ADHESION AND CLUSTERING OF DIELECTRIC PARTICLES IN THE SPACE ENVIRONMENT. 2. The Electric Dipole Moments of Lunar Soil Grains

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Introduction. Determination of dipole moments of individual lunar soil grains and the volume polarization of 78501.14 soil have been described in a companion paper (1). Dipole strengths are found to vary as functions of mass and composition. For interpretation, the experimentally determined dipole strengths should be further correlated with parameters such as irradiation history, impurity content and density of structural discontinuities. Our goal is to clarify the processes that lead to particle adhesion and to try to understand the long term persistence of adhesion. We know that corpuscular radiation damage has extensively modifed a 500-1000 Å thick surface layer of the exposed and electrically polarized grains and that the density of tracks of ionizing heavy nuclei falls off exponentially with depth as exemplified by Fig. 1 (2).

Against this background we consider it important to distinguish between surface charges and any internal charge accumulations with polarizability. The persistence of charge separation and the dipole fields caused by this appear related to DC-conductivity, conduction mechanism involved, grain composition and impurity distribution of the various zones (3).

Dipole moment as a function of grain mass. The experimental data now at hand (1) indicate a practically linear relationship between dipole moment p and grain mass M. Hence p is proportional to l^3 where l is the linear dimension of an isometric grain. Since p is the product of charge Q and l, Q is proportional to l^2, which means that the charge which gives rise to the dipole is proportional to the surface area of the grain. This is understandable if the polarization is caused by irradiation of grain surfaces and specifically by the anisotropic irradiation found by Macdougall to be characteristic of lunar grains, Fig. 2 (2). Evaluation of measurements needs discussion of induced dipoles as opposed to permanent dipoles. The latter are material characteristics for the lunar grains already on the Moon, while temporarily induced dipoles observed in the laboratory would indicate interaction between the grain material and an ambient terrestrial field. It is equally important to distinguish between the effect of polarization of surface charges and that of the electric volume polarization, the resultant vector for a series of local dipoles.

Induced polarization. The lunar soil consists mainly of dielectric materials with dielectric constant about 2.5 at frequencies of 10^2 - 10^6 Hz in vacuum. The DC conductivity of 10^{-15} mho/m is low compared with that for terrestrial minerals (3). Literature data for induced dipoles in dielectrics of the order of 1 to 10 Debye are low compared to the lunar grain moments of 10^9 - 10^{14} D, i.e. negligible as significant error sources.

Dipole of grain interior. The dipole moment determined for a lunar grain in untreated condition, is undoubtedly a combined electric moment for the polarized surface charges and an internal polarization. Any excess surface charge has also to be considered. There is a remarkable structural difference

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S. K. Asunmaa and G. Arrhenius

between the very surface layer and the interior part of the grains exposed to solar radiation on the Moon. Some of the compositional and structural differences between the 500-1000 Å surface layer and the grain interior are known from extensive studies of fossil tracks, structural damage, accumulation of implanted atoms etc.

We have attempted to design experiments which could distinguish between surface polarization and polarization of the interior grain. Dipole moments for untreated lunar grains were compared with data for grain aliquots whose surface charges were removed by two alternative techniques: a) discharging by thermal stimulation with grains in mechanical contact with a heating element or exposed to IR radiation; b) elimination of charges by removal of the surface layer suspected to be the location of the great majority of charge carriers.

Comparison of dipole moments in aliquots with and without application of charge removal techniques, indicates that an essential fraction of the grains retains an electric dipole. This is understandable as an interfacial Maxwell-Wagner type polarization that occurs in heterogeneous dielectrics where adjacent components have differing electrical properties. The numerical value of the average electric dipole moment is reduced in many grains in the two treatments but grains with dipole strength of the same order of magnitude as in the untreated material, are not uncommon. Consequently lunar soil grains appear to possess internal volume polarization. Since the lunar grain interiors now have been shown to have dipole moments, the persistence of the adhesion between grains can be explained as interaction between these internal dipoles. For understanding the indicated polarization of the grain interiors, we discuss the various sets of interfaces and discontinuities that can produce charge separations in electric fields such as have been measured on the Moon's sunlit surface.

Internal interfaces as polarization sites. Active interfaces in the lunar grain interiors are noted as diffraction contrast in electron transmission and as satellites and pattern distortion in electron diffraction. These phenomena are probably caused by irradiation and thermal cycling of the soil and surface rocks.

Structural disturbance along the path of cosmic rays, point defects and vacancies and interstitials trapped in the structure, as well as ion implantation are known from the fossil track and other microstructural studies of lunar fines. Extensive studies are reported in the literature where the modification of materials properties have been studied by introducing defects under controlled conditions, simulating those prevailing on the Moon. Such studies include the formation of pn-junctions and a charged subsurface layer corresponding to the projectile mean free path in the material (4). Electrical resistivity, density and mechanical properties are drastically changed in irradiated materials (5). Condensation of point defects by migration results in formation of dislocations which in turn act as sinks for new vacancies. Quenching defects, 25 - 100A dark spots, and their coalescence products such as stacking faults are well documented in metals and ceramics as results from a variety of thermal treatments. The density per unit

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S. K. Asunmaa and G. Arrhenius

volume of quenching defects is in general measured by an increment in electrical resistivity (6). Since particle impacts e. g. cause intense local thermal effects on the Moon, it is reasonable to assume that quenching defects, shock front induced discontinuities etc. contribute to regions of disorder and strain that lead to increments in electrical conductivity i.e. to local liberation of charge carriers. Similarly, impurities are known to induce extrinsic liberation of electrons and holes in terrestrial materials. The same mechanisms must produce charge carriers at phase and impurity interfaces in the lunar grain interior, as evidenced by Figures 3 and 4. The DC conductivity measurements for both lunar soil and rocks indicate low values in the range of 10^{-15} mho/m. This is partly explained by the low water content of lunar rocks (3) but undoubtedly disorder and irradiation effects further contribute to the high resistivities in the soil grains. Impurity nucleation, negative crystals and trapping of implanted solar wind and flare ions in addition to strain fields and defects induced by thermal and irradiation effects provide excess charges and traps for charge carriers. Twinning is common in pyroxene and feldspar where twin planes represent another class of discontinuities. Indications of defect clusters below the resolving limit of the instruments used have been indicated by obstacles in dislocation movements in both technical materials and in lunar specimens. All the defect modes enumerated would provide electrostatically active interfaces as sites of polarizable space charges. The numerous interfaces of the various types discussed above are likely to be locations of space charges whose polarization would provide local dipoles with a resultant vector sum dipole as observed. We propose that it is a dipole-dipole interaction of this kind that results in the observed adhesion of lunar grains. The persistence of the adhesion is understandable as due to negligible charge leakage in the highly dielectric material where a charge transport is likely to take place through a hopping mechanism.

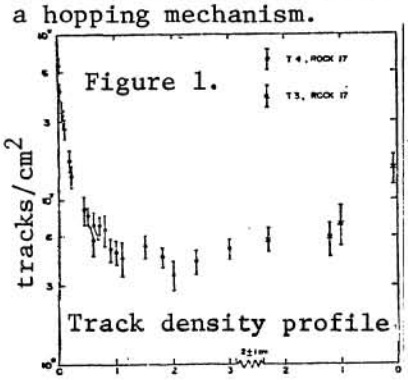

Figure 1.
Track density profile

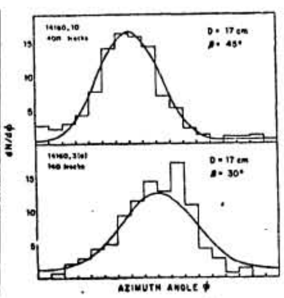

Fig.2. Azimuth angle distribution

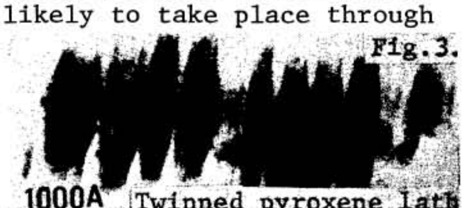

Fig.3.

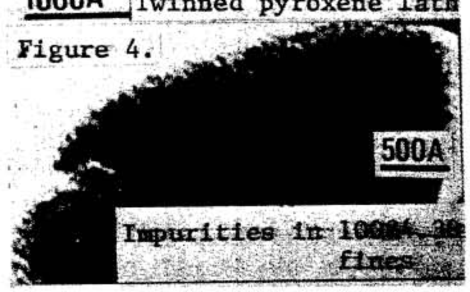

Figure 4.
Impurities in 1000A-38 fines

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