a gradient of pressures from many megabars down to less than one kilobar and of temperatures from about 0.5×10^6 °K to ambient. Along these gradients, the structural integrity of single crystals is modified but may not be completely destroyed. Because of the unusual intensity and very short duration of impacts, the response of crystalline material might be expected to be characteristically different from effects imposed by normal metamorphic processes.

Unusual differences were sought in single crystals by using (a) single crystal x-ray diffraction methods to detect disruption of crystalline order and (b) microscopic observations of scattering of optic axes of subgrain fragments or of strained portions within disturbed single crystals. Observations were also made of the light-scattering properties of various rock specimens and single grains under illumination by a laser beam.

The samples investigated came both from accepted impact craters and from other non-impact environments, in order to provide specimens from a diversity of metamorphic and non-metamorphic conditions. Specimens included material from chemical and atomic explosions, volcanic bombs, slickensides, shatter cones, and fracture cones (Table 1 lists the materials used in the x-ray studies).

In addition, deformation effects were produced in polycrystalline compacts and cemented wafers during high-pressure experiments which employed opposed-anvil apparatus to simulate quasi-shock conditions.

X-RAY DIFFRACTION STUDIES

The x-ray procedures used were first described by Dachille, Meagher, and Vand (1964). Typical grains or single crystals are selected from rock samples, preferably from freshly-broken, unweathered surfaces. Under a binocular microscope, grains 0.05 to 0.1 mm in diameter are mounted on the end of fine glass fibers, and then examined in an immersion cell with a petrographic microscope in order to select those which appear to be single crystals. Such grains are then mounted in 114.6-mm diameter Debye–Scherrer x-ray diffraction cameras and exposed to Ni-filtered CuKα radiation, or to other wavelengths if necessary. The specimen is rotated during exposure.

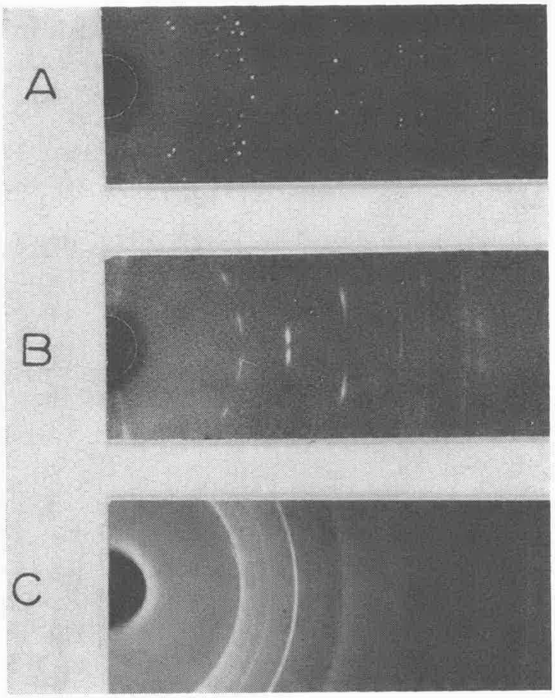

Fig. 1. X-ray diffraction spot pattern obtained from a small, undistorted crystal of beryl (A), contrasted with elongated spots of a deformed single zircon crystal in a sample from Ries, Germany (B), and with the "powder arc" pattern of a small crystal of albite, also from the Ries (C).

The resulting x-ray diffraction photographs reveal the relative perfection of these crystals. A good single crystal will yield a pattern of typical rounded spots, a mildly disturbed one will produce diffraction spots with varying degrees of elongation (asterism) and a highly shocked "single crystal" will yield arcs characteristic of powder patterns (Fig. 1). A critical point is that these types of patterns are all obtained from individual grains 0.1 mm or smaller in size.

Certain minerals may be more difficult to use than others for demonstrating differences in crystalline damage because of individual peculiarities of structure or because of very fine grain size. However, even micas, whose layered structure produces patterns indicating a high degree of orientation and curvature of lattice planes, can demonstrate effects of shock damage.

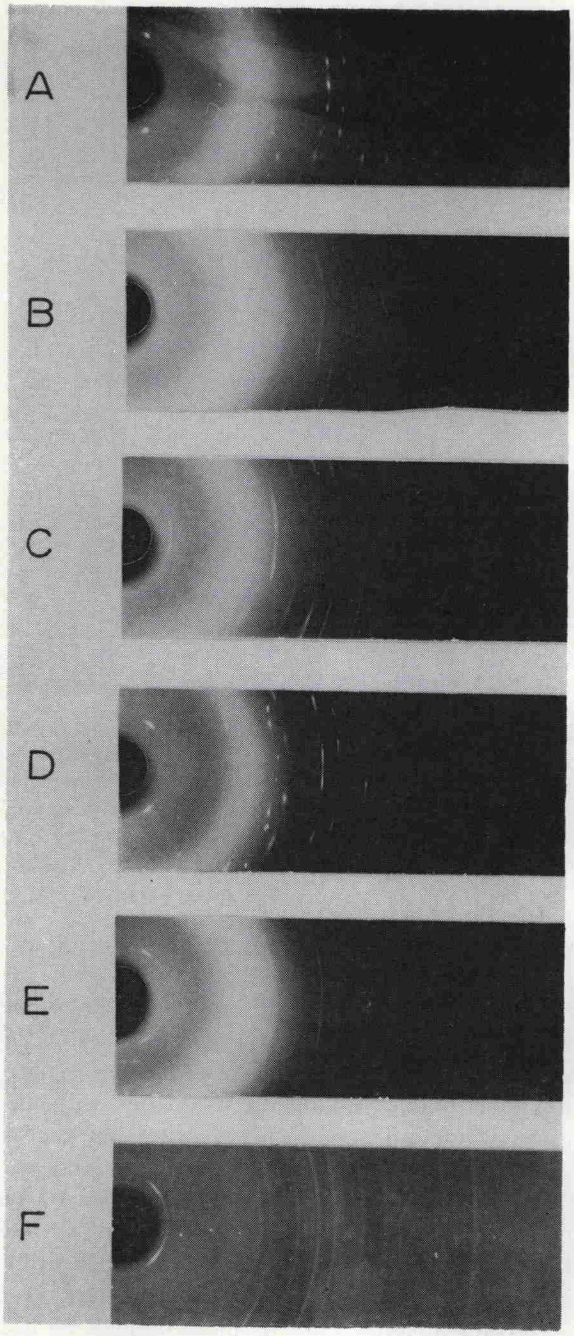

Fig. 2. "Single crystal" x-ray diffraction patterns obtained from micas; (A) typical, undeformed; (B), (C), (D), and (E), artificially subjected to 30 kb, 60 kb, 90 kb, and 120 kb respectively (see text); (F), a Ries, Germany sample.

In Figure 2, photographs (A) and (F) contrast patterns obtained from a small crystal of mica from an igneous rock (actually a "book" of crystals) with that of a mica crystal from a specimen of shocked rock from the Ries crater, Germany.

Limestones and dolomites are usually made up of very fine crystals, too small for normal use as indicated above. With such materials, small grains of equal volume can be used to provide roughly comparable patterns. In Figure 3, the diffraction pattern obtained from a limestone (A) and from the surface of a fracture cone formed in this limestone by dynamite during quarrying operations (B) are contrasted with the diffraction pattern of a grain from a shatter cone from the Steinheim Basin, Germany (C). It is apparent that the relatively mild quarrying explosion has served to break up and disorient the calcite crystals, but not to the extent indicated by the smooth, homogeneous arcs of the Steinheim sample.

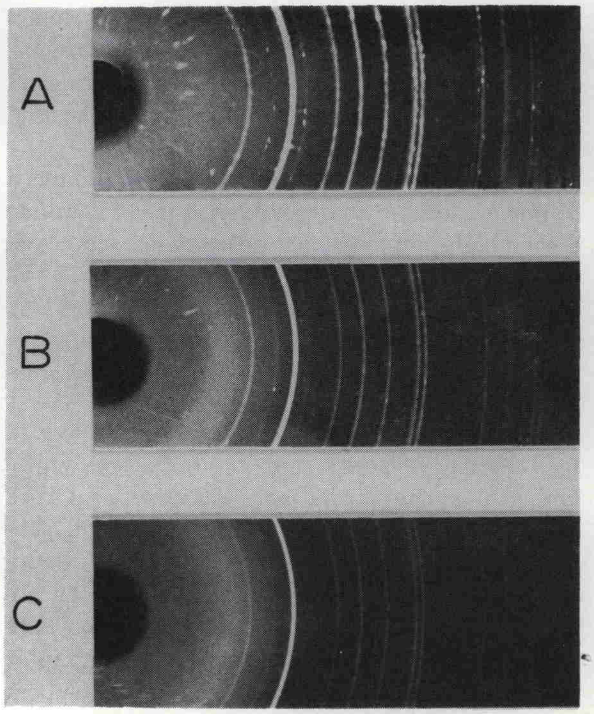

Fig. 3. X-ray diffraction patterns obtained from small grains of limestone from: (A) Trenton 1s.; (B) Trenton 1s. fracture cone; (C) Steinheim Basin shatter cone.