Note of a poster display at the Annual Conference of the Ussher Society, January 1997

A GEOCHEMICAL DICHOTOMY IN THE CORNUBIAN BATHOLITH

M. STONE

Geochemical comparisons, using the main granite types in each pluton, reveal significant differences in TiO_2, total iron, Nb, Zr and Y between the coarse-grained megacrystic granites of Dartmoor (DT), St Austell (SA) and Land's End (LE) on the one hand and the small megacryst granites of the Isles of Scilly (SC), Carnmenellis (CM) and Bodmin Moor (BD) on the other. These differences, which largely reflect differences in biotite composition and associated accessory minerals, are seen also in multivariate treatment of selected and bulked data and in REE patterns, recent Nd-isotope and age data. They reflect a geochemical change from an older, more typical S-type post-orogenic granite suite (SC, CM, BD) to a younger, somewhat more basic suite (LE, SA, DT). The latter suite is associated with more abundant basic microgranite enclaves, some of which have partial I-type granite characteristics, and Li-mica granites, which are believed to have originated in the lower crust with contributions from the mantle.

Whilst the main energy source for the genesis of all these granite plutons is probably mantle-derived, as indicated by almost contemporaneous mafic volcanism, a mantle contribution is more clearly evident in the case of the later granite suite.

M. Stone, Earth Resources Centre, University of Exeter, Devon EX4 4QE

INTRODUCTION

Dangerfield and Hawkes (1981) distinguish between a coarse-grained megacrystic granite, in places poorly megacrystic, in the Lands's End (LE), St. Austell (SA) and Dartmoor (DT) plutons, and a coarse-grained granite with small megacrysts in the Isles of Scilly (SC), Carnmenellis (CM) and Bodmin Moor (BD) plutons, i.e. an alternating pattern of two textural types. In a comparison between the coarse-grained megacrystic (CGM) granite of the Dartmoor pluton and the coarse-grained small megacryst (CGm) outer granites of the Carnmenellis and Isles of Scilly plutons, Stone (1995) shows that, in terms of a femic constituent suite, the Carnmenellis and Isles of Scilly CGm-granites are similar but differ markedly from the Dartmoor CGM-granite and suggests that the alternating pattern in texture along the batholith is reflected also in the geochemistry. The batholith is composed predominantly (>90%) of medium- to coarse-grained megacrystic biotite granites, i.e. the CGM and CGm granites which make up the type B granites of Exley and Stone (1982), so that these granites are the most appropriate for making comparisons.

The aims of this study are to extend the geochemical comparison of the principal granites of each pluton along the batholith in order to investigate more comprehensively differences between plutons already known or suspected, to link these with published REE patterns, Nd isotope data and age determinations and attempt to explain the observed patterns petrogenetically.

GEOCHEMICAL DATA

Data sets

Available geochemical data sets include those obtained at (i) Exeter for SC, CM and DT, (ii) Keele for SA (Exley, personal communication) and BD (Exley, 1996) and (iii) BGS (Darbyshire and Shepherd, 1985) for LE, CM, SA, BD and DT. Additional data occur in Watson *et al.* (1984) for DT, Webb *et al.* (1985) for CM, Charoy (1986) for CM, Manning and Hill (1990) for SA, Ward *et al.* (1992) for DT, Van Marcke de Lummen (1986) for LE, and older 'classical' papers, e.g. Brammall and Harwood (1932) for DT and BD, Ghosh (1927) for BD and (1934) for CM. The older sources and Booth and Exley (1987) for LE, lack trace element data.

Problems arise in pooling analytical data owing to interlaboratory bias. This is apparent in the overviews of major element patterns using cluster analysis (Stone and Exley, 1978; Exley *et al.,* 1983) which show clusters that correspond with granite type and subclusters that correspond with individual plutons (studied in different laboratories). Wide differences between laboratories result in wide data spreads that can hide both real differences between similar rocks and significant trends that may contain petrogenetic information. Use of data from all sources increases 'background noise', although differences/patterns that show through this may be more significant than indicated.

A compilation of averages for selected oxides/elements in the CGM and CGm granites of the six major plutons (Table 1) shows some of the problems in pooling data, but also reveals similarities, for example, within CM (rows 11-13) and DT (rows 1-3). Each of the Exeter and BGS data sets, which cover several plutons, should be internally consistent and can be used in an initial appraisal of differences. The close similarity between data from both these sources (Table 1 and the discriminant analysis referred to below) means that the data can be pooled, although the more limited data for LE, SA and BD in the BGS data set lead to wide differences between sample numbers and result in wider confidence limits. Table 1 shows that TiO_2, tFeO, Nb, Zr and Y and probably Ce are higher in LE, SA and DT than in the adjacent plutons irrespective of source.

Means with 95% confidence intervals

Marked differences between plutons are revealed by large F-values (i.e. between pluton variance/within pluton variance) and the absence of marked overlap of the confidence limits about means. Differences between DT on the one hand and SC and CM on the other (using Exeter data alone) reveal enrichment of TiO_2, tFeO, MgO, Nb, Zr and Y (i.e. the 'femic suite') in the former relative to the latter (Stone, 1995). These patterns are extended to all plutons by using the pooled Exeter (EX) and BGS data. The distinctive zig-zag pattern, as shown by TiO_2 (Figure la), tFeO (Figure lb) and Nb (Figure 1c) is also typical of Zr, Y (and especially Nb+Y), Th and, to a lesser extent, Ce and V, indicating that the LE, SA and DT (LESADT) plutons are enriched in these constituents relative to values in the adjacent SC, CM and BD (SCCMBD) plutons. Within the zig-zag patterns, the SCCMBD plutons have similar values of these constituents that are significantly different from those in the LESADT plutons. The latter also have similar valus, especially LE and SA, but

Pluton		Type	Lab	No	TiO_2	Al_2O_3	tFeO	CaO	Nb	Zr	Y	Sr	Ce	Th	Ga
1	DT	CGM	EX	14	0.36	14.54	2.6	1.03	17	146	38	81	64	32	17
2	DT	CGM	BGS	3	0.39	14.22	2.73	1.22	20	151	35	88	72	21	22
3	DT	CGM	W	9	0.37	14.23	2.7	1.37	19	172	23	101	65	nd	nd
4	DT	PM	EX	12	0.21	12.94	1.77	0.5	17	109	36	37	40	28	16
5	DT	PM	BGS	3	0.17	13.1	1.76	0.4	20	97	32	19	35	14	23
6	DT	PM	W	5	0.25	13.6	2.09	0.76	16	140	21	58	37	nd	nd
7	BD	CGm	BGS	5	0.24	14.94	1.63	0.78	13	111	18	95	58	13	25
8	BD	CGm	K	38	0.24	15.26	1.8	0.75	14	84	12	90	65	nd	nd
9	SA	CGM	BGS	4	0.32	14.39	2.16	0.96	22	150	29	77	77	21	22
10	SA	CGM	K	8	0.37	14.39	2.27	0.9	37	123	10	80	75	nd	nd
11	CM	CGm	EX	34	0.25	15.13	1.6	0.96	12	110	16	87	73	14	21
12	CM	CGm	BGS	12	0.23	14.82	1.61	0.81	14	106	19	92	61	16	26
13	CM	CGm	BC	7	0.26	14.8	1.62	0.69	nd	100	12	85	63	20	nd
14	LE	CGM	BGS	5	0.29	14.51	2.1	0.72	22	140	27	71	84	22	25
15	SC	CGm	EX	22	0.24	14.84	1.5	0.81	12	117	16	108	78	27	21

Pluton: DT = Dartmoor, BD = Bodmin Moor, SA = St. Austell, CM = Carnmenellis, LE = Land's End, SC = Isles of Scilly. Granite type: CGM = coarse-grained megacrystic, PM = poorly megacrystic, CGm = small megacryst.
Lab. (i.e. source): EX = Geology/ERC, Exeter University; BGS = British Geological Survey (Darbyshire and Shepherd, 1985), W = Ward *et al.* (1992), K = Geology, Keele University (Exley, 1996 and personal communication), BC = Charoy (1986). nd = not stated or determined.

DT is even richer in TiO_2, tFeO and Y, although poorer in Nb compared with LE and SA. Means for Al_2O_3 and Sr show inverse zig-zag patterns that overlap in their confidence intervals. In general, SC, CM and BD, are more aluminous compared with the other plutons, a feature reflected in the common occurrence of andalusite and, rarely, sillimanite. The Fe-rich and generally more Mg-rich nature of LE, SA and DT result in the sporadic occurrence of cordierite and almandine not associated with observed pelitic xenoliths. Means from several other sources are also shown in Figure 1: most lie close to those of the pooled data or actually enhance the zig-zag pattern. Although the data points of Stimac *et al.* (1995) often lie away from the BGS/EX means, they generally enhance the zigzag pattern and, indeed, despite their single data points, show a clear and consistent zig-zag pattern of their own.

Table 2. Q-mode cluster analysis summary

Pluton	Source	No. of Samples
Mixed SC, CM	EX	8
DT	EX	3
BD	K	1
Mixed SC, CM	EX	11
BD	BGS	1
CM	BGS, BC, EX	14
Mixed CM, BD	BGS, BC, K	25
CM	EX	1
Mixed LE, SA, DT	BGS	8
DT	EX	6
SA, DT	BGS	3
DT	EX	4
LE	BGS	1
SA	K	11

No of samples from top downwards in computer output.
Elements used: Ti, Fe, Mg, Ca, Zr, Y, Sr, V, Ba, La, Ce.
Total samples = 97; total variables = 11.
Output matrix = Pearson correlation matrix.
Abbreviations as in Table 1.

Cluster analysis

Q-mode cluster analysis of Exeter data (not shown) reveals a partial clustering of DT samples and largely intermixed CM and SC samples. For cluster analysis using data from all six plutons, some data selection was necessary, using random numbers, from plutons having large numbers of analyzed samples (DT, CM, SC) in order to simplify computer handling. A cluster dendrogram for all variables (not shown) produces clearer clustering of SC, CM and BD on the one hand from LE, SA and DT on the other. This grouping is well marked in the condensed cluster "dendrogram" (Table 2) using only the 'femic suite' of constituents, although there is some laboratory subclustering. Apart from three DT samples that fall within the SCCMBD group, marked clustering of the LESADT plutons on the one hand and the SCCMBD plutons on the other, points to some fundamental differences in those elements that go mainly into the femic mineral biotite and associated accessory minerals.

Discriminant analysis

The Minitab package gives the Mahalanobis D^2 or squared distance between multivariate means and the efficiency of classification (misclassified samples are listed with probabilities). The smaller the value of D^2, the closer are the means. Linear discriminant analysis using the nine major oxides, the five constituents TiO_2, tFeO, Nb, Zr and Y, or these constituents and Al_2O_3, Sr and Ce, consistently group the SC, CM and BD plutons together, whereas in the LESADT group, LE and SA have closest similarity and lowest D^2 values whilst DT has higher values, although its closest similarity is with LE and SA. The D^2 values between SC, CM and BD in Table 3 are consistently low, as are those between LE and SA, but DT stands somewhat apart from these two, except in the DT row where the lower values (though high compared with other low values) correspond with LE and SA. The dichotomy is seen also in the classification given in Table 3. Columns correspond with the original plutons, so that the sums (N) correspond with the original number of samples from each pluton. Rows show the way that the discriminant analysis has classified the samples: thus, of the 17 samples in the DT column, 12 are actually classified with DT and 4 with LE + SA. The only aberrant sample is one DT that has been classed with BD. Most samples are either correctly classified or are classed with granites of the same group and

Table 3. Discriminant analysisoutput

Classification

	Original					
New	DT	BD	SA	CM	LE	SC
DT	12	0	0	0	0	0
BD	1	4	0	16	0	3
SA	3	0	4	0	1	0
CM	0	0	0	25	0	4
LE	1	0	0	0	4	0
SC	0	1	0	5	0	15
N	17	5	4	46	5	22
N*	12	4	4	25	4	15
NLESADT	16	0	4	0	5	0
NSCCMBD	1	5	0	46	0	22

D^2 values

	DT	BD	SA	CM	LE	SC
DT	0.0	25.6	12.4	27.6	17.5	36.9
BD	25.6	**0.0**	30.4	**1.1**	32.2	**2.1**
SA	12.4	30.4	0.0	33.3	1.2	41.1
CM	27.6	**1.1**	33.3	**0.0**	34.4	**2.5**
LE	17.5	32.2	1.2	34.4	0.0	43.0
SC	36.9	**2.1**	41.1	**2.5**	43.0	**0.0**

Pooled samples (EX and BGS). Eight variables (TiO_2, Al_2O_3, tFeO, Nb, Zr, Y, Sr and Ce). Pluton abbreviations as in Fig. 2.
N = total in column (i.e. total samples from each pluton); N* = no. classified in pluton; NLESADT = no. of samples put into LE, SA and DT; NSCCMBD = no. put into SC, CM and BD.
D^2 = Mahalanobis distance between multivariate means.
Similarities in SCCMBD group in bold type; those in LESADT group underlined.

there is mixing of samples within the SCCMBD group. SA values plot in the SA group only, although some DT data (in col. 1) plot with SA and LE (most likely the result of a larger data set). A similar pattern occurs when data from more sources are used (140 analyses), resulting again in a clear cut SCCMBD group and a LESADT group with a clear LE and SA similarity and a slightly more distant DT.

If we use the five constituents TiO_2, tFeO, Nb, Zr and Y from all six plutons and four laboratories, giving 15 different data sets (data from Charoy (1986) are omitted owing to lack of Nb analyses) we get consistent multivariate similarities between BGS and Exeter data (not shown) that supports the initial decision to pool these data.

Data plots

Moderate to high positive correlation coefficients consistent with marked positive linear trends are common between elements/oxides of the femic suite'. Such trends, e.g. Zr vs TiO_2 (*cf.* Fig. 3a in Stone, 1992), are apparent in rock sequences showing diminishing contents in later evolved rocks. However, it is clear that both within individual plutons of the Cornubian batholith and in the batholith as a whole, these coarse-grained megacrystic CGM and CGm biotite granites *on their* own show similar, elongate, though less extended fractionation trends. Some laboratory differences are apparent, yet there is a clear distinction between the fields of data points for the LESADT and SCCMBD granites; the former are consistently higher and give a bivariate representation of Figs la and lb. However, the covariation between Zr and TiO_2 (and many other pairs of elements/oxides in the femic suite') in each field reflects the common fractionation process indicated on the larger scale when data from later intrusions (e.g.Carnmenellis and Isles of Scilly inner granites and aplites/microgranites) are included (Figure 2).

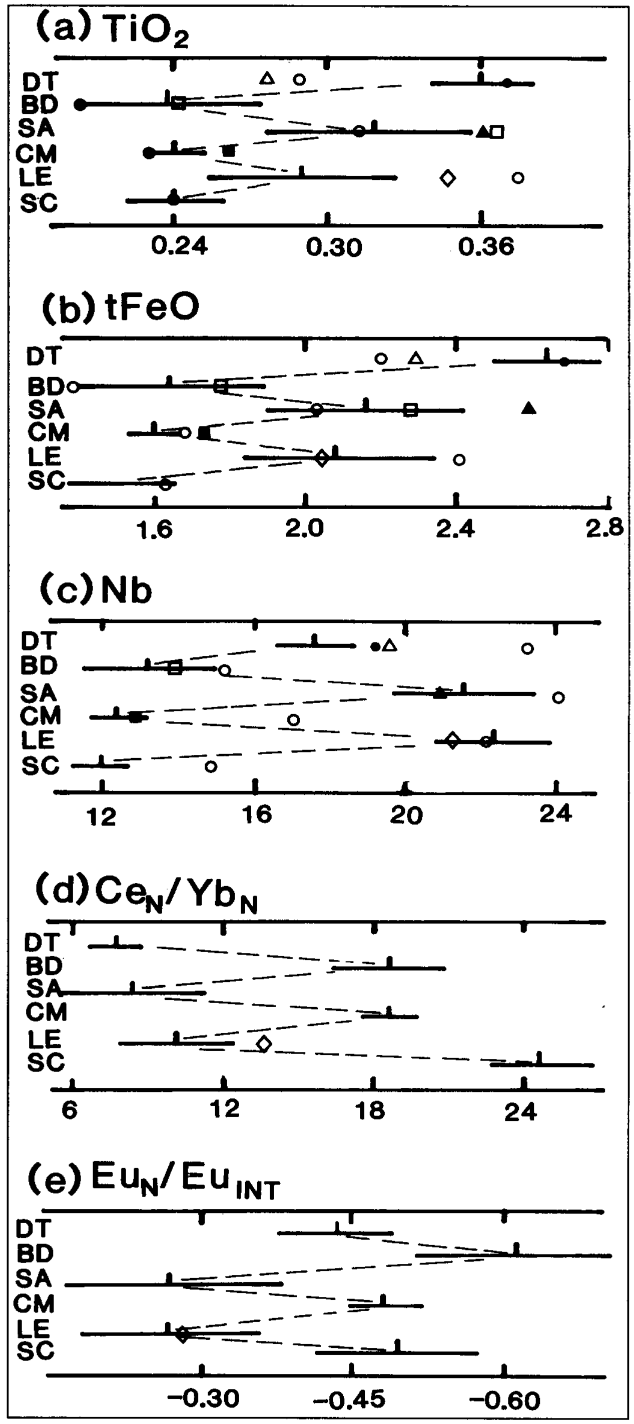

Figure 1. Means and confidence intervals for (a) TiO_2 (wt.%), (b) tFeO (wt.%), (c)Nb (ppm), (d) $Ce_{N/YbN}$, (e) Eu_N/Eu_{INT}, where N refers to chondrite-normalized values and Eu_{INT} is the interpolated value of Eu_N between Sm_N and Gd_N. Left hand side abbreviations indicate pluton (as in Table 1). Number of samples, firstly in a, b and c, then in d and e, as follows: DT (17, 10), BD (5, 3), SA (4, 2), CM (46, 15), LE (5, 3), SC (22, 4). F-values for TiO_2 =22.2, tFeO= 37.9, Nb = 49.8, CE_N/Yb_N= 57.1, Eu_NN/Eu_{INT}= 8.7 note that these figures show marked betweenpluton differences (betweenpluton similarity is indicated when F approaches 1). Other sources: small closed circles -Ward et al. (1992); closed squares - Webb et al. (1985); closed triangles - Manning and Hill (1990); open circles - Stimac et al. (1995); open squares - Keele (Exley, 1996 and unpublished); open triangles - Watson et al. (1984); open diamonds - Van Marcke de Lummen (1986).

Separation of composition fields between DT and SA on one hand and CM and SC on the other is apparent in the Rb *vs* Nb+Y and Nb *vs* Y discriminant plots (*cf.* Fig. 4b in Stone, 1992). It is clear from Figure 1 and the fairly constant Rb range in all these granites that the LESADT data will plot close to the within-plate granite (WPG) field and that, in the Nb vs Y plot DT, SA and LE data fall together and, as in Fig. 4a of Stone (1992), will overlap into this field, whereas BD, CM and SC data plot well within the syn-collision granite (Syn-COLG) field of Pearce *et al.* (1984).

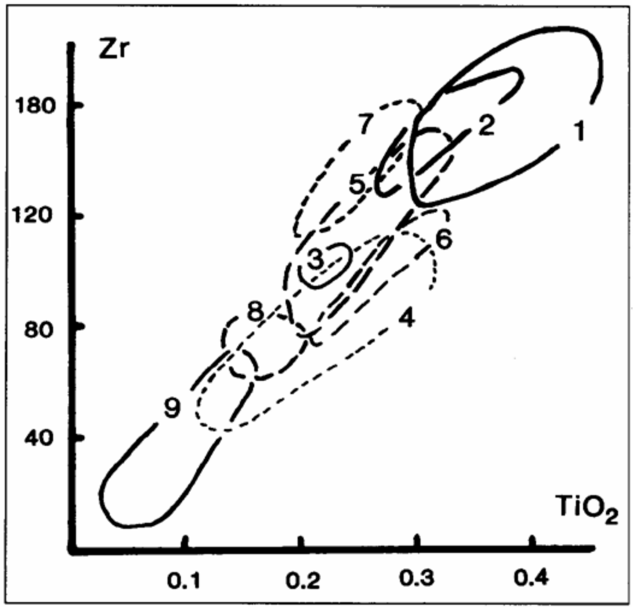

Figure 2. Zr (ppm)vs TiO_2 (wt.%) plot showing generally elongate fields of data points directed towards the origin for the CGM granites infields 1 = DT (EX and BGS) and 2 = SA and LE (BGS) and the CGm granites in fields 3 = BD (BGS), 4 = BD (K), 5 = CM (EX and BGS), 6 = CM (BC), and 7 = SC (EX). Data sources are given in brackets: these and pluton abbreviations are given in Table 1. Some later differentiates are shown in fields 8 = CM inner granite and 9 = aplites and microgranites from CM and SC.

REE, ND ISOTOPES AND AGE DATA

Data for Ce_N/Y_N (obtained by XRF analysis) suggest a zig-zag pattern, although there are marked overlaps in confidence limits. However the limited REE data show a clear zig-zag pattern for Ce_N/Yb_N (Figure 1d), which emphasizes the lower slopes for LE, SA and DT and the steeper slopes of CM and BD shown by Darbyshire and Shepherd (1985). Separate plots for the two parts of the REE slopes, Ce_N/Gd_N (omitting Eu) and, especially, Gd_N/Yb_N also reveal similar zig-zag patterns. The europium anomaly, Eu_N/Eu_{INT}, also reveals a similar pattern (Figure le). In particular, LE and SA have low negative values (both -0.27), whilst DT has a value (-0.43) between these and the higher negative values in SC (-0.50), CM (-0.49) and BD (-0.61).a

The relationship between REE abundance and slope is given in plots of tREE or Sm_N *vs* Ce_N/Yb_N , like that given in Stone (1992, Fig. 7), which shows similar REE abundances in both granite sets but lower slopes in DT and SA, to which we can add the LE data. Differentiates from each set show both a fall in REE abundance and flattening of slope. From Figure 1, it can be seen that a Ce_N/Yb_N *vs* Eu_N/Eu_{INT} plot would show two very distinct fields, SCCMBD with both higher slope and lower europium anomaly and LESADT, with lower slope and higher Eu anomaly. Clearly, the REE data separate the two granite types and hence, the two sets of plutons.

Darbyshire and Shepherd (1994) show that the Nd isotope data are robust and give ε_{Nd} values for the main plutons as follows: DT -4.7, SA -6.2, LE -6.2 for the CGM granites and CM -6.9, BD -7.1 for the CGM granites. Clearly, the lower values of -6.2 alternate with the higher values in CM and BD. DT has a much lower value than those in the LE and SA granites, a value which is supported by -4.7 for the PM granite and -4.5 for the garnet-cordierite bearing raft at Sweltor Quarry. DT again stands alone though closer to LE and SA than the other two.

Revised age dates using $^{207}Pb/^{235}U$ from two sources (Chen *et al.,* 1993; Chesley *et al.,* 1993) show remarkable agreement for LE, CM, SA and DT. SC is given only in Chen *et al.* (1993) and there is a 11 Ma discrepancy in the ages for BD (280.1 and 291.4 Ma). Again, we have two broad sets of age dates with LE (276), SA (281) and DT (281) belonging to one set and SC (290), CM (293) and BD (average = 286, although it is tempting to opt for the age of 291 Ma given by Chesley *et al.,* 1993).

DISCUSSIONS AND CONCLUSIONS

Using univariate, bivariate and multivariate comparisons, this study clearly distinguishes the higher femic element content of the CGM granites of the Land's End, St. Austell and Dartmoor plutons (LESADT group) from the lower amounts in the CGm granites of the Isles of Scilly, Carnmenellis and Bodmin Moor plutons (SCCMBD group) and relates these differences to significant differences in recent Nd-isotope and age data. The former group has lower negative ε_{Nd} values (-4.7, -6.2) than the latter *(ca.* -7.0) and is younger in age (- 280 Ma) compared with the latter (- 290 Ma). Bivariate plots indicate similar patterns of magmatic differentiation in both groups, but the lower Ce_N/Yb_N slope, yet generally higher total REE in the CGM granites suggest crystallization from a more primitive magma (Stone, 1995). The Dartmoor coarse-grained poorly megacrystic (PM) granite is considered to be a differentiate of the CGM granite (Ward *et al.,* 1992; Stone, 1995) - although the earlier age of a sample of the former casts some doubt here (Chen *et al.,* 1993) - and could be equated with the CGm granites if we assume that the latter were derived also from a CGM granite (currently unexposed or eroded). However, there are marked differences in chemistry between the Dartmoor PM granites and the CGm granites of SCCMBD (Table 1, especially data from BGS and EX; Fig. 1 in Awad *et al.,* 1996) and particularly in the REE patterns *(cf.* Stone, 1995, fig. 4 and Table 3), where total REE, Ce_N/Yb_N and Eu_N/Eu_{INT} in the PM granite are low compared with values in the CGm granites and in Nd-isotope data (Darbyshire and Shepherd, 1994) where Dartmoor PM and CGM granites have identical εNd values that are significantly different from those of the CGm granites.

The principal differences between the CGm and CGM granites lie in those elements that go into biotite and the commonly associated accessory mineral suite (e.g. monazite, xenotime, zircon etc.) suggesting different source components or different amounts of similar source components whether biotite and the accessories are restite in origin or crystallized early. Indeed, Darbyshire and Shepherd (1994) point out that the significant variation in Nd-isotope signatures between plutons "... suggest the involvement of more than one distinct source in the partial melting". They also point out that their data cannot preclude a significant (LIL element enriched) mantle contribution.

Many recent authors invoke a partial mantle role in the genesis of the Cornubian batholith. Some (Watson *et al.,* 1984; Leat *et al.,* 1987) suggest an actual mantle source enriched in LIL elements that underwent strong fractional crystallization and/or marked crustal assimilation followed by strong fractionation to produce the present granite compositions. However, most authors favour a dominantly crustal origin by partial melting of greywacke/pelite compositions in the lower crust (Darbyshire and Shepherd, 1985, 1994; Charoy, 1986; Stone and Exley, 1986; Chen *et al.* 1993; Chesley *et al.,* 1993; Floyd *et al.,* 1993). Their evidence is reviewed in Floyd et al. (1993, pp. 157-159). Suffice it to say here that most authors also favour an input to the crustal source from the mantle of LIL elements (e.g. Thorpe, 1987) and underplating by basic magma from the mantle (Huppert and Sparks, 1988) to provide the thermal energy necessary for partial melting in the lower crust.

Perhaps the most convincing evidence for mantle participation comes from the sparse basic microgranite enclaves (ME) and almost coeval basic magmatism. Some ME have an Aluminium Saturation Index (ASI) < 1, whilst very rare hornblende and sphene, reported by Brammall and Harwood (1932), have been observed by the present writer. These features, together with their greater prominence in the LESADT plutons, although they are also present in SC and BD, but not CM (Stimac *et al.,* 1995), and the lower negative ε_{Nd} in the CGM granites referred to above, point to some partial I-type character as suggested by Stone (1995). Stimac *et al.* (1995) also point out that CM and BD have higher ASI (~ 1.25-1.28) than DT and SA (~ 1.18) and contain a higher proportion of aluminous enclaves. These authors provide mineralogical and textural evidence for a more basic protolith for the ME and, like other investigators of ME, interpret them as `pillows' of quenched hybrid melts that have undergone varying degrees of chemical interchange with the host magma. They also show that potential mixing arrays of elements, defined by the granites and ME project into the field of the basaltic rocks from the Exeter Volcanic Series, although a definite link is not established. However, the almost coeval and spatially associated Exeter volcanics and lamprophyric rocks do suggest a mantle source for some components (Simpson *et al.,* 1979, Stone and Exley, 1986; Leat *et al.,* 1987; Thorpe, 1987; Floyd *et al.,* 1993), especially the LIL elements, and certainly a heat energy source. This was available, presumably, over the whole period of batholith emplacement *(cf.* Chesley *et al.,* 1993) or possibly in two broad episodes as indicated by the dichotomy referred to and discussed in this paper. Thus, a change from a post-orogenic dominantly crustal source to a slightly more mantle-contaminated source perhaps associated with crustal extension is implied.

ACKNOWLEDGMENT

Grateful thanks go to Dr Colin Exley and an anonymous referee for useful suggestions that improved the manuscript and to Dr John Merefield and Mr Ian Stone for the analytical work done at Exeter University.

REFERENCES

AWAD, N.T., MEREFIELD, J.R., SCRIVENER, R.C. and STONE, M. 1996. Geochemistry and petrogenesis of volcanic clasts in the Permian breccias around Exeter. *Journal of the Geological Society of London,* **153,** 669-672.

BOOTH, B. and EXLEY, C.S. 1987. Petrological features of the Land's End granite. *Proceedings of the Ussher Society,* **6,** 439-446.

BRAMMALL, A. and HARWOOD, H.F. 1932. The Dartmoor granites: their genetic relationships. *Quarterly Journal of the Geological Society of London,* **88,** 171-237.

CHAROY, B. 1986. The genesis of the Cornubian batholith (southwest England): the example of the Carnmenellis pluton. *Journal of Petrology,* **27,** 571-604.

CHEN, Y., CLARK, A.H., FARRAR, E., WASTENEYS, H.A.H.P., HODGSON, M.J. and BROMLEY, A.V. 1993. Diachronous and independent histories of plutonism and mineralization in the Cornubian batholith, southwest England. *Journal of the Geological Society of London,* **150,** 1183-1191.

CHESLEY, J.T., HALLIDAY, A.N., SNEE, L.W., MEZGER, K., SHEPHERD, T.J. and SCRIVENER, R.C. 1993. Thermochronology of the Cornubian batholith in southwest England: implications for pluton emplacement and protracted hydrothermal mineralization. *Geochimica et Cosmochimica Acta,* **57,** 1817-1837.

DANGERFIELD, J. and HAWKES, J.R. 1981. The Variscan granites of SW England: additional information. *Proceedings of the Ussher Society,* **5,** 116-120.

DARBYSHIRE, D.P.F. and SHEPHERD, T.J. 1985. Chronology of granitic magmatism and associated mineralization, SW England. *Journal of the Geological Society of London,* **142,** 1159-1177.

DARBYSHIRE, D.P.F. and SHEPHERD, T.J. 1994. Nd and Sr isotope constraints on the origin of the Cornubian batholith, SW England. *Journal of the Geological Society of London,* **151,** 795-802.

EXLEY, C.S. 1996. Petrological features of the Bodmin Moor granite, Cornwall. *Proceedings of the Ussher Society,* **9,** 85-90.

EXLEY, C.S. and STONE, M. 1982. Hercynian intrusive rocks: petrogenesis. In: *Igneous Rocks of the British Isles.* Ed: D.S. Sutherland, Wiley, Chichester, pp. 311-320.

EXLEY, CS., STONE, M. and FLOYD, P.A. 1983. Composition and petrogenesis of the Cornubian granite batholith and post-orogenic volcanic rocks in south-west England. In: *The Variscan Fold Belt in the British Isles.* Ed: P.L. Hancock, Adam Hilger, Bristol, pp. 153-177.

FLOYD, PA., EXLEY, C.S. and STYLES, M.T. 1993. *Igneous Rocks of South-West England,* Chapman and Hall, London.

GHOSH, P.K. 1927. Petrology of the Bodmin Moor granite (eastern part), Cornwall. *Mineralogical Magazine,* **21,** 285-309.

GHOSH, P.K. 1934. The Carnmenellis granite: its petrology, metamorphism and tectonics. *Quarterly Journal of the Geological Society of London,* **90,** 240-276.

HUPPERT, H.E. and SPARKS, R.S.J. 1988. The generation of granitic magmas by intrusion of basalt into continental crust. *Journal of Petrology,* **29,** 599-624.

LEAT, P.T., THOMPSON, R.N., MORRISON, M.A., HENDRY, G.L. and TRAYHORN, S.C. 1987. Geodynamic significance of post-Variscan intrusive and extrusive potassic magmatism in SW England. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **77,** 349-360.

MANNING, D.A.C. and HILL, P.I. 1990. The petrogenetic and metallogenetic significance of topaz granites from the southwest England orefield. In: *Ore-bearing granite systems; petrogenesis and mineralizing processes.* Eds: H.J. Stein and J.L. Haunch, Geological Society of America Special Paper, **246,** 51-69.

PEARCE, J.A., HARRIS, N.B.W. and TINDLE, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal *of Petrology,* **25,** 956-983.

SIMPSON, P.R., BROWN, G.C., PLANT, J. and OSTLE, D. 1979. Uranium mineralization and granite magmatism in the British Isles. *Philosophical Transactions of the Royal Society of London,* **A, 291,** 385-412.

STIMAC, J.A., CLARK, A.H., CHEN, Y. and GARCIA, S. 1995. Enclaves and their bearing on the origin of the Cornubian batholith, southwest *England. Mineralogical Magazine,* **59,** 273-296.

STONE, M. 1992. The Tregonning granite: petrogenesis of Li-mica granites in the Cornubian batholith. *Mineralogical Magazine,* **56,** 141-155.

STONE, M. 1995. The main Dartmoor granites: petrogenesis and comparisons with the Carnmenellis and Isles of Scilly granites. *Proceedings of the Ussher Society,* **8,** 379-384.

STONE, M. and EXLEY, C.S. 1978. A cluster analysis of chemical data from the granites of SW England. *Proceedings of the Ussher Society,* **4,** 172-181.

STONE, M. and EXLEY, C.S. 1986. High heat production granites of Southwest England and their associated mineralization: a review. *Transactions of the Institution of Mining and Metallurgy,* **95,** B25-36.

THORPE, R.S. 1987. Permian K-rich volcanic rocks of Devon: petrogenesis, tectonic setting and geological significance. *Transactions of the Royal Society of Edinburgh: Earth Science,* **77,** 361-366.

WATSON, J., FOWLER, M.B., PLANT, J.A. and SIMPSON, P.R. 1984. Variscan -Caledonian comparisons: late orogenic granites. *Proceedings of the Ussher Society,* **6,** 2-12.

WARD, C.D., MCARTHUR, J.M. and WALSH, J.N. 1992. Rare earth element behaviour during evolution and alteration of the Dartmoor granite, SW England. *Journal of Petrology,* **33,** 785-815.

WEBB, P.C., TINDLE, A.G., BARRITT, S.D., BROWN, G.C. and MILLER, J.F. 1985. Radiothermal granites of the United Kingdom: comparison of fractionation patterns and variation of heat production for selected granites. In: *High heat production (HHP) granites, hydrothermal circulation and ore genesis,* Institution of Mining and Metallurgy, 409-424.

VAN MARCKE DE LUMMEN, G. 1986. Geochemical evolution of the Land's End granite (south west England) in relation to tin potential in the light of data from western marginal areas. *Proceedings of the Ussher Society,* **6,** 398-404.