A NOTE ON THE ORIGIN OF BRAZIL TWINS IN LAMELLAR QUARTZ

HARALD CARSTENS

Norges Geologiske Undersøkelse, Trondheim, Norway

CARSTENS, H.: A note on the origin of Brazil twins in lamellar quartz. *Norsk Geol. Tidsskr. 48*, pp. 61-64, Oslo 1968.

The occurrence of Brazil twins in relation to internal morphology and habit is studied. It is shown that the formation of Brazil twins is favoured by rapid growth. The twins are consistently associated with dislocations.

INTRODUCTION

Brazil twins are intergrowths of right- and left-handed quartz chystals, the twin plane being $(11\bar{2}0)$. The blue or violet variety of quartz called amethyst is nearly always twinned according to the Brazil law (Frondel 1962). In fact, some authors think that the criterion for amethyst is not the colour but its characteristic twinned structure. Repeated Brazil twinning also commonly occure in colourless quartz crystals, for example in so-called lamellar quartz, i.e. quartz having a mimetic structure of optically biaxial lamellae (Bambauer, Brunner & Laves 1961). It seems to be rare, however, in quartz characterized by lineage structures. In contrast to the Brazil twins of amethyst, the twins of lamellar quartz are usually confined to the peripheral parts of the crystals. Brazil twins cannot be produced mechanically (Klassen-Neklyudova 1964), and always form by growth processes. The energy of the twin boundary is low (McLaren & Phakey 1966), and twinning would be expected to occur relatively easily. The cause of the initiation of the twins is not known, and the aim of the present note is to contribute towards an understanding of this problem. Lamellar quartz crystals from Madagascar, Switzerland and Norway were at the author's disposal.

OBSERVATIONS

Notwithstanding the hexagonal symmetry of the prism $(10\bar{1}0)$, an apparent threefold growth pattern is commonly rather conspicucous. In accordance with Padurow (1948), let the prism faces below the positive rhombohedra r $(10\bar{1}1)$ be termed m′, and those below the negative rhombohedra z $(01\bar{1}1)$ m″. Then it is usually observed that the surface topography of the faces m′ and m″ is different. For example, m′ may consist of oscillating prism and various

rhombohedral faces, whereas m″ may be covered with vicinal faces, a structure termed 'Riefung' by Padurow. In addition, m' and m'' may respond differently to the attack of etchants. Thus it was found that natural etch pits in some Norwegian crystals were developed on the m″ faces only. The rates of growth of m′ and m″ usually differ. The relative growth rate is easily observed in Dauphine twins, because in crystals twinned according to this law, m′ and m″ are coplanar. The rates of growth of m′ and m″, however, as a rule are much lower than the rate of growth of the rhombohedra ($V_m \ll V_r < V_z$), and the major part of the crystals formed by rhombohedral growth. The growth pyramids of m′, m″, r, and z are usually easily disclosed by X-ray irradiation or by the etching of successive z-cut sections. When colourless quartz crystals are irradiated with X-rays, they generally become coloured (Lell, Kreidl & Hensler 1966). The colour usually varies from one growth sector to another because of the selective adsorption of impurities. The r and the z sectors may become brown or yellow of various shade and intensity, whereas the sectors of m′ and m″ are coloured brown, yellow or violet or remain colourless. Rarely, Brazil twins are revealed by the irradiation colours, a smoky brown colour being selectively distributed in the twins of one hand.

It appears that the Brazil twins primarily occur in the m′ growth sectors, suggesting some influence of surface topography on the nucleation of the twins, Fig. 1. The lamellar structures, on the other hand, seem to be more abundant and more distinctly developed in the m″ growth sectors. The r and the z sectors are usually completely devoid of Brazil twins. The twins commonly nucleated at or near the boundary between the m′ and the r growth sectors. This may be of importance regarding the genesis of the twins. Because even small amounts of structural impurities change the lattice parameters in quartz (Frank-Kamenetskii & Kamentsev 1962, 1966), the transition from r growth to m growth may be considered as epitaxial, or more precisely as autoepitaxial. It is well known (Pashley 1965) that crystals formed by epitaxial growth are very imperfect and contain dislocations, low-angle boundaries, stacking faults and twins.

The effect of habit on the occurrence of Brazil twins is shown by quartz crystals from Hattfjelldal in Northern Norway. Most of the crystals from this locality display a Dauphiné habit. What characterizes this is the predominance of one of the rhombohedral faces, usually an r face, over the other rhombohedra. According to Grigor'ev (1965) this kind of asymmetric growth may be due to the position of the crystal in the gravitational field or to the orientation with respect to the direction of flow of the solutions. The m growth sectors are usually thickest on the same side as the smaller fast-growing rhombohedra. Whatever the conditions which cause some faces to lag behind others during growth, the fact is that the Brazil twinning is always confined to the fast-growing sectors while the sheltered sectors are twin-free, Fig. 1. It is also of interest to note that when Brazil twins occur beneath the z faces, these sectors are usually twinned according to the Dauphiné law. A change from m″ growth to m′ growth is thereby attained.

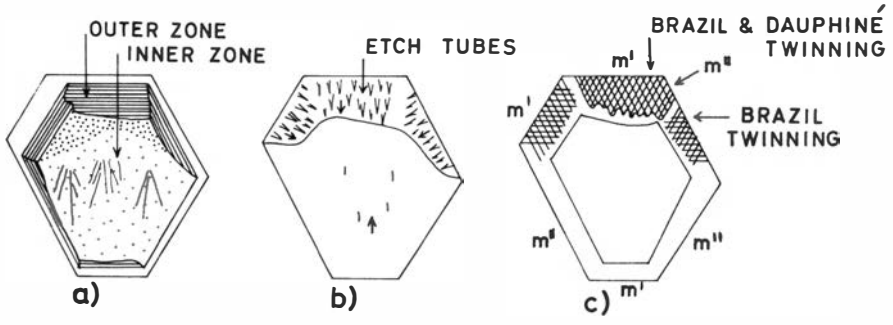

Fig. 1. Basal plane slice of quartz showing the distribution of X-ray irradiation colours (a), dislocations (b) and Brazil twins (c). The Dauphiné habit is revealed by the secretorial distribution of smoky colours in the inner zone. The growth sector of the large positive rhombohedron is light brown. Heavy stippling denotes a dark brownish colour. The outer zone is violet (banded) or colourless. Dark brownish tree-like defects are of unknown origin. The arrows indicate the dip of the dislocations. The V-shaped needles always point towards the base. Hattfjelldal, Norway.

It is commonly observed that inclusions are of frequent occurrence in Brazil twinned regions, and Johnston & Butler (1946) believed that foreign material deposited on a growing surface might induce twinning. On the other hand, the etching of quartz plates shows that twinned sectors always contain a large number of dislocations compared with the twin-free sectors which are commonly poor in dislocations detectable by etch metod, Fig. 2[1].

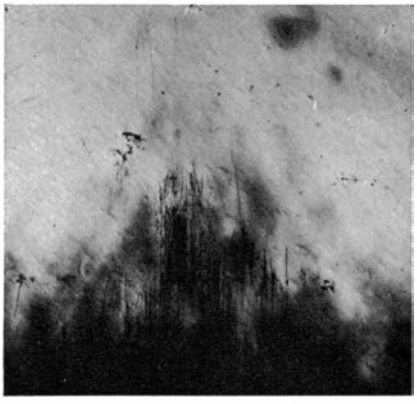

Fig. 2. Etch tunnels associated with triangle-shaped Brazil twins. View parallel to the c-axis in polarized light. Evje, Norway. ×30.

The association of inclusions and dislocations is, however, not surprising because it is known that inclusions in quartz are important dislocation sources (Carstens 1968). Some of the dislocations seem to originate at the twin boundaries and extend from the boundaries almost at a right angle. Schlössin (1965) suggested that the Brazil twins in amethyst nucleated

[1] It has been etablished (Hanny 1964, Lang & Miuscov 1967) that the solution channels produced in quartz by hydrofluoric acid are formed along dislocation lines.

at dislocations emerging on the rhombohedral faces. The rôle of the dislocations in the genesis of the twins described above, however, is not understood but is is clear that a detailed understanding of twin nucleation depends upon considerations of factors which control the formation of the dislocations.

CONCLUSIONS

Any explanation of the origin of Brazil twins in lamellar quartz must be consistent with the following observations:

1. The tendency for twin formation is mainly a property of the m′ surfaces.
2. The formation of twins is sensitive to the speed of growth; rapid growth favouring the nucleation of twins.
3. The twins commonly nucleate near the boundary between the rhombohedral and the prism growth pyramids.
4. Brazil twins are always associated with inclusions and dislocations. However, the occurrence of such imperfections does not necessarily imply that twins are present.

ACKNOWLEDGEMENT

I should like to thank Professor I. Th. Rosenqvist for reading and commenting on parts of the manuscript.

Norges Geologiske Undersøkelse, Postboks 3006, Trondheim, Norway. 6th December, 1967.

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