A PETROGRAPHIC, ELECTRON MICROPROBE, AND ION MICROPROBE STUDY OF MINI-ANGRITE LEWIS CLIFF 87051. G. McKay[1], G. Crozaz[2], J. Wagstaff[3], S.-R. Yang[3] and L. Lundberg[2] ([1]SN2 NASA-JSC, Houston, TX 77058; [2]Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis MO 63130; [3]Lockheed ESCO, 2400 NASA Rd. 1, Houston, TX 77058)

Introduction. Preliminary examination of antarctic meteorite LEW 87051 (total weight, 0.6 g) by Mason [1] revealed mineralogical and chemical affinities to the angrites Angra Dos Reis (ADOR) [2] and LEW 86010 [3]. To further characterize the sample, we performed optical and backscattered electron petrographic investigations and electron microprobe chemical analyses on polished thin section LEW 87051,2. In addition, we used the Washington University ion probe to measure trace element contents of minerals in this sample.

General Sample Description. LEW 87051 is porphyritic in texture, with equant, euhedral to subhedral olivine phenocrysts up to ~0.5 mm wide set in a fine-grained groundmass of euhedral plagioclase laths (up to ~50 μm wide and several hundred μm long), and interstitial fassaitic pyroxene, Fe-rich olivine, kirschsteinite, and minor ilmenite, merrillite, and troilite. Textural relationships suggest the crystallization order was olivine, plagioclase, pyroxene, kirschsteinite. Margins of groundmass olivines display spectacular alternating concentric bands of kirschsteinite and fayalite. Each phase contains μm-scale lamellae of the other. We believe the bands formed during crystallization, and the lamellae formed by exsolution during cooling. Microprobe modal analysis of 721 points yielded 26 vol% olivine phenocrysts, 14.0% groundmass olivine, 34.1% plagioclase, 20.5% pyroxene, 4.7% kirschsteinite, and a trace of merrillite, troilite, and ilmenite. A portion of the section is discontinuously rimmed with fusion crust.

Mineral Compositions: Major and Minor Elements. Most **olivine phenocrysts** have homogeneous cores, with strong zoning confined to ~10 μm Fe-enriched rims. Core compositions are typically FO_{79-83}, but a few grains have more magnesian cores, ranging up to FO_{91}. **Groundmass olivine** and rims on olivine phenocrysts are strongly zoned, with compositions becoming nearly Mg-free. Ca-Fe-Mg zoning is shown in Fig. 1, along with compositions from LEW 86010 and ADOR. Phenocrysts in LEW 87051 are *much* more Mg-rich than olivine from the other two angrites. Moreover, LEW 87051 is the only one of the three retaining primary igneous zoning of olivine. Larnite (LA, Ca_2SiO_4) is positively correlated with *fm* (100 x Molar Fe/Mg+Fe) in LEW 87051 olivine, approaching 20 mole% for grains with *fm*>95. Although zoning between **kirschsteinite** and Fe-rich olivine appears continuous in Fig. 1, discrete boundaries are observed in BSE images, so the points with intermediate LA content are probably analyses were the beam overlapped exsolution lamellae. **Minor elements** in olivine are strongly correlated with Fe/Mg. Cr_2O_3 decreases from 0.22 wt% in FO-rich phenocryst cores to 0.09-0.11% in typical cores, to <.01% in olivine with *fm*>~85. At equivalent Fe/Mg, LEW 87051 olivines have more Cr than those from ADOR or LEW 86010. Mn increases from 0.10 wt% in FO-rich cores to 0.85% in Fe-rich rims, with a slight corresponding decrease in FeO/MnO from 90 to ~75. Fe/Mn is identical in olivines of similar Fe content from both LEW samples, while that from ADOR is slightly lower (63).

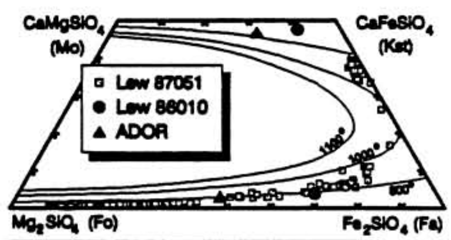
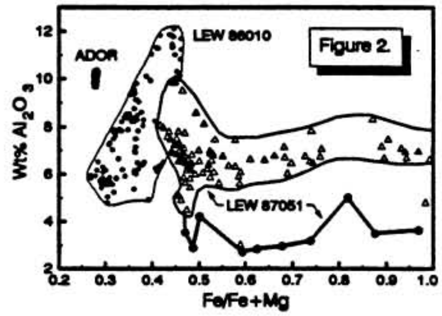


Figure 1. Angrite olivine compositions.

Plagioclase is essentially pure anorthite, with Na_2O < 0.1 wt%. Most grains have FeO contents between 0.5 and 2 wt % and MgO contents up to 0.5 %

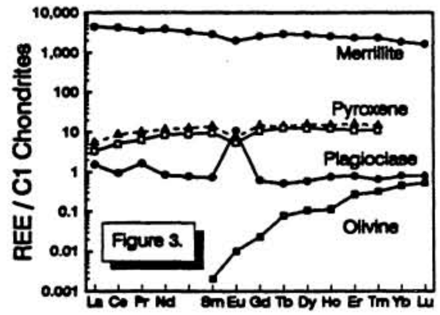
Fassaitic clinopyroxene is strongly zoned, with *fm* ranging from ~40 to >99, while CaO is nearly constant at 22-23 wt%. The strong positive correlation of Al with *fm* observed for LEW 86010 [2] is not found in LEW 87051 (Fig. 2). Al_2O_3 content is typically ~8 wt% in the most Mg-rich pyroxenes (although a few grains with up to 10% were observed), drops sharply to ~6% or less as *fm* increases to 50, then remains nearly constant or increases slightly as *fm* increases to >95. Cr_2O_3 content is typically ~0.8 wt% in the most Mg-rich pyroxenes (although a few grains with up to 1.3% were observed), and drops sharply to <0.1% for pyroxenes with *fm*>55. TiO_2 contents of Mg-rich pyroxene zones are typically ~2%, dropping to 1.5% or less at *fm* values of ~50, but then increasing significantly throughout the remainder of pyroxene crystallization, reaching as much as 5% in some Fe-rich zones. Molar Ti/Al is highly correlated with *fm*, increasing smoothly from ~0.15 in Mg-rich zones to ~0.5 in



Fe-rich zones.

Pyroxenes lie on distinctly different trends for each angrite. They also differ in the extent of zoning, with ADOR pyroxenes essentially unzoned, LEW 86010 pyroxenes moderately zoned in Fe/Mg and highly zoned in minor elements, and LEW 87051 pyroxenes highly zoned in both Fe/Mg and minor elements. We interpret this as reflecting differing crystallization rates and degrees of diffusive homogenization during cooling.

<u>Mineral Compositions: Trace Elements</u>. REE and selected trace element concentrations were measured in individual grains of pyroxene, olivine, plagioclase, and the largest merrillite grain (~5x30 μm) found in the section. The REE results are summarized in Fig. 3. As in the other angrites [4], the mineral with the highest REE concentrations in LEW 87051 is merrillite. However, the merrillite pattern is less steep (Ch-norm La/Tm ~ 1.9) than those of LEW 86010 (La/Tm ~ 32) and ADOR (La/Tm ~ 11). REE patterns of plagioclase (almost flat with a pronounced positive Eu anomaly) and olivine (characterized by HREE enrichment) are typical for these minerals. However, REE concentrations in LEW 87051 olivine phenocrysts are lower (by up to a factor of 100) than in the other angrites, consistent with the lower Ca concentration of LEW 87051 olivine phenocrysts.



A slight zoning is observed in LEW 87051 pyroxene, with the ratio of extreme REE concentrations being ~1.6. However, because of the fine grain-size, it was not possible to analyze the most extreme Fe-rich zones, so the extent of REE zoning is probably larger than we observed. The pyroxene HREE pattern is flat, compared to those of the other two angrites, which show a decrease from Gd to Tm. Otherwise, the REE patterns of LEW 87051 and LEW 86010 pyroxenes are similar. Zr, Ti, and Y concentrations correlate positively with REE abundances. LEW 86010 and LEW 87051 pyroxenes with identical Fe/Mg have different REE, Sc, Ti, V, Cr and Zr concentrations. Thus the trace element data support formation of the two meteorites in separate magmatic events.

<u>Bulk Composition</u>. Average mineral compositions were measured during the modal analysis, and the following bulk composition (wt%) was estimated by modal recombination: SiO_2, 38.9; TiO_2, 0.6; Al_2O_3, 11.3; Cr_2O_3, 0.1; FeO, 22.1; MnO, 0.3; MgO, 13.1; CaO, 12.7; Na_2O, <0.1; P_2O_5, 0.1. However, this composition has significantly higher Al, Ca, and Fe, and significantly lower Mg and Mg/Fe than the bulk composition determined by [5] using fused bead EMP and INAA. This discrepancy can be resolved if the modal analysis underestimated the proportion of olivine phenocrysts in the sample by nearly a factor of two and the proportion of plagioclase to pyroxene by ~25%. It is not clear whether this disagreement results from a real sampling problem or from unrecognized difficulties in performing the modal analysis on such a fine-grained sample. However, considering the agreement between fused bead and INAA results, we believe the fused bead composition is probably more representative and reliable.

<u>Discussion</u>. LEW 87051 is clearly an igneous rock. One major question is whether its highly olivine-normative bulk composition is that of a melt, or whether it is enriched in cumulus olivine. Its bulk composition will crystallize extensive olivine before the entry of any other silicate. If it was formed by partial melting at low pressure, a significant part of the olivine and all of the other silicates in the source region were incorporated in the melt, leading to enrichments in incompatible elements of ~10xCI [5].

However, the large proportion of homogeneous FO_{80} olivine phenocrysts strongly suggests that the sample is a partial olivine cumulate. These phenocrysts are too Fe-rich to have been in equilibrium with a melt of the bulk *mg* of LEW 87051 (64 [5]). For an olivine/melt $^{Fe/Mg}K_D$ of 0.29 (from our experimental studies of LEW 86010 analogs), the FO_{80} olivines last equilibrated with a melt with *mg* of 56. The proportion of LEW 86010 required to be cumulus olivine in order that the remaining melt have *mg*=56 is 25%, assuming bulk composition determined by [5]. Concentrations of olivine-incompatible elements in this melt would be 33% higher than those reported by [5]. Note that this is still much more magnesian than the bulk composition of LEW 86010 (*mg*=41,[6]). Whether the LEW 87051 melt could evolve into a melt resembling LEW 86010 in both major and trace element abundances remains to be explored.

REFERENCES: [1] Mason (1989) *Antarctic Meteorite Newsletter* 12, no. 1. [2] Prinz *et al.* (1977) *EPSL* 35, 317. [3] McKay *et al.* (1988) *LPS XIX*, 762. [4] Crozaz *et al.* (1990) *EPSL*, in press. [5] Mittlefehldt and Lindstrom (1990) *LPS XXI*, this volume. [6] Mittlefehldt *et al.* (1989) *LPS XX*, 701.