, Analysis of body wave spectra for energy determination, Ph.D. thesis, is University, St. Louis, Missouri,

I. A., Earthquake magnitude and ameters, *Bull. Seismol. Soc. Amer.*, 82, 1969.

P-travel times, magnitude, and earthume (abstract), *EOS, Trans. Amer. Union, 50*, 239, 1969.

B., Amplitudes of *P*, *PP*, and *S* and of shallow earthquakes, *Bull. Seis-Amer., 35*, 57–69, 1945*a*.

B., Magnitude determination for deep quakes, *Bull. Seismol. Soc. Amer., 35*, 45*b*.

B., and C. F. Richter, *Seismicity of* 2nd ed., Princeton University Press, N. J., 1954.

B., and C. F. Richter, Magnitude and earthquakes, *Ann. Geofis., 9*, 1–15,

P. Arnold, B. A. Bolt, G. E. Claw-Engdahl, H. W. Freedman, D. W. L. Hales, J. L. Lobdell, O. Nuttli, y, J. Taggart, and W. Tucker, 1968 al tables for *P* phases, *Bull. Seismol. 58*, 1193–1241, 1968.

thquake magnitude, earthquake fault, dimensions, *J. Earth Sci. Nagoya* 15–132, 1965.

S., Body wave magnitude and source , *Seismic Data Lab. Rep. 225*, Tele-1968.

d L. Knopoff, Stress drop in earth-*ll. Seismol. Soc. Amer., 58*, 249–258,

imensions of the source region for ow earthquakes, in *Proceedings of C Conference on the Source Mecha-allow Seismic Events, VESIAC Rep.* 55–164, 1967.

Earthquake energy and ground break-*Seismol. Soc. Amer., 48*, 147–152, 1958.

Lower limit of the total energy of s and partitioning of energy among ves (part 1), Ph.D. thesis, California f Technology, Pasadena, 1966.

nd J. N. Brune, Seismic moment, source dimensions for earthquakes in nia-Nevada region, *J. Geophys. Res.*, 94, 1968.

(Received August 27, 1969.)

A Theory of Brittle Creep in Rock under Uniaxial Compression

D. M. CRUDEN[1]

Department of Geology, Imperial College, London, United Kingdom

Scholz's theory of brittle creep is rejected. A new theory based on Charles's theory of the subcritical growth of pre-existing cracks in the specimen by stress-aided corrosion is put forward. It is a successful explanation of new experiments on the creep of Pennant sandstone and Carrara marble under uniaxial compression at room temperature.

INTRODUCTION

Many creep experiments on rock under compression were conducted under conditions where the specimen is brittle, that is, it fractures at small strains with loss of cohesion between the fracture surfaces.

Brittleness has certain implications. *Pratt* [1967] has pointed out that, for a material to be able to undergo a general deformation, 'there must be a sufficient number of independent slip systems, distributed homogeneously and able to interpenetrate, with enough mobile dislocations on them to accommodate the applied strain rate.' At least one of these conditions is not fulfilled for most rocks at room temperature.

For the rocks to be capable of a general deformation the component minerals should be deformable. Observed slip systems for rock-forming minerals have recently been compiled by *Handin* [1966] and *Watchman* [1967]. Data on calcite have been added by *Santhanam and Gupta* [1968]. Calcite and quartz are the two minerals that have been most intensively studied, and in neither mineral was there appreciable dislocation mobility at room temperature.

In general, deformation by crystal twinning or slip is insensitive to confining pressure. Only calcite, marble, and halite have been reported to show stress-strain curves insensitive to confining pressure [*Paterson*, 1967]. Deformation in other rocks can be supposed to be cataclastic. The increasing ductility of rocks with increasing confining pressure is due to the inhibiting of fracture propagation [*Pratt*, 1967]. *Murrell* [1965] has shown that the brittle–ductile transition observed in rocks occurred when the stress required to propagate a crack rose to the stress required to overcome sliding friction on the crack. Other features of the stress-strain curves of rocks are also adequately explained on the assumption that the rock is a perfectly elastic body containing an array of pre-existing cracks [*Walsh and Brace*, 1966].

This paper therefore develops a theory of creep in brittle materials based on the assumptions that (1) dislocation motion is negligible, and (2) the material contains pre-existing cracks.

SCHOLZ'S THEORY OF BRITTLE CREEP

It seems that only one theory, that of *Scholz* [1968], has been developed specifically to describe creep in brittle rock. It is reviewed briefly below and is shown to be unsatisfactory.

Scholz suggested that a creep specimen could be considered as a large number of small homogeneous regions (elements) that undergo static fatigue according to equation 1,

$$t_f = (1/a) \exp [(E/KT) + b(F_m - F_a)] \quad (1)$$

where a and b are constants. E is the activation energy of the corrosion reaction that leads to static fatigue. F_m is the instantaneous failure stress of the element, and F_a is the stress on the element causing failure at t_f, the mean fracture time.

Two further assumptions were necessary; as each element fails, it contributes an amount v to the axial strain, and each region acts

[1] Now a post-doctorate fellow at Elliot Lake Laboratory, Mining Research Centre, Mines Branch, Department of Energy, Mines and Resources, Elliot Lake, Ontario.