A METHOD OF EFFECTIVELY INCREASING THE RESOLVING POWER OF A MICROSCOPE TO REVEAL UNSUSPECTED DETAIL IN THIN SECTIONS

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Abstract

The resolving power of an ordinary microscope can be effectively doubled by the use of narrow pencils of highly inclined light. This illumination technique reveals many details in rock thin sections not previously reported in the literature. A mineral with a slightly higher index of refraction than its matrix can be made to exhibit tremendous positive relief. Orthoclase can easily be distinguished from quartz under plane polarized light thus making grain counting procedures much simpler.

Twinning in some feldspars can be observed under plane polarized light. Worm-shaped paths occur in quartz, feldspars and biotite. These are presumed to be paths along which material has migrated through the rocks.

Introduction

One of the great problems facing petrologists today concerns the mechanism of metasomatism: how do ions or ion complexes move through rocks and minerals where they can react with others to produce new phases? If ions not identical to those already in a structure move through crystals, as well as around them, it is difficult to believe that they do not leave some traces of the paths along which they have traveled. In an attempt to detect such paths an investigation was made of methods of improving the resolving power of the microscope.

The modern petrographic microscope not only has a very well designed optical system but is in most cases well designed from a mechanical point of view. As a matter of fact, it is so well designed that it can be used for most petrographic purposes with very little adjustment or none at all except for minor corrections to ensure centering of the objectives. This has been the situation for so long that the textbooks from which most geologists get their training in optics and optical mineralogy hardly do more than mention the various parts of the microscope, consequently most petrographers do not utilize to the fullest the fine optical system they have at their disposal. To get photomicrographs of the highest quality, the microscope must be so adjusted that the field is adequately illuminated but, of equal importance, the optical and mechanical elements of the system must be so adjusted that the maximum attainable resolving power can be achieved. Wright pointed out, as long ago as 1911, that much greater resolution could be obtained in a petrographic microscope by combining a slightly different method of illumination than is ordinarily used combined with critical focusing of the various optical elements. Apparently these suggestions have been overlooked. It is the purpose of this paper to recall attention to Wright's pioneering work in this field and to indicate what an immense improvement in resolution can be realized and to illustrate the consequent wealth of information and detail that ensues.

Adjustment of the Illumination

The image seen in a microscope is produced in quite a different manner from the one observed through a telescope. Light transmitted through a non-self-luminous object is diffracted and forms a diffraction pattern at the rear of the focal plane of the objective of a microscope. The observed image is derived from this diffraction pattern. The details of this theory were first worked out by Abbe and are conveniently summarized by Wright (pp. 42–46, 1911) from whom the following very brief outline has been taken.

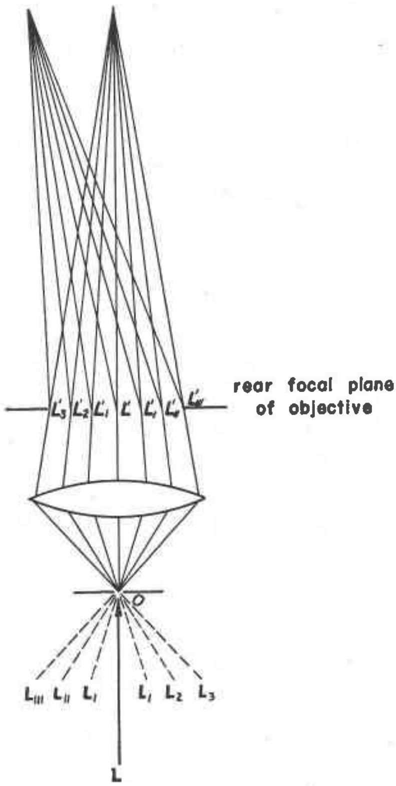

Fig. 1 (After Wright).

A light beam L (Fig. 1) impinging on the object O will be diffracted along the paths indicated by the lines radiating from above the object. If these lines are extended below the object, it would appear as if the object were illuminated from light sources located at L_1, L_2, L_3, etc. Rays from these apparent light sources are brought to a focus by the objective at its rear focal plane. The actual observed image is formed from these radiant points. These points L_1, L_2, L_3, etc. are actually produced from the single radiant point L and are therefore coherent[1] and produce waves arriving at the focal plane of the objective at different times, hence produce interference effects.

To produce any interference effects at all, and consequently to attain any resolution, the aperture of the objective must be large enough to allow at least *two* waves (L' and L_1') to reach the focal plane where they can produce one diffraction maximum. If only the central beam L' is transmitted, no diffraction will result and hence no image will appear.

We are interested in determining the minimum distance that two spots must be separated in the object O so that they can be distinguished as two distinct spots in the diffracted image which appears at the rear focal plane of the objective. This minimum distance e is the limit of the resolving power of the system.

In the diffracted image, let us call the distance from the central beam (L') and the first diffracted beam (L_1') e'. This distance is related to the spacing between the two diffracting spots in the object as follows:

$$e' = Ne$$

where N is some whole number.

If L_1' or L_3' were eliminated by some suitable stop, the distance between the central beam and the first diffracted beam would be

$$e' = \frac{Ne}{2}.$$

The same result can be obtained by stopping L_1, L_3, etc. Since the detail in the image is directly related to the number of radiant points illuminating the object which produce diffraction maxima, elimination of these

[1] In order to produce interference fringes, all the light must come from the same source. It is impossible experimentally to produce interference fringes from two separate light sources. To produce interference effects the path differences of two waves are converted to phase differences (phase difference $=2\pi/\lambda$ path difference). To do this however we must use perfectly plane polarized monochromatic light with a train of waves infinitely long. In practice, light sources do not produce waves of infinite length. Phase changes occur in any train of waves in a very short period of time (approximately every 10^{-8} seconds) consequently the waves are of finite length, hence interference effects can only be produced experimentally from wave trains emitted by the same source (coherent radiation) that will produce the same changes in all waves at the same time.

rays would halve the detail that could be seen. Conversely, by increasing the number of radiant points the detail observable in the image can be increased. At most, the number of radiant points can be effectively doubled.

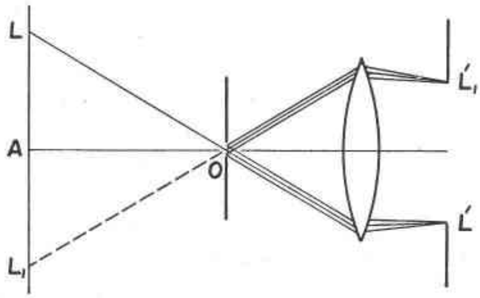

FIG. 2 (After Wright).

Now if only oblique illumination is used (see Fig. 2) with a light source at L, diffraction would occur at the object as if the light came from A; in addition a symmetrical beam (L') would be produced which appears to come from radiant point L_1. In other words, by using oblique illumination two radiant points are produced—an apparent one for each "real" one—hence two diffraction maxima will appear in the image for each "real" radiant point. It follows from this that twice as much detail can be seen in the image if oblique illumination is used than if ordinary vertical illumination is employed. This is equivalent to doubling the resolving power of the microscope without altering any of the lens elements of the system.

Not only will more details appear in the image if oblique illumination is used, but slight differences in index of refraction will appear as great relief differences. Advantage is taken of this fact when determining indices of refraction of minerals in a mixture using oblique illumination produced by partially shading the substage mirror with an index finger placed in the beam from the microscope lamp.

ADJUSTING THE CONDENSER

The condenser of a microscope is designed to furnish as wide a cone of incident light as can be possibly accommodated in the objective used. The object is said to be "critically illuminated" where the rays traveling through the condenser are properly focussed on the object. This is accomplished by adjusting the position of the condenser.

The numerical aperture of the condenser should not be larger than that of the objective in use, or else the field will be flooded with light.

The effective numerical aperture of the condenser can be reduced by suitably adjusting the diaphragm built into the condenser housing.

To emphasize the differences in refractive index of the minerals being examined, a narrow beam of sharply focussed light from the condenser should be used. A wide cone of light illuminates the grains from all sides, causing them to appear equally bright hence much of the detail is "washed out." This type of illumination increases the amount of reflected and refracted light which also tends to eliminate detail. Wright pointed out (pp. 88–90, 1911) that almost parallel rays (from the condenser) must be used to detect very slight differences in indices of refraction. By stopping down the diaphragm or by lowering the condenser this condition can be readily satisfied and, as the following photomicrographs will show, extremely small differences in index of refraction between zones in an *individual* grain can give rise to Becke lines which can readily be photographed or observed.

Results

The photomicrographs pictured here were obtained by adjusting the substage diaphragm, critically focussing the condenser, and using oblique illumination transmitted through an ordinary petrographic microscope. The amount of detail seen could sometimes be enhanced by cutting out some of the light as it passed through the microscope tube. This can be conveniently done by inserting one of the accessory plates part way into its slot. Only a microscope and a bellows were used to take the photomicrographs.

To obtain "crisp" photographs, particular care must be taken to get a good focus of the image on the photographic plate. Best focussing results were obtained by removing the plate holder from the bellows and viewing the image through a lens held in the eye like a monocle. The upper lens element from a low power eye piece is ideal for this purpose. This technique gives much better results than the use of a ground glass focussing plate.

Sample Preparation

An inspection of the photomicrographs shows that Becke lines delimit the edges of the channels. On raising the focus, the Becke lines move away from the channels indicating that the material within them has a lower index than the bulk of the crystal. This applies to both quartz and feldspars. It is thought that the relief features, the apparent "surface" details and the channels, welts, circular depressions, etc., all arise from compositional differences between individual grains and slight compositional differences within individual minerals.

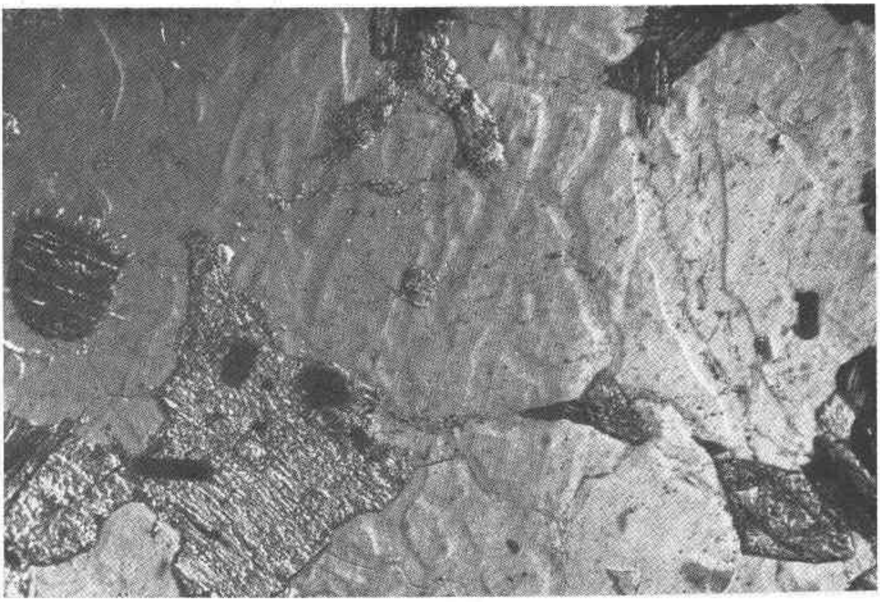

FIG. 3. Highly inclined, plane-polarized light. Mag. 66×. This section contains quartz and highly altered biotite. Note the great differences in relief between the mineral types and details in each. Of principal interest are the numerous "channels" which transect the quartz. These do not appear to follow any crystallographic direction in the quartz. In some cases isolated islands of various shapes remain.

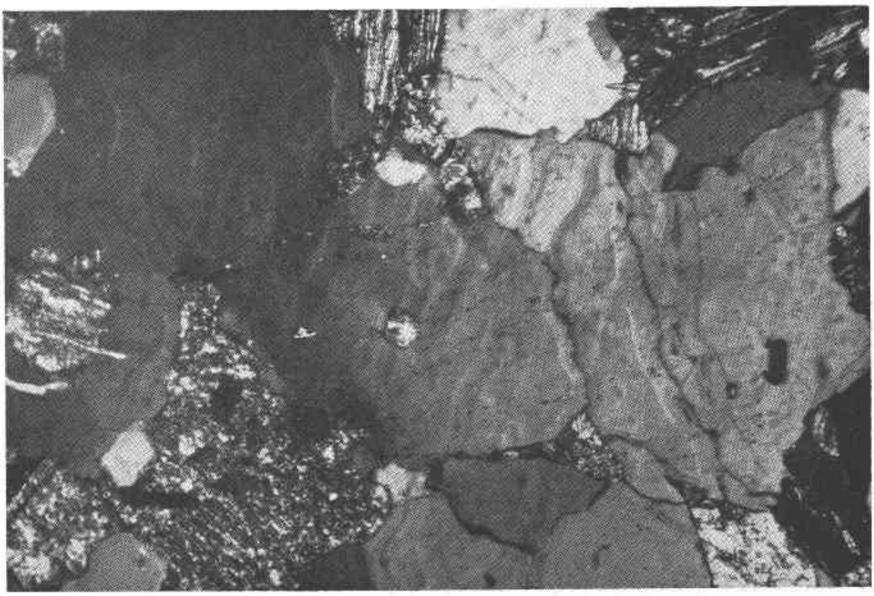

FIG. 4. Same as 3 except under crossed nicols. Note the undulatory extinction in the quartz. It frequently seems to start adjacent to the alteration zones and is thought to be due to a partial collapse of the quartz structure resulting from chemical attack rather than to any physical deformation by outside stresses.

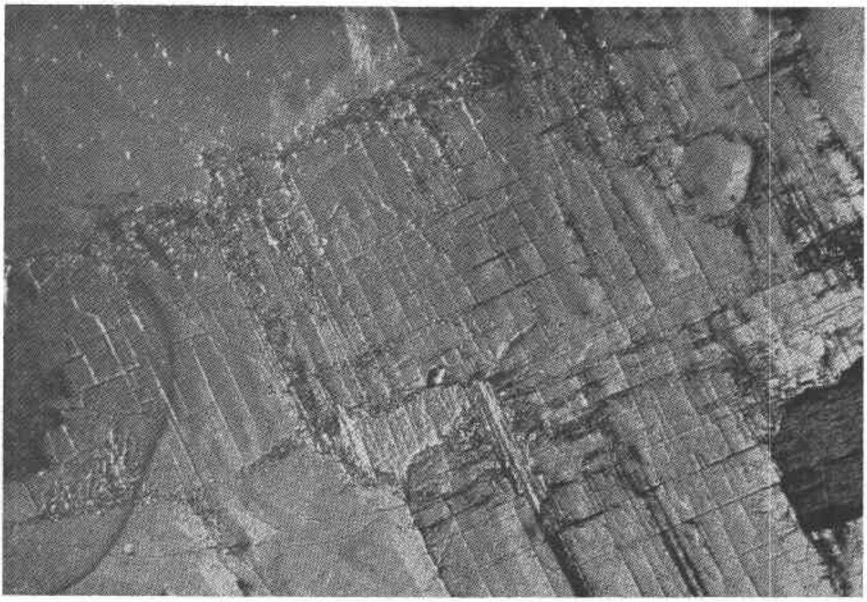

FIG. 5. Highly inclined, plane-polarized light; mag. 66×. The section contains quartz, oligoclase and muscovite plus an alteration product. The "channels" in quartz follow a sinuous course whereas those in the plagioclase follow the twinning directions as does the alteration. Note that both the albite and pericline twinning lamellae can be clearly seen in *plane polarized light* as relief ridges.

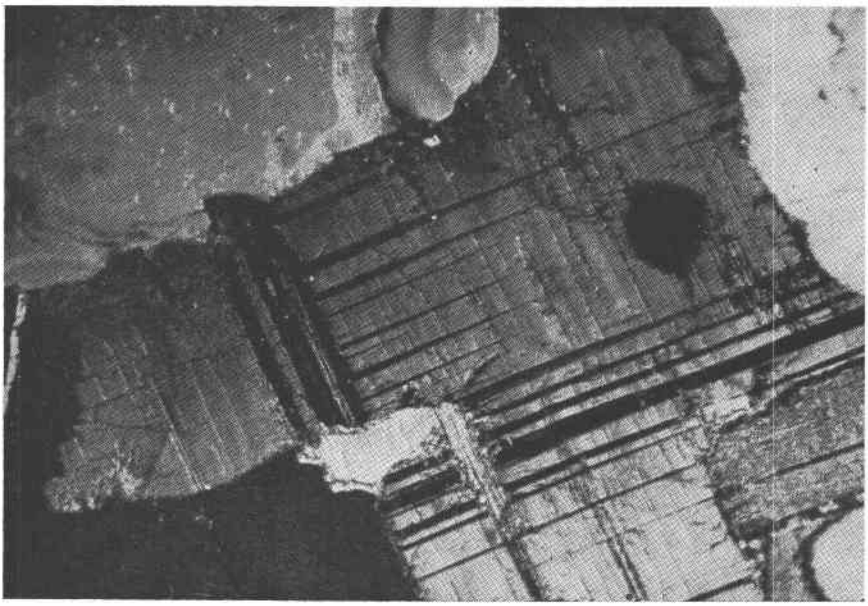

FIG. 6. Crossed nicols of 5. Compare the relief ridges in Fig. 5 with the blacked-out twins.

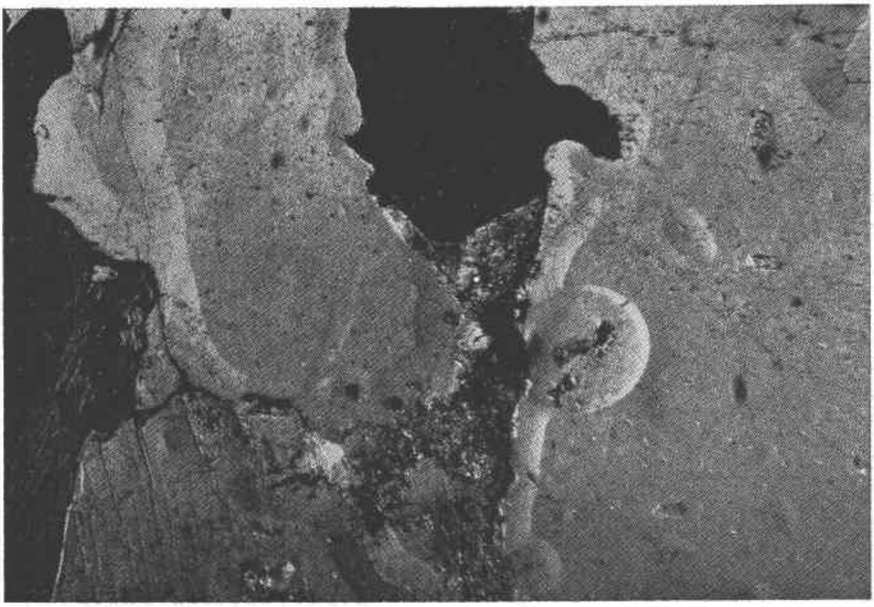

Fig. 7. Highly inclined, plane-polarized light; mag. 66×. This section contains quartz, biotite, plagioclase and finer-grained alteration product. Note in particular the welts in the quartz and the elliptically-shaped low-relief area. These are apparently related to alteration zones in the quartz which now are filled with a fine-grained muscovite-like product. These circular "depressions" are thought to be cross sections of the sinuous channels seen in this and other thin sections. The channel in the oligoclase appears to be independent of any crystallographic direction.

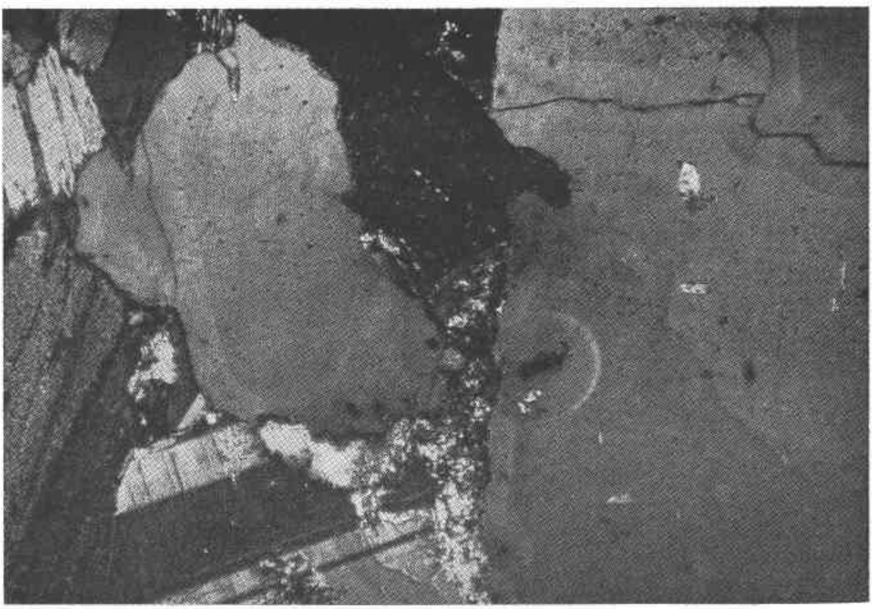

Fig. 8. Same as 7 except taken under crossed nicols. The channels transect both quartz and oligoclase. Small relief ridges remain on parts of the plagioclase.

FIG. 9. Highly inclined plane polarized light; mag. 66×. Only quartz, microcline and sericite show in this field of view. This photomicrograph clearly illustrates the great relief differences that can be produced by minerals with relatively small differences in indices of refraction by the use of this technique. A great amount of detail is apparent in both the microcline and quartz. Even the grid twinning of the microcline can be seen under this plane-polarized light. This technique makes it very easy for the petrographer to distinguish by inspection between quartz and orthoclase—a feat not always easy under ordinary circumstances—and hence greatly increase the precision and speed of making grain counts without having to resort to tedious and frequently unsatisfactory staining techniques.

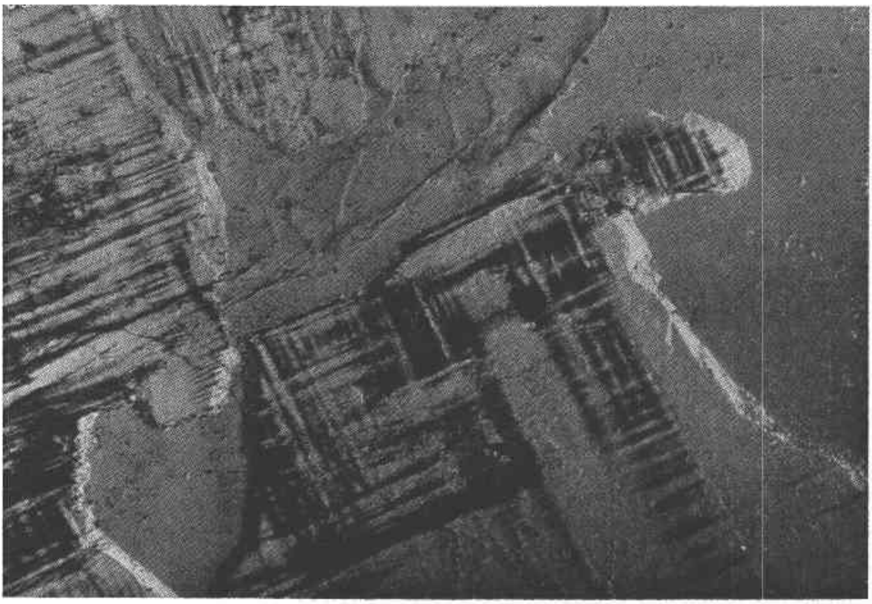

FIG. 10. Same as Fig. 9 except under crossed nicols. The details in the quartz can be seen more clearly than in Fig. 9. These also are thought to be channels but are much more irregular. All transitions between these and the more regularly shaped channels and elliptical zones sometimes can be seen in one thin section.

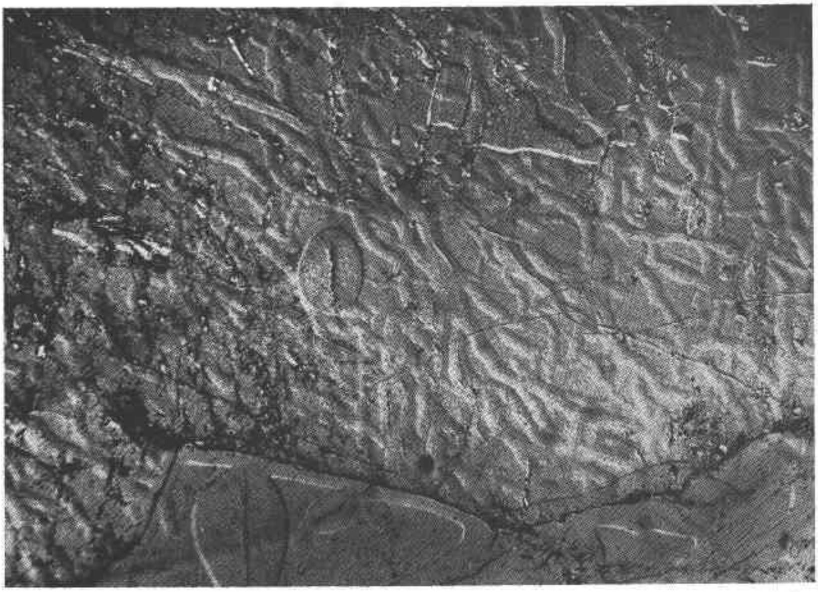

FIG. 11. Plane polarized inclined illumination. Mag. 44×. Notice the swarms of channels through the quartz and oligoclase. The small grains of low relief in the oligoclase are microcline (see the characteristic twinning in Fig. 12). In this section, no relationship exists between channels and crystallographic directions. Note that the channels cross the microcline which is known to be a relatively late mineral to develop in these rocks. The channels can be used as an aid to help solve paragenetic problems.

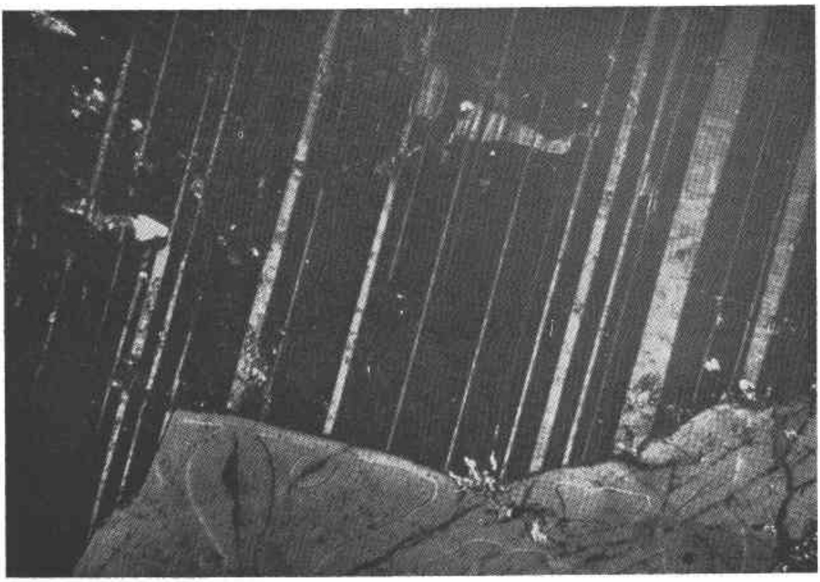

FIG. 12. Crossed nicols photomicrograph of Fig. 11. Note the circular and oval channels in the quartz. Some of the sericitic alteration develops in the oligoclase at the "mouths" of channels leaving the quartz grains. Potash and water, at the very least, must be introduced in the system to permit the development of the sericite (if the sericite did not grow from colloidal particles). The channels appear to be the paths along which this material has moved.

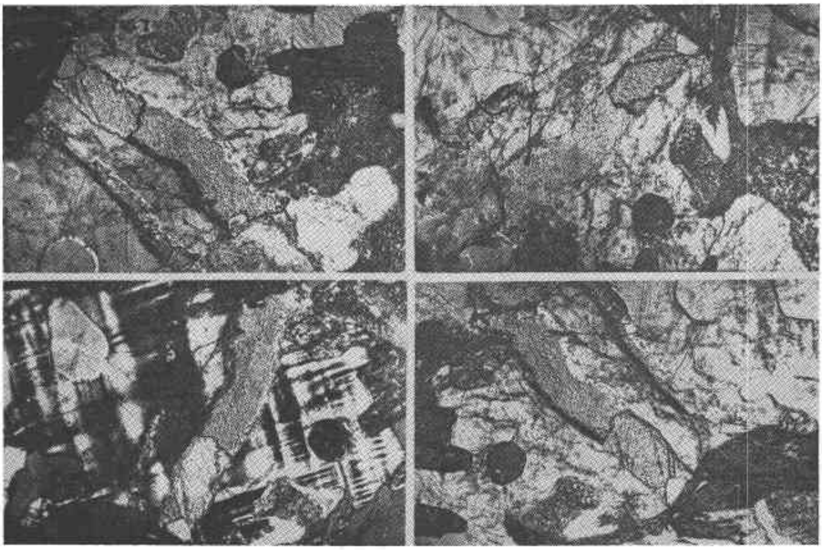

FIG. 13. These photomicrographs illustrate the changes in relief of calcite for different orientations. The stage was rotated 90° after each plane-light photomicrograph was taken (starting at upper left). The calcite is the two rough-surfaced, elongated stringers diagonally across the matrix of microcline. The dark, fibrous material is biotite; the pear-shaped, clear grain is quartz. This and other grains of quartz have higher relief than the microcline.

Note that it is possible to count the color fringes along the edges of the calcite crystals. At least 6 orders can be seen in the original photomicrographs.

From this sequence it is quite clear that the relief features seen in these photomicrographs are neither due to some oddity in the method of preparation of the sections nor to some mounting medium of slightly different properties which might have worked up along grain boundaries before the thin section was covered.

When the channels were first observed, the possibility that they might be due to the method of preparation of the thin sections was investigated. Canada balsam and several synthetic resins were used as mounting media for different thin sections prepared from the same specimen. In each case the channels remained.

The channels are not due to surface irregularities. Thin sections polished on both sides were made and tested with an optical flat. Although not perfectly flat, the departure therefrom was on an entirely different scale than would be produced by the channels. The Newton-ring patterns did not resemble in any way the photographed patterns of the channels.

From the experiments it can be reasonably concluded that the relief features and the Becke lines which delimit the edges of the channels are truly an optical phenomenon and not due to physical features or surface irregularities on the rock slices. This is further confirmed by the series of photomicrographs showing the relative relief of calcite in microcline for various positions of the microscope stage. The calcite can be made to appear higher, equal to, or lower in relief than the microcline. (See Fig. 13.)

The writer had access to the huge collection of thin sections at the University of Oslo, Norway. Sections prepared for Eskola and Goldschmidt many years ago were examined and they too exhibited the channels. This is further confirmation that the phenomena illustrated in the photomicrographs do not arise from some special method of preparation. After discovering this, all succeeding thin sections were prepared in the ordinary manner—and the channels and other features could still be seen when studied under the illumination technique described herein.

All of the thin sections used for this study were made from rocks from the environs of Kragerø, Norway. The metamorphic rocks in this region include quartzites, amphibolites, hyperites, albitites, a variety of pegmatites and a series of rocks containing sillimanite, andalusite, cordierite, anthophyllite and garnets. These rocks are not unique. The channels and other features shown in the following figures have been observed in rocks from other parts of Norway, from Sweden and England. It is believed, therefore, that features such as these should also occur in similar rocks from other parts of the world.

No attempt will be made in this paper to "explain" the origin and significance of the "channels." A hypothesis accounting for them was presented at the *XIX International Geological Congress in Algiers* (Section XII): a paper offering additional detail is in preparation.

Acknowledgments

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Reference

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