THE BULK COMPOSITION OF COARSE-GRAINED METEORITES FROM LASER ABLATION ANALYSIS OF THEIR FUSION CRUSTS. N. Shirai[1], M. Humayun[1], and A. J. Irving[2], [1]National High Magnetic Field Laboratory and Department of Geological Sciences, Florida State University, 1800 E. Paul Dirac Drive, Tallahassee, FL, 32310, USA (shirai@magnet.fsu.edu, humayun@magnet.fsu.edu), [2]Department of Earth & Space Sciences, University of Washington, Seattle, WA 98195, USA (irving@ess.washington.edu).

Introduction: Many new meteorites representing rare achondrite groups are being recovered from both hot and cold deserts. A significant fraction of these meteorites are both coarse-grained in texture and small in size, making accurate determinations of bulk rock compositions rather challenging. We successfully obtained elemental analyses of several angrites using ~1 mm^2 rasters of polished sections by laser ablation ICP-MS [1, 2]. This technique yielded inconsistent answers for two coarse-grained angrites, NWA 4590 and NWA 4801, leading us to try an alternative method for sampling one of these coarse-grained meteorites by means of analysis of its fusion crust.

The fusion crust covering a meteorite is formed by the melting of the surface minerals during passage through the Earth's atmosphere. Due to the dynamic environment under which it forms, the elemental abundances of fusion crust may be sufficiently representative of the bulk composition of the meteorite [3]. The degree to which fusion crusts are representative of a meteorite's bulk-rock composition must be interpreted cautiously as mineral point-sources may contribute heterogeneity [4].

Meteorites recovered from the hot deserts of Oman, Libya and Northwest Africa pose an additional challenge, since it is well known that elemental abundances of such meteorites can be significantly influenced by terrestrial weathering [e.g, 5]. In this study, we report new results on the composition of the fusion crust of a coarse-grained angrite (NWA 4590) and an olivine basaltic shegrottite (NWA 4468), and on the cleaning protocol that removed most of the terrestrial contaminants from their fusion crusts.

Samples and Analytical method: NWA 4590 is a fresh, coarse-grained (0.6-12 mm) plutonic igneous cumulate angrite covered with fusion crust [6]. NWA 4468 is a superbly fresh, olivine basaltic shergottite [7]. We analyzed two chips of fusion crust from each meteorite by directly ablating the exterior surface of the fusion crust without epoxy mounting or polishing. The fusion crust fragments of NWA 4590 were analyzed both before and after application of a surface cleaning procedure. To remove terrestrial contaminants, the fusion crust surfaces of each meteorite were brushed with a nylon toothbrush and DI water, then polished using 1 μm alumina powder. The polished samples were washed in deionized water in an ultrasonic bath.

Determination of elemental abundances for unwashed NWA 4590 fragments (FC1, FC2) were performed on a New Wave UP213 laser ablation system coupled to a Finnigan Element™ ICP-MS, and for washed FC2, and NWA 4468 fragments (FC12, FC13) on a New Wave UP193FX excimer laser coupled to a Thermo Element XR™ ICP-MS. A portion of the fusion crust was rastered using a 65 μm beam spot, at 5μm/s, 10 Hz, 0.8 mJ laser energy on the UP 213, or a 50-100 μm beam spot, at 5-20 μm/s, 20 Hz, 2-4 mJ laser energy, on the UP193FX. The estimated crater depths are 10-20 μm. The peaks ^{23}Na, ^{24}Mg, ^{27}Al, ^{28}Si, ^{31}P, ^{32}S, ^{39}K, ^{44}Ca, ^{45}Sc, ^{47}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{56}Fe, ^{59}Co, ^{60}Ni, ^{65}Cu, ^{66}Zn, ^{69}Ga, ^{74}Ge, ^{75}As, and ^{77}Se, were monitored in medium resolution mode (R = 4300). In a separate scan, the peaks ^{7}Li, ^{9}Be, ^{23}Na, ^{25}Mg, ^{27}Al, ^{29}Si, ^{31}P, ^{34}S, ^{43}Ca, ^{45}Sc, ^{47}Ti, ^{51}V, ^{53}Cr, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{71}Ga, ^{74}Ge, ^{82}Se, ^{85}Rb, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{93}Nb, ^{95}Mo, ^{97}Mo, ^{121}Sb, ^{123}Sb, ^{133}Cs, ^{138}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{144}Nd, ^{147}Sm, ^{151}Eu, ^{154}Gd, ^{158}Gd, ^{159}Tb, ^{164}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{174}Yb, ^{175}Lu, ^{180}Hf, ^{181}Ta, ^{182}W, ^{193}Ir, ^{232}Th, and ^{238}U, were monitored in low resolution (R = 300). Elemental abundances were obtained by using relative sensitivity factors obtained from reference values for MPI-DING glasses, ML3B-G, StHs6/80-G and ATHO-G, and from NIST SRM 612. Murchison (CM2) matrix was used for quantification of S and Se abundances.

Results and Discussions: Analytical results for fusion crusts of NWA 4590 and NWA 4468 are shown in Table 1. Each raster scan was examined in time-resolved mode to check for homogeneity. The abundances of Sr, Rb, Ba, REE, and U, in hot desert meteorites are known to be influenced by weathering [e.g., 5]. The effect of terrestrial contaminants is inhomogeneously distributed on the NWA 4590 fusion crust fragments. The effect of terrestrial contaminants was then examined by searching for correlations with Ba, the element with the most contamination. Most elements showed no dependence on Ba, except for La, Ce, Pr, Nd, Th, and U, which were all enriched in high Ba regions. The analyses lowest in Ba were then averaged for these elements, while for other elements a straight average of all analyses was used. For angrite NWA 4590, average elemental compositions obtained for FC1 and FC2 are summarized in Table 1, and the CI chondrite-normalized Rare Earth Element (REE) patterns are shown in Fig. 1. Variations of major element abundances, except for Na, K, and P, are less than 10% in the analyzed areas and are homogeneously distributed in the fusion crust of NWA 4590. The relative standard deviations of minor and trace elements are higher than that of major elements, and at least some of this is due to compositional heterogeneity, with washed FC2 exhibiting a higher pyroxene content, seen most strongly in Y abundances (Table 1).

Figure 1 shows the REE abundance patterns for washed FC2, unwashed FC2, and brown soil from the bottom of a ~20 µm pit on FC2. The washed FC2 sample is characterized by a flat REE pattern with negative Eu anomaly (Fig. 1), while the unwashed FC2 sample exhibits a LREE enrichment including a notable positive Ce anomaly. The REE abundance pattern for the soil attached to FC2 is strongly LREE enriched with a positive Ce anomaly. However, the HREE abundances of the soil analysis are dominated by the fusion crust. Based on the analyses of these two endmembers, the contribution of terrestrial weathering to unwashed FC2 is about 30%. Fig. 1 also compares the REE pattern of washed FC2 with that of LEW 86010. The abundance pattern of washed FC2 is similar to that of LEW 86010, indicating that our washing protocol is effective at removing most terrestrial contaminants.

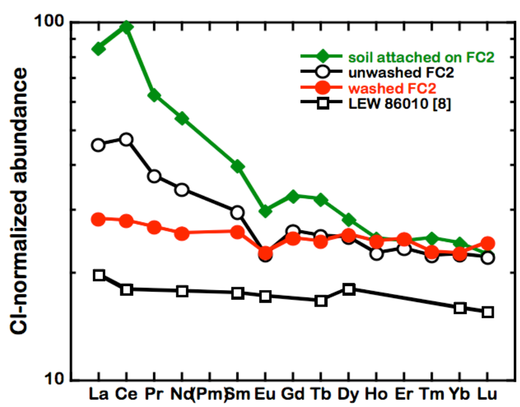

Fig. 1. CI chondrite-normalized REE abundances for fusion crust fragments from NWA 4590 (unwashed FC2, washed FC2, soil attached on FC2) and bulk LEW 86010 [8].

Moderately siderophile element ratios $(Ga/Al)_{CI}$, $(Ge/Si)_{CI}$, $(Mo/Nd)_{CI}$, $(Sb/Nd)_{CI}$ and $(W/La)_{CI}$ for NWA 4590 are 0.0080, 0.0057, 0.021, 0.019 and 0.15, respectively. $(Ga/Al)_{CI}$, $(Ge/Si)_{CI}$, $(Mo/Nd)_{CI}$, $(Sb/Nd)_{CI}$ and $(W/La)_{CI}$ for NWA 4468 are 0.31, 0.0054, 0.030, 0.19 and 0.33, respectively. The use of these ratios reduces the impact of elemental heterogeneity in the fusion crusts.

The application of this technique, which is relatively easy, and consumes virtually none of the precious meteorite sample, should help recover bulk elemental abundances for other achondrites. Application to Antarctic meteorites may be more straightforward, since these meteorites mostly have less significant terrestrial contamination on their fusion crusts.

References: [1] Shirai N. et al. (2008) *MAPS 43, A144*. [2] Shirai et al. (2009) *LPS XL*, this conference. [3] Genge M. and Grady M. M. (1999) *MAPS 34,* 341-356. [4] Thaisen K. G. and Taylor L. A. (2008) *LPS XXXIX*, #1374. [5] Barrat J. A. et al. (2001) *MAPS 36,* 23-29. [6] Irving A. J. et al. (2006) *EOS, Trans. AGU 87*, #P51E-1245; Kuehner S. M. and Irving A. J. (2007) *LPS XXXVIII*, #1522 [7] Irving A. J. et al. (2007) *LPS XXXVIII*, #1526. [8] Warren P. H. et al. (1995) *AMR 20*, 261-264.

Table 1. Elemental abundances for fusion crust (FC1 and FC2) of NWA 4590 and NWA 4468 (oxides in wt%, others in ppm).

	NWA 4590			NWA 4468
	FC1 unwashed	FC1 unwashed	FC2 washed	FC12, 13 washed
SiO_2	36.83	38.15	39.33	44.10
TiO_2	1.42	1.49	1.78	0.51
Al_2O_3	8.37	8.62	7.42	5.41
FeO	28.07	26.25	22.28	23.08
MnO	0.31	0.30	0.25	0.49
CaO	17.51	18.16	22.31	4.67
MgO	6.95	6.64	6.52	19.42
Na_2O	0.11	0.10		0.76
K_2O	0.17	0.18		
P_2O_5	0.17	0.19	0.11	0.66
S	0.19	0.17	0.32	0.07
Li		7.4		1.3
Be		0.76	0.98	0.35
Sc	64	61.3	68	26
V	151	167	171	166
Cr	615	629	389	5950
Co	32	30	26	77
Ni	47	45	31	311
Cu	7.6	15		
Zn	14	19		
Ga	1.7	1.6	0.57	9.9
Ge	0.3	0.21	0.32	0.34
As	3.2	3.9		
Se	2.3	2.6		
Rb		2.9	0.89	6.9
Sr		131	127	95
Y		34	44	12
Zr		98	148	49
Nb		3.6	3.9	2.8
Mo		0.88	0.5	0.38
Sb		0.18	0.069	0.36
Cs		0.22	0.13	0.42
Ba		235	133	233
Hf		2.9	3.3	1.5
Ta		0.22	0.25	0.16
W		0.39	0.41	0.57
Th		1.3	0.78	0.56
U		0.40	0.16	0.26