haps by orders of magnitude, than that of the crystal. The elastic strain energy (W) in the samples is given, in matrix notation (Nye, 1957, p. 137), by

$$\begin{aligned} W &= \tfrac{1}{2} C_{ij}\, \varepsilon_i\, \varepsilon_j \\ &= \tfrac{1}{2} \sigma_i\, \varepsilon_i \\ &= \tfrac{1}{2} S_{ij}\, \sigma_i\, \sigma_j \end{aligned}$$

Substituting values of the compliance constants (Nye, 1957, p. 148) and the stress in the samples immediately before rupture, the strain energy density (in cylinders compressed parallel to the *c*-axis and normal to *m*) is found to be approximately 3 × 10^9 ergs/cm^3. The strain energy in the larger samples (volume 2 cm^3) is therefore of the order of 6 × 10^9 ergs.

Thus the energy necessary to cause fusion along the faults, to the extent indicated by the isotropic material, is less than the elastic strain energy of the crystal by only a small factor. It should also be remembered that the work done in producing the fractures is also derived from the strain energy of the system. However, inasmuch as the elastic strain energy of the apparatus is much greater than that of the crystal, it appears to be possible that the isotropic material originated by fusion, if the elastic strain energy was rapidly dissipated as heat along the faults, as a result of friction.

It was shown that the refractive index of the isotropic material was variable but invariably greater than that of the common form of silica glass, lechatelierite. This may be due to imperfect destruction of the quartz structure, or the packing of the atoms or Si-O groups may be denser, because of the extremely high pressures of formation, than in lechatelierite.

Although the conditions in the samples at rupture probably are within the stability field of coesite (from a linear extrapolation of the phase boundary determined by Boyd and England, 1960b) coesite was not expected to form in the experiments in view of the sluggishness of the transformation, Quartz ⇄ Coesite, at low temperatures (MacDonald, 1956; Boyd and England, 1960b). MacDonald found that runs made in a simple squeezer at 400°C require almost a day to yield coesite. However, the transformation may have been accelerated locally along the faults by heat derived from the sudden conversion of strain energy at rupture, just as fusion may have taken place in the vicinity of the faults.

Geological Significance.—The conditions in the experiments do not simulate those in the earth's crust under normal conditions: the mean pressures are equivalent to those at depths of about 100 km, and the temperature is that of rocks at the surface; moreover, the stress differences ($\sigma_1 - \sigma_3$) at rupture are much greater than those which may exist within the crust in normal circumstances. The experiments were originally designed to attempt to produce plastic deformation of quartz and from this viewpoint they demonstrate only that *extensive* plastic deformation does not take place under these conditions.

The experiments may, however, be of direct relevance for studies of quartz-bearing rocks at the sites of meteoritic impact, where the initial deformation is extremely rapid and may take place at low temperatures. Extremely high pressures and differential stresses are also generated on impact. The conditions locally at impact sites may be similar to those in our experiments, and structures like those in our samples may be produced in rocks which are not completely disrupted or heated to high temperatures near the center of impact.

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REFERENCES

Averbach, B. L., Felbeck, D. K., Hahn, G. T., and Thomas, D. A., eds., 1959, Fracture: New York, John Wiley and Sons, 646 p.

Billings, M. P., 1954, Structural Geology (2d ed.): New York, Prentice-Hall, Inc., 514 p.

Bloss, F. D., 1957, Anisotropy of fracture in quartz: Am. Jour. Sci., v. 255, p. 214-225.

Bond, W. L., and Andrus, J., 1956, Photographs of the stress field around edge dislocations: Phys. Rev., v. 101, p. 1211.

Borg, I., Friedman, M., Handin, J., and Higgs, D. V., 1960, Experimental deformation of St. Peter Sand, *in* Griggs, D. T., and Handin, J., eds., Rock Deformation, Geol. Soc. America Mem. 79, p. 133-191.

Boyd, F. R., and England, J. L., 1960a, Apparatus for phase-equilibrium measurements at pressures up to 50 kilobars and temperatures up to 1750°C: Jour. Geophys. Research, v. 65, p. 741-748.

———— 1960b, The quartz-coesite transition: Jour. Geophys. Research, v. 65, p. 749-756.

Bridgman, P. W., 1940, New high pressures reached with multiple apparatus: Phys. Rev., v. 57, p. 342-343.

———— 1941, Explorations toward the limit of utilizable pressures: Jour. Appl. Physics, v. 12, p. 461-469.

Carter, N. L., Christie, J. M., and Griggs, D. T., 1961, Experimentally produced deformation lamellae and other structures in quartz sand [abs.]: Jour. Geophys. Research, v. 66, p. 2518-2519.

———— in press, Experimental deformation and recrystallization of quartz: Jour. Geology, in press.

Christie, J. M., Carter, N. L., and Griggs, D. T., 1961, Experimental evidence for a basal slip mechanism in quartz [abs.]: Science, v. 134, p. 1427.

———— in press, Experimental evidence of basal slip in quartz: Jour. Geology, in press.

Coes, L., Jr., 1955, High pressure minerals, Am. Ceramic Soc. Jour., v. 38, p. 298.

Cottrell, A. H., 1953, Dislocations and plastic flow in crystals: Oxford, Clarendon Press, 223 p.

———— 1959, Theoretical aspects of fracture, *in* Averbach, B. L., Felbeck, D. K., Hahn, G. T., and Thomas, D. A., eds., Fracture: New York, John Wiley and Sons, p. 20-44.

Fairbairn, H. W., 1939, Correlation of quartz deformation with its crystal structure: Am. Mineralogist, v. 24, p. 351-368.

Goranson, R. W., 1942, Handbook of Physical Constants: Geol. Soc. America Spec. Paper 36, sec. 16, p. 223-242.

———— 1949, Effect of pressure on physical phenomena in the crust: Am. Geophys. Union Trans., v. 30, p. 187-189.

Griffith, A. A., 1921, The phenomena of flow and rupture in solids: Royal Soc. [London] Philos. Trans., ser. A, v. 221, p. 163-198.

———— 1925, The theory of rupture: Internat. Cong. Appl. Mech., 1st, Delft 1924, Proc. p, 55-63.