Warren et al. (2009), Siderophile and other geochemical constraints on mixing relationships among HED-meteoritic breccias — Electronic Annex

The main purpose of this Electronic Annex is to include several additional tables and diagrams. Tables EA-1, -2 and -3 give results for some additional elements, left out of the main paper's Tables 1, 2 and 3 (respectively) in order to keep those tables to manageable sizes. Table 4 (in three parts) lists instances of unusually high uncertainty for the results of Tables 1-3 and EA-1, -2 and -3. Table EA-5 is self-explanatory. Figures EA-1 and EA-2 illustrate/constrain the same basic mixing process addressed (in general, more effectively) by Figs. 1-4 of the main paper; and the database and symbols employed for these figures is identical to the database and symbols employed in Figs. 1-4. Figure EA-3 uses a database restricted to pristine-igneous (unbrecciated or monomict-brecciated) eucrites, with the aim of illustrating the distinctiveness and limited La diversity of Nuevo Laredo trend. The Annex begins with a supplementary section on classification issues and outlier samples.

Additional discussion of analysis methodology: sampling representativeness

This section is essentially a continuation of Section 2 in the main body of the paper.

Because HED achondrites are diverse in texture and composition, it is impossible to generalize about the relationship between sample size and representativeness. While a few tens of milligrams might be fairly adequate for major elements in one of the more fine-grained noncumulate eucrites, even 10 grams might be inadequate for trace elements (although perhaps adequate for element:element ratios involving geochemically similar, e.g., incompatible, element pairs) in a cumulate eucrite or a diogenite. As indicated in Tables 1-3, our sample size (for each individual analysis) was generally 0.2-0.5 g.

In 29 instances, comprising 9 noncumulate nonpolymict eucrites, 5 cumulate eucrites, 1 diogenite, 10 polymict eucrites and 4 howardites, we analyzed 2 or 3 separate chips from a single meteorite. (In most such cases, however, the chips were originally adjacent masses and were only separated in our clean room). The degree of agreement between our separate analyses for these samples provides some insight vis-a-vis the representativeness issue.

For noncumulate nonpolymict eucrites, agreement between the separate-chip analyses is almost uniformly good (scatter not much beyond that expected from purely analytical shortcomings). Millbillillie is the one clear exception, but Millbillillie is also one of two cases (the other being howardite NWA 1182) where our multiple samples were deliberately chosen for their disparate appearances, so as to emphasize diversity within the meteorite. (Millbillillie is also conceivably, in toto, polymict, albeit our analyses show little evidence for siderophile-element "contamination".) QUE 97014 also shows a strange lack of agreement for one moderately siderophile element, Co.

Unsurprisingly, for one of the cumulate eucrites (EET 87520) and the only diogenite so tested (NWA 1461), agreement is very poor for incompatible trace elements. Such elements are at low concentration, and probably reside in a relative few scattered tiny grains (e.g., phosphates) in these rock types. Only one of the cumulate eucrites shows good agreement across the range of elements: Y-791195, which is also very unusually fine-grained (most grains 0.1-0.2 mm across: Yanai and Kojima, 1987), by HED-cumulate standards.

Polymict breccias are by definition heterogeneous, except for cases where the blending process has been especially thorough, such as regolith breccias. Not surprisingly, agreement is generally poor (scatter well beyond that expected from purely analytical shortcomings) for the 10 polymict eucrites and 4 howardites (all non-regolithic) for which we obtained separate-chip analyses. The grossest heterogeneities are found for polymict eucrites LEW 85303, LEW 87295 and TIL 82403, and howardites MET 96500 and NWA 1182; in most cases involving incompatible trace elements as well as siderophile elements. Polymict eucrites Y-791826 and Y-794002, and to a lesser extent EET 82600 and LEW 87004 (but note its scatter for Ir), disobey the general trend by showing good agreement between chips.

Additional discussion of classification issues and outlier samples

This section is essentially a continuation of Section 3.2 in the main body of the paper.

The "Mg-rich eucrite" breccia LEW 87002 is difficult to classify. Mason (1988) and Delaney (1989) reported a narrow range of compositions for its pyroxenes (mostly low-Ca, $En_{66}Wo_3$), which tends to suggest a monomict breccia, and Mason (1988) opted for the "Mg-rich eucrite" classification because he found LEW 87002 "lacks the diogenitic pyroxene characteristic of the howardites." Actually, some diogenitic pyroxenes are similar to the dominant LEW 87002 pyroxene. The low-Ca pyroxene of the Y-75032 diogenite is tightly clustered near $En_{66}Wo_2$. Also, although most of our 62 analyses of pyroxene from section LEW 87002,5 are close to $En_{66}Wo_2$, we also found more magnesian compositions, up to $En_{76.1}Wo_{1.2}$ (cf. an especially low-Wo but otherwise very typical diogenitic pyroxene: Fowler et al., 1994). The most magnesian orthopyroxene contains ovoid inclusions of olivine (Fo_{62-65}) up to 0.23 mm across. Our data also show a wide range in plagioclase composition (49 analyses scattering across the range $An_{87.6-95.9}$). In general, the texture of LEW 87002 is that of coarse-grained material that has undergone moderate brecciation. But also present is a smattering of clasts with incongruously fine-grained subophitic "melt" texture (e.g., Fig. 5; the pyroxenes in this clast conform to the main LEW 87002 clusters, ~$En_{66}Wo_{2.5}$ and $En_{44}Wo_{43}$, but show an unusually high augite:opx ratio of about 4:6). Finally, siderophile elements (Tables 3 and EA-3) show mild but consistently significant enrichments over the levels associated with pristine igneous HEDs (cf. the unbrecciated, monomict and cumulate eucrites in Tables 1 and EA-1). As a diogenite-dominated polymict breccia, LEW87002 is probably best classified as a howardite.

Four of our eucrite samples have a current Meteoritical Bulletin classification of simply "eucrite." Two of these, A-881819 and A-9029, are Asuka meteorites that the updated (on-line) NIPR catalog lists as breccias. In bulk composition, A-881819 closely matches the cumulate eucrite A-881394, including the low incompatible element levels (Fig. 3b) that among HEDs indicate a cumulate origin.

Pending a future RNAA, the siderophile evidence is ambiguous (Ni at ~ 9 μg/g would be high, even for a cumulate eucrite, but note that A-881394's RNAA-determined Ni content is only 1 μg/g lower). In any event, A-881819 is either a brecciated eucrite or a polymict breccia that consists almost purely of cumulate (incompatible-element-poor, possibly A-881394 paired) eucrite. In our figures, we plot it with a cumulate eucrite symbol. In the case of A-9029, our study of thin section A-9029,51-1 indicates the breccia is polymict (included in an otherwise nondescript eucritic breccia is an incongruous 1.5×0.5 mm clast of dark brown glass studded with crystalline inclusions); and the siderophile evidence (Ni, 38 μg/g) unambiguously implies a polymict eucrite. Agoult is an unusual granulitic eucrite. Y-981651 is unbrecciated-vesicular but shows evidence of incomplete assimilation of older Cr-spinel (Fig. 5; the reaction rims are as much as 20 wt% poorer in Cr_2O_3 than the cores) and silica. In principle, assimilation-mixing might have occurred without involvement of any impact; and pending a future RNAA, the Y-981651 siderophile evidence is ambiguous. However, noting that Barrat et al. (2003) found surprisingly low Ni (5.4 μg/g) in NWA 1240, which is clearly an impact-melt breccia, we tentatively classify Y-981651 as an impact-melt form of polymict eucrite.

Y-791438 has a current Meteoritical Bulletin classification of "eucrite-monomict." Like A-881819, Y-791438 has low incompatible element levels (Fig. 3b; also low Sc, Fig. 4) that imply it is a (brecciated) cumulate eucrite. Our Ni and Ir data (Table 2) suggest that the "monomict" classification of the eucrite breccia Igdi is incorrect. Even though Igdi appears to be dominated by a single, compositionally distinctive ferroan and incompatible-rich (i.e., Nuevo Laredo Trend; Warren and Jerde, 1987) material, it is a siderophile-enriched polymict eucrite.

The extraordinarily fine-grained eucrite PCA 82502, although listed as "unbrecciated," actually is a genomict breccia with discrete clasts of unbrecciated material set in a cataclastic matrix (Bermingham et al., 2008). We note that thin section PCA 82502,29 contains a smattering (~0.5 vol%) of round vesicles, mostly 0.1-0.2 mm across, up to 0.3 mm. Except for Ibitira, which appears to represent a separate parent asteroid (Mittlefehldt, 2005), vesicles are rare among eucrites. To our knowledge, the only other vesicular eucrites are the obvious impact melt NWA 1240 (Barrat et al., 2003), the suspected impact melt Y-981651 (see above), and another extraordinarily fine-grained Pecora Escarpment eucrite, PCA 91007. Both PCA 91007 and 82502 have barely detectable but significant enrichments of siderophile elements above the levels normal for pristine-igneous eucrites. In principle, such minor proportions of chondritic contamination might have been assimilated when a surface lava flowed over a contaminated regolith, without direct involvement of any impact. But if so, the final lava composition has nonetheless been subtly altered from a normal igneous composition. Based on the siderophile data, coupled with limited textural evidence for brecciation, we believe both PCA 91007 and 82502 are best classified, admittedly with an unusual degree of uncertainty, as the impact-melt form of polymict eucrite. They may also be paired, although our PCA 91007 analysis features 2.2 times higher La than the average of our two (rather disparate, for La) PCA 82502 analyses.

As described by Yamaguchi et al. (2001), EET 90020 is a mineralogically consistent yet texturally complex breccia. Yamaguchi et al. (2001) even infer that an early (~4.50 Ga) impact-shock caused partial melting. However, since these textural complexities appear to be local in scale, and we did not detect Ni or Ir, we leave unchanged this meteorite's prior "eucrite-monomict" classification. The meteorite appears compositionally heterogeneous. Our La results of 1.28-1.37 μg/g average 1.7 times the results (0.75 and 0.78 μg/g) of Mittlefehldt and Lindstrom (2003). Taken at face value, any eucrite La concentration <<1.5 μg/g (i.e., below the low end of the "Main Group") suggests a possible cumulate origin. However, as discussed by Mittlefehldt and Lindstrom (2003), diverse complex processes potentially affected the final composition of EET 90020.

Another "eucrite-monomict" sample requires explanation. Stannern has been widely studied, but our sample (0.5 g which G. Kurat kindly loaned to us for nondestructive INAA) is from the small (6-g) mass that the Naturhistorisches Museum, Wien, acquired as a possible specimen of an early 19th century meteorite shower at Constantinople. The Wien "Constantinople" specimen has long been considered probably Stannern (see Grady, 2000). But the scarce available data for "Constantinople" led Heymann et al. (1968) to marginally incline toward "an independent fall." Subsequent bulk analyses for a few minor and trace elements (Laul et al., 1972; Schmitt et al., 1972) (actually, Heymann had seen a preview of the Schmitt et al. data) did not remove the ambiguity. However, our data and the distinctively incompatible-rich Stannern show a close match, confirming that "Constantinople" is very probably a piece of Stannern.

Classification of the Y-791200 diogenite-dominated polymict breccia is difficult. This meteorite contains a "small" component of cumulate eucrite (Takeda and Mori, 1985), and the piece we analyzed has such a large plagioclase component (imparting, e.g., 6.0 wt% Al_2O_3), we suspect the meteorite may be an exceptionally diogenite-rich howardite. However, petrographic (Takeda and Mori, 1985) and noble-gas isotopic (Miura, 1995) evidence suggests that Y-791200, as a "Y75032 type achondrite," is paired with Y-75032, which is usually regarded as a monomict diogenite. For plotting purposes (Fig. 1, etc.), we deviate from our usual practice of averaging data for paired samples, and instead regard Y-791200 as a polymict diogenite distinct from Y-75032. Although polymict breccia PCA 02009 is officially classified as a howardite, the piece we analyzed appears to be a polymict but nearly pure diogenite. It remains unclear whether PCA 02009, as a whole, is a (polymict) diogenite or truly a howardite.

In Fig. 1, most of the scatter off the two-component mixing line comes from samples that are believed to be cumulates: the NWA 1461 and Y-75032 diogenites, the cumulate eucrites, and A-881819 and Y-791438, which (see above) we would reclassify as cumulate eucrites. Igdi is a noncumulate (and by our reclassification, polymict) eucrite that strays to the low-MgO side of the mixing trend; and also features a uniquely high CaO, for a noncumulate HED (Fig. 4; our Igdi data agree well with Barrat et al., 2003). Saharan weathering of Igdi has probably caused slight enrichment in CaO, and conceivably even MgO and Al_2O_3 (Fig. 1) show noticeable effects. Among diogenites, besides being extraordinarily magnesian, NWA 1461 is unusually low in Sc (Fig. 1b) and V (Fig. 3a). NWA 4283 appears exceptionally rich in both V and Cr, but in diogenites Cr, and to a lesser extent V, are largely concentrated into a single minor phase, Cr-spinel (Bowman et al., 1999), for which our single 0.47-g sample might be unrepresentative.

Other samples with outlier compositions include EET 96003 and Y-791192, which have unusually low Sc compared to other HED polymict breccias with ~ 10-11 wt% Al_2O_3 (Fig. 2; for Y-791192, cf. Mittlefehldt and Lindstrom, 1993). Y-791192 is also, by polymict breccia standards, oddly poor in siderophile elements Ni (Figs. 2 and 6a) and Ir (Fig. 6a), and in incompatible elements such as Sm (Fig. 3b; we use the middle REE Sm as exemplar of incompatible elements, in part because INAA determines Sm with high sensitivity and precision). We follow Saiki et al. (2001) in classifying Y-791192 as a polymict eucrite (rather than a howardite), albeit it features a very unusual preponderance of cumulate over noncumulate eucrite. The eucrites QUE 97014 and GRA 98098 are unusually V-poor (Fig. 3a), while Y-82202 is V-rich (Fig. 3a; caveat: our Y-82202 sample was only 51 mg). GRA 98098 is also extraordinary for its low Cr and (for a eucrite of moderate incompatible-enrichment) high Na. Eucrites LEW 88010 and Stannern were previously known to be unusually Sm-rich (Mittlefehldt and Lindstrom, 2003). Bluewing 001 is even more enriched. LEW 87002 is anomalously Sm-rich for an HED with its high MgO. The howardite Muckera 002 is oddly Sm-rich, but probably only as a result of weathering.

Table EA-1. Bulk-rock compositional results for 19 elements in 25 noncumulate eucrites, 9 cumulate eucrites and 6 diogenites.

	Sample*	Weathering	Mass	K	Zn	Ge	As	Br	Zr	Cd	Ce	Nd	Tb	Dy	Ho	Yb	Ta	Re	Os	Au	Th	U
				mg/g	µg/g	ng/g	µg/g	µg/g	µg/g	ng/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	pg/g	pg/g	ng/g	µg/g	µg/g
Noncumulate eucrites: unbrecciated (1-10), brecciated-monomict (11-22), or brecciated with mixing state uncertain (23-25)																						
1	Agoult	W1	555	0.18	<10		<0.3	0.81	50		5.9	4.4	0.39	3.1	0.50	1.60	0.137			<2	0.24	0.053
2	Bluewing 001	W1	174	0.60	<20		15.4	0.49	69		15.9	11.9	0.80	6.1	1.05	2.67	0.40			5.7	0.81	0.63
3	EET 92004,13	A/B	379	0.254	<22		<0.3	0.30			5.5		0.33		0.43	1.40	0.159			<1.1	0.21	<0.2
4	GRA 98098,31-A	B	434	0.37			<1	<1	85		6.9	5.3	0.53	3.0	<1.4	2.21	0.19			<30	0.41	0.118
	GRA 98098,31-B		440	0.35	<10		<1	<1	67		6.7	5.1	0.50	3.9	0.68	2.18	0.18			<30	0.39	0.120
5	LEW 88009,4	A	224	0.321	<30		<0.3	0.38			7.6		0.40		0.55	1.63	0.159			<1.4	0.26	<0.2
6	LEW 88010,5	A	428	0.57	1.54	1.6	<0.3	0.34			12.4		0.79		0.99	2.68	0.37	<14	80	0.016	0.58	<0.2
7	PCA 91078,10-a	A/B	310	0.245	0.97	1.22	<0.4	<0.24			4.6		0.27		0.40	1.12	0.111	<2.4	116	0.017	0.19	<0.2
	PCA 91078,10-b		305	0.204	<21		<0.4	0.27			4.9		0.28		0.37	1.17	0.133			<1.0	0.19	<0.1
8	PCA 91245,11-a	B	323	0.247	<10			0.24[§]	<60		3.8	3.0	0.248	<4	0.38	1.14	0.076			<0.8	0.17	
	PCA 91245,11-b		327	0.223	<10		<0.4	0.25	<60		3.4	2.7	0.237	1.5	0.34	1.06	0.078			<0.8	0.17	0.06
9	QUE 97014,20-A	A	308	0.500	<20		<0.3	0.37	39		6.0	5.0	0.395	3.8	0.60	1.64	0.147			<1.2	0.29	0.08
	QUE 97014,20-B		306	0.48	<20		<0.7	0.27	<60		7.1	5.4	0.50	<4	0.52	1.85	0.175			<2	0.34	0.11
10	RKP 80224,6	A	132	0.35					<70		4.0	2.6	0.267	2.4	0.49	1.60	<0.1			<3	0.153	<0.2
	RKP 80224,7	A/B	218	0.43	1.59	2.0			<61	<5	5.4	4.2	0.31	2.8		1.77	0.102	4.0	13[§]	0.016	0.25	<0.06
11	EET 87542,7	A	306	0.39	0.41	1390			<100	0.7	8.1	5.3	0.52	3.5		2.08	0.18	0.6[§]	3.8	0.06[§]	0.36	<0.14
12	EET 90020,8-a	A	326	<0.3	<20		<0.5	0.29	44		3.0		0.35	<3	0.41	1.39	0.105			<1.2	0.17	
	EET 90020,8-b		332	0.240	<20		<0.5	0.28	45		3.0		0.37	2.9	0.45	1.44	0.119			<0.8	<0.2	
13	LEW 86002,10-A	A/B	375	0.250	<3.1		<0.2	<0.2	62		5.0		0.23	<2.3		1.22	0.12			<0.8	0.24	<0.14
	LEW 86002,10-B		400	0.262	1.6	0.75	<0.5	<0.2	<110	<4	5.6		0.26	<6		1.34	0.12	1.1[§]	3.6	0.0097	0.26	<0.09
14	LEW 87010,6	A	171	0.33	0.70	1.5	<0.2	<0.3	48	<4	5.6		0.37	<6		1.72	0.14	4[§]	2.8[§]	0.013	0.27	<0.14
15	Millbillillie-A(CG)		148	0.53	2.2	2.1	<0.6	1.02	<200	<30	9.1	7.1	0.67	5.2	0.90	2.38	0.31	2.3	<6	0.032	0.52	
	Millbillillie-B(FD)		222	0.43	1.9	1.8	<0.4	0.75	<110	<40	9.8	7.4	0.60	3.8	0.85	2.11	0.27	6.4	68	0.22	0.53	
	Millbillillie-C(FG)		164	0.39	1.4	0.78	<0.4	0.70	<130	<300	6.9	5.1	0.44	3.2	0.57	1.63	0.17	<4	5.6	0.037	0.39	<0.15
16	Peramiho	fall	483	0.286	<6		<0.6	1.11	42		5.8	5.2	0.46			1.83	0.24			7.58	0.29	<0.10
17	RKP 80204,14	A	320	0.51	1.12	1.5			<73	<400	6.6	4.1	0.32	2.2	0.47	1.47	0.149	6.9	5.2	0.046	0.30	0.073
18	Sioux County	fall	279	0.243	<20		<0.3	0.55	80		5.4	2.8	0.31	1.7[§]	0.71	1.35	0.125			1.25	0.143	
19	Stannern?	fall	502	0.73	<20		<0.3	0.74	47		11.7	8.9	0.81	4.8	1.00	2.78	0.311			19.0	0.58	0.13
20	Y-791186,88-A		270	0.51	0.90	10.5	<0.5		79	<10	9.2	5.7	0.44	3.1		1.99	0.27	6.4	<5.6	0.032	0.49	0.13
	Y-791186,88-B		260	0.45	<10		<0.4	0.46	100		8.4	7.3	0.52	3.1	0.65	2.21	0.29			<1.4	0.45	0.15
21	Y-82037,64		372	0.270	1.64	3.8	<0.7		50	12	5.3	3.7	0.35	2.1		1.46	0.08	1.3	1.5[§]	0.015	0.120	<0.07
22	Y-82202,63		51	0.43	<21		<0.4	1.42			7.9		0.46		0.62	1.71	0.131			<1.1	0.36	<0.1
23	GRA 98006,12	A/B	612	0.31	<15		<0.2	0.69	<70		5.9	5.1	0.45	<6	0.55	1.83	0.18			<1	0.24	<0.3
	GRA 98033,11	A/B	581	0.294	<7		<0.7	0.90	<60		7.5	5.3	0.47			1.94	0.137			1.1[§]	0.31	0.10
24	QUE 99005,6-A	B	302	0.219	<20		<0.6	<0.7	65		6.3	5.8	0.45	2.5	0.72	1.73	0.152			<2	0.29	0.10
	QUE 99005,6-B		405	0.219	<20		<0.3	0.30	58		7.9	6.0	0.45	3.5	0.62	1.79	0.181			<2	0.33	0.09
25	QUE 99006,7	B	506	0.39	<10		<0.1	0.80	59		7.7	3.7	0.38	2.0	0.45	1.61	0.24			<3	0.36	
Mg-rich (EET 87520) and cumulate (2-9) eucrites																						
1	EET 87520,10-A	B	327	0.33	0.46	0.70			89	<3	10.4	6.5	0.48	2.9		1.71	0.25	<1.7	2.6[§]	0.0048	0.46	0.12
	EET 87520,10-B		328	0.29	<2.6				39		5.1	3.9	0.32	2.7	<1.1	1.49	0.06			<0.6	0.22	<0.09
2	ALH 85001,25-a	A/B	330	0.084	<10			0.25	<70		2.0	1.6	0.135	<1.7	0.204	0.61	0.050			<1	<0.2	
	ALH 85001,25-b		330	0.123	0.72	19	<0.3	0.35	<40		2.7	<3	0.124	<2	0.173	<1	0.053	4.4	<15	0.0077	<0.2	
3	A-881819		320	0.178	<7		<0.5	1.42	<50		1.42	0.95	0.097			0.47	0.053			<1	0.047	<0.04
4	A-881394,56-A		273	0.04[§]	0.29	2.9		0.25	<32	<20	1.08	<2	0.085	<2		0.36	<0.05	16	7	0.028	<0.04	<0.1
	A-881394,56-B		271	0.044	<10			0.23	<40		1.1	<0.9	0.089	<1.8	<0.2	0.40	<0.014			<2	<0.1	
5	EET 87548,7-A	B/C	341	0.124	<10				<61		<0.44	<1.4	0.04	<2.2		0.37	<0.06			<2.3	<0.061	<0.11
	EET 87548,7-B		344	0.107	1.13	26			<48	3.6[§]	<0.5	<1.0	0.06	<1.9		0.37	<0.07	5.6	4.0	0.038	<0.057	<0.10
6	PCA 91159,5	B	378	0.177	0.95	31		0.31	<70		3.0	2.3	0.218	<2.0	0.34	0.99	0.077	8.9	<5	0.032	0.112	
7	Talampaya-A	fall	316	0.086	<20			0.28	<50		<1	<0.6	<0.03		0.054	0.14	<0.1			0.6[§]	<0.1	
	Talampaya-B		323	0.174					<30				0.026		<0.3	0.14				2.27	<0.06	
8	Y-791195,73-A	A	235	0.307	0.92	1.9	<0.4		<32	<10	1.9	1.18	0.100			0.52	<0.08	<5	<20	<0.013	<0.06	<0.07
	Y-791195,73-B		244	0.395	<10		<0.4	0.42	<40		1.6	<2	0.101	<2	0.137	<1	0.028			<2	0.076	<0.03
9	Y-791438,54		300	0.113	1.90	0.72	<0.2	0.50			2.4		0.14		0.17	0.52	0.035	<7	119	0.0079	0.101	<0.1
Diogenites (monomict, except Y-791200)																						
1	ALH 77256,96-a	A/B	381	0.026	1.2	63		0.29	<60		<60	<1.33	<0.07	<1.6	<1.8	0.27	<0.026	6	98	0.36	<0.1	
	ALH 77256,96-b		369		<20		<0.2	0.26	<30		<7		0.038	<3	0.056	0.22	<0.05			<1.6	<0.2	
2	LAP 91900,26	A/B	561	<0.033	0.58	<20		0.21	<90		<5	<2	<0.1			0.074	<0.1	5.2	81	0.064	<0.2	
3	NWA 1461-A		445	0.123				0.13			<0.6	<0.8	<0.1	<2	<0.02	<0.2	<0.12			<0.33	<0.08	
	NWA 1461-B		571	0.007				0.40			<1.5	<1.3	<0.06	<2	0.019	0.057	<0.08			0.40	<0.1	
4	NWA 4283		465	0.019				0.20			<0.6	<0.6	<0.06	<3	<0.02	0.033	<0.06			0.45	<0.03	
5	Y-75032,90	A	506	0.052	0.82	12.5		0.31	<60	<2	1.2	<1.2	0.106	<1.9	0.18	0.66	<0.021	10	24	0.039	<0.2	
6	Y-791200,86		273	0.215	0.55	16.4	<0.2	0.46	<70		3.5		0.12	<3	0.194	<1	0.040	11	194	0.060	0.079[§]	
Relative uncertainty[▼]				8	7	8	10	8	8	8	7	8	5	7	6	5	6	8	8	8	6	10

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.

[▼] Normal uncertainty limits (% relative) for 70% confidence. Sampling errors sometimes predominate, however.

[§] Uncertainty greater than 30% relative; for a more complete itemization of uncertainties, see Table EA-4.

Table EA-2. Bulk-rock compositional results for 19 elements in 31 polymict eucrites.

	Sample*	Weathering	Mass	K	Zn	Ge	As	Br	Zr	Cd	Ce	Nd	Tb	Dy	Ho	Yb	Ta	Re	Os	Au	Th	U
				mg/g	µg/g	ng/g	µg/g	µg/g	µg/g	ng/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	pg/g	pg/g	ng/g	µg/g	µg/g
1	ALH 78132,99	A	337	<0.78	<20			0.32[§]	61		9.5	4.2	0.45	2.7	0.53	1.69	0.140			<3	0.50	
	ALH 78132,102		375	0.307	1.03	12.4	<0.3	0.29	<80		8.1		0.31	<4	<2.5	1.36	0.137	67	1150	0.23	0.33	
2	A-9029		221	0.198	<7		<0.5	2.2	49		6.8	3.8	0.317			1.39	0.178			<1	0.27	0.08
3	Bialystok	fall	329	0.214	<7		0.19	<0.3	<40		3.7	2.53	0.219		0.33	0.98	0.092			119^	0.155	0.13
4	Dar al Gani 391		421	0.40	<8		<0.4	0.29	65		7.4	5.6	0.48	5.0	0.71	1.90	0.19			<2	0.34	0.13
	Dar al Gani 411	W0	197	0.42	<12		0.12[§]	2.3	67		7.7	5.7	0.49	<7	0.64	1.97	0.22			<0.8	0.34	<0.1
5	EET 79005,93	A	310	0.113	0.84	18	<0.5		58	<600	7.8	4.7	0.43	2.8	0.61	1.70	0.166	51	640	0.19	0.29	<0.13
	EET 79005,95		305	0.56	1.3	13.2	<0.5		42	12	8.0	6.6	0.44	2.4	0.53	1.53	0.145	36	480	0.058	0.31	<0.13
6	EET 82600,2-A	Ae	534	1.31	<7		<0.6	1.05	43		5.4	3.1	0.275	<6		1.22	0.19			0.4[§]	0.32	0.093
	EET 82600,2-B		526	1.31	<6		<0.7	0.80	40		5.3	4.3	0.321	<6		1.29	0.157			1.03	0.31	0.11
	EET 82600,7		605	0.69				<0.5			4.7	3.0	0.24	2.0	0.36	1.08	<0.2			<0.8	0.21	<0.2
7	EET 92023,9-a	A	316	0.226	5.7	1500		0.27[§]	<40	<6	2.7	<4	0.207	<3	0.35	1.08	0.064	6300	40000	16.2	0.118	
	EET 92023,9-b		313	0.175	5.3	1320	0.16	0.22			3.2		0.22		0.32	1.04	0.054	4400	53000	15.9	<0.4	<0.2
8	FRO 97045,23		461	0.325	<8		<0.4	<0.3	66		7.2	3.7	0.34	<3	0.52	1.43	0.21			<2	<0.9	3.9
9	Igdi-A		479	0.50	<10		0.31	0.96	67		8.4	7.2	0.62	3.2	0.74	2.31	0.29			0.62	0.47	
	Igdi-B		244	0.47	<18		<0.8	1.4[§]	109		8.5	6.5	0.57	3.0	0.72	2.35	0.22			<2	0.38	0.14
10	LEW 85303,90	A/B	306	0.306	<20		<1	<1.2	91		5.0	4.9	0.37	<3	0.51	1.68	0.152			0.91	0.30	0.11
	LEW 85303,94		297	0.64	<20		<1	<1.3	<50		7.7	6.4	0.52	3.7	0.66	2.29	0.36			3.52	0.79	0.14
11	LEW 87004,14	A	337	0.35	1.7	71	<0.5		37	3.2	7.4	6.4	0.47	3.2	0.68	1.78	0.17	72	1150	0.26	0.26	<0.16
	LEW 87004,19		328	0.40	1.8	76	<0.6		86	12	7.8	6.5	0.52	3.2	0.87	1.87	0.19	116	1280	0.43	0.28	<0.16
12	LEW 87026,7	A	305	0.50	1.7	27	<0.2	<0.3	60	<2	8.1		0.27	<5		1.44	0.18	142	2460	0.44	0.34	<0.2
13	LEW 87295,7	B	283	0.57	4.0	610	<0.5		65	9.2	6.4	4.3	0.35	2.4	0.50	1.43	0.123	670	10020	2.1	0.23	<0.13
	LEW 87295,8		97	1.08	<10		<0.4	1.11	100		6.1	<5	0.29	<10	0.38	1.20	0.079			5.2	0.183	<0.3
14	LEW 88005,19	B	655	0.313	<12		<0.6	<1.3	54		6.0	2.55	0.26	<4	0.43	1.32	0.112			<2	0.23	<0.3
15	Macibini	fall	382	0.43	<7		0.88	1.29	31		7.3	5.3	0.44	<8	0.68	1.79	0.23			1.46	0.35	<0.09
16	PCA 82502,85	A	218	0.226	<30			0.29	110		9.6	3.7	<0.5		0.49	1.57	0.136			<1.1	0.39	
	PCA 82502,86		224	0.282	<20			<0.7	52[§]		5.3	1.17	0.213		0.40	1.32	0.135			<1	0.24	
17	PCA 91007,4	A/Be	328	0.34	3.5	6.2		0.23[§]	69		8.6	5.7	0.49	3.1		2.08	0.174	20	290	0.072	0.38	0.103
18	QUE 97004,7	A	309	0.335	<10		<2		<300		5.4	4.4	0.36		0.59	1.47	0.18			2.79	0.37	<0.26
19	TIL 82403,30	A	310	0.35	<15		<0.5	<0.6	<90		8.2		0.44	2.9	0.82	1.54	0.198			<1.5	0.37	
	TIL 82403,31		404	0.49	1.2	8.7		0.20	<60		3.2	2.5	0.224	<3.2	0.39	1.41	0.18	26	750	0.074	0.21	
20	Y-74159,79-a	A	349	0.42	<15		<0.5	<0.6	<100		9.4		0.58	4.0	<0.9	2.06	0.23			<3	0.33	
	Y-74159,79-b		349	0.45	<22		<0.5	<0.7	<100		8.4		0.53	<5	<1.2	2.05	0.23			<2	0.30	
21	Y-74450,111	A	543	0.50	<20			0.17[§]	60[§]		14.2	6.3	0.81	5.6	0.70	2.48	0.23			<3	0.83	
22	Y-75015,88	A	535	0.41	<20			<0.5	<300		11.1	5.7	0.67		0.54	2.19	0.21			<2	0.63	
23	Y-790007,84	A	526	0.50	<20			0.28	160		14.4	18.9	0.75		0.94	2.46	0.24			<2	0.56	
24	Y-790260,91	A	521	0.35	<20		<0.4	0.95	30		9.5		0.49	3.6	0.64	1.97	0.23			<3	0.39	
25	Y-790266,102	A	523	<0.58	1.47	4.4		0.66[§]	110		14.3	6.3	0.65	4.2	0.44	2.35	0.25	38	720	0.023	0.53	
26	Y-791192,81-a		331	0.298	<30		<0.4	0.79	<50		2.8		0.131	<3	<0.7	<1	0.042			<2	<0.12	
	Y-791192,81-b		333	0.267	0.74	11.8	<0.4	0.69			2.2		0.160		0.34	0.80	0.062	6.1	35	0.035	0.049[§]	<0.8
27	Y-791826,57-A		345	0.51	<30			<1.2	119		11.3	6.8	0.70	4.7	0.56	2.42	0.25			<5	0.80	
	Y-791826,57-B		347	0.58	<20			<1.1	51		11.2	7.5	0.65	4.1	0.49	2.29	0.21			<2	0.68	
28	Y-793164,68-a		317	0.41	<20		<0.5	<0.7	<60		9.5		0.44	4.3	0.56	1.99	0.23			<2	0.35	
	Y-793164,68-b		314	0.49	<20		0.49[§]	0.57	66		9.0		0.48	3.9	0.67	2.00	0.24			<1.6	0.39	
29	Y-794002,60-A		351	0.41	<20			<0.8	<150		15.1	4.9	0.61	4.0	0.55	2.21	0.22			<3	0.68	
	Y-794002,60-B		340	0.46	<20			<1.1	<120		9.7	4.3	0.66	2.4	0.47	2.12	0.22			<3	0.66	
30	Y-82052,63		567	0.275	0.83	34	<0.6	<0.9	79		8.5	3.2	0.33	2.1	0.43	1.35	0.144	83	760	0.32	0.21	<0.3
31	Y-981651,65		250	0.217	<12		<0.3	1.58	<30		3.1	<3	0.30	<4	0.39	1.27	0.048			<0.9	0.062	<0.03
Relative uncertainty▼				8	7	8	10	8	8	8	7	8	5	7	6	5	6	8	8	8	6	10

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.

▼ Normal uncertainty limits (% relative) for 70% confidence. Sampling errors sometimes predominate, however.

[§] Uncertainty greater than 30% relative; for a more complete itemization of uncertainties, see Table EA-4.

^ Bialystok results are anomalously high for Ir (Table 2) and especially Au; we suspect artificial contamination.

Table EA-3. Bulk-rock compositional results for 19 elements in 31 howardites.

	Sample*	Weathering	Mass	K	Zn	Ge	As	Br	Zr	Cd	Ce	Nd	Tb	Dy	Ho	Yb	Ta	Re	Os	Au	Th	U
				mg/g	µg/g	ng/g	µg/g	µg/g	µg/g	ng/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	pg/g	pg/g	ng/g	µg/g	µg/g
1	Chaves-a	fall	327	0.235	4.1	44	0.17		52		4.4	2.7	0.22	1.55	0.35	0.94	0.086	95	1050	47	0.179	
	Chaves-b		303	0.233	<10		0.13	0.16	52		4.7	2.5	0.21	1.48	0.30	0.93	0.085			47	0.177	
	Chaves-c		294	0.252	<12		<0.5	<0.7	50[§]		3.8	3.0	0.23	<2		0.96	0.113			32	0.155	
2	CRE 01400,10	B	569	0.201	<4		<0.3	0.92	<25		3.6	3.3	0.293	<4	0.37	1.01	0.093			<1.1	0.145	<0.05
3	Dar al Gani 779	W1	602	0.43	<15		2.4	1.02	30		3.0	1.92	0.181	<5	0.24	0.83	0.066			<0.8	0.166	0.18
4	EET 96003,8	A	312	0.13	<9		<0.2	1.49	28		2.95	<3	0.233	<4	0.29	0.92	0.086			<1	0.096	<0.2
5	EET 99408,7	A/B	568	0.255	<4		<0.3	0.67	70		6.4	5.7	0.48	<8	0.66	1.71	0.129			<0.9	0.24	0.07
6	GRO 95574,7	A	426	0.160	<20			0.21	57		3.81	1.74	0.191		0.30	0.85	0.069			1.18	0.103	
7	GRO 95581,8	A	562	0.194	<5		<0.4	<0.4	<60		3.9	2.46	0.243			1.04	0.127			1.66	0.172	<0.05
8	HaH 285	W2	307	0.323	<5		0.59	0.99	30		4.3	3.0	0.177	<4	0.267	0.80	0.072			1.52	0.199	0.24
9	Hughes 004-A	?? (shiny	347	0.251	<50		<0.3	0.32	<50		3.6	2.2	0.250	<4	0.34	1.09	0.115			1.67	0.21	<0.1
	Hughes 004-B	crust)	186	0.201	<2		<0.3	0.38	<60		3.4	2.69	0.206	<4	0.30	0.82	0.095			0.98	0.183	<0.08
10	Jodzie	fall	484	0.43	19			0.53	44		5.19	3.2	0.25			1.04	0.13			12.7	0.19	<0.14
11	LEW 85313,32-a	B	373	0.219	6.0		<1	<1.1	<60		2.96	1.7	0.213	<4	0.32	0.99	0.091			8.9	<0.2	<0.14
	LEW 85313,32-b		378	0.207	5.5		<1	0.77	<60		2.82	2.05	0.216	<3	0.40	0.92	0.065			10.1	<0.2	<0.12
12	LEW 87002,7	Ae	240	0.041	0.92	16			<70	4.1	6.0	3.6	0.284	1.8	--	1.02	0.14	16	400	0.036	0.24	<0.2
13	LEW 87005,8	A	376	0.24	1.7		<0.3	1.17	72		5.0	4.1	0.38	3.0	0.48	1.50	0.16			4.9	0.24	<0.3
14	MAC 02666,9	B	496	0.229	<3		<0.3	1.21	58		5.6	4.2	0.39	<4	0.58	1.46	0.162			2.9	0.22	<0.08
14	Mässing	fall	373	0.193	<4		<0.5	0.20	<35		4.3	3.4	0.259			1.12	0.145			21.5	0.182	0.06
16	Melrose (b)		232	0.38	<6		1.10	2.2	<65		3.7	3.8	0.285	<4	0.46	1.31	0.136			0.9[§]	0.27	0.11
17	MET 00423,5	A/B	534	0.174	<2		<0.3	1.07	46		4.6	3.1	0.31	<3	0.43	1.27	0.108			2.01	0.192	<0.09
18	MET 01087,6	B	363	0.15	<6		<0.2	1.30	45		3.7	<2.3	0.156	<4	0.27	0.79	0.101			<2	0.20	<0.2
19	MET 96500,11	B	540	0.30	<5		<0.3	0.85	77		5.4	2.19	0.296	<5	0.35	1.03	0.132			1.32	0.30	<0.2
	MET 96500,12		594	0.17	<7		<0.3	0.81	<45		6.4	6.1	0.55	<5	0.67	1.81	0.136			2.34	0.196	<0.2
20	Muckera 002		171	0.58	<15		<1	1.00	101		13.9	9.2	0.71	4.7	0.85	2.56	0.27			<4	0.58	<0.2
21	NWA 1182-A (light)		593	0.20	<12			0.64	<40		3.4	2.0	0.22	1.2	0.24	0.83	0.105			3.4	0.17	0.07
	NWA 1182-B (dark)		248	0.32	<20			1.66	<30		4.0	2.8	0.29	2.1	0.33	1.08	0.157			12.1	0.20	0.05
22	NWA 1282		401	0.30				<0.4			6.0	5.2	0.40	2.4	0.56	1.7	0.14			0.7	0.30	
23	Pavlovka	fall	340	0.122	15			0.30	25		3.1	2.48	0.18			0.75	0.07			1.96	0.106	<0.1
24	PCA 02009,5^	A/B	408	0.020	<8		<0.2	1.05	<60		<0.4	<3	0.028	<4	0.045	0.17	0.018			0.64	<0.1	<0.05
25	QUE 94200,21	A/B	514	0.16	<8		<0.3	0.85	<40		3.7	2.60	0.273	<4	0.31	0.98	0.096			1.10	0.145	<0.2
26	QUE 97001,8	A	493	0.228	9		<2		<60		3.3	2.3	0.23		0.32	0.85	0.167				0.18	<0.15
27	QUE 99033,11	A/B	630	0.169	<8		<0.3	0.78	<50		3.5	2.57	0.246	<3	0.32	0.91	0.095			<0.3	0.166	<0.3
28	Y-7308,108		312	0.060	<7		<0.5	0.97	<40		1.72	1.14	0.118	<3		0.54	0.061			<0.8	0.077	<0.03
29	Y-791573,83		460	0.224	<5		<0.5	0.26	<40		3.5	3.0	0.226	<3		0.94	0.112			2.7	0.138	<0.1
30	Y-82049,65-A		354	0.173	0.68	77	<0.6	0.33	<70		6.2	1.75	0.24	<5	0.29	1.02	0.080	252	4600	1.00	0.134	<0.3
	Y-82049,65-B		325	0.27	<40		<0.6	<0.9	<70		4.4	3.2	0.28	<2		1.23	0.125			0.81	0.142	
31	Zmenj	A/B	473	0.091	<4		<0.4	<0.8	<40		2.8	<3	0.162			0.76	0.084			<1	0.075	<0.05
Relative uncertainty[▾]				8	7	8	10	8	8	8	7	8	5	7	6	5	6	8	8	8	6	10

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.

[▾] Normal uncertainty limits (% relative) for 70% confidence. Sampling errors sometimes predominate, however.

[§] Uncertainty greater than 30% relative; for a more complete itemization of uncertainties, see Table EA-4.

^ Although PCA 02009 as a whole is a howardite, the chip we analyzed is a polymict but nearly pure diogenite.

Table EA-4.1. Notably high uncertainties associated with compositional results (Tables 1 and EA-1) for 25 noncumulate eucrites, 9 cumulate eucrites and 6 diogenites.

	Sample*	K	Ni	Zn	Ga	Ge	As	Br	Sr	Zr	Cd	Ba	La	Ce	Nd	Sm	Eu	Tb	Dy	Ho	Yb	Lu	Hf	Ta	Re	Os	Ir	Au	Th	U
		% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.
Noncumulate eucrites: unbrecciated (1-10), brecciated-monomict (11-22), or brecciated with mixing state uncertain (23-25)																														
1	Agoult		36		22			6	11	14		27		10	20				15											24
2	Bluewing 001																													
3	EET 92004,13				26			11	8			17			9									7			7		8	
4	GRA 98098,31-A	9							13	7		9																		7
	GRA 98098,31-B	8							15	13		11			6				29											11
5	LEW 88009,4				14			9	13			15			8									7					6	
6	LEW 88010,5				27			15	6			15																		
7	PCA 91078,10-a		14		30				11			22			11					9				10			10		8	
	PCA 91078,10-b				20			21	13			17			9					10				9					10	
8	PCA 91245,11-a	8			21			35	14						15					13				10					11	
	PCA 91245,11-b																													
9	QUE 97014,20-A																													
	QUE 97014,20-B	7	32					18	15			12								7										14
10	RKP 80224,6								15					12	15				25	12									20	
	RKP 80224,7		13																18						25	32	13			
11	EET 87542,7		17		13				18						12				19						34	20	35			
12	EET 90020,8-a							13	16	22				7						6				6						
	EET 90020,8-b				25			25	13	24				8					21	7										
13	LEW 86002,10-A				12				11	18		28		10																
	LEW 86002,10-B				11	10			14			23		9											39	15	25	7		
14	LEW 87010,6		14		12	7			12	23		30												9	38	38	22	10		
15	Millbillillie-A(CG)		10		17	9		15							9				10	9				11	16		20		8	18
	Millbillillie-B(FD)		16		18	9		10				29			12				12	6				9		15		7	7	
	Millbillillie-C(FG)		7		23	12		12							11				15	8				12		8			8	
16	Peramiho	9	19		10			7	8	15		29								8								7		
17	RKP 80204,14				10				20			30		9					25	12					11	16				
18	Sioux County		23	7	18				30	27		12			14				32					6				22	14	
19	Stannern?								11	17		8							18											10
20	Y-791186,88-A		21																						26					
	Y-791186,88-B																													
21	Y-82037,64								12	18	8	28			9				22	13				14	24	36	17	7	10	
22	Y-82202,63			7	21				14						10									19			7		9	
23	GRA 98006,12				17				12			20			13															22
	GRA 98033,11	20						25	7			30								9								34		25
24	QUE 99005,6-A																													
	QUE 99005,6-B																													
25	QUE 99006,7				35				12	13		11							15											7
Mg-rich (EET87520) and cumulate (2-9) eucrites																														
1	EET 87520,10-A		38		13	11			12	16		25			12											33	9	13		
	EET 87520,10-B				13				14						11				20					17						
2	ALH 85001,25-a	16			20			23	13	20				7	25					30				15						
	ALH 85001,25-b	9			20			6	12			22								7				13	8					
3	A-881819	19	22		27				7						12					9				21					17	
4	A-881394,56-A	40			25			10	15					10				7		12		6				12		11		
	A-881394,56-B	23			19			16	14					9				6												
5	EET 87548,7-A				30								10					24												
	EET 87548,7-B										36							20								23	8			
6	PCA 91159,5	10			35			18	18			30			19					14				10			12		23	
7	Talampaya-A	13			19			10					6	8									32					39		
	Talampaya-B																													
8	Y-791195,73-A		15																											
	Y-791195,73-B																													
9	Y-791438,54	9			17	13			15			23			11								7	24					16	
Diogenites (monomict, except Y-791200)																														
1	ALH 77256,96-a	23	13		20			16									29				6	8	29							
	ALH 77256,96-b		17					7									22	21		25		6								
2	LAP 91900,26		35					15								8					14	18			8					
3	NWA 1461-A							11				11								14							30	14		8
	NWA 1461-B							9				20		12				14		27		8	12					11		
4	NWA 4283		31														16				14									
5	Y-75032,90	13			33			10						11				7		16			6							
6	Y-791200,86		32		13		29											6		8			6	16	9					

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.
Colors indicate severity of uncertainty (blue, moderate; purple, high; yellow, >25%; yellow with red font, >30%), on a scale that, for blue and purple, varies from element to element.

Table EA-4.2. Notably high uncertainies associated with compositional results (Tables 2 and EA-2) for19 elements in 31 polymict eucrites.

	Sample*	K	Ni	Zn	Ga	Ge	As	Br	Sr	Zr	Cd	Ba	Ce	Nd	Tb	Dy	Ho	Hf	Ta	Re	Os	Ir	Au	Th	U
		% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.	% rel.
1	ALH 78132,99		33					33	16	30			6	13		25	9		5					7	
	ALH 78132,102		36					17	28						5				9					7	
2	A-9029	11	11		18			2	17	24		15		8		13			5					5	10
3	Bialystok	6	12		11		10		10			32		7					9			see note^		20	6
4	Dar al Gani 391	7	6					20	8	10		9				25									7
	Dar al Gani 411		14		17		32		13	11		9		9			7					18			
5	EET 79005,93				23				11	18		14		7		25	13		5					5	
	EET 79005,95								11	19	19	21		5		29	15		5						
6	EET 82600,2-A		33					6	9	17		32		6			9						34		16
	EET 82600,2-B		22					30	8	30		30					15						22		22
	EET 82600,7		11		20			30		11		19		8		25						20			11
7	EET 92023,9-a	8			21			34	15				11				15		12					12	
	EET 92023,9-b	8			12		13	11	6			25	5	12				7	18					6	
8	FRO 97045,23	6	20		22				6	20		9					10								
9	Igdi-A				21		16	6		9		3				13						9	30		
	Igdi-B	6	14					39	14	8		8	5	7		22			5			22			13
10	LEW 85303,90	7	7						16	11		19		8					5			10	26	6	9
	LEW 85303,94	6							16			10		7		29							9		11
11	LEW 87004,14									21		22				23	19								
	LEW 87004,19									6	12	27		6		22	14		5					5	
12	LEW 87026,7				20					25		30													
13	LEW 87295,7								14	25		25		10		27	13		7					6	
	LEW 87295,8			17	30			7		28					5		10		11			11	12	15	
14	LEW 88005,19	9		6					12	29		28		15			12							9	
15	Macibini	14	12				15	8	25	25							9					33	26		
16	PCA 82502,85	12			28			9	11	12		20		11										5	
	PCA 82502,86	8	28		19				16	32		18		29			16							7	
17	PCA 91007,4	7			33			36	16	22				10		22	8		6					7	22
18	QUE 97004,7	14										19		8	5		11		13			17	17	7	
19	TIL 82403,30	6	34													30	15							5	
	TIL 82403,31	6			30			23	14			23	10	22			7							9	
20	Y-74159,79-a	8	32						24			15				22								6	
	Y-74159,79-b	8	40						32										6						
21	Y-74450,111		20		21			33		31			6	14		12						32		5	
22	Y-75015,88				18				16				6	11										5	
23	Y-790007,84				28			22		9			6											8	29
24	Y-790260,91		20		27			9	21	25						21	19							5	
25	Y-790266,102		23					31	25	20		32	6	15		14	22							8	
26	Y-791192,81-a	6		10				16	29				15		8			8	17						
	Y-791192,81-b				13			7	16				20	13			15		13		8			32	
27	Y-791826,57-A	10	32							15			6	16		15	22							5	
	Y-791826,57-B	17	34						12	22		10	5	7		25	16					33			
28	Y-793164,68-a	8							18							19	11							6	
	Y-793164,68-b	6	27		32		31	13	15	19						17	10							5	
29	Y-794002,60-A	10												16		21	8							7	
	Y-794002,60-B	7			14								6	20		29	18							6	
30	Y-82052,63	9	24		32				21	14		16		9		19	9							7	
31	Y-981651,65	6			34				14			14							8					27	

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.
Colors indicate severity of uncertainty (blue, moderate; purple, high; yellow, >25%; yellow with red font, >30%), on a scale that, for blue and purple, varies from element to element.
^ Bialystok results are anomalously high for Ir (Table 2) and especially Au; we suspect artificial contamination.

Table EA-4.3. Notably high uncertainties associated with compositional results (Tables 3 and EA-3) for 19 elements in 31 howardites.

	Sample*	K % rel.	Ni % rel.	Zn % rel.	Ga % rel.	Ge % rel.	As % rel.	Br % rel.	Sr % rel.	Zr % rel.	Cd % rel.	Ba % rel.	Ce % rel.	Nd % rel.	Tb % rel.	Dy % rel.	Ho % rel.	Yb % rel.	Hf % rel.	Ta % rel.	Re % rel.	Os % rel.	Ir % rel.	Au % rel.	Th % rel.	U % rel.
1	Chaves-a	6	7		35		28		21	25		30	20	12		18	11			10					9	
	Chaves-b	6	7		26		20	15	18	17				20		21				8					10	
	Chaves-c	8	10		31					31		23		10		15	12			7					11	
2	CRE 01400,10	9	7						13			35		7			8			6		8	21		7	
3	Dar al Gani 779								9	17				17			14						11		7	21
4	EET 96003,8		14		11				11	14		30					8						37		8	
5	EET 99408,7	9	8						7			20											23			14
6	GRO 95574,7	7								18		28		15						6			16	14	12	
7	GRO 95581,8	10							14					8			11			8			9	12	7	18
8	HaH 285¥	11		9			12	10	8	30				9			13			7			15	26	7	8
9	Hughes 004-A		30		18			20	12			21		13			6							17	7	
	Hughes 004-B	8			26			22	13	14		29		11										30	8	
10	Jodzie				9			9		18		11		8							9					
11	LEW 85313,32-a	12		11						22		25		13			9			10					13	30
	LEW 85313,32-b	14		10				24	11					16			11			14					10	
12	LEW 87002,7				30						9			25		15										
13	LEW 87005,8	8		23	33				20	16		26		13		26	9							10		27
14	MAC 02666,9	11							19	15		20		7			7					7		21		
14	Mässing	11			25			29	18			34		6						6			30			28
16	Melrose (b)	14	9		32		9	7	27					7			10						24	37		16
17	MET 00423,5	13							12	12		21		9			7							25		
18	MET 01087,6								14	15		25					9								7	
19	MET 96500,11		6		24				11	10				19			8						8	23		24
	MET 96500,12	9						11	12			17		7									7	23	7	
20	Muckera 002	6						14	14	8						29	6									
21	NWA 1182-A (light)																									
	NWA 1182-B (dark)																									
22	NWA 1282		7		13					29		8				29							17	30		18
23	Pavlovka	19			28			26	10	16		21		9						7			9	21	12	
24	PCA 02009,5^	20													17		15		14	21			11	12		
25	QUE 94200,21	9							22			18		11			8						9	24	9	
26	QUE 97001,8	11	8	11										11									30		10	
27	QUE 99033,11	13	8						22					16			10						26		8	
28	Y-7308,108	28	12		20				33					11			8			16					11	
29	Y-791573,83	9			21			9	20					8						10				7	7	13
30	Y-82049,65-A	14	6					24	19					18			10			7			7		11	
	Y-82049,65-B	7							20			37		8						6			14	30	12	
31	Zmenj	15			19				20								8	6		13			14		13	22

* In sample names, an ending of -A or -B designates analysis of separate chips; an ending of -a or -b designates replicate analyses of aliquots from a single powder.
Colors indicate severity of uncertainty (blue, moderate; purple, high; yellow, >25%; yellow with red font, >30%), on a scale that, for blue and purple, varies from element to element.
¥ Hammadah al Hamra 285
^ Although PCA02009 as a whole is a howardite, the chip we analyzed is a polymict but nearly pure diogenite.

Table EA-5. Bulk-rock compositional data (literature averages) for 22 elements in 10 howardites.

Meteorite	Na_2O wt%	MgO wt%	Al_2O_3 wt%	SiO_2 wt%	CaO wt%	MnO wt%	FeO wt%	Sc µg/g	Ti mg/g	V µg/g	Cr mg/g	Co µg/g	Ni µg/g	Ga µg/g	Sr µg/g	Ba µg/g	La µg/g	Sm µg/g	Eu µg/g	Lu µg/g	Hf µg/g	Ir ng/g
Bholgati	0.27	15.90	8.33	49.23	6.24	0.51	18.30	24.7	2.7	109	4.98	35.1	532	1.13		21.0	1.47	0.96	0.33	0.16	0.63	19
Bununu	0.33	14.29	8.50	48.67	7.09	0.51	19.34	26.0	3.1	86	4.1	33.9	456	1.2	44.2	18.5	1.75	1.09	0.38	0.17	0.82	19.7
Frankfort	0.19	20.19	4.62	50.38	3.66	0.53	17.39	19.4	1.6	117	7.1	21.7	80	0.6	24.5	12.0	1.29	0.79	0.24	0.13	0.91	3.8
Kapoeta	0.30	14.27	8.14	50.08	6.65	0.52	17.13	21.3	2.1	95	4.32	26.2	341	1.12	48	17.7	1.55	0.91	0.35	0.17	0.64	20.8
La Teilleul	0.22	17.07	6.97	50.37	5.62	0.52	17.77	21.3	1.8	106	6.2	23.5	179	0.9	39.3	13.4	1.40	0.86	0.31	0.15	0.66	3.4
Lohawat	0.30	15.42	7.97	50.91	6.65	0.55	18.40	22.2	2.9	92	5.01	12.4	217				2.18	1.3	0.40	0.21	0.93	
Malvern	0.38	12.22	9.93	49.18	8.00	0.51	19.00	27.1	2.8	91	4.0	30.3	345	1.3	59	22.0	2.25	1.26	0.37	0.18	0.90	17
Molteno	0.30	13.73	9.01	49.55	6.79	0.47	20.08	24.9	2.5	99	4.1	84.8	2860	1.1	76		2.29	1.14				31
Muckera 001	0.28	14.84	8.16	49.63	7.08	0.44	17.82		2.5				900									
Washougal	0.20	16.50	6.77	50.21	5.60	0.52	18.18	20.1	1.6	120	5.9	24.9	101	1.0	32.5	14.8	1.30	0.82	0.31	0.14	0.51	17

Data were compiled from sources too numerous to list in full, but include Chou et al. (1976), Mittlefehldt (1979), Jerome (1970), McCarthy et al. (1972), Schmitt et al. (1972), Palme et al. (1978), Mason et al. (1979), Dreibus et al. (1980) and Jarosewich (1990).

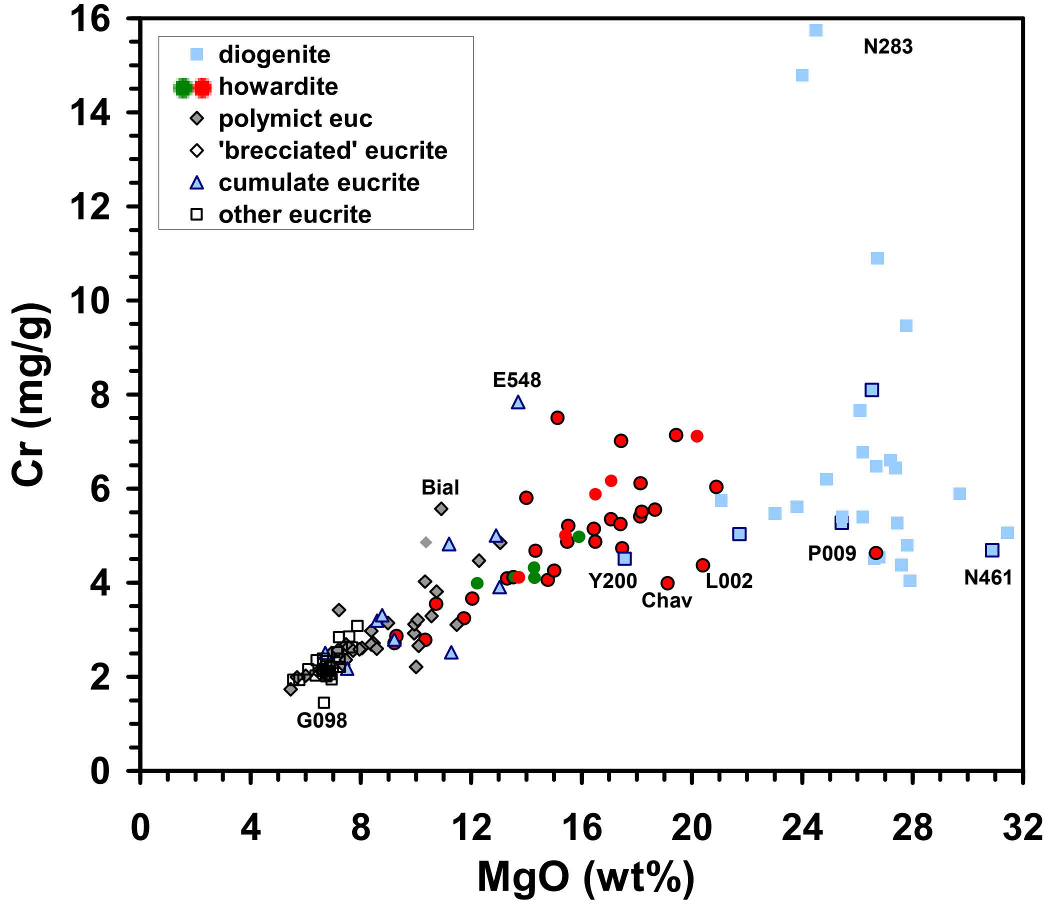

Fig. EA-1. The HED mixing trend: bulk-rock MgO vs. Cr. This diagram is largely analogous to MgO vs. V (Fig. 3a in the main paper).

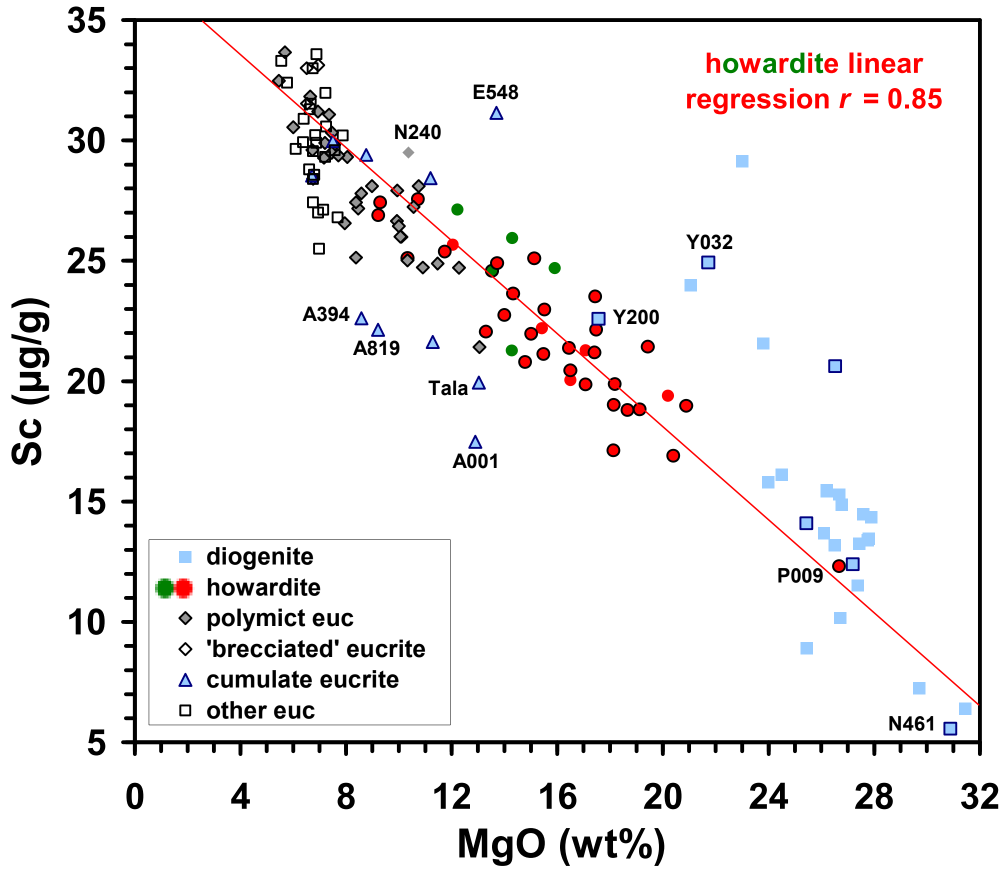

Fig. EA-2. The HED mixing trend: bulk-rock MgO vs. Sc. This diagram is largely the inverse of Al_2O_3 vs. Sc (Fig. 1a in the main paper). The regression line is based on all howardites excepting our atypical sample of PCA 02009. Note that magnesian diogenite NWA 1461 is exceptionally Sc-poor but nonetheless in line with the general trend of HED compositions.

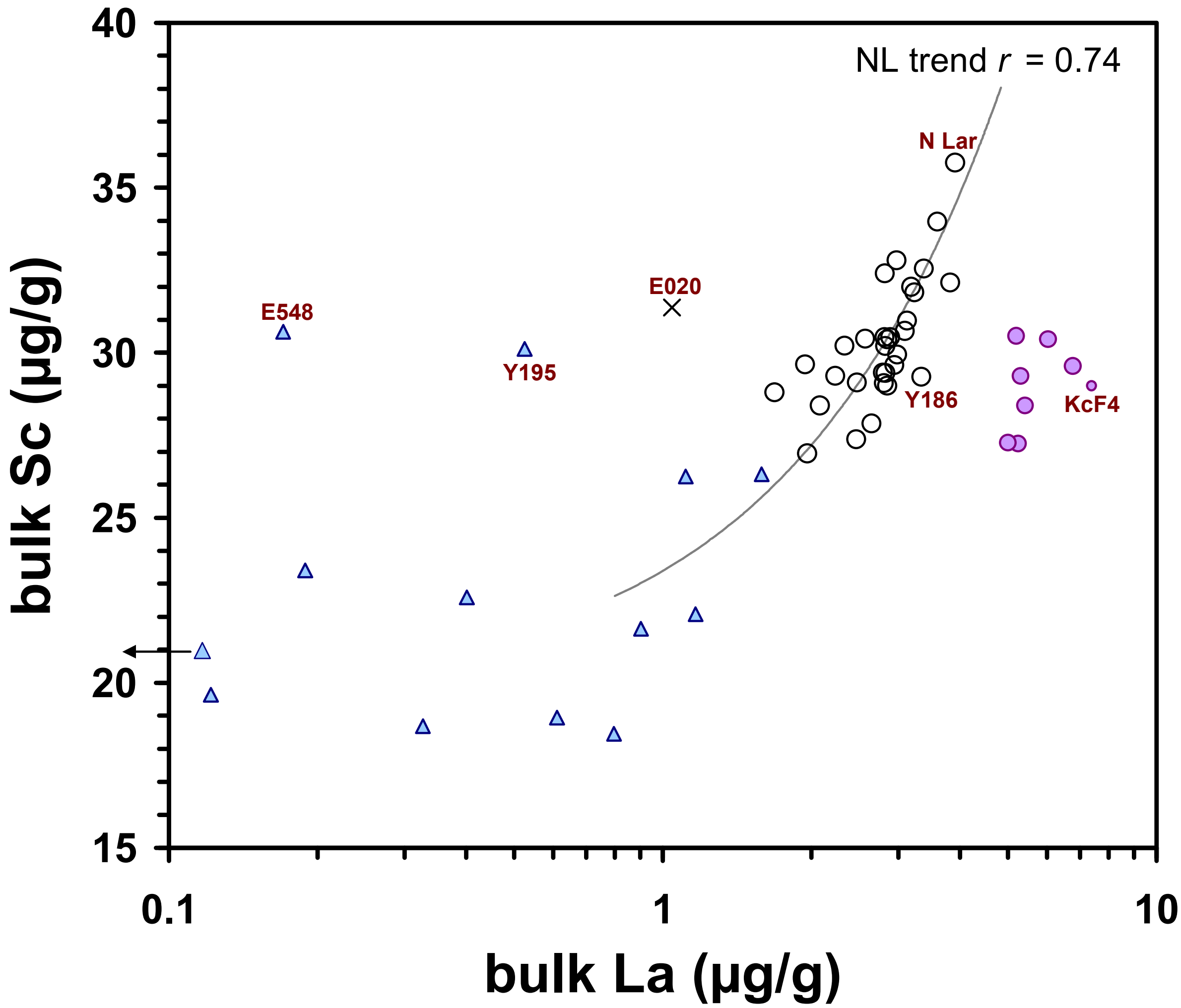

Fig. EA-3. The Nuevo Laredo trend: bulk-rock La vs. Sc for pristine-igneous (unbrecciated and monomict-brecciated) eucrites. This diagram, our update of one originally shown by Gardner and Mittlefehldt (2004), is useful for showing the distinction between the Nuevo Laredo trend (unfilled circles), of probable fractional crystallization origin (e.g., Warren and Jerde, 1987) and the other noncumulate eucrites, i.e., the Stannern trend (lavender-filled circles), which probably formed by partial melting. Cumulates are shown by blue-filled triangles. The noncumulate but complexly metamorphosed EET 90020 (Yamaguchi et al., 2001) is a eucrite that we assign to neither the Neuvo Laredo trend nor the Stannern trend. The plotted Stannern trend samples, in order of increasing La, are: Pomozdino (a partial cumulate), Stannern, LEW 88010, ALH 81001, PCA 82501, Bouvante, Bluewing 001, and (distinguished by smaller symbol) clast F4 from Kapoeta. Data are from literature sources too numerous to list here, but include Barrat et al. (2003; 2007) and Mittlefehldt and Lindstrom (1993; 2003); see Warren and Jerde (1987) for numerous citations of older literature.

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