INTER-ELEMENT RELATIONSHIPS BETWEEN THE MOON AND STONY METEORITES WITH PARTICULAR REFERENCE TO SOME REFRACTORY ELEMENTS.

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We have analysed one Apollo 15 and five Apollo 14 specimens by XRF analysis. We use these data, together with other data obtained in this laboratory on lunar samples and stony meteorites, to discuss some selected interelement relationships in these materials. Other interelement relationships will be discussed elsewhere.

Zr and Nb: Abundances of Zr and Nb in lunar materials examined by us vary by a factor of 10, and are higher than those measured in howardites and eucrites, as indicated in the following table.

Sample description		Zr, ppm	Nb, ppm	Zr/Nb
10017,70	Rock	499 ± 2	30.4 ± 1.0	16.4
10084,173	Fines	309 ± 2	21.5 ± 1.0	14.4
12002,113	Rock	102 ± 2	7.9 ± 1.3	12.9
12038,77	"	182 ± 2	10.4 ± 1.0	17.5
12053,24	"	133 ± 2	9.2 ± 1.3	14.5
12063,52	"	128 ± 2	7.1 ± 1.3	18.0
12032,38	Fines	705 ± 2	47.8 ± 1.3	14.8
12070,88	"	523 ± 2	36.9 ± 1.3	14.2
14053,43	Rock	215 ± 2	17.4 ± 1.2	12.4
14310,117	"	852 ± 2	60.6 ± 1.0	14.1
14305,121	Breccia	1158 ± 2	78.6 ± 1.1	14.7
14163,56	Fines	1022 ± 2	71.6 ± 1.0	14.3
14259,59	"	961 ± 2	68.8 ± 1.0	14.0
15101,67	"	313 ± 2	19.8 ± 1.0	15.8
Chaves	Howardite	27.5 ± 0.9	1.7 ± 0.5	16.3
Malvern	"	36.3 ± 0.9	2.5 ± 0.5	14.5
Haraiya	Eucrite	36.2 ± 1.0	2.1 ± 0.5	17.1
Sioux County	"	42.3 ± 1.0	2.8 ± 0.5	15.3
Cachari	"	45.1 ± 1.0	2.8 ± 0.5	16.3
Juvinas	"	45.6 ± 1.0	2.7 ± 0.5	16.8
Bereba	"	52.0 ± 1.0	4.0 ± 0.5	13.1
Pasamonte	"	52.5 ± 1.0	3.5 ± 0.5	15.2
Macibini	"	54.3 ± 1.0	3.4 ± 0.5	15.8
Stannern	"	87.1 ± 1.0	6.3 ± 0.5	13.8

The Zr-Nb relationship in lunar materials is exceptionally well developed and the variation in Zr/Nb is smaller than that shown for well-known geochemically coherent pairs such as K/Rb, K/Ba and La/Yb; the Zr/Nb coherence approaches that shown by Th and U. The lack of Zr/Nb fractionation in all types of lunar materials, and specifically in lunar soils where Zr/Nb varies from 14-16, attests to similar behaviour of Zr and Nb during partial melting/crystal fractionation processes. Other workers report the presence of K, REE, Zr and P rich phases in late stage residua in Apollo 11, 12 and 14 rocks and high concentrations of Nb are present in some late Zr minerals (1). Published data (2) show that lunar ilmenites contain up to 3000 ppm Zr, and either they are not important as liquidus phases (Apollo 11) or Zr/Nb is similar to that of the co-existing liquids (Nb data are not available).

KREZP (KREEP) and other similar materials must have higher Zr and Nb contents, but similar Zr/Nb ratios. We draw attention also to the relative constancy of the K/Zr ratio (a volatile/refractory pair) in lunar materials. This observation indicates similar behaviour of K and Zr (and Nb) in lunar magmatic processes, it argues against large-scale volatilization of the heavier alkalies from lunar lavas, and it allows calculation of Zr (and Nb) in KREZP materials. Average KREZP glass (Apollo 12) contains $\sim$ 9000 ppm K (3). Using K/Zr = 4.5, Zr/Nb = 15, KREZP glass should contain about 2000 ppm Zr and 130 ppm Nb. These abundances are far in excess of those measured by us for terrestrial basaltic rocks, and indicate that very small degrees of partial melting and/or large amounts of crystal fractionation must have been operative during the production of KREZP basaltic materials.

The similarity of Zr/Nb in all types of surface lunar materials implies a similar ratio for the moon as a whole and the ratio is, within experimental error, apparently the same as in the eucritic and howarditic achondrites, for which we report the first Nb measurements. The only available chondrite data are for Allende where Zr/Nb = 10 (4). Terrestrial oceanic and continental basaltic rocks have Zr/Nb varying from 4 - 40; in kimberlitic peridotites the ratio ranges from 2 - 7.

In terms of fundamental properties of atoms (ionic radius, nature of bond and crystal field effects), it is not clear why Zr and Nb should preserve such a close coherence in a wide variety of extra-terrestrial materials. In terrestrial rocks these elements are exclusively present as Zr^{4+} and Nb^{5+}. The radius of Zr^{4+} is 0.80 Å and that of Nb^{5+} 0.69 Å, but if Nb is in a reduced state, as is possible in the eucrites and the moon, we should consider the existence of Nb^{4+} (0.75 Å) and of Nb^{3+} ($\sim$ 0.8 Å). The latter value is a new estimate based on ionization potential considerations (5) which also support the existence of Nb^{3+} as a stable oxidation state (6). It is noteworthy that Nb in tranquillityite has been reported as Nb_2O_3 (7).

Ca and Al. The importance of the Ca - Al relationship in stony

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meteorites and the lunar surface has been stressed by us (8). We have determined these two elements in 23 additional carbonaceous chondrites, howardites and eucrites. With the exception of the CIII chondrites, Coolidge and Leoville and the eucrites Serra de Mage and Moore County, this information confirms that a Ca/Al ratio of about 1.10 is typical of these stony meteorites. We have stated that this ratio may be typical of most extra-terrestrial material, including the sun and the earth. However, the mesosideritic value of 0.87 should be borne in mind because such a ratio appears to be typical of Apollo 14 fines. Our interpretation of the Ca/Al data in the fines from all areas sampled is that it varies from ~0.86 to a little more than 1.2 with an average close to that of the stony meteorite value. In contrast specific lunar rocks and impact glasses show a wider variation in Ca/Al; nevertheless, the range observed varies almost equally on either side of the stony meteorite and lunar fines average,with mare materials tending to have higher and non-mare materials tending to have lower ratios.

Inter-element slopes and condensation processes. The possible importance of inter-element slope relationships (rates of increase of concentration) of the refractory elements between various meteorite types and the lunar surface has been discussed before (8,9). Slope might have a bearing on the nature of condensation processes including the possibility of placing an element in a condensation sequence such as that proposed by Lord, Larimer, Anders and others. Examples will be given.

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