SOLAR WIND AND LUNAR WIND MICROSCOPIC EFFECTS IN THE LUNAR REGOLITH.

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ABSTRACT

In the present report we first confirm the solar wind radiation damage origin for the ultra-thin amorphous coatings on lunar dust grains. We then evaluate the possible use of the coatings for determining the thermal properties of the ancient solar wind and for tracing back the history of lunar magnetic fields. Finally we discuss the contribution of the solar and " lunar " winds to the microscopic redistribution of matter in the lunar regolith.

SIMULATION OF LUNAR PROCESSES IN THE LABORATORY.

The solar wind (SW) and lunar wind (LW) (1) possibly play dominating roles in the microscopic redistribution of matter in the lunar regolith, which we have attempted to evaluate in the following ways : 1. the direct irradiation effects of the SW were simulated by exposing micron-sized mineral fragments (μ-grains) on electron microscope grids to high fluxes (up to 10^{17} ions/cm^2) of low energy ions ($0.2 < E < 4$ keV/amu) ; 2. the fate of atomic species sputtered away from various targets (rock 15475, muscovite and quartz) by this artificial SW was estimated by collecting such species both on μ-grains and on gold foils ; 3. an artificial LW was obtained by fusing a chunk of rock 15475 with an electron gun under vacuum ; the resulting " vapor phase " was deposited on various substrates including μ-grains, gold foils and a quartz balance ; 4. finally we searched for " surface to volume " effects in lunar dust grains by etching with a chemical reagent various size fractions (5 microns residue, 400, 200 and 100 Mesh fractions) of samples 10084 and 14141, and by evaporating the resulting solutions on gold foils.

The μ-grains were then observed with the 1.5 MeV electron microscope at the Institut d'Optique Electronique du CNRS, both before and after thermal annealings. The various deposits on the gold foils were analyzed at ONERA with a new type of ion analyser (2) that allows the multi-element analysis of samples both over a large range of atomic mass and as a function of the depth in the samples. With the same apparatus we expect very soon to characterize the chemical composition of the quartz and mica surfaces that were heavily irradiated (up to 10^{18} ions/cm^2) in the artificial SW.

ORIGIN OF THE ULTRA-THIN COATINGS ON LUNAR DUST GRAINS.

We have already pointed out that the direct implantation of solar wind nuclei in μ-grains produces a marked " rounding + coating " effect which is very similar to that observed in the finest lunar dust grains. We are now convinced that the coatings are SW radiation damaged layers and not " vapor type " deposits for the following reasons : 1. only the direct exposure of the μ-grains in SW ions reproduces the " rounding + coating " effect ; on the contrary the deposition of vapor phases (induced either by ion sputtering or by vacuum sublimation) results in the formation of tiny crystals ; 2. the thickness, Δ, of the coatings is uniquely related to the " projected radiation

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damage range ", R_p^d, of the incident ions ; 3. Δ reachs a constant " plateau " value above a critical flux value Φ_c ; on the contrary the thickness of both SW and LW deposits increases as a function of the irradiation time ; 4. the abrupt contrast discontinuity observed between the coating and the underlaying crystal can be explained very simply with a model in which implantation depth profiles are gradually modified by the erosion rate associated with SW sputtering ; 5. the coatings are annealed upon heating at the same temperature as nuclear particle tracks.

THERMAL PROPERTIES OF THE ANCIENT SOLAR WIND AND LUNAR MAGNETIC FIELDS.

The thickness of the ultra-thin amorphous coatings, $\Delta \sim E^{1/2}$, gives an estimate of the average energy of the solar wind during the last $\sim$300 years of the exposure of the grains in the solar wind (all previously formed coatings are erased by ion sputtering !). Last year we reported a preliminary analysis of the distribution of the coating thicknesses, $\delta = dN/d\Delta$, where 130 grains from all missions were mixed together. This year we have repeated the same procedure with more than 200 grains, but in addition we have attempted to classify the grains on the following basis : their landing sites (Apollo 11, 12, 14, 15, 16 and Luna 16 and 20 missions) ; their depth in the well stratified Apollo 15 core tube and ; the intensity of the local magnetic field as measured by the astronaut portable magnetometer.

Our main results are : 1. the " mixed " distribution confirms our previous results : the " average " speed of the solar wind that bombards the moon varies over a broad range ($100 < V < 1500$ km/sec) and there is a high probability for periods of low energy solar wind at the moon ; 2. the distribution in the core tube shows various types of stratification but no secular trend with the depth has so far been observed ; furthermore a layer with " broken " coatings has been observed at great depth ; 3. the " landing site " distribution does not show marked correlation either with the intensity of the local magnetic field or with geological " parameters ".

The observation of grains showing the " rounding + coating " effect in the deepest layer of the Apollo 15 core tube clearly shows that the solar wind was bombarding the moon as early as 500 millions years ago, with an average energy of about 1 keV/amu. We were then quite convinced that we could help in fixing some limits on a possible lunar dynamo by injecting this observation as a boundary condition into an equation giving the decay with time of a lunar magnetic dipole field ($\partial H/\partial t = A - B$). Unfortunately Dr. Sonnet (personal communication) made the following sad statement " the rate of decay of dynamo fields cannot be determined theoretically ". Therefore to contribute to the history of lunar magnetic field activity we have still to probe the solar wind energy at a much earlier time !

REDISTRIBUTION OF MATTER IN THE LUNAR REGOLITH.

We first present the following new results that are relevant both to the subject discussed in this section, and to the origin of lunar albedo (3) : 1. the ion analyser reveals that the chemical composition of the 5 μ-residue in a given soil sample is very different from that of the 400, 200 and 100 Mesh

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fractions, which are roughly similar. In particular the residues show a shocking depletion in light elements ; furthermore their Ti/Al ratio greatly varies from one soil sample to the other and is much higher (up to a factor of 10 !) in the more mature (4) soil samples ; 2. the concentration of glassy objects in the 5 μ-residues (which we determine from electron diffraction patterns) is much smaller ($\lesssim 10$ %) than that estimated in the coarser fractions by others ; 3. the various grains in the lunar regolith are eroded at very different rates by SW sputtering : the pyroxenes and the glassy grains are eroded at a faster rate than the feldspars, and the erosion of the ilmenite particles is much smaller ; 4. in the dark soil samples the micron-sized grains show a very complex structure : i. their SW coatings have an index of refraction smaller than that of the underlaying grains ; ii. they are loaded with very high densities ($>10^{11}$ tracks/cm^2) of nuclear particle tracks that have been " aged " by various processes ; as a result the clusters of atomic defects that are concentrated along the " old " tracks are more stable than those found in the core of " fresh " tracks (5) and they could act as high temperature electron traps ; iii. they form complex microaggregates of welded dust ; both the proportion, P(WA), of the aggregates and the average number of constituant particles per aggregate, N, increase with the index of maturity of the soil.

By combining these results to those already published elsewhere, we deduce the following tentative conclusions concerning the microscopic redistribution of matter in the regolith : 1. there is a complex balance of grains in the 5 μ-residues : the SW differential sputtering can cause an enrichment in ilmenites and simultaneously decreases the content in glassy objects and pyroxenes ; in addition " vapor type " deposition processes contribute to a new generation of tiny grains. We expect very soon to complete the analysis of the artificial SW and LW deposits on the gold foils in order to determine if one of these winds is responsible for the very strange elemental fractionation in the 5 μ-residues ; 2. as a result of dust collisions in the regolith the smallest particles get stuck to the grains with a coating and the values both of P(WA) and N increase with the number of times that the grains get processed as part of ejecta blankets ; 3. in the lunar dust samples the homogeneity of the SW coatings around the micron-sized grains has to be contrasted with the very inhomogeneous solar flare track gradients in the $\sim$100 microns grains ; therefore the microgardening seems to be more efficient for the finest grains. Our preliminary computations clearly show that the expanding gas clouds forming the lunar wind could well account for the frequent and selective turn over of the finest grains : for the more abundant micrometeorite events, the micron-sized grains will be more readily disturbed by the gas than the larger ones and this will allow the finest grains to be more uniformly irradiated than the coarser grains.

REFERENCES

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(2) - R. Hernandez (1972) Recherches Aéronautiques n° 62.
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(4) - The definition of soil maturity has been given by J.B. Adams and T.B. Mc Cord (1971) Geochim. Cosmochim. Acta, Suppl.2, vol.3, 2183.
(5) - See our companion paper to be presented at this meeting.