ON PYROXENE TWINNING

E. A. V. PRASAD & M. G. CHAKRAPANI NAIDU

Prasad, E. A. V. & Naidu, M. G. Chakrapani: On pyroxene twinning. *Norsk Geologisk Tidsskrift,* Vol. 51, pp. 15–23. Oslo 1971.

Petrographic features of samples taken along a profile from the contact towards the centre of a dolerite dyke are described.
The incidence of twinning in plagioclase is high near the contacts and decreases progressively towards the centre of the dyke. The converse is observed with respect to pyroxene twinning.
It is suggested that the twinning in pyroxene is secondary and represented by two genetic types: glide twinning and synneusis twinning.

E. A. V. Prasad & M. G. Chakrapani Naidu, Department of Geology, Sri Venkateswara University Colleges, Tirupati (A. P.), India.

Dolerite dykes occur in the Mid Pennar Reservoir Project area in the Anantapur District of Andhra Pradesh, South India (topographic sheet No. 57, F/5). One dyke near Rampuram temple has an exceptional thickness of about 250 feet. Samples have been collected from the contact towards the centre of this dyke at approximately equal intervals. The rock at the contact is tachylitic. As the size of the grains increases, the texture becomes subophitic, whilst in the central region, it changes again to subhedral granular, the pyroxene having lost its ophitic texture. The contact rock consists of a few phenocrysts of lath-like plagioclase and untwinned pyroxene in a groundmass composed of microlites of plagioclase, pyroxene and abundant minute magnetite granules. Occasionally the ground mass may be devitrified glass. In the more crystalline portions of the rock, away from the contact, the dolerite is composed of stout laths of plagioclase, subophitic pyroxene, and interstitial granophyre and iron ore with amphibole, biotite, chlorite and apatite forming the accessories. The plagioclase in the core of the crystals is labradorite with anorthite content 50–55 per cent. It is twinned after albite, pericline and Carlsbad laws and shows progressive and continuous zoning, which brings the anorthite content of the rim down to 40 per cent. Oscillatory zoning is occasionally encountered. Feldspar laths are not perfectly idiomorphic as the peripheral parts of the crystals are often intergrown with quartz, and granophyre occupies the plagioclase lath interstices. High elongation ratio of both plagioclase and pyroxene is typical in all the samples. Pyroxene is mostly titaniferous augite, which is distinctly pleochroic from brown to reddish brown. Its optical

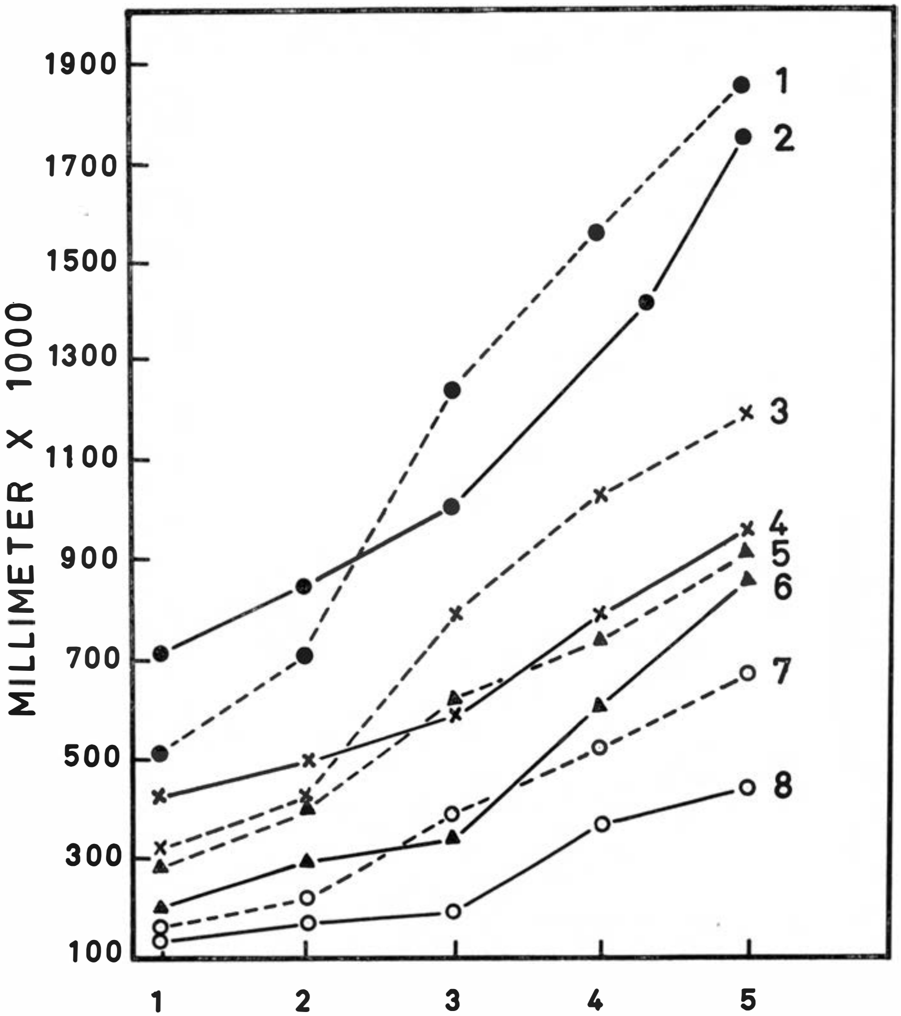


Fig. 1. Variation in grain size in pyroxene (dashed line, 1, 3, 5, 7) and plagioclase (solid line, 2, 4, 6, 8). Maximum length (1, 2), average length (3, 4), maximum breadth (5, 6), and average breadth (7, 8).
Numerals on the X-axis in Figs. 1–3 represent the numbers of the samples across the dyke, from nearer the contact towards the centre.

properties are $Z \wedge C = 45–47°$, $2V_z = 52–62°$, $N_z–N_x = 0.024$, distinct to weak dispersion. Pyroxene is also represented by colourless augite: $Z \wedge C = 40–42°$, $2V_z = 40–45°$, $N_z–N_y = 0.022–0.025$. In addition to the usual (110) cleavage, (001), (100) and (010) partings are prominent. Twinning with (100) as twin plane is the most common.

The detailed petrographic variations in sections taken from about 15 inches from the contact along a profile towards the centre of the dyke are shown in Figs. 1–3.

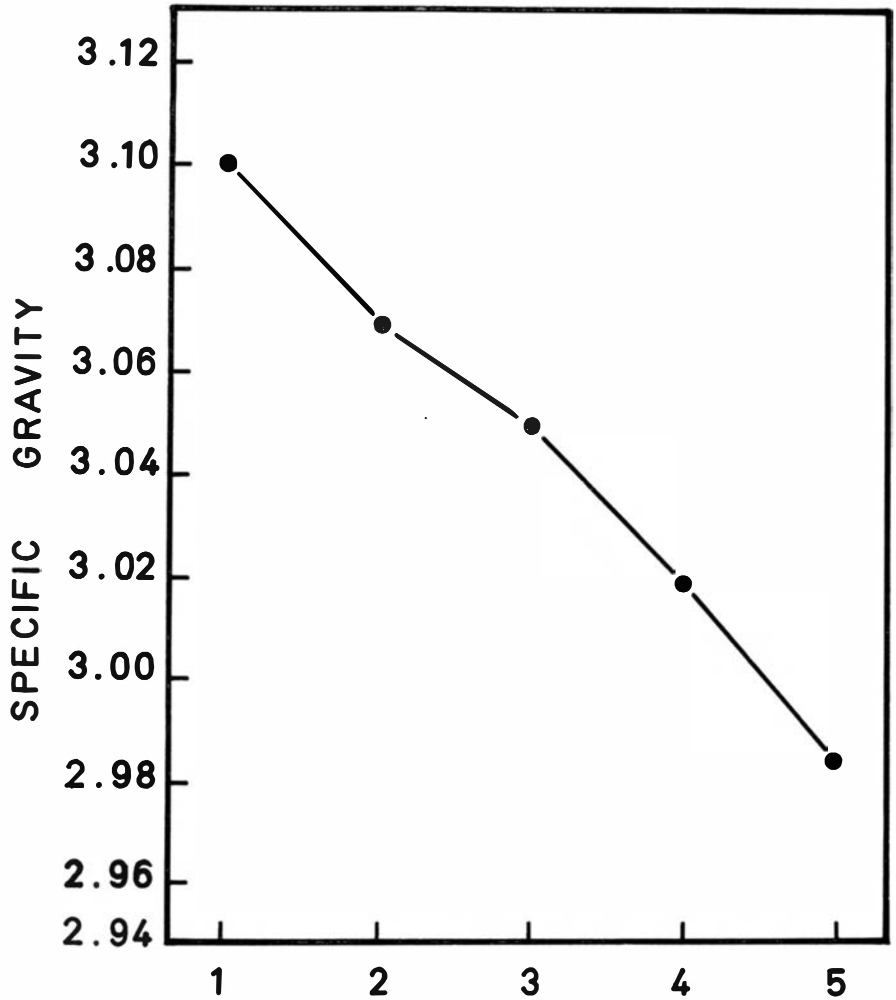


Fig. 2. Variation in the specific gravity of the dolerite samples.

The most striking and consistent feature in all thin sections examined is that the twinned grains of pyroxene occur in clusters (Figs. 4–7). The twinned grains in any cluster may be parallel or sub-parallel or randomly oriented with respect to each other; in a few cases twinned grains are nearly perpendicular, each in touch with the other or partly penetrating into the other. A few interpenetration twins are observed but are rare. When they occur in parallel or sub-parallel groups they appear as bundles. They appear to be 'pressed' against two 'rigid' masses which are plagioclase grains. In such cases the long prisms of pyroxene appear slightly curved or wavy together with the twin planes (Figs. 4 and 5). The cleavages may become obliterated or may appear to dwindle off at such portions where they are

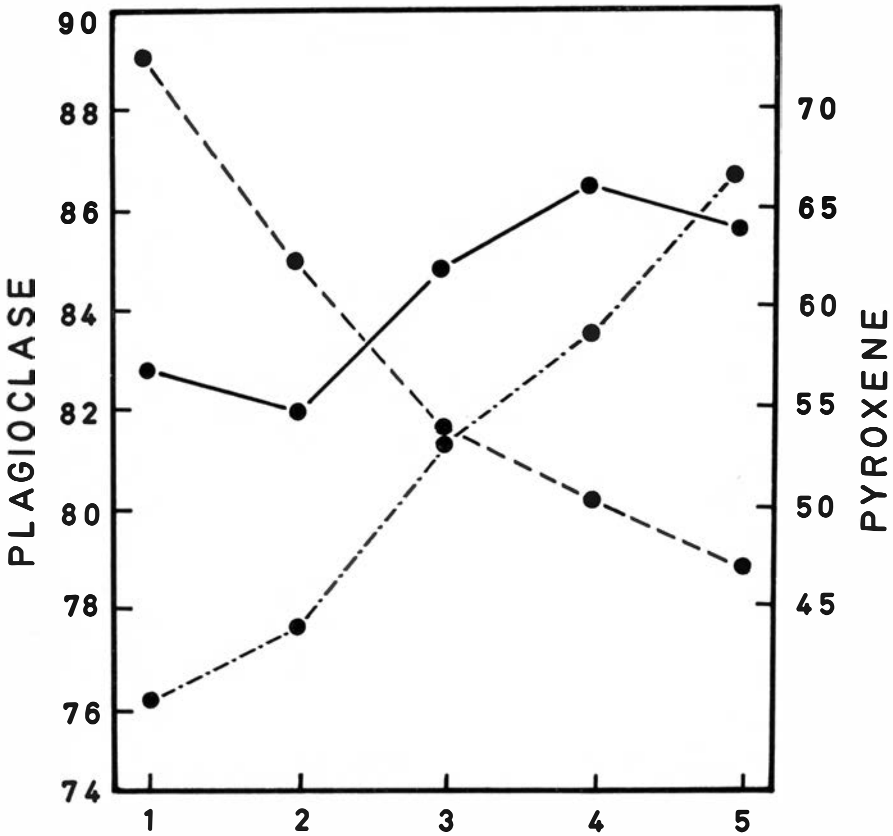


Fig. 3. Variation in the frequency of twinned plagioclase (dashed line) and twinned pyroxene (dash-and-dot line), and variation in the volume percentage of twinned pyroxene with respect to untwinned pyroxene (solid line).

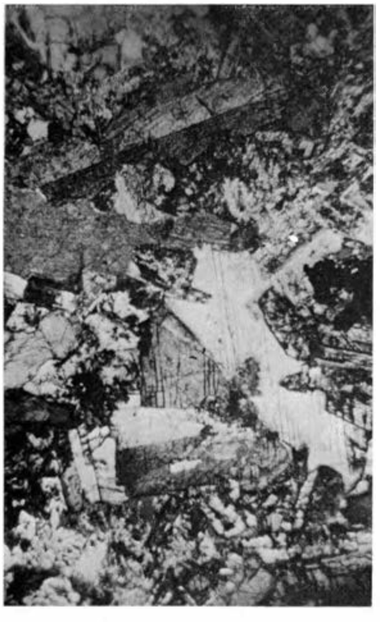
'pressed'. Twinned grains are always much larger than the untwinned grains. Clusters of untwinned grains are rare. One portion of a twinned grain may appear to have the same optical relationship to a neighbouring untwinned grain as it has to its twin component thus simulating a twinned relationship.

The twin planes are curved in the bent crystals. In a few cases, the twin plane is found to be 'terraced' or 'step-like', and there is occasionally evidence of more than one twin plane.

The individual twins, most commonly, show only two sub-individuals; occasionally three and rarely four lamellae are seen. Further, the middle lamellae has a uniform width but abruptly stops halfway without reaching the other end of the grain, or it has a uniform width for some distance and then the width increases or decreases. Cracks may be developed along a twin plane which may be straight, curved, sinuous or irregular. Twin planes in some grains are marked with yellow or light yellowish brown iron oxide staining; as a result the twinned nature becomes very emphatic.

4

5



6

7

Figs. 4–7. The general character of pyroxene twinned grains in the dolerite, emphasizing the secondary nature of twinning. Microphotographs (crossed Nicols, X 40) of thin sections from dyke near Rampuram Temple, Anantapur District, Andhra Pradesh, South India.

The untwinned plates are fragmented into crystal aggregate. The individual grains present sutured and serrated borders with the surrounding grains.

It is evident that there is a general and progressive decrease in the incidence of plagioclase twinning from the contact of the dolerite dyke towards the centre (Fig. 3). This observation agrees with that of Ingerson (1952), who explained the phenomenon as follows:

1. Early formed crystals appear to have a greater tendency to twin than the later crystals of the same minerals. This is primarily due to the mechanical disturbance and also due partly to the higher temperature.
2. There is a higher incidence of twinning near the contacts, which may be brought about by the greater differential stresses to which the growing crystals are subjected.

Ingerson points out that the above interpretations hold good in the case of twinning frequency in quartz also and suggests that they might be extended to other mineral species. This suggestion is, however, refuted by the present observations which show that the distribution of twinning in pyroxene is the reverse of that found in plagioclase, with a general increase in the incidence of twinning towards the centre of the dyke.

According to a review article by Smith (1962), the following factors make for abundance of twins in feldspars:

1. High temperature of crystallisation.
2. Growth from liquid (magma) rather than from solid (in a metamorphic rock).
3. Rapid growth.
4. Small size of crystals.
5. Euhedral crystals.

All of these factors are consistent with those of the dyke under study. The authors have been unable to find comparable generalisations concerning the control of the twinning in pyroxene. However, with its quite different structure, one can think of no *a priori* reasons why pyroxene should respond to the above-mentioned factors in the same way that feldspar does. Most of the twinned pyroxene grains have two sub-individuals. A few grains show irregular polysynthetic twinning with three or at the most four lamellae. Plagioclase invariably exhibits very high relative frequency of twinning. Further, the simplicity of the twinning in pyroxene contrasts very strikingly with the variety and complexity of twinning, exhibited by plagioclase. The factors which control the formation of plagioclase twinning are connected with physical, chemical, and physico-chemical circumstances; these obviously differ in their methods of controlling the formation of twinning in pyroxene.

This interpretation at once raises the question as to why pyroxene twins occur abundantly in some rocks and are rare or absent in others. According to a theory, mentioned by Donnay (1943), differences in twinning behaviour of similar minerals are much more probably due to differences in space-lattice structure than to direct influence of external conditions such as temperature. Donnay (1940, 1943) assumes that twinning in plagioclase is a phenomenon of crystal growth and is controlled mainly by the geometry of the space lattice. The exactly opposing view that the twinning in pyroxene is essentially a secondary phenomenon holds good, as is evidenced from the petrographic features of the twinned grains of pyroxene. Of course, it is not known whether the twinning in plagioclase is primary or secondary, and in spite of the investigations by several earlier workers, it is still an open question.

The secondary nature of pyroxene twinning is upheld because:

1. There is no regular relation between the distribution of twin lamellae and external morphological form.
2. Twinning is common in bent, twisted, or fractured crystals as is so often the case with secondary twinning.
3. The lamellae are not regular and one or two (of the three or four lamellae present in polysynthetically twinned pyroxenes) terminate abruptly within a crystal independently, without showing any systematic distribution.
4. The twinned grains clearly indicate stress or strain directed at certain portions, and the crystals are not disturbed all along their projected continuation.
5. The gross outer form of the individual grains or the aggregate of twinned crystals also clearly reveals the secondary nature of the pyroxene twinning (Figs. 4–7).

In studying the lamellar twinning in hypersthenes, Henry (1942) distinguishes two types of lamellae:

1. Simple gliding, with only a movement of molecules in one direction, sometimes accompanied by bending round an axis.
2. Gliding resulting in the twinning of the individuals. Similarly the polysynthetic lamellae in the hypersthenes of charnockites have been explained by Naidu (1954) as glide twins.

Thus the twinning in pyroxene is regarded as secondary. Again secondary twinning includes three types, namely:

1. Gliding twins.
2. Transformation twins of Buerger (1945, p. 477) and
3. ‘Synneusis’ twins or the ‘combination’ twins of Ross (1957, p. 650).

The third type is much less widely appreciated and is not reported in pyroxenes in the literature accessible to the authors; but this genetic type is, in our opinion, prominently displayed by the pyroxene twins in the dyke under study. In thin sections examined, isolated twinned grains are rare or absent. Invariably they occur in glomeroporphyritic clusters with twinned individuals in parallel, sub-parallel, or random orientation. It appears that twinning behaviour, crystal habit, and the nature of the crystal boundaries are affected differently by crystallisation (Vance & Gilreath 1967) of pyroxene in an essentially solid medium. The occurrence of pyroxene twins in clusters suggests that the pyroxene crystals drifted together in an essentially fluid medium and combined to form twinned crystals. The abundance of Carlsbad twins in igneous plagioclase is explained by Vance (1961) as due to their development by synneusis, a process operating exclusively in a fluid medium where free movement of crystals is possible.

In addition to synneusis twinning, a second type of secondary twinning has been identified which is the result of gliding in the lattice. Pyroxenes with well-developed deformational fabric show this type of twinning. Existence of stress is indicated by bending, twisting, and fracturing of individual grains and aggregates and by strongly-developed strain shadows, which indicate continuous deformation during crystallisation of the magma. Glide twinning is believed to have formed in order to relieve strain set up during slow cooling and contraction. Under such circumstances the atomic layers in the two sub-individuals of a synneusis twin might yield by gliding and form polysynthetic twins. Since synneusis requires a fluid medium and glide twinning operates under stress, the two processes of formation of secondary twinning are mutually exclusive and cannot have operated simultaneously; in all probability, synneusis was followed by glide twinning.

Free movement of crystals, and thus twinning by synneusis, occurred more readily and for a longer period in the centre of the dyke. It is also presumed that the stress distribution within the dyke has tended or aided production of the same pattern of frequency in glide twinning. Thus, in contrast to the frequency of plagioclase twinning, a progressive increase in the frequency of incidence of pyroxene twinning towards the middle portion of the dyke is accounted for. In proposing the above working hypothesis, the authors are aware of the breadth of the problem and the limitation of the data presented. Consequently the conclusion is tentative and merits scrutiny in the light of more detailed investigation.

ACKNOWLEDGEMENTS. We are deeply indebted to Professors Earl Ingerson, H. H. Hess, R. C. Emmons and Dr. Felix Chayes for kindly going through the manuscript and making suggestions for its improvement.

The help rendered by Mr. G. Sudhakar Rao of the Department of Botany in drawing the figures is deeply appreciated.

29 April 1968

REFERENCES

Buerger, M. J. 1945: The genesis of twin crystals. *Am. Mineralogist 30,* 469–482.

Donnay, J. D. H. 1940: Width of albite-twinning lamellae. *Am. Mineralogist 25,* 578–586.

Donnay, J. D. H. 1943: Plagioclase twinning. *Geol. Soc. America Bull. 54,* 1645–1652.

Henry, N. F. M. 1938: A review of the data Mg. Fe clinopyroxenes. *Mineralog. Mag. 25,* 23–29.

Henry, N. F. M. 1942: Lamellar structure in orthopyroxenes. *Mineralog. Mag. 26,* 179–189.

Ingerson, E. 1952: Twinning frequency in feldspar phenocrysts from a quartz lattite sill at Sierra Blanca, Texas. *Am. Jour. Sci., Bowen Volume,* 189–202.

Naidu, P. R. J. 1954: Minerals of charnockites from India. *Schweizer. min. petr. Mitt. 34:* 2.

Ross, J. V. 1957: Combination twinning in plagioclase feldspars. *Am. Jour. Sci. 255,* 650–655.

Smith, J. V. 1962: Genetic aspects of twinning in feldspars. *Norsk geol. tidsskr. 42,* 244–263.

Vance, J. A. 1961: Polysynthetic twinning in plagioclase. *Am. Mineralogist 46,* 1097–1119.

Vance, J. A. & Gilreath, J. P. 1967: The effect of synneusis on phenocryst distribution patterns in some porphyritic igneous rocks. *Am. Mineralogist 52,* 529–536.