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"Impact and Collisional Processes in the Solar System"

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We are carrying out a program of experimental research dealing with the mechanical and thermodynamic aspects of shock impact cratering and accretionary processes on solid planets and satellites.

1. Impact Spall and the Spall Strength of Rocks

The recently proposed model of Melosh (1984), describing the physics controlling the size and velocity of only lightly shocked spalled ejecta surrounding the crushed rock region of an impact crater, has provided a model for possibly delivering meteorites such as ALHA81005 (the "lunar meteorite") from the Moon to the Earth.

The model appears to provide a good framework for relating dynamic tensile (spall) strength to crater spall thickness for gabbro. Gabbro, the only rock-type for which we have tested the theory (Lange et al., 1984A) has given results which provide strong impetus for further experimentation.

In an attempt to provide experimental data to test the Melosh (1984) spallation model, a series of experiments has been developed to determine spall velocities and to map the shape of the detached shock wave for impacts into competent rock.

We have started to carry out some spall velocity measurements. Our work carried out at the Ames gun has demonstrated that impact spalls could be easily obtained on that facility in a "recovery" mode. At Caltech our first simple experiments employed projectiles of aluminum and lead fired from a rifle at targets of San Marcos gabbro. The impact velocity in these experiments was near 1 km/sec.

The resulting velocities were 11 m/sec and 17 m/sec for the lead and aluminum bullets, respectively. This is approximately 2% of the impact velocity and 5-80 times lower than the velocity predicted by the Melosh model. However, there are a number of reasons which could explain this discrepancy.

We are presently carrying out a series of impact spall experiments for use in the vertical gun facility to be impacted in a 4 to 6 km/sec range. Initial targets are of anorthosite and gabbro.

2. Shock Temperatures in the Heterogeneous Regime

Because knowledge of shock and post-shock temperatures are crucial to construct complete equations of state of planetary materials, we are carrying out measurements based on radiative techniques of shock temperatures of silicates and volatile-bearing minerals.

Quantitative knowledge of shock and post-shock temperatures provide the physical basis for describing the melting and partial vaporization and phase transitions associated with planetary accretion and impact.

New spectra and radiative temperatures of shear bands (which we believe are at the melting point) have been acquired for shocked minerals. Also simultaneous framing camera images acquired for calcite, both fused and crystal quartz and sodium chloride. Because quasistatic melting data for Mg_2SiO_4 are available to 15 GPa we have recently prepared a series of high quality peridot samples for shock temperature, shear band measurements. The hypothesis that shear bands are at the melting point needs rigorous testing. If we can show that this is the case, this technique has promise to allow determination of the melting point of quite a large number of minerals and cosmochemical interest at high pressures. We have acquired samples of a series of solar system materials and expect to carry out experiments during the next year.

3. Impact Devolatilization of Minerals and Accretion of Planetary Atmospheres

Volatile-bearing minerals, especially phyllosilicates, carry much of the water of carbonaceous chondrites, and control their oxidation state and contribute to the atmosphere of planets (Earth, Venus, Mars, and Titan) during accretion. We have been obtaining the first release adiabat data for this class of materials. Shock compression Hugoniot data for serpentine, brucite, gypsum, calcite, and aragonite have demonstrated that these minerals undergo shock-induced phase changes to high pressure phases. Although the compression behavior of these materials was approximately known, the shock pressures, which correspond to various infall velocities required to cause incongruent vaporization upon adiabat release and produce volatile release, were previously unknown or poorly defined (Lange and Ahrens, 1982).

During the last year we have carried out new measurements of the release isentropes of $CaCO_3$ (both polycrystalline and porous), as well as new Hugoniot and release isentrope experiments on $Mg_3Si_2O_5(OH)_4$ (chrysotile) to 22 GPa. In this recent work we have improved on the earlier buffer-method of laboriously obtaining one or two release datum or data per experiment. We are now constructing multiple particle velocity electromagnetic gauge targets and measuring wave profiles upon release in several positions in the targets. This method permits continuous release isentrope measurements to be carried down to pressures of 2 to 3 GPa in a single experiment where we can begin to see the effect of the partial pressure of the volatile in the post-shock environment.

We have also carried out more recovery experiments on porous calcite in addition to the single crystal experiments, these data and an accompanying model, at least in a simple way, the range of planetary sizes which control the generation and occurrence of CO_2-rich atmospheres on the Hadean earth, Venus, and Mars via the following reactions which may occur upon accretion of carbonaceous chondrites. We also carried out some recovery experiments on the Murchison chondrite to compare volatile release with data for phyllosiliate minerals.

We have started to examine the effect on the water budgets of the planets, of reactions which occur when metallic iron, which would be present in chondritic material, is introduced in a simple accretion model. Reactions such as

$$Mg_3Si_2O_5(OH)_4(\text{serp.}) \xrightarrow{\text{shock}} 2H_2O + Mg_2SiO_4 + MgSiO_3 \quad (1)$$

$$2H_2O \rightarrow 2H_2 \text{ (escape)} + O_2 \quad (2)$$

$$MgSiO_3 + Fe + H_2O \rightarrow 1/2Fe_2SiO_4 + 1/2\ Mg_2SiO_4 + H_2 \text{ (escape?)} \quad (3)$$

may control the total fayalite (or ferrosilite) budget of planetary mantles. Ringwood has pointed out the importance of reaction (3) in the evolution of the terrestrial planets. We believe our study is the first serious quantification of this issue.

Publications:

Impact cratering and spall failure of gabbro, by Manfred A. Lange Thomas J. Ahrens, and Mark B. Boslough, Icarus, 58, 383-395, 1984.

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CO_2 loss in shock-loaded calcite and implications for primary atmospheres, by M. A. Lange and T. J. Ahrens, to be submitted to Earth and Planetary Science Letters, 1984.

FeO and H_2O and the homogeneous accretion of the Earth, by M. A. Lange and T. J. Ahrens, Earth and Planetary Science Letters, in press, 1984.

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