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On Volatile Element Trends in Gas-Rich Meteorites

(NASA-CR-157837) ON VOLATILE ELEMENT TRENDS IN GAS-RICH METEORITES (Purdue Univ.) 18 p HC A02/MF A01 CSCL 03B

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Abstract - Study of 10 volatile elements (and non-volatile Co) in co-existing light and dark portions of 5 gas-rich chondrites indicates patterns of distinct but non-uniform enrichment by dark admixing material (DAM). DAM is enriched in Cs; Bi and Tl covary in it. It is compositionally unique from known types of primitive materials and is apparently not derived by secondary processes from such materials.

INTRODUCTION

Gas-rich meteorites exhibit unusual features of genetic interest in addition to the ones encountered in otherwise - similar chondrites and achondrites containing "normal" gas amounts and composition. From the major element standpoint, these meteorites consist of compositionally - similar light and dark portions in sharply - defined contact; large differences for some major elements are seen in achondrites and more subtle ones in the chondrites (Müller and Zähringer, 1966). In some instances, clasts of distinctly different composition are present (e.g. Schultz and Signer, 1977) cf. Motylewski, 1978) so that the breccia is more obviously polymict than monomict. Numerous studies (e.g. Schultz and Signer, 1977) demonstrate that the large amounts of trapped gas present in the dark portions of such meteorites was introduced during exposure of fine-grained regolithic material to corpuscular radiation on the surface of parent bodies. This portion, possibly light material darkened during irradiation, was then compacted with unirradiated light material and subsequently ejected as meteoroids by impacts (Ashworth and Barber, 1976) on parent bodies (e.g. Schultz and Signer, 1977 and studies cited therein).

The gas-containing portions of such meteorites apparently acquired their dark color by admixture of volatile-rich dust. The nearly-ubiquitous C- enrichment in such meteorites (e.g. Müller and Zähringer, 1966; cf. Begemann and Heinzinger, 1969) and very scattered data for a few volatile trace elements led Müller and Zähringer (1966) and Mazor and Anders (1967) to suggest that the adulterant dark admixing material (DAM) was carbonaceous chondrite-like, in at least one howardite, Jodzie. From additional trace element data, Hertogen *et al*. (1978) re-stated this conclusion for Jcdzie but suggested that several meteoritic classes constituted DAM in the Kapoeta howardite while DAM in the Khor Temiki aubrite was E-chondrite dust. On the other hand, the He, B, C and In enrichment pattern mis-match for five H-group chondrites with Murray (C2) led Rieder and Wänke (1969) to state that DAM could be carbonaceous chondrite only if unreasonable fractionation processes are invoked.

To study this question further we determined volatile Ag, Ga, Se, Cs, Te, Zn, Cd, Bi, Tl and In (and non-volatile Co) in co-existing light and dark portions of five gas-rich chondrites. These ten volatile elements are known to be uniformly depleted in carbonaceous chondrites (relative to C1 chondrites) and have characteristic abundance patterns in primitive ordinary and enstatite chondrites (cf. Binz *et al*., 1974, 1976). Thus, their relative enrichment patterns in the dark/light portions of gas-rich meteorites should "fingerprint" the nature of DAM in these chondrites.

Experimental

We chipped samples from co-existing light and dark portions of the H4 chondrites Tysnes Island (Me 1719) and Weston (2419 L1), the H5 chondrites Cangas de Onis (987M) and Leighton (Me 768) and the LL6 chondrite St. Mesmin (368); regions sampled seemed free of obvious clasts. The dark portions of the chondrites obtained from the Field Museum of Natural History (Tysnes Island and Leighton) were considerably darker than corresponding portions of the three obtained from the Muséum National d'Histoire Naturelle in Paris. All samples were irradiated in the CP5 reactor, processed chemically and counted as described by Ikramuddin *et al*. (1976); chemical yields were at least as high as reported there. In that study and subsequent ones by several members of our group, replicate analyses of homogeneous chondrite powders yielded estimated relative standard deviations from the mean of <10%, typically 3-5%. We assume these precisions to hold in this study since they represent the limitations of our techniques at the ppm-ppb level.

RESULTS AND DISCUSSION

There exist few published data with which our results (Table 1) can be compared. The Te estimates of Clark et al. (1967) for Leighton are so uncertain that little can be made of their being considerably higher than our own. Published Ga data for the light and dark portions of Leighton, Tysnes Island and Weston are systematically lower than ours (Table 1) by 0-30% (Rieder and Wänke, 1969). We have no reason to doubt our data but, as we show below, the systematic difference is unimportant since dark/light Ga patterns for these chondrites in our study and that of Rieder and Wänke (1969) are identical. Indium is another matter. In three cases (Leighton dark, Tysnes Island dark and Weston light) our data (Table 1) and those of Rieder and Wänke (1969) agree well. However, their data for Leighton light and Weston dark are factors of 18 and 2, respectively, higher than ours while our datum for Tysnes Island light is 33 times theirs; we cannot reconcile this difference. We note however that Rieder and Wänke's datum for Leighton light falls outside the range reported for In in H5-6 chondrites while our result is within the range in H3-4 chondrites (cf. Binz et al., 1976). Fortunately, our conclusions are unaffected by these discrepancies.

The tabulated data for 11 elements in 5 gas-rich chondrites reveal numerous instances of significant volatile enrichment by DAM. [In view of the experimental precision established for our techniques, we take a 10% enrichment or depletion in dark relative to co-existing light material as signaling significant differences.] Only Cs is enriched in all cases; other elements are enriched in dark portions of some meteorites while being depleted in others (e.g. Tl) or are uniformly concentrated in both portions (e.g. Te). Furthermore, in no case are <u>all</u> volatile elements enriched in the dark portion of a given meteorite. Tysnes Island and Leighton exhibit the largest degree and number of such enrichments but two elements in each are exceptions: In in Tysnes Island is significantly depleted while Cd in that meteorite and Ga and Se in Leighton are uniform (as is Co which, being non-volatile, is present in equal concentration in both portions of all chondrites studied here).

The data of Table 1 are depicted in Fig. 1 in the usual manner (e.g. Rieder and Wänke, 1969; Hertogen *et al.*, 1978), i.e. as the (dark-light) atomic abundance relative to that in Cl chondrites. Rieder and Wänke's observation is confirmed by additional data: volatile elements are not enriched by addition of DAM similar in composition to carbonaceous chondrites since the 10 volatile elements are not enriched to an equal extent in any chondrite. For example, while Cs and In in Leighton are at near-Cl levels, Ga, Se and Cd are a hundred-fold less (fig. 1). The other chondrites exhibit similar trends.

We attemped to match the observed enrichment patterns to those of E4 and unequilibrated ordinary chondrites (Binz *et al.*, 1974, 1976) and ureilites, which also seem to reflect admixture by a volatile-rich component (Binz *et al.*, 1975); no suitable match was found in any case. The compositions of all light and dark portions as well as the DAM enrichments (Table 1, Fig.1) do not correspond to those of "mysterite," hypothesized late nebular condensates (Higuchi et al., 1977). In short, we are unable to identify any known meteorite or meteoritic constituent with compositions similar to those of either part of light-dark chondrites or DAM.

There is no evidence that the DAM composition is a unique one. Table 2 summarizes all enrichment/uniformity/depletion trends for the 10 volatile elements studied here in all gas-rich meteorites for which data are available. In seven instances, duplicate sets of results exist and, except for In in Tysnes Island, all duplicate data - sets agree. All elements are enriched in the dark portion of at least two meteorites; Cs is the only element of those studied here which is enriched in the dark-portion of all gas-rich chondrites (Table 2).

Apart from the prominence of the Cs - enrichment, no DAM feature in any chondrite is reproduced in another (Fig. 1). Leighton and, to a lesser extent, Tysnes Island (the chondrites with the most pronounced dark portion) are richest in volatiles; thus, as noted for C (Begemann and Heinzinger, 1969) darkening and volatile-enrichment go hand-in-hand.

While we recognize that DAM may not be a single constituent in all meteorites we treated it as such to determine whether any pairs of elements correlate significantly in DAM from the chondrites we studied. A surprisingly large number of element-pairs exhibited high correlation coefficients but we could establish only four statistically-significant correlations in which DAM enrichments occur in at least four chondrites [Fisher's Z-transformation involves n-3 degrees of freedom.] The linear correlations of Cs with Bi and Tl ($r = 0.97$ and 0.99, respectively) are heavily-weighted by Leighton. Linear and exponential correlations of Bi and Tl ($r = 0.998$ and 0.996, respectively) seem well-established and indicate a coherent trend of slope 1.6 between these elements in DAM from all chondrites (Fig. 2). Measurement of these elements in additional meteorites should clarify whether additional elements, e. g. Ag, In, vary coherently in DAM.

CONCLUSIONS

In contradistinction from the situation in achondrites, DAM in gas-rich chondrites does not correspond compositionally to any known primitive meteorite. It is difficult to imagine a secondary fractionation process that could transform such a known composition to those observed in the dark portions of such chondrites. DAM is not compositionally constant but it is enriched in Cs; Bi and Tl (and perhaps other elements) covary in this material. While it is disappointing that DAM in gas-rich chondrites remains unidentified, it is exciting that such chondrites constitute a source for yet another and hitherto - unknown sort of primitive nebular material.

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Table 1. Trace element concentrations in coexisting light and dark portions of gas-rich chondrites.

Table 1.

Element	Tysnes Is. (H4) light	Tysnes Is. (H4) dark	Weston (H4) light	Weston (H4) dark	Cangas de Onis(H5) light	Cangas de Onis(H5) dark	Leighton (H5) light	Leighton (H5) dark	St. Mesmin (LL6) light	St. Mesmin (LL6) dark
Co (ppm)	775	696	799	848	791	888	836	824	394	388
Ag (ppb)	7.2	63	22	32	46	24	34	43	60	67
Ga (ppm)	6.37	7.59	5.70	5.90	6.44	6.83	6.25	6.36	5.58	5.57
Se (ppm)	6.13	8.59	7.62	8.17	9.22	8.46	8.38	8.00	8.26	8.73
Cs (ppb)	52.0	199	12.8	132	69.6	205	18.6	288	97.4	146
Te (ppb)	52.1	428	273	461	433	450	347	996	410	401
Zn (ppm)	36.7	51.9	50.4	49.1	39.5	52.5	41.6	53.0	62.0	58.8
Cd (ppb)	44.1	48.3	27.8	27.4	3.19	2.89	36.7	45.8	8.01	22.4
Bi (ppb)	1.85	32.9	1.30	20.1	0.87	8.19	1.35	95.9	15.9	4.79
Tl (ppb)	4.26	37.3	2.90	15.6	0.97	3.18	0.77	150	4.80	1.97
In (ppb)	46.2	19.6	0.99	7.99	0.05	2.38	0.89	170	8.18	1.60

Table 2. Truth table for volatile element enrichments in dark portion relative to light in gas-rich meteorites.

Elements*

Meteorite	Ag	Ga	Se	Cs	Te	Zn	Cd	Bi	Tl	In
Cangas de Onis	-	0	0	+	0	+	0	+	+	+
Fayetteville		0[b]	0[d]		+[c]	+[d]		+[d]	+[d]	+[b]
Jodzie			+[e]		+[e]	-[e]			+[e]	+[e]
Kapoeta					+[c]					
Krähenberg		-[a]		+[a]						-[a]
Leighton	+	0/0[b]	0	+	+/+[c]	+	+	+	+	+/+[b]
Pantar	0[f]							+[f]		
St. Mesmin	0	0	0	+	0	0	+	-	-	-
Tysnes Island	0	+/+[b]	+	+	+	+	0	+	+	-/+[b]
Weston	+	0/0[b]	0	+	+	0	0	+	+	+/+[b]

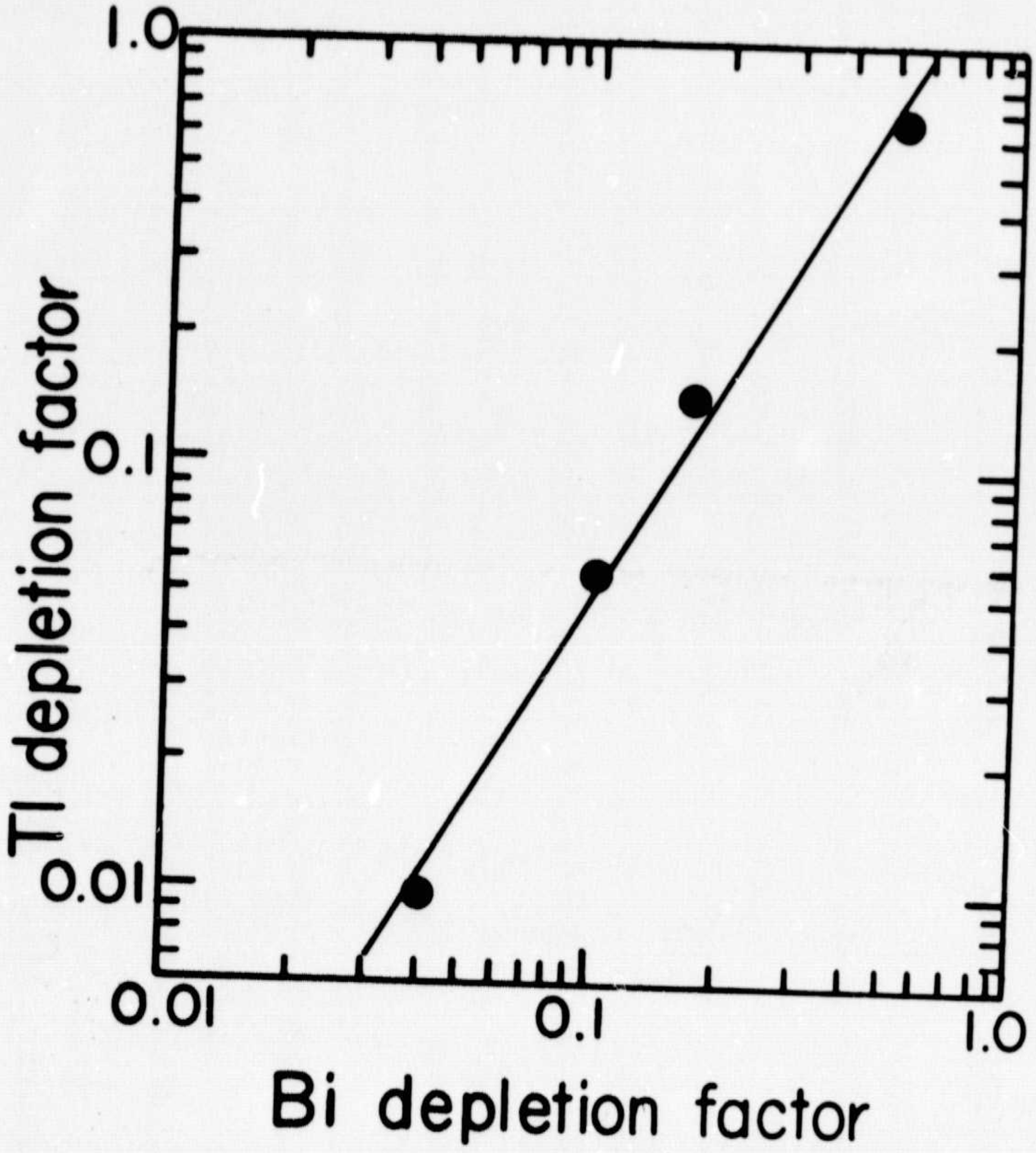
Note to Table 2.

* All entries determined from dark/light ratios: +, ratio >1.1; 0, ratio ≥0.90 but ≤1.1; -, ratio <0.90. All entries based upon results of this study and/or by others where noted: a-Kempe and Müller (1969); b-Rieder and Wänke (1969); c-Clark _et al_. (1967); d-Laul _et al_. (1970 a,b), Case _et al_. (1973); e-Hertogen _et al_. (1978);f-Reed (1963).

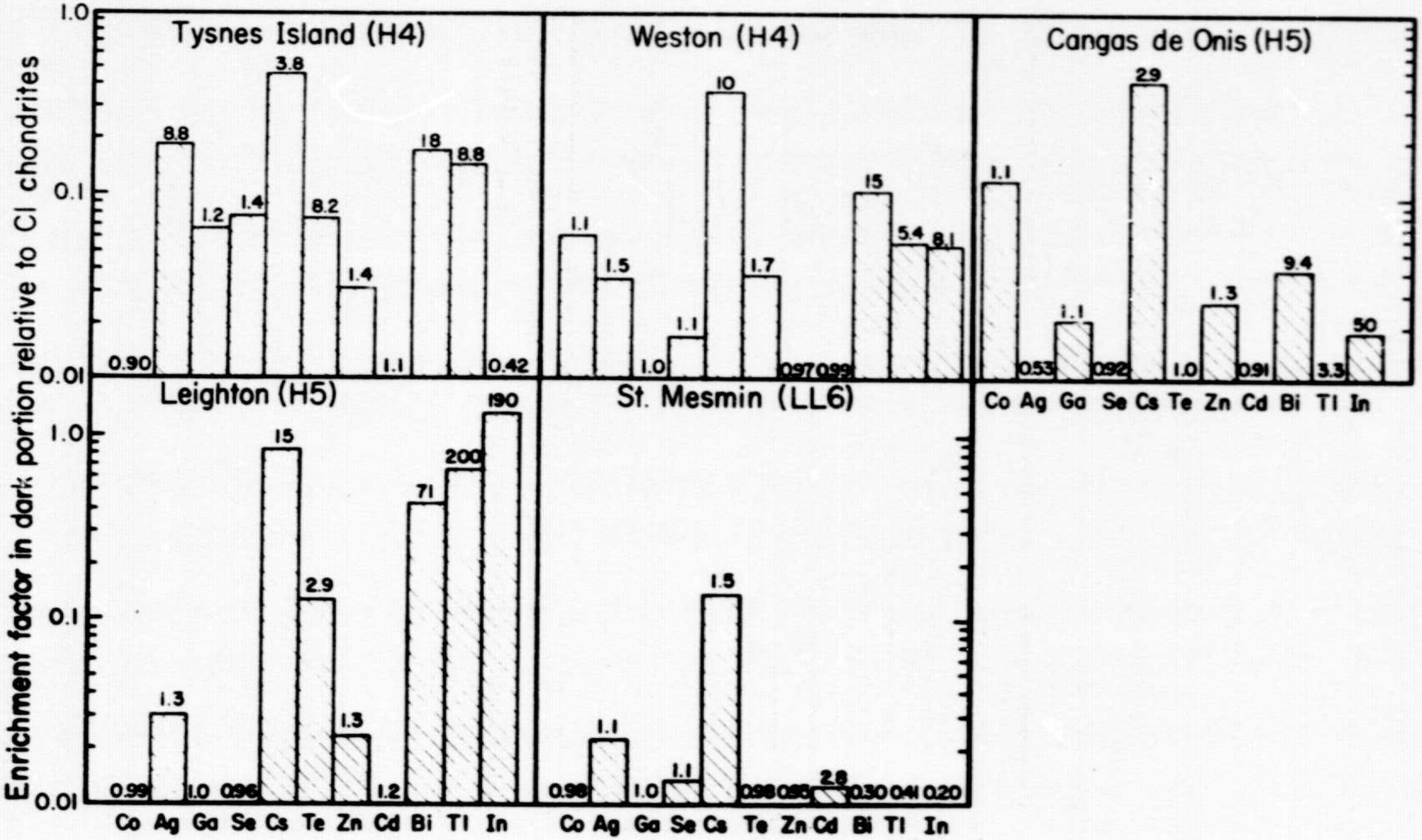
Figure Captions

Fig. 1. Volatile element enrichment/uniformity/depletion of dark, gas-containing portions relative to co-existing light parts of gas-rich chondrites. All atomic abundances are expressed as proportions of cosmic (i.e. Cl) abundances. Numbers indicate dark/light ratios for each element. Cesium is uniquely enriched (i.e. ratio >1.1) in all chondrites. Tysnes Island and Leighton exhibit the largest amount and number of enriched elements but In is significantly depleted (i.e. ratio <0.90) in the dark part of Tysnes Island while other elements are uniformly concentrated ($0.90 \leq$ ratio ≤ 1.1) in both parts of a given chondrite. In no case does the enrichment pattern seem to reflect addition of a primitive component of any known chondritic type (see text).

Fig. 2. Correlation of Bi and Tl excess in the dark portions of four gas-rich chondrites. These data correlate at >99% confidence level and suggest that the covariance of these elements is a characteristic of DAM in chondrites.



1.0
0.1
0.01
Tl depletion factor
0.01
0.1
1.0
Bi depletion factor



Enrichment factor in dark portion relative to CI chondrites
Tysnes Island (H4)
Weston (H4)
Cangas de Onis (H5)
Leighton (H5)
St. Mesmin (LL6)
1.0
0.1
0.01
0.90
8.8
1.2
1.4
3.8
8.2
1.4
1.1
18
8.8
0.42
1.1
1.5
1.0
1.1
10
1.7
0.97
0.99
15
5.4
8.1
1.1
0.53
1.1
0.92
2.9
1.0
1.3
0.91
9.4
3.3
50
0.99
1.3
1.0
0.96
15
2.9
1.3
1.2
71
200
190
0.98
1.1
1.0
1.1
1.5
0.98
0.95
2.8
0.30
0.41
0.20
Co Ag Ga Se Cs Te Zn Cd Bi Tl In