Millour and Airdrie Hill

[NX 950 595]

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Introduction

The outcrops around Millour and Airdrie Hill (Figure 8.36), some 2–3 km south of the summit of Criffel, provide very good exposures of the outer contact and marginal zones of the Criffel pluton. A general introduction to the pluton and a discussion of the zoning is given in the Lotus Quarries to Drungans Burn GCR site description.

The marginal clinopyroxene-biotite-hornblende granodiorite facies contains abundant titanite and shows all the geochemical and isotopic characteristics of I-type granites (Stephens *et al.,* 1985). Features thought to be indicative of diapirism, including sharp contacts, steeply outward-dipping host rocks, mineral and enclave foliations with similar trends to the host rocks, and flattened enclaves, are well displayed. The evidence used in the stoping versus diapiric emplacement controversy (Phillips, 1956; Phillips *et al.,* 1981, 1983; Holder, 1983; Courrioux, 1987) can be examined here, as can many of the petrological features associated with the least evolved facies of the zoned pluton.

This site has been selected for the quality of the exposures and the range of features contained within a relatively small and accessible area. In particular, the site has among the best examples of discoidal enclaves in the UK, rivalling those of the classic Ardara pluton in Donegal (Pitcher and Berger, 1972; Holder, 1983; Pitcher, 1993).

Description

The outer contact of the pluton can be seen in the Kirkbean Burn in the SE corner of the site. The Silurian greywackes in contact with the granodiorites dip south-eastwards away from the contact at 50–60°. The contact may be traced along the break of slope in a south-westerly direction. The NE–SW strike of these contact rocks is more-or-less parallel to the regional strike but elsewhere, along the NE and SW contacts of the pluton, the regional strike is deflected into parallelism with the contact. For this reason, Phillips (1956) argued that the structures in the aureole are at least in part due to the emplacement of the pluton, and that the magma was emplaced forcefully (Phillips *et al.,* 1981). Veins of granitic material, rather more acidic than the local granodiorite, locally intrude along planar structures in the greywackes. These greywackes are recrystallized as a result of contact metamorphism, with significant growth of new biotite.

On the south and SE slopes of Millour and Airdrie Hill the clinopyroxene-hornblende-biotite granodiorite (Figure 8.34)a has a strong foliation, contains abundant mafic-rich enclaves (i.e. dark xenolithic inclusions) and is cut by microgranodiorite and microgranite dykes, and veins of aplite and pegmatite. The granodiorite consists of hornblende, commonly with cores of clinopyroxene, together with biotite and zoned plagioclase feldspar (andesine-oligoclase), some alkali feldspar and quartz. Titanite, zircon and apatite are the principal accessory minerals with some opaque minerals. The enclaves have the same mineralogy as the host granodiorites, but the mafic phases and plagioclase are more abundant. Country rock xenoliths can be seen on the southern slopes of Millour, close to the outer contact (i.e. near the break of slope), and these are aligned within the main foliation in the granodiorites. They decrease in number and size away from the contact and few are found beyond 100 m into the pluton.

Late stage veins of aplite are fairly common, usually just a few centimetres thick and whitish in colour, reflecting their dominant quartz and feldspar mineralogy. They cut across the enclaves and the main foliation in the granodiorites, but in places they show a deformation that is approximately parallel to the fabric in the host. Some pegmatites may also be found in these outcrops. Also present are dykes of 'porphyrite', a microgranodiorite with hornblende and/or plagioclase phenocrysts, and 'porphyry', a microgranite with quartz, plagioclase and/or biotite phenocrysts. These dykes are typically 20 cm to 1 m wide and trend approximately NW–SE towards the central granite.

The key feature of this site is the very strong foliation apparent in the granodiorite. This takes the form of a strong alignment of mafic enclaves combined with a parallel mineral alignment in the host. The enclaves appear as dark pod-shaped masses, typically 10 cm to 1 m in maximum length and disc-shaped in three dimensions. Measurements of the enclave dimensions by Courrioux (1987) show that the maximum:minimum length ratio varies from about 4 up to 20, indicating considerable deformation if the enclaves were initially equidimen-sional. The strong mineral foliation in the host rock is due to the alignment of feldspars, amphiboles and biotites. In thin section this is seen to be accompanied by strong deformation, with mortar texture of small quartz grains around large plagioclase crystals (protoclastic texture), bent plagioclase crystals and kinked biotites. These features indicate that the granodiorite suffered a high degree of deformation and, as all the quartz is seen to be deformed, the strain was taken up largely in the solid state. The foliation dips outwards at 45–65° to the SE or SSE, bracketing the dip of the country rocks.

Interpretation

The field observations described above accord closely with the classic features of pluton emplacement by diapirism (i.e. magmas forcing their way into high levels of the crust by deforming their host rocks). The emplacement of granitic plutons is currently the subject of much debate, in particular concerning the role of diapirism at high crustal levels (Hutton, 1988a; Paterson *et al.,* 1996; Petford, 1996). The present view is that diapirism needs heat to be effective; deformation of hot plastic rocks by magmas may be possible but it is mechanically impossible to deform cold brittle rocks in the same way. Thus, according to many authors, diapirism is confined to the hotter middle crust and is not appropriate to the emplacement of granites at a high crustal level. The evidence for the emplacement of at least part of the Criffel pluton by diapirism is compelling, yet several features place it in the mesozonal category of plutons emplaced within the upper crust. It was intruded at the end of Silurian time but was already unroofed and providing material to form local arkose deposits in the Late Devonian.

There is a partial reconciliation of this problem in the work of Courrioux (1987). Phillips (1956) and Phillips *et al.* (1981, 1983) argued that the alignment and increasingly discoidal form of the enclaves away from the pluton margin is the result of convective flow. However, Holder (1983) and Courrioux (1987) suggested that the flattening is a consequence of ballooning of the magma during emplacement. The enclaves therefore provide evidence of the distribution of strain over the magma body during emplacement. An increase in strain within the granodiorites towards the internal boundary with the granites was interpreted by Courrioux as the effect of the emplacement of the inner granite magma pulse on the outer, largely consolidated granodiorite. At this time the outer granodiorite envelope would certainly have been at a high temperature and thus potentially capable of being deformed by an intruding magma. It is less easy to reconcile the emplacement of the first granodiorite pulse by diaprism into cold Silurian host rocks, although the evidence of the steepening and rotation of these rocks indicates that they have been deformed by the intruding pluton. This pluton, and these outcrops in particular, provide an excellent location to study this lingering problem.

Samples from these outcrops have contributed to various geochemical and isotopic studies with the aim of understanding the origin of the magmas and their subsequent evolution into a zoned pluton, as described in the Lotus Quarries to Drungans Burn GCR site report. The granodiorites in these outcrops are among the most primitive of the whole pluton and may represent a magma that was parental to more evolved facies. The SiO_2 content locally is about 62%, whereas levels of 10% higher occur in the centre of the pluton.

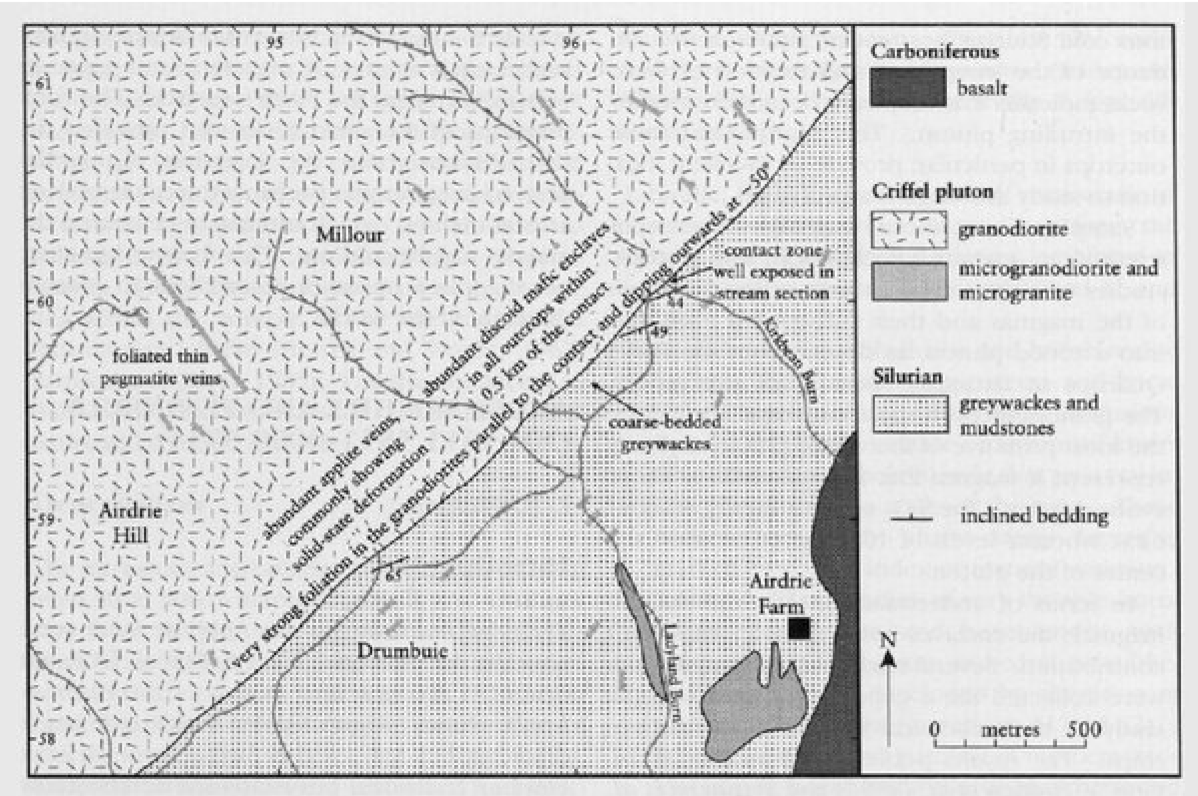
In terms of understanding the origin of the magmas, the enclaves have made an important contribution. Several enclave–host sample pairs were collected for a geochemical and isotopic study of their chemical equilibration relationships. The results published by Holden *et al.* (1987), Holden *et al.* (1991) and Stephens *et al.* (1991) indicate that considerable disequilibrium is recorded in these enclaves. The enclaves are invariably more primitive and mantle-like in their Nd isotopic signatures than the host (■Nd of *c.* –2 for the granodiorite, compared with ■Nd of *c.* 0 for the enclaves), indicating that their residence time in the main magma was limited to less than that at which full equilibrium would be achieved for all elements and isotopes. These authors provided the first firm indication that such enclaves may be the partially equilibrated remains of mantle-derived basic magmas that intruded the crust, bringing heat to assist the melting of deep crustal rocks to generate granodioritic magmas. This is not the only interpretation of the data, and the enclaves could represent exotic magmas mingled at the emplacement level, although there is no independent evidence for this at

Criffel, or that they represent disequilibrium fragments of restite.

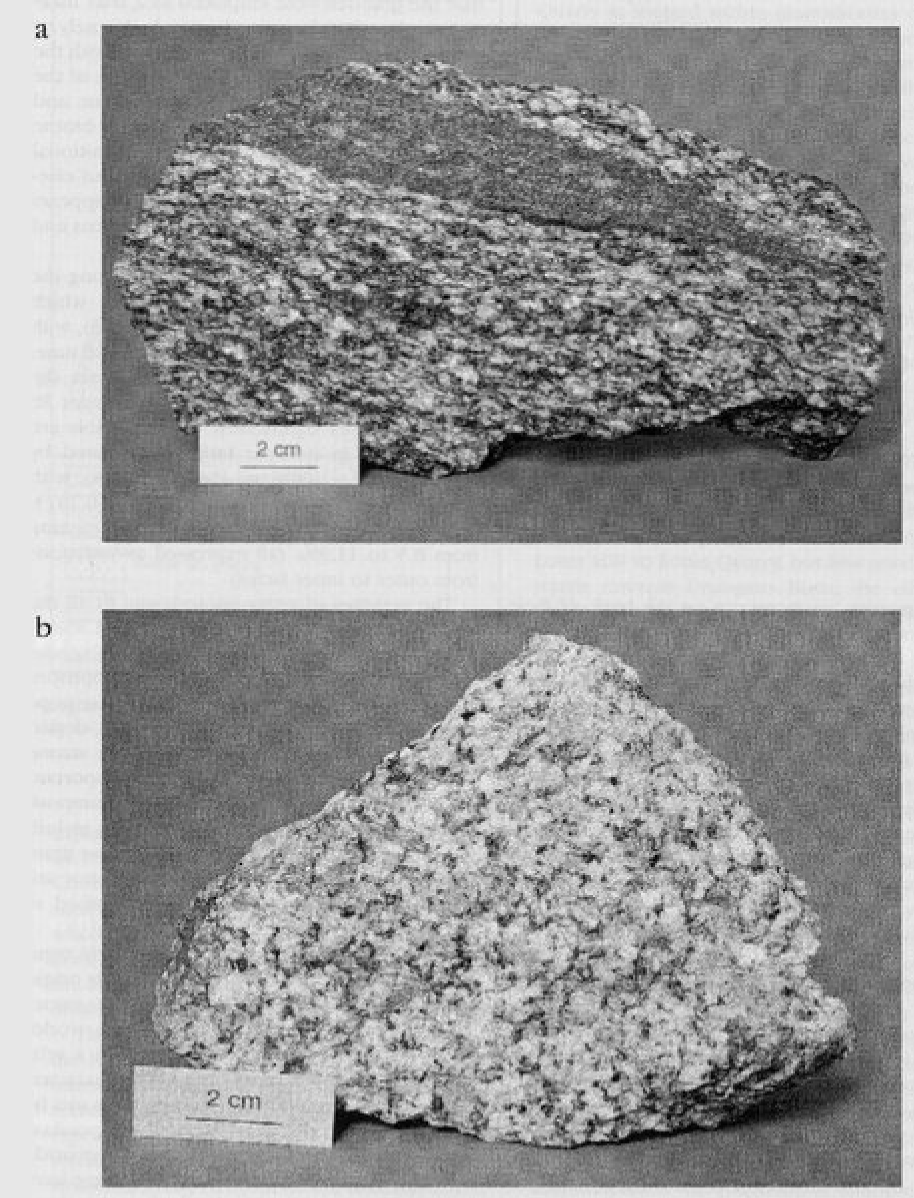
Conclusions

The Millour and Airdrie Hill GCR site exhibits, in a small area, all the main features of the early granodiorites of the Criffel pluton, which are of international importance. The structures preserved have allowed a partial reconstruction of the emplacement history of the pluton and this is contributing to the worldwide debate on how such large volumes of magma found space to occupy very near the Earth's surface. The compositions of the same rocks also provided the first evidence that the injection of mantle-derived magmas was probably the cause of deep crustal melting, which ultimately generated the magma for this pluton. This finding has since been applied by other researchers to plutons throughout the world.

References



(Figure 8.36) Map of the area around the Millour and Airdrie Hill GCR site, Criffel pluton, based on Phillips (1956), BGS 1:50 000 Sheet 5E (Dalbeattie) (1993) and observations by W.E. Stephens.



(Figure 8.34) (a) Typical clinopyroxene-biotite-hornblende granodiorite, with enclave from the margin of the Criffel pluton. (b) Biotite-muscovite granite from the interior of the Criffel pluton. (Photos: W.E. Stephens.)