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# A note on photography in structural geology

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**Abstract**—When photographs of outcrops are required for detailed and/or accurate structural work the photographic image should be parallel to the outcrop surface. A method has been developed which allows oblique photographs to be corrected when processed. The method imposes certain restrictions on the combinations of camera and enlarger lenses which will yield a correctly proportioned print, and graphs are presented which predict suitable combinations for a wide range of conditions. The technique has been successfully applied to several problems, one of which is presented as an illustrative example.

## INTRODUCTION

IT IS often convenient to use photographs for recording structural data, for example in elucidating the structural geometry of sub-vertical outcrops such as cliffs, road and rail cuttings and quarry faces (e.g. Cooper *et al.* 1983). A photographic montage allows data to be recorded at its correct location, and hence spatial relationships between structures will be accurate. Another circumstance where photographs are advantageous is when a large number of accurate measurements are required, for example, in strain analysis. The data can be quickly and efficiently obtained from a photograph using a digitizer and microcomputer; taking these measurements directly from the outcrop may often be impractical.

The major drawback to this method is that unless the surface of the outcrop is perpendicular to the axis of the camera lens then, as discussed by Anderton (1985), the image will be distorted and hence measurements made on the print will be in error. Ideally all geological photographs should avoid this problem by careful planning, but the nature of outcrops and local topography often make this impractical. The purpose of this note is to describe a simple procedure for obtaining corrected photographs for subsequent work. The method we describe is only one of several possible suitable methods; however, it has the advantage of using only standard photographic equipment, but does impose some restrictions on the choice of camera and enlarger lenses. We present an analysis of suitable lens combinations, which is rigorously based on optic theory (see Cox 1961 for a thorough treatment) and we have also tested the method empirically.

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## METHODOLOGY

The method developed is easily set up, requiring little specialized equipment. Small white cardboard squares are placed flat on the surface, one centrally and one in each corner. If photographed obliquely the squares will be distorted on the negative. This distortion can be removed, to a first approximation, by printing on to an enlarger masking frame which can be tilted. We have constructed such an instrument from a standard masking frame attached to a camera mini-tripod. The mini-tripod has a ball and socket joint at the top which allows the masking frame to be tilted to any angle desired (Fig. 1). By placing graph paper on the masking frame the shape and the size of the square images are obtained. When printed the image will be effectively corrected and measurements may now be taken. We have illustrated the method using a photograph of deformed mudcracks on a bedding surface which were used to calculate the strain (Fig. 2). When the image was corrected using the method described above, the shape of the mudcracks changes (Fig. 3). To keep the whole image in focus on the tilted masking frame we recommend that the enlarger lens be set to its minimum aperture. We have also found that because the distance from the light source is not constant, the density of the print is variable. This problem can be overcome by using the technique of 'shading-in' the print. This requires a piece of card larger than the print, which is used to intermittently cut out the light producing the image on the up-tilted part of the masking frame and hence, the potentially over-exposed portion of the print. Some trial and error is required to determine the percentage of time for which the image should be shaded. The area of the image that the card obscures should be progressively decreased to prevent a sharp edge between areas of different exposure on the final print.

In the case of long linear outcrops a series of photographs with an overlap of one-third are taken and subsequently montaged. If the prints are not undistorted prior to montaging then the result will be a complex curve as each print will be an irregular trapezohedron. In the simplest case if the camera was consistently pointing downwards the montage will be convex-up. During work on the Basse Normandie duplex (Cooper *et al.* 1983) this problem was overcome by measuring the inclination of the camera lens and tilting the masking frame to that angle when printing. However, the method we have described above using squares is far more convenient and the squares facilitate accurate scale matching and consistency from print to print. This method will also aid the compilation of accurate montages when the camera has to be positioned at varying distances from the outcrop.

## POTENTIAL SOURCES OF ERROR

The problem of oblique photography inducing distortions is well known from architectural photography. When accurate photographs of buildings are required the usual practice is to use an architectural camera (Langford 1977). This camera has the facility to swing the lens out of parallelism with the film plane and to move the lens up or down and sideways with respect to the film plane. This allows an undistorted image to be recorded on the negative; however, such cameras are costly and cumbersome.

The method described appears to be an ideal solution to the problems of oblique photography of outcrops. However, whilst the technique successfully corrects angular distortions, it can introduce substantial errors in the proportions of the image, causing the squares to be stretched or compressed into rectangles. This is due to the selection of an unsuitable combination of camera and enlarger lenses; if the lenses are not compatible then this method will yield an incorrectly proportioned image (Cox 1961).

The amount of stretch $\mu$ can be calculated from $\theta$ the angle of obliquity of the camera lens and $R$ the ratio of lenses, using the formula

$$\mu = \sqrt{\frac{(1 + R^2 \tan^2 \theta)}{(1 + \tan^2 \theta)}}. \quad \text{(Cox 1961)}$$

Figure 4 illustrates curves for stretches ($\mu$) of 1.01, 1.02, 1.05 and 1.10 on a plot of $R$ vs $\theta$. This graph indicates the maximum $R$ value for any $\theta$ value selected, which will not cause the stretch to exceed the chosen limit. An $R$ value of 1.1 thus produces a 1% stretch at $\theta = 20°$, 2% at $\theta = 30°$ and 5% at $\theta = 45°$. We therefore consider that any lens combination which yields an $R$ value of 1.1 or less will produce an acceptably proportioned image.

The $R$ value for any lens combination can be calculated using the formula

$$R = \frac{(Me + e)\cdot(u - f)}{Meuf}, \quad \text{(Cox 1961)}$$

where $M$ is the degree of enlargement, $e$ is the equivalent focal length of the enlarger lens, $u$ is the distance of the object and $f$ is the equivalent focal length of the camera lens. The equivalent focal length of the lens is normally inscribed on the lens.

A simple computer program was used to calculate all combinations of these variables, which yield an $R$ value in the range 0.9–1.1. $M$ and $u$ have a limited effect on the $R$ value, but there is only a narrow band of $e$ and $f$ values that will yield a value of $R$ within the accepted range.

We present two graphs of $e$ vs $f$, which can be used to determine acceptable combinations of camera and enlarger lenses. Figure 5 shows acceptable lens combinations for various object distances at an enlargement of 4 (a 12.5 × 7.5 cm print from a 35 mm negative). This indicates that at short focal lengths the combinations are independent of object distance and that the enlarger lens should be of a focal length 5–10 mm shorter than the camera lens. At long lens focal lengths the relationship is similar, if at short object distances; however, if the object distances are greater than 5 m, then the correct enlarger lens focal length will be up to 30 mm shorter than that of the camera lens. There is more latitude for longer focal length lenses.

Figure 6 illustrates the effect of varying degrees of enlargement at a constant object distance of 5 m. Again, at short focal lengths the variation is minimal and the enlarger lens should have a 5–10 mm shorter focal length than the camera lens. At longer lens focal lengths the reduction in enlarger lens focal length decreases as the degree of enlargement increases.

Using these graphs it is possible to determine the combination of lenses suitable for successfully undistorting obliquely photographed surfaces. Sets of graphs showing suitable combinations for a larger range of $M$ and $u$ values can be supplied on request.

We used these equations to select suitable combination of lenses for two empirical tests on the method. The first test involved photographing graph paper with the camera lens inclined at measured angles, between 0 and 70°, from the perpendicular. This test generated slight stretching of the squares, which was as predicted from the mathematical simulations of Figs. 4–6. It demonstrates that the method is sufficiently sensitive to enable corrected prints to be produced which are within acceptable limits of the true proportions of the outcrop. The test at 0° inclination revealed that towards the edges minor scale changes occurred; these are the result of unavoidable edge effects of the optical lenses used.

In the second empirical test we compared measurements of the mudcracks on the corrected print (Fig. 3) with measurements taken directly from the bedding plane in the field (Fig. 7); the differences between the two data sets were trivial and within the 5% stretch curve on Fig. 4.

We conclude from this analysis that provided a suitable combination of lenses is selected by using Figs. 4–6, the method we describe will produce accurately corrected prints from obliquely photographed outcrops. The only data required to accomplish this is the angle of obliquity $\theta$, the degree of enlargement of the negative, $M$, and the distance of the outcrop from the camera, $u$.

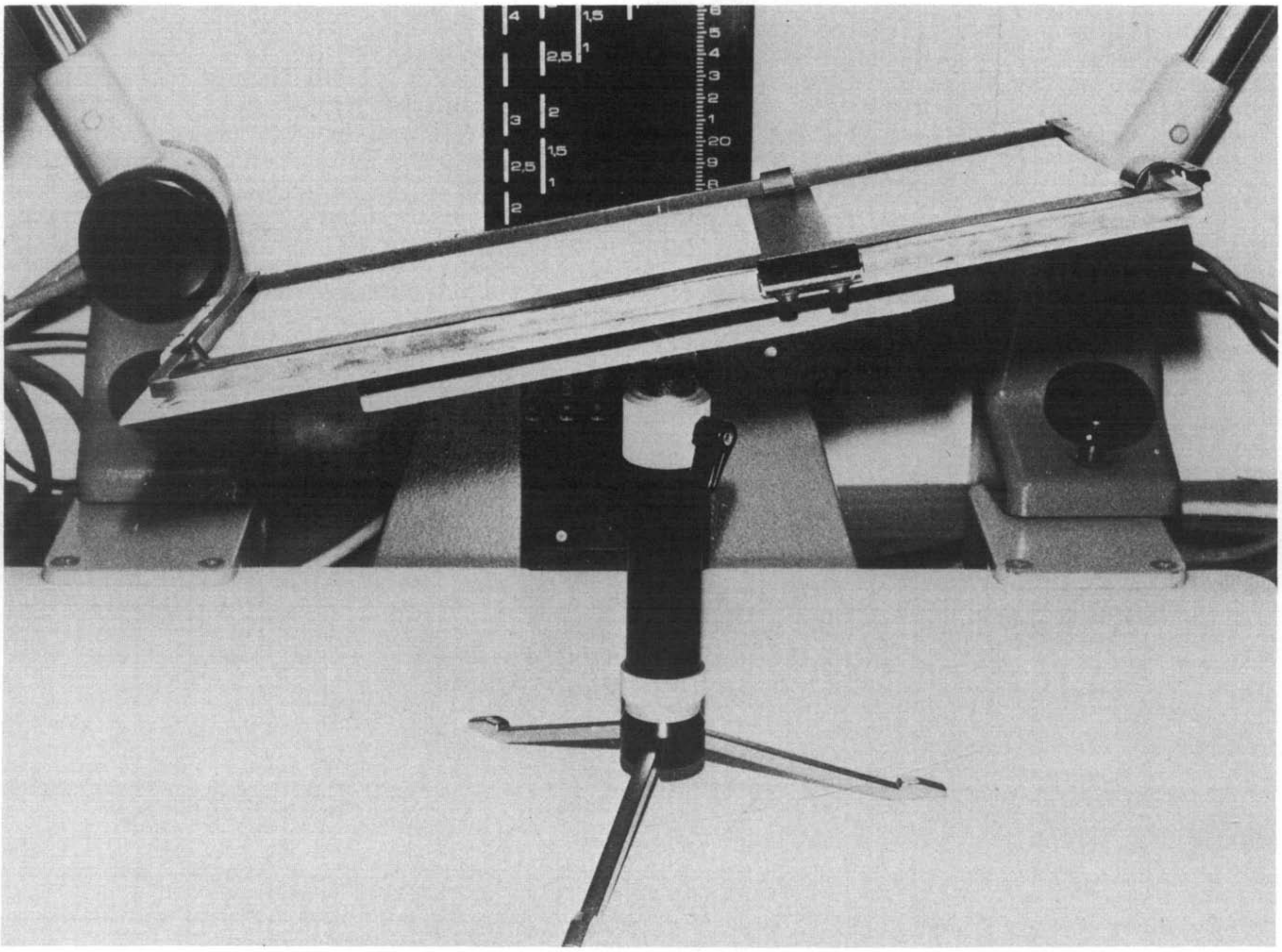


Fig. 1. The tiltable enlarger masking frame: the ball and socket joint may be locked in position once the undistorted image is produced.

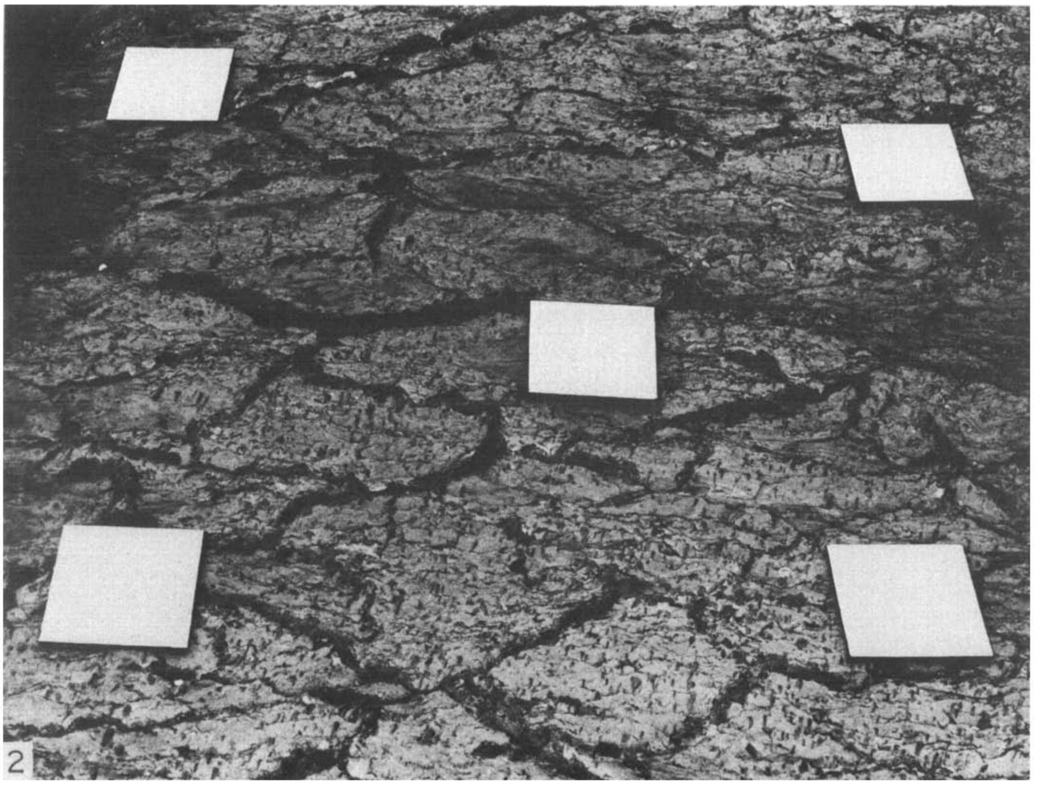

Fig. 2. Mudcracks from the Toe Head Formation on the Old Head of Kinsale, Co. Cork (Eire) photographed obliquely at an angle of approximately 45°. Sheets of cardboard are 10 $cm^2$. Equivalent focal length of the camera lens is 50 mm and that of the enlarger lens is 40 mm.

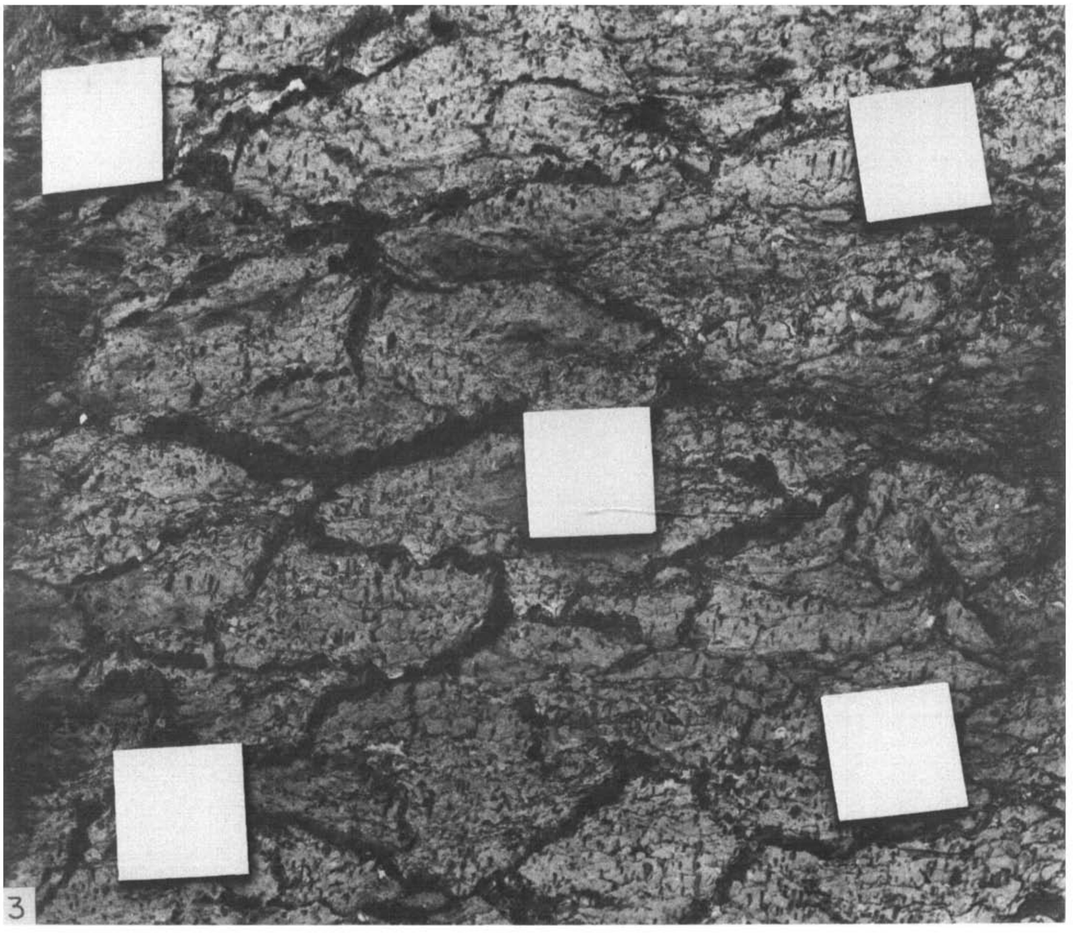

Fig. 3. The result of undistorting the image in Fig. 2 using the method described. Sheets of cardboard are 10 $cm^2$. Note how the square in the bottom right-hand corner has not been properly corrected, this is due to unevenness of the bedding surface at this point.

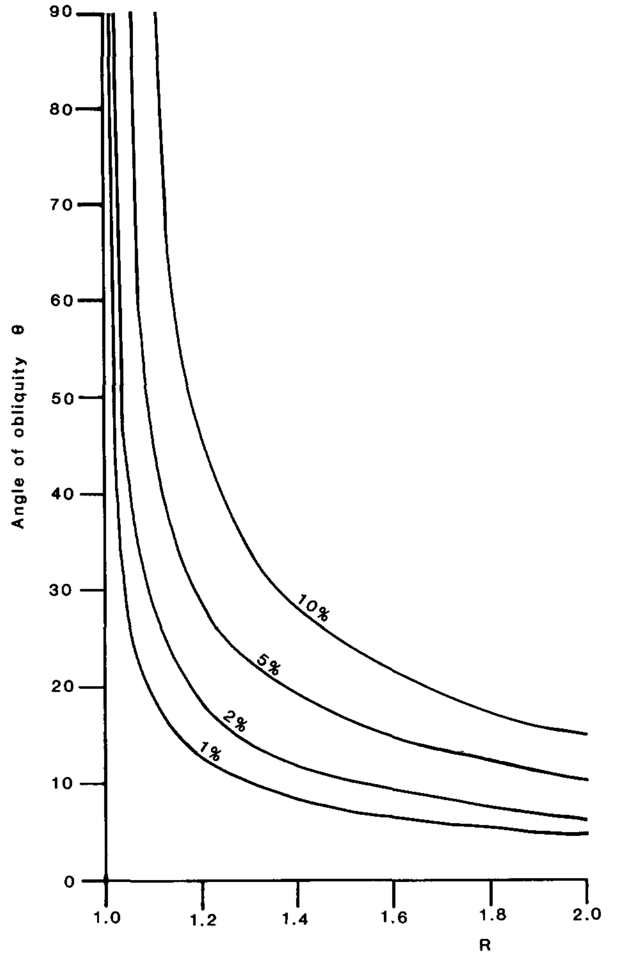


Fig. 4. Curves for stretches of 1.01 (1%), 1.02 (2%), 1.05 (5%) and 1.10 (10%) on a plot of $R$ against $\theta$. At low $\theta$ values induced stretches are low even at high $R$ values. The stretch curves have an exponential form.

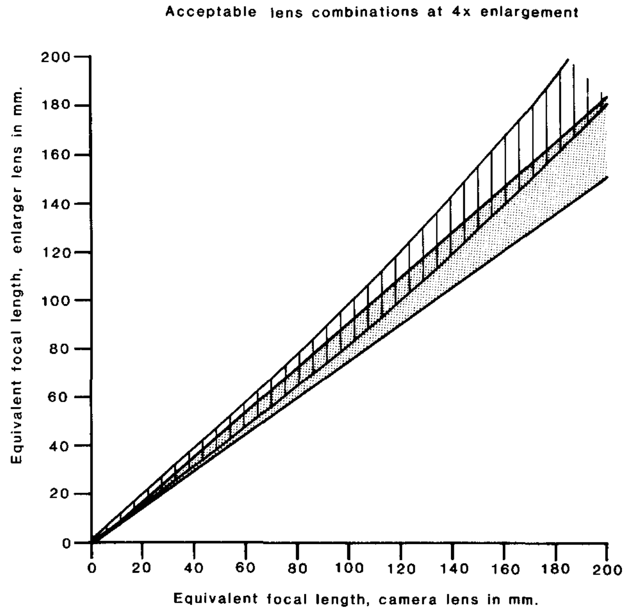


Fig. 5. Acceptable lens combinations which will produce an $R$ value in the range 0.9–1.1 for a four times enlargement at object distances of 1 m (vertical ruling), and >5 m (stippled).

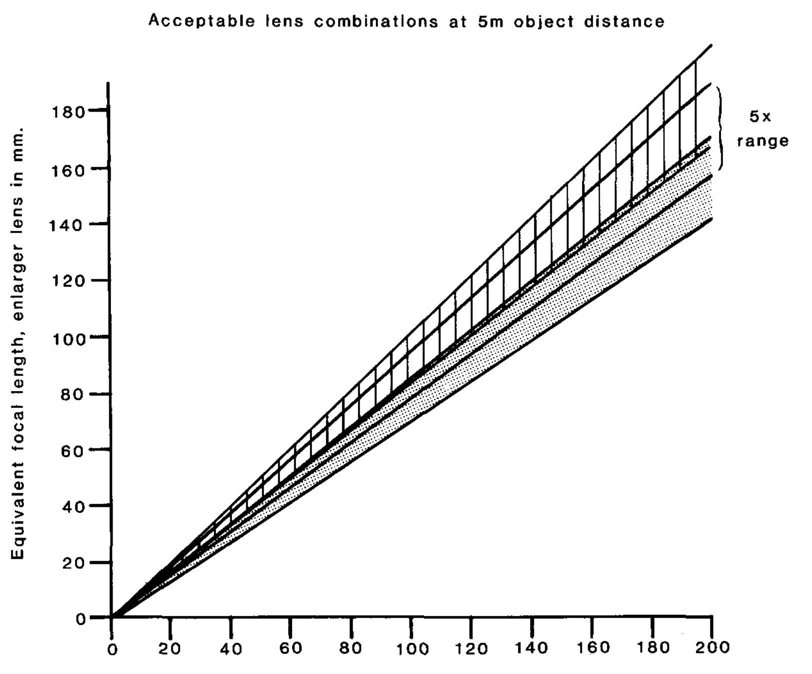


Fig. 6. Acceptable lens combinations which produce an $R$ value in the range 0.9–1.1 for an object distance of 5 m at three (vertical ruling), five and seven (stippled) times enlargements.

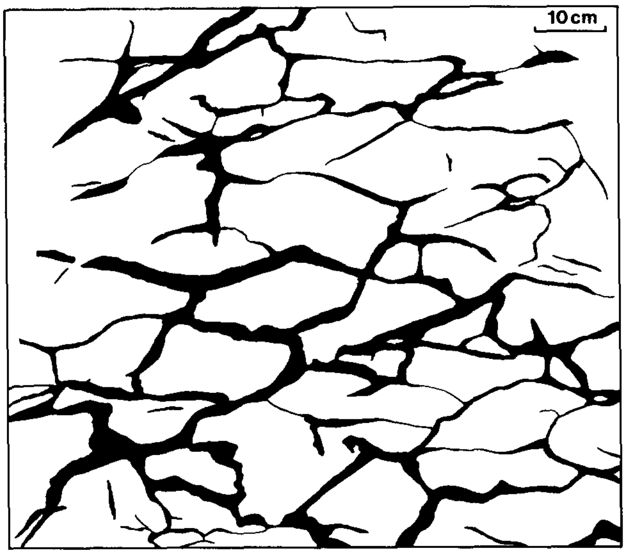


Fig. 7. An accurately measured plan of the mudcracks taken directly from the bedding plane by using an overlay of tracing paper.

We recommend that the enlarger lens be chosen first and the camera lens tailored to provide a suitable combination. This is usually readily accomplished by using interchangeable lenses or the increasingly common zoom lenses on the camera.

The problem of surface relief cannot be cured even with a technical camera. This can be minimized by siting the camera at sufficient distance from the surface that scale differences will be minimal. If this is impractical we have found that an effective remedy is to chalk around areas of anomalous relief so that they can be omitted from measurements. Apart from aiding the operation of setting the orientation of the masking frame, the use of more than one cardboard square in a photograph means that any error in any single square's orientation may be checked against the other squares when printing. This is shown in Fig. 3 where the cardboard square in the top left-hand corner has not been restored properly. However, the mudcracks are similar to those drawn in the field (Fig. 7).

## ALTERNATIVE METHODS OF CORRECTING DISTORTED IMAGES DURING PROCESSING

A more sophisticated method of producing the correction is available on certain enlargers which allow the negative to be tilted as well as the masking frame. Other enlargers have the facility to tilt the enlarger lens. Both of these methods are less susceptible to errors induced by the choice of unsuitable lens combinations. However, in our experience such enlargers are not standard equipment in Geology Department dark rooms. A full treatment of the optical theory behind these and other methods of printing connected images from obliquely photographed negatives is given by Cox (1961, pp. 304–310).

## APPLICATIONS

We have successfully applied this technique to a wide range of problems encountered during structural and sedimentological studies of the Irish Variscides. These include: measurement of strain from mudcracks, estimation of shortening in pressure solution cleavages, the variability in orientation and spacing of pressure solution cleavages, orientation of tool marks and the structural geometry of cliff sections. Sanderson (oral communication. Field photography + microcomputer = data, Tectonics Studies Group AGM 1983) described a similar method using a microcomputer to determine the algorithm necessary to undistort the square and hence the digitized data. We consider that our method is preferable in that the whole image is corrected rather than points which are digitized. Clearly for producing montages on which to record structural geometry the Sanderson method would not be suitable. Our technique can also be used as a quick method of producing fold profiles perpendicular to the fold axis. In this case the square is oriented such that it is perpendicular to the axis rather than parallel to the surface. When 'corrected' during printing a fold profile will result. This should not, however, be attempted where a fold is suspected to be markedly non-cylindrical.

## CONCLUSIONS

(1) Our method provides a fast and efficient way of producing accurate photographs of rock surfaces on which data an be recorded.

(2) No experience and little specialized equipment is necessary.

(3) To obtain a corrected image with acceptably accurate proportions a suitable combination of camera and enlarger lenses must be used. Our analysis allows such combinations to be predicted for a wide range of conditions. As the angle of obliquity increases, the range of suitable combinations decreases, but as a general rule the equivalent focal length of the enlarger lens should be 10 mm less than that of the camera lens.

(4) If the central portions of negatives are used, errors will be minimized and the matching of montages will be improved.

(5) The method has been successfully tested on several problems.

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## REFERENCES

Anderton, R. 1985. Clastic facies models and facies analysis. In: *Sedimentology: Recent Developments and Applied Aspects* (edited by Brenchley, P. J. & Williams, B. P. J.). *Spec. Publs geol. Soc. Lond.* **18**, 31–47.

Cooper, M. A., Garton, M. R. & Hossack, J. R. 1983. The origin of the Basse Normandie duplex, Boulonnais, France. *J. Struct. Geol.* **5**, 139–152.

Cox, A. 1961. *Optics: The Technique of Definition*. Focal Press, London.

Langford, M. J. 1977. *Basic Photography*. Focal Press, London.