CHROMIUM PARTITIONING BETWEEN OLIVINE AND PYROXENE AND THE REDOX STATE OF LUNAR ROCKS; Petr Jakeš, Lunar Science Institute, Houston, Texas, and Geological Survey, Prague, Czechoslovakia, and Arch M. Reid, NASA-Johnson Space Center, Houston, Texas, 77058.

A substantial body of evidence indicates that lunar crustal rocks crystallized at lower oxygen fugacities than terrestrial crustal rocks. Direct measurement of oxygen fugacities of lunar rocks by Sato et al. (1) yields a restricted range of oxygen fugacities, at a given temperature, for all lunar samples studied. Philpotts et al. (2) suggest that the redox state of lunar highland samples, as expressed by the calculated ratio Eu^{2+}/Eu^{3+}, is comparable to that of the mare basalts. Thus if differences in redox states among the lunar rocks are to be recognized, rather sensitive indicators will be required.

In a reducing environment low oxidation states will occur for some transition elements and chromium, in particular, may be present as Cr^{2+} and Cr^{3+}. We make the assumption that Cr^{2+} is preferentially incorporated into olivine whereas Cr^{3+} predominates in oxides and in pyroxenes (though Cr^{2+} may also be present, Boyd and Smith, 3). Haggerty et al. (4) suggested that the high Cr contents of lunar olivines, in comparison to terrestrial samples, occur because Cr^{2+} could be incorporated into the olivine structure. Olivine and magnesian pyroxene are generally among the earliest phases to crystallize from lunar basalts and may record the state of the melt uninfluenced by the redox changes that accompany crystallization or subsolidus reduction. Under these assumptions the partitioning of Cr between olivine and pyroxene is a function of the ratio of Cr^{2+} and Cr^{3+} and thus of the redox state of the system. New data on Cr contents of pyroxenes and olivines in lunar rocks are summarized below and the hypothesis that Cr partitioning can lead to estimates of relative redox state of lunar rocks is explored.

It should be noted that Burns et al. (5) found evidence of Cr^{3+} in lunar olivine: the presence or absence of Cr^{2+} could not be ascertained from the absorption spectra in the presence of substantial amounts of iron. Meteorites have also formed at low oxygen fugacities yet contain olivines with low Cr contents. Analyses of meteoritic silicates show that Cr is also very low in most pyroxenes coexisting with olivine and thus the partitioning of Cr between olivine and pyroxene is comparable to the lunar case.

Pyroxenes strongly fractionate Cr because of the strong octahedral site preference of Cr^{3+} and the Cr content decreases rapidly with increasing Fe in zoned pyroxenes from mare basalts (e.g. 4). Fig. 1 shows that the pyroxenes from different regions of the moon occupy distinctly different fields on a Cr versus Mg/Fe plot, though all show the same general trend of decreasing Cr with Mg/Mg+Fe. Pyroxenes from mare basalts have higher Cr contents than pyroxenes from highland rocks, for the same Mg/Mg+Fe values. Apollo 12 and 15 mare basalt pyroxenes are more Cr-rich than those from Apollo 11 and 17. For a given mare basalt the core pigeonites and the most magnesian augites have similar Cr contents.

A range of Cr contents exists in lunar olivines (Fig. 2) from less than 0.01 wt. percent in some highland rocks up to 0.6 in some Apollo 12 mare basalts. Cr content increases inversely with the Mg/Mg+Fe ratio of the olivine for the mare basalts. Olivines in highland rocks have lower Cr contents

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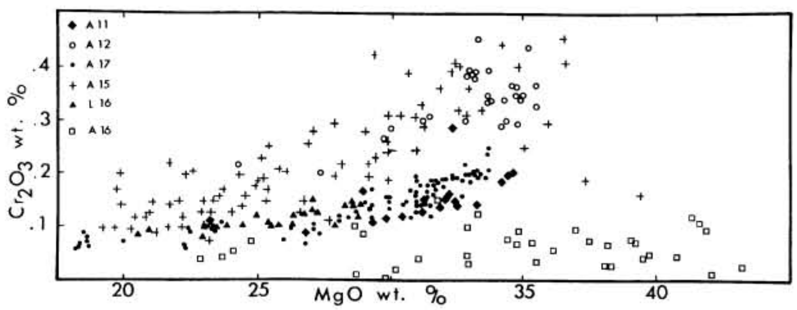

Fig. 2. Cr_2O_3 vs. MgO plot for olivines from different lunar missions (A-Apollo, L-Luna captions in left hand corner). (new data)

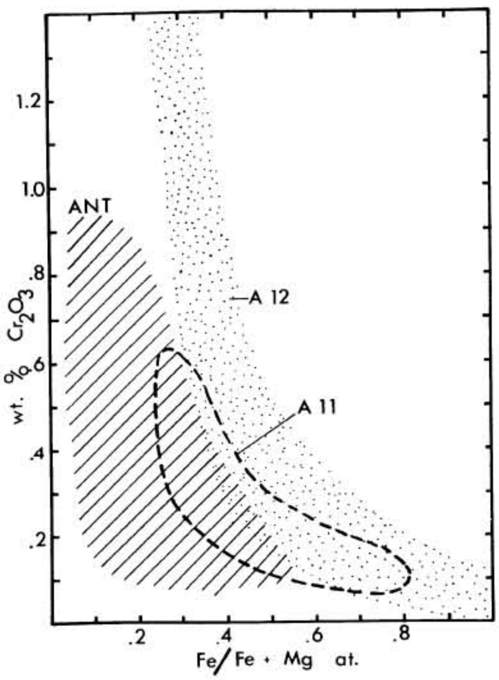

Fig. 1. Cr_2O_3 content vs. Fe/Fe+Mg in three different suites of lunar rocks. A-12 - Apollo 12 mare lavas, A-11 - Apollo 11 mare basalts, ANT - series of highland rocks from A-16.

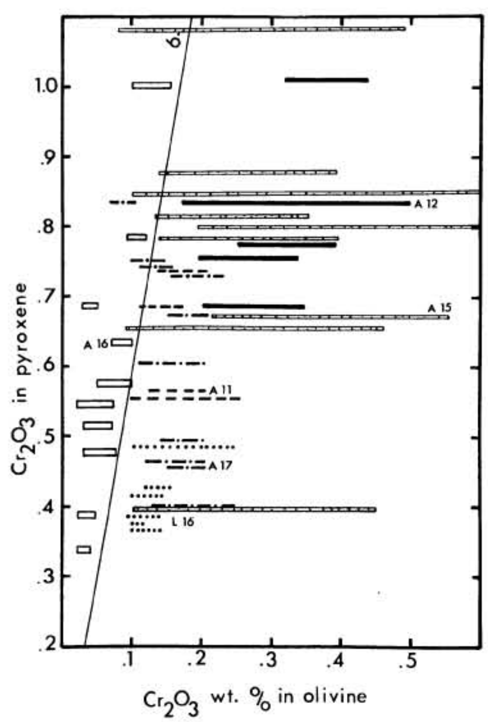

Fig. 3. Cr_2O_3 contents in most Mg pyroxene plotted vs. range of Cr values in lunar olivines in a given rock.

than olivines in mare basalt but there is no well-defined trend with respect to Mg/Mg+Fe ratio. Within the mare basalt data the highest Cr contents are for olivines in the Fo_{65-80} range. Olivines from Apollo 12 basalts have the highest Cr contents followed in order of decreasing Cr by Apollo 15, 17 and 11, for the same Mg/Mg+Fe ratio in the olivine.

No reliable criteria are available to determine the specific olivine and pyroxene compositions that coexisted at equilibrium for lunar rocks containing a range of olivine and pyroxene compositions. Since olivine generally crystallizes early in lunar rocks we compare in figure 3 the total range of olivine compositions with the most magnesian pyroxene. From this plot it is possible to estimate the extent to which Cr is partitioned between pyroxenes and olivine and, if the basic assumption is correct, the relative redox state of the system. Figure 3 shows that Cr partitioning is distinctly different for different suites of rocks. The conclusions, under the above assumptions, are as follows.

1. The highland rocks are more oxidized than the mare basalts.

2. The Apollo 11 and 17 basalts are more oxidized than most of the Apollo 12 and 15 basalts.

3. There is a trend of decreasing redox state from highland rocks to Apollo 11 to 17 to 15 to 12 mare basalts that correlates with decreasing age of the rocks.

4. Luna 16 basalts occupy a field close to the Apollo 17 rocks and have characteristics transitional between highland and mare rocks. The Luna 16 age of 3.4 b.y. (7), does not fit into the above sequence.

The different suites of lunar rocks may have crystallized under somewhat different oxygen fugacities and these may correlate with age so that the younger rocks are more reduced. The more reduced basalts, in this model, are more Cr-rich and Cr may be preferentially incorporated into partial melts under reducing conditions. The proposed sequence may be related to different source regions for the mare basalts, as might be produced by progressive degassing of the lunar mantle or by partial melting at progressively greater depths.

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