

*A simple method for the measurement of the refractive indices of the feldspars.*

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THE method described is one that can be used to measure the refractive indices of minerals when no refractometer is available. The readings are consistent to  $\pm 0.002$  and are in reasonable agreement with those obtained using a refractometer.

The principle of the method is to mix two liquids with different refractive indices. One of these is a typical immersion liquid with a very low volatility. It must have a refractive index greater than that of the mineral under investigation. The other, more volatile liquid has a refractive index less than that of the mineral. The two liquids selected must be miscible in all proportions, but must not react together. The mineral is completely immersed in a mixture of the two liquids. The more volatile liquid evaporates, and there is a corresponding rise in refractive index. The mineral is kept under observation, and the times when its highest and lowest refractive indices correspond with that of the liquid are noted. The actual value of the indices of the mineral can be read off from a suitable time-refractive index graph.

*Technique.*—The method can be adapted for use with any mineral, provided that suitable liquids are chosen. The measurement of the refractive indices of the feldspars is described here. The anorthite percentage of a plagioclase feldspar can be estimated either from the refractive index or from optical measurements made on the universal stage—and this provided a useful means for checking the method.

The liquids used were ortho-toluidine ( $n$  1.570) and toluene ( $n$  1.490), in the proportion of 3 drops of ortho-toluidine to 6 of toluene. This was suitable for feldspars with an anorthite content from 20 to 60 %; the proportions would need to be adjusted to deal with feldspars outside this range, or with any considerable changes in temperature. The small quantities of liquid required were measured with a glass dropping-pipette into a glass cell—capacity about 0.05 c.c.—made by fusing a glass ring on to a microscope slide.

A number of preliminary experiments were carried out, using minerals of known refractive indices, to determine the rate of evaporation of the mixture, and hence the rate of change of refractive index. These experiments showed that the rate of change of refractive index is a function of the time such that if the refractive index is plotted against the logarithm of the time a straight-line graph is obtained.

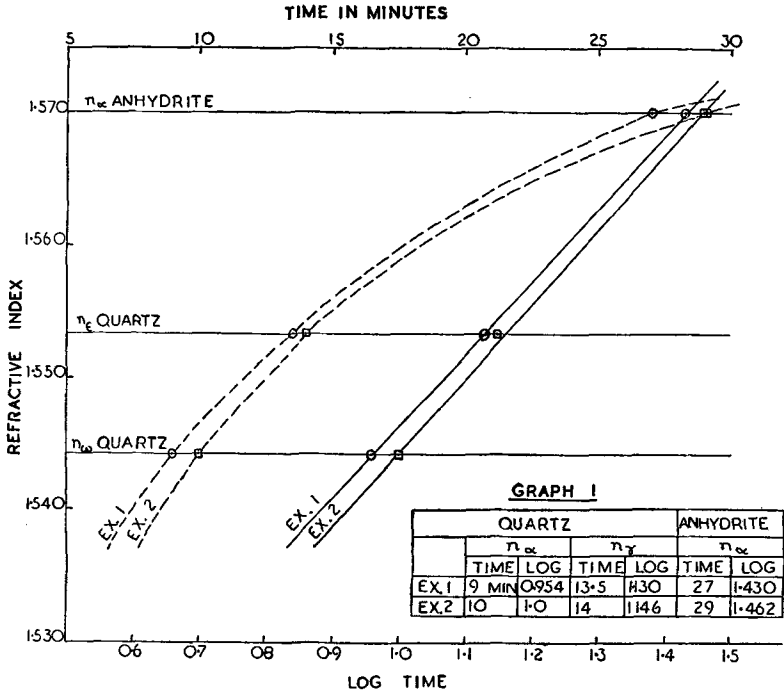


FIG. 1. Evaporation curves with minerals of known refractive indices.

Graphs 1 and 2 (figs. 1 and 2) show the results of two such experiments, using minerals of known refractive indices. The first employed were anhydrite (of which only  $n_\alpha$  fell within the range of the liquids used) and quartz. The dotted line shows the curve obtained by plotting refractive index against time in minutes, and the unbroken line the graph of refractive index against log time. The second graph shows a similar linear relationship between quartz and a sample of labradorite on which  $n_\alpha$  had been independently determined.

These preliminary experiments showed that readings obtained in the

first three or four minutes after the liquids have been mixed are unreliable. It is advisable therefore to adjust the proportions of the liquids so that the required refractive index range is reached after about five minutes.

The different graphs obtained with successive repeated experiments showed that the small quantities of liquid involved were not being mea-

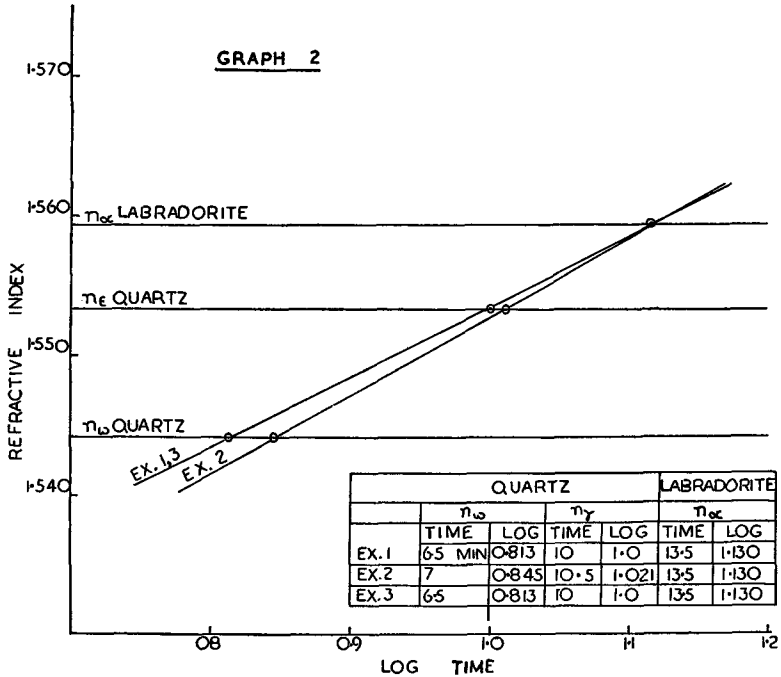


FIG. 2. Evaporation curves with minerals of known refractive indices.

sured very accurately. The rate of evaporation is, in addition, very sensitive to changes in temperature and humidity. It was not possible therefore to construct a standard refractive index-time graph, for use with a given mixture at a specific temperature. To increase the accuracy of measurement would have required more elaborate apparatus, and it was simpler to use instead a 'control mineral', i.e. a mineral with constant chemical composition and known refractive indices which fall within the range of the liquid mixture. Synthetic glasses with suitable refractive indices could equally well be used.

The control mineral is placed in the same cell as the mineral being investigated. The two known refractive indices of the control mineral are observed under the same conditions as those of the undetermined mineral, both minerals being observed in the appropriate extinction positions. The time values of the control mineral are plotted on a refractive index-log time graph, and a straight line drawn between the two points. The refractive index values of the second mineral can then be read off from this graph.

Quartz is an ideal control mineral for the measurement of the feldspars. The refractive indices for  $n_{\omega}$  and  $n_{\epsilon}$  are 1.5442 and 1.553, and, since quartz is a trigonal mineral, both are displayed in a vertical section. A thin section of quartz cut parallel to one of the prism faces and ground down to a thickness of 0.05 mm. was used. This was found to be most suitable, as it was thin enough for accurate measurement, but still thick enough to be easily handled.

The standard refractive index immersion technique uses crushed rock fragments, the assumption being that if a large enough number of randomly orientated fragments are observed some are bound to show  $n_{\alpha}$  and  $n_{\gamma}$ . The earlier experiments were made with such samples (-100 +150 sieve fraction) and were not very satisfactory. The careful observation of a large number of small fragments is more than usually difficult when there is time factor to contend with. Most minerals fragments have jagged and irregular edges, and it is difficult to observe the Becke line against such edges. Hornblende, for example, with its good prismatic cleavage, gives sharply angular fragments; also it crushes more readily than some of the other common minerals with the result that the final sieve fraction contains a much lower proportion of hornblende than the original rock.

A mineral with a single good cleavage—such as biotite—has thin cleavage fragments which are very suitable for the determination of some of the refractive indices, in this case  $n_{\beta}$  and  $n_{\gamma}$ .  $n_{\alpha}$  is seen in a vertical section only; these occur infrequently, and tend to be thick and irregular.

Plagioclase cleavage fragments do not show  $n_{\alpha}$  or  $n_{\gamma}$ , and allowance is generally made for this when dealing with them. Many rocks containing plagioclase feldspars also include quartz and orthoclase or microcline. If the rock is fine-grained it is difficult to separate these, and it is often equally difficult to distinguish between crushed fragments of the several minerals when determining the refractive index of any one.

These were the sort of difficulties experienced with the particular rocks

being investigated. An obvious alternative was to substitute thin sections of rock for the mineral fragments, and this was done with some success. In the method now employed the slice of rock is ground down to a thickness of 0.05 mm., i.e. it is almost twice the thickness of the normal thin section; quartz and feldspar then show a maximum interference colour of orange-yellow and yellow respectively. The section is polished, and washed with alcohol until free from Canada balsam. It is then examined under the microscope, and a feldspar crystal displaying maximum birefringence selected and broken off. This is placed in the immersion liquid, together with the vertical section of quartz, and the refractive indices of both minerals observed in both positions of extinction. One of the advantages of this method is that the same crystal can be measured as often as required.

If the crystal selected is not correctly orientated to show  $n_\alpha$  and  $n_\gamma$ , the time difference between the two refractive indices that are observed will be too small. Hence the corresponding anorthite percentages will differ, that for  $n_\alpha$  being greater than that for  $n_\gamma$ . This provides a useful check.

*Results.*—Graphs 3 and 4 (figs. 3 and 4) show the results obtained when single feldspar crystals (from the Dalbeattie, Kirkcudbrightshire, 'porphyrites') were investigated by this method. The refractive index results for repetitions of the same experiments do not vary by more than 0.002, and the percentage anorthite values for  $n_\alpha$  and  $n_\gamma$  are in reasonable agreement with each other.

The four experiments on each individual crystal were carried out in succession, so that the variation in the shape of the graph is presumably due, not to variation in the external conditions, but to the liquid mixture having a different initial composition. The shift produced by a change in external conditions is shown in graph 4, where the broken line is the graph of one of the experiments of graph 3. It is obvious that the temperature and humidity do have a considerable effect on the shape of the graph, and the use of a control mineral seems to be the only simple way of dealing with this problem.

The results of a number of experiments are summarized in tables I and II. Table I compares results obtained by the evaporation method with values of anorthite percentage estimated by the universal stage, using the same sample of rock, but not the same thin sections. The plagioclase phenocrysts are zoned, and the universal stage results show a variation in anorthite percentage from 25 to 45, with an average value of 30%. This is in good agreement with the anorthite values

corresponding to the refractive index measurements. Crystal II from rock specimen 59 provides an example of a badly orientated crystal where the extreme refractive index values were not displayed.

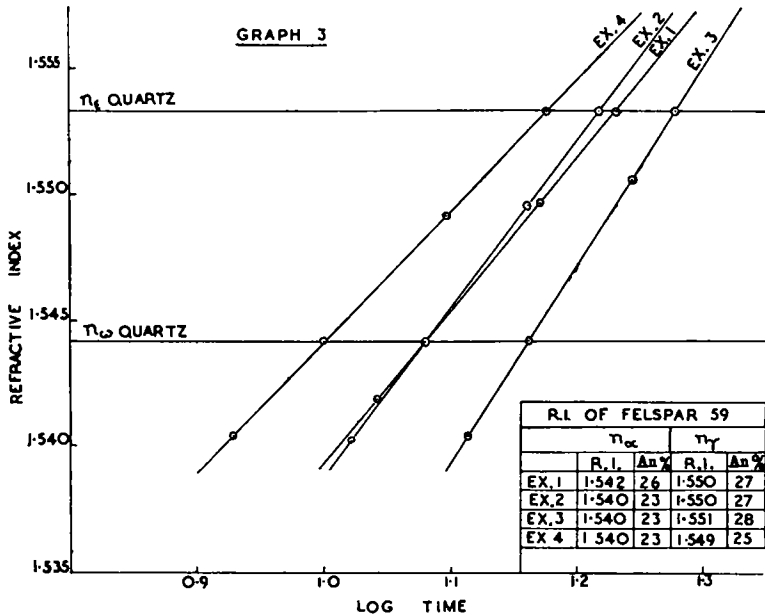


FIG. 3. Evaporation curves with feldspars of unknown refractive indices.

TABLE I. Plagioclase phenocrysts from the Dalbeattie, Kirkcudbrightshire, 'porphyrites'.

Rock.	Refractive index measurements.				Universal stage results.				
	Crystal.	No. of readings.	$n_{\alpha}$	% An.	$n_{\gamma}$	% An.	Crystal.	No. of readings.	Anorthite % Range. Mean.
50	I	3	1.548	38	1.555	37	A	2	— 30
	II	4	1.542	26	1.552	30	B	5	28-40 33
	III	4	1.5405	24	1.550	27	C	4	33-45 37
59	I	4	1.541	25	1.550	27	A	1	— 27
	II	4	1.546	35	1.550	27	B	2	25-29 27
	III	4	1.540	23	1.549	25	—	—	— —
	IV	4	1.540	23	1.548	24	—	—	— —

Table II compares results obtained by this evaporation method with those obtained using an Abbe refractometer. In two cases (49, 2 and 49, 3) the same crystal was measured by both methods. The difference

between the values obtained by the two methods ranges from 0.0004 to 0.0035. The discrepancy is probably due in part to the zoning of the crystals. However, the maximum variation between repeated refracto-

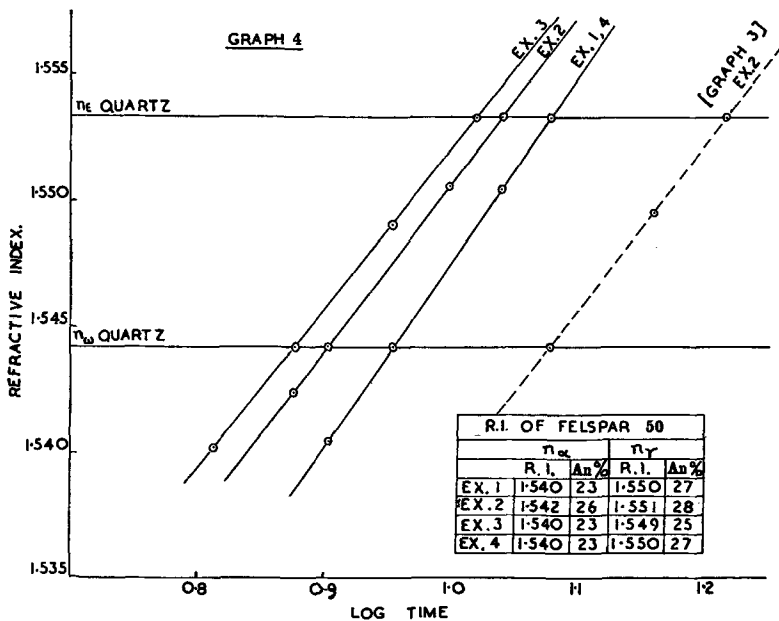


FIG. 4. Evaporation curves with feldspars of unknown refractive indices.

TABLE II. Comparison of refractive index values obtained by two methods.

Rock.	Crystal.	Evaporation method.		Refractometer readings.			Maximum variation.	
		No. of readings.	$n_\alpha$	$n_\gamma$	No. of readings.	$n_\alpha$		$n_\gamma$
49	1	4	1.539	1.549	—	—	—	
49	2	6	1.540	1.550	6	1.5406	1.5465	0.0026
49	3	6	1.540	1.548	4	1.5431	1.5484	0.0024
W. 87	—	3	1.560	1.567	3	1.5594	1.5705	0.0036

meter readings is of the same order of magnitude. It may very well be that improved accuracy of measurement here might lead to closer agreement between the two sets of values.

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