with land slopes as steep as 20°, which may be estimated from published photographs; and relief in the surrounding country amounts to thousands of feet. Yet Noakes claims that " the lineaments [major landscape features] . . . seem to be legacies from the Palaeozoic ", with fault-line scarps that separate them becoming higher " as erosion progressed " since that time. In other words, a single erosion cycle has not only been in progress since Palaeozoic times, but has not yet passed beyond the stage of early maturity characterized by waxing relief. An argument that the land must have remained low-lying " to escape deep erosion " between the Triassic and the Tertiary, or that it has remained " at or near base level . . . since the Palaeozoic ", is of no significance in view of the existing strong relief, whether this be attributable to erosion during that interval or be assumed to have survived through it. It is not difficult to understand why the country has not been dissected to stronger relief, but the mystifying question is why strong relief which either was present initially or developed early in the cycle has not subsequently been destroyed by erosion which has been going on for 150 million years, whether the land remained low-lying or not.

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## DETERMINATION OF [001] AXES IN MUSCOVITE

SIR,—I have read with great interest the paper " Regional Study of Epidote, Mica, and Albite Fabrics of the Moines " by C. B. Crampton, which appeared in your issue of March-April, 1957. It is particularly interesting because the author has determined the fabric of epidote and albite, minerals which are rarely dealt with in petrofabric analyses. The author has also made a large number of determinations of muscovite [001] Axes, another rather neglected problem in structural petrology. On this part of the paper I would like to make the following comments.

1. The author seems to have little confidence in a diagram of muscovite [001] Axes, published by me in 1945, because it was " measured from a section perpendicular to the foliation " and " it is impossible to differentiate between the Y and Z axes within sections perpendicular to the foliation ".

The impossibility of differentiating between the Y and Z axes in muscovite grains having the [001] cleavage planes perpendicular to the section is, I hope, a well known fact to all who have made such determinations. If, however, the angle between cleavage plane and thin section is about 70 degrees or less, the differentiation can easily be made, provided the optic angle is not abnormally low. After having placed the Y or Z axis parallel to $A_4$ (E-W horizontal axis) on the universal stage, the stage is rotated 45° about the $A_5$ (microscope axis), and the change in birefringence by rotation about $A_4$ is observed. If, for instance, 340 is read on the $A_4$ scale when the [001] plane is vertical, a rotation to 50 would bring one of the optic axes parallel to the tube of the microscope, if Y is parallel to $A_4$. If Z is parallel to $A_4$, the same rotation would bring parallel to the tube a direction in the XY plane which is 30 degrees from X. If by rotation on $A_4$ the X direction can be brought parallel to the tube, a very low birefringence is usually observed. Besides the angle between the observed direction and the [001]

cleavage the gypsum plate can in most of these cases be used to determine whether X or an optic axis is parallel to the tube.

The diagram referred to by Crampton was made from a section normal to the megascopic foliation, but as the maximum of [001] poles made an angle of 30 degrees with the normal to the foliation, a large majority of the grains had an orientation which permitted a reliable identification of Y. Only such grains where this could be done were included in the diagram. For further control some measurements were made in the section parallel to the megascopic foliation, which, however, contained fewer grains than the section used for the diagram.

These details were not included in my paper, as the position of the maximum of [001] poles was given in the text and could be clearly seen in the diagram. This omission has apparently given rise to doubt as to the accuracy of the diagram.

Recently I checked my old slides and arrived at the same result as in 1945. I can therefore assert that my diagram was correct.

2. The method of measuring the azimuth of Z′ as a substitute for the more time-consuming procedure of determining the Y axis, a method that was introduced by Sander, and has been used among others by Crampton, has, unfortunately, great disadvantages, and unless it is used with great caution may easily lead to erroneous results. The method is based on the assumption that Z′ is perpendicular to the Y axis. In muscovite with $2V = 35–40°$ this assumption is valid only when the angle between [001] of the grain and the thin section is less than about 10°. With greater angles between [001] and the thin section the angle Z′ to Y may vary considerably. In the interval 20° to 30° the angle Z′ to Y may change from 90° to 0°, with a change of only a few degrees in the position of the X axis.

Rocks where the great majority of muscovite [001] planes make angles of less than about 10° with the foliation are extreme s-tectonites, which are not common in metamorphic rocks. In order to obtain reliable results with the Z′ method, one must restrict the measurements to the grains having [001] very nearly parallel to the slide. This procedure involves the difficult task of deciding which grains are sufficiently parallel to the slide to justify a measurement. Further, it leaves the orientation of Y in the other grains, which usually constitute the majority, entirely unknown.

If the measurements are not restricted to the grains having [001] very nearly parallel to the slide, the rapid change in the angle Z′ to Y for grains having [001] at 20°–30° to the slide may in the diagram indicate a spreading in the orientation of Y where there is none. If several grains with larger angles between [001] and the slide are measured, the diagram may give the impression of a definite concentration of Y axes in the tectonic *ac* plane in cases where this concentration by an accurate determination of the Y axes is found to be very problematic.

That these objections to the method are serious, can be seen by measuring Z′ and determining the XYZ axes in a sufficiently large number of muscovite grains in a slide and plotting them in a diagram.

I have recently made some such diagrams. The study is not completed, but the results so far have convinced me that if one wants to obtain reliable information about the orientation of [001] in muscovite, there is no substitute for the time-consuming method of determining the Y axis on the universal stage. The importance commonly attached to these diagrams is so great that the extra amount of time spent is justified. In the discussion of problems of great importance to the understanding of the tectonic history of an area, it is better to have a few diagrams which are known to be correct than to have many diagrams which may possibly be correct, but which may also be so inaccurate as to give a rather different picture from that which the accurate diagrams would have given.

I therefore have arrived at the conclusion that the Z′ method of determining the orientation of the [001] axes of muscovite should preferably be discarded altogether.

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