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# Trace element variation in the leucogranites within the main Galway Granite, Connemara, Ireland

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## Abstract

Six hundred and forty four gamma-ray spectrometer assays of U and Th obtained within the late Caledonian Galway Granite western Ireland are presented. The data cover the range of granodiorites, adamellites and leucogranites (Murvey Granite) present in the batholith. There is an overall increase in U and Th abundances with petrological evolution. The broad scatter of values that characterizes the Murvey Granite reflects the geographically separate occurrences of this leucogranite. Rubidium and strontium data imply varying degrees of fractionation among these separate Murvey Granite occurrences. Y and *HREE* are notably enriched in the Murvey granite at Costelloe which also contains the highest Th levels amongst the leucogranites. Thorite, uraninite, monazite and Y-zircon are present in this leucogranite and are responsible for the observed enrichments in U, Th, Y and *HREE*.

KEYWORDS: Galway Granite, Murvey Granite, trace elements, leucogranites, uranium, thorium, Rb/Sr data, yttrium, rare-earth elements.

THE results of a quantitative gamma ray spectrometer survey on the Galway Granite have been outlined by Feely and Madden (1986) but no detailed description or interpretation of the U and Th fractionation trends was attempted. This paper presents an interpretative account of the behaviour of these two radioelements during fractionation. Other trace element data (Rb, Sr, Y and *REE*) from both published and unpublished sources are also presented.

## Geology of the Galway Granite

The Galway Granite occupies approximately 600 $km^2$ along the northern shoreline of Galway Bay in the west of Ireland. A southerly offshore extension beneath the bay is inferred from gravity and aeromagnetic data (Murphy, 1952; Max *et al.*, 1983). The batholith intrudes high-grade Dalradian metamorphic rocks on its northern, eastern and western margins (Leake and Leggo, 1963) and lower grade rocks of the South Connemara Group (Ordovician?) to the south on the islands of Lettermullan and Gorumna (McKie and Burke, 1955). The Granite is a late Caledonian intrusion emplaced at approximately 400 Ma (Leggo *et al.*, 1966; Pidgeon, 1969). Andalusite and cordierite-bearing hornfelses were developed in South Connemara Group rocks; minor developments of andalusite are observed along the northern Dalradian–Granite contact. The batholith is unconformably overlain to the south and southeast by Carboniferous limestone (Coats and Wilson, 1971; Max *et al.*, 1978; and Figure 1).

This composite batholith is composed of four domes, i.e. Carna, Spiddal, Galway-Kilkieran, and Roundstone Domes (Max *et al.*, 1978). Wright (1964) and Leake (1974) have shown that marginal zones of the batholith are occupied by a leucogranite—the Murvey Granite—which passes inwards to less silicic adamellite termed the Errisbeg Townland Granite (E.T.G.). Murvey Granite also occurs in the central section of the batholith e.g. at Costelloe (M.G.1) and Kilkieran (M.G.4)—see Fig. 1.

The batholith is composed of granodiorites (Carna and Spiddal Granites), adamellites (E.T.G. and Roundstone Granite) and Murvey Granite (Max *et al.*, 1978). Textural variants of these main varieties also occur. The area between

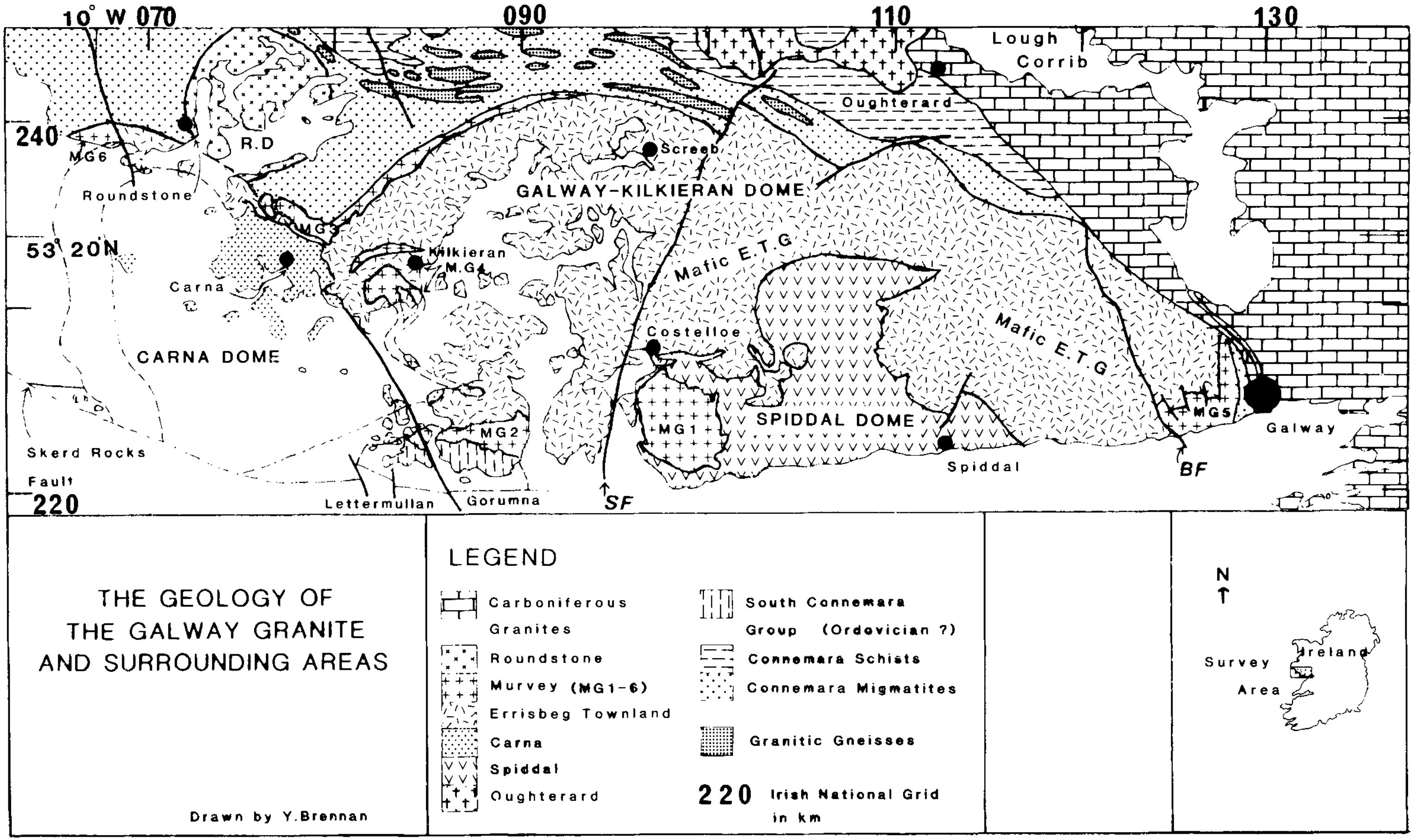


Fig. 1. Geological map showing the distribution of the main granite types in the Galway Granite. The geographically separate occurrences of Murvey Granite are numbered M.G.1 to M.G.6. (R.D. = Roundstone Dome; S.F. = Shannawona Fault; B.F. = Barna Fault). Adapted from Max *et al.*, (1978), Leake (1978) and Leake *et al.*, (1981).

the NE–SW trending Shannawona Fault and the NW–SE trending Barna Fault is occupied by a mafic E.T.G. which has been partially mapped by Plant (1968), Coats and Wilson (1971), and Feely (1982).

Wright (1964), Leake (1974), Coats and Wilson (1971), and Lawrence (1975) report major and trace element variations in the Galway Granite that are typical of a progressively fractionating calc–alkaline magma. Fractionation has resulted in a comagmatic suite of granite types that display a progressive increase in silica and alkalis with concomitant decrease in Fe, Mg, Ti, Ca, Al, Mn and P, ranging from diorite xenoliths to granodiorites and adamellites and finally to the leucocratic Murvey Granite. Leake (1974) showed, from a traverse of chemically analysed rocks and biotites from the western end of the batholith that the Carna Granite crystallized from the outside inwards. Furthermore the marginal Murvey Granite (M.G.6—Fig. 1) formed from a residuum in the E.T.G. which was drawn out of the latter into 'zones of rarefaction' (Leake, 1974) left behind by the foundering of stoped blocks of country rock.

Finally, Leake (1978) notes that the Galway Granite is spatially associated with the extension of the Southern Uplands Fault in Ireland, a major splay of which probably passed through the zone now occupied by the batholith to emerge in the Skerd Rocks (Fig. 1). There, major pre-granite faulting separates South Connemara Group rocks from the Connemara Dalradian. Leake links the generation and emplacement of the Galway Granite to this major deep fault.

## Uranium and thorium variation in the Galway Granite

A Geometrics GR410A four-channel gamma-ray spectrometer was used to determine 644 assays of eUppm[1] and eThppm[2] on the main granite types (excluding the Roundstone Granite) in the batholith (Feely and Madden, 1986). The spectrometer was calibrated at the Riso National Laboratory, Roskilde, Denmark, using large doped concrete pad sources simulating outcrops of known radioelement concentrations. The overall error of a field spectrometer assay with known calibration constants ranges between 5 and 10% on the U and Th channels (Lovborg, 1984). A summary of the U and Th contents in the main granite types is presented in Table 1.

[1] 1 ppm eU = 1 ppm U in radioactive equilbrium with $\gamma$-emitting daughters.
[2] 1 ppm eTh = 1 ppm Th in radioactive equilibrium with $\gamma$-emitting daughters.

TABLE 1 Mean eUppm and eThppm contents for the Main granite types in the Galway Granite.

| Granite Type (no. of samples) | Mean eUppm | Mean eThppm |
|---|---|---|
| Mafic Errisbeg Townland Granite (112) | 4.08 | 15.23 |
| Spiddal Granite (91) | 4.68 | 16.79 |
| Carna Granite (47) | 5.82 | 17.17 |
| Errisbeg Townland Granite (310) | 6.01 | 20.87 |
| Murvey Granite (84) | 10.16 | 33.55 |

There is an overall increase in mean radioelement (U and Th) abundances from the least evolved mafic E.T.G. through the Spiddal and Carna Granites towards the E.T.G. and Murvey Granite (Figs. 2A, B). Furthermore, there are statistically significant differences in mean U and Th levels between the geographically separate Murvey Granite outcrops, e.g. M.G.1 and M.G.2. Mean Th/U ratios remain relatively constant through the series of granites. The Murvey granite on the islands of Lettermullan and Gorumna (M.G.2) has a high mean Th/U ratio, while the Carna Granite possesses the lowest ratio (Fig. 2C).

The fields defined by all major granite types in Fig. 3A show that, despite the scatter of values within any one granite type, there is a general trend of increasing U and Th contents with petrological evolution. The greatest degree of scatter is evident in the Murvey Granite data. Fig. 3B shows that the large Murvey Granite field is composed of four discrete smaller fields defined by M.G.1, M.G.2, M.G.6 and M.G.3–5. A fractionation trend is drawn from the granodiorites to the adamellite towards the Murvey Granite.

Uranium enrichment trends in the M.G.1 and M.G.6 Fields (Fig. 3B) are based upon field and spatial distribution studies (Feely and Madden, 1987). Spatial distribution studies on the circular Murvey granite body at Costelloe (M.G.1) show that U increases in abundance from its margin to its centre while Th levels decrease slightly in the same direction. Leake (1974) showed that the Murvey granite at the western end of the batholith (M.G.6) becomes more fractionated and garnetiferous towards the margin of the batholith. The trend in the M.G.6 field reflects a marked enrichment in U from the non-garnetiferous M.G.6 to the marginal garnet-bearing leucogranite. The field defined by the Murvey granite on Lettermullan and Gorumna islands (M.G.2) shows that this leucogranite is poorer in U relative

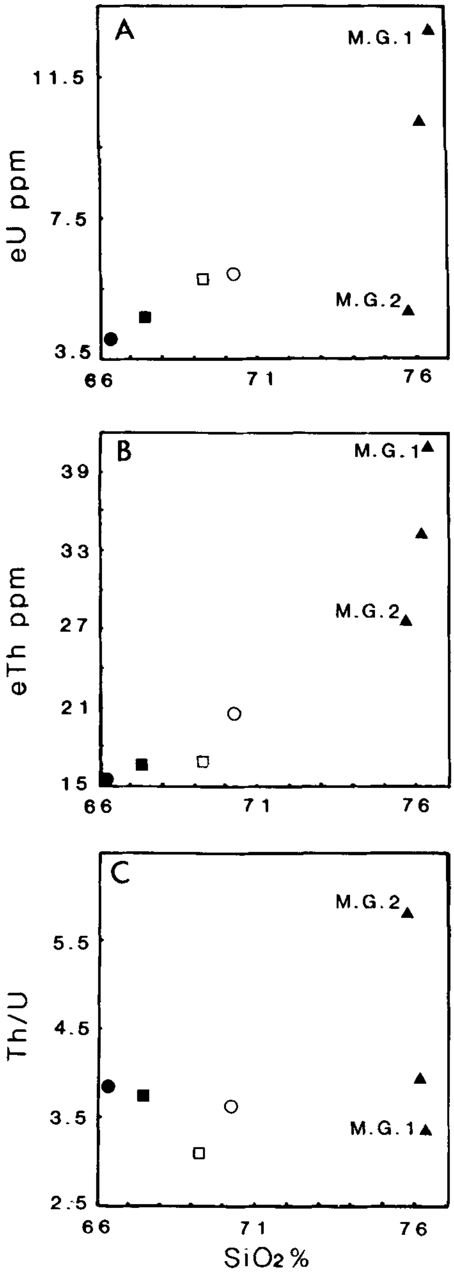


FIG. 2. A, B and C: mean eU ppm, eTh ppm and Th/U ratios *v.* whole-rock $SiO_2$% for the five major granite types. M.G.1 and M.G.2 are also plotted for comparison. The $SiO_2$% values are averages calculated from the following sources: Wright (1964), Coats and Wilson (1971), Leake (1974), Lawrence (1975) and Feely (1982). Symbols: ● Mafic E.T.G., ■ Spiddal Granite (S.G.), □ Carna Granite (C.G.), ○ Errisbeg Townland Granite (E.T.G.), ▲ average Murvey Granite (M.G.).

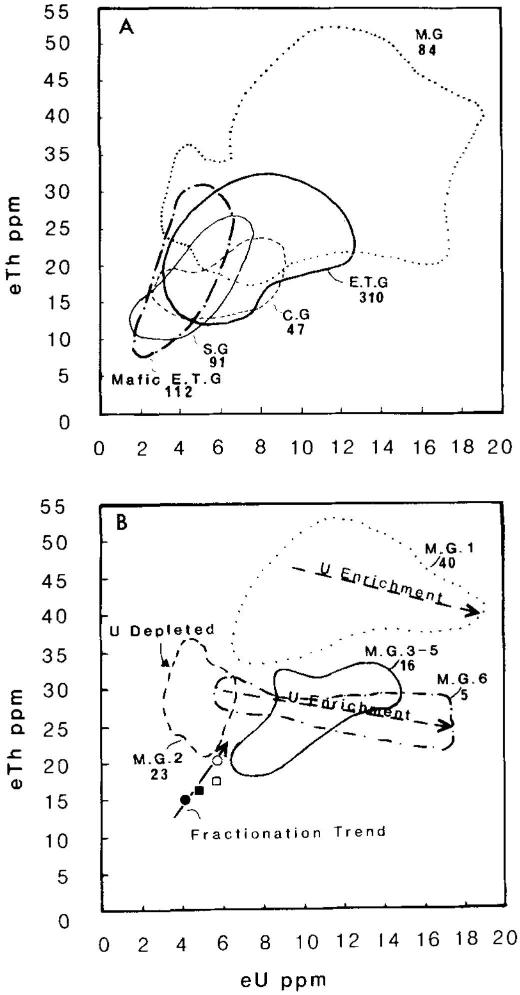


FIG. 3A. Plot of eU ppm *v.* eTh ppm showing the individual granite fields. The number of data points defining each field is shown. B. In this plot the Murvey Granite field displays four separate sub-fields. A fractionation trend is drawn from mafic E.T.G. to the E.T.G. U-enrichment trends are shown in the M.G.1 and M.G.6 fields. The number of data points defining the four Murvey Granite fields are shown. The granite symbols are the same as in Fig. 2.

to the other Murvey granites. The three remaining leucogranites (M.G.3–5) show no marked enrichment or depletion of U and Th relative to the other Murvey granites. The differences in U and Th abundances among the Murvey granites can be summarized as follows: (*a*) M.G.1 contains the highest Th levels; (*b*) M.G.2 has significantly lower U levels than the other Murvey granites;

(*c*) The centre of the M.G.1. body and the marginal garnetiferous Murvey in M.G.6 contain the highest U levels of all.

*Rubidium and strontium variation in the Galway Granite.* A trend with mean Rb contents increasing from the least evolved mafic E.T.G. through the Spiddal and Carna Granites towards the E.T.G. and Murvey Granite is clear (Fig. 4; see also Coats and Wilson, 1971, and Lawrence, 1975). The Murvey Granite data occupies the largest field due to the significant differences in the mean Rb and Sr levels of individual Murvey Granite outcrops. Both M.G.1 and M.G.6 (garnetiferous) display high mean Rb contents in contrast to M.G.2, M.G.3, M.G.4 and M.G.5—these four define a separate grouping with lower mean Rb and higher mean Sr contents. This suggests differences in the degree of fractionation between the two groups, i.e. M.G.1 and M.G.6 (garnetiferous) are the most fractionated leucogranites. Noteworthy is the fact that the highest U and Th levels occur in M.G.1 while M.G.6 (garnetiferous) also contains similarly high U but lower Th levels.

*Y and rare-earth element (REE) variation in the Galway Granite.* Coats and Wilson (1971) showed that as fractionation proceeds in the Galway Granite from the mafic E.T.G. to the Murvey Granite (M.G.5) the *LREE* (La, Ce, Nd and Sm) become depleted relative to Y. This trend continues into garnet-bearing aplites which are enriched in Y (up to 46 ppm)—a reflection, probably, of Y substituting for Mn in garnet (Coats and Wilson, 1971). Feely (1982) showed that Y becomes depleted with magmatic evolution until M.G.1 is reached. M.G.1 becomes enriched in Y (Fig. 5A). Furthermore, no garnets have been observed in thin sections of M.G.1. Chondrite normalized *REE* profiles (Fig. 5B) demonstrate

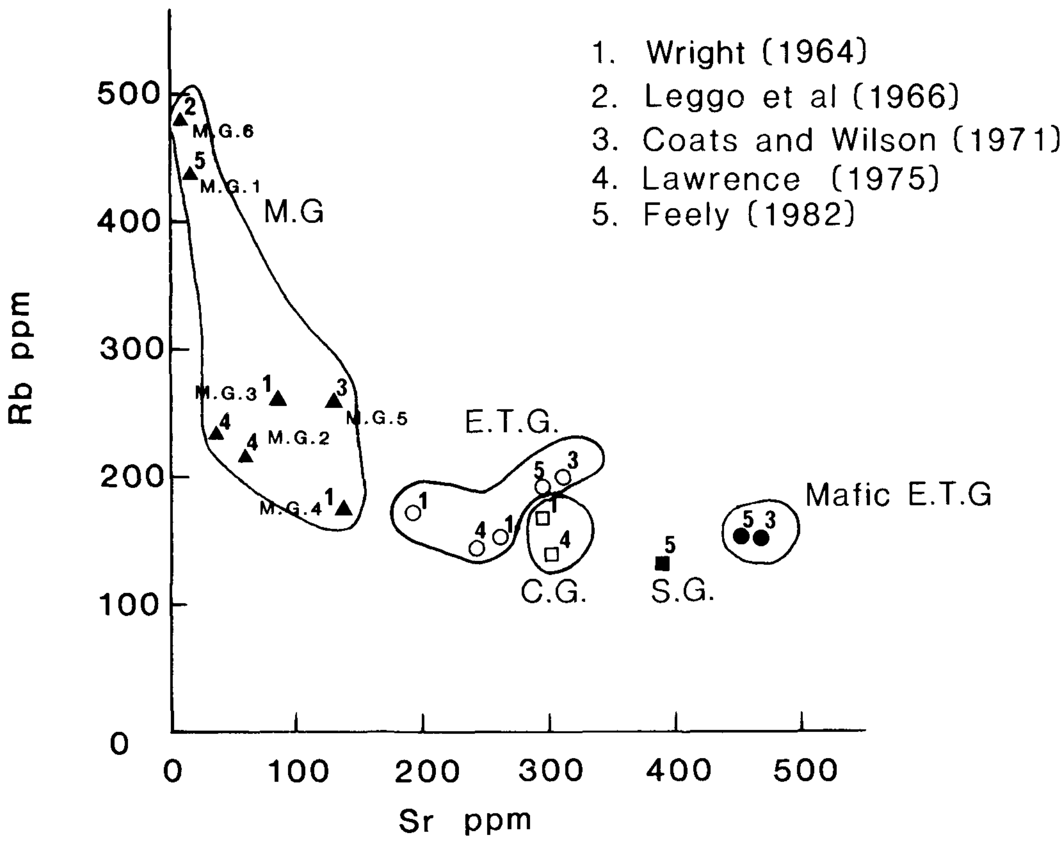


FIG. 4. A plot of mean Rb ppm *v.* Sr ppm for the five major granite types. Data from the separate occurrences of Murvey Granite are also plotted. Lawrence (1975) published Rb and Sr data for both a garnetiferous and a non-garnetiferous Murvey Granite, hence the two data points for M.G.2. Symbols for granites as in Fig. 2. All trace element data determined by X-ray fluorescence.

that there is an overall depletion in total *REE* from the Spiddal Granite to the E.T.G. There is also an apparent absence of significant Eu anomalies in these profiles. However, in the absence of Gd determinations no accurate assessment of the magnitude of Eu anomalies can be made. M.G.2 displays a perceptible increase in *HREE* while M.G.1 is markedly depleted in *LREE* and enriched in *HREE*—this latter feature compliments the Y trend in Fig. 5A, as Y behaves geochemically like the *HREE* during the evolution of granite magmas (Wedepohl, 1970). The *REE* data are presented in Table 2.

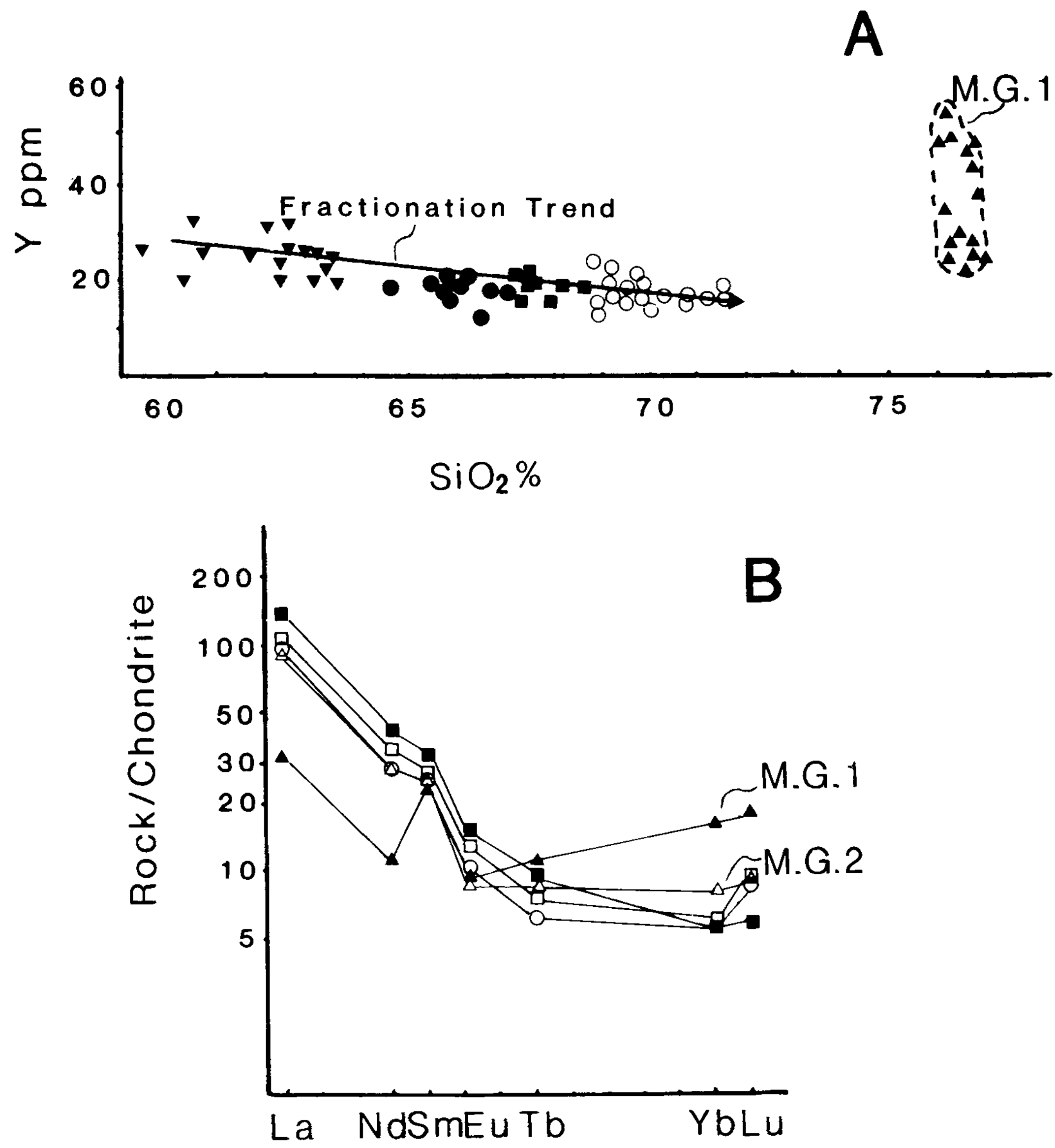


FIG. 5A. Plot of Y ppm *v*. $SiO_2$%. A fractionation trend is drawn from diorite xenoliths (▼) to the E.T.G. This trend is disrupted by a notable enrichment of Y in M.G.1. Granite symbols as in Fig. 2. B. *REE* patterns of major granite types within the Galway Granite. Granite symbols as in Fig. 2 except where indicated. *REE* normalizing values from Haskin *et al.* (1968). The Nd point on the M.G.1 profile is from Feely (1982).

## Discussion and conclusions

The radioelements (U and Th) in the Galway Granite display a progressive increase in abundance from the least evolved granodiorites to the highly evolved leucogranites. The latter display a wide variation in U and Th contents typical of highly fractionated granites (Rogers and Ragland, 1961; Tilling and Gottfried, 1969). M.G.1 and M.G.6 (garnetiferous), the most fractionated Murvey granites, contain the highest levels of U.

M.G.2 contains similar Th levels (excepting M.G.1) to the other leucogranites all of which also contain higher U abundances. U and Th behave geochemically in a similar fashion during magmatic evolution both tending to accumulate in residual liquids. However, U is capable of forming the stable uranyl ion ($UO_2^{2+}$) which is extremely soluble and causes preferential partitioning of U relative to Th into residual fluids (see Rogers and Adams, 1978). These volatile-rich fluids can escape leaving the residual melt depleted in U. Post crystallization hydrothermal activity can also leach U from primary magmatic sites and redistribute it along grain boundaries or maybe remove it totally from the rock. This divergence in the behaviour of U and Th during late-stage magmatic evolution may account for the anomalously high Th/U ratios (5–7) in M.G.2. The Buchanan Granite massif, Texas, U.S.A., has similarly high Th/U ratios and are taken to strongly indicate major secondary redistribution of U and indeed Th (see Cook and Rogers, 1968). Of note here is the fact that M.G.2 intrudes the low-grade metamorphic rocks of the South Connemara Group. Circulation systems interacting between M.G.2 and the country rock could cause leaching of U from this leucogranite.

M.G.1 is unique in that it contains high U levels coupled with the highest levels of Th among the Murvey granites and furthermore, it is also notably enriched in Y and *HREE*. Accessory phases rich in these elements are present in the Costelloe Murvey granite. Preliminary microprobe analysis by C. T. Williams, Dept. of Mineralogy, British Museum (Natural History) of three sections from this leucogranite confirm the presence of thorite, uraninite, monazite and zircon (containing up to 7.7% $Y_2O_3$). These accessory minerals play an important role in the fractionation of *REE* (Miller and Mittlefehldt, 1982; Sawka *et al.*, 1984) and of U and Th (O'Connor *et al.*, 1982; Webb and Brown, 1984; and Webb *et al.*, 1985). In the Skiddaw Granite, for example, Th clearly decreases with fractionation due probably to crystallizing monazite depleting Th from successively fractionated liquids (Webb and Brown, 1984). Jefferies (1985) concluded that *REE* (in particular Y and *HREE*) within the Carnmenellis pluton were strongly partitioned into the radioactive mineral assemblage of monazite, xenotime, zircon, apatite and uraninite. It is concluded therefore that the crystallization of the radioactive accessory mineral assemblage, present in the Costelloe Murvey granite, contributed to its relatively high concentrations of U, Th, Y and *HREE*.

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TABLE 2. REE abundances for the main granite types in the Galway Granite

| Granite Type | Rare Earth Elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | La(ppm) | Nd(ppm) | Sm(ppm) | Eu(ppm) | Tb(ppm) | Yb(ppm) | Lu(ppm) |
| Spiddal Granite | 46.3 | 24.0 | 5.8 | 1.02 | 0.43 | 1.1 | 0.20 |
| Carna Granite | 32.7 | 20.0 | 4.7 | 0.86 | 0.35 | 1.26 | 0.34 |
| Errisbeg Townland | 31.5 | 16.0 | 4.5 | 0.67 | 0.29 | 1.08 | 0.29 |
| Murvey Granite (MG1) | 10.3 | <20.0 | 4.2 | 0.64 | 0.52 | 3.2 | 0.6 |
| Murvey Granite (MG2) | 31.1 | 17.0 | 4.5 | 0.56 | 0.39 | 1.54 | 0.3 |

Analyses by I.N.A.A. at the Universities Research Reactor, Risley, Warrington, England. One sample, of each granite type, was analysed.

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