

INTERPRETING THE CARBON ISOTOPIC COMPOSITION OF UREILITES. A. Wright¹, J. Parnell¹, H. Tsikos¹, ¹Dept. of Geology, University of Aberdeen, Aberdeen AB24 3UE, U.K., (J.Parnell@abdn.ac.uk),

Ureilites and carbonaceous chondrites: The origin of ureilite meteorites has been consistently regarded as problematic [1]. A distinctive feature of ureilites is that they contain carbonaceous matter up to 6 wt. %, particularly in the form of graphite in veinlets between silicate (mostly olivine) crystals, and along their cleavage planes. The carbonaceous matter within them suggests a relationship with carbonaceous chondrites, so that a range of models developed in which carbonaceous chondrites were either a precursor to the ureilite parent body or had impacted into the parent body [2, 3, 4]. Current models still assume at least partial derivation of ureilites from carbonaceous chondrite-like material [5, 6, 7]. Support for this lies in trace element composition [8], oxygen isotope composition [9], noble gas composition [10] and silicate petrography [11]. However, a perceived problem with this origin is the carbon isotopic composition of ureilites, which is mostly in the range $\delta^{13}\text{C}_{\text{PDB}}$ -10 to -2 ‰ [12, 13], while the composition of carbonaceous chondrites is typically -21 to -11 ‰ [14]. This difference has been interpreted to indicate that ureilites could not have been derived from carbonaceous chondrites [12]. We re-evaluate this by study of a terrestrial analogue for derivation of vein graphite from a carbonaceous precursor.

Analogue for ureilite carbon: For an analogue study, the requirement was a setting where a hot body of magma interacted with carbon-rich rocks at a geologically rapid rate. Our choice is a set of Ordovician gabbroic intrusions in Neoproterozoic graphitic pelites in northeast Scotland. The intrusions are the so-called 'Newer Gabbros' [15]. The pelites are the Easdale Subgroup of the Dalradian Supergroup [16].

This is a good analogue because of numerous similarities to what is observed in ureilites:

1. The intrusions have ultramafic to basic mineralogy, from peridotites (olivine cumulates) to troctolites (olivine-plagioclase cumulates) to gabbros (pyroxene-feldspar cumulates) [15].
2. Partial melting occurred in the pelitic country rocks, evident in both the aureoles of the intrusions and in xenoliths within the intrusions [17].
3. Intermingling occurred between the intrusions and the country rocks.
4. A mobile carbonaceous phase was generated from the country rock to precipitate graphite in fractures.
5. The rocks containing fracture-bound graphite have a carbon content greater than the source rocks.
6. The carbonaceous matter in the country rocks was already refractory (graphitic) at the time of intrusion,

as the intrusions overprinted a pre-existing metamorphic mineralogy [18].

7. The temperature reached up to 850 °C in the inner aureole [19]. This approaches the temperatures interpreted to explain the reduction features in ureilites [6, 20]. The pressure in the aureole was up to 5000 bars, substantially higher than in the ureilites, but in both cases the fluid pressure of the graphite-precipitating fluid exceeded the confining pressure.

Data: Vein graphite occurs within the magmatic rocks at several localities close to the boundary between the magmatic bodies and their country rocks (Fig. 1). Graphite was sampled at four of these localities for determination of carbon isotopic composition. Samples were also taken from the country rock pelites at a coastal exposure at Portsoy (Fig. 1):

Vein graphite

Knock	-18.2 ‰	Rothiemay	-15.5 ‰
Huntley	-14.1 ‰	Bodiebae	-19.1 ‰

Graphitic pelites

Portsoy A	-26.4 ‰	Portsoy B	-26.6 ‰
Portsoy C	-26.5 ‰		

The mean value for the vein graphites (-16.7) is 10 ‰ heavier than that from the graphitic pelites (-26.5). The explanation for this difference is that progressive devolatilization of organic matter, such as occurs in metamorphic rocks, causes release of light fluids (most likely methane; [21]) that are enriched in ¹²C, to leave a ¹³C-rich residue [22]. In metamorphic rocks, where parent organic matter would have a 'biological' composition of about -25 to -30 ‰, the graphite after devolatilization should have a heavier composition, as in this case. Where a fluid phase is mobilized, there will be fractionation between volatiles and the liquid that resolidifies in a fracture system. Thus the value for the graphitic pelites represents the composition before the devolatilization that occurred by interaction with the magma. The value from the vein graphites represents a devolatilized product. This exemplifies a general trend of heavier composition as carbon is progressively used up [23] (Fig. 2).

Implications for ureilite carbon: The isotopic shift between carbonaceous chondrites and ureilites is of similar magnitude and the same direction (heavier) as the shift observed between the country rock and the mobilized graphite in the case study (Fig. 2). Given the close analogy between the two systems, this suggests that it is possible to explain the isotopic composition of ureilites in terms of derivation from carbonaceous chondrites, and so removes a problem in this widely inferred relationship.

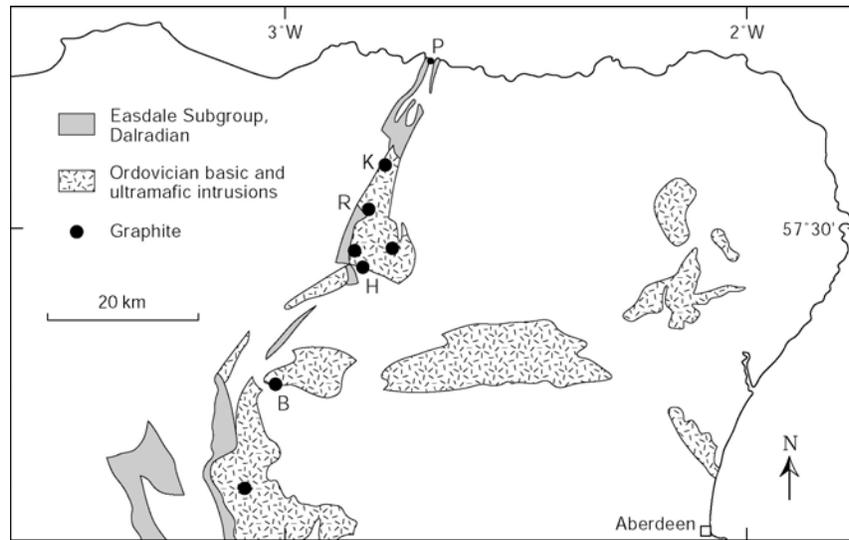


Fig. 1. Occurrences of graphite near margins of Ordovician magmatic bodies and Dalradian (Neoproterozoic) graphitic pelites, NE Scotland. Localities: B, Bodiebae; H, Huntley; K, Knock; P, Portsoy; R, Rothiemay.

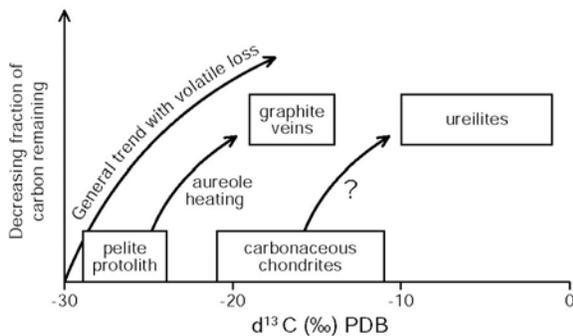


Fig. 2. Isotopic shift due to progressive loss of light volatiles. Vein graphite from aureole of intrusions enriched in ^{13}C relative to graphitic protolith; based on data in NE Scotland. Typical values for ureilites and carbonaceous chondrites show similar shift, and suggest a genetic relationship is plausible.

Acknowledgement: Graphite samples were kindly made available by the National Museum of Scotland. AW and HT received support from the EPSRC and Leverhulme Trust respectively.

References: [1] Goodrich C.A. (1992) *Meteoritics*, 27, 327-352 [2] Rubin A.E. (1988) *Meteoritics*, 23, 333-337. [3] Tomeoka K. & Takeda H. (1990) *Geochim. Cosmochim. Acta*, 54, 1475-1481. [4] Warren P.H. & Kallemeyn G.W. (1992) *Icarus*, 100, 110-126. [5] Goodrich C.A. et al. (2002) *LPSC XXXIII* 1379. [6] Singletary S.J. & Grove T.L. (2003) *Meteoritics Planet. Sci.*, 38, 95-108. [7] Kita N.T. et al.

(2004) *Geochim. Cosmochim. Acta*, 68, 4213-4235. [8] Spitz A.H. & Boynton W.V. (1991) *Geochim. Cosmochim. Acta*, 55, 3417-3430. [9] Clayton R.N. & Mayeda T. (1988) *Geochim. Cosmochim. Acta*, 52, 1313-1318. [10] Göbel R. et al. (1978) *Jour. Geophys. Res.*, 83, 855-867. [11] Jaques A.L. & Fitzgerald M.J. (1982) *Geochim. Cosmochim. Acta*, 46, 893-900. [12] Grady M.M. et al. (1985) *Geochim. Cosmochim. Acta*, 49, 903-915. [13] Franchi I.A. et al. (1998) *LPSC XXIX*, 1685. [14] Robert F. & Epstein S. (1982) *Geochim. Cosmochim. Acta*, 46, 81-95. [15] Wadsworth W.J. (1982) in Sutherland D.S., ed., *Igneous Rocks of the British Isles*. Wiley, NY, 135-48. [16] Harris A.L. et al. (1994) in Gibbons W. & Harris A.L., eds., *A Revised Correlation of Precambrian Rocks in the British Isles*. Geological Society, Bath, 33-53. [17] Gribble C.D. & O'Hara M.J. (1967) *Nature*, 214, 1198-1201. [18] Ashworth J.R. (1975) *Geol. Mag.*, 112, 113-36. [19] Droop G.T.R. & Charnley N.R. (1985) *Jour. Geol. Soc.*, 142, 53-62. [20] Sinha S.K. et al. (1997) *Geochim. Cosmochim. Acta*, 61, 4235-4242. [21] Connolly J.A.D. & Cesare B. (1993) *Jour. Met. Geol.*, 11, 379-88. [22] Valley J.W. (1986) *Min. Soc. Amer. Revs. Mineral.*, 16, 455-489. [23] Bebout G.E. et al. (1999) *Am. Mineral.*, 84, 1495-1505.