importance.¹ I may add that snow-beds appear to have, comparatively speaking, a protecting influence. Still, snow-fields and glaciers in the upper part of a range act as storehouses for the water, and so keep the torrents always full; the former also give rise to endless streams which have a plunging action, and form precipitous cliffs, as may be seen in cirques; the latter increase the erosive power of torrents by rendering their waters muddy. I believe, therefore, that, wherever there is unprotected ground, the process of excavation is aided and accelerated by the existence of snow-fields and glaciers in the upper parts of the ranges. Hence I should infer that the sculpture of the more elevated regions progressed most rapidly when that of snow and ice was least extended.

V.—ON A MODE OF USING THE QUARTZ WEDGE FOR ESTIMATING THE STRENGTH OF THE DOUBLE-REFRACTION OF MINERALS IN THIN SLICES OF ROCK.

By Major-General C. A. McMAHON, F.G.S.

IN some cases it is of practical importance to petrologists to estimate the strength of the double-refraction exhibited by doubly-refracting minerals in thin slices of rock under the microscope.

Babinet's compensator, a description of which will be found in Rosenbusch's *Microscopische Physiographie der Mineralien und Gesteine*, affords a means of accurately calculating the refractive indices of the rays into which light is divided in its passage through doubly-refracting crystals. Michael-Lévy also devised another exact method based on observations made on the tints presented by slices of doubly-refracting minerals, an account of which appeared in the *Bulletin de la Société Mineralogique de France*, and which is discussed in a work recently published by Michael-Lévy and Lacroix.

As these exact methods of calculating the double-refraction of crystals require special apparatus and are somewhat complicated, it may be worth while to describe a rough and ready method based on the use of the quartz wedge, which I have employed for some years, and which has yielded me useful results.

In order to explain this mode of using the wedge, I will suppose, in the first place, that we have our microscope arranged on our table with crossed Nicols, and that we have inserted a quartz wedge, made in the usual way (which is too well known to need description), in a slot in the eye-piece at an angle of 45° to the plane of polarization. If we look through the microscope with the apparatus fixed in this position, and before any object has been placed on the stage, a series of chromatic bands will be observed in the quartz wedge, each band consisting of a spectrum of colours in an ascending order; the colours of the first order of Newton's scale being the nearest to the thin edge of the wedge. The width of these bands depends on the thickness of the quartz and on the slope of the wedge, being broader in a flat wedge than in one cut at a considerable angle.

The usual way of employing the wedge for the purpose of estimat-

¹ Discussed in a part of the lecture not included in this extract.

ing the strength of the double-refraction of minerals is to compare the tint of the mineral with the corresponding tint in one of the chromatic bands in the wedge. The eye of the observer may thus be trained to determine whether the tint of the mineral under observation belongs to the first, second, or higher order of Newton's scale. This method is based on the rule that the stronger the double-refraction of a mineral, the higher will be the order of the tint exhibited by it when sections of different minerals cut in slices of uniform thickness and at the same angle to an optic axis are examined in transmitted light under a microscope.

In working this method I employ a quartz wedge specially made for the purpose,¹ which is similar to the ordinary wedge in all respects but one; namely, my wedge only occupies half the depth of the slot, so that the observer is able to directly compare the tint

FIG. 1.—Diagram of quartz wedge used by the author.

of a mineral, say at *d* (Fig. 1), with the spectra seen in the wedge *a-b-c*, and so determine satisfactorily whether the observed tint belongs to the 1st, 2nd, or higher order of Newton's scale.

The method, however, which I desire to describe in the following pages differs from the above. It depends not on the order of the tint exhibited by the mineral under observation, but on the character of the phenomena produced in the quartz wedge by the passage of light through the mineral to the quartz.

Having fixed our microscope in the manner above described, viz. with a quartz wedge inserted in the *eye-piece* at an angle of 45° to the plane of polarization, let us examine a second quartz wedge placed on the stage of the microscope in a position at right angles to the axis of the wedge in the *eye-piece*. In this position the velocity of the extraordinary ray is retarded in one of the two plates of quartz and accelerated in the other; and, at the point where the velocity of the extraordinary ray, on emergence from the upper quartz wedge, becomes the same as that of the ordinary ray, there is no double-refraction and a dark line appears.

If we examine the thin edge of the quartz on the stage of the microscope with the wedge in the *eye-piece*, the black line will be seen near the thin edge of the analyzing wedge, with spectra of the 1st, 2nd, 3rd, and higher orders rising in succession beyond it towards the thick end of the wedge. If we allow the analyzing quartz wedge in the *eye-piece* to remain stationary, and move the wedge on the stage of the microscope so that thicker and thicker portions of the quartz are successively brought within the range of

¹ The wedge should be a tolerably flat one so as to give a wide spread of colour.

vision, we shall find that the black line, above alluded to, moves gradually along the analyzing wedge from its thin towards its thick end, and spectra (in inverse order) of the 1st, 2nd, 3rd, and higher orders of Newton's scale, come in between the black line and the thin end of the analyzing quartz wedge. These chromatic bands of colour, as they rise in the scale of Newton's orders, become fainter, and fainter, until at last the eye fails to detect them and the spectra merge into white light.

This experiment shows that, other things being equal, the distance of the black line from the thin end of the wedge is proportional to the thickness of the quartz on the stage of the microscope.

If we now substitute for the quartz on the stage of the microscope a wedge of calc spar cut in precisely the same way with reference to its optic axis as the quartz wedge is cut, and of the same thickness as the latter, and placed in such a position on the stage that the axis of greater elasticity of the calcite is parallel to the axis of less elasticity of the quartz, we shall find that the thick end of the analyzing quartz wedge is insufficient to make the dark line and the spectra visible when we examine even the thin edge of the calcite. Indeed, so much more powerful is the double-refraction of calcite than that of quartz, that even the thick ends of two ordinary quartz wedges, superposed one above the other in the eye-piece,¹ are insufficient for the purpose.

If for wedges we substitute flat slices of different minerals of uniform thickness cut at the same angle to the optic axis, but differing from each other in the intensity of their double-refraction, we shall find the distance of the dark line from the thin edge of the analyzing quartz wedge, and the *number* of chromatic bands that come in between it and the thin end of the wedge, depends upon the intensity of the double-refraction of the mineral under observation.

I find, in short, by noting the position of the dark line in the quartz wedge, and by observing the number of the chromatic bands that appear between it and the thin end of the wedge, that it is possible to estimate the comparative thickness of the slice, when we are dealing with slices of the same mineral; or the strength, or feebleness, of the double-refraction possessed by a mineral when we have several sections of the same mineral in a slice of rock prepared for the microscope.

The application of the above principle to the examination of thin slices of rocks is complicated by the fact that the sections of minerals contained in them vary not only in thickness (for few slices, microscopically considered, are exactly equal to each other in thickness), but also in the angle to an optic axis at which they are sliced.

This difficulty, however, must be faced, for it is one that is not peculiar to the method described in these pages, but is common to *all* methods of estimating the double-refraction of minerals scattered promiscuously in rock-sections.

¹ The eye-piece of my microscope is furnished with two slots, one above the other, so I can either use two wedges at once or combine one wedge with an eye-piece micrometer.

When a mineral contained in one slice has to be compared with a mineral in another slice, we must, if we desire to be exact, measure the thickness of our slices, and take the disturbing element of the difference of their thickness into consideration. But for the rough and ready mode of estimating double-refraction now under description I have not found this necessary. Rock-sections prepared by a skilful lapidary—especially if we compare slices of rocks of the same class¹—do not differ greatly in thickness; and if we always employ the same lapidary, we shall not go far wrong if we assume that our slices are, for the purpose in hand, of fairly equal thickness.

The difficulty connected with the fact that slices of rocks for microscopic study are made promiscuously without reference to the orientation of individual minerals, and that the sections of the latter are consequently cut at varying angles to their optic axes, may to a great extent be overcome by selecting for examination those crystals that display the brightest colours under crossed Nicols; for the sections that polarize brilliantly are presumably those made approximately parallel to an optic axis.

Notwithstanding the difficulties alluded to above, the quartz wedge is a delicate, as well as handy instrument, of great value in the practical determination of the minerals met with in rock-sections. It enables one, for instance, to separate at a glance such minerals as rutile, dolomite, calcite, sphene, anatase and zircon, from all others likely to be met with. It will enable us to detect even a speck of granular calcite of microscopic size imbedded in another mineral. The double-refraction of the above minerals is so powerful that when they are tested in the way above described, the dark line² does not come into view until the thick end of the wedge begins to pass over them, and the spectra, instead of being of normal width and distance apart, are narrow and crowded together. The character of these narrow and crowded spectra is so remarkable that an observer who has once seen them can never mistake them for those of a mineral possessing a less intense double-refraction.

So powerful is the double-refraction of rutile, calcite, and sphene, that I sometimes find it necessary to employ two quartz wedges, one above the other, in order to bring the spectra within the range of vision. Occasionally the mass of a crystal resists even the double wedge, and the spectra can only be seen in portions of the crystal, where, owing to its brittleness and liability to fray in the process of grinding, or from its edges overlapping other minerals, specially thin sections are exposed to view.

Minerals of feeble double-refraction, on the other hand, may be separated from those of strong, or of even average double-refraction, with equal confidence. If we examine such minerals as chlorite, nepheline, and apatite, we find that the dark line, described above, either appears on the *very edge* of the quartz wedge, or is just

¹ Basalts, for example, are usually sliced thinner than granites.

² When testing for double-refraction the stage must be revolved until the dark line appears in the mineral under examination. The azimuth in which this appears affords another valuable means of distinguishing between different species.

beyond the range of vision. In the latter case I call in the aid of the $\frac{1}{4}$ undulation plate: on inserting this above the object-glass, the spectra seen in the quartz wedge are shifted up the wedge towards its thick end, and the dark line previously beyond the range of vision is brought on to the edge of the wedge.

In the case of the above-mentioned minerals possessing very feeble double-refraction, the dark line appears, as just stated, at the *very edge* of the quartz wedge. In the case of sanidine, orthoclase, and other minerals of equally weak¹ double-refraction, the dark line appears *clear* of the edge of the wedge, but no chromatic band comes in between it and the edge. As we examine minerals of higher and higher double-refraction, we shall find the position of the dark line is more and more shifted towards the thick end of the wedge, and more and more chromatic bands come in between it and the thin end of the wedge.

Thus, to give a few examples drawn from my own experience of slices prepared by different lapidaries which are *not* all of equal thickness, I find that quartz in such sections rarely exhibits more than one and never more than two chromatic bands between the dark line and the edge of the wedge; whilst such minerals as muscovite, olivine, and actinolite, commonly present three, and not unfrequently as many as five such bands.

We have here, then, a means not only of comparing sections of minerals of equal thickness in the same slide, but sections of crystals in different slides, and we have a standard by which we may estimate the strength of their double-refraction. A mineral of strong double-refraction sliced at so high an angle to an optic axis as to approximate a plane normal to that axis will, of course, exhibit little or no double-refraction, and in the phenomena it presents will resemble a mineral of feeble double-refraction sliced approximately parallel to an optic axis; but a mineral of weak double-refraction can never exhibit the phenomena characteristic of one of strong double-refraction. When therefore, on testing a mineral with the quartz wedge, we find two, three, or five, chromatic bands appear between the dark line and the edge of the wedge, we know for certain that the mineral possesses stronger double-refraction than those minerals which never, in slices of normal thickness, present to our view more than *one* such chromatic band.

Even in the case of minerals of strong double-refraction sliced approximately normal to an optic axis, we gain something by examining them with the quartz wedge, for we learn from the position of the dark line² that the section is one either approximately normal to an optic axis, or is one of a mineral of feeble double refraction. If the former is the case, the mineral will exhibit characteristic appearances when examined in converging polarized light. If, on the contrary, it does not show any phenomena capable

¹ I use the word *weak* to indicate a slightly higher double-refraction than *feeble*. Thus, γ — α for chlorite is 0.001, but for sanidine is 0.008.

² The dark line will not appear in any azimuth in a section *quite* normal to an optic axis.

of interpretation when examined in the usual way with converging polarized light, we know that we have before us not an axial section, but a mineral of weak double-refraction sliced in another direction.

In cases where a mineral is of such microscopic size as to be less in diameter than the width of one of the chromatic bands exhibited by it, we can still easily count the number of chromatic bands that come in between the dark line and the thin edge of the wedge, if we confine our observations to one colour (red I find the most convenient), and, as we move the wedge forward over the mineral, count the number of times it assumes that colour before extinction takes place on the micro-crystal entering the dark line or region of no double-refraction.

In the examination of pounded fragments of minerals with the aid of a quartz wedge we must carefully consider the element of thickness, and we must confine our observations to flat surfaces parallel to the plane of the glass slide.

As an illustration of the close approach to accuracy that may be obtained by the use of the quartz wedge in the way described above, I may mention the following example. As Rosenbusch does not give the value of $\gamma - a$ for sphene in his *Microskopische Physiographie*, I recently wrote to inquire of a friend whether he could give me the required information, and I expressed at the same time my conviction that the double-refraction of sphene was, in intensity, somewhere between that of zircon and calcite. It turned out that the refractive indices of sphene have been worked out by M. Lévy and Lacroix, and are given in their book *Les Minéraux des Roches* just published. ($\gamma - a$) or $(n_g - n_p) = 0.121$. So that sphene really occupies the position I had assigned to it on the evidence afforded by the rough and ready use of the quartz wedge; the values of $\gamma - a$ for the three minerals being: calcite, 0.172 (Rosenbusch); sphene, 0.121 (M. Lévy); and zircon, 0.060 (Rosenbusch).

VI.—ON A REMARKABLE DYKE IN THE SERPENTINE OF THE LIZARD.

By ALEX. SOMERVAIL.

THE dyke in question occurs at the extreme north end of Pentreath Beach, which is about a quarter of a mile to the south-east of Kynance Cove.

The dyke forms a portion of the "granulitic group" of Prof. Bonney, which is now known to be of igneous origin, and consists of banded gneissic rocks, some of which are like a granite, other portions like a diorite, the latter always more or less porphyritic.

This rather complex rock is here, as in many other localities, thrust through the serpentine, but, in this particular instance, it exhibits more remarkable features than any other dyke known to me in the Lizard area.

The dyke forms the central part of a small chine or gully. It rises from the shore to the top of the cliff, which is about 150 feet in height, and can easily be followed throughout its entire upward course, as the cliff here is not very precipitous. The decomposition