IMPACT EXPERIMENTATION AND THE MICROGRAVITY ENVIRONMENT:

AN OVERVIEW

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The following is a summary of a brief presented to the Space Station Planetary Experiments Panel at NASA Headquarters, Washington, D.C., on the 13th June, 1985.

INTRODUCTION

Impact occurs when bodies collide. It is thus an ubiquitous physical process in the solar system. Impact occurs on all solid bodies and operates over a spectrum of scales. It influences geologic processes ranging from accretion, the early evolution of planetary bodies, the petrogenetic and spatial relations of lunar samples, the surface characteristics and interpretation of spectral data of asteroidal bodies, to the nature of some meteorites. Understanding impact phenomena is therefore paramount in constraining and underpinning a large number of research efforts into fundamental problems in planetary geology.

Natural impact processes can not be observed directly. For example, the present understanding of impact cratering comes from the integration of direct and remote observations of impact craters on earth and other bodies, the results of relatively small-scale laboratory experiments, man-made explosions, and theoretical calculations. Gravity is an important parameter in the cratering process, affecting the size of crater excavation, the post-excavation modification of the cavity by gravitational collapse, the spatial distribution of ejected materials, and the effectiveness of this ejecta in producing secondary cratering events. With few exceptions previous experimental studies of cratering processes have been undertaken at gravitational accelerations of 1g or higher. These are not the gravity conditions occurring on most solid bodies in the solar system. The physical environment offered ultimately by Space Station represents an unique opportunity to extend the experimental aspect of impact studies into the microgravity (<1g) regime.

CURRENT EXPERIMENTATION

Previous and current experimental studies of impact phenomena address a variety of problems. Flat plate accelerators are used to determine the petrographic effects produced in rocks and minerals by specific shock pressures and to determine the general behaviour of geologic materials at ultra-high pressures. Other experiments are designed to investigate disruption phenomena associated with regolith development and solid body collisions. The bulk of impact experimentation, however, has been concerned with crater growth and scaling. Experimental data have established that at impact energies above $\sim 10^{18}$-10^{19} ergs (equivalent to the impact of an iron meteorite in the meter-size range impacting at 20 km s^{-1} in a 1g environment), crater excavation occurs in the so-called "gravity regime", where target strength effects are unimportant. This condition is simulated experimentally by using low strength materials, such as sand or water, and by the use of elevated gravitational accelerations. The effect of elevated gravity is to displace the onset of the gravity regime to lower energies. Such experimentation has led to the development of scaling relations, where cratering efficiency is related to a dimensionless parameter which includes the effects of projectile velocity and size, and gravitational acceleration.

FUTURE EXPERIMENTATION IN THE MICROGRAVITY ENVIRONMENT

"Large" impact events

There has been some recent criticism of the dimensionless scaling relationships. For example, it has been suggested that additional parameters such as the shape of the experimental projectile and variable energy losses due to waste heat in the target are not fully accounted for in the dimensionless parameters. Thus continuing work is required in this area. The opportunity to conduct new experiments at gravities directly applicable to that of planetary bodies will contribute to determining and refining the relevant scaling relations for large craters. Apart from their importance in problems concerned with cratering mechanics, such relations are required to correctly relate crater densities on different solar system bodies to absolute surface ages.

An additional advantage of the microgravity environment is that, is for a given impact event, reduced gravity increases the crater growth time. It will be possible, therefore, through high-speed photography to observe the crater growth and ejecta dynamics in considerably more detail than in previous 1g experiments. This will lead to a better understanding of the relative importance of rebound and collapse phenomena in crater formation and the nature of the ejecta plume as an erosional and depositional agent.

"Small" impact events

In the low energy impact regime ($<10^{18}$ ergs), target strength parameters become increasingly important. In the low strength materials used in impact experiments under terrestrial conditions, gravitational forces dominate other bonding forces, such as surface tension, electrostatic effects etc. This may not be the case under highly reduced gravity conditions, which prevail on small asteroidal bodies. Even if current dimensionless scaling relations are shown to be substantially correct for large planetary craters, they can not be applied to this regime. Cratering experiments at highly reduced gravities, corresponding to asteroidal bodies, will therefore provide basic and currently unavailable information on cratering and regolith development or lack of it on these bodies.

Spatial distribution and state of ejecta

Previous experimentation provides little or no information on the spatial distribution, source region and physical state of ejecta under different gravity conditions. The few experiments designed to address these fundamental questions all have been undertaken at 1g. Similarly, the only direct observational data on these questions are from terrestrial craters. It is well-established that for a specific impactor size and velocity and target materials, crater size will increase with decreasing gravity. However, peak shock pressures and the spatial distribution of shock isobars in the target are not a function of gravity and will remain constant. Thus, the equivalent impact event under reduced gravity will excavate a greater proportion of less shocked materials than its counterpart at higher gravity. The reduced gravity environment afforded in near-earth orbit provides an opportunity to consider the questions of ejecta source and shock state and its final distribution under varying gravitational accelerations. These questions are highly germane to problems such as the physical and thermal state of ejecta blankets and regolith development on both planetary and smaller bodies. These relate directly to questions in lunar sample and meteorite analyses and the interpretation of remotely-sensed spectral and geochemical data.

Body Collisions

The microgravity environment opens up new and potentially rewarding area of impact experimentation not previously possible. Through the use of free-floating targets it will be possible to explore in detail phenomena associated with the collision of bodies. These experiments will address questions regarding early and late accretional processes, catastrophic disruption and asteroidal evolution, as well as the effects of large impacts on the momentum and spin of the target bodies. The last question is of considerable topical interest with respect to the origin of the moon by a Mars-sized impact on the early Earth.

VIEWGRAPHS USED FOR PRESENTATION

TO SPACE STATION PLANETARY EXPERIMENTS PANEL,

NASA HEADQUARTERS, WASHINGTON

D.C. 13th JUNE, 1985

IMPACT OCCURS WHEN BODIES COLLIDE. IMPACT IS THEREFORE A FUNDAMENTAL PHYSICAL PROCESS IN THE FORMATION AND EVOLUTION OF THE SOLAR SYSTEM. IT DOMINATES OR INFLUENCES:

- ACCRETION
- CRUSTAL EVOLUTION
- SURFACE EVOLUTION
- BIOLOGICAL EVOLUTION

UNDERSTANDING IMPACT PHENOMENA IS KEY TO CONSTRAINING OTHER SUBDISCIPLINES OF PLANETARY SCIENCE. FOR EXAMPLE, IN THE GEOLOGICAL SCIENCES UNDERSTANDING IMPACT PROCESSES PLAYS A ROLE IN THE INTERPRETATION OF:

- RELATIVE AND ABSOLUTE SURFACE AGES
- PETROGENESIS AND SPATIAL ORIGIN OF EXTRATERRESTRIAL SAMPLES
- SPECTRAL REFLECTANCE MEASUREMENTS

AS IMPACT IS A TRANSIENT, HIGH ENERGY EVENT, THERE ARE INHERENT DIFFICULTIES IN ITS STUDY AND UNDERSTANDING. PRESENT UNDERSTANDING ARISES FROM A NUMBER OF SOURCES:

- TERRESTRIAL CRATERS
- PLANETARY CRATERS
- EXPLOSIVE EXPERIMENTS
- IMPACT EXPERIMENTS
- MODEL CALCULATIONS

THE BULK OF THE PAST AND PRESENT EFFORTS CENTER ON CRATERING AND ASSOCIATED PHENOMENA.

INDIVIDUAL SOURCES OF INFORMATION HAVE ADVANTAGES AND DISADVANTAGES FOR UNDERSTANDING CRATERING PHENOMENA. FOR EXAMPLE,

TERRESTRIAL CRATERS

- LARGE RANGE OF ENERGIES BUT LITTLE KNOWLEDGE OF INITIAL CONDITIONS
- POTENTIALLY GOOD CONTROL OVER FINAL GEOLOGICAL/STRUCTURAL FORM BUT POOR PRESERVATION

IMPACT EXPERIMENTS

- KNOWN INITIAL CONDITIONS BUT SMALL AND LIMITED RANGE OF ENERGIES
- DYNAMIC CONDITIONS BUT ON A VERY SHORT TIME-SCALE

CURRENT AREAS OF IMPACT EXPERIMENTATION

• SHOCK METAMORPHISM	FLAT PLATE ACCELERATOR
EQUATION OF STATE DATA	
• CATASTROPHIC DISRUPTION	NASA-JSC VERTICAL GUN
	NASA-AMES FACILITY
• CRATER GROWTH AND SCALING	NASA-AMES FACILITY; VARIABLE ANGLE, 1g (ONE SERIES AT < 1g)
	BOEING 600g GEOTECHNIC CENTRIFUGE; VERTICAL, 1-600g

CURRENT PROBLEMS BEING ADDRESSED THROUGH EXPERIMENTATION

- CALIBRATION OF PETROGRAPHIC FEATURES WITH SHOCK PRESSURE
- SPECIFIC ENERGY REQUIRED TO DISRUPT MATERIALS
- SOURCE, DISTRIBUTION AND PHYSICAL STATE OF EJECTA AT 1g
- CRATER GROWTH AND SCALING

SOME PROBLEMS WHICH CANNOT BE ADDRESSED ADEQUATELY IN CURRENT EXPERIMENTATION

- RELATIVE IMPORTANCE OF REBOUND AND COLLAPSE PHENOMENA IN CRATER GROWTH
- SOURCE, DISTRIBUTION AND PHYSICAL STATE OF EJECTA ON BODIES OTHER THAN EARTH
- CRATERING ON SMALL BODIES
- REGOLITH DEVELOPMENT AND CHARACTER ON SMALL BODIES

ADVANTAGE OF MICROGRAVITY ENVIRONMENT FOR IMPACT EXPERIMENTATION

TRADITIONAL AREAS

- SLOWS DOWN CRATER GROWTH FOR BETTER OBSERVATION OF DYNAMICS
- PROVIDES DIRECT INFORMATION ON SCALING AND EJECTA CHARACTER AT $< 1g$

NEW AREAS

- "ACCRETION" EXPERIMENTS - COLLISION OF FREE FLOATING BODIES
- DETERMINATION OF MATERIAL PROPERTY EFFECTS ON IMPACT DYNAMICS