

atoms on both sides of the crack and this may be derived from the strain energy of the crystal; this distinguishes it from "ductile fracture", in which material must be deformed plastically at the ends of cracks for propagation to take place (Orowan, 1949). The work done in the latter process is much greater than that required to overcome the cohesive forces. The initial flaws or cracks which give rise to either brittle or ductile fracture may be produced by small plastic deformations. However, this hypothesis implies that there need be no relationship between the measured strengths and the curve predicted by the Griffith equation (above) since the factor which controls strength in this hypothesis is the stress necessary to induce the movement of dislocations (plastic flow) which produce the initial cracks, rather than the stress necessary to propagate pre-existing cracks.

In recent years the mechanisms of fracturing in many different materials have been intensively studied (Averbach and others, 1959). It has been shown that plastic deformation commonly precedes brittle fracture and that several dislocation mechanisms may give rise to cracks large enough to be "dangerous" in the Griffith sense and propagate as brittle fractures. In particular, high stress concentrations may develop at the intersections of primary and secondary slip bands, due to the pile-up of dislocations, and give rise to the initial cracks (Cottrell, 1959). This mechanism has been demonstrated in MgO crystals by Parker (1959) and Stokes, Johnston, and Li (1959). Parker considers that most cracks originate in a $\{100\}$ cleavage plane, which is equally inclined to the two $\{110\}$ slip-planes at their intersection, though he also reports some cracks originating parallel to the slip-planes. Stokes, Johnston, and Li (1959) have shown that the cracks in their experiments all originate in the $\{110\}$ slip-planes. The resulting fracture is typically brittle in these experiments. Various other dislocation models have been suggested for initiating cracks, which may subsequently grow as either brittle or ductile fractures (Orowan, 1954; Hahn and others, 1959; Cottrell, 1959).

The most satisfactory hypothesis to explain the crystallographic nature of the faults is that cracks were initiated by yielding and slight plastic flow on certain planes, notably c , r , and z , and then propagated rapidly in these planes by the brittle fracture mechanism.

The Nature of the Microtextures.—The larger birefringent haloes or rosettes are generally, though not invariably, associated with extension fractures parallel to the ends of the cylinders, formed during unloading of the samples. This suggests that they may be due to residual stress at the leading edge of the cracks. To test this, a polished basal plate of quartz, less than 2 mm thick, was fractured so that some cracks extended part way into the crystal; the plate was observed on a polarizing microscope with the analyzer rotated to compensate for the rotation of the plane of polarization in the plate, and a crack was propagated slowly by pressure on the plate. The birefringent halo at the end of the advancing crack was minute compared with the features in our samples, in spite of the greater thickness of the plate. It is therefore clear that the haloes in the samples are not due merely to residual stress at the ends of the extension cracks. This implies the presence of comparatively large permanent strains at the sites of the birefringent features. It is probable also that the

transverse extension fractures originated at these sites, where the residual stresses must also be large. The existence of isolated haloes and the termination of some cracks in a halo at each end are consistent with this conclusion.

The birefringent haloes are similar in general character to a birefringent rosette photographed with polarized infrared radiation in silicon by Bond and Andrus (1956). This was attributed to the stress around a single edge dislocation; the rosette is considerably smaller than those in the deformed quartz. Similar features have been observed in corundum and Rochelle Salt crystals and attributed to the stress around "macroscopic edge dislocations" (Indenbom, 1958). Such a macroscopic dislocation would most probably consist of a locked array of actual edge dislocations of similar sign lying in one plane. The stresses due to such an array would be much greater than those around a single dislocation (Koehler, 1952). The association of some of the large haloes in our samples with short fractures parallel to the main faults suggests that the faults may originate at regions similar to those represented by the haloes. Thus the birefringent haloes probably constitute visible evidence of plastic deformation which preceded the fracturing along fault-planes.

The Origin of New Phases.—The isotropic material along the faults in the samples may be glassy material which originated by fusion of the quartz along the faults or it may have been formed by extreme mechanical disruption of the quartz in the immediate vicinity of the shear-planes. In view of the very small displacements on some of the faults the latter alternative is doubtful, and the former will be considered in more detail.

Most of the large samples contain less than 50 faults of area 1 cm^2 , and the average thickness of the zones of isotropic material is less than 10 microns; the total volume of isotropic material in these samples is therefore less than 0.05 cm^3 . The heat required to raise the temperature of this quartz to the melting point and produce fusion can be calculated approximately. The temperatures of the α - β transition and melting at the high pressures of the experiments are not known, but it is assumed that the transition will occur at approximately 1200°C and melting at 2000°C , consistent with the extrapolated and inferred phase boundaries given by Boyd and England (1960b). From the data given by Goranson (1942) on the heat capacities and heat of fusion of quartz, the heat content at the melting point plus the heat of fusion is approximately 600 cal per gm. These data were determined at one atmosphere, but calculations show that the values of heat content at 30 kb differ by only a few percent from those at one atmosphere. Since the volume of isotropic material in the large samples is 0.05 cm^3 or approximately 0.12 gm, the energy required to heat and melt this material is 72 cal; the mechanical equivalent of this energy is approximately 3×10^9 ergs. This should be compared with the elastic strain energy of the system immediately before rupture of the samples to determine whether actual fusion of the quartz along the faults might have occurred.

The elastic strain energy of the system comprises the strain energy of the crystal and that of the apparatus, including the piston, pressure vessel, hydraulic system, and structural framework. Of these, only the elastic strain energy of the crystal sample can be estimated. The apparatus is very large compared with the crystal, and the strain energy of the apparatus is greater, per-