LUNAR REGOLITH EVOLUTION, R. M. Housley, Rockwell International Science Center, Thousand Oaks, California 91360.

Since the first lunar regolith samples were returned by the Apollo and Luna missions, a large amount of effort has been devoted to characterizing them and to identifying the processes that have been important during their formation and evolution. This is an attempt to synthesize what has been learned and to outline a consistent working model that can account for the key observations in a plausible way.

Upon microscopic examination, it is immediately apparent that hypervelocity impacts have played the dominant role in altering lunar regolith materials. At a typical collision velocity of 20 km/sec, the kinetic energy of impact is more than enough to vaporize the meteorite and to melt several times its mass of the target. It is important to determine how this energy is actually partitioned.

This can be approached by making use of the residues from partial vaporization that are now recognized in the regolith (1-5). The high alumina, silica poor HASP glasses (2-4) found in highlands regolith are the most widely accepted. Using the data summarized in (2), we can infer that they constitute about 0.4 percent of mature highlands fines. It can be convincingly argued (3) that many additional glasses, including the highland gabbroic anorthosites, have lost lesser amounts of silica. Using the modal data in (3) and (4), we can estimate these to have an abundance of about 1.5 percent. Using the analysis of (2) and (4), we find that HASP and gabbroic anorthosite glasses have respectively lost at least about 20 and 6 percent of their initial mass by silica vaporization. Combining these results, we see that about 0.17 percent silica vaporization can be documented from mature highlands regolith.

There is no obvious reason why results from other sites should be drastically different.

It is now important to enquire into the initial temperature of these droplets, which will be close to the temperature where most of the vapor was evolved. Since the evaporation rate depends exponentially on $1/T$ while radiative cooling depends on $T^4$ we can expect that at high enough temperatures evaporative cooling will dominate. De Maria et al. (7) have shown that silica evaporates primarily as SiO plus O from melts of lunar composition and have presented vapor pressure versus $1/T$ data. Using this, we find that evaporation is the dominant cooling mechanism above about 2500°K. We can derive the following simple formula to relate change in mass $M$ and change in temperature $T$ in the high temperature regime.

$$\left(\frac{M_f}{M_i}\right)^{4/9} = \frac{L - 4RT_i}{L - 4RT_f}.$$  

The subscripts $i$ and $f$ refer to initial and final, $L$ is the low temperature latent heat of evaporation of SiO$_2$ plus the heat of dissociation to SiO+O and is taken to be 185 kcal/mole, $R$ is the gas constant. Using this we find that the gabbroic anorthosite glasses had initial temperatures around 3000°K, typical HASP glasses had initial temperatures around 4400°K, and the most silica depleted HASP glass (2) had an initial temperature of 5300°K. These latter temperatures are high enough that largely unfracti onated evaporation may have occurred. Therefore, the total mass of material vaporized and the true initial temperatures may exceed these estimates.

The above estimates of vaporized fraction and initial temperature are on the low side, but within the ballpark, of those required to account for
observed isotopic fractionations in the regolith (8) by partial loss of impact vapor from the moon (6). There is evidence that alkali metals (5) and probably sulfur have been vaporized from a much larger fraction of lunar glass particles. Hence they would preferentially be sited on grain surfaces, available for sputtering. Oxygen would be depleted in material redeposited following partial vapor loss essentially independent of composition.

Solar wind sputtering must occur, but its global effects cannot be quantitatively predicted since no information is available on the velocity distributions or partial sputtering yields of species sputtered from lunar material by H and He. Probably sputtering makes a substantial contribution to the isotopic effects in K and S (8). Sputtering should probably also lead to an essentially composition independent preferential loss of oxygen.

Considerable evidence shows that the rate of production of fine-grained Fe metal in lunar agglutinates is proportional to the FeO content at the site. There is no explanation for this if either partial vapor loss or sputtering is the primary reduction mechanism. However, it follows simply from thermodynamics if reduction by solar wind hydrogen is assumed to be dominant,

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\frac{[H_2O]}{[H_2]} = K \frac{[FeO]}{[Fe]},
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with K around one. Some subtle points connected with this will be discussed.


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