# Magma mixing in the South Leicestershire Diorite pluton at Croft Quarry

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## Abstract

At Croft Quarry, exposures of a pluton belonging to the South Leicestershire Diorite suite have revealed a complex history of multiple intrusion. Soon after emplacement of the main-stage quartz-diorite, the partially crystallised pluton received an influx of magma which became dispersed and is now seen as partially assimilated dioritic xenoliths. A much later episode of intrusion occurred when the pluton had cooled sufficiently to be capable of fracturing. It resulted in a spectacular swarm of synplutonic quartz-diorite/tonalite sheets with contacts indicating that the host quartz-diorite was locally remobilized, disrupting and net-veining the later sheets. These features are typical of 'magma mixing' phenomena, and suggest an underlying process that may account for some of the geochemical and petrographical variations previously noted within the South Leicestershire diorites.

## 1. Introduction and regional setting

The 60 m-high conical landmark of Croft Hill (SP 510 967) surmounts the largest of several quarried inliers (Fig. 1) exposing the South Leicestershire Diorite suite of intrusions (Worssam and Old, 1988). These inliers protrude above an unconformable cover of Triassic strata and are intriguing because many are now only partly accessible, due to flooding or vegetation overgrowth, yet provide tantalising insights on the nature and evolution of igneous activity within the Precambrian to early Palaeozoic 'basement' to the outcropping Carboniferous and Mesozoic strata of the East Midlands (Le Bas, 1968; 1972, 1981). The rocks at Croft have been exploited since at least Roman times, and today they are superbly exposed within the adjacent aggregate quarry, which is one of the largest of its type in Europe.

The significance of the intrusive rocks to Midlands basement geology in part revolves around their age. A U-Pb date of 449 ±18 Ma was obtained by merging the data for zircons separated from plutonic rocks exposed at Enderby, to the north-east of Croft (Fig. 1), with values for zircons from granodiorites of the closely related Mountsorrel Complex (Pidgeon and Aftalion, 1978, recalculated by Noble et al., 1993). This age confirms that the South Leicestershire Diorites and Mountsorrel Complex were emplaced during an intrusive event of Ordovician (late Caradoc) age, contemporary with the subduction-related, Caledonian magmatism of central Wales and the Lake District (Pharaoh et al., 1993). Boreholes in the region (Le Bas, 1972) indicate that from Hinckley to at least as far as Leicester in the east, the South Leicestershire Diorite intrusions and Mountsorrel Complex are emplaced into mudrocks of Lower Cambrian to Tremadoc (earliest Ordovician) age. These strata are part of the Stockingford Shale Group, which is exposed 15 km farther west at Nuneaton (Bridge et al., 1998), and their considerable extent has been attributed to tectonic repetition within a structurally complex basement (Carney, 2007). In the Croft area, this basement represents part of a tectonically-bounded crustal block known as the Midlands Microcraton (Pharaoh et al., 1987), which although faulted and folded largely resisted the main effects of late

Caledonian deformation. Structures attributed to the latter event(s) are suggested by Pharaoh et al. (1987) to be mainly developed within the adjacent 'Eastern Caledonides', a concealed early Palaeozoic orogenic belt forming the basement to the east of the Mountsorrel Complex (Fig. 1) and extending eastwards beyond the North Sea coastline.

The geochemistry of the South Leicestershire Diorite intrusions and Mountsorrel Complex supports a subduction zone tectonic setting similar to that of the age-equivalent rocks of Wales and the Lake District. On an FMA major element variation diagram they exhibit a strong calc-alkaline variation trend (Le Bas, 1972, 1981; Webb and Brown, 1989). Furthermore, trace element abundances for the Croft rocks show moderate enrichments of large ion lithophile (LIL) elements (K, Rb and Ba), Th and Ce, and relative depletion of Nb and Ta, which are patterns typical of calc-alkaline magmas arising within a volcanic arc founded on continental crust (Pharaoh et al., 1993). The subduction zone above which the magmas were generated may have been situated to the east of the present-day English coastline in late Ordovician times, its activity related to a phase of plate convergence which closed the Tornquist Sea, located between the continents of Avalonia and Baltica (Noble et al., 1993; Pharaoh, 1999). That event pre-dated collision along the Iapetus Suture Zone by about 50 million years.

Regionally, the South Leicestershire Diorites and Mountsorrel Complex represent only the westernmost part of a much larger Caledonian plutonic province in the East Midlands. The partially exposed plutons shown in Fig. 1 are emplaced into the Midlands Microcraton, but farther east a number of wholly concealed plutons occur within the adjacent Eastern Caledonides basement block. These include the granodiorites proved in boreholes at Rempstone and Kirby Lane (Wreake Valley), respectively 8.5 km to the north and 16.5 km to the east of the Moutsorrel Complex (Carney et al., 2004), as well as a scattering of granitoid plutons suggested by Pharaoh et al. (1993) to extend as far east as The Wash. The evidence for these easternmost plutons is provided by a Bouguer gravity survey showing a series of small, circular to oval anomalies (Evans and Allsop, 1987). With regard to local basement structure, shown in Fig. 1, the South Leicestershire Diorites are developed in an area where the geophysical expression of the Thringstone Fault appears to die out. That structure uplifted the Precambrian rocks of Charnwood Forest during end-Carboniferous time, but it may also have a Caledonian inheritance as it is parallel with the Midlands Microcraton boundary, shown in the north-eastern corner of Fig. 1. The intrusions are evidently confined to the east by the north-west trending Boothorpe Fault, a displacement hidden beneath thick Triassic cover in the study area but detected by its geophysical trace (Allsop and Arthur, 1983). This structure may be of greater magnitude than the Thringstone Fault as it coincides with a prominent linear Bouguer gravity anomaly gradient (Worssam and Old, 1988; fig. 28) interpreted as a major axis of basement uplift.

## 2. Petrographic variation within the South Leicestershire Diorites

The Croft rocks have been studied petrographically by several researchers covering a long period of time. They were originally described as syenites (Hill and Bonney, 1878) before Whitehead (in Eastwood et al., 1923) suggested that they were mineralogically more comparable to quartz-diorite or tonalite.

Le Bas (1972) proposed that, at depth, these rocks may form part of a composite batholithic body about 16 km wide at maximum. A broad compositional zonation within this batholith was suggested on the basis of petrographic studies (Le Bas, 1968; 1972) that indicated variations in the proportions of quartz, alkali feldspar and plagioclase feldspar (Q-A-P), between the various exposures shown in Fig. 1. A map was constructed (Le Bas, 1968; 1972), showing that diorite and quartz-diorite occupied the western part of the batholith, exposed at Barrow Hill and Stoney Stanton (Cary Hill and Clint Hill quarries of Fig. 1), with tonalite occupying a central position at Croft and the quarries at Enderby Hill and Enderby Warren. Microtonalite, exposed in the small quarries at Enderby and Narborough, and proved at depth in the Cottage Homes borehole at Countesthorpe (Poole et al., 1968), forms the eastern zone of the pluton.

Modal analysis was carried out by Worssam and Old (1988) on ten thin sections from the South Leicestershire Diorites. All contained less than 8 per cent modal alkali feldspar; however Worssam and Old's findings, particularly with respect to modal quartz content, departed somewhat from those of Le Bas (1972). Of the six samples analysed by Worssam and Old (1988) from Croft, Narborough and Stoney Cove, five samples were classified as quartz-diorite on the Q-A-P triangular diagram, although with quartz contents of between 15-22% (mean of 18%) they verge towards tonalite (>20% quartz). A further four samples, from Enderby and The Yennards, also fall within the quartz-diorite classification, but have much lower quartz contents of 7-12% (mean of 10%) and in mineralogical composition are therefore closer to diorite (<5% quartz). A petrographic survey of thin sections from the collection by Eastwood et al. (1923), from the small quarries between Clint Hill and Calver Hill, showed that most were quartz-diorites (Bridge et al., 1998), with between 10 and 15 per cent modal quartz (visual estimates only). Some diversity is suggested at Cary Hill Quarry, however, where inequigranular quartz-diorites contain up to 20 per cent quartz and thus verge towards tonalite in mineralogical composition. There are also finer grained varieties ('rammel' in quarrymen's terms), which have only 5-10 per cent quartz. Some fine-grained diorites with intergranular textures show fluxional alignment of plagioclase laths, such as might occur along the margins of a late intrusion into the main body of magma.

These petrographic surveys hint at a more complex distribution of igneous rock-types than was originally portrayed by Le Bas (1972). Such differences may be due to 'laboratory' variations in modal analytical procedures, but they may also be an artefact of ad hoc sampling, either between different workers or, in the case of the larger quarries, without regard to a thorough assessment of the variability presented by these exposures. This article will show that the plutonic rocks at Croft Quarry have experienced a complex history of multiple igneous intrusion, which may be relevant to the underlying causes of compositional variation within the South Leicestershire Diorites and could even operate within the confines of a single exposure.

## 3. Igneous structure of the Croft pluton

Further investigations have been made during recent visits to Croft Quarry (Fig. 2), although in many places it was not possible to approach the faces due to safety concerns. Sufficient evidence has been gathered, however, to indicate that the rocks there are more heterogeneous than previously thought, with four major igneous components recognised:

a) Quartz-diorite host rock, typically with a coarsely inequigranular texture,
b) Dioritic xenoliths showing all stages of assimilation by the host rock,
c) A swarm of synplutonic intrusive sheets, of quartz-diorite to tonalite composition,

d) Coarsely inequigranular tonalite, newly exposed at the base of the quarry.

*Host quartz-diorite*. This component is most conveniently viewed at the natural exposures around Croft Hill, where its inequigranular texture is emphasized by conspicuous, 4-7 mm size, pale grey plagioclase phenocrysts set in a yellow or brown, medium-grained weathered groundmass. In the very extensive exposures on the western quarry face, below Croft Hill, the inequigranular texture features abundant crystals of pale grey euhedral plagioclase up to 6 mm long (Fig. 3A). These are enclosed within a grey to pink, medium-grained quartz-feldspar matrix studded with black, euhedral Fe-Ti oxides (magnetite). Dark green-grey, somewhat amorphous areas comprising about 20-30 per cent of the rock indicate the sites of mafic silicates and their alteration products. In a thin section (Fig. 3B) the large plagioclase crystals are euhedral and optical determinations indicate that they are zoned, from labradorite cores outwards to grainy, inclusion-filled albite rims. Surrounding them are aggregates of smaller, inclusion-filled sodic plagioclase, some partly euhedral but most forming interlocking granular aggregates that include quartz and minor amounts of untwinned K-feldspar. Clinopyroxene forms sporadic euhedra and aggregates that are largely altered to intergrowths of pale green amphibole and chlorite (the dark green-grey areas seen in hand specimens); there are also small flakes of partially chloritised brown biotite and about 5 per cent of scattered, opaque euhedra of magnetite. Alteration of plagioclase by the growth of albite patches and veinlets is all-pervasive. Pumpellyite occurs interstitially, and in other samples Webb and Brown (1989) noted radial prehnite infilling cavities and zeolites occupying veins. These minerals are related to pervasive, and locally intense alteration of the pluton (e.g. King, 1968).

*Diorite xenoliths*. These are ubiquitous in all parts of the host quartz-diorite that were accessible for examination, although they vary in proportion, from very sporadic to common and closely packed. As shown in Fig. 3A, they are typically pink to grey in colour, with rounded outlines and shapes that vary from roughly spherical to ovoid or ellipsoidal. Sizes range from a few centimetres to about 15 cm. The xenoliths were not examined in thin section; however, Le Bas (1968) notes that they consist of sericitised augite-microdiorite, with pale green hornblende, Fe-Ti oxides and minor quartz. There appears to be limited compositional variation between xenoliths, with some darker grey in colour, and thus possibly more basic, than others. Most xenoliths are finer grained than the host quartz-diorite. They are also more equigranular, although some xenoliths contain isolated crystals or clusters of pale grey plagioclase phenocrysts, identical to those in the host rock (Fig. 3A). This is reminiscent of the 'xenoporphyritic' texture described by Blundy and Sparks (1992) and attributed by them to a process of mixing and assimilation between xenolith and host. Most xenoliths are surrounded by a prominent rim of dark grey, fine-grained chlorite-hornblende intergrowths, which may be a reaction interface formed after incorporation of the xenolith into the host rock. Xenoliths without such rims have extremely diffuse, shadowy outlines and in this respect appear to be in more advanced stages of assimilation into the host.

*Synplutonic intrusive sheets* within the host rock were first reported by Carney and Pharaoh (1999), and are currently visible in the c.100 m high western and eastern faces of Croft Quarry. The sheets are suggested to delineate a magmatic injection zone (MIZ), shown in Fig. 2. Most sheets are between 1 and 2 m thick and together they form a swarm of several parallel bodies generally spaced at intervals of between about 3 and 10 metres (Fig. 4A), although some also bifurcate along their length. The swarm as a whole is inclined to the north-east at angles of between 15 and 20$^o$. An easterly dip of about 20$^o$ was, however, estimated for one sheet in a new face opened at the base of the quarry during 2009, and as the quarry is progressively deepened further complexities will doubtless be revealed.

The synplutonic sheets are of a medium- to dark-grey colour and thus stand out against the pale grey host rock. In detail sheet margins are irregular and in particular, the upper contacts are markedly cuspate (Figs. 4B and C), with pillow-like forms locally developed (Fig. 4D). The latter example shows that in places the sheets have been completely disrupted by the host rock, which also back-intrudes the sheets resulting in net-vein complexes (Fig. 4E). Thin, subvertical intrusions are seen in the vicinity of the larger sheets (Fig. 4F) and in places merge into them, suggesting that they are offshoots. These thinner sheets show greater susceptibility to disruption by the host diorite, some appearing to be reduced to shadowy, ellipsoidal inclusions (Fig. 4D, F), similar to the diorite xenoliths found elsewhere (cf. Figs. 3A and 4F). They appear to have chilled margins (Fig. 4F), but generally no significant chilling marks the contacts between the larger intrusive sheets and the host quartz-diorite.

In thin section (Fig. 3C) the synplutonic sheets are of similar mineralogy to the host rock, but have marginally higher quartz contents (c. 20-25%, visual estimate), which places them in the tonalite field on the Q-A-P diagrams. Mafic minerals are less abundant than in the host rock; they consist of chlorite-green hornblende aggregates and about 3 per cent magnetite. The example shown in Fig. 3C has an inequigranular texture due to the presence of large plagioclase crystals; however, overall these are generally less abundant than in the host quartz-diorite.

*Tonalite*, with a quartz content estimated to be in excess of 20 per cent, is only now being revealed by blasting in the lowest parts of the quarry and represents a further, newly-discovered component to the Croft body. This rock has an inequigranular texture, which in part is caused by the presence of large plagioclase crystals. An additional feature, however, is the presence of sporadic but prominent 'eyes' (ocelli) of grey, glassy quartz; these are generally several millimetres in size, but some consist of xenolith-like masses up to 20 mm across (Fig. 5).

## 4. Magmatic evolution

Outstanding features of the Croft intrusion are the abundant dioritic xenoliths in various stages of assimilation by the host rock, and the swarm of synplutonic tonalitic sheets that make up the MIZ. Such phenomena are widely recognised in other parts of the world, in plutons ranging in age from Cenozoic (Blundy and Sparks, 1992) to Jurassic (Wiebe et al., 2002), late Caledonian (El-Desouky et al., 1996), Neoproterozoic (D'Lemos,1992) and Palaeoproterozoic (Lundmark et al., 2005). Mostly the lithologies involved belong to the granite-tonalite-granodiorite-diorite clan, and so are comparable to the range of igneous rocks making up the South Leicestershire Diorites and Mountsorrel Complex (Le Bas, 1972).

The relationships between the synplutonic sheets and host quartz-diorite seen at Croft are typical of igneous associations where processes of closely simultaneous intrusion, resulting in 'magma mixing', have been proposed (e.g. Blundy and Sparks, 1992). The intricate nature of the contact developed along the intrusive sheets suggests the operation of at least three, interrelated magmatic processes. First, the cuspate, crenulated outlines of the sheet margins are attributed to cooling of the intruded magma against the host quartz-diorite, resulting in shapes analogous to the pillows that form when magma is discharged into water or water-saturated sediment. These pillowed contacts, however, also indicate that the host rock was hot enough to flow around and therefore to accommodate the developing pillows. Second, the sheets must have cooled sufficiently to undergo brittle deformation, resulting in the fractures that allowed the host to invade and in places net-vein the sheets. This mobility of the host quartz-diorite is attributed to a third process, whereby the heat transmitted from the sheets was sufficient to locally re-melt the host, thus lowering its viscosity. The fact that the synplutonic sheets lack fine-grained, truly 'chilled' margins against the host rocks is further evidence that both were at similar, elevated temperatures during intrusion of the sheets.

Parallel synplutonic sheet swarms with similar contact relationships to those seen at Croft have been described from California by Wiebe et al. (2002), who attributed them to the successive flowage of hybrid dioritic magmas across the floor of a crystallising pluton below a more fluid, crystal-poor granitic magma. At Croft, the quartz-diorite host rock shows little evidence for fluidity, crystal accumulation or convection required for such a process of large-scale 'macrorhythmic' magma influx, which in any case is unlikely to occur in more viscous magmas of intermediate composition. Therefore, at Croft, introduction of the sheets by lateral intrusion is the preferred explanation. This mechanism operated within a dioritic host that, although still-hot, was solid enough to undergo brittle deformation, splitting to produce a stack of low-angle fractures that was exploited by the later magmas. Space is required for such a process to operate, suggesting that the magma chamber occupied by the host was capable of expansion and therefore was probably still rising into the East Midlands crust.

These field relationships are consistent with the suggestion of Furman and Spera (1984), that new batches of magma can reactivate an otherwise cooling intrusion, initiating a process of thermal equilibration that results in the re-fusion and remobilization of the nearly solidified host immediately adjacent to the fractures that acted as conduits for the new magma. They further proposed that when magmas interact like this, a continuum of mixing states is possible, depending on magma chemistry and physical properties. Their calculations suggest that for a granodioritic pluton of 20 km diameter hosting magma with low crystallinity, of about 30-50 per cent, mixing can be found at exposure-scale and will include disconnected inclusions or trains of inclusions. The small, isolated xenoliths found in the Croft quartz-diorite are consistent with this relatively early stage of magma introduction and mixing. In these xenoliths, the 'xenoporphyritic' texture indicates that the larger plagioclase crystals of the host had been able to enter the newly introduced magma, suggesting that both were in a largely molten condition. By contrast, when the host is still hot but has cooled sufficiently to undergo brittle deformation, new magma influxes will crystallise as intrusive sheets that are relatively coherent. These new intrusions, however, will be capable of localised disruption by the host wherever the latter has been remobilised as a result of additional heat transferred from them. This physical condition of the host represents a crystallinity in excess of 70 per cent (Furman and Spera, 1984), and could plausibly reflect the situation at the time of intrusion of the synplutonic sheets at Croft. The calculations of Furman and Spera (1984) further suggest that such conditions might prevail about a million years after initial emplacement of the host magma.

## 5. Conclusions

The Croft quartz-diorite has experienced a complex history of multiple intrusion, which is speculated to have spanned a period of about a million years. Following initial emplacement of the pluton, a batch of magma was added when the crystallinity of the main body was relatively low (30-50 per cent), sufficient to support movement and mixing between host and introduced magma. The composition of this new magma cannot now be determined as it was effectively dispersed and mixed with the host, and is now recogniseable only as isolated, small, partially assimilated dioritic xenoliths. A rather later introduction of tonalitic magma occurred when the host quartz-diorite was still hot but had largely solidified, with a crystallinity probably in excess of 70 per cent. This event was structurally controlled, perhaps by fractures generated during continued inflation of the main pluton. It resulted in a swarm of synplutonic sheets showing intricate contact relationships that support a process of thermal equilibration between intrusion and host, the latter having been locally remobilised along the sheet margins. The significance of the quartz-eye tonalite, newly uncovered at the base of Croft Quarry, remains to be evaluated.

A similar history of multiple intrusion can be suggested for other East Midlands Ordovician intrusions. For example, granodiorite of the Mountsorrel Complex is xenolithic and contains stock-like bodies of hornblende gabbro and quartz-diorite. Close to the latter, at Kinchley Hill, the granodiorite contains abundant diorite xenoliths with intricate boundaries against the host. The features recorded suggest that the xenoliths represent a batch of magma emplaced prior to solidification of the host, and subsequently partially dispersed within it (Lowe, 1926; Le Bas, 1968; Carney et al., 2009).

The magmatic features at Croft may help to explain the regional variability of compositions within these Ordovician intrusions, and is a complication to the zonal scheme of diorite-tonalite-microtonalite bodies proposed for the South Leicestershire Diorites by Le Bas (1972). For example, Blundy and Sparks (1992) suggest that during early-stage magma mixing, represented by the xenoliths at Croft, there may be significant chemical modification of the host magma as a result of reaction with, and partial assimilation of the new magma influx. On the other hand, emplacement of the synplutonic sheets represents a later stage at Croft, when the host quartz-diorite was largely crystalline. It would not have greatly influenced host rock compositions, but when added to the evidence of the xenoliths it draws attention to a process that could have continued throughout the emplacement history of the Croft pluton, profoundly influencing its composition.

These findings suggest that Croft Quarry would be an ideal subject for geochemical studies aimed at constraining more closely the petrogenetic evolution of the South Leicestershire Diorites. The scope of such a project could be widened to include similar studies on age-equivalent rocks of the Mountsorrel Complex.

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## Figure captions

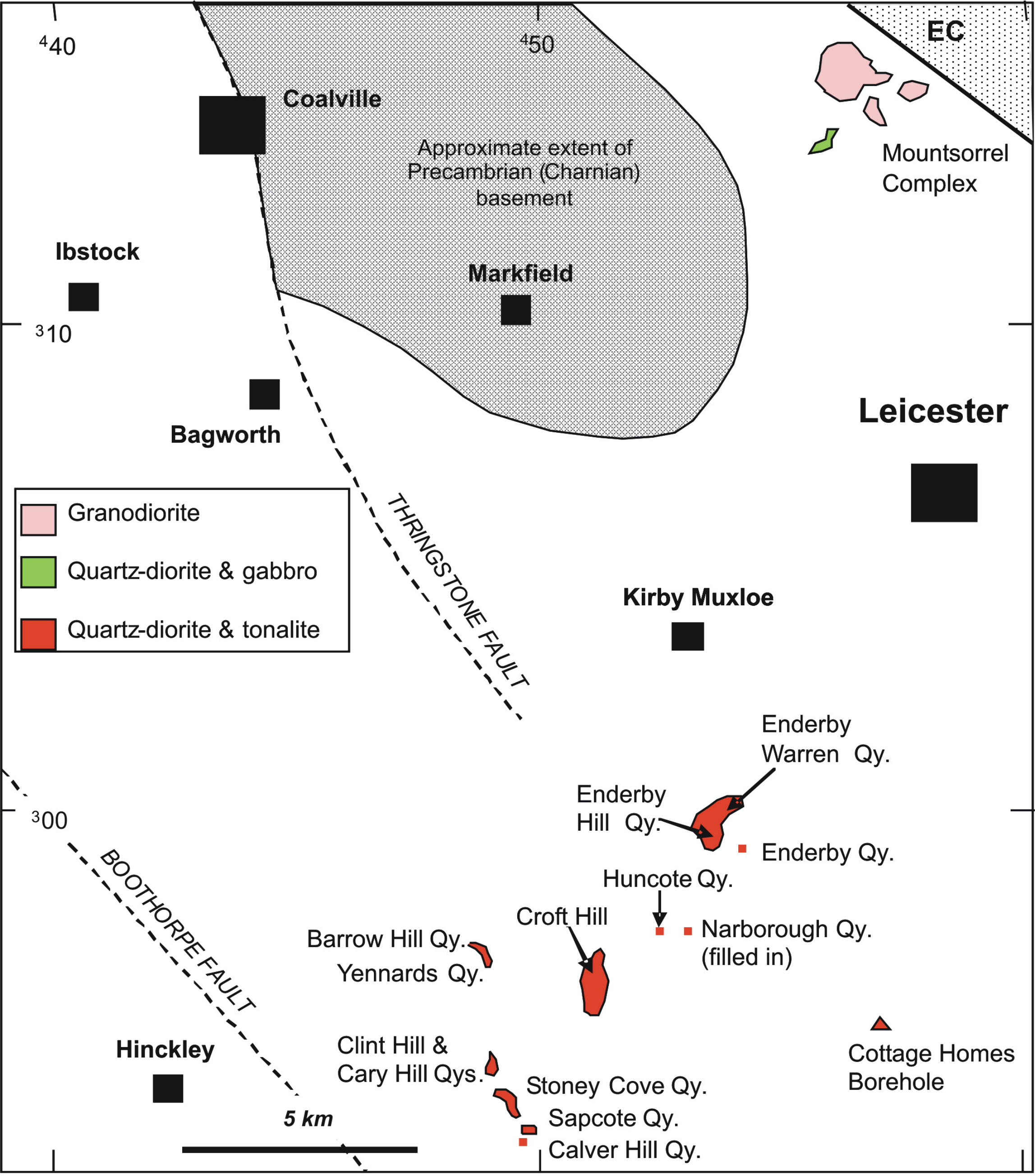
1. Sub-Triassic inliers of South Leicestershire Diorite and Mountsorrel Complex in relation to major basement structures. The unshaded area represents Midlands Microcraton (early Palaeozoic) basement beneath Late Carboniferous to Mesozoic cover strata. EC = inferred sub-Mesozoic extent of Eastern Caledonides basement.

2. Geology of Croft Quarry. QD, quartz-diorite host rock; MIZ, Magma Injection Zone; T, tonalite (not exposed in 2006). Arrows show the approximate dip of synplutonic sheets in the MIZ. The topographical backdrop is derived from a Google Earth image taken in July, 2006. The image is by courtesy of Infoterra Ltd. & Bluesky (2010) and Tele Atlas (2010).

3. A) Quartz-diorite of the main Croft intrusion, showing inequigranular texture featuring abundant plagioclase phenocrysts (pale grey to white). Early-stage xenoliths are emphasized by their dark rims; they contain sporadic clusters of pale grey plagioclase phenocrysts (e.g. below tip of pen). B) Photomicrograph of host quartz-diorite, showing large, grey, inclusion-filled plagioclase phenocrysts; quartz is represented by white to pale grey areas within the granular matrix surrounding the phenocrysts (x-nicols). C) Photomicrograph of synplutonic sheet, showing plagioclase phenocrysts. The granular matrix is texturally identical to that in 3B but is slightly more quartz-rich (x-nicols).

4. Aspects of the Magma Injection Zone (MIZ). A) View of the eastern quarry face, showing synplutonic sheets (outlined in yellow for clarity). The height of this exposure is estimated to be 30-40 m. B) Zoomed-in view of red rectangle in 4A, showing cuspate upper contact of a c. 1 m-wide synplutonic sheet. C) Zoomed-in view of the western quarry face, showing a synplutonic sheet with strongly cuspate upper margin. The height of this exposure is estimated to be 10-12 m. D) Close-up of disrupted synplutonic sheet on the western quarry face, showing crenulated (‘pillowed’) upper margin (white outline) against the host quartz-diorite. Note disconnected subvertical offshoot at upper left. Vertical height of this exposure is about 1.5 m. E) Net-veining of synplutonic sheet (dark grey areas) by the host inequigranular quartz-diorite, western quarry face. Height of exposure is c. 0.8 m. F) Strongly elongated, dark-rimmed xenolith on western quarry face, interpreted as a disrupted vertical offshoot to a synplutonic sheet close by. Height of image is about 0.6 m.

5. Tonalite newly exposed in the floor of the quarry. The pale grey ‘eyes’, or ocelli, consist of quartz, a cluster of three being present to the right of the large oval quartz xenolith seen above and to the right of the hammer head. The dark grey mottling represents mafic-rich areas within a pink to grey, granular matrix of quartz and plagioclase feldspar.



440
450
EC
Coalville
Approximate extent of Precambrian (Charnian) basement
Mountsorrel Complex
Ibstock
Markfield
310
Bagworth
Leicester
Granodiorite
Quartz-diorite & gabbro
Quartz-diorite & tonalite
THRINGSTONE FAULT
Kirby Muxloe
Enderby Warren Qy.
Enderby Hill Qy.
300
Enderby Qy.
Huncote Qy.
BOOTHORPE FAULT
Croft Hill
Narborough Qy. (filled in)
Barrow Hill Qy.
Yennards Qy.
Clint Hill & Cary Hill Qys.
Hinckley
Cottage Homes Borehole
Stoney Cove Qy.
Sapcote Qy.
5 km
Calver Hill Qy.


Fig. 1V2

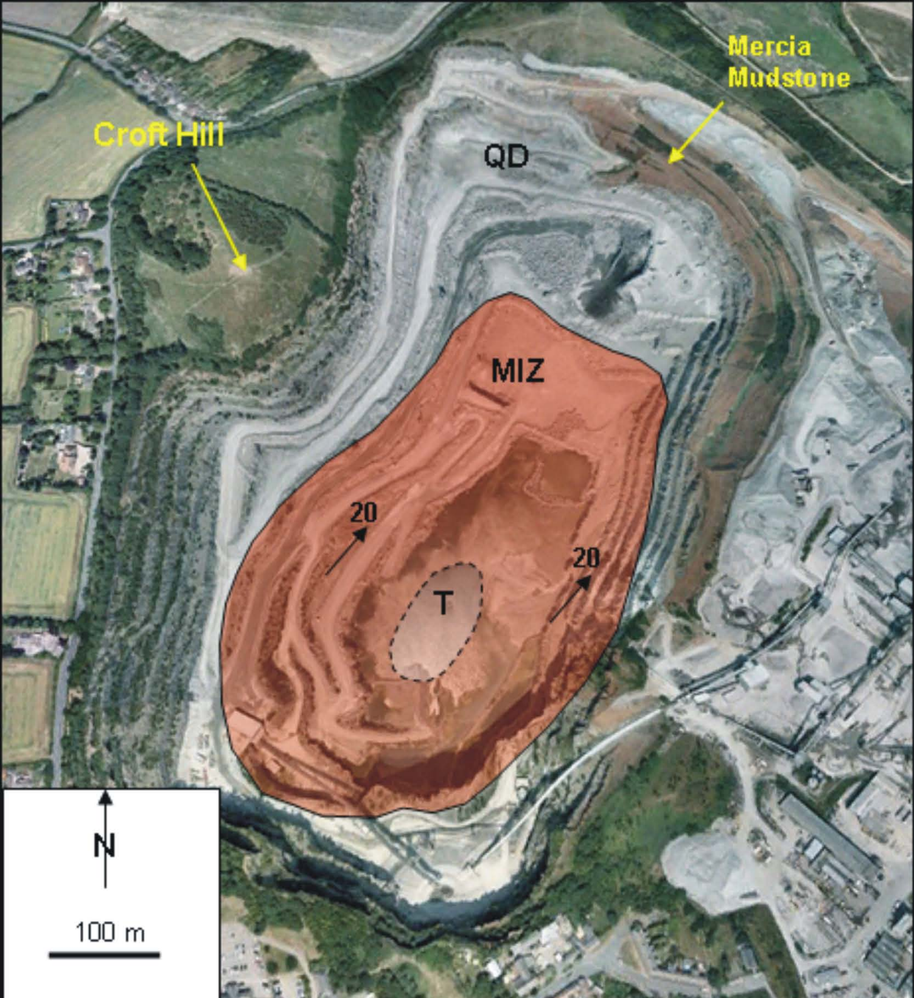



Fig. 2


A
1000 µm
B
1000 µm
C

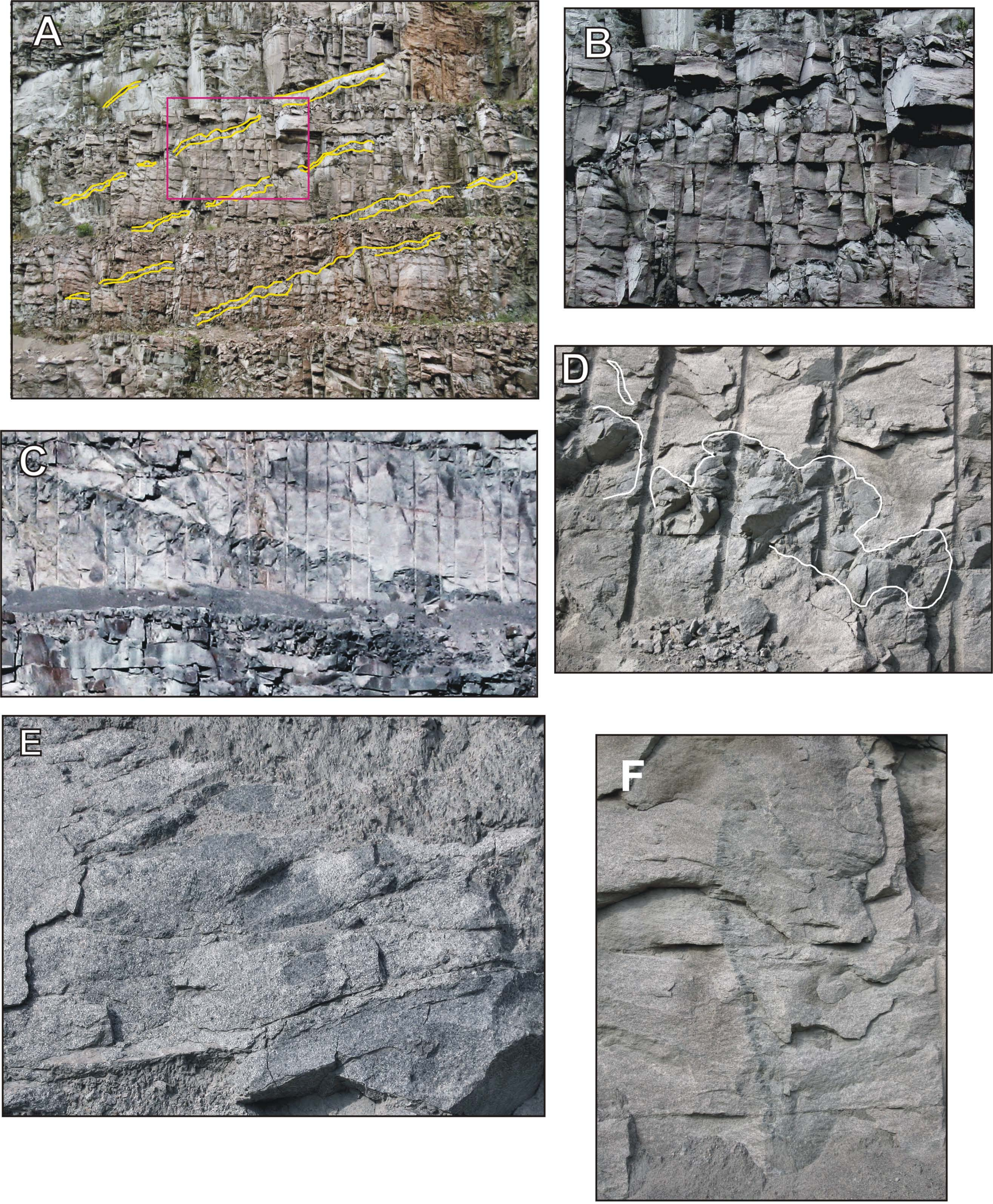



Fig. 4

Fig. 5