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MECHANICAL TWINNING IN NATURALLY AND EXPERIMENTALLY DEFORMED DIOPSIDE

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ABSTRACT. Lamellar twinning on (100) and to a lesser extent on (001) are present in clinopyroxenes of deformed mafic and ultramafic rocks. Twins having similar appearance and orientation have been produced in deformation experiments at a confining pressure of 5 kilobars and temperatures up to 1000°C. The twinning elements and shear strain for each twin-glide system have been determined by a technique described herein. For the narrow, closely spaced twins on (100), K_1, the twin-glide plane, = (100), η_1, the twin-glide direction, = [001], K_2 = (001), η_2 = [100], and s = 0.57. For the broader, discontinuous twins on (001), K_1 = (001), η_1 = [100], K_2 = (100), η_2 = [001], and s = 0.57.

Both sets of twins are mechanical in origin and form where the resolved shear stress on the twin-glide system is high. Statistically, compression axes most favorably oriented for twin gliding in each of a large number of grains are aligned sub-parallel to the direction of maximum compression in experiments. In some deformed diopside-bearing calc-silicate rocks from South Australia, compression and tension axes deduced from twinning are consistent with principal stresses deduced from faulting. It is concluded that lamellar twinning in clinopyroxenes may be used for determination of the direction of principal stresses in natural deformations of rocks.

INTRODUCTION

In deformation experiments on peridotites it was found (Raleigh, 1965) that diopside grains became mechanically twinned in multiple narrow lamellae parallel to (100). Lamellar twinning on (100) in diopside has been described in granulites (Naidu, 1954) and calc-silicate hornfels (White, 1959), and our experience indicates that it is of common occurrence in metamorphic and plutonic mafic and ultramafic rocks. If, as in the experiments, these twins formed in response to externally applied differential stresses, it should be possible to determine the orientation of the principal stresses in the deformation giving rise to the twinning.

The principal stress-directions in experimental and natural deformations of marble have been determined from twinning in calcite and dolomite using a statistical treatment developed by Turner (1953). From universal stage measurements, compression and tension directions most favorably oriented for twin-gliding are determined for the best-developed set of twins in each grain. For a large number of randomly oriented grains, the compression axes should be statistically parallel to the maximum principal stress, σ_1, and the tension axes parallel to the least principal stress, σ_3. This method of dynamic analysis has been used in the present study of diopside twinning.

Analysis of the experimentally deformed diopside was performed by Raleigh at the Australian National University; the dynamic analyses of the naturally deformed diopside-marbles were carried out by Talbot at the University of Adelaide.

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EXPERIMENTS

Experimental procedure.—The purpose of the experiments was twofold:

1. to determine the twin-glide elements, that is, the glide plane and line and the sense and amount of shear, and
2. to produce a deformed aggregate of diopside in which the known principal stress directions could be compared with those deduced from the dynamic analysis.

For determination of the twin-glide elements, half-cylinders of peridotite containing olivine, enstatite, and minor diopside were polished on their diametral median planes and fitted together with 0.001 of an inch of platinum foil between the polished faces. The cylinder was then placed in an annealed copper jacket of 0.010 of an inch wall-thickness in preparation for experimental deformation in M. S. Paterson's apparatus. The technique for sealing the specimen and a brief description of the apparatus are given by Raleigh and Paterson (1965). The specimens were then deformed at a confining pressure of 5 kilobars and temperatures ranging from 200° to 1000°C. The experiments were run at constant strain-rate in the range between 5 x 10^{-2} sec^{-1} and 5 x 10^{-5} sec^{-1}. For the dynamic analysis, a core of a diopside-scapolite rock from Milendella, South Australia, containing about 60 percent diopside was strained 8 percent in compression at 5 kilobars and 800°C. The diopside-scapolite rock was used rather than the peridotite because many more grains were available for analysis in a single thin section.

In both rocks the diopside grains were free from twinning or exsolution lamellae prior to being deformed experimentally.

Experimental results.—Mechanical twinning on (100) was the principal mechanism of plastic deformation of diopside in all these experiments. Minor twinning on (001) and slip on the (100) plane in the direction [001] were produced also in the experiments and have been reported previously by Griggs, Turner, and Heard (1960). On the polished surfaces of the deformed polycrystals, evidence for translation glide on T = (100), t = [001] was provided by slip lines parallel to (100) and normal to kink bands whose boundaries were approximately normal to [001]. The grains were so oriented that the resolved shear stress for slip on (100), [001] was high but in the reverse sense for twinning on the same system. Details of the technique used for determining the slip mechanisms on polished surfaces of polycrystals are given by Raleigh (1965).

The twins on (100) produced experimentally (pl. 1) are narrow and tend to be closely spaced. They are indistinguishable from naturally-occurring polysynthetic twins in diopside. The basal twins tend to be few in number, broader, and discontinuous. Where the basal twins end within a crystal, the strain resulting is adjusted by a complementary external rotation of the lattice (pl. 1-A) in the remainder of the crystal.

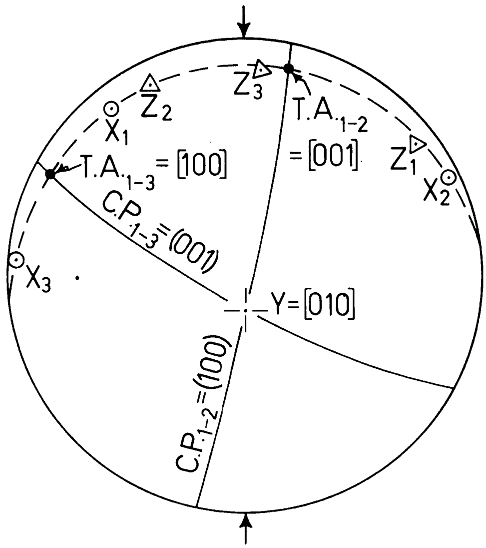


Fig. 1. Re-orientation of optic directions, X, Z, in mechanical twins on (100) and (001) in experimentally deformed diopside grain illustrated in plate 1-A. CP = composition plane; TA = twin axis. Equal-area projection. Compression north-south.

The external rotation is brought about by an increase in the density of the lamellar (100) twins in the bent region.

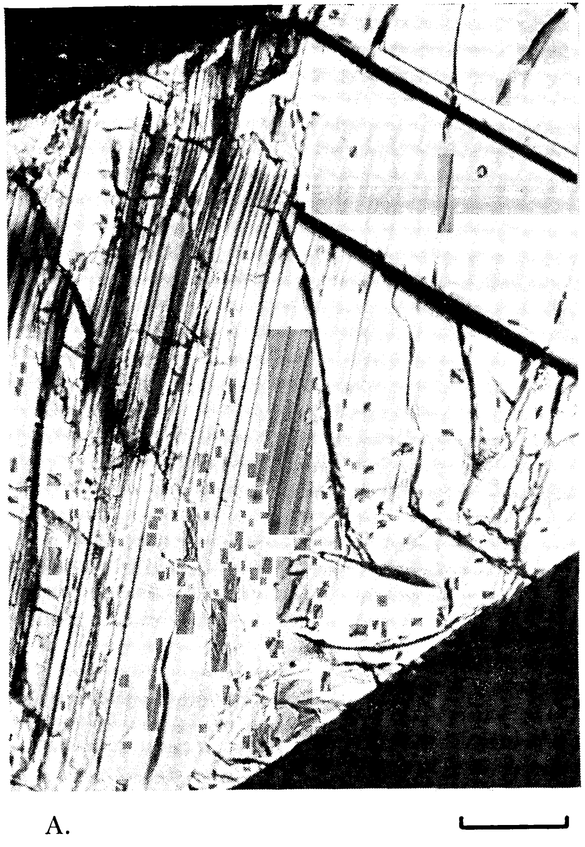
Measurements on a universal stage of the orientation of the optic directions, X, Y, and Z in (001) and (100) twin lamellae and in the host crystal of diopside ($Z \wedge [001] = 39°$, $2V_Z = 58°$) are shown in figure 1. The grain and twins are illustrated in plate 1-A. The composition planes, (100) and (001), are the twin planes and relate the host to the twinned orientations by mirror reflection. Alternatively, the twinned and host orientations can be brought into coincidence by a 180-degree rotation about twin axes, $T.A._{1\text{-}2} = [001]$ in twins on (100) and $T.A._{1\text{-}3} = [100]$ in (001) (fig. 1).

Growth twins on (100) are common in clinopyroxenes of igneous rocks, and the symmetry elements are the same as those of the mechanical twins. The growth twins differ from the polysynthetic mechanical twinning, however, in being broad with only one or two subindividuals in a grain. Furthermore, the composition planes of the growth twins are commonly stepped in contrast to the mechanical twin boundaries which are continuous.

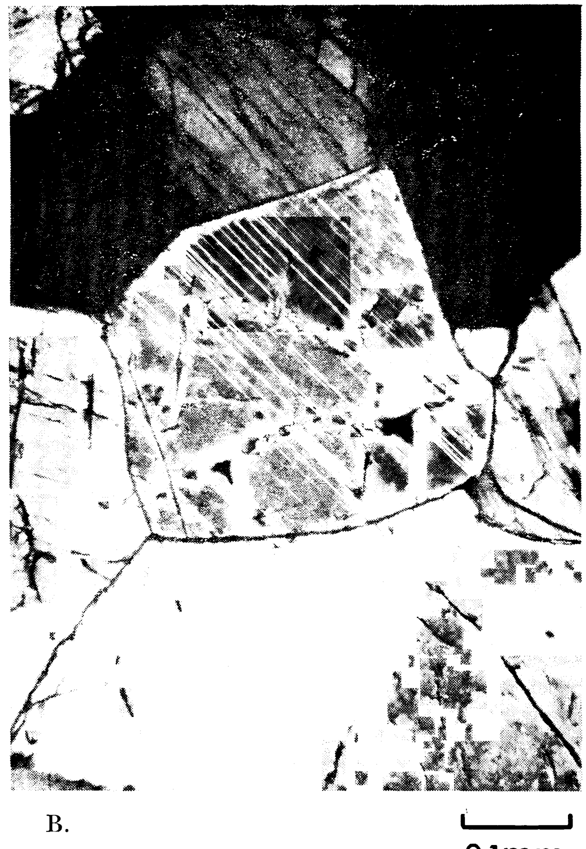
Exsolution lamellae of orthopyroxene on (100) in clinopyroxenes are similar in appearance to thin (100) twins but can be distinguished from them on the following grounds:

1. The exsolution lamellae of orthopyroxene have [001] and (100) in common with the host clinopyroxene (Poldervaart and Hess, 1951), and therefore the optic direction, Z, in the lamellae is parallel to [001]

PLATE 1



A.



B.

A. Lamellar twinning on (100) (NNE) and (001) (WNW) produced by deforming diopside at 5 kilobars, 800°C. Optical orientations in twins and host shown in figure 1. Compression north-south. Polished thin section in transmitted light. Crossed polarizers.

B. Lamellar twinning on (100) in diopside deformed 5 kilobars, 1000°C. Crossed polarizers.

C.

D.

C. Diopside with natural deformation twinning on (100). In calc-schist from Palmer area, South Australia. Crossed polarizers.
D. Lamellar mechanical twinning on (100) in diopside granulite from Sleaford Bay, South Australia. Crossed polarizers.

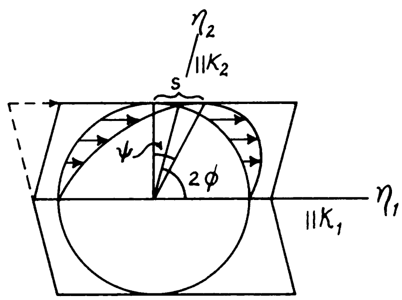


Fig. 2. Transformation of sphere to ellipsoid by homogeneous simple shear in mechanical twinning. K_1 is parallel to the shear plane and one of the circular sections of the strain ellipsoid. K_2 is the other circular section, η_1 is the shear direction, and η_2 is the line in K_2 normal to its intersection with K_1. The shear, s, is the tangent of ψ.

in the host. The exsolution lamellae therefore should have parallel extinction whereas in the twin lamellae the extinction will, in general, be inclined.

2. The lamellar twins on (100) commonly extend to the grain boundary; exsolution lamellae terminate within the crystal a short distance from the boundary.

Determination of twin-glide elements.—The deformation in mechanical twinning can be described by a homogeneous simple shear which for a given twin law has fixed shear strain. A sphere inscribed within a crystal will therefore transform to an ellipsoid upon twinning (fig. 2), and the twin law may be specified by describing the orientation of the ellipsoid with reference to the crystal axes. Conventionally, the circular sections, K_1 and K_2, of the strain ellipsoid, the twinning direction, η_1, and the line, η_2, in K_2 normal to its intersection with K_1, are the elements whose crystallographic orientations are to be determined (Cahn, 1954). K_1 is the glide plane, and K_2 is the second circular section. The angle, 2ϕ, between the two circular sections gives the twinning shear, s, by the relation

$$s = 2 \cot 2\phi. \quad (1)$$

The shear is also given by the tangent of the angle, ψ, through which a plane normal to η_1 is rotated by the simple shear, thus

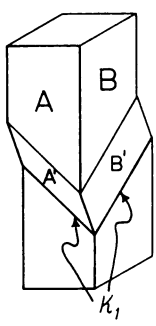
$$s = \tan \psi. \quad (2)$$

K_1 and η_1 are parallel to the twin plane and twin axis in diopside and are readily determined in thin section with a universal stage. The shear is determined from the rotations of free surfaces of crystals upon twinning, and K_2 and η_2 may then be derived from the relation (1) above.

Greninger and Troiano (1949) have devised a solution for the stereographic projection from which the shear strain can be calculated from these rotations. A single crystal of known orientation is prepared with two polished faces at right angles. After twinning (fig. 3A), the original surfaces A, B (dashed great circles, fig. 3B) are rotated to orientations A′, B′ (solid great circles). The data are plotted on the projection with the twin-glide plane, K_1, on the primitive circle. In simple shear, lines move in planes (great circles on the projection) containing the shear direction. The great circle containing the line, AB, defined by the intersection of surfaces A and B, and its rotated equivalent, A′B′, must therefore intersect K_1 in the glide direction, η_1. The angle of shear, ψ, may now be obtained by constructing an imaginary surface, C, at right angles to η_1 and finding on the projection the angle through which it would be rotated by the shear to the twinned orientation, C′. The lines of intersection, AC and BC, of C with surfaces A and B move on the projection along great circles defined by AC and η_1 and BC and η_1.

The lines of intersection, A′C′ and B′C′, of the twinned surfaces, lie in these great circles and also in the planes, A′, B′, and C′. The great circle, C′, for the twinned orientation of C may now be drawn through the points A′C′ and B′C′ and the angle of shear, ψ, is measured between C and C′.

Single crystals of diopside of sufficient size and quality were not readily available at the start of our experiments so that it became necessary to adapt the above method to polycrystals. The grains in the split cylinders used in these experiments are cut by a single polished free surface, the diametral median plane of the cylinder. The angle through which the polished surface is rotated by twinning in a grain can be measured with a two-axis universal stage in reflected light. A thin section is then made on the polished surface after a light grind to remove irregularities. With the slide mounted upon a universal stage, the crystallographic orientation of the grain, the orientation of the twin boundaries (= K_1) and the twin axis (= η_1), can be measured and plotted on a sterographic projection. On the projection are plotted the plane, A, representing the polished surface and the same plane, A′, rotated by

A.


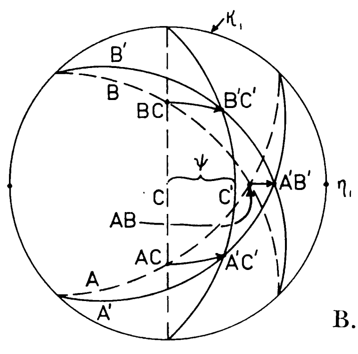
B.


Fig. 3. A. Rotation of free surfaces, A and B, of single crystal by homogeneous simple shear in twinning. B. Determination of twinning shear angle, ψ, from rotations of surfaces A and B in single crystal.

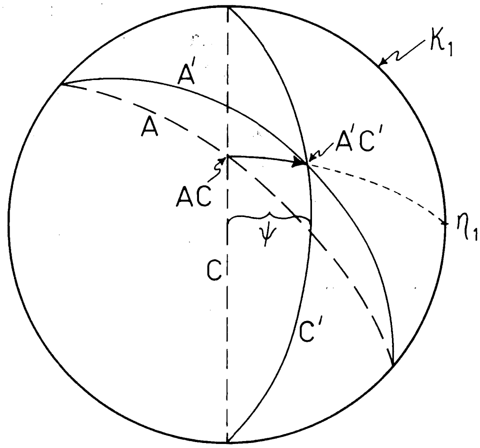


Fig. 4. Determination of sense and amount of twinning shear in twinned polycrystals.

twinning through the measured angle around an axis parallel to the intersection of the twin-glide plane, K_1, and the polished surface. If the projected data are then rotated so that K_1 occupies the primitive circle as in figure 4, the projection is like that in figure 3B, and the twinning shear can be determined. The great circle, C, normal to η_1 is plotted and its intersection, AC, with the polished surface is moved along a partial great circle toward η_1. The rotated plane, C′, must pass through the intersection of the partial great circle with the plane, A′. As the rotation of C takes place about the line of intersection of C and K_1, the great circle, C′, is specified. The angle between C and C′ is ψ, the angle of shear, and for twinning on (100) the sense of shear is positive, that is, toward the positive end of the [001] axis (fig. 5).

This method is imprecise because of the difficulty in measuring the angle of rotation of the free surface and in ensuring that the thin section is cut parallel to the polished surface in a particular grain. Measurements on 12 grains gave an average ψ of 32° ± 3°. The shear, tan ψ, is 0.62, and therefore the angle, 2ϕ, between K_2 and K_1 is 73°. As the angle β, (001) $\wedge$ (100), in diopside is 74°, K_2 is parallel to (001) and η_2 is [100] (fig. 5) within the limits of error of measurement. The corrected value of the shear, s, from (1) is 0.57. Similar measurements in the basal twins give $K_2 =$ (100), $\eta_2 =$ [001] with $K_1 =$ (001), and $\eta_1 =$ [100]. The shear in the basal twins is also 0.57.

Where, as in diopside, two sets of twins have elements such that the indices for K_1 and η_1 of one set are the same as K_2 and η_2 for the other set they are described as reciprocal twins, and Cahn (1954) considers that the movements of atoms in both are likely to be closely related.

In crystals of low symmetry, mechanical twins will be related to the host by reflection across the twin plane or by rotation about a twin axis.

Given K_1 as parallel to a twin plane, then η_1 cannot be determined from the symmetry relations between host and twin, no twin axis being present. As shown in figure 3, however, the shear direction may be determined as the line in K_1 toward which the intersection of two surfaces is rotated by twinning. If measurements of the rotation of the polished surface of polycrystals are made on two or more grains and referred to the standard projection as in figure 4, the direction of rotation of the edges (for example, AC to A′C′) may be used to find η_1. In twins on (100) in diopside, the twin axis [001] proved indeed to be parallel to η_1 by virtue of such measurements of surface rotation.

The foregoing description of mechanical twinning is based on a model of twinning as a homogeneous simple shear parallel to the twin plane in the direction of the twin axis. The net strain is indeed a simple shear, but movements of individual atoms do not necessarily correspond to the net shear (Laves, 1952). In figure 5, a projection of the diopside structure on (010) is adapted from Warren and Bragg (1928) and shows the structure in (100) and (001) twins reflected across the twin boundaries from the initial structure. The structural planes taken as composition planes are chosen for providing the best fit of atoms across the boundaries, although planes displaced by a/2 for the (100) twins or c/2 for the (001) twins would be equally suitable. The atomic movements in the (001) twins are, in general, *not* parallel to η_1. In the (100) twins most of the atoms are translated along the axis, η_1, but the displacements are not, in general, proportional to the distance from the twin boundary as they would be if undergoing homogeneous simple shear. The degree of departure from simple shearing motion of the atoms does not appear to be significantly reduced by considering the

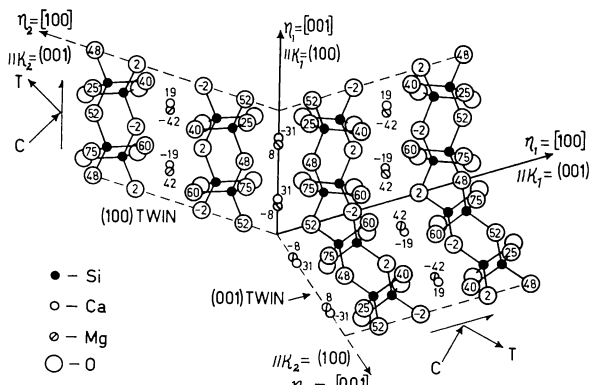


Fig. 5. Idealized structure of diopside viewed along [010] (after Warren and Bragg, 1928) showing twins on (100) and (001) with twinning elements and sense of twinning shears. C and T are directions of compression and tension most favorably oriented to give shear in the correct sense.

twin boundaries as planes of glide reflection rather than of mirror reflection.

Klassen-Neklyudova (1964) lists many other examples of twinning where the displacements on an atomic scale fail to correspond to simple shear. It seems doubtful that in the silicate minerals, because of the complexity of their structures, there are any situations in which homogeneous simple shear of atoms in twinning can result in a structural arrangement having mirror symmetry with regard to the untwinned structure.

DYNAMIC ANALYSIS

To carry out the dynamic analysis it is assumed that twinning in an aggregate takes place preferentially in grains in which the resolved shear stress on the twin glide system is high. The most favorable orientation of the crystal to stress for twinning on (100) is with the maximum compression, C, at 45° to (100) and [001], and the least compression or tension, T, 90° from C as shown in figure 5. For each twinned grain in a rock, C and T are plotted on the projection (fig. 6) with C at 45° to [001] or the normal to (100) and near the optic direction, X. T is 90° away in (010) near Z. After a sufficiently large number of randomly oriented grains have been measured, 100 or so, the maximum concentration of C is taken to be parallel to the maximum principal stress, σ_1, and T parallel to σ_3. Where the C and T axes have axial symmetry, for example, a girdle of tension axes is normal to a point maximum of compressions, the principal stresses are assumed to be axially symmetric.

Dynamic analysis of experimentally deformed diopside.—The dynamic analysis of twinning in the diopside-scapolite specimen deformed experimentally was carried out on a thin section cut longitudinally through the cylinder axis. The cylinder was compressed axially

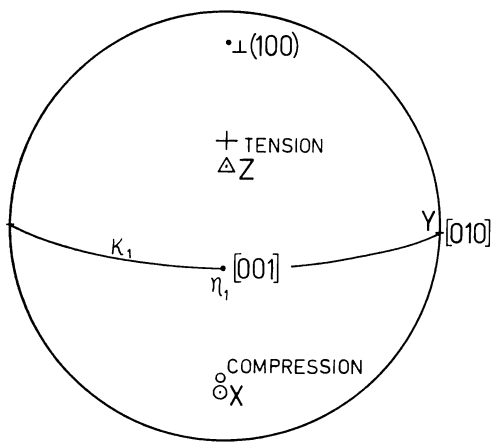


Fig. 6. Compression (o) and tension (+) axes for (100) twinning plotted on equal-area projection of crystallographic orientation of diopside.

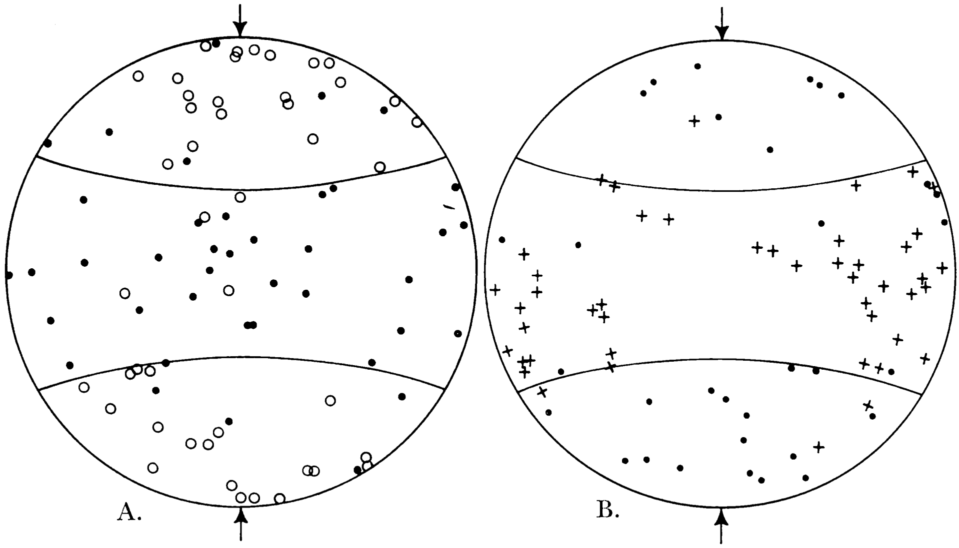


Fig. 7. A. Equal-area projection of 78 X from diopside in specimen 371 shortened 8 percent at 5 kilobars, 800°C. X = compression (o) in 45 twinned grains; in 33 untwinned grains X is represented by (•). Cylinder axis = σ_1 is north-south in diagram. B. Z = tension (+) in 45 twinned grains; in 33 untwinned grains Z is represented by (•).

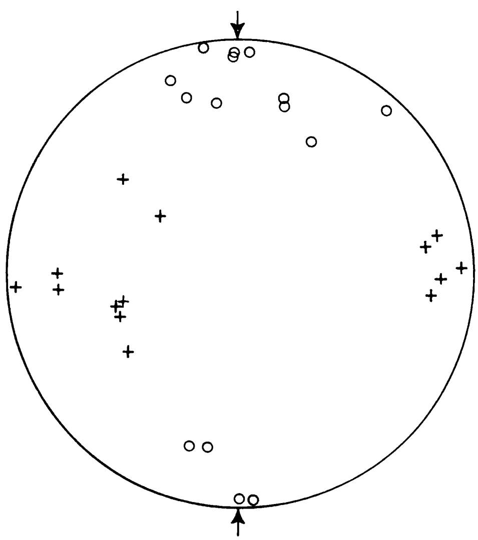


Fig. 8.

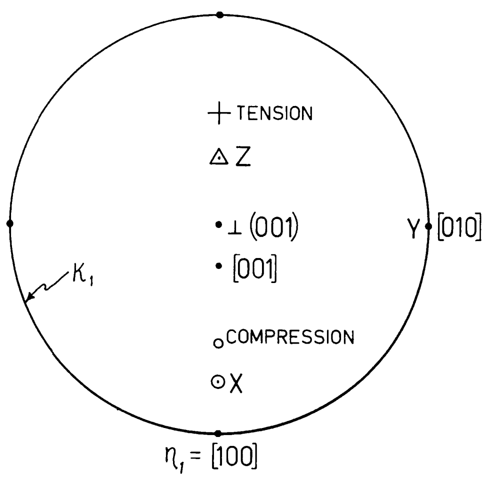


Fig. 9.

Fig. 8. Compression (o) and tension (+) axes from diopside grains most heavily twinned on (100) in experimental specimen 371.

Fig. 9. Equal-area projection showing orientation of compression and tension with respect to K_1 = (001) and η_1 = [100] for basal twinning in diopside.

under confining pressure so that the principal stresses were axially symmetric with $\sigma_1 > \sigma_2 = \sigma_3$. The angle Z $\wedge$ [001] in the diopside is approximately 45°, and as compression and tension are plotted at 45° to the glide direction and pole of the glide plane, Z = T (tension) and X = C (compression).

Measurements of X and Z of the host grain in 78 grains in several traverses were made and plotted separately on equal-area projections (figs. 7A, B). A plot of X = C for 45 grains twinned on (100) and X in 33 untwinned grains in figure 7A shows the compressions concentrated near the cylinder axis parallel to the maximum principal stress, σ_1. In the majority of the untwinned grains, X is unfavorably oriented for twinning. In figure 7B, Z = T for the 45 twinned grains lie in an incomplete girdle in the plane of the least principal stress, $\sigma_2 = \sigma_3$, normal to the cylinder axis. In most of the untwinned grains, Z, like X, is unfavorably oriented for twinning.

The scatter in the distribution of C and T (figs. 7A, B) can be reduced by selecting grains that are more heavily twinned. In the experimental specimen, grains that are approximately one-third to half-twinned give a relatively narrower spread of compressions and tensions than in lightly twinned grains (fig. 8).

Twinning on (100) predominates in the experiments and in the naturally deformed rocks, but if the clinopyroxenes in a rock should show a predominance of (001) twinning a dynamic analysis could also be carried out. The shear sense is negative, and the compression and tension axes lie at 45° to (001) and [100] in the (010) plane as shown in figure 9. Although only a few such twins are present in the experimental specimen

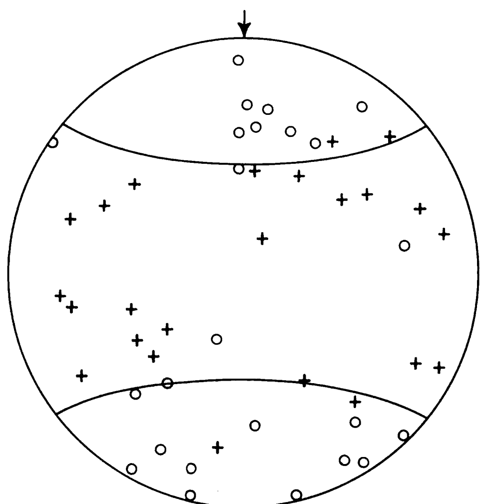


Fig. 10. Compression (o) and tension (+) axes in 24 diopside grains with basal twins in experimental specimen, 371. Compression north-south.

the distribution of compressions and tensions agrees well with the known principal stress directions (fig. 10).

Dynamic analysis of naturally deformed diopside.—To test the method of dynamic analysis on naturally deformed diopside, several oriented specimens of a diopside-bearing calc-silicate rock were collected from near a major fault in the Palmer Area, South Australia. These rocks, metamorphosed to amphibolite facies (White, 1959), are constituted principally of quartz, scapolite, calcite, and about 10 percent diopside. The diopside shows well-developed lamellar twinning on (100), and the calcite is heavily deformed, having a phyllonitic texture in some specimens. Three orthogonal thin sections were prepared from each of two specimens for measurement of twins in diopside and in calcite for comparison. The data have been rotated to the horizontal in the projections in figure 11.

In both specimens the distribution of compression-tension axes is similar. Maxima of compression axes trend east-west normal to girdles of tension axes although there is a second maximum of compressions trending north-south in one specimen (fig. 11A). The fabric of the diopside is random in both specimens, and the distribution of compressions and tensions is therefore considered to reflect the orientation of the principal stresses responsible for the twinning. Mills (ms) has studied the faulting in the Eastern Mount Lofty Ranges in which the Palmer area is located, and from his conclusions it appears that the stress directions from the dynamic analyses may be tentatively correlated with one of the major episodes of deformation. The sequence proposed by Mills is as follows:

1. An early Paleozoic series of north-south trending thrust faults follows the contemporaneous folding and metamorphism to amphibolite facies. The maximum principal stress is postulated to lie horizontal and east-west.
2. Numerous, small second-order faults trend north-northwest to northwest with left-lateral offset and west to southwest with right-lateral offset.
3. Mid-Paleozoic (?) normal faults trend north-south and have been reactivated during Tertiary.

We suggest that the twinning of the diopside under east-west compression could have coincided with the thrust faulting which is considered to be the most severe post-metamorphic deformation (Mills, ms; Sprigg, 1946).

For comparison with the results for diopside, a dynamic analysis of the *e*-twinning in calcite (Turner, 1953) in the rocks was carried out. The pattern of compression and tension axes was random in one specimen and weak in the other. The scatter is a result of the high incidence of twinning, two or three sets being apparent in nearly every grain in thin section. The random nature of the twinning is taken to be indica-

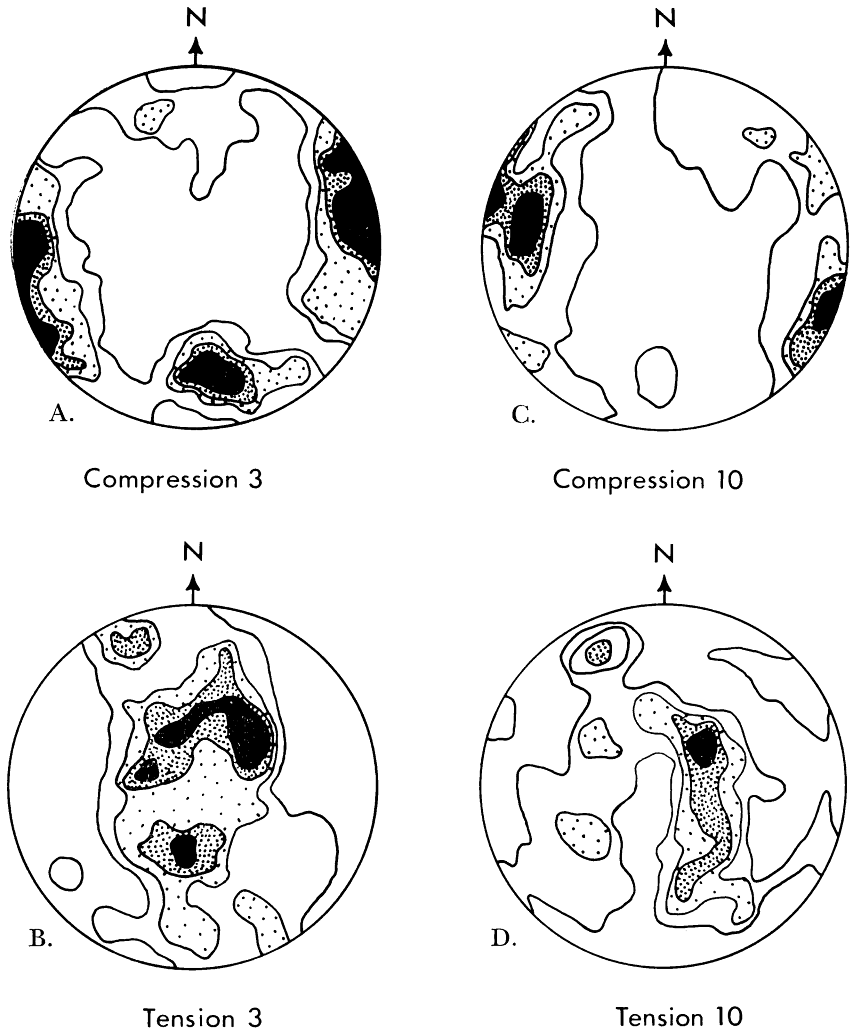


Fig. 11. Compression and tension axes for (100) twinning in naturally deformed diopside from Palmer area, South Australia. Equal-area projections with primitive circle horizontal; arrow points to north. Contours 1, 2, 3, 4 percent per 1 percent area. A. 130 compression axes in specimen 3; B. 130 tension axes in specimen 3; C. 115 compression axes in specimen 10; D. 115 tension axes in specimen 10.

tive of multiple, non-coaxial deformations. Calcite twins under a stress difference that is small compared to that for diopside, and it is possible that one of the later deformations of which Mills (ms) gives evidence, could have resulted in further twinning of the calcite without affecting the diopside.

Conclusions.—Mechanical twinning on (100) and (001) produced experimentally in diopside strongly resembles lamellar twinning in the naturally deformed mineral. The twin-glide elements and shear have been determined using an adaptation of a metallographic technique. The experimental observation that twins form preferentially where the resolved shear stress on the twin-glide system is high indicates that twinned diopside may be used for dynamic analyses, that is, for the determination of the direction of the principal stresses in natural deformations. Studies on naturally deformed diopside-bearing calc-silicate rocks from South Australia support this contention.

Dynamic analyses of deformed minerals have heretofore been restricted to rocks containing quartz or carbonates (for example, Carter and Friedman, 1965). The range of rock types capable of being analyzed is therefore greatly extended by this addition. In particular, deformed peridotites and mafic rocks in which quartz or carbonates are lacking can now be treated.

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REFERENCES

Cahn, R. W., 1954, Twinned crystals: Advances in Physics, v. 3, p. 363-445.

Carter, N. L., and Friedman, Melvin, 1965, Dynamic analysis of deformed quartz and calcite from the Dry Creek Ridge Anticline, Montana: Am. Jour. Sci., v. 263, p. 747-785.

Greninger, A. B., and Troiano, A. R., 1949, The mechanism of martensite formation: Jour. Metals, v. 1, p. 590-598.

Griggs, D. T., Turner, F. J., and Heard, H. C., 1960, Deformation of rocks at 500° to 800°C, *in* Griggs, D. T., ed., Rock deformation: Geol. Soc. America Mem. 79, p. 39-104.

Klassen-Neklyudova, M. V., 1964, Mechanical twinning of crystals: New York, Consultants Bureau, 213 p.

Laves, Fritz, 1952, Über den Einfluss und Unordnung auf mechanische Zwillingsbildung: Naturwissenschaften, v. 39, p. 546.

Mills, K. J., ms, 1965, The structural petrology of an area east of Springton, South Australia: Ph.D. thesis, Univ. Adelaide, 497 p.

Naidu, P. R. J., 1954, Minerals of charnockites from India: Schweizer. Mineralog. Petrog. Mitt., v. 34, p. 203-279.

Poldervaart, Arie, and Hess, H. H., 1951, Pyroxenes in the crystallization of basaltic magma: Jour. Geology, v. 59, p. 472-489.

Raleigh, C. B., 1965, Glide mechanisms in experimentally deformed minerals: Science, v. 150, p. 739-741.

Raleigh, C. B., and Paterson, M. S., 1965, Experimental deformation of serpentinite and its tectonic implications: Jour. Geophys. Research, v. 70, p. 3965-3985.

Sprigg, R. C., 1946, Reconnaissance geological survey of a portion of the western escarpment of the Mount Lofty Ranges: Royal Soc. South Australia Trans., v. 70, p. 313-347.

Turner, F. J., 1953, Nature and dynamic interpretation of deformation lamellae in calcite of three marbles: Am. Jour. Sci., v. 251, p. 276-298.

Warren, B. E., and Bragg, W. L., 1928, The structure of diopside, $CaMg(SiO_3)_2$: Zeitschr. Kristallographie, v. 69, p. 168-193.

White, A. J. R., 1959, Scapolite-bearing marbles and calc-silicate rocks from Tungkillo and Milendella, South Australia: Geol. Mag., v. 96, p. 285-306.