EXPERIMENTAL AND ANALYTICAL STUDIES OF CRYSTALLINE DAMAGE USEFUL FOR THE RECOGNITION OF IMPACT STRUCTURES

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Large-scale effects of high-energy impacts have their counterparts in individual mineral crystals within the affected masses. Minerals of great stability preserve a record, decipherable by x-ray and optical methods, which may outlast grosser deformational features of the impact site.

X-ray methods can reveal internal fragmentation of crystals subjected to shock by the degree of asterism of the characteristic diffraction spots. For this study, and for the detection of high pressure phases, it is most practical to use the Debye-Scherrer technique with a single crystal (0.05–0.10 mm) rotated in the beam. Specimen crystals of quartz, calcite, and other minerals were examined from shatter cones, meteorite craters, volcanic and metamorphic rocks, atomic and chemical explosion sites, and elsewhere. Of special interest is the discovery of coesite in samples from the Sedan nuclear cratering event. Also examined were compacted powders of quartz and other minerals subjected to pressures of up to 120 kb at various strain rates in an opposed-anvil apparatus. The asterism-pressure relations found were comparable to those of granite samples from the Hardhat nuclear event, taken from known pressure zones.

Where the original location of a sample in the impact structure is not known, the asterism may be compared directly with that of samples ranging from undisturbed crystals to massively shocked ones. On a log–log plot of asterism vs. the asterism/line breadth ratio, a linear trend is obtained which is almost identical for both carbonate minerals and quartz. Volcanic and metamorphic samples give low values, while crystals from shatter cones or from shocked rocks have higher values, covering over two orders of magnitude.

An optical method for recognizing rocks subjected to shock processes is based on measurements of the spread of the optic axes of individual fragments of damaged single crystals. A Schmidt net plot of the fragment poles of a crystal provides a measure of its disruption. Averaged over 25 to 50 grains, the spread is greater for samples from meteoritic craters or explosion sites than for those from typical metamorphic, volcanic or undisturbed environments.

Observations made of light scattering from various rock specimens and single grains under illumination by a low intensity gas laser beam may have bearing on the reflective properties of the lunar surface.

INTRODUCTION

This conference on shock metamorphism attests to an expanding recognition of cosmic collision as a significant geological process. Investigations in this field are concerned with structures ranging in size from craters ($\leq$500 km) through large masses of chaotic breccia and individual shatter cones and down to individual lamellae less than a micron wide in discrete mineral grains. Some 12 orders of magnitude in linear dimensions are thus covered in such investigations, using visual methods from telescopic to microscopic. This work represents an extension to even lower limits of observation, by the use of x-ray and other methods to investigate small-scale structural effects which may be characteristic of high-energy impact processes.

Many lines of evidence are needed to detect or confirm remaining traces of meteorite impacts. Both the large structural features of craters, and even the metastable high-pressure phases of silica so useful as "index" minerals, are subject to erasure and alteration (Skinner and Fahey, 1963; Dachille, Zeto, and Roy, 1963; Gigl and Dachille, 1967). The effectiveness of these alteration processes is emphasized by the fact that, although about one million crater-forming impacts are

TABLE I

Sources of the minerals used in x-ray studies

Structure and locality	Rock type	Mineral studied
Meteorite impact craters		
Ries Kessel, Germany	suevite	quartz
Meteor Crater, Arizona	Coconino ss.	quartz
Steinheim basin, Germany	limestone	calcite
Wabar, Arabia	sandstone	quartz
Odessa, Texas	sandstone	quartz
Holleford, Canada	granite	quartz
Explosions		
Nuclear; Bonanza King Formation, Nevada	limestone	calcite
Nuclear; Hardhat Shot, Nevada	granodiorite	quartz
Nuclear; 100 kton-Sedan	granite	quartz
High Explosive (1000 lbs. TNT)	sandstone	quartz
Shatter cones ("crytoexplosion" structures)		
Decaturville, Missouri	limestone	dolomite
Wells Creek, Tennessee	limestone	dolomite
Sudbury, Canada	quartzite	feldspar
Sudbury, Canada	quartzite	quartz
Sierra Madera, Texas	sandstone	quartz
Steinheim basin, Germany	limestone	quartz
Vredefort, Africa	sandstone	quartz
Kentland, Indiana	sandstone	quartz
Metamorphics		
Nottingham, Pennsylvania	chlorite-magnetite mica-phyllite	quartz
Pilar, Norway	Metaquartzite	quartz
Arendale, Pennsylvania	biotite granite gneiss	quartz
Baker, Pennsylvania	phlogopite-tremolite marble	calcite
Pomeroy, Pennsylvania	marble	calcite
Volcanics		
Mt. Shasta, USA	volcanic bomb	quartz
Ubehebe Crater, California	volcanic bomb	quartz
Little Glass Mt., California	volcanic bomb	quartz
Mono Craters, California	pumice	quartz
Single crystals		
Large, euhedral crystals, source unknown:		
4 inches	natural quartz crystal	
2 inches	natural calcite crystal	

estimated (Dachille, 1962) to have been sustained by the Earth during its history, the number of structures which have even been considered to be of impact origin is presently under 120 (O'Connell, 1965; Freeberg, 1966). The number of accepted impact craters or possible craters actively being studied at this time is only about 50. Even at the optimistic rate of one crater discovery per month, only a small gain will be made, even in several centuries, in accumulating evidence of large numbers of catastrophic impacts. It is to be expected that, with time, more evidence will have to be sought at the lower end of the structural dimension scale, thereby placing increasing emphasis on microscopic and x-ray methods in the study of rock specimens and of individual crystals.

SCOPE OF THE STUDY

The conversion of the energy and momentum of a cosmic impact sets up, among other things,