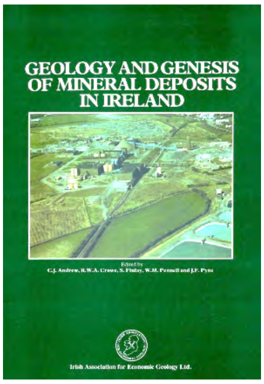

GEOLOGY AND GENESIS OF MINERAL DEPOSITS IN IRELAND

Edited by
C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell and J.F. Pyne

Irish Association for Economic Geology Ltd.

Uranium mineralization in the Irish Caledonides

P.J. O'Connor

To cite this article: O'Connor, P.J. (1986) Uranium mineralization in the Irish Caledonides. *In:* Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M., and Pyne, J.F. '*Geology and Genesis of Mineral Deposits in Ireland*', Irish Association for Economic Geology, Dublin. 157-175. DOI:

To link to this article: https://

Uranium mineralization in the Irish Caledonides.

P. J. O'Connor

Geological Survey of Ireland,
Haddington Road, Dublin 4.

Abstract

Irish late Caledonian granitoids are classified as radioelement-rich (Barnesmore, Galway), normal (Ardara, Thorr, Trawenagh Bay, Rosses, Newry and Corvock) or radioelement-poor (Leinster, Main Donegal) plutons according to their relative abundances of U, Th and K.

The radioelement-rich plutons are"permitted", metalliferous intrusions which are not U-mineralized. Secondary uranium minerals (autunite, torbernite) are developed on fracture zones traversing the most fractionated granitic facies of these plutons (e.g. the Murvey type of the Galway batholith and the aplogranite of the Sheet Complex in the Barnesmore pluton).

Uranium mineralization has been discovered within the radioelement-poor "forceful" plutons of Donegal and Leinster. In the Main Donegal pluton, primary uraninite mineralization occurs typically in NE linear zones within biotite pegmatites. The age of the uraninite mineralization is concordant with the age of emplacement of the Main Donegal granite at about 407Ma, and the distribution of linear uraniferous zones in the pluton suggests a dominant structural control i.e. they may represent annealed shear zones. Later, fracture-controlled, pitchblende mineralization is closely associated spatially with the area of maximum uraninite mineralization in the SW end of the Main Donegal pluton.

Extensive uraniferous peat deposits occur over the Tullow pluton of the Leinster batholith. Their distribution appears to be related to transverse fracture zones in the pluton. The primary source of uranium in the peat deposits is uncertain, but it may have been derived from a radioelement-rich muscovitic adamellite or from radioactive, fluorapatite-bearing, quartz breccias, both of which are present in the southern part of the Tullow pluton. The quartz breccias, which also occur in the Blackstairs pluton, may have developed by explosive hydrothermal action in cupola environments. Perigranitic mineralization is represented by pitchblende-quartz veins in the contact schists of the Blackstairs pluton. Pre-granite volcanogenic or syngenetic uranium enrichments are also known as are post-granite epigenetic mineral showings in the Old Red Sandstone sediments to the west of the batholith.

The close interaction between deformation and granite emplacement seems to have been a critical factor in localizing primary intra-granitic uranium mineralization in certain Irish late Caledonian granitoids.

Introduction

In Ireland, EEC-funded uranium exploration commenced in 1976. The principal reconnaissance exploration techniques employed were car-borne gross-count scintillometry (O'Connor, 1981a), regional soil, stream sediment, and stream water geochemistry. Some airborne radiometric surveys were flown, particularly over parts of Counties Kerry, Cork, Waterford and Donegal, but results were disappointing. The ground surveys succeeded in defining targets in Leinster, Connemara and Donegal, mainly associated with late Caledonian granitoid plutons. Detailed follow-up surveys of target areas, which had to cope with the many problems associated with exploration in heavily glaciated terrain, included extensive ground radiometric surveys, employing both gross-count scintillometry and gamma spectrometry, emanometric surveys ("radon-sniffing"), Track-Etch surveys, conventional soil, stream sediment and stream water geochemical surveys, deep overburden sampling and a range of geophysical techniques, especially IP, Resistivity and VLF. For a given target and/or terrain type, success in defining the nature and extent of any uranium mineralization usually depended on using a judicious combination of exploration techniques. The purpose of this paper is to review the setting and characteristics of the uranium occurrences associated with the late Caledonian granitoid plutons.

Classification of Irish late Caledonian granitoids

Reviews of the geological setting of Irish Caledonian granitoids are given in Brindley (1969), Pitcher and Berger (1972), Leake (1978), Parkhurst et al. (1981) and Plant (this volume). Collectively, about twenty-five separate plutons cover an area in excess of 400km^2 (Fig. 1). Individual plutons range in size from 5 to 500km^2, and most are domelike masses usually extending to depths of 4-10km (Cook and Murphy, 1952; Young 1974). The plutons are mainly calc-alkaline in composition, ranging from diorite and granodiorite to granite; the largest plutons are dominantly granitic. Emplacement of the late Caledonian granitoids occurred about 405 ± 10Ma ago ($\lambda^{87}Rb = 1.42\times10^{-11}yr^{-1}$). The Irish plutons are clustered into three main geographic groups in Leinster, Connemara and Donegal. Each cluster represents a batholith as defined by Pitcher (1979). The relevant geological and geochemical features of the late Caledonian granitoids referred to here are given in Table 1.

Read (1961) established a temporal/structural classification of Scottish late Caledonian granitoids in which these plutons were broadly categorized as either earlier "forceful" or later "permitted" intrusions. Read's structural subdivision is valid for Irish late Caledonian plutons although the temporal aspect does not apply among the plutons of the Donegal suite. Read considered the Main Donegal, Ardara and Leinster plutons (Table 1) to be "forceful" intrusions with synkinematic schist aureoles and the Rosses and Barnesmore granitic centres as "permitted". Extending his scheme to other granitoids in Table 1, the various plutons of the Galway batholith (Leake, 1978; Max et al., 1978), the Corvock granite (Inamdar and Kelly, 1979) and the Trawenagh Bay pluton (Pitcher and Berger, 1972), all of which have static hornfels aureoles, may be considered "permitted" intrusions. The Newry granodiorite (O'Connor, 1975) and Thorr granite (Pitcher and Berger, 1972) do not neatly fit this scheme as they display both synkinematic and static features.

Other classifications have been developed for British late Caledonian granitoids based on geophysical, geochemical and/or isotopic parameters (Dewey and Pankhurst, 1970; Brown and Locke, 1979; Plant et al., 1980; Pankhurst et al., 1981). Elements of these classifications are equally valid for Irish late Caledonian granitoids. Of relevance in the present context of uranium mineralization is the distinction made by Plant et al. (1980, 1983) between metalliferous (containing high primary concentrations of metals in silicate minerals), mineralized (in which metals are in secondary concentrations in ore minerals) and barren intrusions in the orthotectonic zone of the Scottish Caledonides. Analogies with Irish plutons would suggest that the more evolved (fractionated) intrusions are metalliferous, while the less evolved tonalite-granodiorite plutons are non-metalliferous. Mineralized plutons would be those of Leinster (Li, U), Galway (Mo, U), Main Donegal (U, Mo) and Rosses (Be).

Irish late Caledonian granitoids have initial ^{87}Sr/^{86}Sr ratios in the range 0.704-0.710 (Table 1) with no clear age or isotopic distinction between "forceful" and "permitted" plutons, distinctions noted by Pankhurst (1979) for British analogues. Plutons emplaced in the orthotectonic zone in Ireland tend to have low I-type, initial Sr ratios in the range 0.704-0.706 while those emplaced in the paratectonic zone have slightly higher ratios in the range 0.706-0.710. Inherited zircons occur in "forceful" late Caledonian granitoids north of the Highland Boundary Fault (e.g. Foyers, Helmsdale, Thorr; see Pidgeon and Aftalion, 1978), whereas the granitoids investigated south of this Fault generally lack inherited zircons. "Permitted" late Caledonian granitoids, regardless of their location in the orogen, lack inherited zircons. Inherited zircons, preserving ages of 1,000-2,000Ma, provide evidence that crustal rocks were incorporated (whether by melting or assimilation) in the forceful Caledonian granitoids north of the Highland Boundary Fault. Leake (1978) has suggested that the Caledonian granitoids arose by remelting of lower crustal rocks of pyroxene granulite composition similar to the Scourian gneisses. The author has argued (O'Connor, 1974a; O'Connor, 1975; O'Connor and Brück, 1976 and 1978; O'Connor et al., 1982b) on the basis of Sr isotope data that the Irish late Caledonian granitoids could have been derived from either an upper mantle or a juvenile lower crustal source. A mantle component in the genesis of Caledonian granitoids cannot be excluded; the appinite suite is tangible evidence of the existence of contemporaneous, mantle-derived, basic magmas associated with some of the forcefully-emplaced plutons (e.g. Ardara, Leinster, Newry).

Radioelement geochemistry

The radiolement geochemistry of Caledonian and Pre-Caledonian crustal rock groups is poorly understood. Abundances of the three radioelements for some suites of interest are given in Table 2. The Scourian and Laxfordian gneiss groups of Scotland have very low contents of heat-producing and other incompatible elements (Rb, Cs), possibly as a result of having undergone high-grade metamorphism (Tarney et al., 1972). The Moine schists have much higher U and Th contents comparable to that of 'average' crust (Richardson and Powell, 1976). The Scottish and Irish Dalradian rocks studied are stratigraphically equivalent and lithologically similar; in both areas the pelites/semipelites have a mean U content of 2-3ppm and a mean Th content of 17ppm (Atherton and Brotherton, 1979; O'Connor and Long, 1985). Other Dalradian lithologies such as limestone, quartzite, and amphibolite have low contents of these elements. The Lower Palaeozoic rocks show the highest radioelement levels, and among these the acid Caradocian volcanic rocks in SE Ireland are most remarkable with 10.9ppm U and 34.3 ppm Th on average (O'Connor, unpublished data). Most acid volcanic rocks of similar lithology and age in the paratectonic zone are also likely to show high levels of these elements. Thus, the exposed crustal rocks, which may have been involved in the genesis of the late Caledonian granitoids by anatexis or assimilation, have a wide range of radioelement abundance.

Concentrations of U, Th and K in Irish late Caledonian granitoids have recently been reported (O'Connor, 198lb; O'Connor et al., 1981; O'Connor et al., 1982a; O'Connor et al., 1983). Several accounts of the abundance and distribution of radioelements in British Caledonian granitoids have also been published; Bowie et al. (1973) and Simpson

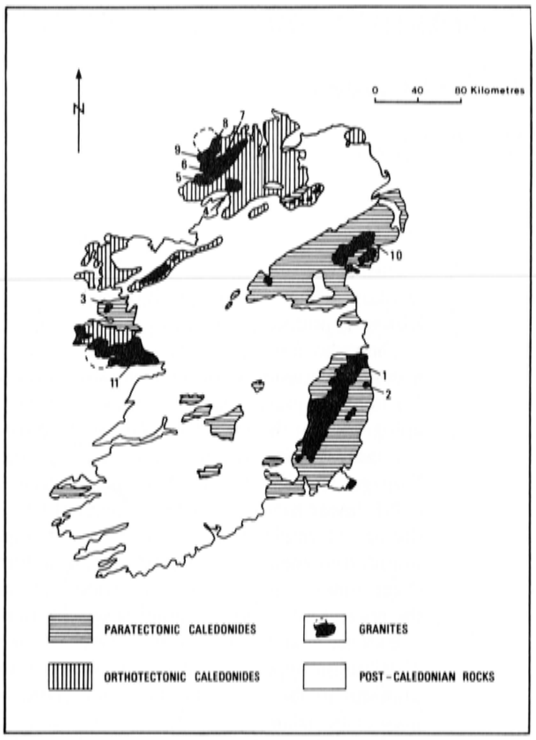

Figure 1. Irish late Caledonian granitoids. Numbered plutons referred to in the text and Table 1 are: (1) Leinster, (2) Carrigmore, (3) Corvock, (4) Barnesmore, (5) Ardara, (6) Trawenagh Bay, (7) Main Donegal, (8) Thorr, (9) Rosses, (10) Newry, (11) Galway.

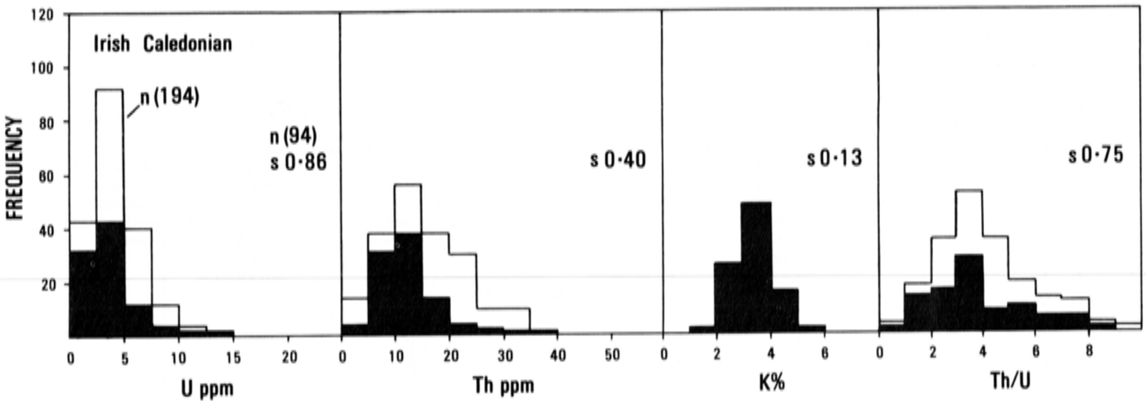

Figure 2. Comparative sample frequency histograms of U, Th, K, Th/U in late Caledonian granites from Britain (N=194 samples, line only) and Ireland (N=94 samples, solid) (data from O'Connor et al. 1983 and Hennessy pers. comm.). 's' is Pearson's second coefficient of skewness.

et al. (1976 and 1979) have provided data on U distribution in some of the granitoids of Scotland, while U and Th contents for these granitoids have been given by Hennessy (1981).

Mean U and Th contents of 11 Irish late Caledonian granitoids are presented in Table 1 and Figure 2. All of the data, except those for the Galway batholith which were determined by XRF (Coats and Wilson, 1971), were determined by epithermal neutron activation analysis at the Risley reactor (U.K.). The radioelement levels in Irish late Caledonian granitoids are similar to their British counterparts (Fig. 2) and combined mean values for 288 samples, from the data of Hennessy (1981) and O'Connor (1981b) are 4.0ppm U and 14.1ppm Th. These means are comparable to the published clarke for granite (Rogers and Adams, 1969). The mean U-Th compositions of late Caledonian granitoids are shown in Figure 3 on which the British and Irish fields overlap; both suites show a positive correlation between U and Th.

The Irish late Caledonian granitoid plutons are divided into three groups on the basis of their radioelement contents as follows:

Group I:	Radioelement-poor granitoids with U<3ppm and /or Th <10ppm (e.g. Leinster, Main Donegal).
Group II:	Normal granitoids with U contents of 3-6ppm and Th contents of 10-20ppm (e.g. Ardara, Thorr, Trawenagh Bay, Rosses, Newry and Corvock).
Group III:	Radioelement-rich granitoids with U>6ppm and/or Th >25ppm (e.g. Barnesmore, Galway). These plutons may provide potential sources for geothermal energy.

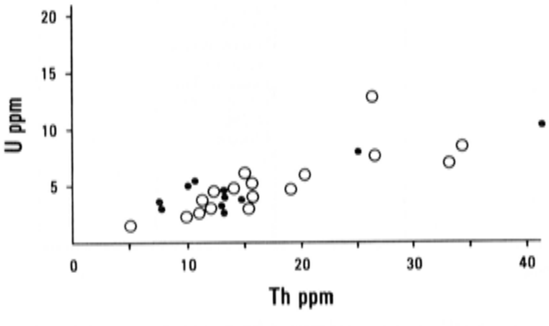

Figure 3. Variation of U and Th for British and Irish granitoids. Closed circle = Irish late Caledonian granitoids (data in Table 1); open circle = British late Caledonian granitoids (data from Hennessy 1981 and Plant et al. 1980).

In some Irish plutons, primary magmatic processes (e.g. fractional crystallization) have been largely responsible in controlling radioelement distribution, and these elements are mainly bound in resistate accessory minerals (zircon, apatite, sphene and Fe-Ti-Mn oxides). In other plutons, susceptible elements (e.g. U) have undergone a certain amount of redistribution during late-stage alteration, and now occupy more labile interstitial sites in the granite host-rock.

Uranium mineralization

Uranium mineralization is associated with the Main Donegal and Leinster intrusions, and less significant showings of secondary U minerals occur in the Rosses, Barnesmore and Galway plutons.

Rosses pluton

The Rosses pluton (Table 1 and Fig. 4) is a centred complex about 8.5km in diameter and consists of four concentrically arranged granites, G1-G4, emplaced 404±4Ma ago (Halliday et al., 1980) by cauldron subsidence within the Thorr pluton, Co. Donegal (Pitcher and Berger, 1972). The granites are practically structureless and have sharp contacts against each other. The later granites, G3 and G4 are muscovitized. Beryl-bearing greisens are developed along the G2-G3 contact. Burke et al. (1964) report the rare occurrence of torbernite (with pyrite along a joint plane) and uraninite (in a heavy mineral concentrate) in the main greisen lens at the Sheskinarone beryl locality; 50t of beryl averaging 13% BeO are estimated to be present in this greisen body. Carborne radiometric surveys over the Rosses area (e.g. O'Connor, 1981a) revealed no major anomalies.

Table 1

Characteristics of certain late Caledonian Granitoid Plutons in the Irish Caledonides.

		Orthotectonic Zone						
	Intrusion	Main Donegal (7)	Ardara (5)	Thorr (8)	Trawenagh Bay (6)	Rosses (9)	Barnesmore (4)	Fanad (14)
Geological Features	Setting	Emplaced in active NE-SW sinistral shear zone into Dalradian pelites.	Emplaced diapirically in Dalradian pelites; Extensive appinite suite.	Emplaced by active stoping and reaction with Dalradian metasediments. Early distension of envelope followed by static phase.	Emplaced by stoping into the Thorr and Main Donegal plutons and their high-grade metamorphic envelopes.	Emplaced passively by cauldron subsidence within Thorr pluton.	Emplaced passively by cauldron subsidence in Dalradian meta-greywackes.	Emplaced by stoping into Dalradian metasediments.
	Aureole	Synkinematic (Ky, And, Sil, Kf, St, Gn, Bt, Cl, Cld, Crd) Schists.	Synkinematic (Crd, Sil, And, Bt, St, Ky, Gn, M, Cld) Schists.	Synkinematic-Static (And, Sil, Crd, Bt, M) Hornfelses.	Static (Very slight mineralogical changes in envelope rocks)	Static (Almost undetectable as country rocks are quartz diorite and tonalites of Thorr pluton)	Static (And, Sil, Kf, M, Bt, Crd) Hornfelses.	Static (And, Sil, Crd, Gn, Kf, Bt, M, Cor) Hornfelses
	Area and Form	NE-SW elongate pluton (400 km^2)	Circular (50 km^2)	Elongate N-S pluton (>350 km^2)	Rectangular pluton (50km^2)	Circular (55km^2)	NW-SE elongate pluton (52km^2)	NE-SW (<30km^2) (fragmentary)
	Structure	NE-SW raft trains, banding, min. foliation.	Strong xenolith and min. alignment.	Gradational internal contacts; min. foliation.	Gradational internal contacts; weak or no min. foliation.	Sharp internal contacts of 4 granite types; weak min. foliation.	Sharp internal contacts of 4 granite types; no min. foliation.	Sharp, steep contacts. marginal veining. highly xenolithic; weak min. foliation.
	Composition	Gd (Gt)	Qm (Gd)	Tn, Qd, Gt.	Gt (LGt)	Gt	Gt (LGt)	Qm (Tn, Gd)
	Mineralogy	P, Kf, Q, Bt, M, Ep, Ap, Zr, Cl, Sp, Ru, Fe.	P, Kf, Q, Bt, Hb, Zr, Ap, Fe, Cl.	P, Kf, Q, Bt, Hb, Ep, Al, Cl, Sp, Ap, Zr, Fe.	P, Kf, Q, Bt, Cl, M, Ep, Gn, Fe.	P, Kf, Q, Bt, M, Ep, Zr, Ap, Sp, Al, Fe.	P, Kf, Q, Bt, M, Sp, Al, Fe, Ap.	P, Kf, Q, Hb, Bt, Cl, Zr, Ap, Sp, Al, Fe.
Geochemistry	Radio-elements	N=27	N=9	N=12	N=4	N=4	N=3	
	U(ppm)	2.5 (1.5)	4.4 (1.8)	3.1 (1.4)	5.0 (1.1)	5.6 (4.9)	8.1 (1.9)	—
	Th(ppm)	12.9 (5.1)	13.2 (6.0)	13.0 (3.4)	10.1 (4.9)	10.6 (2.3)	25.1 (2.3)	—
	Trace Elements	Rb/Sr (0.8-4.0) K/Rb (180-360) Zr (50-200) Ba (700-1200)	Rb/Sr (0.15-0.4) K/Rb (170-330) Zr (80-300)	Rb/Sr (0.3-2.5) K/Rb (200-350) Zr (~100) Ba (300-1300)	Rb/Sr (0.4-0.7) K/Rb (200-300) Zr (90-130) Ba (650-800)	Rb/Sr (0.7-4.6) K/Rb (100-200) Zr (60-100) Ba (150-900)	Rb/Sr (0.7-25.0) K/Rb (100-150) Be (1-8)	Rb/Sr (0.02-0.21)
	Age (Ma)	407±23	405±15	418±26	405±3	404±4	396±8	402±10
	Sri	0.7063±5	0.7065±2	0.7055±4	0.7052±4	0.7062±3	0.7064±6	0.7050±1
U Mineralization	Type and age of Uranium Mineralization	(a) uraninite-bearing biotite pegmatities distributed in NE-SW linear zones; $^{207}Pb/^{206}Pb$ age 407±4. (b) Pitchblende in NNW-SSE veins $^{207}Pb/^{206}Pb$ age 295±4.	None known	None known	None known	Rare uraninite and torbernite in beryl-bearing greisens located mainly on G2-G3 internal contact	No primary U mineralization. Barren desilicated (episyenite or monzonitic) zones trending NW-SE. U secondaries (autunite) on joints in G3a leucogranite of Sheet Complex	None known.

NOTES

1. Numbers in brackets after intrusion name refer to Figure 1.
2. All U, Th data (except Galway data which were determined by XRF) were determined by neutron activation analysis at the Liverpool and Manchester Universities research reactor (Risley, U.K.).
3. All radiometric age data were determined by whole-rock Rb-Sr isochrons ($^{87}Rb=1.42x10^{-11}$ yr^{-1}). Errors on ages and initial Sr isotope ratios are 2 sigma and incorporate geological scatter i.e. they have been calculated by multiplying the York (1969) *a priori* error by the square root of the MSWD value. Fuller statistical details in original references.
4. Mineral abbreviations are Al-allanite, Ap-apatite, Au-augite, And-andalusite, Bt-biotite, Ch-chlorite, Cld-chloritoid,

			Paratectonic zone			
Easky (12)	Louth Talt (13)	Galway (11)	Leinster (1)	Carrigmore (2)	Newry (10)	Corvock (3)
Emplaced passively in metasediments of Ox Mountains Succession (Dalradian)	Emplaced passively in metasediments of Ox Mountains Succession (Dalradian) and Ox Mountains Granodiorite (480 Ma)	Composite batholith of 5 or more nested plutons emplaced passively by stoping in high grade Connemara Migmatites on SW extension of Southern Uplands Fault.	Composite batholith (5 plutons) emplaced by distension and stoping in N-S Shear Zone in Lr. Palaeozoic rocks. Appinite suite associated with Tullow/Blackstairs schist septum.	One of a number of small zoned diorite bodies emplaced by stoping in the Lr. Palaeozoic Ribband Group sediments of Co. Wicklow.	Composite intrusion comprising two or more zoned plutons emplaced by distension and stoping in Lr. Palaeozoic sediments; associated ultramafic (appinitic), dioritic and monzonitic rocks.	Emplaced passively as a thin sheet into Lr. Palaeozoic sediments. Some appinite-lamprophyre dykes associated.
Static (And, Fib, Crd, Kf, Bt, M,) Hornfelses.	Static (And, Sil, Fib, Kf, Bt, M) Hornfelses.	Static (And, Sil, Kf, Crd, M, Cl) Hornfelses.	Synkinematic (And, Fib, Kf, St, Gn, Bt, M, Cl) Schists.	Static (Crd, M, Cl) Hornfelses.	Static (Dp, Hb, Sil, Bt, Crd, Kf, M, Cl) Hornfelses.	Static (And, Crd, Bt, Kf, M, Cl) Hornfelses.
NE-SW elongate (20km^2)	Rectangular (20km^2)	Elongate E-W (>600km^2)	En échelon NNE-SSW array (>1500km^2)	Elongate NW-SE pluton (4.2 km^2)	Elongate NE-SW (400km^2)	Elongate E-W pluton (25km^2)
Sharp contacts, poorly xenolithic; min. foliation.	Sharp contacts, poorly xenolithic min. foliation.	Sharp-gradational internal contacts; igneous layering; min. foliation.	Sharp-gradational internal contacts; strong min. foliation marginally.	Gradational internal contacts; no mineral foliation.	Sharp-gradational internal contacts of 3 granodiorite types; min. foliation.	No mineral foliation.
Gt	Gt	Gt, Gd (LGt)	Gt(Gd)	D, Qd, Gd	Gd(Gt)	Gt
P, Kf, Q, Bt, Cl, Zr, Ap, Fe.	P, Kf, Q, Bt, Cl, Zr, Ap, Fe.	P, Kf, Q, Hb, Bt, Cl, Zr, Ap, Sp, Gn, To, Tp, Fl, Al, Fe.	P, Kf, Q, Bt, M, Zr, Sp, Cl, Ep, Ap, Fe, Al, Fl, To, Tp.	P, Au, Hy, Hb, Bt, Kf, Q, M, Ap, Zr, Ep, Cl.	P, Kf, Q, Hb, Bt, Sp, Fe, Ap, Zr, Al, Cl, M, Ep.	P, Kf, Q, Bt, M, Ap, Ep, Zr, Fe, Cl.
— —	— —	EBT MURVEY N=111 N=16 10 12 46 56	N=13 3.1 (1.3) 7.7 (2.4)	N=9 3.6 (2.3) 7.6 (3.5)	N=6 4.5 (1.3) 13.2 (2.8)	N=7 3.7 (1.79) 14.8 (4.7)
Rb/Sr (0.3-0.6)	Rb/Sr (~0.17)	Rb/Sr (0.3-9.4) K/Rb (100-220) Zr (100-200) Ba (120-1000)	Rb/Sr (0.5-4.3) K/Rb (100-160) Zr (40-150) Ba (300-600) Be (5-25), Sn (10-20), Li, F	Rb/Sr (0.05-0.6) K/Rb (250-400) Zr (80-200) Ba (350-1050) Cr (300-1000), Ni (90-300)	Rb/Sr (0.1-0.4) K/Rb (240-320) Zr (60-200) Ba (600-1000) Low Be, Sn, Mo	Rb/Sr (0.4-4.6) K/Rb (180-250) Zr (40-120) Ba (160-800)
401±33	401±33	398±2	404±24	409±17	393±10	387±12
0.7066±5	0.7066±5	0.705±1	0.708±2	0.7055±1	0.7059±2	0.7080±3
None known.	None known.	No primary U mineralization. (a) Hydromorphic U peat bogs. (b) Uraniferous fluorite/haematite NE-SW fractures expecially in Murvey Granite facies; age of fractures possibly Hercynian; large porphyry Mo deposit in Murvey facies	Tullow Pluton (a) Extensive hydromorphic U peat bogs: largest ~ 35t(U3O8). (b) Uraniferous quartz breccias, veins and greisens (fluorapatite, autunite, torbernite) Blackstairs Pluton (a) Uraniferous quartz-breccias. (b) Thin pitchblende quartz veins trending N60°E in contact schists	None known	None known	None known

Cor-corundum, Crd-cordierite, Dp-diopside, Ep-epidote, Fe-Fe ore, Fib-fibrolite, Fl-fluorite, Gn-garnet, Hb-hornblende, Hy-hypersthene, Kf-K feldspar, Ky-kyanite, M-muscovite, P-plagioclase, Q-quartz, Ru-rutile, Sil-sillimanite, Sp-sphene, St-staurolite, To-tourmaline, Tp-topaz, Zr-zircon.

5. Rock abbreviations are D-diorite, Gd-granodiorite, Gt-granite, Lgt-leucogranite/aplogranite, Qm-quartz monzotonalite, Qd-quartz diorite, Tn-tonalite. Co-positions in brackets are volumetrically small in any given intrusion.

6. Table compiled from sources in reference list. In addition, the author's unpublished geochemical data for the Main Donegal, Thorr, Trawenagh Bay, Barnesmore, Carrigmore, Newry and Corvock plutons and unpublished Rb-Sr isochron data for the Barnesmore, Fanad and Corvock plutons have been incorporated.

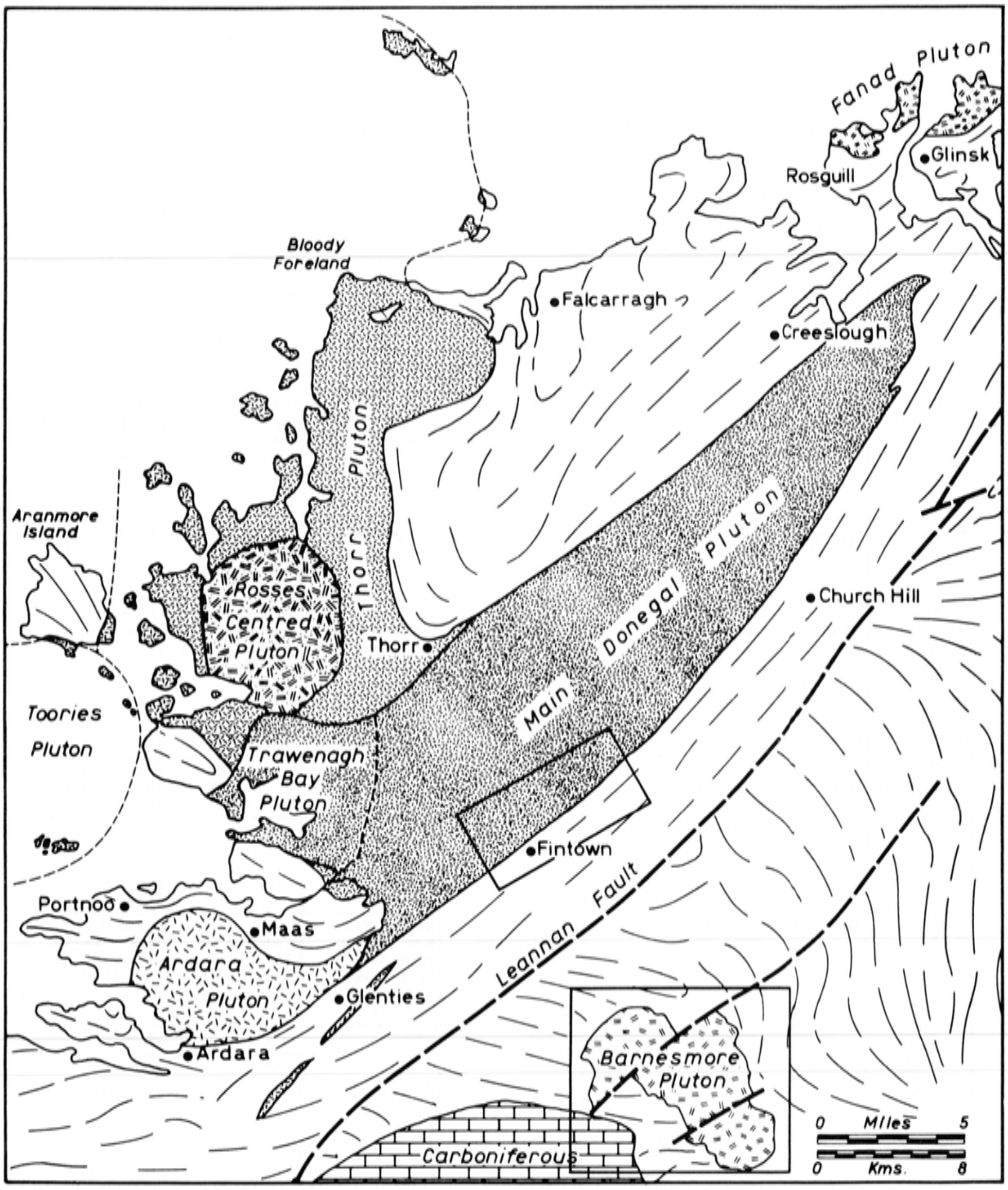

Figure 4. The granites of Donegal, northwest Ireland (after Pitcher and Berger 1972). The Barnesmore and Fintown areas indicated are shown in greater detail in Figures 5 and 6 respectively.

Barnesmore pluton

The Barnesmore pluton (Table 1 and Fig. 5) is isolated from the other Donegal plutons and comprises four granite types passively emplaced by cauldron subsidence into Dalradian metagreywackes (Walker and Leedal, 1954). Apart from a small body of granodiorite (G1), the main granite (G2) is a leucocratic adamellite, and the latest members of the sheet complex have highly evolved aplogranitic compositions (high Rb/Sr > 20, low K/Rb < 100). A Rb-Sr, whole-rock, isochron age of 396±8Ma has recently been determined for the pluton (O'Connor et al., in press). A remarkable feature of the pluton is the widespread development of metasomatic alteration zones in the area west of the NE-trending Belshade Fault. The alteration involves desilication and deep reddening of feldspars in the G2 granite resulting in monzonitic patches of rock up to 30m across, analogous to the 'episyenite zones' in some uranium-mineralized, French Hercynian granitoids. The desilication of the G2 granite post-dates the development of aplite veins but seems to pre-date movement on the Belshade Fault (Walker and Leedal, 1954). Unfortunately, the desilicated zones do not contain uranium minerals. However, most of the numerous autunite showings (Fig. 5) are located mainly within the aplogranite facies, G3a, associated with joint surfaces or margins of Tertiary basalt dykes; U analysis of up to sixty radiometrically-anomalous whole-rock samples gave a range of 10-170ppm (Maugh

Table 2

Radioelement abundances of crustal rocks in Britain and Ireland

Rock Suite	n	U ppm	Th ppm	K%
Scourian Gneisses (Scotland)[1]	154	0.05	1	0.95
Laxfordian Gneisses (Scotland)[1]	39	0.30	11	1.74
Moine Schists (Scotland)[2]	15	2.4	12.8	—
Dalradian Metasediments (Scotland)[4] —pelite/psammite	46	2.3	17.2	3.31
Dalradian Metasediments (Donegal)[3]				
—limestone	5	0.8	2.2	0.42
—pelite	4	2.8	17.3	2.22
—quartzite	3	1.5	5.1	1.03
—amphibolite	1	1.3	1.0	0.36
Lower Palaeozoic Rocks (Leinster)[5]				
—slate	1	3.6	22.5	3.89
—acid volcanics	5	10.9	34.3	6.63
—basic volcanics	4	5.6	17.4	2.30

References:

1. Tarney et al. (1972).
2. Richardson and Powell (1976).
3. O'Connor and Long (1985).
4. Atherton and Brotherton (1979).
5. O'Connor, unpublished data.

Data for references (3), (4) and (5) determined by epithermal NAA at the Risley reactor centre, U.K.

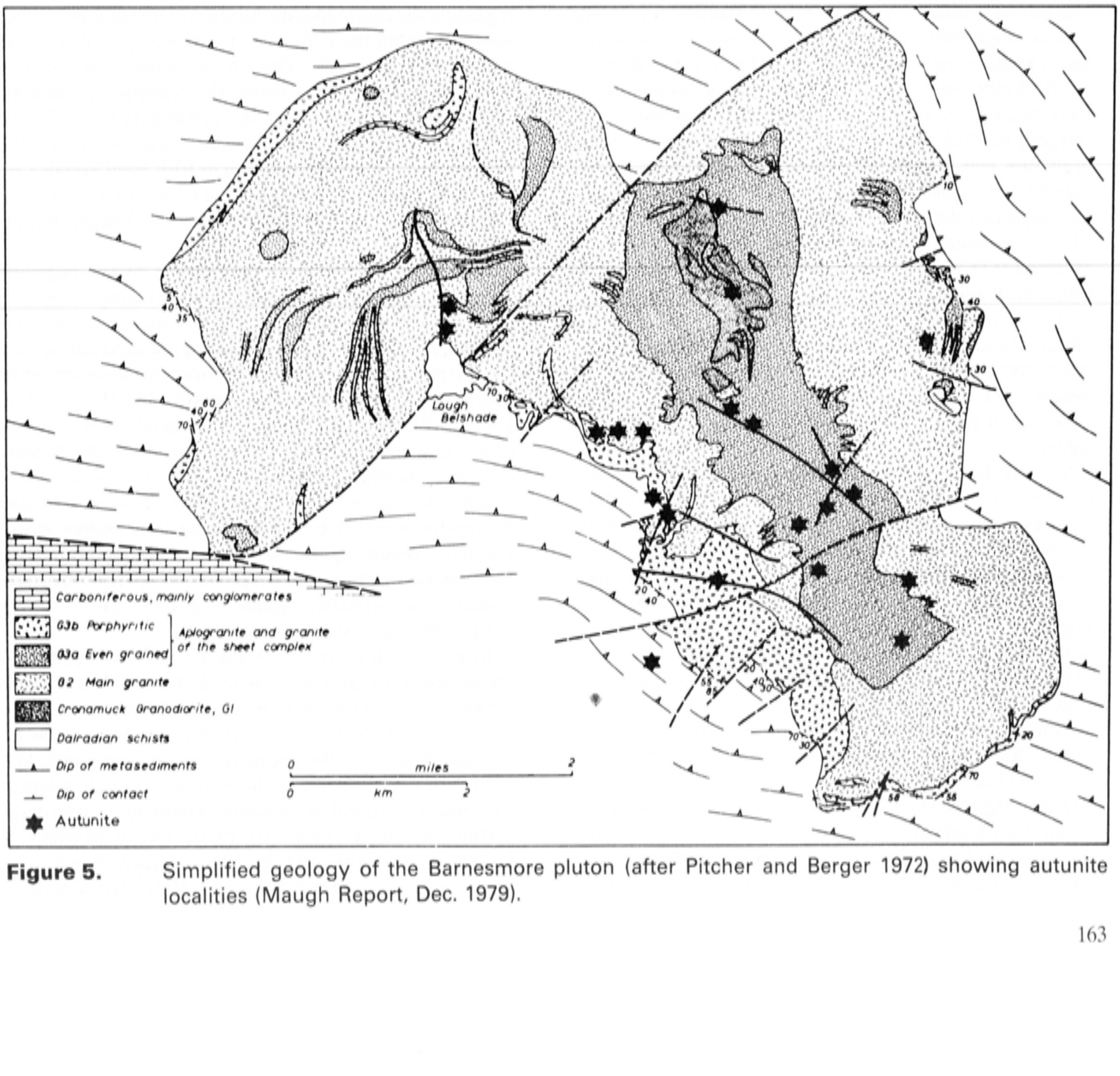

Figure 5. Simplified geology of the Barnesmore pluton (after Pitcher and Berger 1972) showing autunite localities (Maugh Report, Dec. 1979).

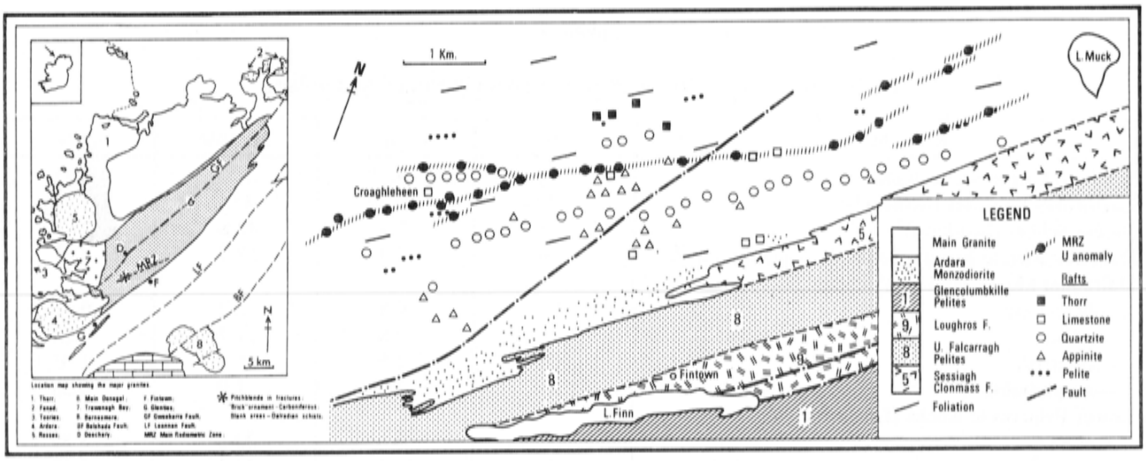

Figure 6. Simplified geology of the Fintown area, Main Donegal pluton (after Pitcher and Berger 1972) shows distribution of raft trains, location of Main Radiometric Zone (MRZ) and pitchblende locality (inset).

Report, Dec. 1979). Uraninite has not been found in whole-rock samples, although a thorough search using autoradiography has not been made.

Main Donegal pluton

The Main Donegal pluton (Table 1) has been intruded into a major transcurrent, sinistral, shear zone (Hutton, 1982). The pluton's elongate form (Fig. 6, inset) is due to emplacement in such a shear zone. The pluton has mainly concordant contacts, a compositional banding, a strong mineral alignment, a preferred orientation of inclusions, and a synkinematic schist envelope (Pitcher and Berger, 1972). Composition varies from biotite granodiorite to more leucocratic granite. The pluton has extensive and complex sheeted contact zones containing both abundant pegmatite and microgranite sheets and numerous strike-parallel, raft-trains of varied Dalradian metasedimentary and igneous lithologies. A revised, 9-point, whole-rock, Rb-Sr, isochron age of 407±23Ma has recently been obtained (O'Connor et al., 1982b) and reaffirms the late Caledonian age of this pluton, previously dated at 487Ma by Leggo et al. (1969). The radioelement content of the pluton (Table 1), averaging 2.5ppm U and 12.9ppm Th is low compared with the clarke of these elements for granite. Fission-track studies (O'Connor and Long 1981) show that U occurs in resistate minerals such as zircon, apatite and sphene.

Most of the radiometric anomalies delineated by ground surveys in the Main Donegal pluton occur in discrete NE-trending zones which strike parallel to the foliation of the pluton and its internal raft-trains. The radiometrically anomalous zones reflect the distribution of biotite pegmatites and, to a lesser extent, muscovite pegmatites and microgranites. The biotite pegmatites tend to be concentrated at or near external or internal contacts (e.g. within raft-trains) of the pluton, though not all biotite pegmatites are mineralized.

The most extensive radiometrically anomalous zone, the "Main Radiometric Zone" (MRZ), lies 3.5km NNW of Fintown (Fig. 6) and can be traced in sparse outcrop over a strike length of more than 9km with an average width of about 20m (Anglo United Annual Report, 1978). Extensive use of ground radiometric surveys, deep-overburden and stream sediment geochemistry, trenching, rock-channel sampling and induced polarization surveys located the best targets for drilling. When they suspended exploration activity in early 1981, Munster Base Metals (Anglo United Annual Report, 1981) had drilled a total of 63 holes (4,200m) and had tested about half of the more promising targets which represents about 15% of the total strike length of the MRZ. Twenty three holes were drilled on one extensive target, "R.A.9", near the southwestern end of the MRZ, and showed that while the continuity of the uranium bearing zone (averaging 0.3kg/t U_3O_8 over a width of 8.7m) could be traced for 520m along strike, predictions regarding the extent and the location of higher grade mineralization within the zone were not possible (Anglo United Annual Report, 1980). This erratic distribution is characteristic of mineralization within the elongate, radiometrically anomalous zones in the Main Donegal pluton. Further to the SW along the general strike extension of the MRZ (Fig. 6), in ground under licence to Irish Base Metals Ltd., "secondary-type" pitchblende veinlets were discovered cutting hornfelsed schist rafts (Northgate Annual Report, 1979).

Drill core specimens of uraniferous biotite-pegmatite were investigated (O'Connor et al., 1984) using autoradiography (to determine the precise location of radioactive minerals), followed by preparation of polished thin sections for examination by optical microscopy, electron probe microanalysis and fission track registration (Bowie et al., 1973; Basham et al., 1982). The pegmatitic host rock is coarse-grained, foliated and composed essentially of microcline-microperthite, quartz and biotite. The biotite occurs as large flakes (up to 0.6cm across) in irregular, lenticular aggregates which give the rock its foliation. Minor muscovite and accessory apatite are associated with biotite. Other common radioactive accessory minerals (zircon, xenotime, monazite and sphene) typical of granites are lacking in these mineralized specimens.

Uraninite, identified by X-ray powder photography, is the principal uranium mineral in the rock, and it occurs as euhedral, cubic crystals from 0.2 to 1.75mm across (Plate 1a, b). These show uniform colour and reflectance and contain minor irregular inclusions of other minerals. Most of the uraninite crystals are located in areas rich in biotite, but some are present as inclusions within microcline-microperthite or apatite (Plate 1d). Pyrite and chalcopyrite are present interstitially, and the former occurs as aggregates surrounding uraninite (Plate 1a, b). Molybdenite occurs as

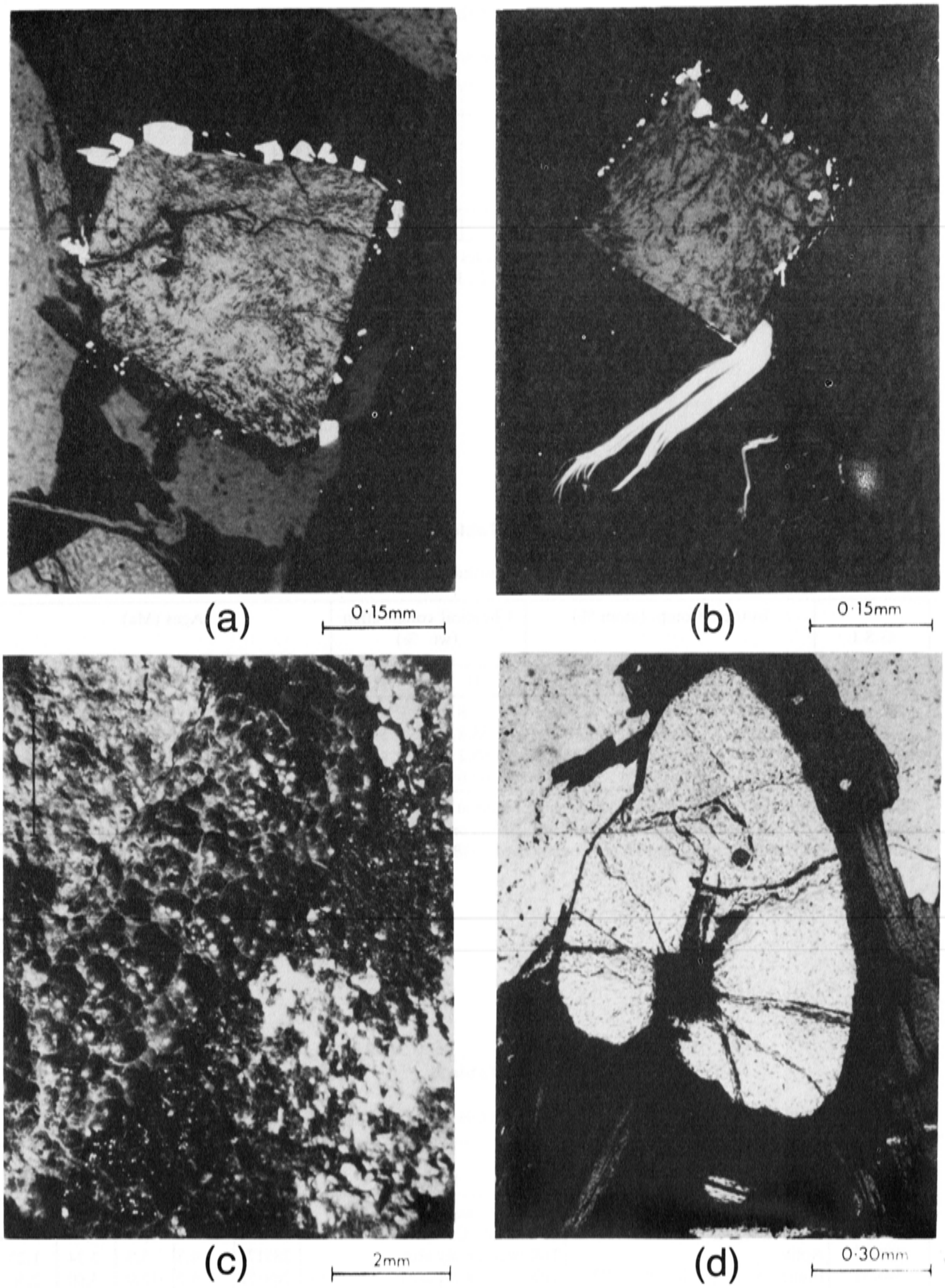

Plate 1 **(a)** Euhedral uraninite in biotite (sample 790929). White-reflecting grains of pyrite within the damage-halo. Reflected light photomicrograph. **(b)** Photomicrograph (reflected light, oil immersion) of molybdenite closely associated with uraninite enclosed in biotite (sample 790930). **(c)** Botryoidal pitchblende on fracture-surface (sample 790926A). Photographed under oblique incident illumination. **(d)** Transmitted light photomicrograph (sample 790930) showing euhedral uraninite partly enclosed in apatite.

Table 3

Electron microprobe analyses of Donegal uraninites

Oxide	790929 (6)*	790930 (8)	790931 (5)
U_3O_8	91.38	91.25	88.22
ThO_2	1.65	1.99	3.74
PbO	5.13	4.90	5.20
Y_2O_3	1.17	0.97	0.71
Total	99.33	99.11	97.90

*Number in parentheses indicates number of points analysed (O'Connor et al., 1984).

Table 4

U-Pb isotopic analyses of uraninite and pitchblende from Donegal*

G.S.I. Number	Isotopic Comp. (atom %)			Chemical composition (wt. %)		Ages (Ma)		
	^{204}Pb	^{206}Pb	^{207}Pb	U	Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
790926A	0.02872	93.544	5.3069	57.8	5.2	599	540	295±4
790929	0.00160	94.059	5.1826	58.8	3.4	393	396	406±4
790930	0.00160	94.060	5.1842	68.2	4.0	401	402	407±4
790931	0.00562	93.648	5.2208	67.6	4.0	402	403	407±4

*Common lead corrections were made using model lead at 400Ma; however, in the case of all except the pitchblende sample (790926A), this correction was not significant. Errors on the U-Pb ages are not given due to difficulties in estimating errors on the XRF analysis for U and Pb (O'Connor et al., 1984).

Table 5

Radioelement data for some rocks and soils over the Tullow Pluton, Leinster Batholith

G.S.I. Number	Lithology	Locality	Grid Ref:	U (ppm)	Th (ppm)	K%	Th/U
760705	Spodumene pegmatite	Aclare House	283519	1.4	0.7	1.65	0.50
760706	Lepidolite greisen	Stranakelly Cross Roads	298171	1294.0	75.0	7.09	0.06
760707	Aplite	Tullow anomaly area	289172	4.3	5.3	3.34	1.23
760711	Equigranular granite (Type II)	Tullow anomaly area	289172	5.2	13.0	3.60	2.50
760717	Brown gritty loam	0.5m deep, Tullow anomaly area	289172	93.3	14.1	2.26	0.14
760718	Brown gritty loam	0.5m deep, Tullow anomaly area	289172	18.5	15.0	3.03	0.81
760719	Brown loam	0.3m deep, Tullow anomaly area	289172	105.0	10.8	2.02	0.10
760720	Grey sandy gley	1.3m deep, Tullow anomaly area	289172	49.6	21.0	2.28	0.42
760704	Peat (-100 mesh fraction)	Surface, Tullow anomaly area.	289172	4656.0	—	—	—

*U, Th and K determined by epithermal neutron activation analysis (Risley, U.K.); errors (2 sigma) on each determination are 0.5ppm or 10%, whichever is greater.

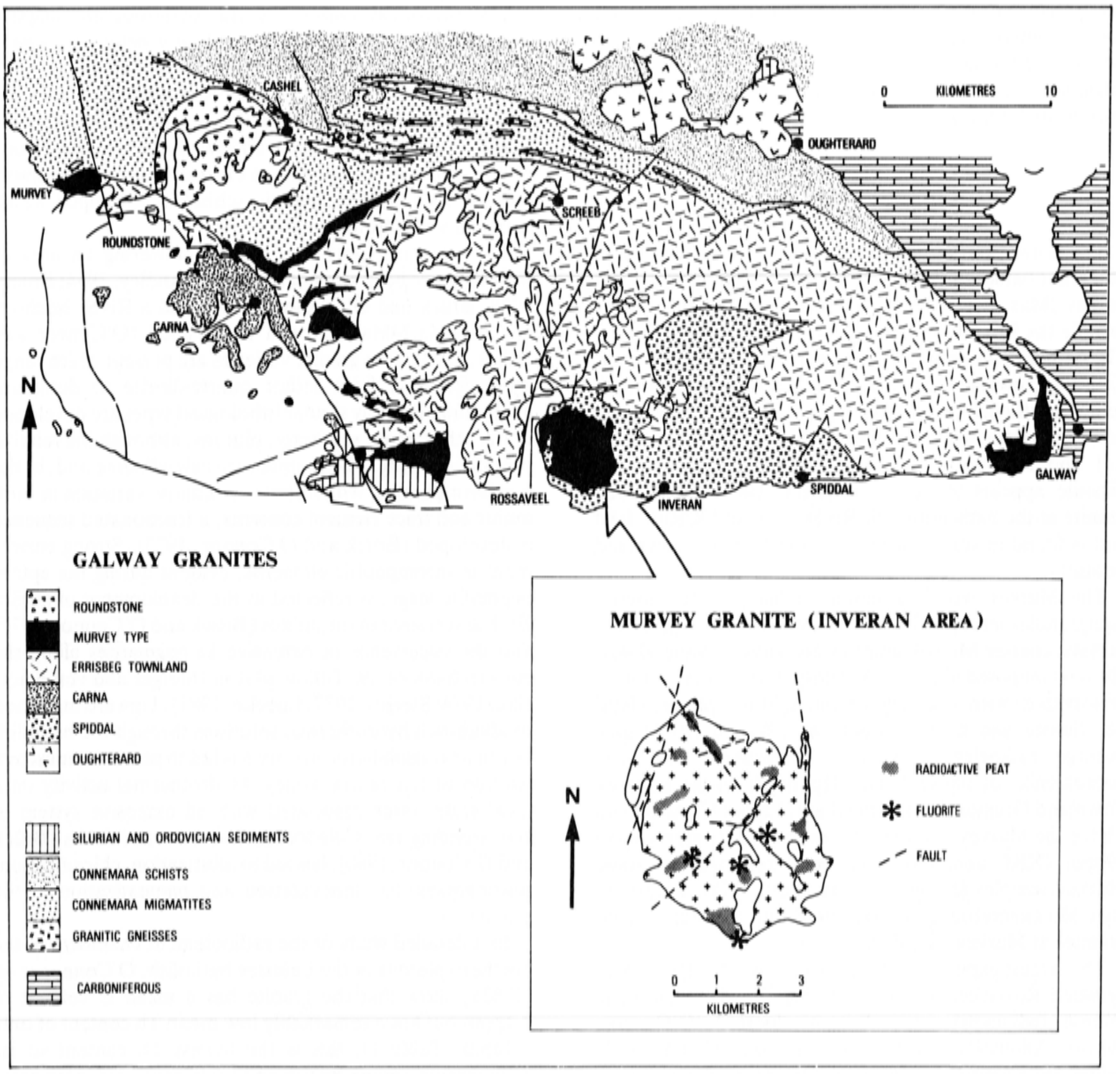

Figure 7. Sketch map of Galway batholith (after Max et al. 1978) showing distribution of radioactive peat bogs and fluorite occurrences in Murvey granite of the Inveran area (Maugh Report, Jan. 1979).

elongate, thin, crenulate flakes along biotite cleavage and as equant crystals up to 0.6 × 2.0mm enclosed in biotite; molybdenite is frequently associated with uraninite (Plate 1b). Electron microprobe analyses of the uraninite (Table 3) show no major variations between grains, and indicate a relatively low thorium content.

Botryoidal pitchblende occurs as thin coatings on fracture surfaces in biotite schist (Plate 1c). Individual botryoids are up to 1mm across and X-ray powder photography gave a characteristic pattern for oxidized uraninite formed at low temperature.

Lead isotopic ages of uraninites from drill-core samples and of pitchblende from surface outcrops are given in Table 4 (O'Connor et al., 1984). The U-Pb ages for uraninite show remarkably good agreement, and are evidently concordant with the Pb-Pb ages. The latter show excellent agreement among the three drill core samples, and indicate a single generation of uraninite forming at 407±4Ma. The U-Pb ages of the vein pitchblende are erroneously high, probably reflecting U loss suggested by the somewhat weathered nature of the outcrop from which the sample was collected. However, there is no obvious reason to doubt the Pb-Pb age of 295±4Ma, as any loss of lead by surface leaching is unlikely to produce isotopic fractionation.

In conclusion, pegmatite-hosted uranium mineralization is particularly well developed at the southwestern end of the Main Donegal pluton in the MRZ. $^{207}Pb/^{206}Pb$ ages indicate a single generation of uraninite formed at 407±4Ma concordant with the Rb-Sr whole-rock isochron age of 407±23Ma determined for the pluton itself. Textural relations of uraninite are consistent with late magmatic introduction of U-bearing fluids during the consolidation of the biotite pegmatites. Magmatic fractionation does not seem to be the dominant process for concentrating U in the biotite pegmatites because some pegmatites are mineralized while others are not; a similar pattern of selective enrichment is present in the microgranite dykes of the sheeted contact zone of the pluton. The radioelement levels in the Dalradian pelite envelope are comparable to the pluton itself, and their incorporation or melting during granite formation would not have led to the enrichment observed. The spatial association of the pitchblende (fracture-fill) mineralization with the pegmatite-hosted uraninite mineralization (at the southwestern end of the MRZ) is very significant; it supports the conclusion that either both had a common origin or the later pitchblende had been derived, under suitable conditions of post-magmatic remobilization, transport and deposition, from the earlier pegmatite-hosted mineralization.

Galway batholith

The Galway intrusion (Table 1) is an E-W elongate post-kinematic batholith comprising two or more discrete granite domes (Max et al., 1978); a number of satellite bodies include the Roundstone, Omey and Inish plutons (Fig. 7). The batholith is composed of a comagmatic series of Carna, Errisbeg Townland, Spiddal and Murvey Granites with some transitional varieties. Compositions range from granodiorite to dominant adamellite (Errisbeg Townland Granite) and leucogranite (Murvey Granite). The Murvey Granite appears to be the youngest and most evolved granite in the batholith (with $Rb/Sr > 10$ and $K/Rb < 100$) and is found in zones marginal to the Errisbeg Townland Granite.

The Murvey type is generally a fine-grained (aplitic) equigranular leucogranite with a few scattered large phenocrysts; coarser Murvey granites are known. Mineralogically it is composed of quartz, K-feldspar, plagioclase, biotite (chloritized) with accessory zircon, apatite, sphene, allanite, thorite and flourite. Coats and Wilson (1971) give average radioelement values, determined by X-ray fluorescence, of 10ppm U and 41ppm Th for the Errisbeg Townland Granite (111 samples) and 12ppm U and 56ppm Th for the Murvey Granite (16 samples); U contents up to 29ppm (XRF analyses) have been reported for some Murvey samples (Maugh Report, Nov. 1978). Porphyry-style Mo mineralization is associated with the Murvey type granites at Murvey and Mace.

The largest exposure of Murvey type is a flat-lying sheet between Rossaveel and Inveran (Fig. 7) where the most intense radiometric anomalies are located (O'Connor, 1981a). Anomalous peat, water and stream sediment U values are abundant in this area. One particular radiometrically-anomalous peat bog extends for over 2km along a NW-trending fault: maximum gross count readings of 10,000 counts per second (SPP2 meter) and U contents up to 400ppm have been recorded (Maugh Report, Jan. 1979). The Murvey Granite in this locality is rich in chlorite and it contains many veins containing haematite and black fluorite. No primary uranium minerals have been found. However, it is possible that a high U+Th primary, accessory mineral (e.g. thorite) is present in the Granite and may have acted as a source of leachable uranium during later hydrothermal redistribution and deposition in fractures along with fluorite and sulphides (see Feely and Madden, this vol.).

Leinster batholith

The Leinster batholith (Table 1) comprises five adjacent, but separate, dome-like plutons (Brindley, 1973) emplaced by distension and stoping into the low grade metamorphic rocks of the Lower Palaeozoic massif of SE Ireland (Fig. 8, inset). The massif is made up of a sequence of slates, greywackes and quartzites with intercalated calc-alkaline volcanic rocks. Sparse radioelement data for some of these lithologies are given in Table 2.

The individual plutons of the batholith are diapiric (Brindley, 1954) and are arranged *en échelon* in a linear NNE-trending array oblique to the northeasterly Caledonide trend of the country rocks. From north to south, the plutons are termed Northern pluton, Upper Liffey Valley pluton, Lugnaquillia pluton, Tullow pluton and Blackstairs pluton. Around each pluton an extensive contact metamorphic aureole of synkinematic schists is developed which varies in width from 1 to 6km.

The two most northerly plutons, covering an area of $600km^2$, have been studied in detail (Brindley, 1954; Brück, 1974; Brück and O'Connor, 1977), and a Rb-Sr isochron age of 404±24Ma has been determined (O'Connor and Brück, 1978). Five granite varieties are present which range in composition from minor quartz-diorite to dominant adamellite. Broadly similar lithological types are developed in the other, more southerly, plutons, although the relative proportions vary. The granites are calc-alkaline and, in the northern plutons, which show systematic variation in both major and trace element contents, a fractionated sequence is developed (Brück and O'Connor, 1977). Strong enrichment in incompatible elements, evident during the aplite-pegmatite stage, is reflected in the development of an Sn-Be-F association in the aplites (Brück and O'Connor, 1977) and the occurrence of extensive Li-pegmatites along the eastern flank of the Tullow pluton (Steiger and von Knorring, 1974; Steiger, 1977; Luecke, 1981). Upward migration of alkali-rich hydrothermal solutions through the batholith late in its consolidation history has led to pervasive muscovitization of the central zones. Hydrothermal activity on a local scale, often associated with an extensive system of NW-trending late Caledonian fractures and faults (Brück and O'Connor, 1980), has led to albitization, chloritization, tourmalinization, sericitization and haematization of the granite.

In a detailed study of the radioelement chemistry of the northern plutons of the Leinster batholith, O'Connor et al. (1982a) show that the granite has a mean U content of 3.1ppm but has a remarkably low mean Th content of only 7.7ppm (Table 1); this is the lowest Th content so far encountered among British and Irish late Caledonian granitoids. Th shows strong correlation with other major and trace constituents, whereas U is poorly correlated (except with alkali elements). Fission track studies show that most of the Th and up to 40% of U is bound in primary accessory minerals such as zircon, sphene (>500 ppm U) and apatite (80-120ppm U). Up to 60% of the U has been precipitated in intergranular areas or is located within late-stage alteration minerals associated with chlorite and sericite. A secondary haematite-magnetite mineral associated with chloritized biotite was found to contain up to 500ppm U, strongly implying that some redistribution of U has occurred during late hydrothermal alteration of the batholith. However, the radioelement-poor nature of the northern plutons suggest that they have a low potential for U mineralization.

Uranium exploration began in earnest on the Tullow pluton when, in 1976, Maugh Ltd. discovered a major radiometric anomaly. A short time after this discovery, the Geological Survey of Ireland carborne reconnaissance of the Leinster batholith independently encountered the same anomaly (O'Connor, 1976) in a peat bog about 5km east of Tullow adjoining the main Tullow-Shillelagh road. Intensive exploration of the Tullow pluton by Maugh Ltd. followed, and by mid-1982, when exploration ceased, most of the batholith had been prospected, and a number of distinct U occurrences defined (Fig. 8).

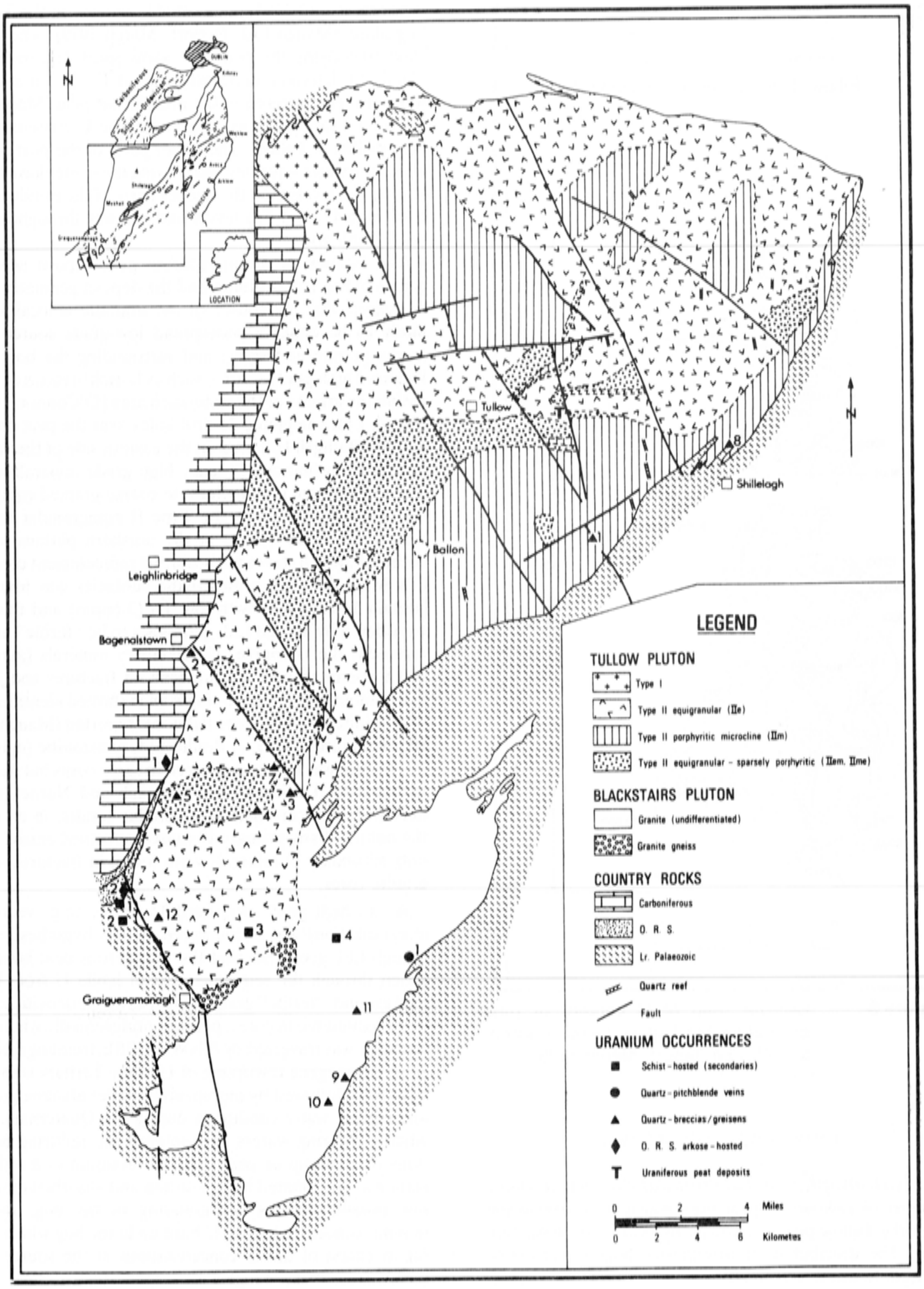

Figure 8. Uranium occurrences in the Tullow and Blackstairs plutons of the Leinster batholith (Maugh Reports). Geology of the Tullow pluton based upon mapping by Maugh geologists.
Schist-hosted occurrences:
(1) Boherkyle, (2) Curraghlane, (3) Sruhraungloragh, (4) Rathgeran.
Quartz-breccia and greisen occurrences:
(1) Blacklion, (2) Bagenalstown, (3) Dunroe, (4) Tower Hill, (5) Kilcumney, (6) Garryhill, (7) Corries Bridge, (8) Stranakelly, (9) Bantry Commons, (10) Bran Scultair, (11) Gowlin, (12) Griffinstown.
Quartz-pitchblende vein occurrence:
(1) Cullentragh.
ORS arkose-hosted occurrences:
(1) Goresbridge, (2) Skeaghvasteen.

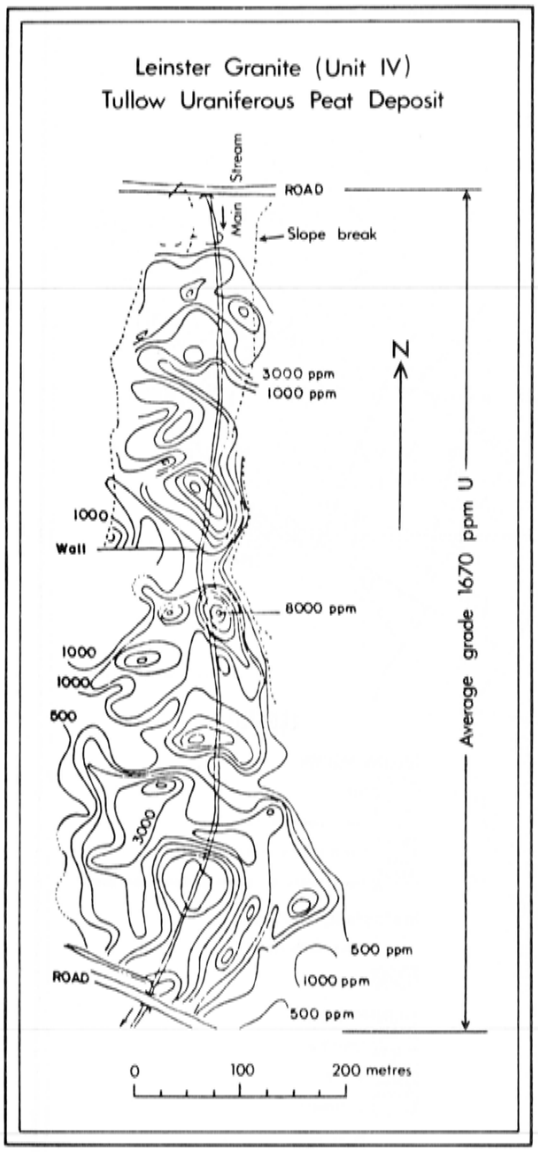

Figure 9. Contour map of U content of peat deposit east of Tullow, Leinster batholith (Maugh Report, March 1979).

Intragranitic occurrences

Hydromophic peat accumulations include a large number of radioactive peat bogs which were discovered over the Tullow pluton, particularly over its southwestern part. The distribution of uraniferous bogs is correlated with photo-lineaments trending mainly N160°E and N120°E (Maugh Ltd. reports). The largest of these bogs was that near Tullow, and a good deal of time and effort was spent in prospecting and evaluating this occurrence using detailed geochemical, radiometric, emanometric and geophysical surveys. The anomaly (Fig. 9) is located in a fault-controlled, N-trending, broad, shallow valley some 2km in length and 0.5km in width. The peat is up to 2m thick, has been dated at 10,000 to 12,000 years B.P. and contains 1,000 to 10,000ppm U (Fig. 9). Assuming a cut-off grade of 500ppm U, an average grade of 2,000ppm U, an average peat depth of 0.6m and a peat density between 0.18 and 0.28, then between 26 and 42t U are probably present in the Tullow bog alone (Maugh Ltd. Report, March 1979). The sandy clays underlying the peat also show some U enrichment (Table 5). Elevated concentrations of Fe, S, Cu and Mo were also encountered in the uraniferous peat. Moreover, a seasonal variation was observed in the U content of the peat profile at Tullow. The upper parts of the peat profile which are water saturated only during the winter have lower U (and Fe) levels than the deeper parts of the profile which have high U (and Fe) levels and are wet throughout the year (Table 6).

The location of the uraniferous peat deposit near the centre of the Tulow pluton and the deposit geometry (Fig. 9) suggest that the source of the uranium is local and is likely to be either a widespread low-grade source such as the granite underlying and surrounding the bog, or a localized high-grade source, such as U-rich breccias or veins within the granite of the watershed area (O'Connor, 1976). Maugh Ltd. completed 25 drill holes over the peat deposit and the Rathgall Hill area on the eastern side of the valley, but failed to find any primary high grade mineralization. The local granite is a medium- to coarse-grained equigranular rock, equated with the Type II equigranular variety defined by Brück (1974) in the northern plutons of the batholith, which shows fairly normal radioelement contents (Table 5). In core, a muscovitic subfacies was found to contain 14-23ppm U with low Th (3-6ppm) and this was considered by Maugh Ltd. geologists to be "fertile" and to represent the U source. U secondary minerals (autunite and torbernite) were encountered on fractures and joints in a number of cores and a single unconfirmed identification of uraninite in a muscovite flake was reported (Maugh Ltd. Report, March 1979). A desilicated, monzonitic (episyenite) granite was also encountered in some cores but was not mineralized. Drilling at the Fennagh and Nurney uraniferous peat occurrences gave similar results; in all cases the nature of any primary U source remained elusive, and only secondary U minerals were found in fractures in the granite cores.

As no high grade, localized U source (e.g. vein-type mineralization) was encountered, it was hypothesized by Maugh Ltd. geologists that the uraniferous peat bogs had arisen through the remobilization of labile U from high-background, "fertile" granite (such as the muscovitic subfacies encountered in core), perhaps preferentially where this lithology was traversed by NNW- or ESE-trending fracture zones. Supergene reworking of U in the Tertiary soils may have been followed by mobilization under alkaline ground and surface water conditions during the Quaternary, and when U-bearing waters encountered the reducing conditions of a swamp or peat bog, the uranium in a reduced state was precipitated from solution and absorbed onto the fine organic detritus accumulating in the bog. In this manner concentrations of U built up in the bog which were far in excess of the U concentrations in the source area (O'Connor, 1976; Maugh Ltd. Report, Feb. 1980).

Uraniferous quartz-breccias, veins and greisens are known at Dunroe, Kilcumney, Blacklion, Tower Hill, Corries Bridge, Bagenalstown, Garryhill, Stranakelly, Bantry Commons, Bran Scultair, Gowlin and Griffinstown. In the southern part of the Tullow pluton and over much of the Blackstairs pluton exposure is better than in the northern part of the Tullow pluton, and a far larger number of mineralized outcrops and boulder trains have been located (Fig. 8) by radiometric prospecting; most of these occurrences have only weak or non-existent

Table 6

Vertical profiles for Fe, Mn and U content in the U-bearing peat deposit near Tullow (Maugh Report, March 1979)

Sample/Depth (m)	Fe Total %	Mn%	U ppm	U/eRa	
Peat					
F18 a 0-0.2	0.68	0.038	600	40	hydromorphic conditions in winter
b 0.2-0.4	0.59	0.020	250	12	
c 0.4-0.6	0.91	0.020	570	33	
					lower level of water-table (important Eh influence)
d 0.6-0.8	1.57	0.035	1,300	108	permanent hydromorphic conditions
e 0.8-1.0	2.87	0.032	2,300	127	
Stream sediment or till					
f 1.0-1.2	1.44	0.032	560	11	
g 1.2-1.4	0.80	0.032	15	2	
Peat					
G28 a 0-0.2	0.80	0.028	170	10	hydromorphic conditions in winter
b 0.2-0.4	0.96	0.030	1,300	56	
					lower level of watertable (Eh influence)
c 0.4-0.6	0.78	0.034	3,000	125	permanent hydromorphic conditions
d 0.6-0.8	1.19	0.030	7,700	84	
e 0.8-1.0	1.32	0.042	17,000	63	
f 1.0-1.2	1.20	0.038	11,000	31	
Stream sediment or till					
g 1.2-1.4	0.63	0.020	190	0.9	

geochemical signatures in soils, stream sediments and waters. Individual occurrences are described in detail in open-file Maugh Ltd. Reports (June 1979, Feb. 1980, Sept. 1980, Feb. 1981 and June 1981). At most of the occurrences radioactive boulders of altered granite (chloritized, haematized, desilicated), brecciated or veined, altered granite, or quartz-breccia are found.

The quartz in the breccias is often jasperoid, and fine-grained secondary U minerals (mainly autunite) are disseminated along fractures, in vugs and in porous desilicated patches. Fluorapatite is often the main radioactive mineral present, together with chalcopyrite, pyrite and haematite; a fluorapatite-bearing breccia boulder from Kilcumney assayed 0.68% U. Microscopically, the breccias have a strong clastic texture, with well-rounded clasts which range from boulder (>50cm) to sub-pebble (<1cm) size (Blacklion) set in a comminuted matrix. This suggests that the breccias may be gas explosion breccias of hydrothermal origin. Analogous breccias occur in outcrop at Blackrock and Kippure Bridge in the northern plutons (Brindley et al., 1976) but none contain any uranium minerals. Drill testing of the Bagenalstown, Kilcumney, Tower Hill and Bantry Commons prospects showed that U mineralization dies out rapidly within a few tens of metres of the surface. The fluorapatite-bearing breccias and greisen masses may have developed in cupola environments (on topographic highs) and may have tabular or lensoid shapes; subsequent supergene reworking may have produced the autunite concentrations within the weathered rock profile which die out at shallow depths (Maugh Ltd. Report, Feb. 1981). It is debatable whether this type of "primary" U mineralization, developed in breccias and greisen masses in the better exposed southern part of the Tullow pluton, could give rise, through leaching, to the concentrations seen in the uraniferous peat bogs further north or whether a different, and as yet undefined, type of primary mineralization is responsible for the uraniferous peat deposits.

The fluorapatite-silica association in the Leinster breccias has been compared with albite-apatite breccia pipes and apatite-rich greisens associated with the Caledonian South Mountain Batholith of Nova Scotia (Chatterjee and Muecke, 1982). These breccia pipes are about 15m in diameter and carry autunite (and possibly pitchblende) replacing apatite.

Elsewhere in the Tullow pluton radioactive lepidolite greisens are known to occur (O'Connor, 1981a) in the complex, sheeted, eastern, contact zone at Stranakelly. Joint surfaces in some blocks are brownish black, and a manganese-rich mineral (? manganotantalite) together with uraniferous microlite have been identified (Steiger, 1977). An analysis of the greisen (Table 5) indicates about 1300ppm U and neglibible Th. Related Li pegmatites at Aclare House have very low U (and Th) contents (O'Connor, 1981a).

Perigranitic occurrences

Quartz-pitchblende veins occur at Cullentragh, on the eastern contact of the Blackstairs pluton, where trenching has revealed two thin radioactive quartz veins striking N60°E in the aureole schist (Maugh Ltd. Report, Feb. 1982). No wall-rock alteration was evident along an exposed length of 100m. Pitchblende was positively identified, and a veinlet sample assayed 4% U, 1,700ppm As and 3,900ppm Pb. Two drill holes confirmed that there was no depth extension to the mineralization.

Volcanic and schist related occurrences are known at Curraghlane, Sruhraunglоragh, Boherkyle and Rathgeran. In view of the known high U and Th content of the Caradocian volcanics of the Avoca belt (Table 2 and O'Connor, 1981a) one might expect to find a large number of volcanic-related U occurrences along the eastern flank of the Tullow pluton, in the Graiguenamanagh belt and elsewhere SW of the Blackstairs pluton. Also, weakly radioactive, black (graphitic) schists with U contents of 150-200ppm seem to be fairly widely developed in the envelope rocks around the Blackstairs pluton (Maugh Ltd. Report, June 1982).

At a number of localities in areas which were under licence jointly to Irish Base Metals Ltd. and Tara Prospecting Ltd., radioactive minerals have been identified (Maugh Ltd. Report, June 1982).

—At Curraghlane, pitchblende has been identified on microfractures in chloritic schist.

—At Boherkyle, rutherfordine has been identified in schists below the unconformity with the overlying Old Red Sandstone and close to the oxidation-reduction interface.

—At Sruhraunglоragh, radioactive boulders of tuff breccia assayed 1450ppm U, and at Rathgeran, secondary U minerals occur in a schist boulder.

Post-granite occurrences

A number of epigenetic mineral showings have been located in the Old Red Sandstone (ORS) rocks which unconformably overlie the Lower Palaeozoic sequences and are exposed to the west of the Blackstairs pluton (Maugh Ltd. Report, June 1982).

—At Goresbridge, radioactive arkosic boulders rich in fluorapatite and U secondary minerals assayed between 400 and 2,800ppm U. The possibility of the existence of a clastic wedge of uraniferous ORS arkoses below the Carboniferous limestone at this locality was tested by drilling, but results were negative; the source of the boulders is unknown.

—At Grenan, mid-ORS purple to red sandstones with pale green oxidation spheres are exposed in a road cutting. Whole-rock U contents of 500ppm were recorded, and the U mineral brannerite has been identified.

—At Skeaghvasteen, pale green ORS arkoses are faulted against the SW termination of the Tullow pluton. U contents up to 800ppm were recorded for the arkose.

None of the epigenetic sandstone-hosted U occurrences, or the intragranitic and perigranitic occurrences discussed above are considered to be of economic importance.

Conclusion

Intensive exploration for uranium has defined significant, though uneconomic, mineralization associated with certain Irish late Caledonian granitoids. Abundances of radioelements classify these granitoids as radioelement-rich, normal or radioelement-poor plutons.

The Irish radioelement-rich granitoids (Barnesmore, Galway) are "permitted" plutons with hornfels aureoles. Their magmas are evolved, they are metalliferous in the sense of Plant et al. (1980), and they may be compared both geologically and geochemically to British granitoids such as Cairngorm and Mount Battock. U and Th are located in primary resistate minerals such as zircon, apatite, sphene, allanite, thorite and Fe-Ti-Mn oxides; uraninite has not been reported from either the Barnesmore pluton or Galway batholith, but an exhaustive search has not been made. These radioelement-rich plutons are not mineralized; U showings are (i) exclusively secondary products (autunite, torbernite), (ii) restricted to areas of the most fractionated granitic facies in the plutons concerned (e.g. Murvey type in the Galway batholith and the aplogranite G3a in the Barnesmore pluton) and (iii) structurally controlled (e.g. often associated with deuteric alteration such as chloritization or haematization along NW-trending fractures/joints). An analogy with Irish Tertiary plutons (O'Connor, 1981b) shows that both have high radioelement contents, were passively emplaced, but have no significant associated U mineralization; this suggests that extreme magmatic fractionation of small volumes of acid calc-alkaline magma does not produce economic concentrations of U.

Intragranitic U mineralization has been discovered associated with the radioelement-poor Irish granitoids of Donegal and Leinster which are "forceful" plutons in the sense of Read (1961) with synkinematic schist aureoles. In the case of the Main Donegal pluton, the host granite is not metalliferous (low levels of U, Th and other incompatible elements), and U and Th occur in resistate accessory minerals (zircon, apatite, sphene). Uranium mineralization is developed in NE-trending linear zones (mainly biotite-pegmatite hosted) associated with the margins of country rock, raft trains and the sheeted contacts of the pluton. The age of the uraninite mineralization is 407Ma, concordant with the age of emplacement of the Main Donegal pluton itself. Textural relations of the uraninite are consistent with late magmatic introduction of the U-bearing fluids. Both the low, whole-rock levels of U (1-5ppm) and the selective nature of the mineralization in certain biotite-pegmatites (but not others) suggest that magmatic fractionation was not the main process of uranium enrichment. The most extensive development of mineralization is at the SW end of the Main Donegal pluton, and the distribution of linear, U-bearing zones in the pluton suggests a dominant structural control. The linear uraniferous zones may represent early annealed shears within the pluton. Independent studies (Hutton, 1982) show that the locus of emplacement of the Main Donegal pluton was an active, NE-trending sinistral, shear zone. It is probably not coincidental that at the SW end of the shear zone an extensive suite of mantle-derived appinitic intrusions preceded emplacement of the contiguous "forceful" Ardara diapir. Thus, the shear zone acted as a locus and pathway for the ascent of both magmas and U-bearing fluids from lower crustal or upper mantle depths. Later, fracture-controlled pitchblende mineralization, dated at 295±4Ma, occurs to the SW along strike from the area of maximum development or uraninite mineralization. These Donegal pitchblende veins may be similar to NW-trending pitchblende veins which occur in the aureole hornfelses of the Criffel-Dalbeattie intrusion in Scotland (Miller and Taylor, 1966).

Enrichment in Li, Sn, Be and F characterizes the later differentiates in the Leinster batholith, with the development of spodumene and beryl-bearing pegmatites, particularly along the eastern flank of the large Tullow pluton. Uraniferous spodumene pegmatites are notably absent, although radioactive lepidolite greisens are known to occur. A muscovitic subfacies of the Type II equigranular granite of this pluton has elevated U contents in the range 10-20ppm and may carry uraninite (single, unconfirmed report). This subfacies may be the primary source of labile U which was remobilized during deuteric alteration of the pluton and concentrated in transverse fracture zones where altered and brecciated granite now carries secondary U minerals. Leaching of these deuterically altered fracture zones has occurred during post-glacial times, and extensive hydromorphic U deposits have been developed. The largest of these is the Tullow uraniferous peat deposit with an estimated content of 26-42t of U.

The only other primary, intragranitic, U mineralization discovered to date in the Leinster batholith consists of fluorapatite-bearing, quartz-breccia veins possibly related to cupola environments and explosive hydrothermal activity. Analogies have been made with uraniferous, apatite-bearing breccias associated with the Caledonian South Mountain Batholith of Nova Scotia, but more extensive studies are necessary to support this comparison.

Wherever desilicated, monzonitic granite has been encountered in drilling (considered a prime target by many French geologists), it has been found to be barren. The only perigranitic mineralization discovered were pitchblende-quartz veins in the contact schists of the Blackstairs pluton. Some pre-granite, volcanogenic or syngenetic, U occurrences are also known, and some post-granite, epigenetic mineral showings have been reported from the ORS sediments west of the batholith.

In Leinster, the exact control of U mineralization associated with the SW part of the Tullow and the Blackstairs plutons remains elusive. These plutons are separated by a major shear zone — the Graiguenamanagh schist septum — in which a distinctive granitic gneiss is developed and upon which an extensive suite of appinite-lamprophyre intrusions is centred (Brindley, 1970 and 1974; McArdle, 1974; O'Connor, 1974b). The shear zone extends to the NE, along the eastern flank of the Tullow pluton, where it exerts a major structural control on the distribution of mineralized (Li, Sn, U) pegmatite and greisen sheets in the aureole schists; further NE, in the vicinity of Ballinglen, scheelite (W) mineralization is developed in late microgranite sheets emplaced within the shear zone (see McArdle et al., this volume). Thus, while this shear zone represents a deep pathway which enabled Li-Sn-U-W mineralizing fluids to migrate in the aureole schists shortly after the emplacement of the main Leinster batholith, its influence on the localization of intragranitic U mineralization cannot yet be demonstrated.

In conclusion, the use of average radioelement contents as a simple criterion of granite "fertility" in the Irish (and British) late Caledonian province is seen to be invalid. As Moreau (1977) suggests, this concept should be restricted to the uraniferous granitoids of the European Hercynian province. The interaction between regional deformation and emplacement of the Irish granitoids seems to be a critical factor in the development and location of primary intragranitic uranium mineralization.

Acknowledgements

Thanks are due to numerous colleagues at the Geological Survey of Ireland, in industry, and at the British Geological Survey for collaboration and fruitful discussion and to the European Commission for partial funding of a number of GSI uranium projects.

References

ANGLO UNITED DEVELOPMENT CORPORATION, Annual Report 1978.

ANGLO UNITED DEVELOPMENT CORPORATION, Annual Report 1980.

ANGLO UNITED DEVELOPMENT CORPORATION, Annual Report 1981.

ATHERTON, M. P. and BROTHERTON, M. S. 1979. Thorium and uranium in some pelitic rocks from the Dalradian, Scotland. *Chem. Geol., 27*, 329-342.

BASHAM, I. R., BALL, T. K., BEDDOE-STEPHENS, B. and MICHIE, U. McL. 1982. Uranium-bearing accessory minerals and granite fertility: II. Studies of granites from the British Isles. In: *Uranium Exploration Methods*. Symposium organised by the OECD Nuclear Energy Agency. Paris 1982, 398-411.

BOWIE, S. H. U., SIMPSON, P. R. and RICE, C. M. 1973. Application of fission-track and neutron activation methods to geochemical exploration. In:*Geochemical Exploration*, Jones, M. J. (ed.) Instn. Min. Metall., 359-372.

BRINDLEY, J. C. 1954. The geology of the northern end of the Leinster granite: Part I — internal structural features. *Proc. R. Ir. Acad., 56B*, 159-190.

BRINDLEY, J. C. 1957. The aureole rocks of the Leinster granite in south Dublin, Ireland. *Proc. R. Ir. Acad., 59B*, 1-18.

BRINDLEY, J. C. 1969. Caledonian and pre-Caledonian intrusive rocks of Ireland. In:*North Atlantic—Geology and Continental Drift*, Kay, M. (ed.), Mem. Am. Assoc. Pet. Geol. *12*, 336-353.

BRINDLEY, J. C. 1970. Appinitic intrusions associated with the Leinster granite, Ireland. *Proc. R. Ir. Acad., 70B*, 93-104.

BRINDLEY, J. C. 1973. The structural setting of the Leinster granite, Ireland — a review. *Sci. Proc. R. Dublin Soc. 5A*, 27-34.

BRINDLEY, J. C., GUPTA, L. N. and KENNAN, P. S. 1976. Explosion breccias and related features in the Leinster Caledonian massif, southeast Ireland. *Proc. R. Ir. Acad., 76B*. 337-348.

BROWN, G. C. and LOCKE, C. A. 1979. Space-time variations in British Caledonian granites: some geophysical correlations. *Earth and Planet. Sci. Letts., 45*, 69-79.

BRÜCK, P. M. 1974. Granite varieties and structures of the northern and upper Liffey valley units of the Leinster batholith. *Geol. Surv. Ire. Bull., 1*, 381-393.

BRÜCK, P. M. and O'CONNOR, P. J. 1977. The Leinster batholith: geology and geochemistry of the northern units. *Geol. Surv. Ire. Bull., 2*, 107-141.

BRÜCK, P. M. and O'CONNOR, P. J. 1980. Major transverse and other linears in the Leinster granite. *Geol. Surv. Ire. Bull., 2*, 349-370.

BURKE, K. C., CUNNINGHAM, M. A., GALLAGHER, M. J. and HAWKES, J. R. 1964. Beryl in the

Rosses granite, northwest Ireland. *Econ. Geol.*, 59, 1539-1550.

CASSIDY, J. and LOCKE, C. A. 1982. Geophysical and radiometric studies of the northern units of the Leinster intrusion. *Geol. J. 17*, 311-322.

CHATTERJEE, A. K. and MUECKE, G. K. 1982. Geochemistry and the distribution of uranium and thorium in the granitoid rocks of the South Mountain batholith, Nova Scotia; some genetic and exploration implications. *In: Uranium in Granites*, Maurice, Y. T. (ed.). Geol. Surv. Canada Paper 81-23, 11-17.

COATS, J. S. and WILSON, R. J. 1971. The eastern end of the Galway granite. *Mineral. Mag., 38*, 138-151.

COOK, A. H. and MURPHY, T. 1952. Measurements of gravity in Ireland. *Geophys. Mem. Dubl. Inst. Adv. Studies, 2*, (4), 27p.

DEWEY, J. F. and PANKHURST, R. J. 1970. The evolution of the British Caledonides in relation to their isotopic age pattern. *Trans. R. Soc. Edin. 68*, 361-389.

HALL, A. 1966. The Ardara pluton: a study of the chemistry and crystallization of a contaminated granite intrusion. *Proc. R. Ir. Acad., 65B*, 203-235.

HALL, A. 1967. The variation of some trace elements in the Rosses granite complex, Donegal. *Geol. Mag.*, 104, 99-109.

HALLIDAY, A. N., AFTALION, M. and LEAKE, B. 1980. A revised age for the Donegal granite. *Nature, 284*, 542-543.

HENNESSY, J. 1981. A classification of British Caledonian granites based on uranium and thorium contents. *Mineral. Mag.*, 44, 449-454.

HUTTON, D. H. W. 1982. A tectonic model for the emplacement of the Main Donegal granite, NW Ireland. *J. geol. Soc. Lond. 139*, 615-631.

INAMDAR, D. D. and KELLY, T. J. 1979. Geophysical study of the Corvock granite, Co. Mayo. *Geol. Surv. Ireland. Bull., 2*, 333-348.

LEAKE, B. E. 1978. Granite emplacement: the granites of Ireland and their origin. *In:* Bowes, D. R. and Leake, B. E. (eds.). *Geol. J. Spec. Issue No. 10*, 221-248.

LEGGO, P. J., COMPSTON, W. and LEAKE, B. E. 1966. The geochronology of the Connemara granites and its bearing on the antiquity of the Dalradian Series. *Q. J. geol. Soc. Lond., 122*, 91-116.

LEGGO, P. J., TANNER, P. W. G. and LEAKE, B. E. 1969. Isochron study of Donegal granite and certain Dalradian rocks of Britain. *In: North Atlantic-Geology and Continental Drift*, Kay, M. (ed.), Mem. Am. Assoc. Pet. Geol. *12*, 354-362.

LUECKE, W. 1981. Lithium pegmatites in the Leinster granite (southeast Ireland). *Chem. Geol.*, 34, 195-233.

McARDLE, P. 1974. A Caledonian lamprophyre swarm in southeast Ireland. *Scient. Proc. R. Dubl. Soc., 5A*, 117-122.

MAUGH REPORT, Nov. 1978, by E. Rothery (GSI Open File).

MAUGH REPORT, Jan. 1979 by K. Downes and E. Rothery (GSI Open File).

MAUGH REPORT, Mar. 1979 by C. Lemoy (GSI Open File).

MAUGH REPORT, June 1979 by C. Lemoy and K. Downes (GSI Open File).

MAUGH REPORT, Dec. 1979 by T. A. Blake (GSI Open File).

MAUGH REPORT, Feb. 1980 by J. P. Guelpa (GSI Open File).

MAUGH REPORT, Sept. 1980 by J. P. Guelpa (GSI Open File).

MAUGH REPORT, Feb. 1981 by J. P. Guelpa (GSI Open File).

MAUGH REPORT, June 1981 by C. Gourmelon and J. P. Guelpa (GSI Open File).

MAUGH REPORT, Feb. 1982 by A. J. Deevy (GSI Open File).

MAUGH REPORT, June 1982 by A. J. Deevy (GSI Open File).

MAX, M. D., LONG, C. B. and GEOGHEGAN, M. A. 1978. The Galway granite. *Geol. Surv. Ire. Bull., 2*, 223-233.

MILLER, J. M. and TAYLOR, K. 1966. Uranium mineralization near Dalbeattie, Kirkcudbrightshire. *Bull. Geol. Surv. Gt. Britain, 25*, 1-18.

MOREAU, M. 1977. L'uranium et les granitoides: essai d'interpretation. *In:* Jones, M. J. (ed.). *Geology, Mining and Extractive Processing of Uranium.* Inst. Mining and Metallurgy, 83-102.

NORTHGATE LTD., Annual Report 1979.

O'CONNOR, P. J. 1974a. Origin of the Carnsore granodiorite. *Geol. Surv. Ire. Bull., 2*, 471-475.

O'CONNOR, P. J. 1974b. Some Caledonian appinitic intrusives in east Carlow, Ireland. *Ir. Nat. J., 18*, 103-108.

O'CONNOR, P. J. 1975. Rb-Sr whole-rock isochron for the Newry granodiorite, NE Ireland. *Sci. Proc. R. Dublin Soc., 5A*, 407-413.

O'CONNOR, P. J. 1976. Uranium Reconnaissance Programme Report No. 2: Preliminary report on the Liscolman radiometric anomaly, Co. Wicklow, 12pp. (GSI Open File).

O'CONNOR, P. J. 1981a. Report on a reconniassance radiometric survey of the Irish Republic. *Geol. Surv. Ire. Rept. Series, 81/1*, 26pp.

O'CONNOR, P. J. 1981b. Radioelement geochemistry of Irish granites. *Mineral. Mag.*, 44, 485-495.

O'CONNOR, P. J. and BRÜCK, P. M. 1976. Strontium isotope ratios for some Caledonian igneous rocks from central Leinster, Ireland. *Geol. Surv. Ire. Bull., 1*, 69-77.

O'CONNOR, P. J. and BRÜCK, P. M. 1978. Age and origin of the Leinster granite. *J. Earth Sci. R. Dubl. Soc., 1*, 105-113.

O'CONNOR, P. J. and LONG, C. B. 1981. Final report to the EEC on the Donegal Uranium Project (Contract PU3/79). (GSI Open File).

O'CONNOR, P. J. and LONG, C. B. 1985. Radioelement abundance data for some Dalradian rocks from Co. Donegal, Ireland. *Mineral. Mag., 49*, 643-648.

O'CONNOR, P. J. and REEVES, T. J. 1979. Age and provenance of the Carrigmore diorite, Co. Wicklow. *Geol. Surv. Ire. Bull., 2*, 307-314.

O'CONNOR, P. J., REEVES, T. J. and HENNESSY, J. 1981. Radioelement abundance data for the Carrigmore diorite and certain minor granite intrusives from east Leinster. *Geol. Surv. Ire. Bull., 3,* 9-16.

O'CONNOR, P. J., HENNESSY, J., BRÜCK, P. M. and WILLIAMS, C. T. 1982a. Abundance and distribution of uranium and thorium in the northern units of the Leinster granite, Ireland. *Geol. Mag., 119,* 67-76.

O'CONNOR, P. J., LONG, C. B., KENNAN, P. S., HALLIDAY, A. N., MAX, M. D. and RODDICK, J. C. 1982b. Rb-Sr isochron study of the Thorr and main Donegal granites, Ireland. *Geol. J., 17,* 279-295.

O'CONNOR, P. J., LONG, C. B. and HENNESSY, J. 1983. Radioelement geochemistry of Irish Newer Caledonian granites. *Geol. Surv. Ire. Bull., 3,* 125-140.

O'CONNOR, P. J., LONG, C. B., BASHAM, I. R., SWAINBANK, I. G. and BEDDOE-STEPHENS, B. 1984. Age and geological setting of uranium mineralization associated with the Main Donegal granite, Ireland. *Trans. Instn. Min. Metall., 93B,* 190-194.

O'CONNOR, P. J., LONG, C. B. and EVANS, J. A. In press. Rb-Sr whole-rock isochron studies of the Barnesmore and Fanad plutons, Donegal, Ireland. *Geol. J.*

PANKHURST, R. J. 1979. Isotope and trace element evidence for the origin of Caledonian granites in the Scottish highlands. In: *Origin of granite Batholiths: Geochemical evidence.* Atherton, M. P. and Tarney, J. (eds.), Shiva Publishing Ltd., England. p. 18-33.

PANKHURST, R. J., SUTHERLAND, D. S., BROWN, G. C. and PITCHER, W. S. 1981. Caledonian granites and diorites of Scotland and Ireland. In: *Igneous Rocks of the British Isles,* Sutherland, D. S. (Ed.), 149-190, Wiley.

PIDGEON, R. T. and AFTALION, M. 1978. Cogenetic and inherited zircon U-Pb systems in granites: Palaeozoic granites of Scotland and England. In: *Crustal evolution in Northwestern Britain and Adjacent Regions,* Bowes, D. R. and Leake, B. E. (eds.). Geol. J., Spec. Issue No. 10, 183-248.

PITCHER, W. S. 1978. The nature, ascent and emplacement of granite magmas. *J. geol. Soc. Lond., 136,* 627-662.

PITCHER, W. S. and BERGER, A. R. 1972. *The Geology of Donegal.* Wiley-Interscience.

PLANT, J., BROWN, G. C., SIMPSON, P. R. and SMITH, R. T. 1980. Signatures of metalliferous granites in the Scottish Caledonides. *Trans. Inst. Min. Metall., 89B,* 198-210.

PLANT, J., SIMPSON, P. R., GREEN, P. M., WATSON, J. V. and FOWLER, M. B. 1983. Metalliferous and mineralized Caledonian granites in relation to regional metamorphism and fracture systems in northern Scotland. *Trans. Instn. Min. Metall., 92B,* 33-42.

READ, H. H. 1961. Aspects of Caledonian magmatism in Britain. *L'pool. Manchr. Geol. J., 2,* 653-683.

REEVES, T. J. 1976. Some diorites in eastern County Wicklow. *Geol. Surv. Ire. Bull., 2,* 15-26.

RICHARDSON, S. W. and POWELL, R. 1976. Thermal causes of the Dalradian metamorphism in the central highlands of Scotland. *Scott. J. Geol., 12,* 237-268.

ROGERS, J. J. W. and ADAMS, J. A. S. 1969. Uranium, Thorium, In: *Handbook of Geochemistry,* Wedepohl, K. H. (ed.), Springer Verlag, 1972, vol. 11-2, 92-B-1 to 92-0-8 and 90-0-5.

SIMPSON, P. R., PLANT, J. and COPE, M. J. 1976. Uranium abundance and distribution in some granites from northern Scotland and southwest England as indicators of uranium provinces. In: *Geology, Mining and Extractive Processing of Uranium,* Jones, M. J. (ed.) Instn. Min. Metall., 126-139.

SIMPSON, P. R., BROWN, G. C., PLANT, J. and OSTLE, D. 1979. Uranium mineralization and granite magmatism in the British Isles. *Phil. Trans. R. Soc. London, 291A,* 385-412.

STEIGER, R. 1977. Prospecting for lithium and tungsten in Ireland. In:*Prospecting in areas of Glaciated Terrain.* Instn. Min. Metall., Helsinki 1977, 14-24.

STEIGER, R. and VON KNORRING, O. 1974. A lithium pegmatite belt in Ireland. *Jnl. Earth Sciences Leeds, 8,* 433-443.

TARNEY, J., SHINNER, A. C. and SHERATON, J. W. 1972. A geochemical comparison of major Archaean gneiss units from northwest Scotland and east Greenland. *Rep. XXIV Int. Geol. Congr. Montreal, 1,* 162-174.

WALKER, G. P. L. and LEEDAL, G. P. 1954. The Barnesmore granite complex, County Donegal. *Sci. Proc. R. Dublin Soc., 26,* 207-243.

YORK, D. 1969. Least-squares fitting of a straight line with correlated errors. *Earth planet. Sci. Lett., 5, 320-324.*

YOUNG, D. G. G. 1974. The Donegal granite — a gravity analysis. *Proc. R. Ir. Acad., 74B,* 63-73.