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DEFORMATION TWINNING IN ORDERED PLAGIOCLASE

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The topic of deformation twinning in ordered plagioclase is a subject that deserves discussion because of the ubiquitous occurrence of plagioclase twinning and its potential as a petrogenic indicator. If plagioclase can twin regardless of structural state, and if this twinning can be dated with respect to the ordering history, plagioclase then becomes a very important tool in petrogenic interpretation. Thus the writers welcome Dr. Laves' (1965) discussion as an opportunity to review our own observations and conclusions with respect to the optical data.

In investigating plagioclase samples from a wide range of petrologic environments, ranging in composition from An_{30} to An_{90}, Vogel (1964) concluded that the scatter of optical orientation with respect to the twin elements indicated that plagioclase could twin mechanically regardless of the structural state. In review, this conclusion was based principally on the following observations (Vogel, 1964, p. 623):

1. There is negligible external optical-crystallographic scatter of deformation twins in plagioclase from volcanic samples and these plots fall on the disordered (high-temperature) migration curves. 2. Similarly, there is negligible external scatter of deformation twins in plagioclase from metamorphic samples and those plots fall on the ordered migration curve. 3. Samples that exhibit extreme external optical-crystallographic scatter of deformation twins are from coarse-grained, igneous-appearing rocks. This scatter commonly covers the area between the disordered and ordered migration curves. 4. When late-stage deformation twins can be recognized they exhibit negligible optical-crystallographic scatter and plot near the ordered migration curve.

Vogel's (1964) interpretation of these observations is that the external optical-crystallographic scatter of plagioclase twins from coarse-grained, igneous-appearing rocks is due to deformation twinning during the ordering process; volcanic samples show no scatter because they have formed, twinned and remained in the disordered state, and metamorphic samples show no scatter because they have twinned and remained in the ordered state. Plagioclase more sodic than An_{30} were not investigated because of the lack of adequate samples from this range (Vogel, 1964).

Seifert (1964), however, worked extensively with acid plagioclase from the Nonewaug granite and documented a sequence of plagioclase twinning, including wedge-shaped pericline twinning, in this granite. In reference to his wedge-shaped pericline twinning Seifert (1964, p. 301) states that:

"Wedge-shaped pericline twins are the youngest of the common twins in discrete plagioclase crystals. There are two petrographically distinct varieties: 1) a jagged variety and 2) a variety adjacent to Manebach composition faces. . . . these varieties have notably different, although overlapping, face pole plots. These plots indicate that the jagged variety formed more recently, when the plagioclase was in a slightly lower structural state. However, face pole plots also indicate that both twin varieties formed when plagioclase was very close to the lowest structural state."

The wedge-shaped pericline twins listed in the above quote as variety 2 are associated with the 001 cleavage which show normal low-temperature optical-crystallographic relationships. There is no evidence for post-twinning recrystallization. Pole plots of these late wedge-shaped deformation twins fall near the ordered migration curve (Fig. 1). Vogel (1964) showed similarly that with intermediate plagioclase when late-stage deformation twinning can be recognized the pole of these twins plot near the ordered migration curve and exhibit negligible optical-crystallographic scatter. An example of this is shown here in Fig. 2. Both Seifert (1964) and Vogel (1964) interpret their data as indicating that these deformation twins formed when the plagioclases were nearly fully ordered. Laves (1952) has shown that artificially prepared disordered albite can readily be twinned by pressing the grain with a needle, whereas experimentally produced mechanical twinning of ordered albite has never been reported. Laves (1952, 1965) suggested that acid plagioclase cannot twin by deformation unless their Al/Si distribution is sufficiently disordered to be "topologically" monoclinic. This suggestion has been extended by others (*eg*. Smith, 1962) to include the whole range of plagioclase compositions. The optical measurements reported by Seifert (1964) and Vogel (1964) have been interpreted by them to indicate that plagioclase could twin mechanically at any structural state. Perhaps Seifert (1964, p. 310) is correct when he hypothesized that his parallel-sided twins formed in the disordered state without breaking strong bonds, whereas wedge-shaped twins resulted when twinning necessitated the breaking of stronger bonds in the more ordered state. Late-stage deformation twins in an individual grain can be recognized by their being controlled by fractures, imperfections, grain boundaries and other features which post-date the formation of the crystal (Fig. 3).

Laves (1965, p. 513) states that: "As nothing is known of the Al/Si distribution in intermediate plagioclases in an intermediate structural state nothing can be predicted about their twinning behavior." Yet Laves (1965, p. 512) is able to contend that Vogel's (1964) interpretation of optical-crystallographic scatter of twin elements in this range " . . . is certainly wrong."

Laves (1965) has also criticized Vogel's Fig. 8 (1964); this exhibits a

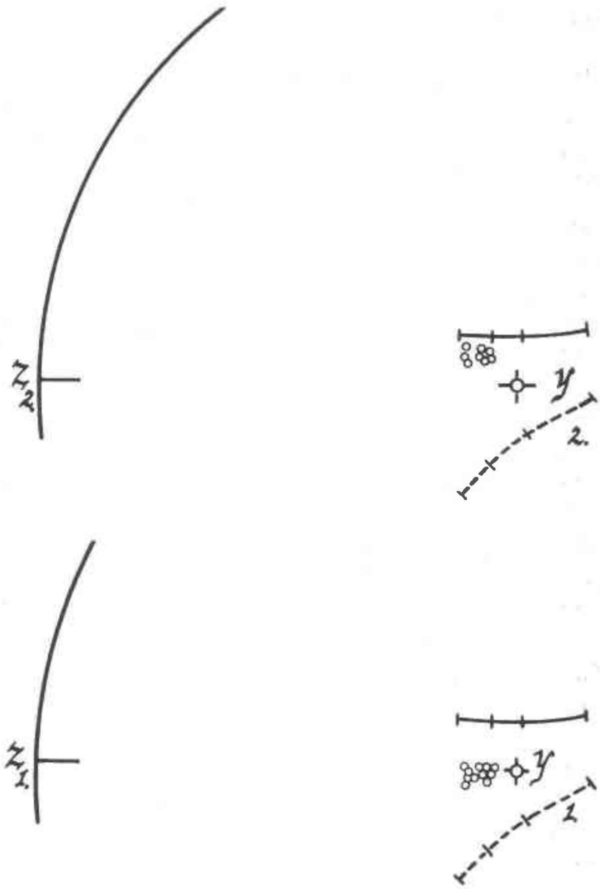

FIG. 1. 1) Composition face pole plots of late deformation wedge-shaped pericline twin lamellae from Nonewaug granite plagioclase; compared with 2) the composition face pole plots of older parallel-sided pericline twins from Nonewaug granite plagioclase. Curves after J. V. Smith (1958). (Solid line-ordered, dashed line-disordered.)

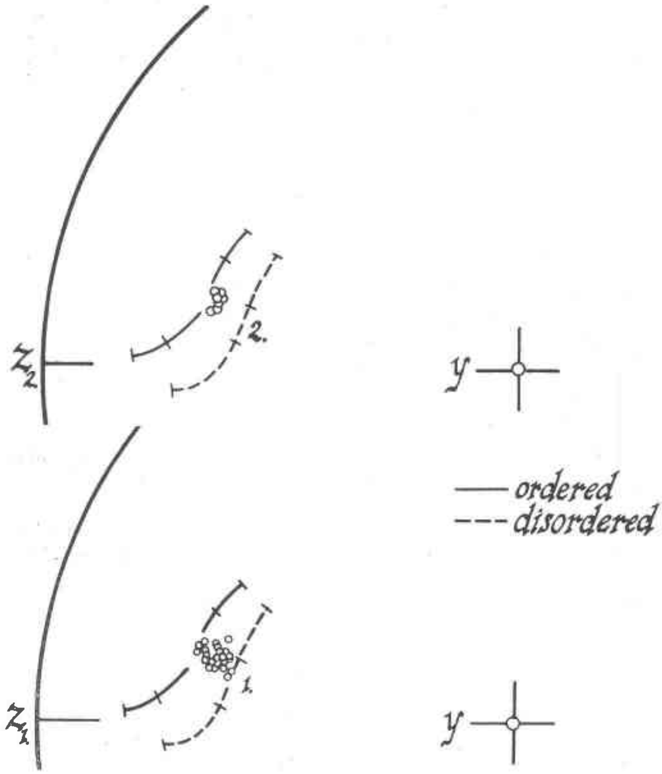

FIG. 2. External optical-crystallographic scatter of the composition face pole plots of albite twins from sample 24A (anorthosite, Essex Co., New York). 1) Overall scatter of the sample excluding recognizable late-stage deformation twins. 2) Recognizable late-stage deformation twins. Curves after Vogel (1964).

Carlsbad twin in which the albite twin lamellae are not parallel to the Carlsbad twin boundary. Laves correctly points out that Carlsbad twinning is due to growth twinning and the twin junction is commonly irregular. Figure 6 of Vogel's original paper illustrated scatter typical of Carlsbad and albite-Carlsbad twins including the grain referred to above; and if this Carlsbad twin boundary is an irregular twin boundary, the other Carlsbad and albite-Carlsbad twins from this sample must have nearly the same irregularity, for there is very little scatter of the plots of these poles. As a general rule, even with these irregularities in growth twins, it is usually possible to orient a plane that is parallel to most of the twin boundary for these irregularities generally occur as small steps; an illustration of this is shown in Figure 4.

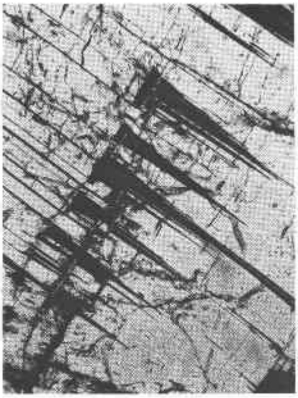

Fig. 3

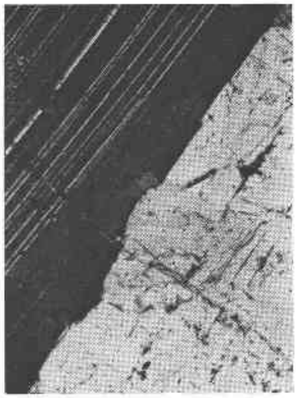

Fig. 4

FIG. 3. Photomicrograph of typical, late-stage, lens-shaped deformation twins. (Sample T-3C, Anorthositic gabbro, Tigerton, Wis.) (63×)

FIG. 4. Photomicrograph of step-like irregularities in a Carlsbad twin. Note the non-parallelism of the albite lamellae and the Carlsbad twin junction. (Sample T-3A, Anorthositic gabbro, Tigerton, Wis.) (26×).

It is hoped that further optical and *x*-ray investigations of twinned plagioclase can reconcile observations with theory.

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