TRACE ELEMENT COMPOSITIONS AND PETROGENESIS OF THE D'ORBIGNY ANGRITE. Christine Floss[1], Marvin Killgore[2] and Ghislaine Crozaz[1], [1]Laboratory for Space Sciences and Dept. of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130, USA; [2]Southwest Meteorite Laboratory, P.O. Box 95, Payson, AZ 85547, USA (email: floss@howdy.wustl.edu).

Introduction: The angrites are a small group of achondrites characterized by unusual mineral assemblages and refractory element enrichments. Research on the angrites [*e.g.*, 1-5] has been hampered by the fact that since the 1980s, they have been represented by only four meteorites, Angra dos Reis (AdoR) itself, and the Antarctic angrites, LEW 86010 (LEW86), LEW 87051 (LEW87) and Asuka 881371 (Asu88), the latter three with a combined mass of only 18.5 g. Last year a fifth angrite, Sahara 99555 (Sah99) was discovered [6,7]. At 2710 g, it significantly increased the amount of material available for study and offered, for the first time in a decade, the opportunity to obtain new information about the petrogenesis of these meteorites.

Now the existence of a 6th angrite, D'Orbigny, has been reported [8]. Found in 1979 by a farmer in a corn field in Argentina, D'Orbigny has only recently been identified as an angrite. At more than 16 kg, it is by far the largest member of this rare group identified to date. We obtained a sample of D'Orbigny and here report on the major, minor and trace element chemistry of this newest angrite.

Experimental and Results: D'Orbigny has a subophitic texture and consists predominantly of plagioclase, fassaite and olivine. Minor phases include spinel, ulvöspinel, troilite and a silicophosphate [8]. Plagioclase is present as laths and blocks of nearly pure anorthite and contains up to 0.95 wt.% FeO and 0.29 wt.% MgO. Fassaite occurs as subhedral to euhedral grains with strong compositional zoning. With increasing fe# [molar Fe/(Fe+ Mg)] from the cores to the rims of the crystals, TiO_2 increases from 1.0 to 4.3 wt.% and Cr_2O_3 decreases from 0.7 wt.% to values below detection limits. Olivine grains are also zoned, with Mg-rich cores (Fo_{64}) and very Fe- and Ca-rich rims. The contacts between cores and rims are typically very sharp, as has been noted for other angrites. Olivine grains are generally anhedral to subhedral. Kirschsteinite grains are also present, but D'Orbigny does not appear to contain xenocrystic olivines such as those found in LEW87 and Asu88.

We used the ion microprobe to measure the trace element distributions in the silicate phases of D'Orbigny. Anorthite REE compositions show little variation: the patterns are LREE-enriched with large positive Eu anomalies. REE patterns in olivine are HREE-enriched and concentrations increase by a factor of 10 from the Mg-rich cores to the Fe- and Ca-rich rims (Fig. 1a). Some grains show LREE-enrichments with negative Ce anomalies, which may be attributed to terrestrial alteration [*e.g.*, 9,10]. Fassaite grains also exhibit REE zoning, with concentrations increasing by factors of 3 to 7 from the cores to the rims of the crystals (Fig. 1b). Abundances of other incompatible trace elements (*e.g.*, Zr, Ti) also increase with increasing fe#, whereas Sc and V abundances decrease (Fig. 2).

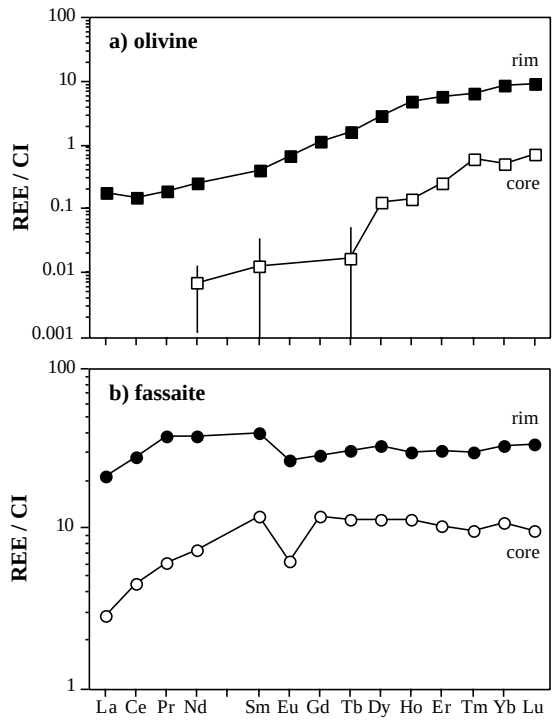

Figure 1. CI chondrite-normalized REE patterns for the cores and rims of a) olivine and b) fassaite from D'Orbigny.

Discussion: The initial investigations of Sah99 [6, 7] suggest that this angrite crystallized rapidly from a melt similar to its bulk composition. Crystallization experiments using a synthetic Asu88 groundmass composition were able to successfully reproduce the texture, mineralogy and zoning patterns of Sah99 [6]. Furthermore, both fassaite and anorthite appear to have crystallized from melts with the same REE composition [7]. Trace element zoning patterns in fassaite and olivine show that Sah99 is closely related to LEW87 and Asu88. All three angrites fall on the same trends of increasing incompatible trace element abundances with fe# [7]. Melt compositions calculated

from LEW87 and Asu88 core fassaites are also identical to those determined for Sah99. In contrast, the trace element trends for LEW86 are distinctly different, suggesting that this angrite did not crystallize from the same magma [7].

Our trace element data for D'Orbigny indicate that it is closely related to Sah99 and the Antarctic angrites, LEW87 and Asu88, as well. Abundances of Ti, Zr, Sc and V (Fig. 2) as well as Y (not shown) in fassaite from D'Orbigny all fall within the ranges observed for these meteorites. Abundances of Y in D'Orbigny olivine also increase with increasing fe# and follow trends similar to those observed for olivine from these angrites.

Using partition coefficients determined by [11], we calculated the REE compositions of melts in equilibrium with the cores of D'Orbigny anorthite and fassaite grains. Both minerals appear to have crystallized from melts with flat REE patterns and abundances of about 20–25 x CI. These melts are very similar in composition to those calculated from Sah99 core fassaite and anorthite and to melts calculated from LEW87 and Asu88 core fassaite [7]. The large variations in REE concentrations observed in olivine and fassaite crystals indicate that crystallization of D'Orbigny must have been essentially a closed system process. The extent of zoning appears to be largest for olivine, suggesting that this mineral crystallized first, followed by fassaite and anorthite.

Conclusions: Both new angrites, D'Orbigny and Sah99, as well as their Antarctic cousins, LEW87 and Asu88, appear to have relatively simple, near closed-system crystallization histories. LEW86 probably also represents a liquid composition [*e.g.*, 3], but does not appear to be co-magmatic with these angrites [7]. The primary challenge to understanding angrite petrogenesis still lies (as it has from the start) in determining the relationship between these angrites and AdoR.

References: [1] Prinz M. *et al.* (1977) *EPSL* **35**, 317. [2] Mittlefehldt D. W. and Lindstrom M. M. (1990) *GCA* **54**, 3209. [3] Crozaz G. and McKay G. (1990) *EPSL* **97**, 369. [4] McKay G. *et al.* (1990) *LPS* **XXI**, 771. [5] Mikouchi T. *et al.* (1996) *Ant. Met. Res.* **9**, 174. [6] Mikouchi T. *et al.* (2000) *LPS.* **XXXI**, #1970. [7] Floss C. *et al.* (2000) *MAPS.* **35**, A53. [8] Grossman J. N. and Zipfel J. (2001) *MAPS* **36**, in press. [9] Floss C. and Crozaz G. (1991) *EPSL* **107**, 13. [10] Crozaz G. and Wadhwa M. (2001) *GCA*, in press. [11] McKay G. *et al.* (1994) *GCA* **58**, 2911.

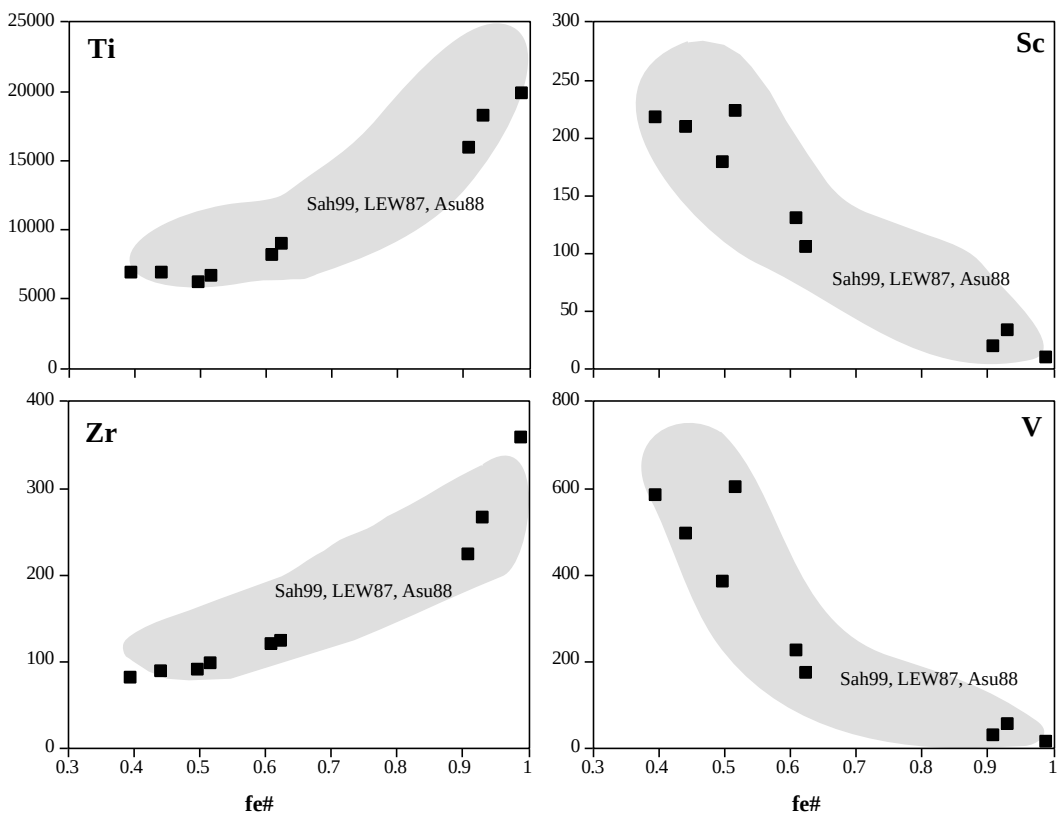

Figure 2. Concentrations of Ti, Zr, Sc and V (ppm) vs. fe# for D'Orbigny fassaite. Shaded areas represent ranges for Sahara 99555, LEW 87051 and Asuka 881371.