

REE ABUNDANCE PATTERNS IN CAIs: A NEW CLASSIFICATION;

T. R. Ireland¹ and B. Fegley, Jr.^{2,3}. ¹Research School of Earth Sciences, ANU, Canberra ACT 2601, Australia. ²LPI, 3303 NASA Road One, Houston, TX 77058, U.S.A. ³Max-Planck-Institut für Chemie, Saarstrasse 23, D-6500 Mainz, Germany.

Mason and colleagues classified Ca, Al-rich inclusions (CAIs) into different groups on the basis of their rare-earth-element abundance patterns [1-3]. In this abstract, we present a new classification system for CAIs based on REE abundances; in a companion abstract [4], we discuss the implications of the REE patterns for nebular processes. Fegley and Ireland [5] have compiled an inventory of ~280 inclusions from 19 meteorites for which REE patterns have been determined. In addition to the groups classified by Mason and colleagues on 35 Allende CAIs, a wide variety of other patterns are observed that are not covered in their classification. Examples of important non-classified patterns are the ultrarefractory-enriched pattern (complementary to Group II) and patterns with large Ce depletions such as HAL. While additional groups could be proposed to accommodate all patterns, the complexity of the classification scheme would negate its usefulness. We propose an alternative scheme that is based on the observed REE patterns that is flexible enough to accommodate new types of patterns which may be observed in the future.

First we note that the REE patterns are not random combinations of monoelemental components. Even though Eu is predicted to be much more volatile than the other REE (e.g. [6]), its behavior is part of a trend involving Ce and Yb. Likewise, the ultrarefractory REE tend to also be fractionated as a group. The observed range in REE patterns can be described in terms of three processes. These are (a) a fractionation which affects the ultrarefractory elements (Gd-Er and Lu), (b) mobilization of the more volatile elements (Ce, Eu, Yb), and (c) an overall fractionation according to ionic radius that changes the overall slope of the pattern but produces no anomalies. Our proposed classification system acknowledges that this third fractionation is distinct from the volatility-derived patterns resulting from (a) and (b), but it is analogous to the igneous-derived patterns commonly observed in REE fractionations on planetary bodies.

Patterns resulting from the ultrarefractory fractionation (F) include ultrarefractory-depleted (F_D) and ultrarefractory-enriched (F_E) types (Fig. 1). Mason and colleagues' Group II is only a subset of the F_D group because the canonical Group II has flat LREE and depletions in Eu and Yb. However, some F_D patterns have LREE fractionated according to volatility and Eu and Yb excesses (note for example the perovskite patterns in [7], Fig. 1). Such patterns have previously been referred to as "modified" Group II (e.g. [8]), but this designation does not give an informative description of the actual pattern.

Mobilization of the more volatile REE, Ce, Eu, and Yb, produces distinctive anomalies on unfractionated (UF) REE patterns, i.e. those that have no ultrarefractory fractionation. These anomalies are generally deficits but excesses are also found, for example in Mason and colleagues' Group I (excess Eu) and Group VI (excess Eu and Yb) patterns. There is a large range in the types of patterns with variable presence or absence of anomalies in one or more of these elements and specification of groups for each type of pattern would be too cumbersome. In order to accommodate the nature of these anomalies we propose a classification using a three figure vector notation based on the relative anomaly in these three volatile REE. For instance a flat pattern with no anomalies (c.f. Allende Group V) would be (000), Ce deficit only would be (100), etc. In this terminology the other groups assigned by Mason and colleagues would be (010) for Group I, (011) for Group III, and (011) for Group VI. In this way the anomalies can be denoted by an algebraic representation rather than an arbitrary compilation into various groups. In the case of the F_D and F_E patterns there is some difficulty in designating whether the volatile elements are anomalous or not since there is a high degree of irregularity in the pattern. Taking normal abundances relative to the trend defined by the LREE and Tm, the canonical Group II would be F_D(011), while the perovskite pattern in Fig. 1 would be F_D(101).

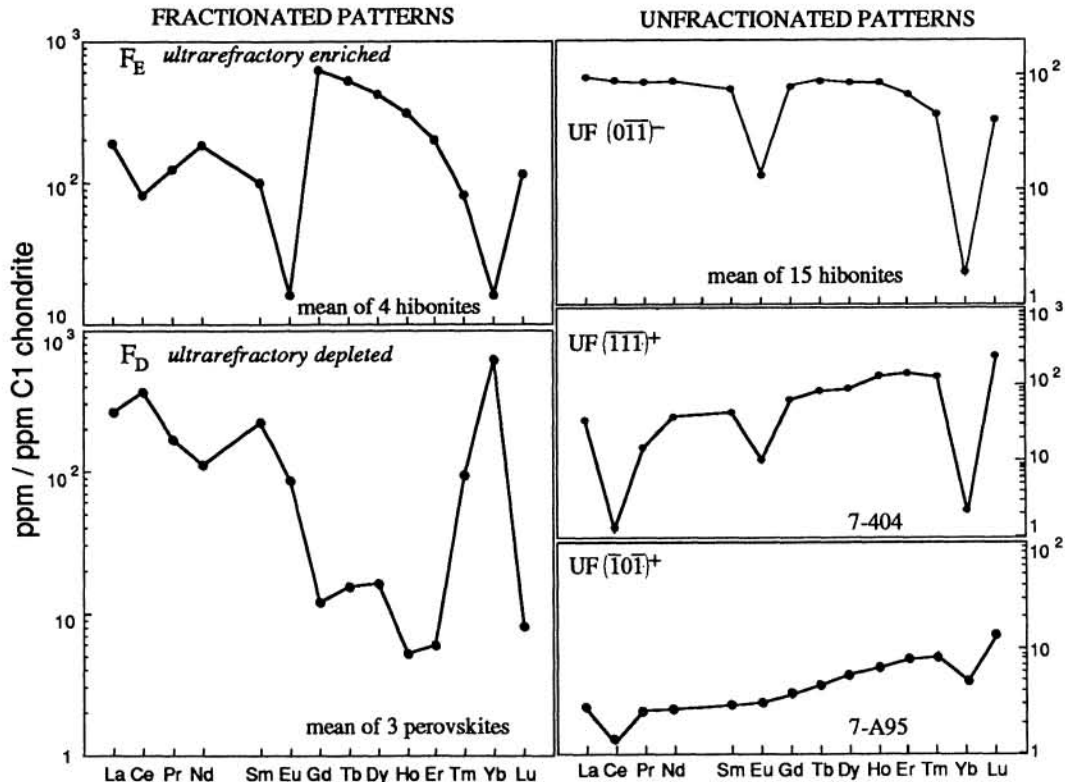
The third fractionation component often present in the CAI patterns is an overall fractionation according to ionic radius. A simple following superscript of + or - can be used to designate if the pattern is LREE-enriched (negative slope), or HREE-enriched (positive slope) respectively.

In addition to CAI classification, this system is applicable to REE patterns observed in other refractory mineral assemblages, e.g. CaS in enstatite chondrites as well as ferromagnesian chondrules. Using this terminology, 265 CAIs compiled by us from the literature [3, 6, 7, 9-42] have been categorized (Table 1).

References: [1] Martin and Mason (1974) *Nature* 249,333 [2] Mason and Martin (1977) *Smiths Contrib Earth Sci* 19,84 [3] Mason and Taylor (1982) *SCES* 25,1 [4] Fegley and Ireland (1991) this conference [5] Fegley and Ireland (1991) *Euro J Solid State Inorg Chem* in press [6] Kornacki and Fegley (1986) *EPSL* 79,217 [7] Ireland *et al* (1988) *GCA* 52,2841 [8] Davis and Grossman (1979) *GCA* 43,1611 [9] Gast *et al* (1970) *Proc Apollo 11 Lunar Sci Conf*, pp1143 [10] Davis *et al* (1982) *GCA* 46,1627 [11] Davis *et al* (1990) *Met* 25, in press [12] Spettel *et al* (1986) *Met* 21,513 [13] Fahey *et al* (1987) *GCA* 51,329 [14] Fahey *et al* (1987) *GCA* 51,3215 [15] Fahey (1988) PhD Thesis, Washington University [16] Hinton *et al* (1988) *GCA* 52,2573 [17] Nazarov *et al* (1982) *LPS* XIII,584 [18] Boynton *et al* (1986) *LPS* XVII,78 [19] El Goresy *et al* (1984) *GCA* 48,2283 [20] Misawa and Nakamura (1988) *LPS* XIX,784 [21] El Goresy *et al* (1985) *LPS* XVI,209 [22] Liu *et*

REE in CAIs - Classification: Ireland T. R. and Fegley B., Jr.

al (1988) *LPS* XIX,686 [23] Kurat (1975) *Tschermaks Mineral Petrog Mitt* 22,38 [24] Ireland *et al* (1990) *GCA* in press [25] Palme and Wlotzka (1979) *Met* 14, 508 [26] Palme and Spettel, pers commun [27] Mao *et al* (1990) *GCA* 54,2121 [28] Sylvester *et al* (1990) *LPS* XXI,1231 [29] Liu *et al* (1987) *LPS* XVIII,562 [30] Liu and Schmitt (1988) *LPS* XIX,684 [31] Ekambaram *et al* (1984) *GCA* 48,2089 [32] Ekambaram *et al* (1985) *GCA* 49,1293 [33] Ekambaram *et al* (1984) *Met* 19,222 [34] Boynton *et al* (1980) *LPS* XI,103 [35] Ireland (1990) *GCA* in press [36] Davis and Hinton (1986) *LPS* XVII,154 [37] Davis and Hinton (1985) *Met* 20,633 [38] Palme *et al* (1982) *EPSL* 61,1 [39] Noonan *et al* (1977) *Met* 12,332 [40] Wark *et al* (1988) *LPS* XIX,1230 [41] MacPherson *et al* (1989) *Met* 24,297 [42] El Goresy *et al* (1990) *Met* 25, in press



Meteorite	Fractionated		Unfractionated											Total	Refs
	F _D II†	F _E	(000) V	(100) I	(010) I	(011) VI	(100) I	(010) I	(001) I	(110) I	(011) III	(101) I	(111) I		
Allende	35		8		45	6	1	4			9			108	[1-3,6,9-11]
Arch					1									1	[12]
Cold Bok.											1		1	2	[13]
Dhajala							1							1	[16]
Efremovka	1		4											5	[14,15,17,18]
Essebi		1												1	[19]
Felix									1					1	[20]
Grosnaja									1		1			2	[21]
Kaba	3										7			10	[22]
Lancé	1	1												2	[15,23,24]
Leoville	2				2					1				5	[25,27,28]
Mighei											1			1	[15]
Mokoia	5													5	[29,30]
Murchison	35	10	1	1	2			2			26	2	3	82	[7,13,15,31-35]
Murray	4	1						2			2			9	[13,15]
Ornans	1	3									1			5	[36-39]
Semarkona	1													1	[15]
Vigarano	3				4		1				1	1		10	[27,28,40]
ALH85085	8	2	2			1		1						14	[41,42]
Total	99	18	15	1	54	7	3	9	2	1	49	3	4	265	
%	37.3	6.8	5.7	0.4	20.4	2.6	1.1	3.4	0.8	0.4	18.5	1.1	1.5		

† Allende Group after Mason and coworkers [1-3].