ELEMENT CORRELATIONS AND THEIR SIGNIFICANCE FOR THE DETERMINATION OF
THE BULK COMPOSITION OF PLANETARY OBJECTS.

Gerlind Dreibus, K. Blum, B. Spettel and H. Wänke
Max-Planck-Institut für Chemie (Otto-Hahn-Institut), 65 Mainz, F.R. Germany

Correlated elements - i.e. pairs of elements which on a given planet occur in various rock types in constant abundance ratios - have been used by a number of authors (1-3) for the estimation of the bulk composition of planets. The general assumptions are: First, the elements do not condense independent from each other but in a few major groups and second, the observed abundance ratios for the correlated elements used for the calculation are valid for the whole planet. Neglecting metallic iron, the sulfides and the highly volatiles, we have three major condensation groups:

1.) The refractory elements
   Al, Ca, Ti, (Mg, Si), Be, Sc, V, Sr, Y, Zr, Nb, Mo, Ru, Rh, Ba, REE, Hf, Ta, W, Re, Os, Ir, Pt, Th, U.

2.) Mg-silicates
   Mg, Fe (FeO), Si, Cr, Li.

3.) Moderately volatile elements Mn, Na, K, Rb, Cs.

The group behaviour of the first two groups seems to be well established, the moderately volatile elements seem to have been fractionated from each other to a varying extent.

Well defined pairs of correlated elements exist among the refractories themselves (e.g. Ba/La) as well as between K/La and K/U, but no useful and fully reliable link has been found so far between the refractories and the Mg-silicates. Dreibus et al. (3) noticed that Li seems to follow the Mg-silicates during condensation and that Li correlates reasonably well with the refractory elements Be and Zr. However, the observed Li/Be and Li/Zr ratios yielded too high abundances of refractory elements for the Moon and the eucrite parent body (4). The reason lies in the fact that Li contrary to Be or Zr enters olivine and orthopyroxene in amounts not negligible for the element balance.

Laul et al. (5) discovered a correlation of Cr and V for lunar samples. However, probably due to the large scatter of the literature data on these two elements, this first observation did not catch the attention it deserved. Wänke et al. (6) added V to the list of elements determined in their multielement program. As in all other cases excellent agreement was found between the data of Mainz laboratory and those of R.A. Schmitt's group (Corvallis) (5-9). Using the Mainz and Corvallis data exclusively, good correlations between V and Cr were found for lunar mare samples as well as for highland samples. However, a distinct difference in the Cr/V ratio of about 35% between mare samples and highland samples is observed (Figs. 1 and 2).

Figs. 3 and 4 illustrate the importance of reliable data; they contain literature data with the exception of those from Corvallis and Mainz. In spite of the fact that we restricted to those analyses in which the data for V and Cr came from the same laboratory, only very little evidence for a correlation is found in Figs. 3 and 4.

There seems to be the general consensus that most of the highland rocks are mechanical mixtures of compounds of quite different origin (10-15). According to the interpretation of Wänke et al. (14,6) the component which brought...
the majority of the mafic elements especially Mg is predominantly of extra lunar origin and was added to the Moon at a time when a solid crust had already been formed. Hence, the Cr/V ratio observed in lunar highland breccias should be close to that of the primary matter as defined by Wänke et al. (6).

The pair Cr-V can be used to relate the refractories with the Mg-silicates. As it can be seen from Fig. 1 relative to Cr and to C 1 the refractory element V is enriched by a factor of 1.57. The small corrections required to account for the presence of material derived from residual liquids in the lunar highlands (6) lower this factor to a value of 1.4, i.e. close to the enrichment factor found by Wänke et al. (6) for the refractories in the primary matter.

The lower Cr/V ratio observed for mare samples is probably not a consequence of a more refractory lunar interior but reflects the change of the Cr/V ratio in the generation of basaltic liquids. Laul and Schmitt (9) found for the lunar dunite 72417 a Cr/V ratio of 44, i.e. considerably higher than the value of 22 in mare basalts.

Preliminary results on achondrites in our laboratory yielded also almost constant Cr/V ratios with a small increase from eucrites to howardites and diogenites and with a mean value close to C 1. The silicate phases of pallasites showed higher Cr/V ratios, especially in those cases in which both elements were mainly contributed by small amounts of chromite.

Wasson et al. (15) have questioned the model of Wänke et al. (6), in which
the Mg-rich component of the lunar highland represents primary matter (PR) only slightly altered by the addition of material from residual liquids of which olivine has been segregated. Wasson et al. introduced SCCRV as a major component of lunar highland rocks. SCCRV is compositionally similar to the PR component of Wänke et al. (6), except it contains much higher amounts of Ti and hence, a primary nature has to be denied. Wänke et al. (6) account for the varying concentrations of Ti in lunar highland rocks by the addition of varying amounts of material derived from residual liquids.

Fig. 5 illustrates the difference between SCCRV and PR. Ti and Mg are in both models predominantly supplied by KREEP and PR or SCCRV, while La comes only from KREEP. Hence, if SCCRV would be a dominant component of the highland rocks the data points of the highland samples should be found in the vicinity of the dashed line connecting KREEP and SCCRV. Samples like 67955, 66075, 61156 and many others far below this mixing line would require the addition of large amounts of olivine, which is prohibited for various reasons. For the mixing computation of the Mg-rich component Wänke et al. (6) used the samples indicated by full circles in Fig. 5. For a La/Mg ratio close to zero - KREEP component zero - a Ti/Mg ratio of 0.02 is found. Correction for the presence of material from residual melts - addition of olivine - results a close to chondritic Ti/Mg ratio in PR. The ferroan anorthosite 67915 could be assumed to represent the residual melts. Thus only small amounts of material like 67915 are sufficient in most cases to raise the data points from the mixing line (dotted line in Fig. 5) of PR and KREEP.