FORMATION OF LUNAR GLASSY SPHERULES: A DYNAMICAL MODEL

A. CARUSI and A. CORADINI
Istituto di Geologia e Paleontologia
University of Rome, Italy

and

M. FULCHIGNONI and G. MAGNI
Laboratory of Astrophysics, Frascati, Italy

Abstract. Glassy spherules ranging from 200 μ to 62 μ in size have been separated from lunar dust samples No. 12001.73, 12057.60, 12070.37. Most of them are regular in size (spherical, ellipsoidic, dumbbell, teardrop, etc.); some are irregularly shaped.

A tentative dynamical model of the evolution of a rotating melted spherical drop of homogeneous glassy material has been built in order to explain the observed forms. We suppose such fluid to be originated from the impact of meteoroids on the lunar surface. The energy balance between the projectile (meteoroid) and the target (lunar surface) has been calculated supposing that the impact gives rise to strong shock waves in both bodies.

Equations of the model have been solved numerically and a good agreement between these results and the experimental data regarding small spherules has been obtained.

1. Introduction

The samples of lunar dust which have been used for the experimental researches are No. 12001.73, 12057.60, and 12070.37 and consist of about half a gram each of lunar fines. The purpose of our studies is to determine some correspondence between the shapes of glassy spherules observed in the sample of lunar dust and the one we obtained from a theoretical model.

We assume the hypothesis of meteoritic origin of lunar spherules; then we studied the impact processes of a meteorite on the lunar surface, which allowed us to formulate a dynamical model correlating the various forms of lunar spherules with the characteristics of a homogeneous fluid generated by impact.

2. Meteoroids Impact Phenomena

The primary meteoritic hypothesis of lunar glassy spherules origin has to be excluded. In fact the chemical composition of the lunar spherules is usually missing among the cosmic dust collected by satellites and rockets. In Table I the average chemical composition of the spherules and of the corresponding lunar soil is reported. The chemical composition of the two is quite similar.

Besides, the probability of finding such a figure ($=1000$ spherules mm^{-3}) of micrometeorites is really low if their spatial distribution follows the mass law [Whipple, 1968]

$$f(m)\,\mathrm{d}m = Am^{-\alpha}\,\mathrm{d}m$$

Urey and Runcorn (eds.), The Moon, 180–184. *All Rights Reserved.*

TABLE I

	Average lunar spherules chemical composition (%)	Average lunar soil chemical composition (%)
SiO_2	0.45	0.42
TiO_2	0.05	0.03
Al_2O_3	0.15	0.14
FeO Fe_2O_3	0.15	0.17
CaO	0.10	0.10
MgO	0.09	0.11
MnO	0.02	0.02
Na_2O K_2O	0.01	0.05

where A and α are constants experimentally determined. Considering the micrometeorites impact as a random event, we will therefore suppose that the spherules are the secondary products of a meteoritic impact on the lunar surface.

It is possible to describe this phenomenon in the following way: at the beginning (compression phase) the meteoroid (projectile) impacts the lunar surface (target) and generates a strong shock wave system which causes both in the projectile and in the target an increase of pressure of up to some megabars.

During this phase the target material is stressed much more than its rupture point, than we can consider the process as a hydrodynamic one.

When the wave front reaches the free surface of the involved materials a rarefaction waves system is generated which precedes the ejection of high velocity material.

Let us now examine the energetic aspects of the phenomenon (Gault and Heitowit, 1963). On first estimate we can describe the phenomenon in the following way. We suppose that the surface of the projectile and the target are plane and semi-infinite.

In a reference system solidale with the unaltered medium the equations by Rankine-Hugoniot are still valid

$$\mathrm{d}_0 W = \mathrm{d}\,(W - w) \tag{1}$$

$$p = \mathrm{d}_0 W w \tag{2}$$

$$E - E_0 = \tfrac{1}{2} p\,(1/\mathrm{d}_0 - 1/\mathrm{d}) = \tfrac{1}{2} w^2 \tag{3}$$

The system is completed by the experimental equation

$$W = a + bw \tag{4}$$

W is front of shock wave velocity and w is the material velocity, a and b are constants experimentally determinated (Al'tshuler *et al.*, 1961; Lombard, 1961; Rice *et al.*, 1958; Kormer *et al.*, 1962).

Adding to preceding equations the condition

$$V_i = w_p + w_t \tag{5}$$

where w_p, w_t are the velocities of the material in the projectile and in the target, it is possible to find the values of the pressure and the energy which belong to the two bodies.

In Table II for an impact velocity of 13 km s^{-1} the projectile and the target material

TABLE II

Impact velocity $V = 13$ km s^{-1}

	Cu	Zn	Ag	Cd	Au	Pb	Bi	Fe
Projectile material velocity (km s^{-1})	8.60	8.08	8.83	8.34	9.70	8.45	8.31	8.44
Target material velocity (km s^{-1})	4.40	4.42	4.17	4.66	3.30	4.46	4.69	4.56
Compression								
Projectile pressure (dyne $cm^{-2} 10^{-14}$)	0.12	0.08	0.15	0.11	0.32	0.13	0.11	0.11
Target pressure (dyne $cm^{-2} 10^{-13}$)	0.12	0.15	0.11	0.13	0.75	0.12	0.14	0.13
% energy trapped in the projectile	0.55	0.53	0.56	0.54	0.62	0.55	0.54	0.54
% energy trapped in the target	0.45	0.47	0.44	0.46	0.38	0.45	0.46	0.46
Rarefaction								
% irreversibly trapped energy in the projectile	0.62	0.54	0.49	0.43	0.44	0.42	0.36	0.57
% irreversibly trapped energy in the target	0.73	0.65	0.77	0.69	0.97	0.72	0.68	0.70

velocity, the projectile and the target pressures, and the percent of energy irreversibly trapped in the compression and rarefaction phases have been reported for some pure element projectile and for basaltic target.

3. Dynamical Model

The energy trapped by the target is enough to provoke the volatilization, the melting and the ejection of prevailingly molten material. The fluid is in dynamic condition; consequently it has a large kinetic energy per unit of volume and therefore has the tendency to divide itself in small fluid particles in rotation too.

Owing to the surface tension those particles get a spherical form. It has been observed experimentally that most of the lunar dust particles have a regular enough form.

About 40% of the glassy particles are almost perfectly spherical forms.

Non-spherical particles can be fully irregular or may show some elements of symmetry; the last ones can be grouped in various classes: ellipsoidic forms, cigars, dumbbells, teardrops (Fulchignoni *et al.*, 1971).

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To explain the observed morphologies we have built a dynamical model of the evolution of a rotating melted material spherical drop governed by simultaneous actions of surface tension and centrifugal force.

Owing to the high available energy it will be possible for a large range of angular velocities to distribute themselves among the fluid particles in a statistical way. The possible situation of stable or unstable equilibrium will depend on the dimensions of the particles and their kinetic energy.

In the case of instability it is possible to calculate the particle breaking-time; these times are comparable to the cooling times obtained by black-body radiation law.

Considering the opacity (Isard, 1971), the solidification time became much larger, therefore it is reasonable to assume that the experimentally obtained forms are equilibrium forms.

Considering for the surface tension potential

$$V_{ts} = T \int_{\sigma} \mathrm{d}\sigma \tag{6}$$

where T stands for surface tension coefficient, and σ is the particle surface and for the centrifugal force potential

$$V_c = \tfrac{1}{2}\omega^2 d \int r^2 d\tau \tag{7}$$

where d is the density of the particle, ω is the angular velocity, r is the radius and τ the volume, the total potential of the system will be

$$V = V_c + V_{ts}.$$

Putting now r function of ϑ, φ all space surfaces can be represented; choosing for r an adequate parametric expression, V_c and V_{ts} will be functions of the adopted parameters $c_1 \ldots c_n$.

To determine the equilibrium conditions of the drop under the action of the above-mentioned forces, let us minimize their total potential with the restricting condition of the volume constant.

This problem has been solved numerically.

In applying the above-mentioned method we have calculated the equilibrium surfaces of a fluid supposed to be homogeneous, obtained varying only one free parameter starting from the spherical configuration. In this particularly simple case the equilibrium surfaces can be nothing but rotation ellipsoids.

On Figure 1 values of the parameter (eccentricity) at the equilibrium in function of ω for some values of the volume have been reported.

Increasing the parameter number and choosing for $r(\vartheta, \varphi)$ an expression

$$r^2(\vartheta, \varphi) = c^2 \cos 2\vartheta + \sqrt{k^4(\vartheta, \varphi) - c^4 \sin^2 2\vartheta}.$$

We can see that increasing ω we obtain some shapes which approximate the entire range of experimentally found shapes.

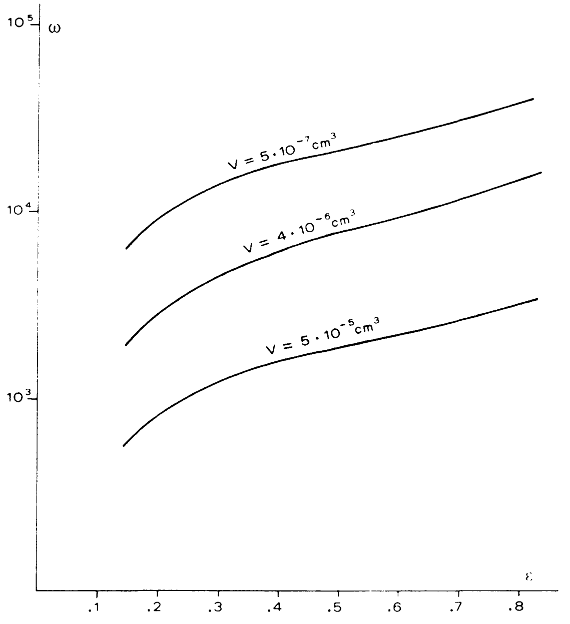

Fig. 1.

The results numerically obtained simulating the meteorite impact of pure metal on the basaltic target give a representation of the phenomenon in agreement with the experimental results.

In fact a large number of particles with a chemical composition similar to soil have been found. The balance between the internal and kinetic energy distributed between the projectile and the target, gives values for the kinetic energy of the ejected melt fluid that are compatible with the minimum threshold required by the dynamic model to obtain the particle morphologies.

The obtained results may be improved by refining the hypothesis. But the lack of complete experimental data (i.e. the coefficients of the equations describing the evolution of the shock wave in the solid) may render useless a more sophisticated approach.

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