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Deformation in the Revenue granite pluton, Mount Isa Inlier, Australia

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Abstract

The Revenue granite pluton in the Mary Kathleen Zone of the Mount Isa Inlier, Queensland, has a complex internal structure due to the interference of two Early-Proterozoic phases of ductile deformation. The granite intruded into calcsilicates dated at 1780–1760 Ma. A D_1 shape fabric, which is present throughout the pluton, is due to intense deformation in a low angle high strain zone, probably associated with a regional phase of crustal extension. A D_2-event of intense E-W shortening around 1550 Ma caused folding of the early shape fabric in the granite, and tight folding of bedding in the country rock. The present dome-shape of the pluton is mainly an effect of non-cylindrical D_2 folding.

Introduction

The central Mount Isa Inlier, Queensland, is characterised by elongate N-S trending belts of Proterozoic rocks, each with a distinct stratigraphic content and metamorphic grade, separated by faults and shear zones (Blake 1987). One of these belts in the central part of the inlier, the Mary Kathleen Zone, was studied in detail as part of the Mount Isa Geotraverse Project of the Australian Bureau of Mineral Resources (Fig. 1; Passchier 1986b, Passchier in press). This paper deals with the complex internal structure of the Revenue granite pluton in the Mary Kathleen Zone, and its relationship with structures in the wall rock.

The Mary Kathleen Zone is a 13 km wide N-S trending zone of medium grade metamorphic rocks (Blake 1987, Reinhardt 1990). Calcsilicates and amphibolites of the Corella formation (Carter et al. 1961), overlie sandstone, felsic volcanics and metabasalt of the Ballara, Argylla and Magna Lynn formations (Fig. 1; Blake 1987). These formations belong to Cover Sequence 2 of Blake (1987) and aredated at 1790–1760 Ma. In the east, the Mary Kathleen Zone is separated from an Eastern Fold Belt, which contains other formations of a similar age but different lithology (Blake 1987; Loosveld 1989), by the brittle Pilgrim fault zone (Fig. 2). To the west it is separated from the Kalkadoon-Leichhardt Belt by a ductile high-strain zone, the Shinfield Zone (Figs 1 and 2). The Kalkadoon-Leichhardt Belt consists of basement and Cover Sequence 1 rocks (all older than 1850 Ma; Blake 1987), overlain by Cover Sequence 2 rocks (Fig. 2).

A number of granite plutons and complex granite-gabbro plutons intruded the Mary Kathleen Zone. One of these plutons, the Burstall Granite, has been dated at 1760–1730 Ma (Page 1983). The plutons are deformed, and contain much information on the local structural evolution. One of them, the Revenue pluton, was therefore selected for a detailed study.

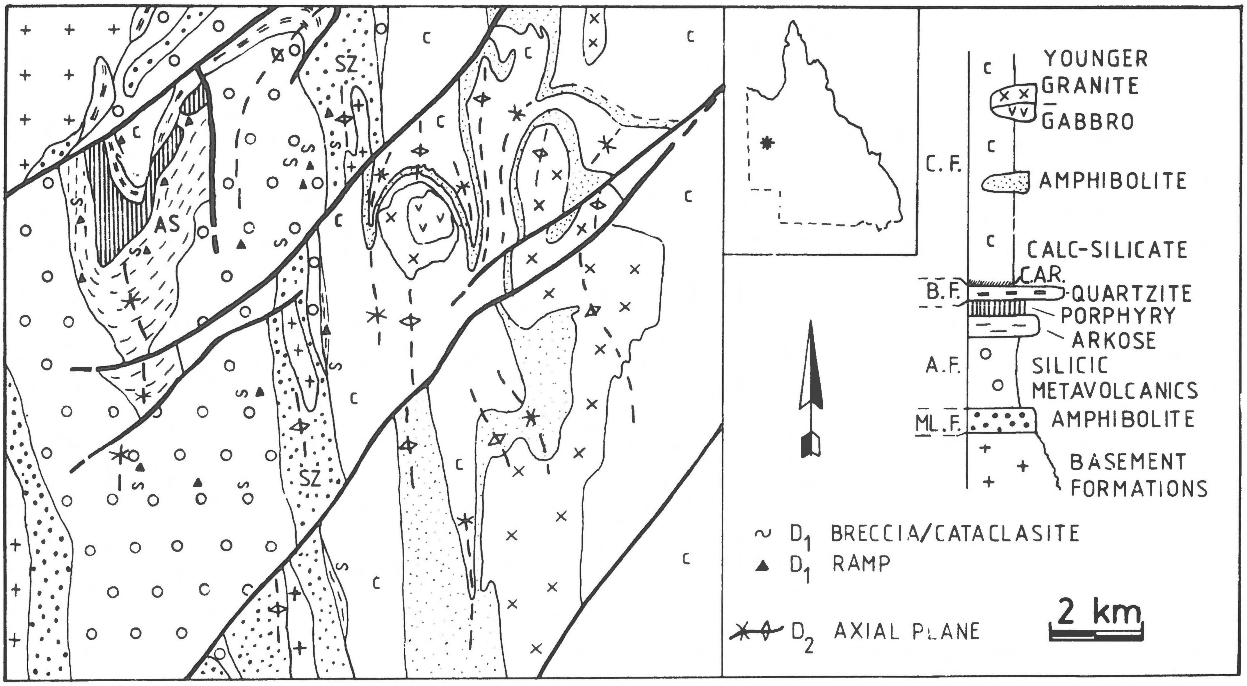

Fig. 1. Schematic geological map of part of the central Mount Isa Inlier, Queensland; C.F. – Corella Formation; C – calcsilicates, Corella Formation; B.F. – Ballara Formation; A.F. – Argylla Formation; ML. F. – Magma Lynn Formation; C.A.R. – Cordierite-Anthophyllite rock; SZ – Shinfield Zone; AS – Alligator syncline. Centre of the map at 21°15′S – 139°50′E.

Revenue pluton

The Revenue pluton is an elongate N-S trending body, 13 km long and up to 3.5 km wide, 6 km north of the town of Duchess. The pluton intruded calcsilicates and amphibolites of the Corella formation (Figs 2 and 3), dated at between 1780 and 1760 Ma (Blake 1987, Loosveld 1989). The calcsilicates consist of K-feldspar, scapolite, carbonate, hornblende, diopside, grossular and allanite (cf. Carter et al. 1961) with a well developed layering of silicate rich competent and carbonate rich incompetent beds.

The Revenue pluton has a core of homogeneous medium-grained biotite granite which gradually passes into a rim of coarse leucogranite up to 200 m wide. The mineral composition of the biotite granite is quartz, K-feldspar, plagioclase, biotite and accessoric hornblende, epidote and scapolite. Quartz and feldspars have a polygonal grain fabric, and commonly show undulous extinction. Subgrain structures are locally present in quartz. Randomly oriented myrmekite and albite rims to plagioclase are common. K-feldspar shows microcline twinning and lens-shaped microperthite lamellae. Sericite is locally seen to replace plagioclase. Biotite is locally replaced by albite and chlorite. The leucogranite consists of quartz, K-feldspar, plagioclase and minor biotite. Quartz grains are up to 5 mm in diameter, with undulous extinction and equidimensional subgrains. K-feldspar and plagioclase are equidimensional with straight grain boundaries and are weakly deformed. K-feldspar displays microcline twinning and lacks perthite-lamellae. Sericite growth over feldspars is common.

Along its eastern and western margins, the Revenue pluton has steeply west-dipping contacts with the country rock, except in a kilometre scale double fold on the western side, where gentle dips occur (Fig. 3). The granite is clearly intrusive; granite veins are injected into the country rock, usually parallel to layering, and xenoliths of country rock material in the granite are common. The overall shape of the pluton shows, that intrusion occurred subparallel to stratigraphic layering in the Corella calcsilicates; even though deformation of the contact zone is locally strong, the contact of the pluton generally follows the trace of the layering in the host rock (Fig. 3). Granite sills of the same age with similar contacts have been found further north in the Mary Kathleen Zone (Holcombe et al. 1987). The country rock has been altered in a rim of up to 500 m wide around the pluton; calcsilicates have lost their distinctive layering and are invaded by diopside and grossular-rich veinlets, up to 3 mm wide and several tens of cm long. Since peak regional metamorphism postdates intrusion, no information can be obtained on the nature of contact metamorphism.

Deformation in the Revenue pluton

D_1

In the Revenue pluton, a penetrative D_1 shape fabric is developed. This fabric is usually planar (S_1), sometimes planar-linear and rarely linear (L_1) (Fig. 4a). Xenoliths have been flattened parallel to the D_1 shape fabric. In thin section, the shape fabric is characterised by polycrystalline lenses and ribbons of quartz or feldspar, in which all minerals approach a polygonal equilibrium fabric.

D_1 shape fabric geometry and orientation is distributed in a rather irregular way over the pluton (Figs 3 and 5). In general, the shape fabric is parallel to the contacts of the pluton and to the layering in the calcsilicates (Fig. 3). Where linear fabrics or fabric elements are present, mainly in the central part of the pluton, they are dominantly W-plunging (Figs 3 and 5). The country rock adjacent to the pluton is strongly deformed in most places, as indicated by attenuated and isoclinally folded layering in the calcsilicate rocks and folded diopside-grossular veinlets around which bedding has been flattened. L_1 stretching lineations in the country rock are parallel to isoclinal fold axes and to L_1 in the granite. Deformation intensity invariably decreases outwards from the pluton. Foliation boudinage and boudinage of competent amphibolite

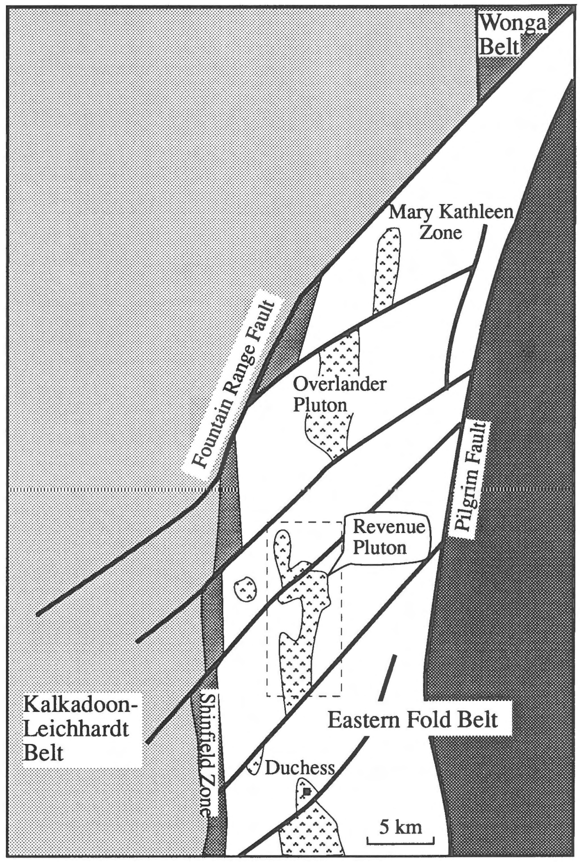

Fig. 2. Schematic map of major lithologic and tectonic units in the central Mount Isa Inlier. Square indicates position of Fig. 3.

layers (Fig. 4b) is common in the deformed calcsilicates on the eastern side of the pluton in the contact zone, with boudin axes subparallel to L_1. Noncoaxiality of progressive deformation can locally be proven for D_1 by foliation deflection in the country rock or along minor shearzones in the granite and by the geometry of sheath folds with a dominant monoclinic shape-geometry in sections parallel to L_1 and normal to S_1 (Passchier et al. 1990 – p 57). However, no consistent dominant shear sense can be found over the granite, and no shear sense domains can be defined.

Late pegmatite veins invaded the granite and the country rock. The D_1 fabric is cut by these pegmatites and the veins are locally folded by D_2. The pegmatite veins are probably associated with the neighbouring Myubee granite pluton which postdates the D_1 fabric (Passchier 1986b, in press).

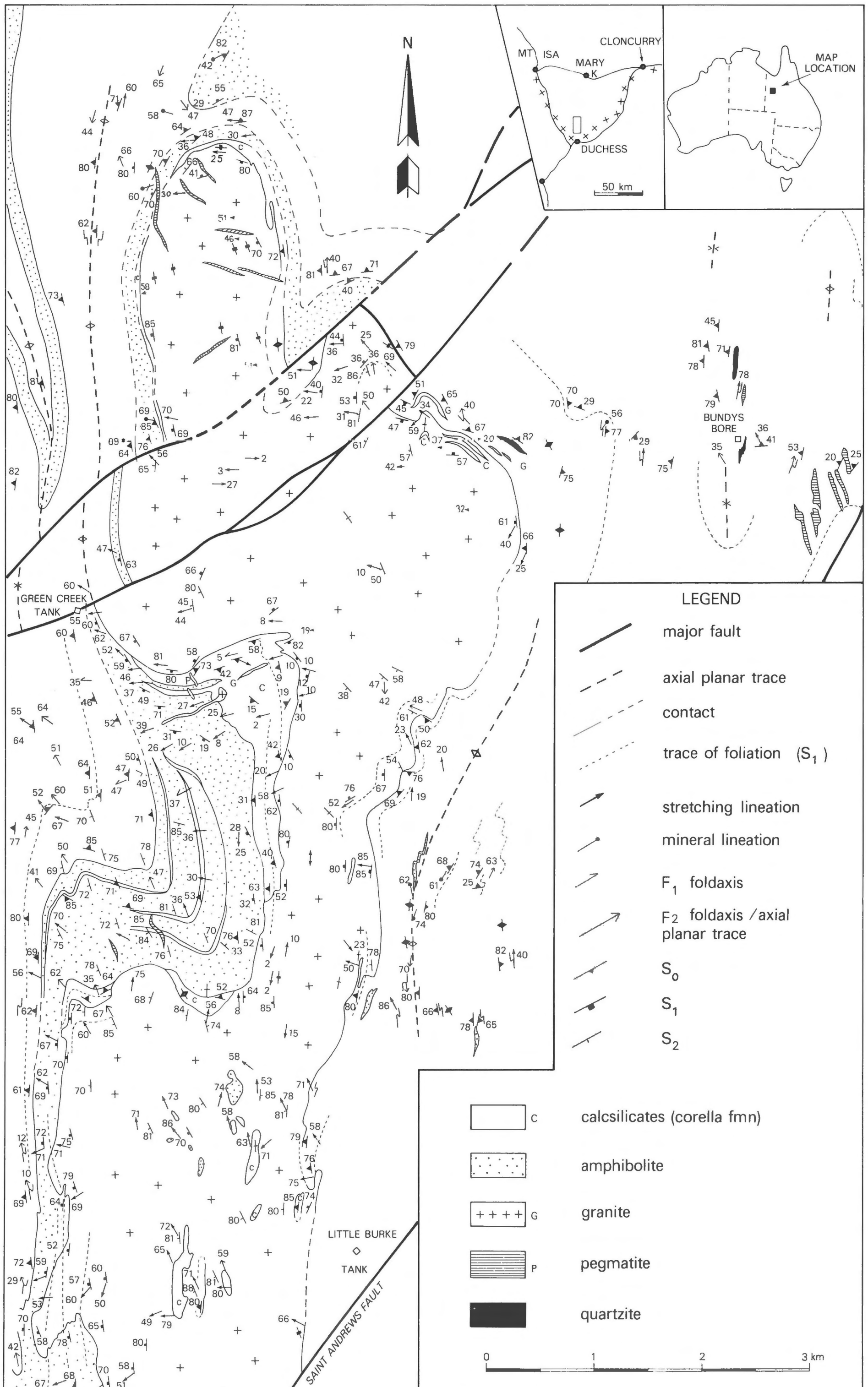

Fig. 3. Map of the Revenue pluton, central Mary Kathleen Zone.

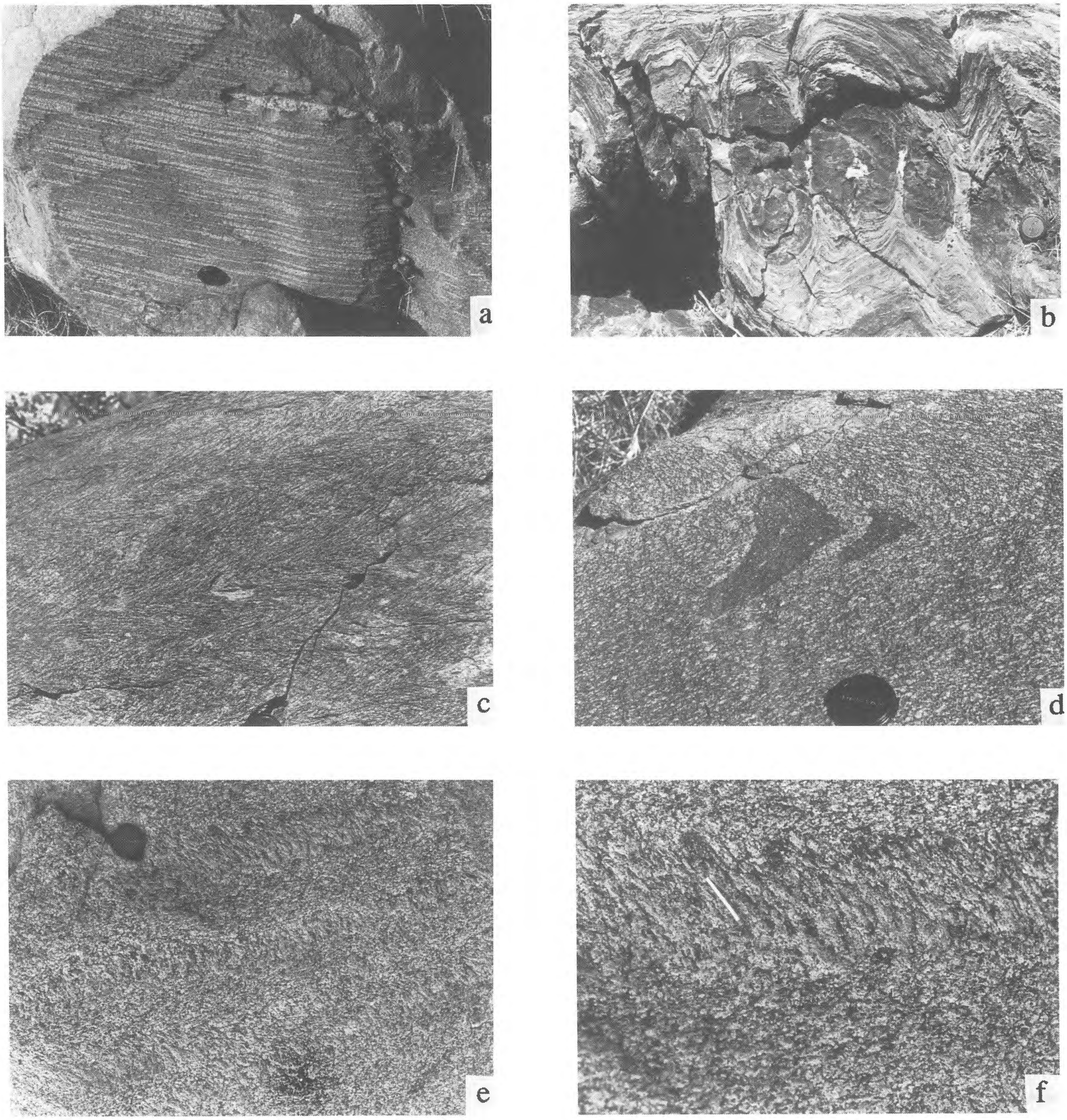

Fig. 4. (a) L_1 stretching lineation affected by open D_2 folding in biotite granite; northern Revenue pluton; (b) D_1-boudins of amphibolite layers in calcsilicate, shortened by D_2. Eastern contact Revenue pluton; (c) tight D_2 chevron folding of S_1 in granite – central Revenue pluton; (d) D_2-folding of xenoliths which had previously been flattened by D_1. S_1 is locally visible in surrounding biotite granite, but transposition errased it in fold hinges. Eastern contact Revenue pluton; (e) 'dot-stripe' pattern on horizontal outcrop surface; this is caused by D_2 folding of an L_1 linear shape fabric with foldaxis parallel to the outcrop surface; central Revenue pluton; (f) as e, enlarged. In a-e lens cap for scale – 5 cm. Match in (f) – 4.5 cm.

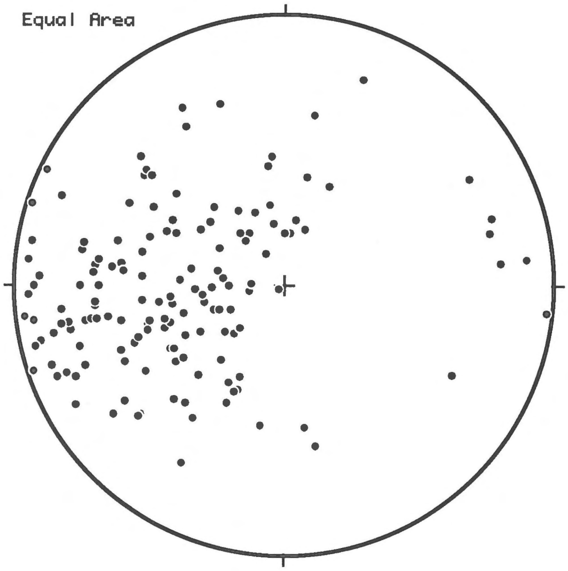

Fig. 5. Orientation of L_1-stretching lineations in the Revenue pluton. Equal area projection.

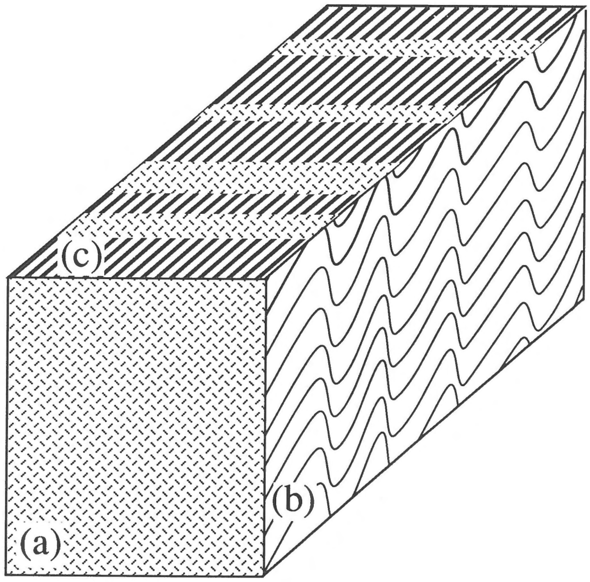

Fig. 6. Interference patterns of L_1 folded by D_2 as observed in the Revenue pluton. (a) surface normal to L_1 showing a structureless fabric similar to undeformed granite; (b) folded lineation as seen on surfaces parallel to L_1; (c) interference pattern as observed on horizontal pavements.

D_2

The D_1-fabric in the pluton is overprinted by a phase of ductile deformation (D_2) which caused extensive folding of S_1 and L_1 (Fig. 4a, c, d). Folds are usually open to tight chevron-type with a wavelength of 10–30 cm (Fig. 4c). Tightening of the folds coincides with disappearance of S_1 in the hingezones (Fig. 4d). With further tightening, a continuous S_2 foliation appears axial planar to folded flattened xenoliths. Development of S_2 in the fold limbs occurs by complete transposition of S_1 to a N-S trending steeply dipping shape fabric in leucogranite and a biotite foliation in biotite granite. Steeply plunging stretching lineations, formed by transposition of L_1, are locally associated with S_2. D_1-boudins in the short limb of D_1 folds in the eastern contact of the granite (Fig. 3) have been shortened (Fig. 4b) during D_2. Where a linear L_1-shape fabric was developed, an interesting interference pattern can be observed (Passchier et al. 1990 – p 93). Folded fabrics dominate on steeply dipping outcrop surfaces (Figs 4c and 6b) and a curious 'dot-stripe' pattern occurs on horizontal pavements parallel to D_2 foldaxes (Figs 4e, f and 6c). The latter resembles a foliated rock transected by undeformed granite veins (Fig. 4e, f) but results from intersection of a folded stretching lineation by the outcrop surface, parallel to the fold axis (Fig. 6). Wherever the linear fabric lies normal to the outcrop surface, the fabric resembles undeformed granite (Fig. 6a).

Axial planes of D_2 folds have a variable orientation over the pluton from subvertical N-S trending in the northern and southern parts to steeply SW dipping in the central narrow part (Fig. 3). D_2-foldaxes generally plunge north in the pluton. Major D_2-folds in the surrounding Corella calcsilicates indicate that the entire Revenue pluton is affected by km-scale synforms and antiforms associated with the small-scale folding and transposition of foliations described above (Fig. 1, 3; Passchier, in press).

D_2 is dated at around 1550 Ma (Blake 1987, BMR 1990), and has been recognized over large parts of the Mt Isa Inlier (e.g. Bell 1983, Blake et al. 1984, Blake 1987, Loosveld 1989). It is synchronous with the peak of regional medium-grade metamorphism (Reinhardt 1990). Extensive static recrystallization of scapolite, diopside and hornblende in calcsilicate rocks indicates that these conditions outlasted D_2.

D_3

Brittle transcurrent faulting caused dextral displacement of segments of the Revenue pluton (Figs 2 and 3). The fault zones are up to 30 m wide and rich in vein quartz which is often affected by the cataclasis. Quartz veins occur in the country rock up to several hundreds of metres away from the main faults. Similar fault systems have been dated at approximately 1480 Ma elsewhere in the Mt Isa Inlier (Blake 1987).

Deformation in the country rock

In calcsilicates and metadolerites of the Corella formation, D_2 is the dominant phase of deformation, producing strongly non-cylindrical folds on a cm-km scale (Figs 1 and 3) with steeply west-dipping axial planes and gently N or S plunging foldaxes (Bultitude et al. 1982, Blake et al. 1984, Passchier 1986b). In amphibolite, an S_2 axial planar foliation defined by a preferred orientation of hornblende and biotite is usually developed. In calcsilicates S_2 is locally developed as a 1–5 cm spaced cleavage in competent beds (Passchier 1986b).

Structures predating D_2 in the Corella formation are restricted to relics of an early shape fabric which mainly occurs around the Revenue pluton. As in the granite, the linear and planar elements are oriented subparallel to the contact of the granite with the country rock, and the deformation intensity rapidly decreases away from the pluton; 500 m away from the contact, the early fabric is absent. As in the granite, the early shape fabric is folded by D_2. Gently plunging stretching lineations of pre-D_2 age do also occur along the western edge of the Mary Kathleen Zone, in the Shinfield Zone (Fig. 1; Passchier 1986a, b, Passchier & Williams 1989) and in the Wonga Belt which is considered to be the northern extension of the Shinfield Zone (Holcombe et al. 1987). These lineations are always N-S trending and occur in basement gneiss and in rocks of the Argylla and Magna Lynn formations (Passchier 1986a, b, Passchier & Williams 1989).

Deformation conditions in the granite

Reinhardt (1990) has estimated metamorphic conditions in the northern Mary Kathleen Zone at 580–640° C and 4 kbar during D_2. The microfabric in the Revenue pluton is in agreement with such conditions. The presence of microcline twinning in polygonal K-feldspar confirms that the shape fabric was produced above the orthoclase inversion temperature (Stel 1984). The absence of melt-related deformation structures (Hibbard 1987) indicates that metamorphic conditions were below the granite solidus. D_2 fold closures display a polygonal, strain free fabric of quartz, plagioclase and K-feldspar. Folded xenoliths of calcsilicate in the granite have a polygonal microstructure of K-feldspar-scapolite-calcite-diopside-hornblende-allanite, usually all strain-free. Undulous extinction and subgrain structures present in some quartz and feldspar grains may be due to D_3.

Metamorphic conditions during D_1 are difficult to assess due to the high-grade overprint during and after D_2. However, D_1-fabric elements can give a rough indication. Brittle structures are notably absent during D_1, except possibly in boudin necks in amphibolite layers. Deformation is relatively penetratively distributed over the granite, without the concentration into narrow shear zones which is so characteristic of low-grade deformation in granitoid rocks (White et al. 1986, Gapais 1989). The absence of feldspar augen in the granite in the presence of a strong linear shape fabric is also noticeable. In domains where the effect of D_2 is weak (Fig. 4a), the D_1 shape fabric consists of oblong ribbons of recrystallised feldspar, alternating with quartz ribbons. Even in the case of extensive static recrystallisation of feldspar, it is unlikely that the general shape of feldspar augen would have been destroyed. It is therefore likely that both plagioclase and K-feldspar deformed ductilely during D_1

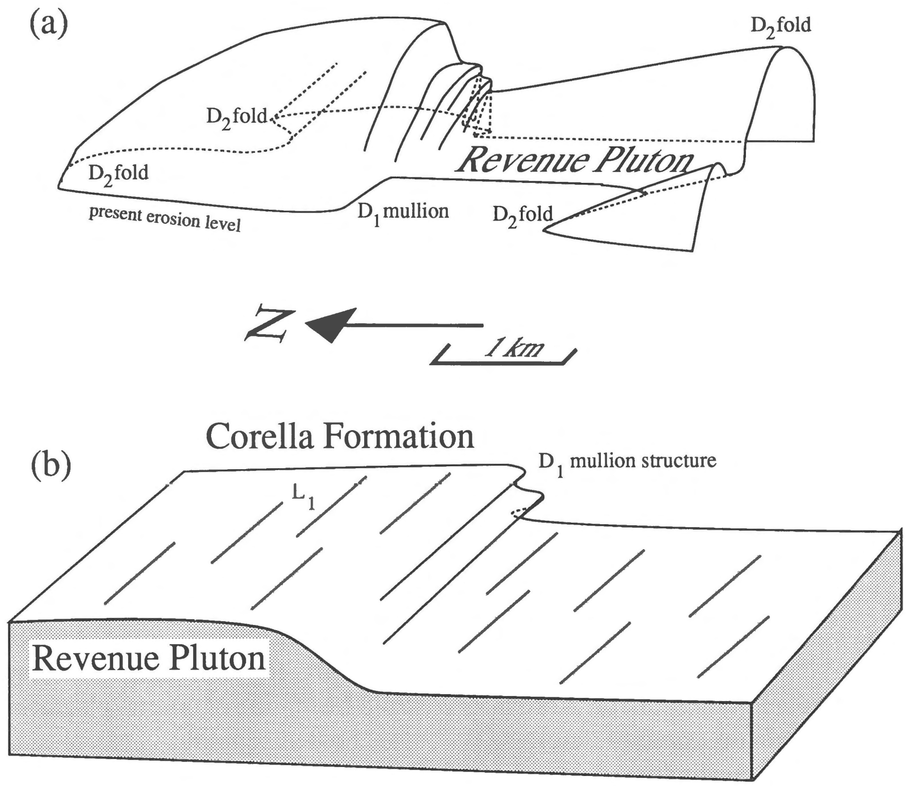

Fig. 7. Schematic interpretation of the deformation of the Revenue pluton; (a) inferred shape of the Revenue pluton above the present erosion level. D_3 faults have been omitted. A refolded D_1 mullion structure and an asymmetric D_2 fold form a major embayment in the western side of the pluton; (b) shape of the roof of the pluton after D_1 and before D_2; a km-scale mullion structure exists parallel to the L_1 stretching lineation.

and recrystallised synkinematically to form ribbons. This suggests, that metamorphic conditions were at least medium grade (Gapais 1989).

The Revenue doublefold

On the western limb of the Revenue pluton, two opposite-facing km-scale folds occur (Figs 3 and 7a). The southern structure can be recognized as an asymmetric D_2 fold with NW plunging foldaxis and a well developed S_2 cleavage fan in Corella formation rocks and in the granite (Fig. 3). The northern structure, 1 km SE of Green Creek Tank (Fig. 3) is more complex. It consists of a gently west-dipping contact with the granite, which steepens to the north and SW (Fig. 3). In this zone, a strong L_1 and S_1 shape fabric is developed parallel to the contact. The linear element plunges gently to the WSW (Fig. 3). Open folds of S_1 and S_0 in calcsilicates, with steep axial planes and foldaxes subparallel to L_1 are common throughout the zone and become gradually tighter towards the northern granite contact. The D_1 shape fabric gradually decreases in strength to the south and west. Where L_1 and the foldaxes are oblique, the former is seen to predate the folding.

The data presented above suggest, that the northern structure is a km-scale D_1-mullion in the contact of the pluton (Fig. 7). In this interpretation, the minor folds in the northern structure are due to late D_1 constriction in the cuspate core of the mullion. Folds on a 100 m-scale in the eastern contact of the pluton are interpreted as part of the same structure, refolded by D_2 (Fig. 7a). This implies, that the mullion axis was originally subparallel to L_1 in the granite (Fig. 7b). As a result of D_2-refolding, the Revenue pluton obtained its curious shape with a narrow central zone and a broad section where the mullion structure is refolded, east of Green Creek Tank (Figs 3 and 7a). Rare asymmetric isoclinal folds in the deformed Corella rocks, and steepening of the foliation towards the contact indicate relative WSW movement of the upper block during D_1 in the western limb of the mullion structure.

D_1 fabric elements similar to those in the Revenue pluton have been observed in the Overlander granite 5 km north of the Revenue pluton (Fig. 2, Passchier, unpubl. data). Since this pluton has a similar N-S elongate shape as the Revenue pluton, both may form part of an extensive granite intrusion underlying Corella metasediments in the Mary Kathleen Zone. The separation of both plutons at the present erosion level may be due to similar mullion structures as observed in the Revenue pluton.

Discussion

The tectonic significance of D_1 is difficult to assess, because few similar structures have been reported from elsewhere in the Mount Isa Inlier (Holcombe et al. 1987, Pearson et al. 1987). D_1-structures in the Revenue pluton have an irregularly distributed orientation (Fig. 5) and symmetry (Fig. 3). The most characteristic aspects are: (1) parallellism of shape fabric elements with the contacts of the pluton; (2) increasing intensity of fabric development, probably due to increasing finite strain, towards the contact of the pluton, both in the granite and in the country rock; (3) irregular distribution of constrictional and flattening strain types, as indicated by the presence of linear or planar shape fabric elements, and by the shape of deformed xenoliths; (4) irregular distribution of shear sense patterns over the pluton. This last point may be partly due to the non-cylindrical nature of D_2 folding, but cannot be entirely attributed to that phase.

S_0 layering in the contact zone of the pluton is overprinted by D_1 boudinage (Fig. 4b) and D_1 folding, both with E-W trending axes. The presence of these structures implies a significant, but variable deviation from plane strain during D_1-progressive deformation. The large scale D_1 mullion is probably the effect of such a local deviation of late D_1-age, imposed upon a general E-W extension. It caused fold-overprinting on an already well developed planar and linear D_1 fabric. Similar structures on a smaller scale, known as oblique folds, occur in many ductile shear zones (Passchier et al. 1990 – p 58). The alternation of linear and planar structures in the pluton must also be due to local deviation from plane strain during D_1.

The nature of D_1 deformation sketched above indicates that the early fabric is due to development of a high strain zone with strongly variable flow pattern in the top of the pluton. An origin of the fabric as a flow structure in a granitic melt is unlikely because of the equal strength of mylonitic fabrics in granite and country rock along the contact, absence of synkinematic intrusion of granite veins (Paterson et al. 1989) and the absence of microstructures critical of deformation of the granite in a partly molten state (Hibbard 1987, Paterson et al. 1989). The presence of quartz ribbons of D_1 age and transection of major xenoliths by S_1 also indicate deformation in a solid state (Paterson et al. 1989). Diapirism of the Revenue pluton to its present geometry as a solid state gneiss dome after intrusion into Corella metasediments is equally unlikely, since structures typical of diapirism are missing. Such structures are: (1) folds verging away from the core of the dome; (2) opposite shear sence on both sides of the dome; (3) radially oriented stretching lineations (Dixon 1975, Van den Eeckhout et al. 1986). L_1 stretching lineations in the northern tip of the pluton do not radiate out, but are folded round the tip and remain E-W trending, like in the rest of the pluton (Fig. 3). Consequently, the present dome-shape of the pluton is mainly due to large scale D_2 folding, and not an effect of D_1. Initially, the pluton may have had a sill-shape, with a roof subparallel to layering in the host rock (Bateman 1984, Castro 1987).

Fabrics of similar nature and relative age as D_1 in the Revenue pluton have been found in the Shinfield Zone (Figs 1 and 2; Passchier 1986a, b) and its northern extension, the Wonga Belt (Holcombe et al. 1987, Pearson et al. 1987). In the Wonga Belt, this fabric can be attributed to a phase of crustal extension in a period from 1750–1730 Ma, during intrusion of granite sills similar to the Revenue pluton (Holcombe et al. 1987, Pearson et al. 1987). D_1 in the Revenue pluton is therefore interpreted as an effect of this regional extension event (Passchier 1986a, b). Stretching lineations in the Shinfield Zone and in the granite are oblique, but this can be explained by a large component of strike-slip along the Shinfield Zone which is not present in the Revenue pluton.

In the Alligator Syncline, 5 km west of the Revenue pluton (Fig. 1), evidence exists for the presence of brittle, shallow level E-W or NW-SE extensional faults, which are overprinted in the Shinfield Zone by the D_1 fabric discussed above (Passchier 1986a, Passchier & Williams 1989). These brittle structures probably belong to the same regional extension event (Holcombe et al. 1987, Passchier & Williams 1989). In the Wonga Belt, the brittle and ductile structures are roughly contemporaneous, but form at different crustal level; some of the granite plutons are thought to intrude as sills along subhorizontal brittle fractures during this event (Holcombe et al. 1987). The Revenue granite may have intruded in this way during a first, brittle stage of regional extension. Subsequently, the pluton became affected by ductile deformation which produced the D_1 fabrics.

Conclusions

The Revenue pluton exposed in the Mary Kathleen Zone, Mt Isa, is affected by a high strain zone which produced a shape fabric and km-scale folding in the granite contact zone. This phase of deformation is tentatively linked to a phase of regional extension in the area between 1750–1730 Ma. The granite probably intruded along a fault or shear zone at an early stage of this event. An overprint by strong E-W shortening around 1550 Ma caused non-cylindrical folding of the entire pluton and gave the Revenue pluton its present dome-shape.

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