Geochemistry of the Isles of Scilly pluton

M. STONE and C.S. EXLEY

Introduction

The Isles of Scilly are situated some 45km WSW of Land's End (GR SW0810-960 0500-180) and are composed almost wholly of granite. Maps published by the BGS (1/500 000 Sheet 357/360, 1974), Jones (1963) and Dangerfield and Hawkes (1981) show an inner finer-grained granite surrounded by a more prominent outer coarser-grained granite (corresponding with types 2 and 3 below, respectively). Previously published work on the Isles of Scilly pluton has been concerned solely with field relations and petrography. This paper sets out to supplement this earlier petrographic work with new chemical data, to compare rock types and examine variation patterns in an attempt to provide a basis for petrogenetic interpretation.

Four granite types coincide with those previously noted. (1) Medium-grained biotite-granite 'enclaves' (ovoid inclusions of Barrow 1906; stage 1 of Osman 1928), petrographically similar to the enclosing outer granite, but having a finer-grained matrix, are commonly tabular, ovoid or rectangular in plan and range in size from several cm to over a metre across. Contacts with the host rocks are usually sharp but are sometimes blurred by a gradual increase in K-feldspar towards the margins. (2) An outer megacyrstic biotite granite (G1 of Jones 1963; stage 2 of Osman) accounts for most of the exposed outcrop. Usually coarse-grained with small megacrysts of K-feldspar, it is grouped with the 'outer' granite of the Carnmenellis pluton and the principal granite of the Bodmin Moor pluton by Dangerfield and Hawkes (1981). (3) A medium-grained central granite (G2 of Jones; stage 3 of Osman) is less megacyrstic, has less biotite and commonly more tourmaline that the outer granite: it appears to be transitional into the latter on Tresco. According to Dangerfield and Hawkes (1981), this granite is the sole representative of its type in the Cornubian batholith. (4) Biotite microgranite sheets and dykes (stage 4 of Osman) containing biotite and/or tourmaline, and aplite dykes with or without pegmatite (stage 5 of Osman) cut the outer granite. The strong resemblance between many fine-grained granite veins and the inner granite, together with the rarity of such veins cutting the latter, led Barrow (1906) to suggest that most of the veins are contemporaneous with and a part of the inner granite, but Osman (1928) refers also to later microgranite and aplite. Field relations observed in this study and chemical similarity do not permit distinction between microgranites and aplites.

Chemical data - minerals

Biotite. Average microprobe analyses and formulae of biotites from the biotite granites (Table 1, cols 1-4) compare with those of other biotites in the Cornubian batholith (Stone et al. 1988). All have octahedral Al > 1 and Fe/(Fe+Mg) > 0.5, consistent with siderophyllite. With a formula Li content (Stone et al. 1988) between 0.5 and 1, these are lithian siderophyllites.

Table 1. Microprobe analyses of micas.

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</table>

nd - not detected; tr - trace.

n - number of points analysed; N - number of samples.

Al(4) and Al(6) refer to Al in tetrahedral and octahedral sites. FeO - total iron as Fe₂O₃. Fe²⁺ - total iron in formula as Fe²⁺.

* - samples from transitional junction between granite types 2 and 3 on Tresco.
Biotites from granite types 1 and 2 are similar in composition (Table 1, cols 1 and 2), as also are those from the type 3 granite on the west side of Tresco (Table 1, col. 3). However, the latter have lower Rb₂O and F and, in this respect, resemble biotite from the type 4 granite (Table 1, col. 4). Biotite from the type 4 granite is markedly enriched in Fe₂O₃ and MnO, but depleted in MgO and F compared with biotites of granite types 1 and 2. High contents of Rb₂O and F and a good positive correlation between them are consistent with those of the trioctahedral micas of the batholith in general (Stone et al. 1988). The trend of octahedral A₁ enrichment in biotites of the later terms, noted by Charoy (1986) in the Carnmenellis pluton and attributed by him to progressive increase in alumina activity, is not apparent here.

A comparison between the full analyses of five Carnmenellis biotites (from the outer granite) and two from the Isles of Scilly (one each from granite types 1 and 2) given in Stone et al. (1988, Table 2) shows that the latter are depleted in Li₂O, Rb₂O, Cs and F, and enriched in Ba, Th and Zr relative to the former.

Muscovite. Average analyses of muscovites from these rocks (Table 1, cols 5-8) show a slight excess in the Y site and, like biotite, a deficiency in the X site. All muscovites are phengitic (Table 2) shows that the latter are depleted in Li₂O, Rb₂O, Cs and F, and enriched in Ba, Th and Zr relative to the former.

Tourmaline. In all rock types this is schorl. The most significant correlation (r = -0.86) reflects a marked substitution of Fe by Mg, one that is much stronger than in the micas and reflects Fe enrichment and increased Fe/(Fe+Mn+Mg) in tourmaline of the later rocks compared with those of granite types 1 and 2 (Table 2). Values of Fe/(Fe+Mn+Mg) range from 0.59 to 0.78, typically lower than those in the Carnmenellis granite (Charoy 1986). Zoned tourmalines have pale-coloured cores and darker brown margins in thin section. The latter are enriched in TiO₂, Fe₂O₃, CaO and F, and usually Na₂O, and depleted in Al₂O₃ and SiO₂ compared with the former (Table 2). Occasional pale outer rims show continued enrichment in Fe₂O₃ and Fe, enrichment in MgO, but depletion in TiO₂, Al₂O₃ and MgO.

K-feldspar. Microprobe analyses show a wide range in composition but little consistent variation with rock type. In general, K-feldspars from granite types 1 and 2 have higher BaO contents (~0.05 to 0.33 wt%) than those from the later granite types (~0.05 wt%) consistent with overall whole rock data and with crystal chemical considerations. A wide range in Na₂O (0.97-1.93 wt%) reflects a formula range of 0.09 to 0.17 Na atoms (on basis of 8 oxygens), but as in the case of Rb, no consistent pattern is evident.

Plagioclase feldspar. Alteration prevents analyses of plagioclase cores from type 1 granites, so that the most anorthite-rich composition, AB₅₅An₄₅, is a minimum. A comparison between rock CaO values of granite types 1 and 2 and the very low P₂O₅ contents of type 1 indicate that its plagioclase has cores that are at least as anorthite rich as those in the type 2 granites (Ab₂₈An₇₂). The ranges shown by analysed points from granite types 3 and 4 (Ab₃₂An₆₈ to Ab₃₂An₇₂) reflect zoning from oligoclase cores to albite margins, but with overall compositions of ablite/oligoclase (ε = Ab₃₅A₃₅). A specimen (411) from the contact zone between granite types 2 and 3 has an average plagioclase composition of AB₅₃An₄₇ suggesting that such rocks be included with type 2.

Chemical data - rocks

Inspection of the raw data (Table 3) suggests that, although the four granite types are distinct in terms of their relationships in the field, some samples are transitional in composition between types 2 and 3, and that one type 4 dyke cutting type 2 granite is richer in TiO₂, Fe₂O₃, CaO, Zr, Ce, V, Th and Ba than the other microgranites and closer in composition to the type 2 granites. Q-mode cluster analysis (not illustrated), using these 8 oxides/elements, suggests some, but little, overlap in chemistry between granite types 1 and 2, whilst type 3 is clearly separated from these. The two fine/medium-grained biotite granite

| Table 3. Average analyses of rock types and results of statistical tests. |
|---------------------------------|-----|-----|-----|-----|-----|
| Column                          | 1   | 2   | 3   | 4   | Mann-Whitney Tests |
| Rock Type                       |     |     |     |     |                   |
|                                | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 1&2 | 2&3 | 3&4 |  |
| SiO₂                            | 72.26| 71.52| 72.96| 73.64| * | * | N  |     |     |     |     |
| TiO₂                            | 0.24 | 0.24 | 0.08 | 0.06 | N | N | ** |     |     |     |     |
| Al₂O₃                           | 14.53| 14.84| 14.42| 14.23| * | N | ** |     |     |     |     |
| Fe₂O₃                           | 0.49 | 0.53 | 0.57 | 0.28 | N | N | *  |     |     |     |     |
| CaO                             | 0.95 | 1.02 | 0.25 | 0.20 | N | N | ** |     |     |     |     |
| MgO                             | 0.33 | 0.36 | 0.17 | 0.24 | N | N | *  |     |     |     |     |
| Na₂O                            | 0.95 | 0.81 | 0.54 | 0.48 | * | N | ** |     |     |     |     |
| K₂O                             | 3.54 | 2.94 | 3.28 | 3.29 | * | N | ** |     |     |     |     |
| CrO                             | 5.06 | 5.42 | 5.04 | 5.04 | * | N | ** |     |     |     |     |
| P₂O₅                            | 0.14 | 0.23 | 0.24 | 0.22 | * | N | ** |     |     |     |     |
| F                               | 0.11 | 0.24 | 0.16 | 0.17 | * | N | N  |     |     |     |     |
| As                              | 0.11 | 9    | 7    | 1    | N | N | N  |     |     |     |     |
| Ba                              | 709  | 420  | 251  | 241  | *  | N | *  |     |     |     |     |
| Ce                              | 81   | 78   | 28   | 4    | N | N | ** |     |     |     |     |
| Cs                              | 28   | 30   | 40   | 32   | N | N | N  |     |     |     |     |
| Ga                              | 17   | 21   | 19   | 21   | ** | N | *  |     |     |     |     |
| La                              | 18   | 25   | 0    | 2    | N | - | -  |     |     |     |     |
| Li                              | 260  | 293  | 206  | 166  | *  | N | N  |     |     |     |     |
| Mn                              | 228  | 236  | 263  | 212  | N | N | N  |     |     |     |     |
| Nb                              | 13   | 12   | 13   | 14   | N | N | N  |     |     |     |     |
| Pb                              | 35   | 37   | 42   | 30   | * | N | *  |     |     |     |     |
| Rb                              | 430  | 441  | 472  | 498  | N | N | *  |     |     |     |     |
| Sn                              | 9    | 9    | 12   | 12   | N | N | N  |     |     |     |     |
| Sr                              | 111  | 108  | 48   | 27   | N | N | ** |     |     |     |     |
| Th                              | 40   | 27   | 6    | 5    | ** | N | N  |     |     |     |     |
| U                               | 8    | 8    | 5    | 4    | N | N | N  |     |     |     |     |
| V                                | 20   | 16   | 6    | 5    | *  | * | N  |     |     |     |     |
| Y                               | 13   | 16   | 20   | 16   | *  | N | N  |     |     |     |     |
| Zn                              | 32   | 37   | 28   | 35   | N | N | N  |     |     |     |     |
| Zr                              | 144  | 117  | 30   | 25   | ** | N | N  |     |     |     |     |
| K/Re                            | 98.7 | 102.5| 88.8 | 89.5 |     |     |     |     |     |     |     |
| Rb/Sr                           | 4    | 4.3  | 11   | 23.6 |     |     |     |     |     |     |     |
| KZnX100/Ti                      | 10   | 8.1  | 6.8  | 8    |     |     |     |     |     |     |     |
| n                               | 19   | 22   | 7    | 8    |     |     |     |     |     |     |     |

1 and 2. Type 2 granite (outer). 3, 4 and 5. Type 3 granite (inner).
samples from the west coast of Tresco, close to the transitional boundary between types 2 and 3 and originally collected as type 3, cluster with type 2 and are included in its average analysis (Table 3, col. 1).

Mann-Whitney tests between granite types 1 and 2 (inclusions and outer granite) reveal markedly significant differences (at \( p = 0.01 \)) in Na, K, P, Ca, Sr, Li, Ba, Ga, Th, V and Zr, but similarities in Rb, La, Pb, As, TiO, FeO, Mn, MgO, CaO, Ce, Cs, La, Li, Rb, Sr, Ti, U, Y and others (Table 3, col. 5). Similar tests between types 2 and 3 (Table 3, col. 6) reveal significant differences in several oxides/elements at the \( p = 0.05 \) level, but only TiO, FeO, CaO, Sr, Th, V, Zn and Zr at the \( p = 0.01 \) level. Types 3 and 4 (central granite and most microgranites) are chemically similar in many respects and differ at the \( p = 0.01 \) level only in Sr and Pb (Table 3, col. 7). As indicated earlier, one of the microgranites may be a minor intrusion derived directly from the outer granite, although it has a significantly lower Sr content than this granite.

Multiple discriminant analysis of all the data using the 'femic suite' of elements/oxides (TiO, FeO, CaO, Zr, Sr, V, Ba, Ce, U and Th) again significantly separates types 1, 2 and 3, with only two misclassified observations out of 48. This suggests that whatever petrogenetic linkage there may be between these types, they are statistically distinct at the present exposure level as far as the femic suite is concerned. However, types 3 and 4 cannot be discriminated, confirming conclusions reached above (Table 3, col. 7).

Chemical variation
An abridged correlation matrix (Table 4) reveals strong positive correlations and hence probable association between members of a "femic element/oxide" suite composed of TiO, FeO, CaO, Zr, Sr, V, Ba, Ce, U and Th again significantly separates types 1, 2 and 3, with only two misclassified observations out of 48. This suggests that whatever petrogenetic linkage there may be between these types, they are statistically distinct at the present exposure level as far as the femic suite is concerned. However, types 3 and 4 cannot be discriminated, confirming conclusions reached above (Table 3, col. 7).

Table 4. Pearson product moment correlation matrix of selected elements.

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All values are significant at the \( p = 0.05 \) level using Student's t statistic. CaO and Zr (Figs. 2a and 2b) behave like most other members of the 'femic suite' in showing a decrease in the time sequence and, like Sr, V, Ba, Cc and Th clearly discriminate types 1 and 2 on the one hand from 3 and 4 on the other. However, the clearest variation patterns are those in which rock type (placed in sequence 1-4) is plotted against mean. Examples like CaO, Zr, Rb/Sr and Zr/Ti, taken directly from the 'one-way analysis of variance' output of the Minitab package (Fig. 2), show both the mean for each type and the 95% confidence limits about the mean (based upon Student's t statistic). CaO and Zr (Figs. 2a and 2b) behave like most other members of the 'femic suite' in showing a decrease in the time sequence and, like Sr, V, Ba, Cc and Th clearly discriminate types 1 and 2 on the one hand from 3 and 4 on the other, but do not separate types 3 and 4. Rb/Sr (Fig. 2c) shows an overall increase in the sequence of rock types 1-4, although types 1 and 2 are almost identical: in the K/Rb pattern (not shown) types 1 and 2 are similar whilst 3 and 4, also similar, have markedly lower values (Table 3). These ratios are often taken as indices of fractionation and Fig. 2 suggests that granite types 1 and 2 had reached similar extents of differentiation, like the coarser-
grained granites of Carnmenellis (Stone 1987, Fig. 3d). Zr/Ti (Fig. 2d) shows a decrease in the sequences of types 1 to 3, in marked contrast with the pattern of constant Zr/Ti of Carnmenellis. Again, types 3 and 4 have similar means and spreads.

REE patterns

Whole rock and biotite REE data (Table 5), normalised using the chondrite values of Evensen et al. (1978) are plotted in Fig. 3. Most analyses were determined by the ICP method, but two, nos. 2 and 5 in Fig. 3, were determined by neutron activation.

Total REE show marked reduction in the later members of the emplacement sequence from granite types 1 to 4 (Table 5). The ratio CeN/YbN is a measure of the overall slope of the line joining the two elements labelled in the ratio, and shows a dramatic fall in the granite types 3 and 4 compared with types 1 and 2. The higher CeN/YbN ratios are roughly parallel with the CeN/SmN ratios (not shown): the highest is that of the single type 1 inclusion, then come the three type 2 granites followed by the two type 3 granites and finally, the single type 4 microgranite.

Actual slopes, obtained by regression of the logarithms of the normalised REE on atomic number for the first 6 analysed elements, i.e. La to Gd, but omitting Eu, are given in the row marked ‘m’ in Table 5. These show a distinct fall in progressing from granite types 1 to 4. The data also show a reduction in the correlation coefficient (r) as the slope diminishes and similarities in slope between host rocks and their biotites (nos. 1 and 4, and 9 and 10 respectively in Table 5 and Fig. 3). Biotite from the Carnmenellis outer granite (no. 11) has a similar but marginally lower slope (-0.12) which is identical with that of its host rock (no. 8).

Petrogenesis

Source. The occurrence of muscovite and commonly abundant K-feldspar megacrysts in these granites together with a strongly

<table>
<thead>
<tr>
<th>Col.</th>
<th>1</th>
<th>4</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<td>46S</td>
<td>448</td>
<td>466</td>
<td>CAV</td>
<td>467B</td>
<td>465B</td>
<td>021B</td>
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<tr>
<td>Type</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>ppm</td>
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<td>Ce</td>
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<td>Yb</td>
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<td>CeN/YbN</td>
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<td>0.999</td>
<td>0.998</td>
<td>0.996</td>
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</table>

Column heading numbers correspond with those in Fig. 3. Nos. 1, 4, 6 and 7 are rock samples and 9 and 10 are biotites from the Isles of Scilly pluton. 8 is average rock (CAV) and 11 a biotite (021B) from the outer granite of the Carnmenellis pluton (Stone 1987). Linear regression parameters on the first six elements excluding Eu are given by c (intercept) and m (slope). r is the negative correlation coefficient.
peraluminous character, high trace-alkali element content, high 
Rb/Sr, low K/Rb and high Sr and U contents, suggest an 
affinity with S-type granites (Chappell and White 1974) and hence, 
a predominantly lower crustal source, although no oxygen or 
strontium isotope data are currently available. However, it is 
unlikely that the source is markedly different from that of the 
other granites of the batholith and these have high $\delta^{18}$O (Sheppard 
1977), high initial Sr ratios (Darbyshire and Shepherd 1985) and 
and Pb-isotope patterns (Hampton and Taylor 1983) that also point 
to lower crustal, largely pelitic or semipelitic, sources. The 
Dartmoor granite also contains primary/restite cordierite (Stone 
1988), considered by White et al. (1986) to be clear evidence for 
a true S-type granite.

As in the Carnmenellis granites, andalusite is a common 
accessory mineral. Evidence considered elsewhere (Exley and Stone 
1982; Stone 1987) suggests that andalusite and biotite (albeit 
modified) is undigested material derived from pelitic material in 
source rocks, although some contamination from wallrock during 
upward transport of magma is also likely. However, 
‘experiments involving partial melting of pelitic, semipelitic and 
granitoid rocks (Winkler 1976; Luth 1976) indicate that moderate 
excesses of melting (say 30-40%) leave residues containing opaque 
ores, andalusite (or sillimanite), cordierite, garnet and much 
biotite and plagioclase. On the basis of REE modelling, Charoy 
(1986) suggested that the megacrystic outer biotite granite of the 
Carnmenellis pluton was derived by the partial melting (c. 30%) of 
Browerian pelitic rocks. Such a source seems reasonable, 
although metagreywackes are commonly more abundant in 
ogenetic belts and are likely to provide a more ‘fertile’ source for 
granite magma (White and Chappell 1988) in the lower crust. 
Further, larger amounts of granitic melt can be expected from a 
feldspathic greywacke source than a pelitic one.

Xenoliths and contamination. There is little evidence of contamination at the present exposure level here or in the 
Carnmenellis pluton. As Jeffries (1985b) pointed out, marked 
assimilation of pelitic material (at the present level of exposure) 
would enrich granite in the REE, Zr and Th and, of this, there is no 
evidence. Most xenoliths and, as suggested above, andalusite, 
biotite and the more calcic cores of plagioclase are considered to be 
restite material, or derived from wall-rock in channelways or 
foundered blocks of country rock at depth (Bromley and Holl 
1987).

The Type 1 granite inclusions are the earliest rocks of the 
complex and would seem to be fragments of an early, only 
slightly less differentiated granite than the present outer granite. Type 
1 formed an initial crust subsequently broken up and incorporated 
in the outer granite at the time of its emplacement as a later magma 
pulse.

Fractionation. Almost continuous chemical variation within the 
sequence of rock types in the Carnmenellis pluton between members of the ‘femic element/oxyde’ suite (i.e. TiO$_2$, FeO, MgO, CaO, Ba, 
Ce, La, Sr, Th and Zr) and their overall depletion in the time 
sequence outer granite, inner granite, microgranites, is believed to 
reflect progressive biotite and accessory mineral fractionation (Stone 
1987). Despite some different abundances compared with the 
Carnmenellis granites, most of these oxides/elements are also 
associated (i.e. positively correlated) and show a similar depletion 
with time in the Isles of Scilly pluton. Thus, fractionation of biotite 
and the accessory minerals again provides the simplest 
explanation for these patterns. Clemens and Wall (1981) also 
considered that fractionation of early-formed biotite together with 
plagioclase explains chemical trends in many S-type granites. 
Comparison between the data of Table 1 of this paper and Table 2 
in Stone (1987) reveals broadly similar TiO$_2$ and Zr trends and 
contents within the structurally equivalent granite types in each 
pluton (outer and inner granites and microgranites). However, 
some separation of Zr and Ti in the Isles of Scilly sequence (i.e. a 
change in Zr/Ti) may indicate different rates of fractionation of 
accessory minerals and biotite and/or more marked change with 
time of biotite composition than in the Carnmenellis pluton. 
Certainly, there is a wider composition range of Ti as well as SiO$_2$ in 
the biotites of the Isles of Scilly granites and, provided that the single 
microgranite biotite is typical, of FeO, MgO and MnO. There is no evidence for crystal fractionation in situ; this must have occurred 
either in a chamber below the presently exposed level or, more 
likely, in transit from the source region.

Magma rising from its deep crustal source would be composed of 
melt, primary crystals (mainly plagioclase + some quartz), restite 
(biotite, equilibrated with magma and perhaps containing some 
magmatic addition + An-rich plagioclase with later magmatic 
envelope + metamorphic minerals, sillimanite/andalusite, 
cordierite, garnet + refractory accessories, monazite, zircon, etc), 
and source ‘xenoliths’. This would be expected to follow paths of 
weakness (deep fractures) to the present site of the pluton. Possible 
changes undergone by magma as it rose to form the present plutons 
include chemical re-equilibration of solid solution phases with the 
magma, fractionation (‘cleaning’) of early crystallization products 
and/or restite phases from melt, progressive disaggregation and 
dispersion of source xenoliths and wall-rock contamination.

Clusters of early crystallized minerals both on the walls of 
channelways and, perhaps, within the moving magma would be 
expected to trap restite material and interstitial melt. The latter, 
having an overall density less than the total solid phases would be 
expected to separate and join the main magmatic stream in the 
channelway. Progressive separation of crystals/restite from melt in 
this manner (cf. Sparks et al. 1984) provides a feasible mechanism of 
progressive fractionation with time to give the granite types observed 
in the Isles of Scilly and Carnmenellis plutons. In particular, this 
kind of mechanism avoids the problem of biotite fractionation by 
gridity in a viscous magma. Initial magmatic pulses would 
contain more biotite and accessory minerals and hence be richer in 
the ‘femic’ suite of oxides/elements and would have An-richer 
plagioclase than later terms; the latter would be progressively 
deposited in these mineral and with this, the ‘femic’ oxide/element 
suite, as biotite and accessory’ minerals were trapped in crystal 
mushes or crystallized early on the walls of the channelways.

Both decreasing K/Rb and increasing Rb/Sr, together with a 
general enrichment in the ‘trace alkali’ suite (Table 3 and Fig. 2c) 
indicate progressive evolution of the granites in the sequence of types 
1-4. However, even the earliest rocks (type 1 granite inclusions), 
are quite highly evolved, with trace alkali elements and Rb/Sr well 
above and K/Rb well below the values found in most granites 
including S-types, although the extent of evolution is less marked 
than in the Carnmenellis granites. Most Rb/Sr values for S-type 
granites in the Lachlan fold belt quoted by White and Chappell 
(1988) range from 1.2 to c. 4.0 although one selected sample has a 
value of 18.1. The earliest rocks in the Isles of Scilly pluton have an 
average Rb/Sr of 4.0 (Table 3). Aluminium Saturation Indices 
(ASI, see White and Chappell 1988) are c. 1.22 in granite types 2, 3 
and 4 but only 1.11 in the type 1 granites. These ASI values 
broadly agree with those of the Lachlan S-type granites.

Markedly evolved granites, like those considered here, can 
suggest small extents of partial melting, but as pointed out by Pitcher 
(1987), there are problems "...in envisaging the physical extraction of 
small volumes of melt.,” particularly in highly viscous S-type 
granite crustal melts that are likely to behave pseudoplastically. 
Crustal fusion events are more likely to produce quite large 
volumes of magma, perhaps involving up to 40% melting. Such 
magmas are capable of undergoing extensive fractionation between 
source and present site.

REE patterns. Several authors (e.g. Mittlefelddt and Miller 1983; 
Gromet and Silver 1983; Michael 1988) have shown that much of the 
REE pattern in granitoids is controlled by the
mainly refractory accessory minerals. Jeffries (1985a)
demonstrated that the accessory mineral suite, composed of
monazite, zircon, uraninite, apatite and xenotime, accounts for
almost all of the rock REE patterns in the Carnmenellis granite.
Subsequent work by Stone (1987) suggested that the LREE pattern
for biotite largely reflects the included monazite pattern.
Part of the HREE pattern is believed to result from
included zircon and tiny amounts of xenotime. In a similar
manner, it is clear that much of the whole rock pattern, particularly
for the LREE is controlled by the biotite pattern and hence,
ultimately, the monazite pattern. The LREE slope for
monazite obtained by regression as described above is
-0.138. This is based upon the mean of three Carnmenellis
monazites given by Jeffries (1985a). If we assume that this
slope is close to that of the LREE slope of monazites in the
early Isles of Scilly granites, it can readily be seen that both
biotite and rock LREE slopes are governed very largely by the
monazite pattern. Also, the marked negative europium anomaly reflects that in monazite rather than the effects of
feldspar fractionation. It is suggested that biotite has included the accessory mineral suite in roughly the same
proportions as it occurs in the whole rock at the time of
metamorphism and anatexis and that the biotite represents
resite material, subsequently modified in composition by
equilibration with evolving magma as it rose in the crust.
Evidence is provided by the close similarity between the
LREE slopes for the Carnmenellis and hence, the Isles of
Scilly) outer granite and a sillimanite-bearing pelitic xenolith,
believed to be source material, in the Carnmenellis outer granite (Jeffries 1985b). Thus, the decrease in the 'femic'
suite of oxides/elements and total REE, together with the
reduction in slope of the LREE is the result of both biotite
and accessory mineral (monazite) fractionation (Miller and
Mittlefehldt 1982; Stone 1987).

Acknowledgements. Thanks are due to Messrs Tim Hopkines and
Dave Plant for help with microprobe work at the Department of
Geology, University of Manchester and to Messrs John Merfield
and Ian Stone for rock analyses at the Department of Geology,
University of Exeter. Fieldwork was partly financed by grants from
the research funds of the Universities of Exeter and Keele.

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