An effect of depth of focus on micrometric analysis.

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Summary.—When using many patterns of integrating stage the depth of focus is so great that it is not possible to distinguish between the upper and lower surfaces of a thin section; this may introduce serious errors into micrometric analyses. A procedure to meet this difficulty is suggested.

THE classic method of micrometric analysis of Delesse required that all measurements should be made on a single plane in a rock and in modern analysis the plane frequently selected is the surface of a thin section (Chayes, 1953, 1954). It is here suggested that under certain conditions of micrometric analysis no such single surface can be differentiated and instead both upper and lower surfaces of a thin section may be in simultaneous focus. When this is so and the analyst is unaware of the fact errors may occur. To eliminate errors from this source measurements can be made on a plane, selected between crossed nicols if necessary, in the centre of the slide. Areas measured on this plane are mean areas and, as such, are directly proportional to volumes.

The reason why no single surface can be differentiated under certain conditions of micrometric analysis is due to the fundamental deficiencies of the optical system of the microscope, whereby a depth of focus, which varies with the numerical aperture, is introduced.

The objectives commonly used in measurement are those of focal lengths about $\frac{2}{3}$ inch, $\frac{1}{3}$ inch, and $\frac{1}{6}$ inch, with numerical apertures of approximately 0·25, 0·45, and 0·65, respectively. On the Leitz stage these objectives give the following performance: The 0·25 N.A. objective gives a clear picture of the full thickness of the slide with both upper and lower surfaces sharply in focus at the same time. The 0·45 N.A. objective allows discrimination of the two surfaces of the slide where the crystal margins are well defined; where the crystal margins are irregular the separation of the two surfaces is not easily obtained and requires both time and care, since a considerable depth of the slide is visible. The 0·65 N.A. objective distinguishes the two surfaces of the slide and has shallow depth of focus.

This is at first sight surprising for the quoted depths of focus for these objectives are of the order of 0·008 mm., 0·0024 mm., and 0·001 mm., all very much less than the thickness of a thin section, so that all might be expected to be capable of focusing sharply on one surface to the exclusion of the other, and to have a shallow depth of focus. The greatly increased depth of focus found in practice is largely due to the conditions under which the objectives operate when used to measure slices on the Leitz integrating stage. This stage is mounted on top of the microscope stage in such a way that the thin section is raised almost an inch above its normal position. The substage condensers cannot be raised to their usual position in relation to the slide and in consequence the objectives and condensers cannot be matched. The high-power condenser cannot be used at all at the increased distance for it gives very inferior illumination and it is necessary to use the low-power condenser of N.A. = 0·22. This gives a satisfactory amount of light but its pencil of rays probably has an aperture, at the increased distance, of about 0·10. (This is a guess on my part but since the distance between condenser and object has been approximately doubled the aperture will be approximately halved.) An objective of N.A. = 0·25 working in conjunction with a condenser of N.A. = 0·10 has an effective N.A. of 0·18. Similarly, objectives of 0·45 N.A. and 0·65 N.A. working with the same condenser will have effective apertures of 0·28 and 0·38. This diminution in aperture increases the depth of focus.

The quoted depth of focus of an objective, *df*, is calculated from the formula:

$$df = \text{Allowed difference of path to produce no loss of definition}/n \sin^2 U/2$$

where n is the refractive index of the medium between object and objective and U is half of the full cone of light entering the objective. The allowed difference of path is usually written as $\lambda/4$, where λ is the wave-length of light used, but it may be greater than this for Rayleigh (1896) states that up to $\lambda/2$ path-difference there is no perceptible loss of definition. Substitution of $\lambda/2$ for $\lambda/4$ in the formula doubles the depth of focus.

The depth of focus based on $\lambda/2$ and the reduced apertures are as follows: 0·25 N.A. objective = 0·031 mm.; 0·45 N.A. objective = 0·013 mm.; 0·65 N.A. objective = 0·007 mm.

These figures are computed as distinct from being measured and so are the minimum depths of focus that can be attained. Any factors which serve to decrease the numerical aperture, such as incorrect thickness of coverslip, stopped-down light, or imperfections in the lens, will serve to increase the depth of focus further. The conclusion to be drawn from the figures is that the 0·25 N.A. objective can focus the full thickness of the section at one time; the 0·45 N.A. objective about half the thickness of the section, and the 0·65 N.A. objective about a quarter of the thickness of the section. This is in agreement with practice.

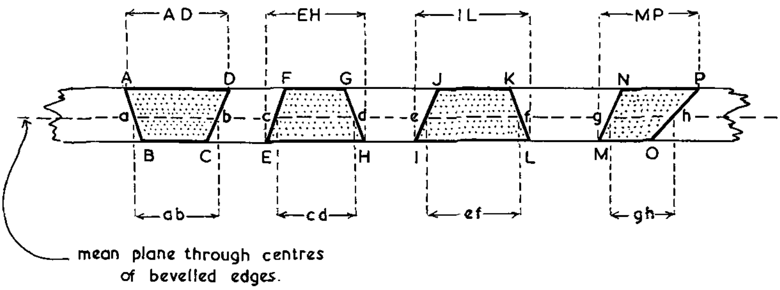

FIG. 1. Cross-section of thin section to show the different grain margins which may be selected for measurement. (*a*) upper surface, $AD+FG+JK+NP+\ldots$; these will give correct mineral ratios. (*b*), lower surface, $BC+EH+IL+MO+\ldots$; these will give correct mineral ratios. (*c*) $AD+EH+IL+MP+\ldots$; these are selected by eye when the whole thickness of the slide is in focus; the error is the superposition error. (*d*) $ab+cd+ef+gh+\ldots$; these are measured from the centres of bevels and give the correct mineral ratios.

Within the depths of focus as established above there is no means of differentiating one plane from another since with monocular microscope vision there is neither stereoscopic differentiation nor aid from perspective, so that all objects in focus are seen to lie in the same plane. Where some considerable depth of focus exists, to accept measurements as those of a single plane is to accept illusion.

These considerations are important when minerals of contrasted relief lie side by side for it is my belief that the eye accepts the maximum diameter, within the depth of focus, of high-relief minerals with inclined margins; and since the horizons of the maxima vary from grain to grain any measurements are effectively taken on more than one plane. When mineral boundaries are inclined, therefore, there is a distinct possibility of superposition error (fig. 1). If the conditions of the analysis allow one to identify, with certainty, that edge of the bevel which intersects the surface of the slide the ordinary procedure can be used, but if there is liable to be any doubt about which is top and which bottom it is possible to eliminate or diminish the error of measurement by measuring, between crossed nicols if necessary, from the centre of one bevelled edge of a grain to the centre of the other. The centres of the bevels will, on the average, be in the centre of the slice and if all measurements are taken on them they will all be made on a plane—a mean plane—and the result will be more accurate than if they were made on a number of planes in the belief that they were one.

Areas measured from the centres of bevels constitute true mean areas of the several minerals in the slide and, as such, are directly proportional to volumes since *vol.* = *mean area* $\times \delta x$, where δx is the thickness of the slide.

The conclusions are that measurements from the centres of bevels are measurements on a plane, that volumes are proportional to areas measured in this way, and that the measurements constitute a direct measurement of volume. This is certainly not the theory of Delesse but it is nevertheless valid in those instances where a considerable depth of focus exists and where the majority of the grains are greater in size than the thickness of the slice.

References.

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