ALLUVIAL OCCURRENCES OF FERGUSONITE AND GADOLINITE IN THE MOURNE MOUNTAINS, NORTHERN IRELAND

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Mineral grains of the rare-earth-element-bearing minerals fergusonite-(Y) and gadolinite-(Y) are reported within alluvial sediment derived from the granitic Mourne Mountains (the Mournes) in northeast Ireland. Fergusonite (ideally $YNbO_4$) has not previously been described from Ireland (Tindle, 2008). A single crystal of gadolinite (ideally $Y_2Fe^{2+}Be_2Si_2O_{10}$) from the Mournes was described by Lacroix (1888) and subsequently Burke *et al*. (1964) mentioned occurrences of gadolinite at two localities, Blue Lough and Diamond Rocks, in the eastern-central Mournes, but to our knowledge no specimens are preserved.

Hyslop *et al*. (1998) describe fergusonite and gadolinite occurring in drusy granite in northern Arran (Strathclyde, Scotland). This was the first in situ occurrence of these mineral species in the British Isles to be confirmed by X-ray analysis. Fergusonite is also recorded from alluvial sediment at several localities in Scotland including Glen Lui, Grampian (Haynes, 1974, cited in Hyslop *et al*., 1998). Occurrences of gadolinite in the granites of the Red Cuillin, Isle of Skye, Scotland, are mentioned by Green and Todd (2001).

The newly discovered occurrences are in samples of heavy mineral concentrate collected by panning as part of a wider study of alluvial gold and cassiterite within the western Mournes (Warner *et al*., 2010). Fergusonite and gadolinite were identified by EMPA in resin-mounted mineral concentrate samples comprising thousands of grains 50-300 µm in diameter that are broken and abraded due to alluvial transport. Optical properties such as colour were not observed as the mineral grains are in coated polished blocks. Of the six samples examined, fergusonite was found in three and gadolinite in one. The fergusonite-bearing samples are from the Rivers Bann and Leitrim near Hilltown [Irish Grid J 219291, 229287 and 213254], and the gadolinite is in a sample from the White Water, south of Pigeon Rock Mountain [J 271221]. Whereas only a few grains of gadolinite were found, the abundance of fergusonite ranges up to approximately 5% by volume of the mineral concentrates.

There is no reason to believe that fergusonite and gadolinite are restricted to these localities, indeed considering the enrichment of the granite in rare earth elements (REEs) (Meighan *et al*., 1984) it is likely that these mineral species are quite widespread in alluvial sediment in the Mournes. This assertion is supported by XRF analyses of the heavy mineral concentrates that show Nb concentrations typically in the range 100-1000 ppm, suggesting the presence of fergusonite and/or other Nb-bearing species in alluvium throughout the western Mournes.

The REE-bearing grains were analysed by EMPA at The Open University using a Cameca SX100 electron microprobe operating at 20 kV and 20 nA (focussed beam) with a Bruker energy dispersive spectrometer, following the procedure described in Tindle (1982). REE-doped glasses obtained from Edinburgh University were used as standards for the REEs. Table 1 shows the compositional range from eight analyses of Mournes fergusonite and a typical composition. Due to substitution, some elements show a considerable range. An analysis of Arran fergusonite by Hyslop *et al*. (1998) is provided for comparison. Fergusonite is a heavy REE enriched species and there is clear similarity between Mournes and Arran fergusonite analyses. Mournes fergusonite has relatively higher Ca, Ce, Tb and possibly U, whereas the Arran fergusonite has higher Ti and Th. We note that EMPA cannot distinguish between fergusonite-(Y) and the monoclinic dimorph fergusonite-beta-(Y): another analytical method (e.g. XRD, TEM or Raman spectrocopy) is required to distinguish between these. We found no evidence of metamict alteration of either fergusonite or gadolinite.

Back-scattered electron (BSE) imaging of Mournes fergusonite grains showed that internal features such as zonation was absent. However, BSE imaging and X-ray mapping of gadolinite grains in the sample from White Water showed internal compositional heterogeneity

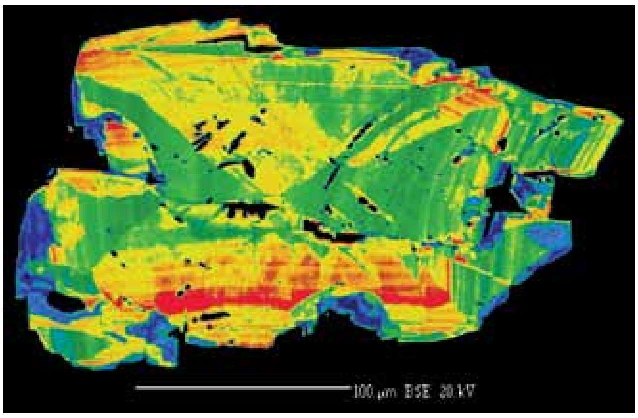

Figure 1. Sector- and oscillatory-zoned crystal of gadolinite-(Y) in a heavy mineral concentrate of alluvial sediment from White Water near Attical in the Mourne Mountains. False colour backscattered electron image: red to yellow indicate a relatively high atomic weight (Y and REE rich) whereas greens and blues indicate relatively low atomic weight (Si and Ca rich).

with oscillatory and sector zonation (Fig. 1). Six EMPA analyses obtained from three gadolinite grains also showed compositional variation with one analysis markedly different to the others in having lower Ca, Y and heavy REEs (Dy, Ho, Er, Tm, Yb and Lu) and a higher proportion of light REEs, particularly Ce. In comparison with the Mournes analyses, Arran gadolinite has much higher Fe and lower light REEs particularly La and Ce.

Also shown in Table 1 is a representative EMPA of monazite-(Ce) from the Mournes samples (this from the River Bann near Hilltown). Monazite-(Ce) is enriched in light REE and depleted in heavy REEs compared to fergusonite and gadolinite from the Mournes. The monazite-(Ce) incorporates relatively large amounts of thorium (7-10 wt% ThO_2) but less uranium (<1 wt% UO_2). This is consistent with previous research on U- and Th-bearing minerals in the Mournes (Moles *et al*., 1995) which showed that monazite contains relatively low U and high Th, whereas zircon contains relatively high U and low Th.

Careful searching should eventually lead to discoveries of gadolinite and fergusonite *in situ* within granite in the Mourne Mountains. The gadolinite and fergusonite occurrences in Arran described by Hyslop *et al*. (1998) occur in drusy granite which was intruded in the Palaeocene, at about the same time as the Mournes granites. Both intrusions share other similarities, including relatively high silica and uranium contents, and distinct Sr, Nd and O isotope geochemistry, which make them distinct from the Palaeocene granites of Skye, Rum and Mull (Meighan *et al*., 1992). These features support a hypothesis of prolonged cooling with less intensive meteoric water-rock interaction resulting in extreme magmatic fractionation and trace element enrichment in the southern sector granites of Arran and the Mournes (Hyslop *et al*., 1998). Gadolinite

	Fergusonite-(Y)				Gadolinite-(Y)		Monazite-(Ce)
	Mournes (this study)			Arran	Mournes (this study)	Arran	R. Bann, Mournes
	Minimum	Maximum	Typical	Hyslop *et al.*	Typical	Hyslop *et al.*	Typical
SiO_2					27.46	23.53	2.23
P_2O_5							27.58
CaO	*0.59*	*0.86*	0.82	0.48	1.67	0.60	0.14
FeO					7.75	12.41	
TiO_2	*0.54*	*1.03*	0.97	1.31			
Y_2O_3	*20.38*	*30.64*	27.49	25.51	23.98	24.20	0.00
Nb_2O_5	*40.88*	*46.57*	44.42	44.93			
La_2O_3	*0.00*	*0.19*	0.11	0.05	0.90	0.18	16.48
Ce_2O_3	*0.75*	*1.68*	0.94	0.57	5.17	1.44	31.14
Pr_2O_3	*0.06*	*0.37*	0.15	0.24	1.27	0.45	3.25
Nd_2O_3	*1.43*	*3.07*	1.82	1.45	6.90	3.87	8.88
Sm_2O_3	*0.92*	*1.52*	1.17	1.07	2.96	3.51	0.74
Eu_2O_3	*0.00*	*0.12*	0.03		0.27	0.01	0.36
Gd_2O_3	*1.83*	*2.49*	2.21	2.00	3.62	5.92	0.65
Tb_2O3	*0.44*	*0.65*	0.55	0.30	0.97	0.56	0.22
Dy_2O_3	*3.96*	*5.73*	4.59	3.89	4.48	5.73	0.40
Ho_2O_3	*0.84*	*1.32*	1.02	0.83	0.82	0.98	0.09
Er_2O_3	*3.00*	*5.02*	3.21	2.99	2.18	2.66	0.00
Tm_2O_3	*0.29*	*2.19*	0.59	0.65	0.10	0.47	0.01
Yb_2O_3	*2.62*	*5.57*	3.53	2.88	1.97	1.67	0.00
Lu_2O_3	*0.00*	*0.35*	0.10	0.66	0.08	0.51	0.00
ThO_2	*1.17*	*4.06*	4.06	6.03		0.49	7.44
UO_2	*1.86*	*4.19*	2.39			0.11	0.70
Total			100.18	95.84	92.54	89.30	100.31

Table 1. Analyses offergusonite-(Y), gadolinite-(Y) and monazite-(Ce) from the Mournes (this study) and from Arran (Hyslop *et al*., 1998). Values (in italics) in the fergusonite columns headed minimum and maximum are the lowest and highest values for each oxide amongst 8 analyses. The Arran fergusonite-(Y) also contains 2.19% Ta_2O_5; U_2O_5 was not determined. Low totals in the gadolinite-(Y) analyses are mainly due to Be which cannot be analysed by ED microprobe techniques; data collected by other techniques indicate BeO contents of ~9 wt% are to be expected in this species.

and fergusonite crystallised from the last residue of evolved granite melt-fluid phase and may be granite-derived hydrothermal in origin.

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REFERENCES

Burke, K.C., Cunningham, M.A., Gallagher, M.J. and Hawkes, J.R. (1964). Beryl in the Rosses Granite, northwest Ireland. *Economic Geology*, **59**, 1539-1550.

Green, D.I. and Todd, J.G. (2001). Twenty years in minerals: Scotland. *UK Journal of Mines & Minerals*, **21**, 9-27.

Hyslop, E.K., Gillanders, R.J., Hill, P.G. and Fakes, R.D. (1998).Rare-earth-bearing minerals fergusonite and gadolinite from the Arran granite. *Scottish Journal of Geology*, **35**, 65-69.

Lacroix, A. (1888). Sur unnoveaugisement de gadolinite. *Bulletin de la Société Française de Minéralogie*, **11**, 68-69.

Meighan, I.G., Gibson, D. and Hood, D.N. (1984). Some aspects of Tertiary acid magmatism in NE Ireland. *Mineralogical Magazine*, *48*, 351-363.

Meighan, I.G., Fallick, A.E. and McCormick, A.G. (1992). Anorogenic granite magma genesis: new isotopic data for the southern sector of the British Tertiary Igneous Province. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 227-33.

Moles, N.R. and Higgins, M.J. (1995). Uranium distribution and radon potential in the Mournes, Northern Ireland. In: J. Pašava, B. Křibekand K. Žák (eds), *Mineral deposits: From their origin to their environmental impacts. Proceedings of the Third Biennial SGA Meeting, Prague, 28-31 August 1995*, pp. 685-688. A.A. Balkema, Rotterdam.

Tindle, A.G. (1982). *Petrogenesis of the Loch Doon granitic intrusion, Southern Uplands of Scotland*. Unpublished PhD thesis, Open University, Milton Keynes.

Tindle, A.G. (2008). *Minerals of Britain and Ireland*. Terra Publications, Harpenden.

Warner, R.A., Moles, N.R. and Chapman, R.C. (2010). Evidence for Early Bronze Age tin and gold extraction in the Mourne Mountains, County Down. *Journal of the Mining Heritage Trust of Ireland*, **10**, 29-36.