Read at the Annual Conference of the Ussher Society, January 198

The geology and geochemistry of the Barfleur granite, Normandy, France

T.S. BREWER and G.M. POWER

Brewer, T.S. and Power, G.M. 1988. The geology and geochemistry of the Barfleur granite, Normandy, France. Proceedings of the Ussher Society, 7, 56-61.

The Barfleur granite, north-east Contentin, France is shown to consist of two main phases, a coarse megacrystic biotite granite (CMB) and a coarse equigranular microcline granite (CEM). They are petrographically and geochemically distinct and cannot be related by simple fractionation. Both show broadly S-type granite characteristics but comparisons with south-west England granites show they do not have the extreme values of Ba, Sr, Rb and Cs and a specific link *is* not obvious.

Dr. T. S. Brewer, Department of Geology, University of Nottingham, Nottingham NG7 2RD.
Dr. G.M. Power, Department of Geology, Portsmouth Polytechnic, Burnaby Road, Portsmouth POI 3QL.

Introduction

The Barfleur granite massif occupies the north-east corner of the Contentin peninsula, Normandy, France (Fig. 1). It forms an almost circular mass of about 250km^2, half on land and half under the sea (Lefort 1978). Exposure inland is rare but around the coast it is usually good and this yields a convenient traverse across the granite. To the west the granite is in contact with late Precambrian Brioverian metasediments but with a very restricted thermal aureole only several hundred metres wide. Triassic sandstones and conglomerates locally overlie the granite.

Published work on the granite appears to be very limited. Jeremine (1932) notes that the major part of the massif is composed of a coarse porphyritic two mica granite and gives a good petrographic description of this phase. She also mentions the presence of pegmatites and aplites and comments that the granite has a gneissose structure towards the western margin. Graindor and Pareyn (1971) in the explanatory notes to the St-Vaast-la-Hougue geological map sheet state that although on the map the whole of the granite is shown with the same ornament there are actually two main types, the Fermanville type to the west, which is a coarse equigranular two mica granite and the Barfleur type around Barfleur, which is a coarse porphyritic two mica granite with microclines reaching ten to twelve centimetres

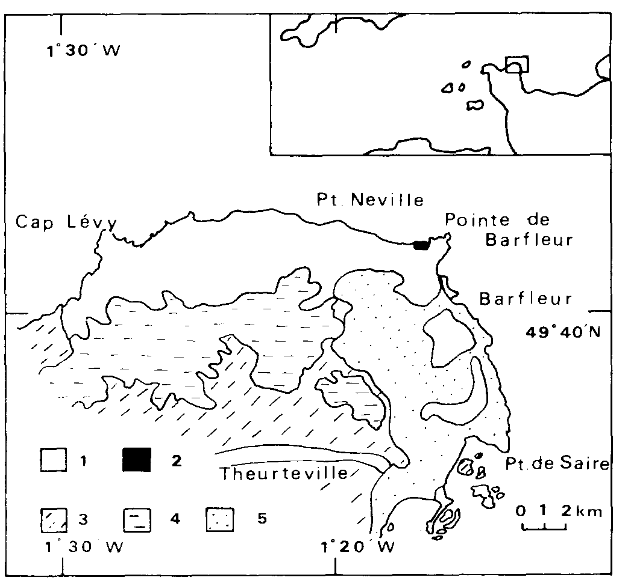

Figure 1. Sketch map of the Barfleur granite.

1: granite; 2: tourmaline leucogranite; 3: Brioverian metasediments; 4: Triassic sandstones; S: superficial deposits.

in length. A shear zone occurs between these two types suggesting a major fault between them. They also mention a third type, the Teurthville-Bocage-St-Vaast-la-Hougue granite which occurs as an imbricated slice within the Brioverian to the south-east of the main granite. This granite is said to have some of the characteristics of the Barfleur granite but comparisons are difficult because of its state of deformation.

The Barfleur granite is often assumed to be Hercynian in age but the only published radiometric age determinations are single mineral Rb/Sr and K/Ar values (Graindor and Wasserburg 1962; Leutwein 1968). These give K/Ar biotite ages in the range 340-330Ma; Rb/Sr biotite ages around 330Ma; and K/Ar Kfeldspar ages of 330 and 300Ma. At best these might only be interpreted as minimum ages.

This paper is based on the results of an initial field survey of the intrusion and thirty eight whole rock chemical analyses by x-ray fluorescence spectrometry for major and trace elements. The analyses are used to outline the chemical variation of the intrusion; to compare this with the chemistry of selected samples from the south-west England pluton; and as a basis for a discussion on the probable tectonic origin of the Barfleur granite.

Field and petrographic subdivision of the Barfleur intrusion

The field work has been limited so far to a rapid reconnaissance of the coastal sections and collection of rock samples for analysis, However this has enabled us to confirm that the intrusion is made up of two main granite types, a coarse megacrystic biotite granite (CMB) which occurs along the east coast and around Pointe de Barfleur, and a coarse equigranular microcline granite (CEM) which occupies most of the western part of the north coast (Fig. 1). So far we have seen no field evidence that establishes the relative ages of these types. West of Pointe de Barfleur near Havre de Roubary a medium grained tourmaline leucogranite is intruded into CMB granite forming a body about 500m wide. Fine grained, aplitic dykes and coarse tourmaline biotite pegmatites occur throughout the massif particularly in the CMB phase.

The coarse megacrystic biotite granite (CMB)

This is the phase that is so similar in field appearance to the coarse megacrystic biotite granites of south-west England. There are extensive tidal platforms formed of CMB granite fringing much of the east coast. This granite is characterised by its coarse grain size and massive nature and particularly by K-feldspar megacrysts which on average are 20-30mm in length but may reach 100mm. In the central part of the east coast between Pointȼ de Fouly and Anse du Hommet the CMB type merges

Table 1 Model anlyses

	BF05	BF11	BF18
Quartz	31.2	37.2	31.6
Plagioclase	24.7	12.9	36.8
K-feldspar	32.5	44.6	18.7
Biotite	10.1	6.2	8.6
Muscovite	1.2	-	4.2
Apatite	0.3	-	-

BF05: CMB granite; BF11: CEM granite;

BG18: medium grained poorly megacrystic granite

imperceptibly into a megacryst-poor medium grained granite. Further north at Landemer a two metre wide dyke of a very similar megacryst-poor granite cuts the CMB phase.

Perhaps the most spectacular section of the CMB granite is around the Pointe de Barfleur near Gatteville Phare. The tidal platform displays many wave-washed surfaces where the relationships between aplite and pegmatite dykes cutting the CMB granite may be studied. In addition to this there are concentrations of large K-feldspars in the granite forming bands and nests so that locally at least the rock is entirely composed of K-feldspar. This feature is outside the scope of this paper but certainly deserves more detailed study.

In thin section the CMB granite is composed of about equal proportions of quartz, plagioclase and K-feldspar (Table 1). The dominant mica is a deep brown biotite with muscovite only present as a sparse constituent.

Quartz forms equidimensional areas 4-5mm in diameter made up of several smaller grains with relatively simple grain boundaries. Plagioclase, sodic oligoclase in composition, occurs as subhedral laths 2-4mm in size and characteristically shows extensive complex relict oscillatory zoning preserved within the grains. K-feldspar is mainly present as euhedral megacrysts although some interstitial grains may also be found. Perthite within the megacrysts is only poorly developed and usually microperthitic. Some megacrysts show some cross-hatch twinning. This is not uniformly distributed across the grain but appears to be concentrated at cracks and other discontinuities and may be strain induced. The megacrysts often enclose other mineral phases including quartz and biotite but most commonly lathshaped shaped plagioclases up to 0.4mm in size. The included plagioclases may be concentrated in discrete zones, sometimes reflected by zoning in the K-feldspar, and their long axes often show a very strong preferred orientation parallel to possible crystal faces of the megacrysts. Graphic quartz intergrowths may occur towards the edge of the megacrysts suggesting simultaneous crystallisation of quartz and K-feldspar. The edges of the megacrysts, when in contact with plagioclase, often have bulbous myremekitic growths along the contacts suggesting some disequilibrium between the two feldspars. Biotite is common and forms 2-3mm red-brown lath shaped flakes. These often contain pleochroic haloes which form around 0.1mm monazite grains. Small prisms of apatite may also be included sporadically in the biotite. Muscovite is present but is not more than about 10% of the total mica and is usually closely associated with the biotite. Tourmaline is only present so rarely as brown-green zoned grains that it is not considered to be an essential mineral.

Medium grained poorly megacrystic granite

As mentioned above this granite is seen both as dykes cutting the CMB granite and as a phase merging imperceptibly into it. Both occurrences show very similar petrographic features. Muscovite is the more important mica and may form up to 70% of the total mica present. Some of the few K-feldspar megacrysts present are mantled by plagioclase in a Rapakivi texture. The other mineral phases appear rather similar to those in the CMB granite although with a smaller average grain size.

Tourmaline granite

The tourmaline granite is medium grained with only a slight tendency for the K-feldspar to be megacrystic. The main distinctive features are the widely dispersed presence of patchy yellow-green grains of tourmaline with irregular boundaries and muscovite occurring as up to 30% of the total mica.

Coarse equigranular microcline granite (CEM)

This granite type occurs all along the north coast from Pointe de Neville. It has a fairly smooth appearance and weathers to either a yellow or pink colour. Under the microscope it is seen to be composed of abundant quartz and microcline perthite with variable amounts of plagioclase and biotite but not muscovite (Table 1). Plagioclase is usually altered and biotite is often recrystallised to aggregates of small flakes occurring together with sphene, epidote and magnetite. All specimens examined showed some evidence of deformation.

Quartz tends to occupy areas of 4-5mm in size made up of several simple grains. Often these grains show undulose extinction and have 0.1 mm polygonal quartz grains developed all around their margins. This is interpreted as strain induced grain boundary recrystallisation.

Plagioclase is variable in abundance but usually very subordinate to K-feldspar. It has an almost bimodal distribution of grain size with smaller grains around 2mm and larger ones around 4mm in size. Some simple compositional zoning occurs but the plagioclase is sodic (An15) in composition. It is invariably cloudy with alteration products. Microcline is always abundant. It is coarsely perthitic and cross-hatch twinning is extensively developed.

Towards the western contact of the massif the granite takes on a marked foliation. The foliation is defined by stringers of quartz and fine grained biotite. The quartz stringers are composed of a mosaic of 0.1mm polyhedral quartz grains. Feldspars are fractured and microcline is broken into a series of lensoid fragments drawn out along the foliation. The petrographic features of the foliated granite support the view that it is a more deformed version of the CEM granite and that the deformation took place at temperatures at which biotite was a stable phase.

Geochemistry

Methods

38 rock specimens from the Barfleur massif were chemically analysed by x-ray fluorescence spectrometry for major, and a range of trace elements. At least 2kg of rock was broken into small chips with a jaw crusher and then a representative sample was crushed to a smooth powder in a tungsten carbide lined Tema swing mill. The major elements were determined on fusion discs and the trace elements on pressed powder pellets using routine procedures at Nottingham University. Table 2 gives results for selected typical specimens.

Results

All the rocks analysed are peralkaline and show a calc-alkaline tendency with wt% K_2O greater than Na_2O. However the two main granite types distinguished by the field and petrographic study may be further differentiated by their geochemical character. Examination of the averages for the CMB and CEM granites in Table 3 shows many significant differences between them particularly in SiO_2, $A1_2O_3$, TiO_2, MgO, CaO, P_2O_5, Ba, Ga, Pb, Sn, Sr, V, Y, and Zr. It might be argued that some of these differences might be ascribed to fractionation processes of a crystallising magma as the mean SiO_2 of the CMB granite is close to 70% and that of the CEM granite nearly 75% and at these high silica contents quite dramatic fractionations may occur. However bivariate plots of major elements against SiO_2 show that where there is a linear trend within the CMB granites then for Fe_2O_3 (Fig. 2A), MgO, CaO, and TiO_2 the CEM granites do not plot on the extension of this trend but have a relatively higher content of the element than might be expected if they were the product of fractionation. Indeed the medium grained poorly megacrystic granites, tourmaline granites and aplites (i.e. the "other" granites)

Table 2. Selected chemical analyses of Barfleur granites

	BF05	BF11	BF18	BF32	BF12	BF14
SiO_2	69.69	74.56	72.02	72.66	73.22	74.83
Al_2O_3	15.64	13.31	I5.02	15.35	14.08	15.08
TiO_2	0.46	0.28	0.27	0.21	0.29	0.07
Fe_2O_3	2.54	1.97	1.56	1.31	2.14	0.46
MgO	0.93	0.23	0.64	0.32	0.59	0.04
CaO	1.8	0.82	1.34	1	0.5	0.59
Na_2O	2.78	3.1	3.1	3.17	3.19	3.55
K_2O	5.16	4.91	4.92	4.86	4.57	4.39
MnO	0.03	0.03	0.06	0.02	0.07	0.07
P_2O_5	0.14	0.05	0.15	0.06	0.06	0.07
LOI	0.82	0.59	0.79	0.7	0.98	0.63
Ba	692	360	514	643	483	44
Ce	78	78	53	57	46	15
Cr	18	9	11	bd1	7	3
Cs	17	4	15	22	9	70
Ga	26	19	26	28	20	30
Hf	8	6	bd1	bd1	7	bd1
La	40	39	35	42	33	15
Nb	12	10	19	16	16	20
Nd	31	28	23	20	28	bd1
Ni	4	2	7	4	4	bd1
Pb	30	20	30	57	18	22
Rb	277	231	338	307	182	429
Sc	4	0	7	3	bd1	2
Sm	8	7	6	6	7	7
Sn	8	0	19	bd1	10	12
Sr	374	67	274	298	101	46
Ta	bd1	bd1	bd1	bd1	bd1	7
Th	29	22	14	21	31	8
U	3	4	2	4	6	2
V	35	19	18	13	21	3
Y	15	39	18	12	55	22
Yb	2	3	2	3	5	3
Zn	39	31	36	26	26	I5
Zr	200	163	133	112	151	36

bd1: below detection limit.

BFO5: CMB granite, near Les Chambres, S of Gatteville Phare.

BE 11: CEM granite, Rocher Ecale, N of Renouville mid N coast. BF18: Medium grained poorly megacrystic granite, Pointe de Fouly. BF32: Tourmaline granite, W of Havre de Roubary, Pointe de Barfleur. BF12: Deformed granite, St-Vaast-La-Hougue.

BF14: Garnetiferous aplite, Pointe de Saire, lower E coast.

are more likely to fall on the trend and on these grounds they could be reasonably considered to be the advanced fractions of the CMB granite.

Bivariate plots for trace elements against SiO_2 show that certain trace elements (e.g. Ba, Ga, Pb, Sr) do show the CEM samples plotting on an extension of the CMB trend. However V (Fig. 2B) clearly does not and if it is accepted that the CMB granite and the "other" granites do form a likely fractionation sequence then many other CEM elements do not fall on this trend (Ce, La, Nb, Nd, Th, Zn and Zr). In addition the Rb values for the GEM granite are actually lower than those for the CMB granite. Fractionation would be expected to produce higher Rb in the more evolved fractions. Finally if the high Y values of the CEM granite were the result of fractionation of the CMB granite then this would require much more extreme fractionation than would he suggested by plots for the other elements. In other words the geochemical evidence strongly supports the argument that the GEM granite is not the product of simple fractionation of the CMB granite and requires a different model for its origin.

Comparison with the chemistry of SW England granites

The similarity in appearance and presumed age of the CMB granite and the coarse megacrystic granites of south-west England invites a comparison of their geochemistry. The analyses given in Darbyshire and Shepherd (1985) have been used to provide a sample of south-west England granites for this purpose. These analyses are nearly all of coarse megacrystic biotite granites. They have the advantage that they were analysed by almost identical procedures to the Barfleur rocks so that inter-laboratory bias should be minimal.Table 3 gives the mean value for the granite samples. The major element comparison shows the south-west England granite sample to lie between the slightly more basic CMB granite and the slightly more acid GEM granite. It is notable that the CMB granite has on average about double the TiO_2, MgO, and CaO and half the P_2O_5 content of the south-west England sample. The south-west England sample shows the well known relative enrichment in Rb and Cs and extreme depletion in Ba and Sr characteristic of the south-west England pluton. The CMB granite, although only about 2.5% lower in SiO_2, has relatively much less Rb and Cs and relatively much more Ba and Sr. Other differences between the two samples are the significantly higher Th, V and Zr of the CMB granite and its lower Sn content.

Although the CMB granite seems the obvious one to compare with the south-west England sample of mainly coarse megacrystic granites, in fact, the CEM granite seems to be much closer to it in major element geochemistry. However there are important differences in trace element chemistry. The average Y content of the CEM granite is double that of the south-west England sample and Y is possibly highest in the foliated CEM granites. Although the CEM granite is more siliceous than the south-west England sample it contains more average Ba, Th and Zn, about the same Sr and less Cs, Rb and Sn.

Fig. 2C is a plot of SiO_2 against Rb for all the granites. It clearly demonstrates the increases in Rb with SiO_2 for the south-west

Table 3.Mean and stansard deviations, Barfleur and SW England granites

	CMB	sd	CEM	sd	SWE	sd
SiO_2	69.98	0.82	74.75	0.49	72.56	1.24
Al_2O_3	15.58	0.33	13.18	0.24	14.43	0.62
TiO_2	0.4	0.06	0.24	0.02	0.24	0.07
Fe_2O_3	2.23	0.25	1.91	0.11	1.96	0.45
MgO	0.83	0.14	0.33	0.07	0.37	0.13
CaO	1.68	0.18	0.92	0.1	0.73	0.24
Na_2O	2.89	0.33	2.92	0.34	3.15	0.23
K_2O	5.33	0.27	4.91	0.22	5.19	0.33
MnO	0.04	0.01	0.04	0.01	0.05	0.01
P_2O_5	0.14	0.02	0.04	0.01	0.24	0.04
LOI	0.69	0.14	0.61	0.05		
Ba	739.6	63	299.7	48.7	171.4	74.4
Ce	78.4	10.5	67.9	28.3	57.9	21.1
Cr	16.6	3.9	9.8	6.1		
Cs	16.7	5.6	7.7	5.3	48.5	15.8
Ga	25.3	1.1	18.1	1.1	25	2.2
Hf	6.5	1.3	6.6	1.5		
La	41.4	4	36.4	8.3	26.3	10.2
Nb	12.5	1.1	10.5	1.3	17.6	4.7
Nd	30.2	2	27.9	8.5		
Ni	6.9	2.3	2.6	2.2	7.7	4.8
Pb	31.5	2.1	19.1	1.3	26.9	5.7
Rb	287.2	19	229.8	19.1	485.4	84.7
Sc	5.1	2	5.8	6.6	3.2	1
Sm	7	2.2	7.3	1.7		
Sn	6.8	2.5	2.4	3.1	12.2	7.4
Sr	326.8	38.6	63.5	7	71.5	31.2
Ta	1.2	1.5	0.2	0.6	2.6	2.3
Th	30.8	3.3	26.3	5.5	15.5	4.9
U	3.5	1.1	4.7	2.1	11.7	4.4
V	33.3	5.6	16.4	2.1	15.3	7.8
Y	15	2	43.9	9.4	23.6	6.2
Yb	2.9	0.7	3.5	1.3		
Zn	39.4	3.9	26.9	3.2	45.4	14.2
Zr	197.4	14.3	148.9	11.8	110.4	27.3

sd: standard deviation

CMB: Coarse megacrystic biotite granite, Barfleur. Mean of 10 rock analyses.

CEM: Coarse equigranular microcline granite, Barfleur. Mean of 10 rock analyses, inc. 3 foliated granites.

SWE: Mostly coarse megacrystic granites, SW England. Mean of 38 rock analyses, (Darbyshire and Shepherd 1985).

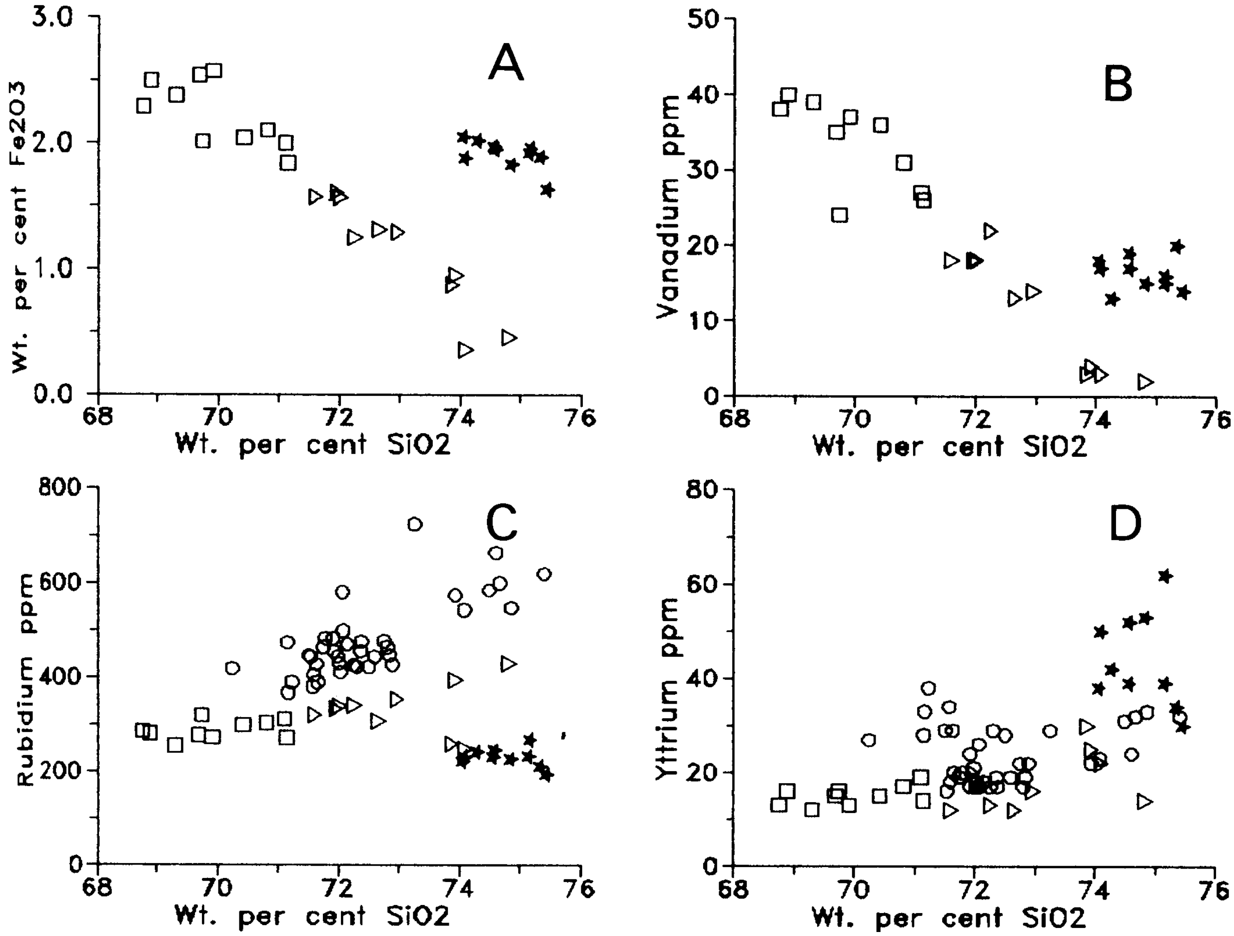

Figure 2. A. SiO_2 wt%v Total iron as Fe_2O_3 wt% for Barfleur granites. B. SiO_2 wt% v Vanadium ppm for Barfleur granites.
C. SiO_2 wt% v Rubidium ppm for Barfleur and south-west England granites. D. SiO_2 wt% v Yttrium ppm for Barfleur and south-west England granites

Key: Squares: CMB granite; Stars: CEM granite; Triangles: other granites (includes poorly megacrystic granites, tourmaline granites and aplites); Circles: south west England granites.

England sample and a corresponding, though less pronounced, increase for Rb in the CMB granite and its other phases and aplites. The CEM granite shows lower Rb than all the other granites. This plot also shows that the south-west England sample is relatively more enriched in Rb than the Barfleur granites at comparable SiO_2 levels.

Fig. 2D shows SiO_2 against Y for all the granites and the southwest England sample straddles the zone between the CMB and CEM granites and emphasises again the relatively high Y content of the CEM granite.

Fig. 3 is a plot of U against Th for all the Barfleur and south-west England granite specimens. It shows that thorium is more abundant and uranium less abundant in both the CMB and CEM granites than in the south-west England granite sample. However because of the probability of varying amounts of uranium loss during secondary processes it is not possible to say much about variations in U/Th ratios.

In summary, plots such as Fig. 2C, 2D and 3, demonstrate that, not only is it impossible to derive the CEM granite from the CMB granite at Barfleur by simple fractionation, but also that the Barfleur granites are not earlier fractions of a single magma that produced both them and the south-west England coarse megacrystic granites by simple fractionations.

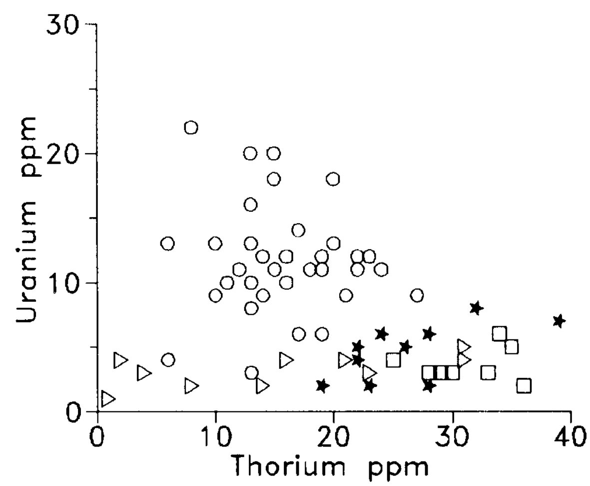

Figure 3. Thorium ppm v Uranium ppm for Barfleur and south-west England granites.

Discussion

The aim of this study was to provide some preliminary information on the petrography and geochemistry of the Barfleur granite in order to define its internal variations and to act as a basis for comparisons with other Hercynian granites. Comparisons with the south-west England granites are of interest for a number of reasons. The Barfleur granite might provide clues as to what a south-west England granite might have been like without the overprint of mineralisation. Close similarity in properties between the two granites might provide support for the suggestion (Shackleton *et al.* 1982) that the south-west England granites were generated to the south and were injected northwards. The Barfleur granite occupies a pivotal position between the south-west England pluton in the external (Rheno Hercynian) zone of the Variscides and the internal (Vendee Moldanubian) zone further south. This might mean totally different source regions for the granites which could be revealed by fundamental differences in their geochemistry. All these comparisons assume a close similarity in age for the granites.

Both the CMB and CEM granites have been shown in this study to have broadly S-type granite characteristics and their Ocean Ridge Granite normalised plots (after Pearce *et al.* 1984) show broadly similar patterns in terms of relative enhancements and depletions to the south-west England sample (Fig. 4). However this is as far as the similarities go between the three granites. This study has also shown that none of the three granites are related by simple fractionation models.

Fig. 5 is a plot of log (Y+Nb) against log (Rb) (Pearce *et al.* 1984). The south-west England sample plots within the Syn-collision granite field and so does the CMB granite sample together with its other phases and aplites. However the CEM granites plot below the Syn-collision field mainly within the Volcanic Arc field. Pearce *et al.* (1984) are most careful to point out that their boundaries are arbitrary and defined by the limited number of sample sets they used to construct the diagram and that tectonic origin should not be based on one line of evidence alone. Syn-collision granites might plot below their proposed field boundary if they were derived from Rb-poor crust or if the fluid component were small. However this plot does emphasise the difference in some particular aspects of the chemistry of the CEM granite and a note of caution is sounded against the assumption that the whole of the Barfleur pluton has a similar tectonic origin. It might be argued that this is reinforced by the field and petrographic evidence that parts of the CEM granite exhibit a very strong deformation fabric.

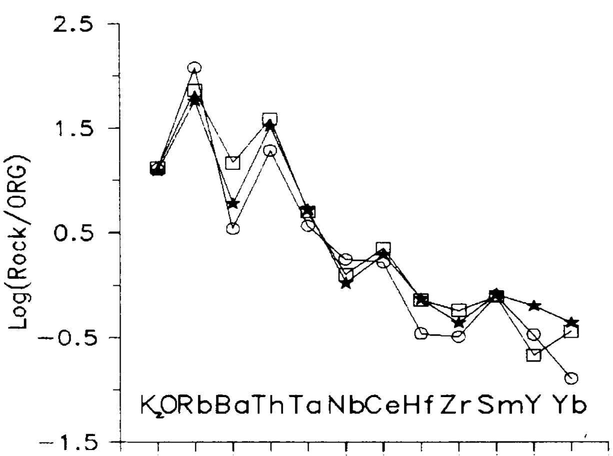

Figure *4*. Mid-Ocean Ridge normalised patterns (after Pearce *et al 1984)* for CMB (squares), CEM (stars) and south-west England (circles) granite average values (Table. 3). Missing values are taken from Pearce *et al. (1984)*.

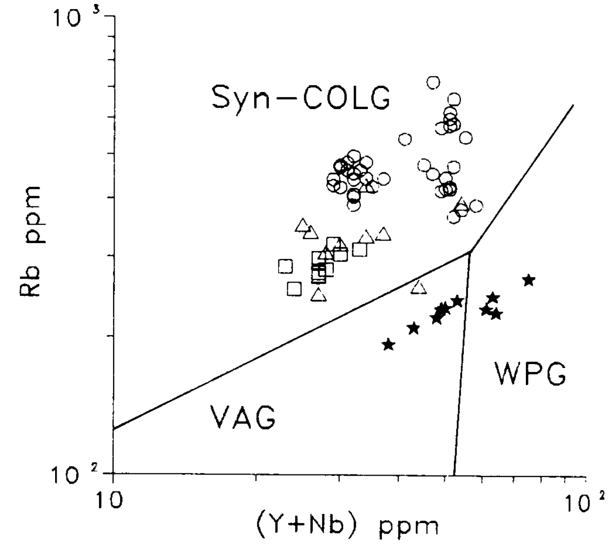

Figure *5*. Plot of log (Y+Nb) v Log (Rb) (Pearce *et al. 1984)* for CMB (squares), CEM (stars) and south-west England (circles) granites. Syncoll Syn-collision granites field. VAG: Volcanic arc granites field. WPG: Within plate granites field.

Further work is in progress on the chemistry of the Barfleur granite particularly on the geochemistry of the rare earth elements and the volatile elements B, F and C1. Isotopic age determinations must be of critical importance. Until this work is completed it would be premature to take our conclusions any further. But when it is complete an obvious next step would be to make comparisons with the chemistry of the Hercynian granites of mainland Europe.

Conclusions

The Barfleur granite has been subdivided into two main phases on both petrographic and geochemical evidence. The coarse megacrystic biotite granite (CMB) contains microperthitic K-feldspar megacrysts, oscillatory zoned sodic plagioclase, abundant biotite, some muscovite and texturally simple quartz grains. The coarse microcline granite (CEM), on the other hand, is more equigranular and contains coarsely perthitic microcline, poorly zoned plagioclase, partially recrystallised biotite with no muscovite and quartz which usually shows some recrystallisation. The CEM granite is strongly deformed near its western margin. There are many significant differences in chemistry between the granites (SiO_2, TiO_2, CaO, P_2O_5, Ba, Ga, Pb, Sn, Sr, V, Y and Zr) and most notably in the Rb and Y levels of the CEM granite and it is concluded that they cannot be related by a simple fractionation model. It is not impossible that there may be a considerable age difference between them.

The CMB and CEM granites both have the broad characteristics of S-type granites and to this extent they are similar to the coarse megacrystic granites of south-west England. However they do not compare in the extreme fractionations of Ba, Sr, Rb, and Cs characteristic of the south-west England granites and neither can be related to the south-west England samples by simple fractionation models.

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