Journal of Structural Geology, Vol. 10, No. 3, pp. 301 to 303, 1988
Printed in Great Britain

0191-8141/88 $03.00 + 0.00

Strain determination using cathodoluminescence of calcite overgrowths

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(*Received* 31 *August* 1987; *accepted in revised form* 15 *January* 1988)

Abstract—Cathodoluminescence is used in a new application to study extensional strains recorded by calcite overgrowths on detrital calcite grains. The geometry of the overgrowths yields an extension of +0.39 that is parallel to a pressure solution cleavage. A volume change of −0.21 was calculated from this geometry and an independently determined strain ratio.

INTRODUCTION

MANY minerals luminesce with different colors and intensities when excited with a beam of electrons. The luminescent properties are controlled by trace amounts of several elements, notably manganese and iron(III) (Sommer 1972), and defects within the crystal structure (Zinkernagle 1978). Because the color and intensity of the luminescence bear little relationship to the optical properties, cathodoluminescence provides a powerful independent tool to study compositional and crystal structure variations in minerals.

Cathodoluminescence has become a standard tool for sedimentary petrologists studying the diagenesis of clastic and carbonate rocks (for example, see Sipple & Glover 1965, Sipple 1968). Only recently has cathodoluminescence been used in structural studies. The method has found its greatest use in the study of brittle microstructures in quartzose rocks. The healing of microfractures with vein material (Sprunt & Nur 1979, Narahara & Wiltschko 1986) and the textures of cataclastic rocks (Blenkinsop & Rutter 1986) are readily studied with cathodoluminescence. Cathodoluminescence also has the potential for recognizing subtle grain microstructures such as dislocation networks (Grant & White 1978). Variations in cathodoluminescence of quartz fibers in syntectonic veins was shown by Dietrich & Grant (1985) to be of use in detailing the strain history.

This paper describes a new application of cathodoluminescence. Calcite overgrowths which are optically indistinguishable from their host can be recognized and used for strain determinations.

Sample preparation

This study uses three sandstone samples from a single outcrop of the Ordovician Martinsburg Formation in the Massanutten synclinorium of northwestern Virginia. Compositionally, the sandstones are greywackes that contain abundant foliated rock fragments, quartz, feldspar and calcite framework grains and a clay-rich matrix.

Martinsburg sandstones in the Massanutten synclinorium are folded, faulted and display a moderately well-developed spaced cleavage (Onasch 1983). The cleavage is defined by seams of insoluble residue, elongate detrital grains and beards of quartz and chlorite.

Thin sections of the sandstone were cut normal to the cleavage and parallel to the down-dip direction of the cleavage. This direction has been shown in many studies to approximate the *XZ* principal plane of strain (Wood 1974, Hobbs *et al.* 1976, p. 233). The thin sections were prepared for cathodoluminescence by polishing down to a final grit size of 0.3 μm. A Technosyn Cold Cathode Luminescence system, operating at 15 kV and 400 mA, was used.

Overgrowth geometry

In cathodoluminescence, calcite overgrowths are generally brighter (higher Mn/Fe) than the calcite host grain (Fig. 1a). In every case, the overgrowth cannot be differentiated from the host in plane or polarized light (compare Fig. 1a to 1b).

The overgrowths occur on the sides of grains that are normal to the cleavage trace. No overgrowths were observed on grain sides facing the cleavage seams. Although the overgrowths are irregularly shaped, they tend to be approximately the same length on each end of the grain. Most overgrowths are internally featureless, but some are faintly fibrous with straight fibers that are parallel to the cleavage trace (Fig. 1a). Many overgrowths are zoned (Fig. 2) suggesting incremental crystal growth from a fluid changing in chemical composition.

USE OF CATHODOLUMINESCENCE FOR STRAIN DETERMINATION

The extension represented by the overgrowth was determined by measuring the total length of overgrowth parallel to the cleavage trace and dividing by the length

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of the grain measured in the same direction (Ramsay & Huber 1983, p. 3). Ten grains were measured on each slide yielding a mean extension for the three samples of +0.39. Extensional strains of similar magnitude have been measured in nearby Martinsburg sandstones using the length of the quartz–chlorite beards on detrital quartz grains (Davis & Onasch 1986). The beards are of limited use because their occurrence is not widespread and they tend to be asymmetrical.

A problem in interpreting the cathodoluminescence data is that the overgrowths could result from: (1) corrosion of previously continuous diagenetic overgrowths; or (2) deposition during tectonic deformation only on the sides of the grain that are normal to the extension direction. The distinction between these two possibilities must be made if the measured extensions are to be correctly interpreted. The first case involves no extension, only shortening normal to the cleavage. The second case involves extension and shortening. Distinction between these two possibilities can be made by considering the host-overgrowth geometry in the plane parallel to the cleavage (XY plane). If the grains are uncorroded and have no overgrowths in the Y direction, then continuous overgrowths did not exist around the grain. Examination of XY sections shows this to be the case. Additional evidence is provided by the lack of continuous overgrowths in weakly deformed samples from other areas. Therefore, it can be assumed that the overgrowths are a product of tectonic deformation, not diagenesis.

Strain in the greywacke is a result of more than one deformation mechanism (Onasch 1983, Davis & Onasch 1986) and the contribution of each must be considered. The elongate shape of the calcite grains is a product of pressure solution and plastic deformation. Because twinning is only weakly developed (Fig. 1b), plastic deformation is considered to have played only a minor role. Pressure solution, however, had a more important role. It altered the grain shapes by corroding the grain sides facing the cleavage seams and depositing material as overgrowths on the ends parallel to the seams. Before the strain significance of the overgrowths can be determined, any volume changes during pressure solution deformation must be considered.

Assuming plane strain, the volume change can be determined if the strain ratio and the amount of extension from pressure solution are known (Ramsay & Huber 1983, p. 16). The extension, e_x, and strain ratio, R_s, are related to the shortening, e_z, by:

$$R_s = \frac{1 + e_x}{1 + e_z}. \quad (1)$$

The volume change, Δ, can be calculated according to:

$$1 + \Delta = (1 + e_x)(1 + e_z). \quad (2)$$

Solving for Δ in terms of R_s and the extension, e_x, yields:

$$\Delta = \left((1 + e_x)\left(\frac{(1 + e_x)}{R_s}\right)\right) - 1. \quad (3)$$

The mean strain ratio for the cathodoluminescence samples is 1.60 as determined by both center-to-center and R_f/ϕ methods applied to both quartz and calcite grains (Davis & Onasch 1986). Substituting this value and the extension measured with cathodoluminescence into equation (3) yields a volume change of −0.21. This value is consistent with other dilation magnitudes for the sandstones in the Martinsburg Formation (Davis & Onasch, 1986), thus confirming the validity of the cathodoluminescence application.

CONCLUSIONS

Cathodoluminescence provides a simple method for determining the geometry of carbonate overgrowths. Because the overgrowths are optically indistinguishable from the host grain, standard petrographic techniques cannot be used. Cathodoluminescence can be used for calculating extensioinal strains in rocks such as sandstones where other methods may not work. This application, along with those already in use, illustrate the great potential for cathodoluminescence studies in structural geology.

Acknowledgements—Comments by William B. Dunne and Robert D. Hatcher, Jr on an early draft, along with later reviews by Edward C. Beutner and Ben Van der Pluijm were helpful in improving the manuscript. Partial financial support was provided by NSF Grant EAR-8500389 to C. Onasch.

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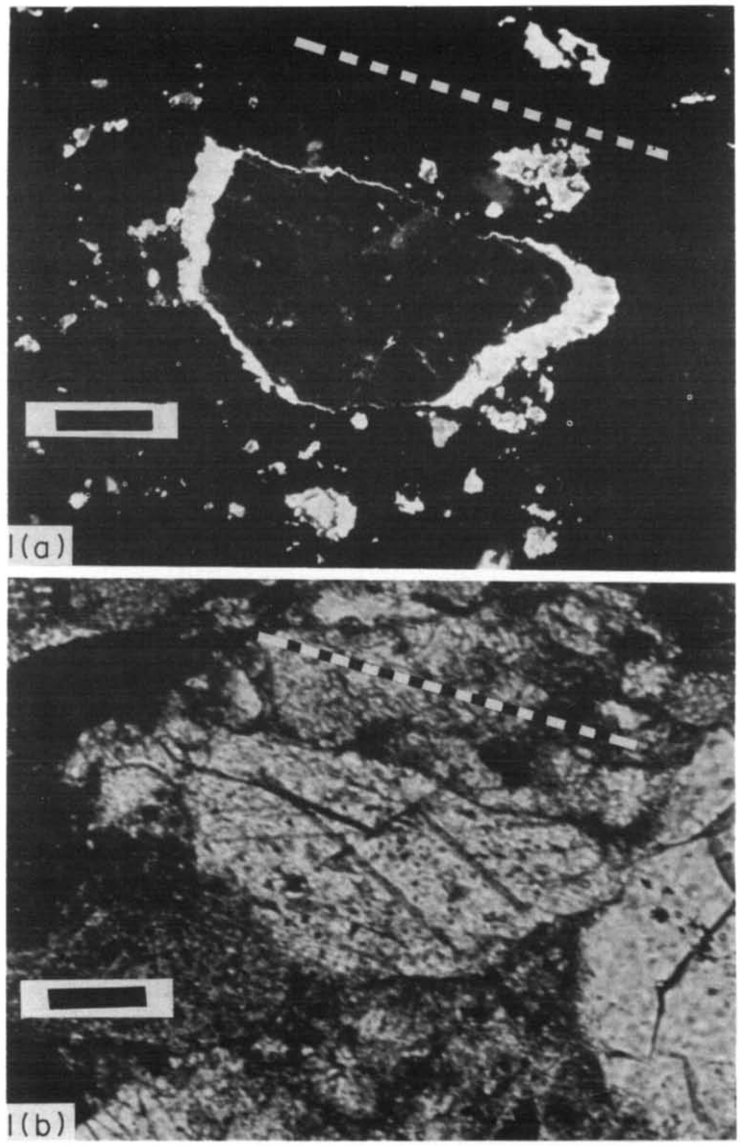

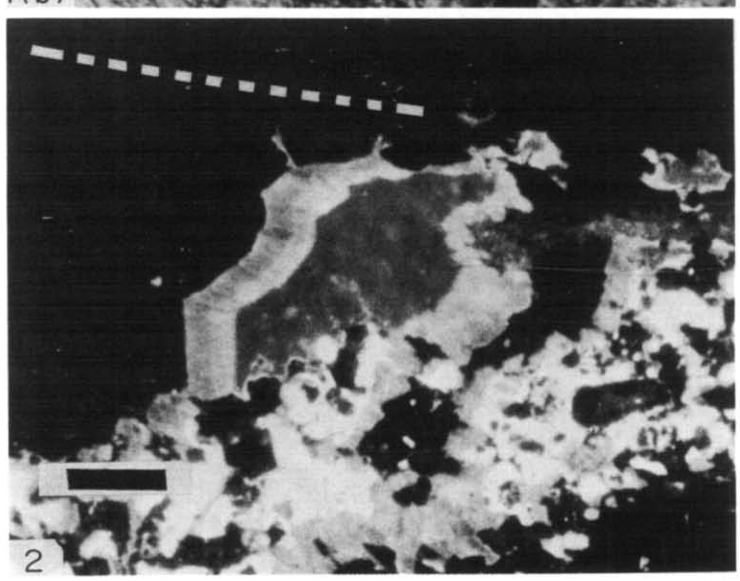

Fig. 1. Detrital calcite grain with overgrowth. (a) Grain in cathodoluminescence. (b) Plane light. Note widely-spaced twins visible in plane light. Dashed line is parallel to cleavage trace in sample. Scale bar (black) is 0.05 mm.

Fig. 2. Zoned, fibrous structure in luminescing overgrowth. Dashed line is parallel to cleavage trace in sample. Scale bar (black) is 0.05 mm.