caused depletion largely by the generation of hydrous solutions derived from dehydration of mafic minerals in the country rocks consequent on the heat influx associated with the intrusion. These hydrothermal solutions metasomatised and migmatised the basic rocks, formed aplite segregations, or were exhausted to higher level.

The late orogenic basic magmatism, which was associated with a shearing deformation, led to the development of granitic plutons which segregated during ascent to leave residual-restite charnockite and released REE and RE-enriched alkali granites with a rapakivi granite signature.

While a CO_2 volatile phase is indicated as important in the late-tectonic episode, it is not evident as a factor in the earlier syntectonic crustal depletion.

Key words: Basic magma, depletion, charnockite, granite.

Introduction

The southern segment of the South West Swedish Province (Fig. 1) occupies a somewhat enigmatic position in the hierarchy of development of the Precambrian rock sequences of the Baltic Shield. Separated from the Svecofennian Province to the east by a major mylonite zone and its associated granites and from the northern segment of the South-West Swedish Province by a series of major thrust zones, it has characteristics peculiar to this region of the Swedish Precambrian. These include an abundance of meta-basic intrusions, the occurrence of granulite facies assemblages within the general upper amphibolite facies terrain and distinctive plutonic associations of alkaline granite and charnockite (e.g. QUENSEL P., 1951; CALDENIUS et al., 1966, MOHRÉN E., LARSSON W., 1968, HUBBARD F.H., 1975, 1978). A Rb-Sr isochron age of 1420Ma was obtained by WELIN and GORBATSCHEV (1978) from a composite charnockite and granite pluton (the Charnockite-Granite Association of the Varberg region, HUBBARD F.H., 1975). This pluton was affected by post-emplacement, hot shearing and thrusting and the date may reflect isotope resetting during this tectonic activity rather than the age of the intrusion. A similar age is, however, found for amphibolites and granitoids in the northern segment of the South-West Swedish Province (e.g. SKIÖLD T., 1976; DALY J.S., PARK R.G., CLIFF R.A., 1979; SAMUELSSON L., AHÄLL K.-I., 1985). The acid plutonic rocks were emplaced in metamorphic sequences which show evidence of a long and complex earlier development history. The impression gained is one of an old sequence of crustal rocks which has undergone extensive, and perhaps repeated, reworking. Unfortunately no firm time scale has been established for the period preceding the late, hot deformation and recrystallisation. However, the rocks of south-west Sweden are clearly old and may represent an Early Proterozoic, or even Archaean, province with a history of Proterozoic reworking. The differences between the rock associations of the South-West Swedish Province and those of the Svecofennian Province to the east may merely be a consequence of the exposure of differing crustal levels but the possibility that the South-West Swedish Province is exotic cannot be ignored. The rocks of south-west Sweden most closely resemble those of the Pre-Caledonian rocks of southern Norway (e.g. TORSKE T., 1985), which have a strong Sveconorwegian (Grenvillian) signature thought, to some extent, to mark overprinting of a younger age on older rocks (PRIEM H.N.A. et al., 1973; VERSTEEVE A., 1975; TORSKE T., 1977; SMALLEY P.C. et al., 1983). While c. 1000Ma ages are fairly common in the northern segment of the South-West Swedish Province (e.g. SAMUELSSON L., 1980; DALY J.S. et al., 1983), they lack similar prominence in the southern segment.

General geology of the Varberg Region

The best exposure of the rock sequences of the southern segment of the South-West Swedish Province is to be found around the town of Varberg, on the Kattegat coast south of Gothenburg (Fig. 1), and contiguous with the limiting northen thrust zone. The geology is dominated by an intrusive plutonic complex which comprises both charnockitic and non-charnockitic granitoid components in intimate association — the Varberg Charnockite-Granite Association (CGA) — (HUBBARD F.H., 1975). The country-rocks to this association are, in large part, upper amphibolite facies grade granitic para-gneisses which have locally developed charnockitic characters (HUBBARD F.H., 1978). Horizons

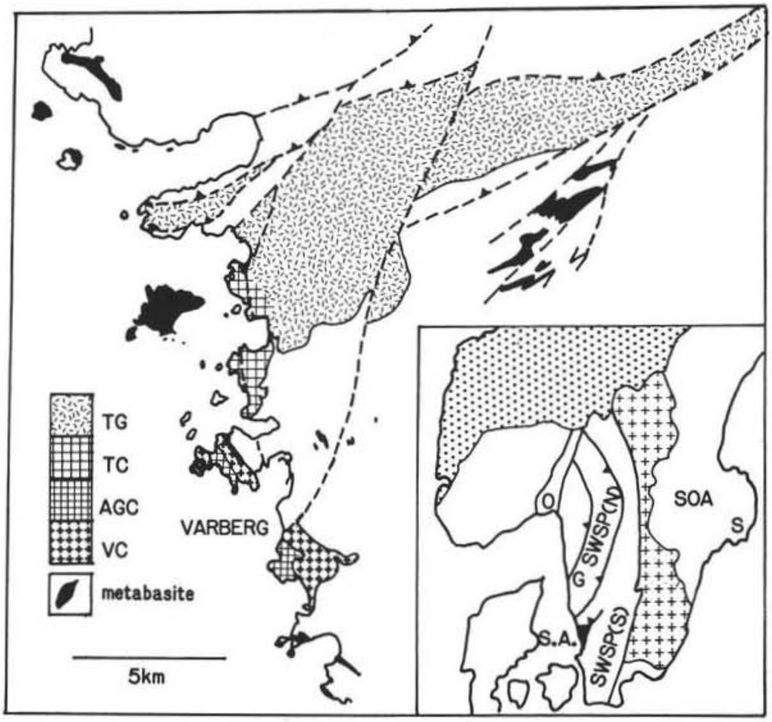

Fig. 1. — Location map (S.A. = study area; G = Gothenburg; S = Stockholm; O = Oslo; SWSP(S)-South-West Swedish Province (southern segment); SWSP(N) = South-West Swedish Province (northern segment); SOA = Svecofennian Orogenic Association; cross pattern = Protogene zone granites; dot pattern = Caledonides) and geological sketch map of the Varberg area (black = meta-basic rocks; VC, AGC and TC = charnockite and sub-charnockite components and TG = the major granite component of the Charnockite-Granite Association, CGA).

of more varied lithology, which include metabasic layers, occur within these rather monotonous granitic gneisses. It is in these compositionally-layered horizons that the structural complexity of the country rock gneiss is most clearly expressed. Metabasic rocks are a feature of both the plutonic complex and the surrounding country rocks; occurring as enclaves, xenoliths and intrusive sheets in the charnockites and as subconformable sheets in the country rocks. Several generations of basic intrusion are indicated (Figs. 2, 3), which are all now represented by metamorphic derivatives. They may be grossly divided into those which predate the granitoid plutonic activity and

Fig. 2. — Folded metabasites cut by younger metabasite in depleted (charnockitic) granite gneiss. Träslövsläge.

Fig. 3. — Agmatite of hornblendite blocks in scapolite-metabaggro. N. Horten.

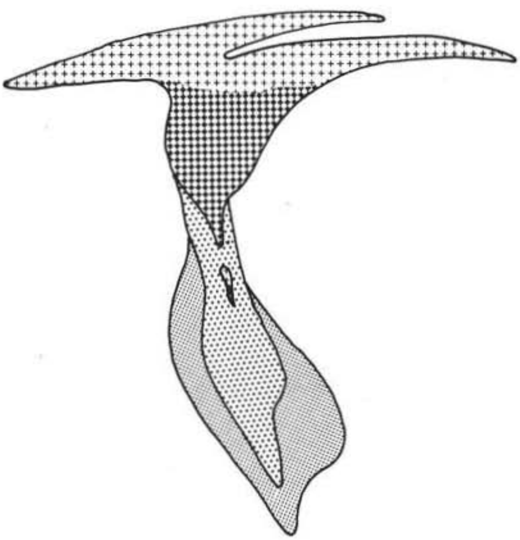

Fig. 4. — Idealised section of the Charnockite-Granite Association. Fine dots = charnockite cumulate (VC of Fig. 1); coarse dots = the active fractionating zone (AGC of Fig. 1); heavy crosses = charnockite and sub-charnockite residuum (TC of Fig. 1); light crosses = the evolved granite (TG of Fig. 1).

those sub-synchronous with the emplacement of the granitoids. The early group of meta-basic rocks are amphibolites and garnet-amphibolites and are commonly linked with migmatisation. The younger group rocks, on the other hand, characteristically occur as garnet-pyribolite, although there are associated local developments of coarse garnet-amphibolite.

The Pre-CGA Meta-basic Rocks

The earliest recognisable basic magmatism is that associated with the lithologically-layered gneiss/granulites within the granitic gneisses, represented by tight, strongly flattened, fold remnants. These may represent a volcanic component of the early supracrustal system of the the gneiss complex. The following cycle of basic magmatic activity was intrusive, polyphasal and syntectonic. Localised, crustal dehydration resulted from this, probably protracted, period of basic magma intrusion, with the basic bodies acting as water sinks during their sub-synchronous, metamorphic transformation to amphibolite.

The Period of Granitoid Plutonic Activity

Although rather severely disrupted by post-emplacement hot shearing and thrusting the general form of the charnockite and granite complex of the Varberg region can be reconstructed with reasonable confidence due to the excellence of the outcropping along this coastal region (Fig. 4). The composite intrusion was emplaced during a period of shearing and shear folding, synchronous with a further basic magma influx into country rocks which already had well-established major structural and metamorphic patterns. The form of the pluton follows the general structural grain of the country rocks with the narrow, deeper, neck lying in a structural steep zone, which was concurrently being further accentuated by shearing. The lateral spread of the pluton at higher levels coincides with a similar change in country rock structure. A parallel distribution can be observed in the products of the accompanying basic activity. This discontinuity of structural grain continued to play a fundamental role during the subsequent major thrusting which established the northern limit of the southern segment of the South-West Swedish Province.

The Charnockite-Granite Plutonic Activity

The plutonic granitoid association of the Varberg region has less well, and less completely, exposed counterparts throughout the province. In some instances, the granite has become detached from its charnockitic associates, in others, there is arrested development, as displayed at Varberg (the Charnockite-Granite Association or CGA of HUBBARD F.H., 1975), where the granite-charnockite link remains intact, thus revealing the mechanism of formation.

The massive charnockite phases of these plutons are interpreted as «cumulate-restites» from the fractionation of anatectic melt-crystal aggregates derived from the local granite-gneiss country rocks; the more buoyant, less viscous, melt fraction rising to crystallise as K-feldspar megacrystic granite with the petrographic and chemical characters of rapakivi granite (HUBBARD F.H., WHITLEY J.E., 1978, 1979). The Varberg complex has the form of a narrow «neck» of charnockitic rocks surmounted by a flattened «cap» of granite, producing a mushroom-like section. The charnockite neck has a complex structure. The flanks are composed of a generally homogeneous, sparsely feldspar-megacrystic, monzonitic charnockite (the Varberg Charnockite or VC of HUBBARD F.H., 1975), locally with abundant xenoliths. The xenoliths of country rock in this intrusive charnockite are generally of granulite-facies grade; largely «charnockitised» granite-gneiss. The nature of the xenoliths indicates that the pluton was emplaced into already depleted country rocks. This depletion to granulite facies is largely localised to the conduit zones established by the early basic intrusions which instigated the depletion. The same conduits were subsequently re-utilised by both the granitoid and the younger basic intrusions.

Central to the neck, an essentially similar rock forms the matrix to segregations of three types:

a) Veins, streaks and schlieren of coarsely feldspar-megacrystic rock of similar composition to the matrix, with charnockitic, or sub-charnockitic, petrographies. (The term «sub-charnockitic» is here used to denote rocks which maintain the dark quartz and feldspar characteristics of charnockite but in which much of the typical pyroxene of charnockite is exchanged for amphibole).

b) Discrete masses of pink, coarse, microcline porphyritic, leuco-granite. The contacts with the enclosing charnockite are sharp.

c) Granite masses, similar to b) above, but with attached «tails» of coarse charnockite or sub-charnockite comparable with the segregations of type a).

These consititute the Apelviken-Getterön Charnockite (AGC) of HUBBARD F.H. (1978).

The major charnockite/sub-charnockite and granite duplex rises from this central fractionating zone, repeating the form of the type c) segregations, but on a greatly expanded scale. At both scales, the transition from charnockite, through sub-charnockite, to granite is progressive and irregular. Sub-charnockite and granite can be observed in the same outcrop, in a manner clearly distinct from the diaphthoretic degradation of charnockite associated with the later shearing activity.

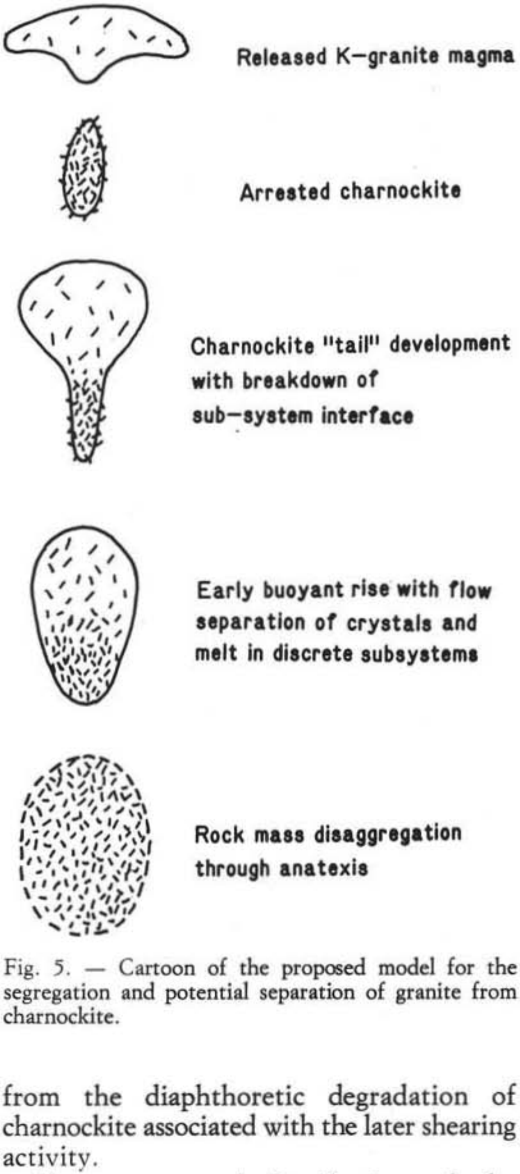

Fig. 5. — Cartoon of the proposed model for the segregation and potential separation of granite from charnockite.

The nature and distribution of the components of the complex suggest a mechanism for the fractionation. Partial melting led to loss of coherence in a mass of country rock undergoing focussed heating during shear deformation and mafic magma intrusion. Segregation of more melt-rich fractions during buoyant rise of the crystal-melt amalgam would result in viscosity and density contrasts developing within the rising columns producing subsystems with sufficiently distinct physical parameters for them to develop as discrete units. The more buoyant subsystems, by aggregating on contact with kindred units, would accumulate to large size and could potentially separate from their more sluggish crystal-rich residues. Internal crystal accumulation during the rise of the segregations, would result in the development of sluggish crystal-rich tails to the rising masses, with greatly reduced viscosity/buoyancy contrast relative to their surroundings. The consequent «braking effect» could lead to retention of the cumulate-residues with separation of the buoyant, lower viscosity, granite melt fractions. The segregations described for the centre of the neck are interpreted as representing stages in these development processes as they affected magma-enriched fractions which were unable to coalesce with the major mass. The cartoon of Fig. 5 summarises the proposed development scheme and can be related to both the small and the large scale bodies. Concentration of available water in solution in the silicate melt phase is in accord with the charnockitic, or sub-charnockitic, nature of the crystal cumulate restites, and the lack of evidence of reaction between the granite and its «dry» charnockitic host.

Discussion

The intrusion of basic magma is of importance in initiating and maintaining metamorphism as it provides an efficient means of transporting heat into, and through, the crust. It also strongly influences the distribution, and the mix, of volatiles within an affected crustal section. Touret J.L.R. (1971) identified the importance of the hydration involved in the conversion of basic intrusions to amphibolites for dehydration of crustal rocks and the development of granulite facies. Current theories on the processes of granulite facies metamorphism fall into two main groups; those which empasise the importance of a massive influx of CO_2 (e.g. Frost B.R., Frost C.D., 1987) and those which emphasise the importance of crustal melting (e.g. Fyfe W., 1973). Any one, or a combination, of three processes may lead to the formation of depleted granulite terrains; CO_2-streaming, partial melting or recrystallisation of original dry rocks (e.g. Lamb W., Valley J., 1984).


Fig. 6. — Mingling of basic and acid (charnockite) magmas. Näs.

In the Varberg area of the southern segment of the South-West Swedish Province, the direct association of crustal depletion with influxes of basic magma is evident. The direct

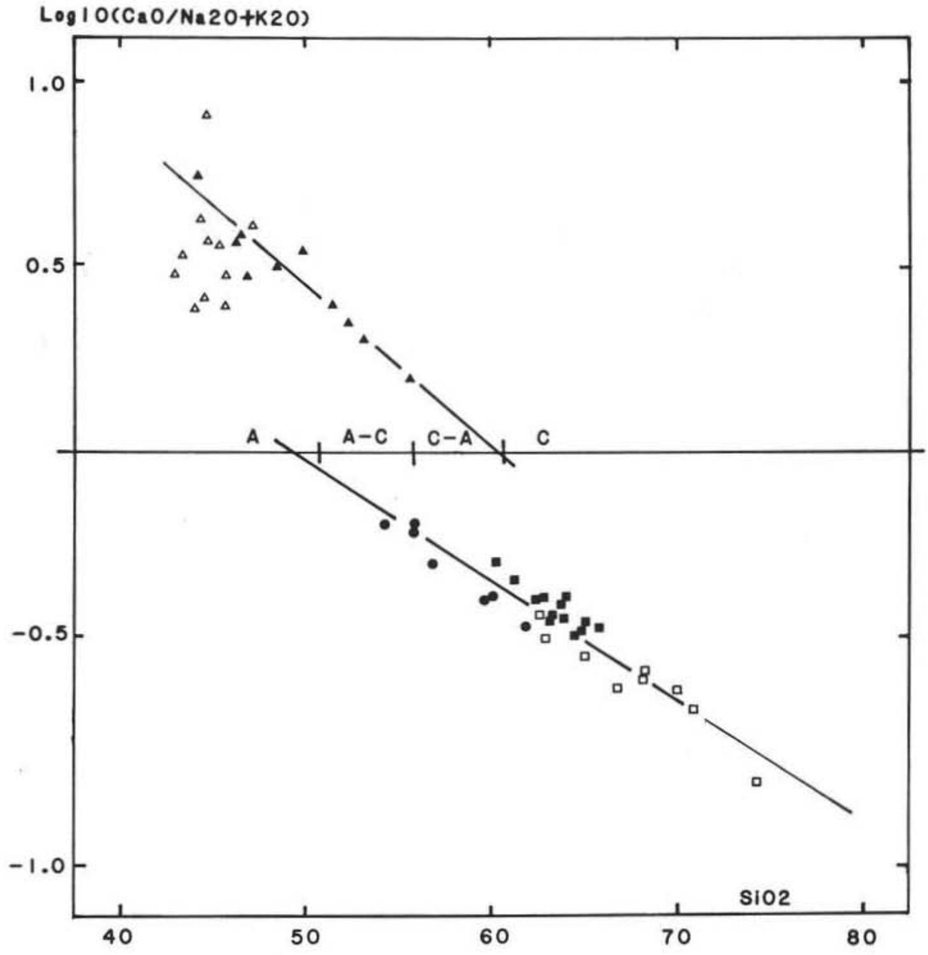

Fig. 7. — Lime/alkali vs. SiO_2 diagram. Filled triangles = younger basic intrusions; open triangles = older basic intrusions; filled circles and squares = charnockite and sub-charnockite members of CGA, respectively; open squares = evolved granite. Since there is considerable data point overlap for the CGA data, only representative points are included.

connection of the charnockitic rocks with crustal melting is demonstrated by the Charnockite-Granite Association (CGA) and the synchronous existence of basic and acid magma is shown by evidence of magma mingling (Fig. 6).

The mean chemical compositions of the major rock types of the region are presented in Table 1 and their general mineralogical compositions in Table 2. The lime/alkali vs. silica plot for the intrusive rocks (Fig. 7) provides petrochemical support for the field and petrographic sub-division of the basic intrusions into two distinctive groups. The older basic rocks (Bas1) vary little in silica content (SiO_2 range = 42.8-47.1 wt.%) and do not define a clear fractionation trend on the plot. The younger basic rocks (Bas2), on the other hand, have an extended silica range (SiO_2 = 44.2-55.6) and display well a calc-alkaline to calcic trend in Fig. 7. The Bas1 rocks are ferrogabbroic (Jotunitic) in character whereas the Bas2 suite are aluminous with an anorthositic fractionation locally evident.

The acid plutonic rocks are divided, in Table 1, into the recognised components of the Charnockite-Granite Association. The Varberg Charnockite (VC) data represent the monzonitic residual charnockite phase from the evolving system. Two data sets are provided from the internal segregating zone, the Apelviken-Getterön Charnockite (AGC), which emphasise the close compositional similarity of the relatively fine-grained charnockitic matrix [AGC(f)] and the coarse-grained segregating sub-charnockitic masses [AGC(c)]. Both range in composition from quartz-monzonite to adamellite. The adamellitic Trönningenäs Charnockite (TC) data relate to the charnockitic and sub-charnockitic «tail» to the main granite segregation, the Torpa Granite (TG). In the lime/alkali vs. silica diagram of Fig. 7, all the components of the CGA lie along a well-defined alkaline fractionation trend. The close fit and rational compositional progression of the CGA components along the trend regression line show that the rocks all belong to a coherent consanguineous igneous suite. The extreme mismatch of the trends of the fractionated basic rocks and the acidic rock association makes it extremely unlikely that they derive from a common parent by assimilation-fractional crystallisation (AFC) processes. Also, there is no compositional evidence to suggest that a mixing regime was important in the development of either rock suite.

The suite of xenoliths found in the intrusive charnockites of the CGA suggests that granulite facies assemblages were already a feature of the country rocks. This depletion episode may reasonably be ascribed to the syntectonic period and, in particular, to the associated, repeated, basic magmatism. One indicated mechanism of depletion is dehydration through amphibolitisation of the basic rock. The transformation of the amphibolite facies country rock granite gneisses to granulite facies equivalents entailed depletion in SiO_2, K_2O and Th (HUBBARD F.H., 1978; CONSTABLE J.L., HUBBARD F.H., 1981) but no significant changes in REE concentrations (Fig. 8). This is more consistent with volatile-flushing depletion than partial melting, although there is evidence of some limited anatexis. However, the quartz grains of the granulite facies gneisses uncharacteristically contain no CO_2 fluid inclusions but only brine (TOURET J.L.R., 1971). There is, therefore, no direct evidence of massive CO_2 infusion. The features described are more readily attributed to the activity of migrating hydrous solutions, developed from metamorphic dehydration of biotite and hornblende at the elevated temperatures engendered by the basic magmatic activity. These metasomatised the basic intrusions, were exhausted to higher levels and/or gave rise to the ductless aplite bodies recognised to occur in the area (QUENSEL P., 1951; HUBBARD F.H., 1975).

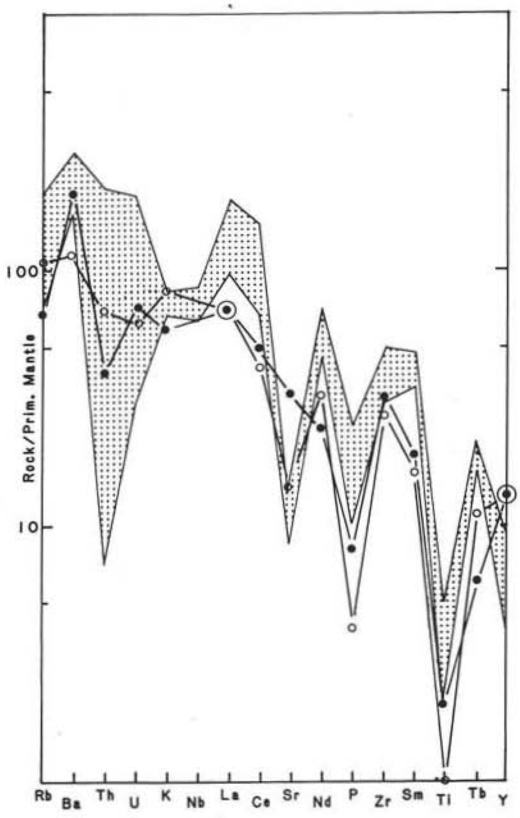

Fig. 8. — Element spidergram, normalised to primordial mantle (normalising values from WOOD D.A., 1979). Open circles = granite gneiss; filled circles = charnockitic granite gneiss; stippled field = variation within CGA components.

The fluid inclusion evidence from the rocks of the CGA, on the other hand, shows the presence of abundant CO_2 during this later event. The quartz of the charnockite components contains 75-95% CO_2 inclusions, the granite 60-70%, associated, but not mixed, with concentrated brine inclusions. This confirms the dissociation in both time and mechanism of the *in situ* country rock depletion and the CGA-type of magma generation and fractionation, as well as the differing hydration-states of the crustal rocks affected. The change in type of the basic magmas active during the shearing-related, late-tectonic period to a more fractionated sequence (Fig. 7), with a calc-alkaline/calcic trend, is also significant.

Conclusions

The rocks of the southern segment of the South-West Swedish Province display crustal depletion processes of different types; always linked with the accession of mantle-derived basic magmas.

The intrusion of hot magma into the already high grade metamorphic rocks of the crustal segment now exposed at Varberg produces local prograde metamorphism from upper amphibolite to granulite facies, largely by mineral dehydration reactions. The expelled water caused metamorphic / metasomatic transformation of the basic magmatic rocks to amphibolite and garnet-amphibolite, subsynchronous with their emplacement. The formation of ductless aplite may also relate to this hydrous volatile phase. The immobility of LREE in the granite gneisses during their transformation *in situ* to charnockitic granite gneiss (Table 1 and Fig. 8) restricts the probability of extensive partial melting during this depletion. There is no evidence remaining of a significant concentration of CO_2 in the volatiles at that time.

High temperatures were maintained, or regained, during the late-orogenic period of shearing deformation by the intrusion of a further suite of basic magmas along the established conduit zones. These fractionated magmas introduced a CO_2-rich volatile phase to the evolving system, which became concentrated in the developing anatectic melt. Buoyant rise of crustal rocks, disaggregated by partial melting, led to the segregation and fractionation processes described to produce LILE-depleted charnockite and LILE-enriched alkaline granite (Table 1). During the evolution of the acidic plutons, release of a CO_2-rich vapour phase to infiltrate and deplete the country rocks would be expected (Mysen B.O., 1976; Mysen B.O. et al., 1976). In the case of the Varberg complex, however, the fluid inclusion data suggest that the excess CO_2 from the charnockite remains dissolved in the evolved granite magma whose quartz grains crystallised with 60-70% CO_2 inclusions. This implies low polymerisation in the granite melt and maintenance of high temperature and pressure (Mysen B.O., 1976). The crystallisation of the granite in close association with the charnockite suggests that the granite magma was not H_2O-saturated. The H_2O-saturated granite solidus lies below the temperatures (700-800°C) indicated by the contemporary basic magma

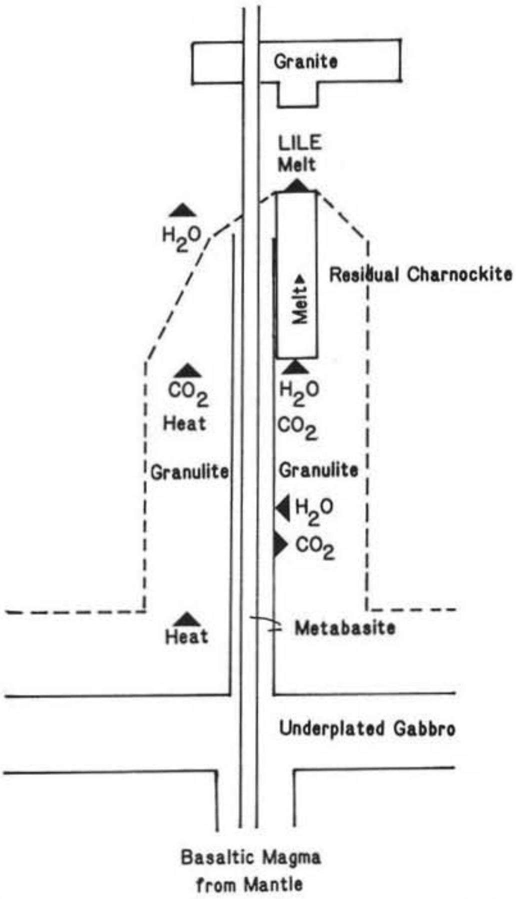

Fig. 9. — Schematic synoptic representation of the model for basic intrusion, charnockite-granite plutonism and crustal depletion, south-west Sweden.

TABLE 1

Mean major oxide and trace element compositions for the major rock units from Varberg. Major oxides in wt%, trace elements in ppm. REE by INAA, others by XRFS. Total iron as Fe_2O_3. *VC = Varberg Charnockite; AGC(f) and AGC(c) = Apelviken-Getterön Charnockite fine-grained matrix and coarse segregations respectively; TC = Trönningenäs Charnockite; TG = Torpa Granite; GG = Granite Gneiss; CGG = Charnockitic Granite Gneiss; Bas1 = early basic intrusions; Bas2 = later basic intrusion*

	VC	AGC(f)	AGC(c)	TC	TG	GG	CGG	BAS1	BAS2
n	7	7	6	9	18	6	8	10	10
SiO2	58.6	64.4	63.4	64.3	70.6	74.4	65.3	46.1	50.7
TiO2	1.4	1.2	1.2	1.1	.5	.3	.5	2.2	1.0
Al2O3	15.3	13.1	14.3	15.5	14.1	13.3	16.1	13.8	16.8
Fe2O3	9.6	7.9	7.3	5.8	3.4	1.4	4.3	15.9	10.3
MnO	.2	.2	.2	.1	.1	.1	.1	.3	.2
MgO	1.6	1.2	1.5	1.4	.9	.7	1.5	6.9	5.6
CaO	4.3	2.9	3.2	3.2	1.7	.8	3.5	11.2	11.2
Na2O	4.5	3.6	3.8	3.8	3.3	3.2	4.6	2.3	2.4
K2O	4.1	4.8	4.7	4.8	5.2	5.7	3.9	1.0	1.4
P2O5	.4	.6	.4	.2	.1	.1	.2	.3	.5
Li	10	20	21	22	18				
Rb	58	86	91	124	192	91	58		
Sr	298	189	210	270	229	348	760	40	
Ba	2167	1522	1472	1457	1140	876	1497		
Zr	281	436	466	369	331	293	349	214	419
Y	32	26	30	51	56	63	63	182	136
Zn	103	108	98	93	80				
Ni	17	20	18	16	12	17	20	74	45
Cr	11	15	19	10	2	12	13	196	72
Nb	37	40	42	50	39	10	13		
Th	1	2	3	2	23	7	4	1	1
U	1	1	3	2	6	2	2	3	2
La	69	74	88	72	119	50	50	21	17
Ce	128	150	180	151	246	79	92	37	137
Nd	69	40	79	63	82	42	31	24	33
Sm	15	16	20	16	12	6	7	7	5
Eu	5	3	4	3	2	1	1	6	2
Gd		7	9	11	5			4	1
Tb	2	2	2	2	1	1	1	1	1
Yb	7	5	7	7	5	3	4	2	3
Lu	1	1	1	1	1	1	1	1	1

TABLE 2

The general mineral assemblage of the rock units. Rock unit abbreviations are as in Table 1. Within each unit the minerals are grouped into felsic, mafic and accessory minerals and are arranged in rough descending order of abundance within each group. pl = plagioclase; pl = antiperthite; mp = microperthite; mi = microcline; qz = quartz; hy = hypersthene; di = diopside; hb = hornblende; bi = biotite; gt = garnet; ap = apatite; zi = zircon; sp = sphene*

Rock Unit	General Mineral Assemblage
GG	mp, qz, pl; bi, hb; ore, ap, zi.
CGG	pl*, qz, mp; hb, hy, di, bi; ore, ap, zi.
VC	pl*, mp, qz; hy, di, hb; ore, ap, bi, zi, gt.
AGC	mp, pl*, qz; hb, di, hy, bi; ore, ap, zi, gt.
TC	mp, pl*, qz; hb, di, hy; ore, ap, gt, bi, zi.
TG	mi, qz, pl; bi, hb; ore, sp, zi, ap.
Bas1	pl, qz; gt, hb, di, hy; bi, ore, ap.
Bas2	pl, qz; di, hy, hb, gt; ore, ap.

crystallisation and the granulite facies metamorphism of the country rocks. The volatile phase associated with the basic magma influx was water-poor and carbon dioxiderich, suggesting that there had been deeper level crystallisation of amphibole to «fix» water. In addition, the crustal rocks affected must already have been water-depleted. Under «normal» conditions, following the model of Frost B.R. and Frost C.D. (1987), the granite generated by basic magma-triggered anatexis would be water-saturated, pass to higher levels before crystallising and be dissociated from its cumulate-restite charnockites.

After the main orogenic activity, which established the general character of the metamorphic regime of the southern segment of the SWSP, basic magmas continued to be generated in the mantle, formed a petrological crustal underplate, and crystallised amphiboles. From this evolved, fractionated, sub-crustal magma source, CO_2-rich, H_2O-poor, hot magma leaked into the crusts during late shearing tectonism to generate the charnockite-granite associations from the already depleted crust now exposed in south-west Sweden. The model proposed is symbolically represented in Figure 9.

REFERENCES

Caldenius C., Larsson W., Mohrén E., Linnman G., Tuulstrom H. (1966) - *Beskrivning till kartbladet Halmstad*. Sveriges Geol. Unders. Ser. Aa, 198, pp. 1-123.

Constable J.L., Hubbard F.H. (1981) - *U, Th and K distribution in a differentiated charnockite-granite intrusion and associated rocks from SW Sweden*. Mineral., Mag., 44, pp. 409-415.

Daly J.S., Park R.G., Cliff R.A. (1979) - *Rb-Sr ages of intrusive plutonic rocks from the Stora Le - Marstrand Belt in Orust, SW Sweden*. Precamb. Res., 9, pp. 189-198.

Daly, J.S., Park R.G., Cliff R.A. (1983) - *Rb-Sr isotopic equilibrium during Sveconorwegian (= Grenville) deformation and metamorphism of the Orust dykes, SW Sweden*. Lithos, 16, pp. 307-318.

Frost B.R., Frost C.D. (1987) - *CO_2, melts and granulite metamorphism*. Nature, 327, pp. 503-506.

Fyfe W.S. (1983) - *The granulite facies, partial melting and the Archaean crust*. Phil. Trans. R. Soc. Lond., A273, pp. 457-461.

Hubbard F.H. (1975) - *The Precambrian crystalline complex of south-western Sweden: The geology and petrogenetic development of the Varberg region*. Geol. Fören. Stockh. Förh., 97, pp. 223-236.

Hubbard F.H. (1978) - *Geochemistry of the Varberg granite gneiss*. Geol. Fören. Stockh. Förh., 100, pp. 31-38.

Hubbard F.H., Whitley J.E. (1978) - *Rapakivi granite, anorthosite and charnockitic plutonism*. Nature, 271, pp. 439-440.

Hubbard F.H., Whitley J.E. (1979) - *REE in charnockite and associated rocks*. Lithos, 12, pp. 1-11.

Lamb W., Valley J. (1984) - *Metamorphism of reduced granulites in low-CO_2 vapour-free enrivonments*. Nature, 312, pp. 56-58.

Mohrén E., Larsson W. (1968) - *Beskrivning till kartbladet Laholm*. Sveriges Geol. Unders., Ser Aa, 197, pp. 1-42.

Mysen B.O. (1976) - *The role of volatiles in silicate melts: solubility of carbon dioxide and water in feldspar, pyroxene and feldspathoid melts to 30KB and 1625°C.*Am. J. Sci., 276, pp. 969-996.

Mysen B.O., Eggler D.H., Seitz M.G., Holloway J.R. (1976) - *Carbon dioxide in silicate melts and crystals. 1. Solubility measurements*. Am., J., Sci., 276, pp. 455-479.

Priem H.N.A., Boelrijk N.A.I.M., Hebeda E.H., Verdurman E.A.Th., Verschure R.H. (1973) - *Rb-Sr investigations on Precambrian granites, granite gneisses and acidic metavolcanics in central Telemark: metamorphic resetting of Rb-Sr whole rock systems*. Norges Geol. Unders., 289, pp. 37-53.

Quensel P. (1951) - *The charnockite series of the Varberg district on the south-western coast of Sweden*. Ark. Mineral., Geol., 1, pp. 229-333.

Samuelsson L. (1980) - *Major features of the Proterozoic of the Göteborg region Sweden*. Geol. Fören. Stockh. Förh., 102, pp. 141-144.

Samuelsoon L., Åhäll K.-I. (1985) - *Proterozoic development of Bohuslän, south-western Sweden*. In Tobi A.C., Touret J.R.L. Eds., The Deep Proterozoic Crust in North Atlantic Provinces. pp. 345-357, REIDEL, DORDRECHT.

Skiöld T. (1976) - *The interpretation of the Rb-Sr and K-Ar ages of Late Precambriàn rocks in south-western Sweden*. Geol. Fören. Stockh. Förh., 96, pp. 163-170.

Smålley P.C., Field D., Raheim A. (1983) - *Resetting of Rb-Sr whole rock isochrons during Sveconorwegian low-grade events in the Gjerstad augen gneiss, Telemark, southern Norway*. Isotope Geosci., 1, pp. 269-282.

Torske T. (1977) - *The South Norway Precambrian Region - a Proterozoic cordilleran-type orogenic segment*. Norsk Geol. Tidsskr., 57, pp. 97-120.

Torske T. (1985) - *Terrane displacement and Sveconorwegian rotation of the Baltic Shield: a working hypothesis*. In Tobi A.C., Touret J.R.L. Eds., The Deep Proterozoic Crust in North Atlantic Provinces. pp. 333-343. REIDEL, DORDRECHT.

Touret J.L.R. (1971) - *Le facies granulite en Norvège: Les associations mineralogiques*. Lithos, 4, pp. 239-249.

Versteeve A. (1975) - *Isotope geochronology in the high-grade metamorphic Precambrian of south-western Norway*. Norges Geol. Unders., 318. pp. 1-50.

Welin E., Gorbatschev R. (1978) - *The Rb-Sr age of the Varberg charnockite, Sweden*. Geol. Fören. Stockh. Förh., 100, pp. 225-227.

Wood D.A. (1979) - *A variably-veined sub-oceanic upper mantle: significance for mid-ocean ridge basalts from geochemical evidence*. Geology, 7, pp. 499-503.