Reprinted from
Int. J. Rock Mech. Min. Sci. Vol. 4, pp. 257–268. Pergamon Press Ltd. 1967. Printed in Great Britain

FRACTURES AND THE STRENGTH OF A SANDSTONE UNDER TRIAXIAL COMPRESSION

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PERGAMON PRESS
OXFORD NEW YORK LONDON PARIS

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(*Received* 18 *December* 1966)

Abstract—Darley Dale sandstone, a fairly isotropic and homogeneous rock, was compressed triaxially under dry conditions and at room temperature. Interest was mainly in the range in which the rock behaved in a brittle manner until failure for confining pressures ranging from atmospheric pressure to 15,000 lb/in². All specimens failed along shear fracture surfaces. The intragranular fractures could be differentiated into 3 types: A—Tensile fractures parallel to the compression axis, B—Shear fractures parallel to the megascopic shear fracture surface, C—Strain release fractures normal to the axis of compression which becomes more significant as the confining pressure is increased. The strain release fractures were observed both megascopically and microscopically in specimens shortened about 15 per cent under 46,000 lb/in² and 56,000 lb/in² confining pressures. They were observed to develop during the release of the differential load. The strength data were interpreted in terms of Mohr and Griffith theories. It is shown that the observed permanent shortening of the sandstone compressed under high confining pressure is mainly due to a process of compaction and fracturing.

1. INTRODUCTION

ROCKS in nature are subjected to different conditions of pressure, temperature and environmental conditions for short or long durations. The literature is now rich in experimental work carried out to reveal the mechanism of deformation of rocks either by observing petrographic changes in rock samples subjected to external loads or observations into the strength properties, which are obviously two interrelated lines of work. Many attempts to deform single crystals of quartz plastically in order to investigate its possible gliding mechanism have been unsuccessful. Thus, GRIGGS [1], GRIGGS and BELL [2], BRIDGMAN [3] and GRIGGS, *et al.* [4] subjected quartz crystals to varying conditions of high pressure and high temperature for varying periods of time in the presence and absence of solutions, yet quartz behaved elastically until failure. In a short note published by CARTER *et al.* [5] undulatory extinction and deformation bands were observed in St. Peter sand when deformed in compression in a squeezer at pressures ranging from 12–100 thousand atmospheres and temperatures ranging from 25–700°C. RAMEZ and ATTEWELL [6] found that the undulatory extinction index derived for quartz in the shock-loaded Darley Dale sandstone showed a pronounced increase as compared with the index derived for the undeformed rock. This increase followed a geometrical pattern directly related to the varying intensity of the imposed stress field. FAIRBAIRN [7] showed that the lattice structure of quartz would make it extremely difficult for translation gliding. BLOSS [8] and BLOSS and GERALD [9] identified the high density planes in a quartz lattice along which cleavage can take place. INGERSON and TUTTLE [10], ANDERSON [11] and CHRISTIE and RALEIGH [12] studied quartzitic

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rocks microscopically in order to define active glide planes and cleavage. Bailey *et al.* [13] examined naturally deformed quartz crystals by X-ray techniques and explained the wavy extinction as the optical expression of plastic deformation through bend gliding and polygonization.

Since fracture is the main mechanism of deformation of quartzitic rocks when subjected to triaxial loading conditions; it is the aim of this work to study the fracture pattern in relation to the geometry of the applied stress field and to relate these observations to the strength properties of the rock under examination.

2. EXPERIMENTAL WORK

2.1 *Properties of the undeformed sandstone*

The study of the deformation of quartzitic rocks was carried out on a Carboniferous sandstone quarried from Darley Dale in Derbyshire. Examination of hand specimens of this rock showed that it is fairly isotropic, i.e. lacking any bedding planes. Microscopically, the rock is formed of about 85 per cent quartz in the form of angular to subangular grains, plagioclase and orthoclase together with microline comprise about 8 per cent of the rock. Mica and some ferruginous matter constitute the rest of the mineralogical content of the rock. The rock has a high porosity, about 21 per cent, as measured by Misra [14]. The undulatory extinction phenomenon and the fractured condition of the quartz grains were observed in 100 gr taken at random following the method previously described by Borg *et al.* [15]. The undulatory extinction index was found to be 182 and the fracture index 115, i.e. the rock can be considered as formed of slightly deformed quartz grains.

Petrographic observations were made on a Lietz microscope fitted with a 5-axes universal stage. All measured data were plotted on an equal area projection net of 20 cm diameter. In every case the lower hemisphere of the projection sphere was projected on the horizontal

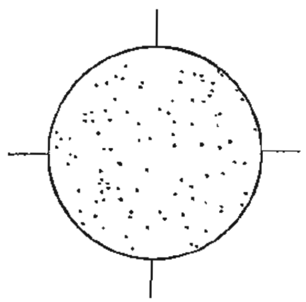

Fig. 1. Preferred orientation of the *c*-axes in 100 quartz grains in Darley Dale sandstone.

plane. The orientation of the crystallographic *c*-axes in 100 quartz grains is shown in Fig. 1, which reflects no strong preference to a particular orientation. Thus the rock could be considered as fairly isotropic and suitable for experimental work.

2.2 *The strength of the rock in compression under different confining pressures*

(a) *Apparatus.* Uniaxial testing of rock cylinders was carried out by means of a hydraulically driven 100-ton Avery testing machine capable of applying loads in five different ranges at a constant rate. The load on the ram can be read directly from an indicator rotating on a calibrated chart. The triaxial apparatus was designed and described in detail by

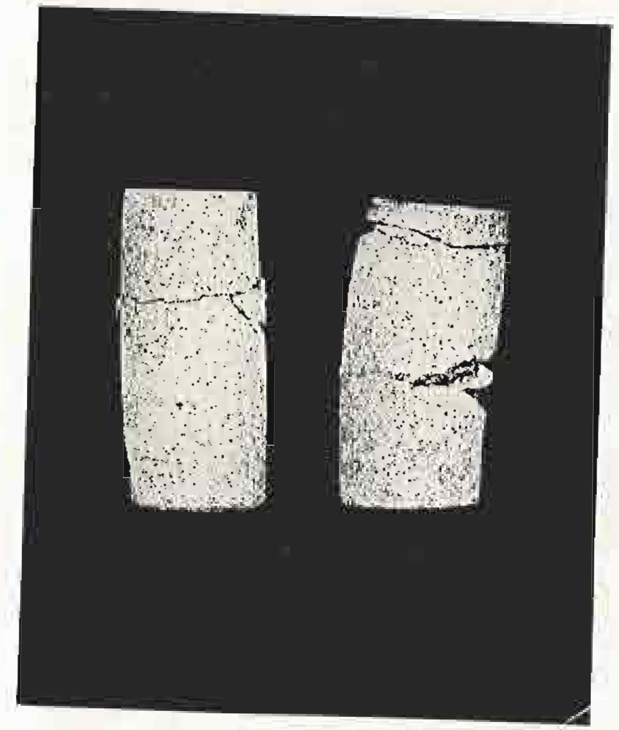

Fig. 2. Sandstone cylinders shortened 15 per cent under 46,000 lb/in² (9R) and 56,000 lb/in² (10R) confining pressures.

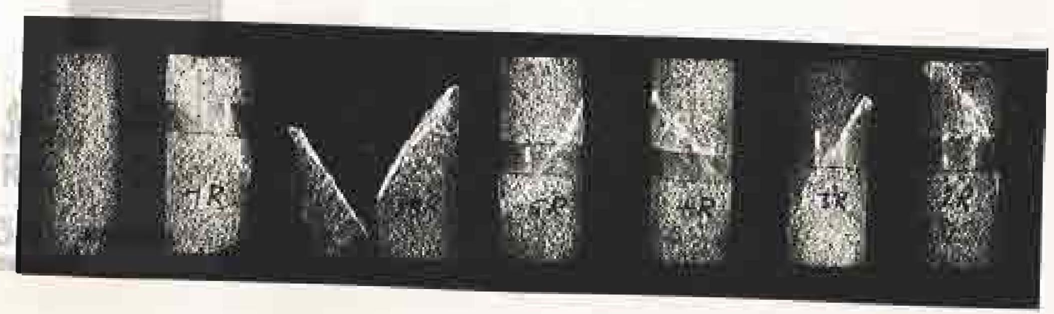

Fig. 3. Sandstone cylinders compressed till failure under different confining pressures (see Table 1).