

The petrographic use of the spindle stage and focal-plane screening in the determination of the optical variation of some zoned minerals

By HEDLEY G. WRIGHT

9 Moray Place, Edinburgh 3

[Taken as read 4 November 1965]

Summary. The Equivibration Curve technique of Joel (1963) is used to determine the orientation of a zoned mineral on the spindle stage axis and an average value for $2V$. A bracketing method enables the extreme values of each refractive index to be determined for sodium light on a single grain, using the Focal-plane Screening technique of Cherkosov (1960).

THE practical model of the spindle stage designed by Hartshorne (1963) can now be obtained commercially and the methods for determining the optical orientation of anisotropic mineral grains on a single-axis apparatus have been worked out in a series of papers by Joel (1963), Garaycochea and Wittke (1964), and Tocher (1964). The attraction to petrologists of these developments is that a simple method for determining α , β , and γ as well as $2V$ on a single mineral grain is now available and it is no longer necessary to assume that a powdered mineral-separate from a rock is composed of grains all having identical optical properties.

The technique of focal-plane screening (Cherkosov, 1957) or 'dispersion staining' (Brown and McCrone, 1963) can be used to simplify the matching of the grain indices of refraction to the immersion liquid as it avoids the ambiguities experienced with Becke Line observations on all but the smallest grain sizes. A further operational procedure will enable the range of optical zoning to be determined within strongly zoned small grains of certain minerals. The technique to be described is strictly applicable only to uniaxial minerals or biaxial minerals of the orthorhombic system (such as olivine or orthopyroxene) but has been applied to monoclinic minerals such as augites when it has been reasonably certain that there was no substantial variation in the $\gamma:c$ angle within the sample, and to triclinic minerals such as a plagioclase in which the range of zoning was not large enough to cause extensive

rotation of the indicatrix. Grains down to slightly less than 0.1 mm can be used conveniently.

Method. (Reference will not be specifically made to the uniaxial case as it is a simplification of the described procedure for biaxial minerals).

Wilcox (1959) gives details for specimen mounting but the use of a new inert epoxy-resin mountant in the *Araldite* range is preferable. A small portion of the rock or mineral concentrate is placed on a glass slide under the microscope and covered with one or two drops of bromobenzene. A suitable grain is manipulated to a separate portion of the slide with a mounting needle and allowed to dry off. On a separate glass slip *Araldite* AY 103 is thoroughly mixed with *Hardner* HY 951 (obtainable on reference to CIBA (ARL) Ltd., Duxford, Cambridge) in the approximate proportion of 10 to 1; the very tip of the stage spindle is covered with the mixture and the spindle should then be touched a few times on another portion of the slip to ensure that there is barely any *Araldite* mixture left on it. The selected, dry mineral grain is then touched with the point of the spindle to which it will adhere; the *Araldite* resin is cured by holding a lighted match to the spindle about three centimetres back from the tip for as long as it takes the match to burn, or a cigarette lighter may be applied for 15 seconds.

The stage base plate is mounted on the microscope and the spindle positioned with the grain in the centre of the field of view and surrounded with a liquid whose refractive index is close to the expected average refractive index of the grain.

There is a rapid method of determining if the grain is in a suitable orientation relative to the spindle axis to make further measurements profitable and this is presented here without theoretical justification (Wright, in preparation). The direction of the spindle axis is rotated on the microscope stage to make an angle of 40° with the vibration direction of either of the crossed polars. If the entire grain or all its various zones can be brought into extinction by rotating the spindle axis the grain is suitably mounted for detailed measurements to be made; otherwise a new grain should be mounted.

The extinction curves and the associated equivibration curve are plotted on a 20 cm net according to the method of Joel (1963), using a high power, large aperture objective to make conoscopic observations; this requires a properly centred Bertrand lens and extinction is judged when the centre of the isogyre lies on the eyepiece crosswires. If the mineral is zoned proper curves cannot be constructed orthoscopically. The conoscopically determined curves should be refined by

more frequent observations in the region of the extremities of the major and minor diameters of the equivibration curve: the principle vibration directions are located as Joel describes. A value for $2V$ may be obtained using Joel's formula relating the angle V with the semi-diameters of the equivibration curve; in the case of a zoned mineral this is an illusory value and its significance will be discussed later.

Measurement of the principle refractive indices is carried out with a standard 16 mm objective screened by insertion of a 1.5 mm aperture at the rear focal plane. This may be effected by blacking out, with Indian ink, all but the central 1.5 mm of a circular cover slip that fits inside the objective in contact with the rear lens element, or, better, with a pierced metal or opaque plastic insert that performs the same function without introducing an extra piece of glass into the optical train. Strong, white, properly centred illumination is used, any top condenser element removed, and the substage diaphragm reduced to a minimum workable aperture.

The three orientations in which the mineral grain can be viewed, with a principle vibration direction parallel to the polarizer vibration direction, are read from the stereogram (Fisher, 1962). The refractive index of the immersion liquid is changed by physical mixing methods to obtain compositions in a suitable order (which depends on the extent of zoning of the mineral) so that for each orientation liquids are obtained that have visually estimated sodium yellow as the highest frequency and as the lowest frequency spectral colour displayed at any point along the grain margin. To perform these manipulations the refractive index liquids should have a markedly different dispersion to that of the mineral (the normal case) and are best contained in pipette stoppered bottles. A separate fine pipette should be used to withdraw excess liquid from the stage cell and a blunted No. 1 hypodermic syringe is useful for transferring the critical liquids to the refractometer cell, in which their n_D is measured. The hypodermic needle should be flushed after each use with two drops of a highly volatile solvent (e.g. benzene).

After all measurements are completed the grain and excess resin are removed from the spindle by gentle use of a sharp blade.

Apologia. Since optically zoned minerals of the orthorhombic, monoclinic, and triclinic systems exhibit undulose extinction in many orientations, plotting of exact extinction and equivibration curves is impossible. In the orthorhombic system zoning does not effect the indicatrix orientation and this is sometimes true in the monoclinic and triclinic systems within limited ranges of chemical composition or

physical state. In these cases the extinction and equivibration curves for the various zones of a mineral grain will pass through common α , β , and γ directions and the grain will unequivocally extinguish as a unit when these directions lie in the plane of the microscope stage. In other positions the curves for the various zones separate and no orthoscopic definition can be attempted. Conoscopic observation will however reveal a composite isogyre formed by the overlap of the individual isogyres of the various zones. If the central, darkest portion of the composite isogyre is taken as the 'extinction position' it is possible to plot modal extinction and equivibration curves for the whole grain. The principle vibration directions obtained from these curves are exact but the value of $2V$ calculated from measurements on the equivibration curve is a modal one since each zone in the mineral is contributing to the equivibration curve with the weight of its volume proportion in the grain.

The two available axes of rotation enable the three principle vibration directions of the crystal to be brought individually parallel to the microscope polarizer, but the crystal cannot be rotated about these optic directions; thus the grain can only be viewed by each wave-normal in two positions, one the opposite of the other. Since one grain may not show the full range of zoning in these positions it is imperative to obtain maximum and minimum values for all three indices if the data is to be used for determinative purposes. The focal-plane screening technique exhibits the zoning of the grain in vivid colour and the smallest area of refractive index mismatch at the margin of the grain stands out. Pure spectral colours are displayed when the grain is properly orientated for measurement and it will be found singularly easy to match the highest and lowest index portions of the grain with a liquid for a visually estimated sodium yellow: persons fearing their judgement may like to check the colour by placing a 'minus-sodium' filter, such as is used on the standard Leitz-Jelley Refractometer, in the accessory slot of the microscope.

Explanation and discussion of the table. The olivine grains examined were separated from a dolerite. All of the six grains measured were 0.1 mm or less in diameter and their marked zoning did not permit conventional methods of refractive index determination to be used. This is probably as extreme a case as will be encountered in routine work.

The limits of α are 1.692 and 1.764, the limits of β are 1.714 and 1.782, and the limits of γ are 1.733 and 1.788. The values of ' $2V_\alpha$ ' only range over three degrees between $77^\circ 50'$ and $80^\circ 50'$. This is

TABLE I. Optical data for olivine grains from a Tertiary dolerite, Morar, Inverness-shire. Bracketed figures are fayalite percentages obtained from the chart of Kennedy as reprinted by Tröger (1953)

Grain No.	$2V_{\alpha}$ modal	α	β	γ
1	80° 50' (33)	1.700:1.764* (34) (67)	1.725:1.756 (35) (49)	1.756:1.770 (42) (49)
2	80° 0' (35)	1.697:1.734 (32) (51)	1.716:1.776 (30) (58)	1.738:n.d. (33)
3	80° 0' (35)	1.696:1.731 (31) (50)	1.738:1.772 (41) (57)	1.746:1.783 (37) (55)
4	79° 0' (38)	1.710:1.758 (39) (64)	1.732:1.782 (38) (61)	1.760:1.788 (44) (58)
5	78° 50' (38)	1.701:1.736 (34) (52)	1.728:1.753 (36) (48)	1.742:1.774 (35) (51)
6	77° 50' (40)	1.692:1.747 (29) (58)	1.714:1.763 (29) (52)	1.733:1.775 (31) (51)

* Only one minute corner of the grain showed rapid zoning to this high value for α .

notable in view of the zoned nature of the grains and the uncertainties to which one is accustomed in Universal Stage measurements on this mineral. If one accepts Kennedy's chart as given by Tröger (1959), this represents a range of composition between Fa_{33} and Fa_{40} and there would be justification for claiming that the average olivine of the rock is $Fe_{63}Fa_{37}$. It may also be stated with reasonable certainty that the olivine of the dolerite is zoned between the compositions $Fe_{71}Fa_{29}$ and $Fe_{33}Fa_{67}$.

Inspection of the refractive index figures for the individual grains, especially No. 1, provides substantiation of the statement that, in view of the restricted number of critical directions in which the grain may be viewed, it is necessary to carry out measurements for all three indices.

Acknowledgement. Dr. M. J. O'Hara kindly read the typescript.

References

- BROWN (K. M.) and McCURRY (W. C.), 1963. *The Microscope*, vol. 13, p. 311.
 CHERKOSOV (YU. A.) [ЧЕРКОВ (Ю. А.)], 1957. Modern methods of mineralogical investigations of rocks, ores and minerals. Gosgeoltekh., Moscow (p. 184); trans. by Ivan Mittin 1960. *Intern. Geol. Rev.*, vol. 2, p. 218.
 FISHER (D. J.), 1962. *Amer. Min.*, vol. 47, p. 649.
 GARAYOCHEA (I.) and WITTKÉ (O.), 1964. *Acta Cryst.*, vol. 17, p. 183.
 HARTSHORNE (N. H.), 1963. *Min. Mag.*, vol. 33, p. 693.
 JOEL (N.), 1963. *Ibid.*, p. 679.
 TOCHER (F. E.), 1964. *Ibid.*, p. 780.
 TRÖGER (W. E.), 1959. *Optische Bestimmung der gesteinbildenden Minerale*, Teil 1. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
 WILCOX (R. E.), 1959. *Amer. Min.*, vol. 44, p. 1272.

[Manuscript received 12 February 1965]