TRACE ELEMENT CONTENTS OF SELECTED ANTARCTIC METEORITES-II: COMPARISON WITH NON-ANTARCTIC SPECIMENS

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Abstract: We used radiochemical neutron activation analysis to determine Ag, As, Au, Bi, Cd, Co, Cs, Cu, Ga, In, Rb, Sb, Se, Te, Tl and Zn in interior portions of 5 Antarctic meteorites—ALHA76004 (LL3), ALHA77081 (Acapulco-like), ALHA77219 (mesosiderite?), ALHA77307 (C3V), ALHA78113 (aubrite)—and Acapulco chondrite. Where comparison is possible, all data for these weathering type A and B ALH meteorites and for 4 others agree well with data for corresponding non-Antarctic meteorites. These agreements are at least as good as those involving only non-Antarctic L6 falls demonstrating that type A and at least some type B ALH meteorites provide compositional data yielding important genetic information. As an example, compositions of Acapulco-like chondrites differ from that of a forsterite (F) chondritic inclusion in Cumberland Falls. Therefore, at least two chondritic groups occupy the compositional gap between E and H chondrites.

1. Introduction

Recent discoveries of large numbers of Antarctic meteorites offer numerous research possibilities. The potential for uncovering samples of rare or previously unknown types is of particular interest and many such specimens have already turned up. These can be studied to obtain information on the origin and evolution of parent bodies in the early solar system provided that the meteorites are essentially uncompromised by weathering during their long terrestrial residence of $10\text{–}800\times10^3$ years (FIREMAN and NORRIS, 1981; EVANS *et al.*, 1981). While all compositional data yield valuable genetic information, elements present at ppm-ppt levels (*i.e.* trace elements) are particularly useful. Because of their low initial concentrations, even a small absolute compositional change induced by some genetic process will be magnified into

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a large relative one. Unfortunately, this very property helps make trace element contents susceptible to weathering, either contaminating a sample or leaching elements from it (LIPSCHUTZ, 1981).

As a first step to establish the degree to which Antarctic meteorites yield useful genetic information, BISWAS *et al.* (1980a) used radiochemical neutron activation analysis to determine 16 trace elements—Ag, As, Au, Bi, Cd, Co, Cs, Cu, Ga, In, Rb, Sb, Se, Te, Tl and Zn—in interior samples of 4 specimens and, for 2 of these, in exterior portions as well. [This list includes many elements known to be affected by weathering in non-Antarctic meteorites (cf. LIPSCHUTZ, 1981)]. Samples were chosen to include volatile-rich (H3 and L3 chondrites) and -poor (ureilite and shergottite) stony meteorites, *i.e.* those in which contamination or leaching should be detected most readily; only type A (*i.e.* the least weathered and fractured) samples were studied (MARVIN and MASON, 1980). In a subsequent trace element study dealing with the genesis of enstatite meteorites, we included an Antarctic achondrite (aubrite) in a suite of other aubrites (BISWAS *et al.*, 1980b). Our results indicate that while Antarctic weathering had altered sample exteriors, compositional data for interior portions generally fell within corresponding ranges for analogous non-Antarctic falls; some results fell outside those ranges (BISWAS *et al.*, 1980a, b).

We interpreted these results as indicating that interior samples of type A Antarctic meteorites are compositionally as pristine as non-Antarctic falls so that all data can be used to gain genetic information on the meteorites' parent bodies. It is, of course, conceivable that data from this limited number of Antarctic samples are affected in some subtle way by weathering; this should be recognizable if the data base is expanded to include representatives of additional meteoritic groups. Here, we report results for the 16 elements listed above, in 5 Antarctic meteorites from Allan Hills (ALH) and a previously unique non-Antarctic chondrite apparently related to one of these. We discuss these data with reference to mean composition in non-Antarctic falls.

2. Experimental

All Antarctic meteorite samples came from regions at least 0.5 cm from the nearest surface of the specimen; we obtained all from the Curatorial Facility at the NASA Johnson Space Center. Meteoritic classifications and weathering/fracturing information on the samples studied are listed in Table 1 (Antarctic Meteorite Newsletter by SCORE *et al.*, 1981). ALHA77081, a unique chondrite, is noted by MASON as "identical in mineral composition and structure to Acapulco, a recent Mexican fall" (Antarctic Meteorite Newsletter by SCORE *et al.*, 1981). We had previously obtained an Acapulco sample from Drs. CHRISTOPHE MICHEL-LÉVY and LORIN of the Université Pierre et Marie Curie (Paris); we report its analysis here because of its resemblance to ALHA77081 (Table 1). We also list data for ALHA78113 and compositional means for aubrites studied by BISWAS *et al.* (1980b) since that investigation did not compare

Table 1. Trace element contents of Antarctic and related meteorites.

Sample, type	Weath./ Fract.	Ag ppb	As ppm	Au ppb	Bi ppb	Cd ppb	Co ppm	Cs ppb	Cu ppm	Ga ppm	In ppb	Rb ppb	Sb ppb	Se ppm	Te ppm	Tl ppb	Zn ppm
ALHA76004, 1 LL3	A/A	67.3	2.39	—	153	9.30	442	197	840	5.22	15.5	2940	240	10.5	1.20	17.5	55.8
Mean*1 LL3	—	180	1.1	160	27	38	500	170	100	5.0	27	2400	97	11	0.36	24	52
ALHA77081, 14 unique chondrite	B/A	82.8	4.79	188	—	3.27	745	1.65	39.1	10.6	0.78	473	56	9.86	1.03	2.93	219
Acapulco unique chondrite	—	51.0	2.85	244	27.1	13.6	941	0.94	79.8	11.7	3.75	236	85	5.45	1.13	19.7	198
ALHA77219, 36 mesosiderite?	B/B	19.9	4.34	304	151	1.41	566	0.99	156	4.62	0.14	34.3	150	2.45	0.67	0.16	0.914
ALHA77307, 21 C3V	A/A	101	4.25	166	46.1	249	630	97.2	83.6	4.81	25.8	1550	82	8.74	1.03	49.3	122
Mean*2 C3V	—	110	1.8	160	50	300	620	83	110	6.4	33.3	1200	95	8.8	1.1	56	110
ALHA78113, 15 aubrite	A-B/A	8.4	0.034	2.18	≤0.83	0.25	6.22	44.0	41.3	0.10	0.32± 0.03	372	4.8	1.12	0.059	0.08± 0.03	2.04
Mean*3 aubrite	—	26	0.074	—	1.1	5.1	2.6	88	15	0.055	0.47	590	—	3.8	0.040	3.2	1.7

*1 Data from BINZ *et al.* (1976) and references listed therein.

*2 Data for As, Co, Cu, Ga from references in MASON (1979). All other data from TAKAHASHI *et al.* (1978) and references listed therein.

*3 Data from BISWAS *et al.* (1980b).

results for the Antarctic aubrite with others.

We irradiated all samples for neutron activation in the University of Missouri research reactor under conditions listed by BISWAS *et al.* (1980a). We processed all samples chemically using techniques established in previous studies to determine the 16 elements listed earlier and counted all samples as in those studies and BISWAS *et al.* (1980a). That paper includes all pertinent references.

3. Results and Discussion

We list data in Table 1 for 16 trace elements in 5 Antarctic meteorites—ALHA-76004 (LL3), ALHA77081 (Acapulco-like chondrite), ALHA77219 (a possible mesosiderite), ALHA77307 (C3V chondrite) and ALHA78113 (aubrite)—and Acapulco. Specific note should be taken of the fact that at least 2 Antarctic samples in Table 1 are of weathering type B. The classification of one of these, ALHA77219, is uncertain and there are too few prior data for mesosiderites to list, even for comparison. There are substantial bodies of data for each element studied in LL3 chondrites (cf. BINZ *et al.* (1976) and references therein), C3V chondrites (cf. TAKAHASHI *et al.* (1978) and references therein; MASON, 1979) and aubrites (BISWAS *et al.*, 1980b). We used these to calculate group means, most of which derive from data exhibiting substantial compositional variability in a given population. We therefore list the means in Table 1 to two significant figures.

Most data for ALH meteorites in Table 1 correspond well with corresponding contents in non-Antarctic meteorites. To quantify this statement we assumed a power law relationship between elemental concentrations in an ALH meteorite (denoted as M_1) and the corresponding non-Antarctic meteorite or group (M_2), *i.e.*

$$M_1 = bM_2^{m}, \tag{1}$$

where m and b would be the slope and y-intercept, respectively, on a log-log plot. The coefficient of simple correlation, r, is a measure of the degree to which the two data sets agree. We illustrate the comparison between ALHA77307 and non-Antarctic C3V chondrites (Table 1) in Fig. 1. As can be seen, the agreement is excellent ($r=0.996$) indicating that Antarctic weathering effects in ALHA77307 are virtually, probably completely, nonexistent.

It is possible to make analogous comparisons for most Antarctic meteorites studied thus far (*i.e.* all but ALHA77219). For this we used data from: Table 1 (and references included in it); Antarctic meteorites studied by BISWAS *et al.* (1980a, b) and MCSWEEN *et al.* (1979); non-Antarctic meteorites studied by LAUL *et al.* (1972), BINZ *et al.* (1974, 1975, 1976) and references cited in these papers. [Due to a typographical error, Tl data listed by BISWAS *et al.* (1980a) should have units of ppb, not ppm as listed in their Table 1.] The comparisons yield coefficients of simple correlation ranging from 0.932 to 0.996 (Table 2).

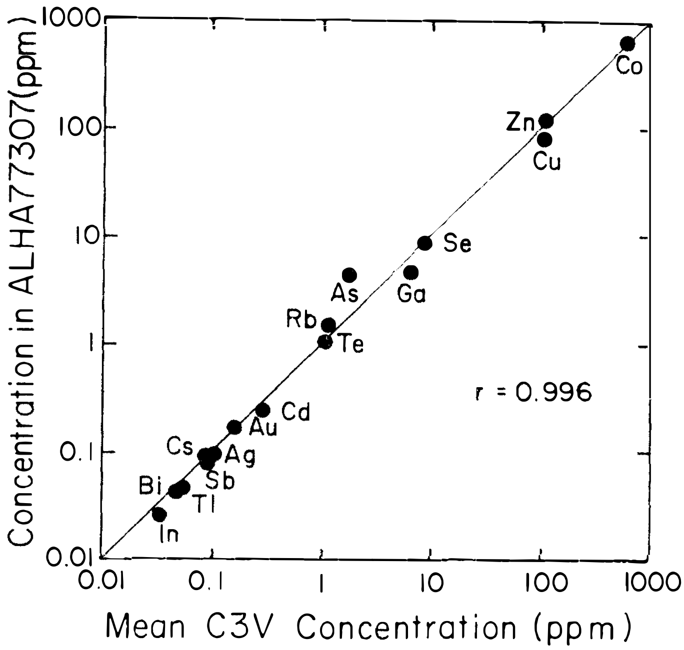

Fig. 1. Relationship between data for 15 elements in ALHA77307 and in non-Antarctic C3V chondrite falls. The data are in excellent agreement as demonstrated both by their accord with a line having 45° slope and by the high value for r, the coefficient of simple correlation. Apparently, ALHA77307, a find, is no more altered by terrestrial weathering than C3V falls.

Table 2. Compositional comparison of Antarctic and other meteorites.

Meteorites	No. of elements	Correlation coefficients
ALHA76004/LL-unequilibrated	16	0.965
ALHA77005/shergottites	12	0.957
ALHA77081/Acapulco	15	0.983
ALHA77257/ureilites	9	0.985
ALHA77278/L-unequilibrated	16	0.943
ALHA77299/H-unequilibrated	15	0.989
ALHA77307/C3V	16	0.996
ALHA78113/aubrites	14	0.932
Holbrook/Tathlith	14	0.960
Ramsdorf/Tathlith	14	0.892

To put these results into perspective, we include in Table 2 comparisons involving data for 3 non-Antarctic L6 chondrite falls from a study of preterrestrial shock on trace element retention (WALSH and LIPSCHUTZ, in preparation). The shock histories of these vary; Tathlith being virtually unshocked, Holbrook mildly shocked to pressures ~20 GPa and Ramsdorf very heavily shocked at ~60 GPa (STÖFFLER, 1972; DODD and JAROSEWICH, 1979). Compositionally, Tathlith and Holbrook are very similar and Tathlith and Ramsdorf are very dissimilar (WALSH and LIPSCHUTZ, in preparation), hence the r values of 0.960 and 0.892, respectively (Table 2). In 5 of 8 comparisons between Antarctic meteorites and non-Antarctic falls, r values exceed that for a pair of non-Antarctic falls *chosen* because of their compositional similarity. In all 8 cases in Table 2, r values exceed that for a pair of non-Antarctic falls of identical chemical and petrologic type, differing only in shock history and, therefore, compositionally (WALSH and LIPSCHUTZ, in preparation). Thus, to the extent that Tathlith, Holbrook and Ramsdorf can be taken as representative, randomly-selected, non-Antarctic falls, *interior portions of relatively unweathered Antarctic meteorites are compositionally at least as similar to such falls as are the falls themselves.* Hence, terrestrial weathering has not affected interiors of type A and at least some B meteorites to a measurable extent.

We discussed the genetic implications of some of our data previously (MCSWEEN *et al.*, 1979; BISWAS *et al.*, 1980a, b) and we plan to consider the unequilibrated ordinary chondrites in context with data for gas-rich meteorites (BISWAS *et al.* (1981) in preparation). Here, we will consider only the data for Acapulco and ALHA77081. In addition to strong mineralogic similarities, both chondrites have similar cosmic ray exposure ages and contents of trapped and radiogenic gas (CHRISTOPHE MICHEL-LÉVY *et al.*, 1979). Concentrations of 7 lithophiles, Ga and Se are quite comparable but the chondrites differ in their contents of 8 major and refractory siderophilic elements (CHRISTOPHE MICHEL-LÉVY *et al.*, 1979). Our data for As, Au, Co, Ga, Se and Zn in Acapulco and ALHA77081 (Table 1) are in very good agreement with corresponding values of CHRISTOPHE MICHEL-LÉVY *et al.* (1979). For the 15 elements for which comparison is possible, our data for Acapulco and ALHA77081 (Table 1) indicate strong similarities with $r=0.983$ (Table 2); only Cd, Cu, In and Tl differ by factors ≥ 2. The similarity in contents of mobile elements is all the more striking in the light of compositional variations in ordinary chondrites of any given petrologic type where differences of 10–100× are often encountered (cf. WALSH and LIPSCHUTZ (in preparation) and references cited therein).

On the basis of mineralogic properties, CHRISTOPHE MICHEL-LÉVY *et al.* (1979) noted that Acapulco and ALHA77081 seem intermediate between E and H chondritic groups and linked these 2 chondrites to forsterite (F) chondrites. Recent experiments uncovered a primitive petrologic suite of F chondrites as inclusions in the Cumberland Falls aubrite (NEAL and LIPSCHUTZ, 1981). Trace element data are available for one such inclusion (BISWAS *et al.*, 1980b) and these differ markedly from those for Acapulco and ALHA77081. The inclusion in Cumberland Falls contains 100–200× more Cs and 10× more Rb than do the 2 chondrites while they contain 2–10× more As, Bi, Co, Ga and In, 10–40× more Tl and 25× more Zn. These cannot be explained by evolutionary differences experienced by common source material. CHRISTOPHE MICHEL-LÉVY *et al.* (1979) deduce equilibration temperatures ~1200°C for Acapulco and ALHA77081 while chondritic inclusions in Cumberland Falls apparently formed at significantly lower temperatures (NEAL and LIPSCHUTZ, 1981). If Acapulco and ALHA-77081 and F chondrites in Cumberland Falls derive from a common source, Acapulco and ALHA77081 should be strongly depleted in mobile elements and perhaps siderophiles like As or Co and enriched in lithophiles. The opposite is observed, indicating that Acapulco and ALHA77081 and F chondrites derive from different source materials.

4. Conclusions

Comparison of our data for 16 trace elements in interior portions of 8 ALH meteorites of various sorts and in similar non-Antarctic meteorites indicate that weathering type A and at least some type B meteorites have not been altered significantly during ALH meteorites' long terrestrial residence. With proper precautions, data obtained from Antarctic specimens are as reliable as those determined from non-Antarctic falls. Thus, Antarctic meteorites promise to be a rich resource for studying the genesis of meteorites and their parent bodies. As an example, chemical dissimilarities between primitive F chondrites and ALHA77081 and its congener, Acapulco, demonstrate the existence of at least 2 chondritic groups in the gap between E and H chondrites. Doubtless, additional surprises await us in Antarctic meteorites.

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