MINERALOGICAL MAGAZINE, MARCH 1974, VOL. 39, PP. 587–94.

Examples of twinning and parallel growth in zircons from some Precambrian granites and gneisses

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SUMMARY. Growth twins, parallel growths, and necked crystals are described from zircon populations from granitic gneisses from the Precambrian of SW. Greenland. From observations of the distribution of internal growth zones it is concluded that whereas twinning takes place early in the growth history of elbow twins it can occur at any time during crystallization of the zircon. Parallel growth is attributed to a process of synneusis or attachment of zircons that have initially undergone separate growth histories. This implies that viscosity conditions of the rocks were low enough to permit the movement and collision of growing zircon crystals. The common occurrence of zircons with central constrictions, sometimes superimposed on transverse fractures, in zircon suites from the granitic gneisses is explained in terms of late-stage chemical corrosion accompanied by brittle fracturing.

SECONDARY growth features have been observed in zircons from rocks suspected of having an anatectic or metasomatic history (Hoppe, 1959; Harris, 1959; Dalziel, 1963; Poldervaart and Eckelman, 1955; Ozhogin, 1968; Berzina and Sotnikov, 1972). Poldervaart and Eckelman (1955) regarded features such as outgrowths, aggregate crystals, and overgrowths as characteristic of autochthonous granites. Similar morphological features have been observed in the Precambrian granites and gneisses of SW. Greenland and NW. Scotland and it is the purpose of this paper to discuss the origin and implications of three forms: twinned zircons, parallel growths, and necked crystals, which are characteristic of zircons from these rocks.

Twinned zircons. The literature contains very few references to twinning in zircons from common rock types. Hintze (1915, pp. 1638 and 1661) gives an early summary of previous research from which it appears that {101} is the only well-established twin-plane in zircon. More recently Frondel (1940) recorded a few 'knee-shaped' zircons, twinned on {101}, from inclusions in muscovite from a pegmatite zone in the Manhattan schist in New York City. Geniculate twinning in zircons has also been reported from the muscovite-bearing gneisses of southern Guernsey in the Channel Islands (Groves, 1927), from quartzite xenoliths (Schidlowski, 1963), and from a sedimentary rock (Ingham, 1929). To judge from the paucity of records twinned zircon is exceedingly rare in common igneous rock types.

During the course of our geochronological investigations we have observed twinned zircons in gneisses and gneissose granites from the Lewisian of Scotland and the Archaean and Ketilidian of West Greenland. Examples of twinned zircons from these rocks are shown in fig. 1: 1–10. For comparison with these forms a number of views of two twinned zircons from the mineralogical collection of the British Museum (Natural History) are shown in fig. 2. Details of these zircons, from a written communication from Dr. A. C. Bishop, are: BM 86767: Interpenetrant zircon twin from Eganville, Renfrew County, Ontario, Canada. BM 72311: V-shaped contact twin also from Eganville. As far as we can ascertain the locality is likely to be 'Short's claim on the north shore of Lake Clear, Renfrew County' as mentioned by Kunz (1892, pp. 259–60).

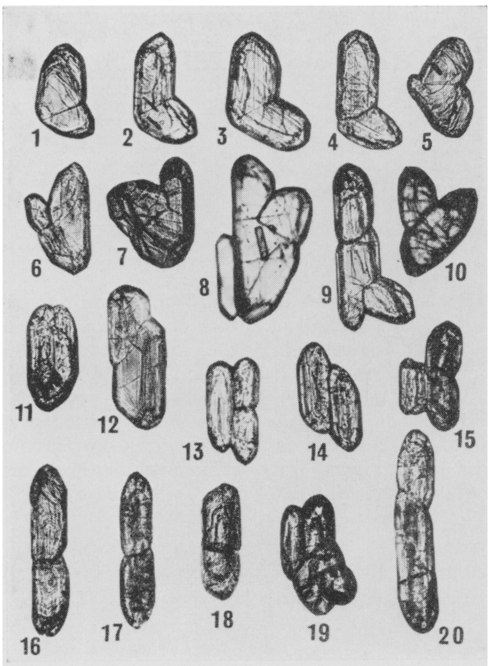

FIG. 1. Examples of twinning, parallel growth, and necked crystals in zircons from Precambrian granite gneisses from SW. Greenland. 1–4: Growth twins of regular habit lying on {100}. These are elbow-shaped forms in which enhanced growth has concentrated along the composition plane {011} tending to eliminate the re-entrant angle. 5–10: Growth twins of irregular habit lying on *a* {100}. These are asymmetrical forms with composition planes {011} partially penetrating prismatic crystals. Enhanced growth where present is concentrated in the direction of the composition plane and tends to fill the re-entrant angle (6, 7, 8) and develop the scalene faces of the tetragonal bipyramid. 11, 13–15: Parallel growths lying on *a* {100} and united along an approximately pyramidal plane. 19 is a composite parallel growth. 16, 17, 18, 20 and 9, 13, 15 show characteristic necked rims. The central constriction transgresses euhedral growth zones in 16.

Typical examples of geniculate or elbow twinning in zircons from the gneisses are shown on fig. 1: 1–4. The composition planes are clearly visible and are perpendicular to {100}, the plane on which the crystals rest. These twins may be described as contact twins, being joined along the composition plane, and can be compared with the geniculate twin some five centimetres in over-all length shown in fig. 2: 9–11.

Examples of a less regular type of twin found in the granites and gneisses are shown in fig. 1: 5–10. Here the crystals are no longer symmetrical about the composition plane. The composition plane itself only partly penetrates the crystal, suggesting an apparent contact twin 'outgrowth' developed on an otherwise untwinned crystal. This development is comparable to the very fine example from the British Museum shown in fig. 2: 1–8, although the museum example has *m* {110} rather than *a* {100} as the prism.

The majority of twinned crystals, with *a* {100} as the dominant prism, show enhanced growth in the direction of the composition plane, which tends to fill in the re-entrant angle (e.g. fig. 1: 1). This is clearly shown by growth zones, seen in many of the twinned zircons, which are distinctly broader in the direction of enhanced growth (fig. 3: 1–2). Associated with enhanced growth is a change in crystal habit, well shown in fig. 1: 6–8, where the scalene faces of the tetragonal bipyramid can be seen to have developed at the expense of the prism faces.

Measurement of the angle between the extinction directions for the two arms on all types of twins fell within the range $113.5 \pm 2^\circ$. This is in good agreement with the angle of 114.3°, calculated for zircons twinned on {101} (Kostov, 1968), which is {112} of Berry and Mason (1959). It was also possible to confirm the twin law, using the relationships of Caruba and Turco (1971), from direct measurements of the angles between faces and the composition plane on a number of grains from the grain mounts.

A number of the zircons illustrated by Berzina and Sotnikov (1972, fig. 1) and by Harris (1959) resemble the twinned crystals shown in fig. 1.

Formation and growth of the twinned zircons. Evidence for the growth history of the twinned zircons can be gathered from the morphological expression of the crystals and from the fine euhedral growth zones evident in many of the twinned forms, especially those from the Archaean 'autochthonous' granite from north of Frederikshåbs Isblink in West Greenland (Hopgood, in press).

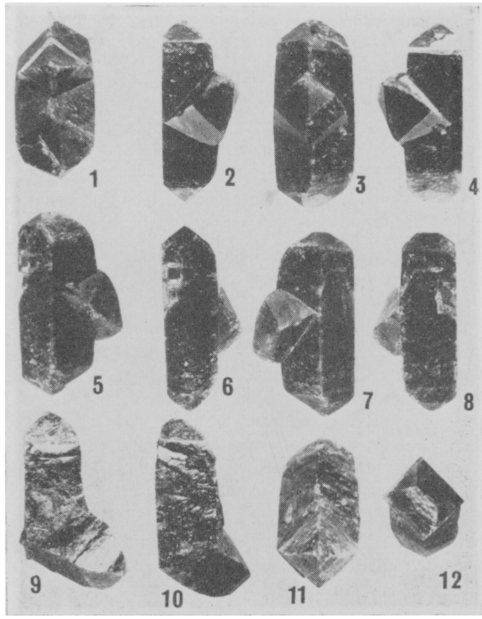

FIG. 2. Examples of twinned zircon crystals from Eganville, Ontario, Canada, from the mineralogical collection of the British Museum (Natural History). 1–8, 12: Twins of irregular habit with *a* {110} as the prism plane and {011} as composition plane (BM 86767). 9–12: Twins of regular habit. Elbow-shaped twin with {011} as composition plane. Shows incipient enhanced growth in the re-entrant angle (BM 72311).

An example of a contact twin with euhedral growth zones is shown in fig. 3: 2. In this crystal a continuous series of growth zones are symmetrically arranged around the composition plane. As far as can be determined optically the first, or innermost, zone is twinned suggesting that the crystal developed initially, or very early in its growth history, as a twinned crystal. In contrast to this fig. 3: 1 shows a twinned zircon with a different history of development. In this crystal the fine growth zones can be traced inwards to a central untwinned section indicating that the zircon grew originally as an untwinned crystal and at a later stage in its growth history a simple twin developed.

In general the twinned crystals were of the average grain size of the population. Only in the population from the Ketilidian Anticlinal granite (van Breemen *et al.*, in press) was there any suggestion that the twinned crystals were significantly larger than the average.

From the examination of growth zones it is evident that whereas twinning takes place very early in the growth history of elbow twins it can occur much later, possibly at any time, during crystallization of the zircon. This, together with the low over-all concentrations of twins, suggests that conditions favourable to twin formation developed locally (within an environment that was generally favourable). Such 'growth twinning' could take place in response to changes or interruptions in the physical and chemical environment or as a consequence of crystal orientation (Donnelly, 1967; Carstens, 1968).

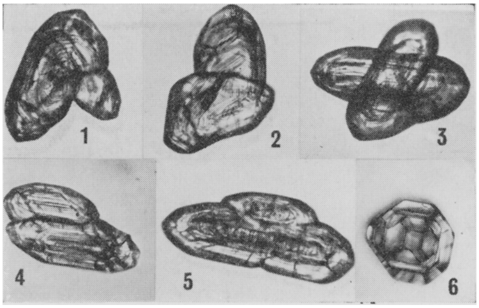

FIG. 3. Examples of internal structures in parallel growths and twins of zircon, photographed by N. Welsh, National Engineering Laboratory, East Kilbride. 1—Initial prismatic crystal shows concentric euhedral growth zones and the later development of an irregular growth twin. The composition plane forms at a later stage in crystal growth. 2—Euhedral growth zones suggest very early or initial development of the zircon as a twin. The composition plane starts from near the crystal nucleus. A rod-shaped inclusion is seen to interrupt the regular growth pattern. 3—Apparent cruciform twin is composed of two anhedral zircon cores united by the subsequent growth of twinned zircon. New zircon growth is concentrated in the re-entrant angle. 4—Concentric growth zones surround central cores in each of two zircon crystals united by subsequent growth of clear zircon. The core of the smaller crystal is broken across the growth zones. 5—Parallel growth; shows distinct cores in both united crystals. Subsequent zircon growth is clearly shown by the concentric pattern of growth zones. 6—Basal grain showing change in crystal habit with growth. Radial and tangential fractures indicate internal strain. By reference to pyramid-bearing crystals it can be shown that {110} is developing as the dominant face over {100}. This is in accord with observations by Pupin and Turco (1972) on zircons from granites.

It is difficult to envisage growth of delicate euhedrally zoned twinned zircons, especially in some of the fine elbow twins (fig. 3: 2), in an essentially 'solid state' metamorphic environment. Rather it is suggested that such forms indicate fluid magmatic conditions and, indeed, Silver (1969) has used the presence of euhedral zones in zircons as a criterion of a magmatic history.

Parallel growth. The term parallel growth is used here to describe two or more zircon crystals joined in parallel arrangement and showing essentially parallel extinction. In this context parallel growth is a purely descriptive term and is not meant to imply any particular mode of origin for these forms. Such composite zircon crystals have been referred to as 'aggregate crystals' by Poldervaart and Eckelmann (1955) and have been observed by Harris (1959) and Poldervaart and von Backström (1950). During our geochronological investigations of zircon U–Pb systems over the last four years we have recognized parallel growth in zircons from granitic gneisses and 'autochthonous' granites from the Archaean and Ketilidian of West Greenland and the Lewisian of Scotland. The proportion of parallel growths in the zircon populations from these rocks varies considerably from rare examples in some gneisses to a maximum of 0·1 to 0·5 % in an Archaean granitic gneiss from north of Frederikshåbs Isblink in West Greenland, described by Hopgood (in press). We have also found a broad correlation between the concentration of parallel growths and the abundance of twinned crystals in any one zircon population. From our wider examination of zircons from igneous as well as metamorphic rocks we have reached the conclusion that parallel growths as described here are rare among zircons from igneous intrusive granites.

Examples of granitic-gneiss zircons showing parallel growth are shown in fig. 1: 8, 11–15 (photos from grain mounts). Grain 8 on this figure is a combined growth twin and parallel growth.

Two kinds of parallel growth have been recognized: *Resting on a* {100}. Within the limitation of our measurements these have parallel extinction. *c*-axes are therefore essentially parallel (fig. 1: 8, 12, 14, 15). *Resting on m* {110}. These are less common and tend to extinguish a few degrees apart. The slight divergence between *c*-axes may be seen by eye (fig. 1: 12). Parallel growths resting on *a* {100} are invariably attached by their prism faces whereas those seen resting on *m* {110} show a tendency to unite along a line approximating that of the pyramid (fig. 1: 12, 19). A maximum variation of approximately four to five degrees was observed in the extinction positions of the 'attached' crystals.

The common association of growth twins with zircon showing parallel growth suggested to us initially that parallel growth itself was a form of growth twin. More detailed observations on the planes of attachment, the morphology of central zircon cores, and the relationship of growth zones has convinced us, however, that this is not the case. The composition plane of the growth twins shown on fig. 1: 1–5 is a clearly defined straight line. The plane of attachment of the crystals joined in parallel growth is irregular (fig. 3: 4, 5) and orientation of the *c*-axes is not always strictly parallel. Also it is generally observed that each separate 'crystal' of a parallel growth has a central zircon core (fig. 3: 4–5). The presence of concentric growth zones around the individual cores (fig. 3: 4) rather than growth zones symmetrically distributed across the plane of attachment provides a strong argument for rejecting growth twinning as an origin for parallel growths.

Poldervaart and von Backström (1950) described aggregates of attached zircons, somewhat similar to the parallel growth forms described here, and suggested that such originated through the mechanical breakdown of zircon crystals and the subsequent reunification of the pieces by additional growth during metamorphism. Dislocation followed by attachment (where initial dislocation could have been related to a process of 'necking' as described in the next section) could explain the complex form shown in fig. 1: 12, where a translucent core is offset in a subsequent growth of clear zircon, and for the example shown in fig. 1: 19 which appears to be a dislocated double crystal. The close optical alignment of these attached forms introduces a difficulty, however, as it requires that major disruption of the crystal followed by reattachment by new growth has taken place in such a way as to maintain a parallel alignment of the *c*-axes. In the 'double' crystals shown in fig. 3: 4, the core of the smaller attached crystal is broken across the internal growth zones whereas in the companion crystal the internal zones appear complete. It is argued that this form cannot represent a single original crystal that has been broken and rejoined. Careful inspection of zonal patterns, where they could be seen in crystals showing parallel growth, has not revealed a single case that could be explained unequivocally in terms of dislocation followed by reattachment.

Poldervaart and Eckelmann (1955), in a study of zircons from autochthonous granites, suggested that parallel growth could have formed by 'the bonding of two or more crystals by new zircon growth'. This mechanism is not unlike that described as synneusis by Vogt (1921) and discussed in detail by Vance (1969). Vance describes synneusis as 'a process of drifting together and mutual attachment of crystals suspended in a melt. This process is episodic, is most characteristic of the earlier stages of consolidation, and appears to be related to magmatic turbulence.'

Parallel growth, as observed in the present zircon suites, fits the requirements of a synneusis structure as the attached crystals can be shown to have had a history of separate development and to have reached a relatively large size 'at the time of initial contact'. The double crystal shown on fig. 3: 4 consists of two independent cores, one broken across the growth zones, subsequently attached in parallel growth. In fig. 3: 5, showing a smaller crystal attached to a larger, each crystal has a separate subhedral core surrounded by concentric growth zones which indicate separate initial development. Detailed examination of the growth zones reveals that growth continued after the attachment of the crystals in parallel orientation. The growth zones from here on are reflected across the plane of attachment in a relationship very like that observed in a growth twin. Vance (1969, fig. 5B) shows a sketch of a form strikingly similar to that shown in fig. 3: 5. He calls this a synneusis twin. He explains this as initial synneusis (coming together) followed by continued crystallization during which the two individuals became intergrown as a penetration twin. He also notes that during subsequent growth the boundaries between the two crystals tend to be extended in the direction of the enlargement of the most rapidly growing face. This observation could equally well be applied to the crystal in fig. 3: 5. Fig. 3: 3 shows what appears to be a cruciform zircon twin with the twin plane clearly expressed as a straight line. However, careful examination shows that each arm of the 'twin' possesses a large central zircon core. One possible explanation for this very rare form is that the two cores met and, either through chance or some realignment, the angle of contact was precisely that which could allow attachment of the cores through the additional growth of twinned zircon. This growth is typical of that already described for twinned zircons in that enhanced growth is evident along the composition plane tending to fill in the re-entrant angle. In this way such a form can be envisaged as a combination of synneusis and late growth-twinning.

The general parallel orientation of 'zircon parallel growths' itself requires explanation. Possible mechanisms proposed by Vance (1969) to explain preferred orientation in crystals attached by synneusis involve minimizing of interfacial energy by rotation of crystals after contact, or random collision with only those crystals adhering that are in the preferred orientation, or 'long-range' forces orienting crystals before contact.

Vance (1969) concluded, from the experimental evidence of Gaubert (1896), Viola (1902), and Shaskolsky and Schubnikov (1933), that turbulence is necessary to bring the crystals into contact. Orientation, by one or other of the above processes, followed by deposition of new zircon would then result in typical parallel growths. In our view the sinking of growing zircon crystals of different sizes under gravity (in approximately horizontal orientation) could also be an important means of bringing zircons into contact along their prism faces.

Necked crystals. A third form characteristic of zircon suites from the Precambrian gneissic granites studied by us is called here a necked crystal. This is expressed as a concentric constriction or embayment frequently associated with a distinct line of fracture. Examples of this form are shown in fig. 1: 8, 13, 15, 16–20. Harris (1959, fig. 4, No. 47) records a similar form from a zircon suite from a granitic gneiss from the Beartooth Mountains in Montana.

From the cross-cutting relationship of the constriction to the growth zones, clearly shown on fig. 1: 16, it is evident that necking takes place late in the growth history of the zircon. In some cases central dislocations appear to be accompanied by slight displacement (fig. 1: 19, 20) though uniform optical extinction is maintained. Larsen (1955) reported that 'multiple fracturing across long prismatic zircons shows micro-boudinage structures with rounding of the broken ends'. Poldervaart and von Backström (1950) also suggested that similar forms could be due to ultra-metamorphism resulting in granulation and recrystallization of the zircons. In some cases (fig. 1: 13, 15) a central constriction is seen to affect only one of an aggregate of two or three grains in parallel growth. This could indicate that formation of the aggregate crystals occurred after one crystal had undergone a 'necking process'. Alternatively the constriction could have post-dated the formation of the double crystals (fig. 1: 13) but been restricted to one crystal of the aggregate. This would suggest that mechanical fracturing and boudinageing had not occurred but that a process of corrosion was largely responsible for the constriction. From our present observations we consider that a late-stage chemical corrosion, frequently associated with brittle fracturing, is the most plausible explanation of the necked crystal forms.

Oval-shaped zircons, which have been observed by us in zircon suites from high-grade metamorphic rocks (Pidgeon and Aftalion, 1973), could represent the end product of a process of chemical corrosion. Such zircons have been interpreted as sedimentary (e.g. Verspyck, 1961; Chowdhary, 1971) although Kalsbeek and Zwart (1967) and Silver (1969) attribute such round forms to metamorphic processes.

The relationship of the described forms to the host rocks. It is argued that the fine euhedral growth zones in the twinned zircons indicate crystallization from a melt rather than recrystallization under solid state conditions.

Our explanation for parallel growth in terms of synneusis or coming together of zircons that have undergone separate initial growth histories also implies a magmatic condition for the rock during crystallization. The rarity of twinning and parallel growth in zircon from magmatic granites (with which we are familiar) is therefore somewhat puzzling. Clearly other factors besides melt conditions are necessary for the formation of parallel growths and twins of zircon. Sudden variations in the rate of crystallization, for instance, could be responsible for twin formation. Also a high proportion of zircon xenocrysts in the melt could induce early zircon crystallization leading to the formation of parallel growths.

The presence of these 'igneous zircons' in gneisses and autochthonous granites is attributed to the resistance of zircon to chemical attack during metamorphism. Partial dissolution of zircon, indicated by rounded surfaces and necked crystals, is most probably due to chemical corrosion during the gneiss-forming (and granite-forming) events.

Acknowledgements. We are indebted to Dr. A. A. Moss for permission to publish photos of twinned zircons from the mineralogical collection of the British Museum (Natural History). We are also grateful to the Geological Survey of Greenland for photographic assistance. We wish to acknowledge the photographic section of the National Engineering Laboratory for the preparation of composite photographs and Mr. N. Welsh in particular for photomicrographs showing internal features of selected zircons.

Dr. F. Kalsbeek and Dr. A. C. Bishop kindly criticized the manuscript. This work is published with the permission of the Director, the Geological Survey of Greenland.

The Isotope Geology Unit of the Scottish Universities Research and Reactor Centre is supported by the Universities of Scotland and N.E.R.C. research grant.

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Manuscript received 10 January 1973]