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Iron meteorites from Antarctica: more specimens, still 40% ungrouped

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Clarke (1986) was the first to recognize that ungrouped irons are more common in Antarctica than in the regions where most irons have been collected; his conclusion was based on the first 21 irons collected in Antarctica. Wasson et al. (1989) reported compositional data for 24 Antarctic irons and reported that 8 were ungrouped; the ungrouped fraction of 0.33 was found to be about twice that (0.153) observed in irons from the remainder of the world. Wasson (1990) reported data for 7 additional Antarctic irons, and reported that 12 of 31 were ungrouped, a fraction of 0.39.

In Table 1 I summarize the data obtained to date on independent Antarctic iron meteorites by our UCLA neutron-activation laboratory. With about 5 exceptions, the listed values are the means of duplicate determinations. We have now analyzed 40 independent iron meteorites; in Table 2 I list 8 other irons that proved to be paired with meteorites listed in Table 1. Because of the close relationship between pallasites and iron meteorites, in Table 3 I also list our data for two Ant-arctic pallasites that were studied at UCLA. Our new results confirm the previously reached con-clusion about the abundance of ungrouped irons. In fact, the ungrouped fraction has increased slightly; of the 40 irons 16 are ungrouped, a fraction of 0.40. The two meteorites with pallasite structures are both small (≈50 g); one is ungrouped, the other a high-Ir anomalous member of the main-group pallasites (PMG).

The ultimate goal of a meteorite taxonomic system is to determine which meteorites formed in the same parent body. There is little doubt that the large magmatic groups IIAB, IIIAB and IVA are each from a single body, and no reason to believe that any other iron-meteorite groups could have formed in the same parent asteroids (even though IIIE is quite similar to IIIAB, it is compositionally resolvable).

Thus, one can hypothesize that we should expect irons from magmatic groups to have nearly constant Ga, Ge, Co and Cu, and inversely correlated Ir and Au; irons from nonmagmatic groups should have relatively small, correlated ranges of all siderophiles. To search for possible related duos or trios among the ungrouped Antarctic irons I sorted the data in terms of Ga, Au and Co. The only possible relationship that suggested itself was between LEW88023 and ALH84233, but even here most of the expected compositional trends are not present. As a result, I tentatively conclude that these two ungrouped irons originated on separate parent bodies.

The chief caveat is that some of the ungrouped irons are so small that they could be slugs from impact altered chondrites or subchondritic regoliths such as Bencubbin, rather than fragments of large (>10 m diameter) metallic magmas. The three smallest (ALH84233, LEW85369, LEW88023) have recovered masses of 8, 10 and 14 g and are all ungrouped. The next smallest, with a mass of 15 g, is classified IIE, but group IIE (a) shows more scatter than most other groups, and (b) may consist of melts generated by impacts onto chondritic asteroids (Wasson and Wang, 1986; Ruzicka et al., 1999)). If six small irons having masses ≤21 g are removed from the data set the fraction of ungrouped drops to 13/34 = 0.38.

Wasson et al. (1989) and Wasson (1990) examined possible mechanisms that could cause irons from Antarctica to have been more efficient at sampling "minor" asteroids than those from the temperate and subtropical latitudes where most iron meteorites have been collected.. As discussed in the latter work, the difference cannot be a latitudinal effect. Even though all Antarctic irons are collected at latitudes >71° whereas most other irons (630 of 660) were collected between 10 and 60°, primarily because of the 23.5° obliquity the Earth's spin axis, simulations show only minor latitudinal effects for a variety of meteoroid orbits (Halliday and Griffin, 1982).

Stochastic variations in meteoroid populations associated with differences in terrestrial ages are also implausible. There is no resolvable difference in terrestrial ages among the two sets of irons (Wasson, 1990).

The key difference seems to be the smaller size of many Antarctic irons. Wasson (1990) noted that the median mass of Antarctic irons of 300-400 g was 100X smaller than that of the nonAntarctic set. This median mass of Antarctic irons remains the same for this larger set if the smallest 1-3 irons are dropped from the list.

Probing further into the relationship between size and classification we discover that only 1 of the 6 Antarctic irons having masses >10 kg is ungrouped, and it (Lazarev) is the smallest of the set. Of the irons having masses in the range 30 g-10 kg, 12/28 (0.43) are ungrouped. Within this range there is no resolvable difference in the ungrouped fraction in sets based on logarithmic increments in mass.

Meteoroids travel from the Asteroid Belt to the Earth via two dominant escape routes: (a) the 3:1 period resonance with Jupiter, and (b) the v6 resonance of the variation of the orbital perihelion direction with that of Saturn. Meteoroids having orbits coincident with one or the other of these resonances are brought into Earth-crossing orbits within a short period of time. Recent work by Morbidelli and Gladman (1998) has shown that this transfer commonly occurs within ≈2 Ma, a factor of 5 shorter than had been indicated by earlier simulations.

Wasson (1990) pointed out that, compared to larger meteoroids, smaller objects are more efficiently transferred into orbits that are appreciably different from that of the parent asteroid. In other words, they tend to wander farther from home. It has long been understood that, during cratering events, the smaller the ejecta, the larger the mean ejection velocity. Thus, the probability that a small meteoroid can directly enter a resonance as a result of cratering ejection from the parent body increases as the size of the fragment decreases. Wasson (1990) also noted that the smaller the fragment, the larger the number of minor collisional events it will, on average, have experienced, and that these "jostling" events lead to a random walk of the orbital parameters away from those of the parent.

A suggested variant of this mechanism is that metallic meteoroids may be swept up by highly porous stony rubble piles. Thereafter the metal will be in an orbit similar to that possessed by the stony material, which can also lead to a random walk away from the parental orbit. A key question is the fraction of metallic meteoroids that would survive such collisions. It seems plausible that the closer the match between the size of the meteoroids and the mean size of the rubble clasts, the larger the fraction that would survive as a single piece.

In summary, the fraction of ungrouped irons in the set Of 40 independent irons from Antarctica is at least twice that of irons from the remainder of the world. The difference is attributed to the >100X smaller median size of the Antarctic irons. It is suggested that the parent-bodies of most ungrouped irons are in orbits far from orbital resonances that transfer meteoroids into Earth-crossing orbits within a few Ma. Independent of the parent-body orbit, the smaller the ejecta fragment, the higher the probability that it can reach a resonance. Thus the smaller the mean size of the collected meteorite, the larger the probability of sampling parent bodies in orbits far removed from the resonances.

Acknowledgements

I am indebted to several key colleagues for the reported INAA data, particularly F. Ulff-Møller, B.-G. Choi, E. A. Jerde and J. W. Richardson. I thank those who provided samples. The majority were provided by the U. S. Meteorite Working group, with most of the bur-den falling on R. S. Clarke. Important samples were also received from H. Kojima, K. Yanai, T. McCoy and L. Schultz. This research was supported in part by NASA grant NAG5-4568

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Appendix: The pairing of Lewis Cliff irons LEW87109 and LEW88631 with LEW85369.

Three tiny slugs of metal from the Lewis Cliff collection site were found to be closely related and should be paired. The total mass involved in these three specimens is only 10 g. The data for these three irons are listed in Tables 1 and 2. The range of compositions is larger than commonly observed within adjacent samples of the iron meteorite groups, but the trends are consistent with those expected for heterogeneous sampling of coexisting kamacite and taenite. Most elements have taenite/kamacite ratios in the range 2 to 5, but Co and As have a greater affinity for kamacite than taenite. Thus, even though Ni, Ir and Au are higher by factors of 1.1 to 1.6 in LEW85369 than in LEW88631, we find it indicative of a close genetic relationship among these three that LEW87109 has an intermediate composition, and that Co and As are higher by factors of 1.05-1.08 in LEW88631 than in LEW85369. The Co in LEW87109 is again intermediate, the As is the same as that in LEW88631 to within experimental uncertainty.

The other paired irons listed in Table 2 have been discussed in earlier papers by our team.

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Table 1. Compositional data for 40 independent Antarctic iron meteorites.

meteorite	mass kg	Cr µg/g	Co mg/g	Ni mg/g	Cu µg/g	Ga µg/g	Ge µg/g	As µg/g	Sb ng/g	W ng/g	Ir µg/g	Pt µg/g	Au µg/g	group
AllanHil ALH84165	0.095	118	5.03	80.6	178	20.1	40.0	4.21	20.0	1.09	3.49	12.9	0.646	IIIAB
AllanHil ALH84233	0.014	12	5.39	64.6	168	14.0	63.0	14.4	273	0.99	<0.003	<0.7	1.040	ungr
AllanHil ALHA76002	19.7	46	4.43	67.6	152	89.2	410	10.8	280	1.33	2.57		1.515	IAB
AllanHil ALHA77255	0.76	418	5.72	122.6	10	0.083	0.058	0.292	<150	1.23	10.0		0.071	ungr
AllanHil ALHA77283	10.5	23	4.87	72.8	145	81.1	320	15.2	399	1.06	2.16	7.0	1.707	IAB
AllanHil ALHA78100	17.8	43	4.38	55.0	136	60.0	182	4.08	52	4.03	27.0		0.544	IIAB
AllanHil ALHA78252	2.79	112	4.05	95.0	154	2.44	0.138	13.3	6.3	0.46	0.374		2.536	IVA
AllanHil ALHA80104	0.882	8	6.81	156.0	299	5.80	10.2	26.1	567	0.41	0.080		2.660	ungr
AllanHil ALHA81014	0.188	69	5.40	108.0	94	7.53	1.52	6.05	10	1.26	3.64		1.110	ungr
DerrPeak DRP78001^	251	35	4.64	63.0	117	56.1	135	9.55	101	0.66	0.014		1.202	IIAB
ElephMor EET83230	0.530	13	4.48	164.0	492	1.34	0.075	13.4	7	0.22	0.105		2.660	ungr
ElephMor EET83245	0.059	22	4.79	60.4	118	55.4	157	9.70	86	0.74	0.026		1.070	IIAB-an
ElephMor EET83333	0.189	19	4.88	80.6	184	74.8	226	15.7	459	0.80	2.88	6.8	1.750	IAB
ElephMor EET83390	0.015	20	4.45	83.1	228	27.8	68.2	11.7	191	1.15	3.86	9.6	1.170	IIE
ElephMor EET84300	0.072	30	5.10	102.2	192	41.3	92.0	13.9	400	0.33	1.82	2.6	1.290	ungr
ElephMor EET87504*	0.041	46	5.29	208.6	1065	22.9	104	29.3	2752	0.39	3.01	8.0	1.957	IAB-an
ElephMor EET87516	0.036	340	4.86	93.1	185	1.71	2.66	6.08	18	0.82	6.24	10.0	0.909	ungr
ElephMor EET92029	2.43	18	5.06	82.2	123	23.8	82	10.1	<100	0.34	0.087	4.4	1.176	ungr
GrosvMtn GRO85201	1.40	67	5.15	84.7	146	20.0	42.3	7.41	68	0.57	0.359	6.2	1.010	IIIAB
GrosvMtn GRO95511	0.064	19	4.87	81.8	197	72.8		16.3	348	0.86	1.99	6.3	1.695	IAB
GrosvMtn GRO95522	0.962	21	5.14	79.4	159	21.2		7.42	<100	0.74	0.650	8.9	0.871	IIIAB
InlandForts ILD83500	2.52	29	9.46	174.5	338	19.3	47.9	11.4	122	0.71	7.15		1.580	ungr
Lazarev	10.0	76	6.93	96.4	226	15.2	24.0	8.94	81	0.90	3.94	10.5	1.020	ungr
LewisClif LEW85369	0.010	50	3.33	74.2	318	46.8	100	13.4	519	0.69	3.49	6.3	1.490	ungr
LewisClif LEW86211	0.163	796	5.41	87.7	463	34.6	280	14.3	350	2.50	31.6	33.9	1.418	ungr
LewisClif LEW86540	0.021	12	5.99	182.9	479	4.30	2.8	28.8	845	<60	0.04	<2.0	1.813	IIICD
LewisClif LEW88023	0.008	12	5.52	69.0	163	11.8	58.9	16.2	337	1.08	0.007	1.1	1.163	ungr
Mt. Wegener	3.48	125	4.99	75.9	158	19.3	38.1	4.27	34	1.01	3.64	11.2	0.614	IIIAB
MtHowe HOW88403	2.48	812	4.34	86.1	382	22.1	53.2	11.9	360	0.96	4.70	7.9	1.249	ungr
NeptuneMountains	1.07	23	4.72	72.0	148	78.2	269	14.4	315	0.91	2.20		1.620	IAB
PecoraEscr PCA91003	0.117	29	4.62	70.8	148	82.6	327	13.0	338	1.11	3.61	5.9	1.504	IAB
PurgPeak PGPA77006	19.1	25	4.69	71.6	148	79.4	284	14.5	426	0.96	2.16		1.579	IAB
ReckIPeak RKPA80226	0.160	23	4.88	82.6	173	67.6	255	17.0	450	0.90	2.06		1.740	IAB
ThielMtn TIL91725	0.091	209	4.70	79.3	98	73.6	234	12.7	429	1.02	3.67	6.2	1.529	IAB
WiscRng WIS91614	0.299	122	4.98	75.7	172	18.6		3.71	<100	1.19	7.910	14.6	0.580	IIIAB
Yamato Y75031	0.392	40	5.93	141.0	452	30.3	232	20.2	990	0.96	0.401	5.7	2.070	ungr
Yamato Y75105	0.020	46	4.87	59.1	132	58.2	170	4.30		2.11	2.50		0.700	IIAB
Yamato Y790517	0.190	36	5.44	70.7	118	19.8	47.0	8.03	55	0.69	0.523		0.924	ungr
Yamato Y790724	2.17	124	4.97	79.8	192	20.4	35.9	3.66	31	1.31	9.25		0.556	IIIAB
Yamato Y791694	0.071	<84	4.69	71.6	148	79.4	255	34.2	3980	<0.3	0.24		1.860	IAB

Analyzed specimens: *EET87506; ^DRPA78009.

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Table 2. Compositonal data for specimens of 8 Antarctic irons paired with meteorites listed in Table 1.

meteorite	specimen	group	Cr µg/g	Co mg/g	Ni mg/g	Cu µg/g	Ga µg/g	Ge µg/g	As µg/g	Sb ng/g	W µg/g	Ir µg/g	Pt µg/g	Au µg/g
ALHA76002p	ALHA77250	IAB	31	4.50	69.4	158	92.7	411	11.3	310	1.82	2.50		1.450
ALHA76002p	ALHA77290	IAB	123	4.45	69.7	165	91.9	423	11.3	320	1.55	2.49		1.460
ALHA76002p	ALHA77263	IAB	29	4.47	66.5	143	97.9		11.9	360	1.51	2.53		1.565
ALHA76002p	ALHA77289	IAB	32	4.57	66.6	145	96.8	408	12.2	242	1.55	2.72		1.510
ALHA78100p	ALHA81013	IIAB	85	4.45	54.8	147	58.3	192	3.86	39	3.74	30.8		0.532
LEW85369p	LEW87109	ungr	34	3.56	64.3	152	53.3		14.3		0.82	2.99	7.4	1.339
LEW85369p	LEW88631	ungr	59	3.61	60.2	165	47.4	135	14.1	290	0.73	2.18	5.2	1.316
Y75031p	Y791076	ungr	15	5.94	139.0	402	32.0	264	24.5	1200	1.17	0.393		2.280

Table 3. Compositional data on two Antarctic meteorites having pallasitic structures. The PCA specimen is an anomalous main group pallasite , the Yamato specimen is an ungrouped pallasite.

meteorite	group	mass kg	Cr µg/g	Co mg/g	Ni mg/g	Cu µg/g	Ga µg/g	Ge µg/g	As µg/g	Sb ng/g	W µg/g	Ir µg/g	Pt µg/g	Au µg/g
PecoraEscr PCA91004	PMG-ai	0.050	32	5.12	95.7	128	23.7	57.4	15.8	170	0.33	0.764	3.0	2.006
Yamato Y8451	Pungr	0.055	90	7.98	145.4	522	19.6	59.1	19.4	1169	1.49	6.87	16.6	2.102