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An experimental setup for the analysis of analogue deformation experiments using the rotating polariser stage

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Abstract

A new experimental setup for the analysis of deformation of rock analogues is presented. The hardware component consists of a rotating polariser stage and the software component includes several specialised pieces of software. During experiments the software is able to construct data sets in the form of specialised images that contain information on grain shape and crystallographic orientations. Several different types of movies with frames spaced as close as 2 min apart can be created during the experiment, which convey crystallographic and shape information in a semi-continuous form. This setup can be adapted to a variety of optical deformation rigs. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Rotating polariser stage; Analogue modelling; *c*-Axis measurements; Deformation movies; Fabric analysis

1. Introduction

The direct observation of the deformation of rock analogues can yield important insights into the deformation mechanisms of real rocks. Analogue materials such as salt, ice, octachloropropane, paradichlorobenzene, norcamphor and camphor behave ductilely and recrystallise readily when deformed at or near room temperature. Numerous studies (Means, 1980, 1981, 1989; Urai et al., 1980; Urai and Humphries, 1981; Wilson, 1981; Burg et al., 1986; Jessell, 1986; Bons, 1993; Bons et al., 1993; Bons and Urai, 1996; Herwegh and Handy, 1996; Bons and Jessell, 1999) have examined various aspects of the textural evolution of analogues. In the majority of these studies the experiments are photographed or videotaped in real time through a microscope for later analysis. In most studies the record simply contains the instantaneous view recorded directly through the microscope. This is unfortunate, as direct and semi-continuous observation of the crystallographic orientation gives insight into ductile deformation mechanisms and can provide constraints for models of deformation of real rocks. Only a few studies (Wilson, 1981; Jessell, 1986; Herwegh and Handy, 1996; Heilbronner and Herwegh, 1997; Herwegh et al., 1997; Herwegh and Handy, 1998) were able to incorporate some form of crystallographic orientation measurement made throughout the experiment. However, this may require termination of the experiment (e.g. Herwegh and Handy, 1996) or interruption (15 min per measurement, M. Herwegh, pers. commun.) of the experiment, as was the case for the IT–HS and LT–HS experiments in the study by Herwegh and Handy (1998) and Herwegh et al. (1997).

This paper describes an experimental setup that is capable of directly monitoring limited crystallographic orientations of uniaxial analogues throughout the experiment. A modified rotating polarizer stage (Fueten, 1997) is used in conjunction with a Urai-type deformation rig as the experimental apparatus. Specialised software is capable of saving several types of movie (AVI) files with frames spaced as close as 2 min apart, and *c*-axes calculated for every frame. This type of experimental setup is ideally suited for the study of rock analogues and could be adapted for use with other deformation rigs.

2. Hardware

The basic experimental setup is shown in Fig. 1. A standard petrographic microscope has been modified to accept both the rotating polarisers and the experimental stage. A Urai-type experimental stage is placed on the existing microscope stage. The fixed microscope polariser has been removed and replaced with the lower rotating polariser. The upper rotating polariser is placed below the digital camera. The basic design of the rotating polarisers are identical to

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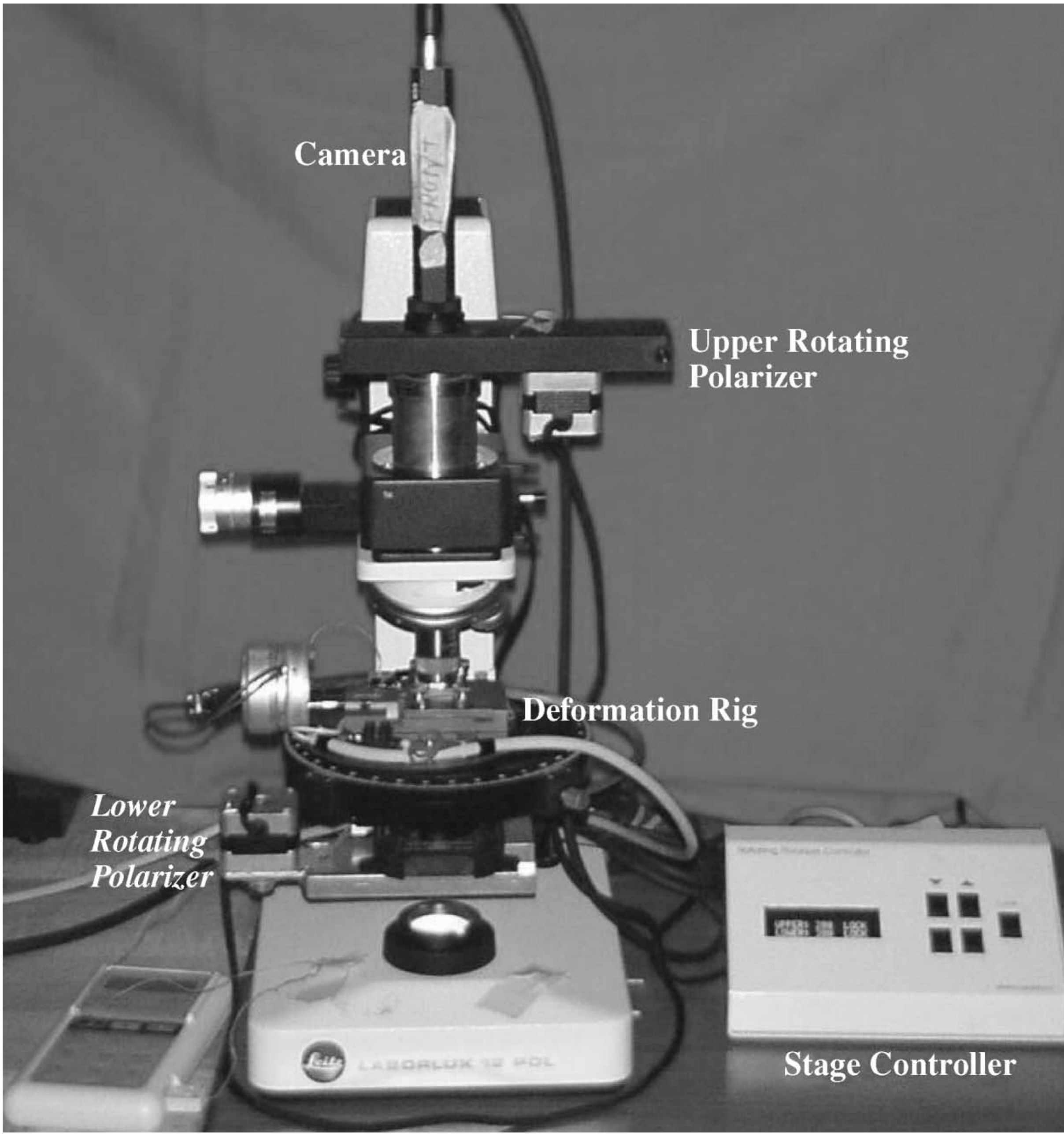

Fig. 1. Experimental setup, including rotating polariser stage and deformation rig.

those of the standard rotating polariser stage (Fueten, 1997). An isolation transformer is used to regulate the voltage of the microscope, minimising light fluctuations due to voltage spikes. Images are captured using a digital camera, connected to a Matrox Meteor II video capture board within a 450 MHz PC.

3. Software

The rotating polarisers and the camera/video capture board are controlled by software designed in-house. The standard methodology (Fueten, 1997) to collect a sample is to step the polarisers through a 180° rotation (200 steps) under cross-polarised light. At each step (0.9°) a frame is captured at a resolution of 640 × 480 pixels in 24-bit colour (8 bits each of red, green and blue) and data is extracted for each pixel. While it would be possible to save each frame, it is not very practicable. A single colour frame at the above stated resolution requires approximately 1 MB of storage. A single sample under crossed-polarised light thus requires 200 MB of storage. Saving all possible frames for a single experiment consisting of 200 samples would result in 40 GB of data, which, even with current equipment, is not easily handled.

Instead, a composite data set is constructed that contains

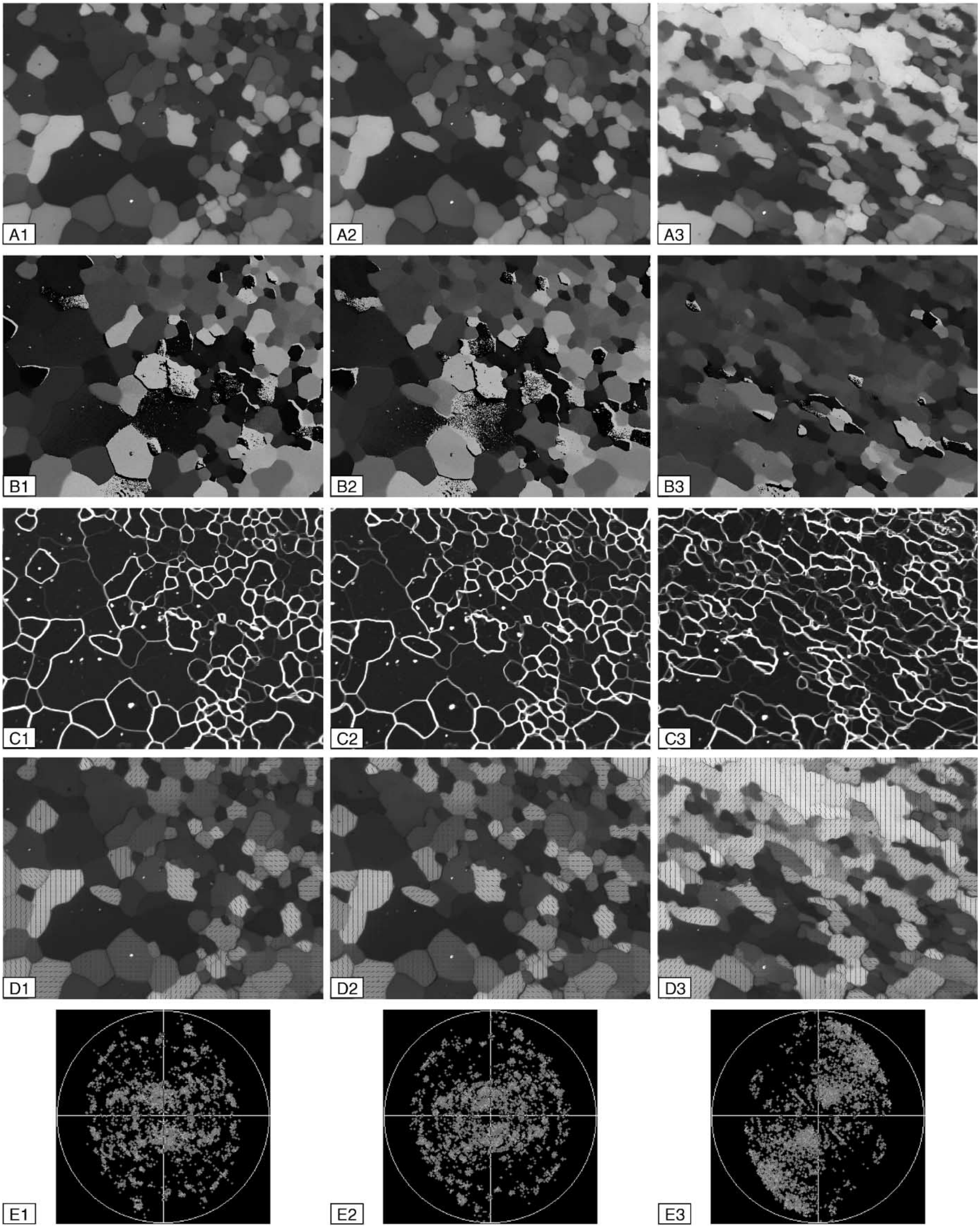

Fig. 2. The example frames are from an experiment of the simple shear deformation of norcamphor. Five different movies are illustrated. For A–E, frames 1 correspond to the start of the experiment, while frames 2 and 3 represent frames 30 and 138, respectively. A1–3 — maximum intensity movie, B1–3 — position movie, C1–3 — gradient movie, D1–3 — *c*-axis movie overlaid on maximum intensity, and E1–3 — Schmid net movie.

selected information obtained for each pixel. The data include the intensity of the pixels within a grain or the orientation of the polarising filters at specified intensity values (Fueten, 1997). This technique reduces the basic data for an experiment of 200 samples to a more manageable 600 MB. *c*-Axes of analogue materials are calculated using the maximum intensity and maximum position images collected under crossed-polarised light, according to the method outlined by Fueten and Goodchild (2001). This technique is in principle similar to the AAVA technique outlined by Stöckhert and Duyster (1999), the CIP technique of Heilbronner and Pauli (1993) and the method proposed by Park (1996).

For the special requirements of analogue modelling the software has been modified to collect samples at specified time intervals. In addition, to avoid the tedium of analysing hundreds of individual sample files, the software has the ability of writing out five different types of movie files (Fig. 2). These movies are written out using the common uncompressed AVI format and can be viewed using a wide variety of PC and Mac applications. Automatically incremented file numbers of the sample files correspond to the frame numbers of the movies to allow for easy correlation of output files.

3.1. Maximum intensity movie

During each sampling, the intensity of each pixel is calculated in each captured frame (Fig. 2, A1–A3). The maximum intensity value corresponds to the maximum interference colour of a pixel within a grain during the 180° rotation of the polarisers. By recording the maximum intensity, intensity variations due to the orientation of the polarisers with respect to the crystal lattice, evident in any instantaneous view, have been eliminated. For uniaxial minerals, the maximum intensity is thus a function of the angle between the *c*-axis and the light path. A movie constructed of maximum intensity frames therefore conveys more information than a movie constructed of instantaneous views.

3.2. Maximum position movie

The position value records the orientation of the polarising filters, that is the step number, when a pixel reaches its maximum intensity value. For a 180 or 200° step rotation, position values have a range of 1–200 and can be represented as grey scale images (Fig. 2, B1–B3). As outlined by Fueten and Goodchild (2001) the position value can be directly related to the trend of uniaxial *c*-axes. This grey scale movie is particularly useful for observing rotation of *c*-axes.

3.3. Gradient movie

During each sampling a gradient operator compares the intensity of a pixel with that of its neighbours (Fueten, 1997) grey-scale gradient image (Fig. 2, C1–C3) is constructed. This image serves as the input for the edge detector presented by Goodchild and Fueten (1998). In this image bright values represent grain boundaries and marker particles, while the interior of grains form dark areas. A movie constructed of gradient images is ideally suited to track grain boundary migration and the motion of passive marker particles.

3.4. c-Axis movies

c-Axes are calculated for all pixels in the field of view, using the method outlined by Fueten and Goodchild (2001). *c*-Axis orientations are displayed as lineations, scaled to plunge on a grid of specified size. They can be overlaid on either the maximum intensity image (Fig. 2, D1–D3) or the maximum position image. This movie provides a direct insight into grain boundary movements as well as rotations of *c*-axes.

3.5. Schmid net movies

A final movie of a Schmid net plot of *c*-axes (Fig. 2, E1–E3) of the grid is saved whenever a *c*-axes movie is specified. Limitations of the *c*-axis data are identical to those outlined by Fueten and Goodchild (2001). The flat stage procedure outlined above can determine the plunge of the *c*-axes and the trend or trend + 180°. The ambiguity in the trend means that the *c*-axes can, for example, either plunge towards the NW or SE, resulting in the symmetry of the Schmid nets. Accuracy of the trend for grains with a *c*-axis parallel to the stage is approximately 1° and exceeds that of the plunge.

4. Post processing

Following the experiment, further processing can be carried out using two different pieces of in-house developed software. A stand-alone program allows for editing of the movie files, as well as the construction of additional *c*-axis movies, using the maximum intensity and position movies as input. This flexibility is required, as it is not always possible at the start of an experiment to determine what the optimum *c*-axis setting will be. Individual samples can be analysed using the software already developed for use with the rotating polariser stage that allows for the calculation of grain size and shapes (Fueten and Goodchild, 2001).

5. System features

The collection of a single sample (i.e. the construction of a single maximum intensity frame) takes a finite amount of time, dependent on the speed of the acquisition computer. It is important that the image in the field of view not change during the acquisition time. For the system described above, acquisition of a single sample or single movie frame takes a little more than a minute. Hence, a practical limit of capturing frames every 2 min exists. During some initial experiments using strain rates of approximately 10^{-4}/s, a 2 min sampling interval proved to be sufficient to provide sharp images.

Initial tests were performed using a Pentium III 400 MHz computer with 64 MB of RAM. The data collection of a single experiment, resulting in movies with 200 frames, requires approximately 1 GB of temporary hard disk. Every single 200 frame movie, except the Schmid net movie, which is constructed using a smaller image, requires approximately 200 MB of permanent storage space. The raw data for such an experiment, consisting of the Maximum intensity, the Maximum position and the Gradient movies can easily be stored on a single CD. All other data can be reconstructed using the AVI editor. It is possible to compress a movie to reduce its size; however, any compression inevitably results in a loss of resolution.

6. Conclusions

In addition to the normally observed deformation textures, the experimental setup described above yields information on the crystallographic orientation of deforming rock analogues. Crystallographic information obtained in this manner will provide a greater insight into the evolution of textures in real rocks. A series of experiments using this setup are currently in progress and will be reported upon later.

This setup could easily be adapted to other types of deformation rigs suitable for uniaxial analogue materials.

Information on the manufacture or purchase of a rotating polariser stage can be obtained by contacting F. Fueten at ffueten@craton.geol.brocku.ca or by visiting http://craton.geol.brocku.ca/faculty/ff/ff1.html.

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