

**TRACE ELEMENT DISTRIBUTION BETWEEN OLIVINE AND KIRSCHSTEINITE IN ANGRA DOS REIS.** M.M. Fittipaldo, R.H. Jones, and C.K. Shearer. Institute of Meteoritics, Dept. of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131 U.S.A. Email: melissaf@unm.edu

**Introduction:** The angrites are a small and enigmatic group of basaltic achondrites that possess unique mineralogical and chemical properties. The dominant mineralogy of the seven angrite members (Angra dos Reis, LEW 86010, LEW 87051, Asuka 881371, Sahara 99555, D'Orbigny, and a new Moroccan member [1]) is fassaite, olivine, and plagioclase. Angrites display a wide range of thermal histories, with Angra dos Reis (AdoR) exhibiting a cooling history different from that of the rapidly cooled members [2,3] and from LEW86010, a more slowly cooled member [4]. AdoR could represent either a cumulate [5] or a porphyritic igneous rock [6] that was later altered by metamorphism.

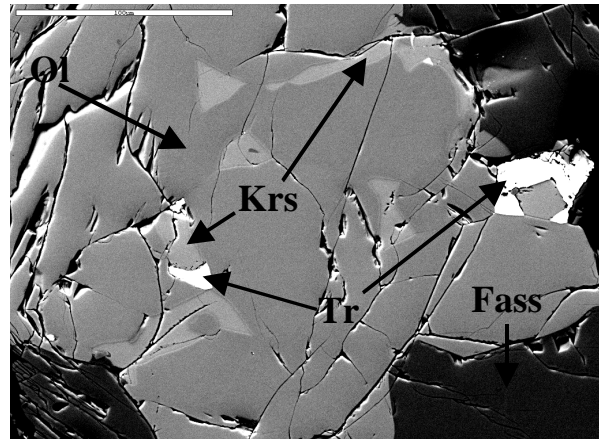
We are re-examining the thermal history of AdoR in light of the more recently described angrite members. Our emphasis is a trace element study of low-Ca olivine, which we refer to as olivine, and high-Ca olivine, which we refer to as kirschsteinite, in AdoR.

**Petrography:** A comprehensive description of the Angra dos Reis meteorite was given by [5]. AdoR is largely composed of fassaite (93%) with minor amounts of olivine and accessory kirschsteinite, troilite, spinel, whitlockite, metallic Ni-Fe, and rare titanian magnetite, celsian, plagioclase, and baddelyite. AdoR is a medium- to coarse-grained igneous rock. Fassaite is present in two main textures: fine-grained (0.1mm) groundmass fassaite and large poikilitic fassaite grains on the order of 1.3mm, which can completely enclose the groundmass fassaite. Olivine occurs as separate grains within the fassaitic groundmass or as aggregates of small equidimensional grains. Some olivine grains reach up to 1mm in size.

We have studied several polished thin sections of AdoR on the JEOL 5800LV SEM at the University of New Mexico in order to examine the relationship between olivine and kirschsteinite. In previous descriptions of AdoR, kirschsteinite has only been described as very rare and occurring as inclusions within olivine [5]. We have observed abundant kirschsteinite occurring within olivine aggregates as interstitial material between olivine grains (Fig. 1). We commonly observe troilite in association with kirschsteinite.

**Major and Minor Element Chemistry:** Electron microprobe analyses were performed at UNM with a JEOL 733 Superprobe. The results of these analyses are shown in Table 1. The compositions that we measured for olivine, kirschsteinite, and fassaite agree

well with data reported by [5]. Fassaite grains have an essentially homogeneous composition, and there is no evidence of zoning. Olivine grains are also homogeneous.



**Figure 1.** BSE image of an olivine aggregate in AdoR. Kirschsteinite occurs interstitially to olivine grains. Grain boundaries are not visible in this image. Scale bar is 100  $\mu\text{m}$ . Fassaite (Fass), olivine (Ol), kirschsteinite (Krs), troilite (Tr).

**Table 1.** Major element content (wt%) of several phases in AdoR obtained by EMP.

	OLIVINE	KIRSCHSTEINITE	FASSAITE
<i>n</i> *	25	18	39
SiO <sub>2</sub>	34.9	33.8	45.0
TiO <sub>2</sub>	0.04	0.01	2.29
Al <sub>2</sub> O <sub>3</sub>	0.02	0.03	10.1
Cr <sub>2</sub> O <sub>3</sub>	b.d.	b.d.	0.22
FeO	38.7	26.4	7.18
MnO	0.59	0.41	0.09
MgO	23.8	8.46	10.2
CaO	1.34	30.5	24.3
Na <sub>2</sub> O	b.d.	b.d.	0.01
Total	99.43	99.54	99.46

*n*\* number of analyses

**Trace Element Analyses:** Trace element abundances in olivine and kirschsteinite in AdoR were determined by secondary ion mass spectrometry, using the Cameca IMS 4f instrument at the University of New Mexico. The kirschsteinite was analyzed using primary O<sup>+</sup> ions accelerated through a nominal potential of 10kV. The primary beam current of 20nA was focused on a spot diameter of ~20 $\mu\text{m}$ . For the olivine analyses, a 30nA O<sup>-</sup> primary beam was used with a diameter of ~30 $\mu\text{m}$ . Energy filtering was employed

with an offset of  $75 \pm 25$  volts to eliminate isobaric interferences. An augite standard (Kaug) was used for both olivine and kirschsteinite analyses. Chondrite normalized REE abundances in olivine and kirschsteinite are shown in Fig. 2. The olivine and kirschsteinite bands in Fig. 2 are comprised of 4 and 5 analyses, respectively, and each set of analyses shows a narrow range.

The chondrite normalized REE patterns for both kirschsteinite and olivine are fractionated with enrichments in the HREEs and depletions in the LREEs and a steeper slope in the LREEs than in the HREEs. Olivine is depleted in all REEs relative to kirschsteinite which is expected due to the higher CaO content in kirschsteinite. For example, the mean Ce value for kirschsteinite is 6x the mean Ce value for olivine, and the mean Yb value for kirschsteinite is 3x the mean Yb value for olivine. There is no significant Eu anomaly in the REE patterns of either phase.

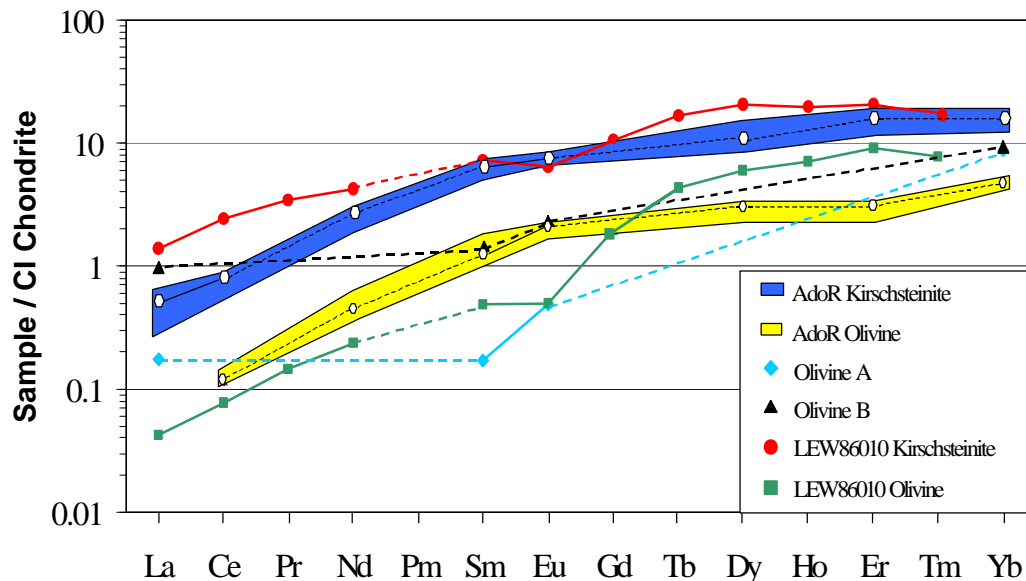
**Discussion:** The REE distribution between olivine and kirschsteinite in AdoR has not been measured previously. INAA analyses obtained on olivine mineral separates from AdoR were reported by [7]. REE data for these olivine mineral separates differ from our SIMS data (Fig. 2). The CaO contents of the olivine A and B separates were 1.2 and 2.0 wt%, respectively. [7] suggested that the difference in REE content between the two olivines could be attributed to more of a kirschsteinite component in olivine B than in olivine A or that olivine B was contaminated with a small amount of clinopyroxene (~3.5%). Our data more accurately represent the REE abundances in olivine

and kirschsteinite in Angra dos Reis.

We can compare the REE distribution between olivine and kirschsteinite in AdoR with the distribution in LEW86010 (LEW86), in which kirschsteinite exsolved from olivine during slow, single-stage cooling [4]. Chondrite normalized REE patterns for olivine and kirschsteinite in LEW86 [8] are shown in Fig. 2. In general, the REE patterns are similar in AdoR and LEW86, although HREE abundances in olivine are higher in LEW86. This is consistent with higher CaO contents in LEW86 olivine: 2.16 wt% in LEW86 and 1.34 wt% in AdoR. REE contents of olivine and kirschsteinite in AdoR appear to be consistent with formation of kirschsteinite by exsolution from olivine during cooling to low temperatures and/or annealing. However, since kirschsteinite occurs interstitially to olivine and in association with troilite (Fig. 1), it is also possible that the kirschsteinite occurred originally as a residual phase.

**References:** [1] Jambon A. et al. (2002) *Met. Planet. Sci.*, 37, A71; [2] Mikouchi T. et al. (2001) *Met. Planet. Sci.*, 36, A134; [3] Mittlefehldt D. et al. (2002) *Met. Planet. Sci.*, 37, 345-369; [4] McKay G. et al. (1998) *Met. Planet. Sci.*, 33, 977-983; [5] Prinz M. et al. (1977) *EPSL*, 35, 317-330; [6] Treiman A. (1989) *Proc. 19<sup>th</sup> LPSC*, 443-450; [7] Ma M. et al. (1977) *EPSL*, 35, 331-346; [8] Crozaz G. and McKay G. (1990) *EPSL*, 97,369-381.

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**Figure 2.** Chondrite normalized REE patterns for AdoR olivine and kirschsteinite, two olivine separates (Olivine A and B) from [6], and LEW86010 olivine and kirschsteinite from [7] (obtained by SIMS analysis). White symbols in AdoR patterns are means.