LOCH DEE

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OS Grid Reference: NX458761–NX466847

Introduction

Loch Dee is located at the southern end of the Loch Doon pluton, which is one of the finest examples in Scotland of a zoned pluton showing inwards progression from a dioritic margin to an acid interior. The Loch Doon pluton stands out for the regularity of its zonation pattern over a very wide compositional range. This regularity has led to the suggestion that the zonation developed *in situ*. Another significant feature of the site is that the intermediate rocks include some of the best examples of hypersthene-mica diorite, the rock type considered to represent the parental magma for the Caledonian plutonic series in the influential model of Nockolds (1941) (see the Garabal Hill to Lochan Strath Dubh-uisge GCR site report).

The pluton was first recognized by the Geological Survey (Peach and Horne, 1899), with Teall (in the same volume) identifying the wide petrological range, which he attributed to differentiation in a deep-seated magma chamber prior to emplacement. The regularity and composite nature of the zonation within the pluton was demonstrated by Gardiner and Reynolds (1932) using a combination of mapping, petrography and density measurements, and the map of the complex has changed only in minor details with subsequent studies (although some of the rock nomenclature has been updated). Gardiner and Reynolds (1932) argued for separate intrusion of three successive magma pulses of increasing acidity.

In the 1950s the ‘granitization' and ‘basic front' transformationist theories of Doris Reynolds were applied to this pluton by McIntyre (1950), Rutledge (1952), and Higazy (1954) who argued on compositional grounds that the complex could be derived through solid-state metasomatic modification of the surrounding metasedimentary rocks. The magmatic versus replacement controversy over the origin of granites was largely settled in favour of the magmatists by the end of the 1950s, and a detailed study of the southern half of the complex (including the area around Loch Dee) by Ruddock (1969) returned to the magmatic view of petrogenesis for the pluton. He interpreted new whole-rock geochemical analyses as supporting the derivation of the complex by differentiation of a single parental magma of intermediate composition. Brown *et al.* (1979), also using a geochemical approach, concurred that a single parental magma was responsible for the complex. They identified the parental magma as monzodioritic, and postulated a two-stage fractional crystallization process. In contrast, Tindle and Pearce (1981), using an approach based largely on whole-rock trace element data, proposed that there had been two distinct parental magmas that evolved by fractional crystallization. These authors proposed that this fractional crystallization occurred *in situ* and the pluton has been widely cited subsequently as a leading example of in-situ fractional crystallization. Halliday *et al*. (1980) showed that the petrogenesis was even more complex, having identified distinctive isotopic signatures within and between the various plutonic members. Most marked is the variation in the oxygen isotope composition from the more primitive outer members to the more evolved interior which was attributed to increasing degrees of contamination of the magmas by metasedimentary rocks.

The pluton was emplaced into Ordovician metasedimentary rocks of low metamorphic grade at 408 ± 2 Ma, according to a mineral-whole rock Rb-Sr isochron (Halliday *et al*., 1980) which is in agreement with U-Pb ages of 406 ± 2 and 410 ± 1 Ma obtained from single zircons

(J. A. Evans in Floyd, 1997).

The Loch Doon pluton is important for understanding the origin of petrological zonation, there being differing views on the mechanism and the extent to which such processes can occur *in situ*. The Loch Dee site was selected for the GCR because it encloses all the important petrological variation in the southern part of the pluton. In this account the IUGS rock names of Le Maitre (1989) are applied using the modal analyses of Mahmood (1986), leading to significant differences with those of Gardiner and Reynolds (1932) and Brown *et al*. (1979).

Description

The hour-glass shaped Loch Doon pluton (Figure 8.30) is located between the Rhinns of Kells and the Merrick in Galloway. Much of the pluton forms low boggy ground between these hills, but the dioritic margins in the south and NW and the central ridge of granite form relatively positive features with moderately good exposure.

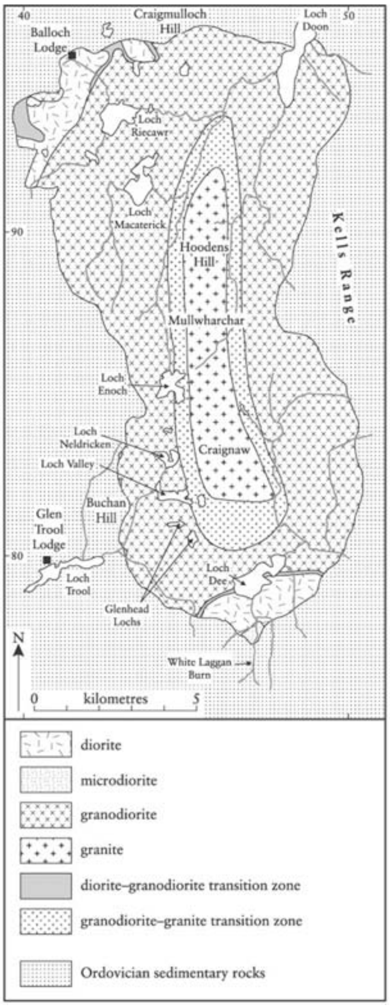

Figure 8.30: Figure 8.30 Map of the Loch Doon pluton, based largely on Gardiner and Reynolds (1932) with modifications from Ruddock (1969).

The outer contacts of the pluton are generally steep to vertical, but in the vicinity of the dioritic rocks of Loch Dee (Figure 8.30) contacts are much shallower and appear to represent a roof zone of the pluton (Stephens and Halliday, 1979). The evidence for this can be seen in small waterfalls that mark the contact zones between the diorite and country rocks in the White Laggan Burn and its tributaries. These all lie at similar topographical levels, suggesting a relatively flat, roof-like contact.

Petrological variation is concentric (Figure 8.30). There is an outer discontinuous zone of dark-coloured diorites, notably two-pyroxene-biotite diorite (fine- and medium-grained varieties with hypersthene, augite and minor olivine) and medium-grained hornblende-biotite diorites. Close to the contact south of Loch Dee these diorites are commonly quite xenolithic enclosing fragments of country rock. Good exposures of these xenolithic varieties, as well as the more normal fine-grained and medium-grained diorites, may be found in the road cuttings in the forestry plantations of this area.

The main mass of the pluton is granodiorite, with a tendency to form the low, poorly exposed ground. The rock is grey, medium- to coarse-grained, with abundant biotite and some hornblende as the principal mafic phases. The nature of the contact between the granodiorite and the dioritic facies is not clear; in places it appears to be quite sharp, but elsewhere a narrow transition zone is present. Passage to the central granite, which forms the ridge of high ground including Craiglee, Mulwharchar and Hoodens Hill, appears to be entirely gradational in the field, and no evidence of a sharp contact has been found. These white to buff-coloured granites have biotite as the only primary mafic phase and cordierite has been recorded in some microgranites at the very core of the pluton (Tindle and Pearce, 1981).

Interpretation

The main point of interest in this pluton is the exceptionally fine petrological variation, and an understanding of the origin of this variation requires combining field studies and geochemistry. The field evidence suggests a steep-sided plutonic body for the most part, except around the diorites which appear to form a roof zone. Three main facies make up the bulk of the pluton, namely diorite, granodiorite and granite. Each shows some internal variation, and the internal contact between the granodiorite and granite, in particular, is a rather broad transitional zone. The overall trend is one of increasing magmatic evolution towards the centre of the pluton.

In compositional terms, the pluton varies from the outer dioritic margin with about 57% SiO_2 (although rare samples of diorite in the NW have as little as 50% SiO_2) to the interior granite with about 72% SiO_2. The rocks are essentially metaluminous except for those with high SiO_2 levels, which are slightly peraluminous. Trace elements show no unusual enrichments or depletions relative to other South of Scotland Suite granitic rocks (Stephens and Halliday, 1984) and tend to vary smoothly through the sequence. Most trace elements decrease in abundance with increasing SiO_2 but Rb shows a continuous and marked increase as, to a lesser extent, does Th (Tindle and Pearce, 1981; Mahmood, 1986).

The concentric petrological variation is mirrored in the whole-rock isotopic composition. Initial $^{87}Sr/^{86}Sr$, for which most data are available, has the range of 0.7041–0.7051 in the diorites, 0.7052–0.7053 in the granodiorites, and increases from 0.7052 to 0.7059 in the granites (Halliday *et al.*, 1980). Whilst these differences are small, they are significant and systematic. There is a similar systematic variation in the oxygen isotopes, although on a smaller dataset. $*^{18}O$ varies from 7.8 to 8.3 ‰ in the diorites, is 8.3 ‰ in a single analysed granodiorite sample, and jumps to 10.2–10.3 ‰ in the granites (Halliday *et al.*, 1980). Nd isotopes may be more restricted with ,Nd values of –1 in the diorites and –1.4 in the granodiorites; no values have been determined for the granites (Halliday, 1984).

Most modern petrogenetic studies of this pluton have concluded that more than one magmatic pulse was involved in its construction, but the lack of clear internal contacts may indicate that at least some of the variation was formed by in-situ processes such as filter pressing and the accumulation of early formed crystals at the pluton walls (Tindle and Pearce, 1981). Such processes are isotopically closed systems and could not generate the observed isotopic variations described above; it would be necessary to involve some simultaneous assimilation of wall rocks in combination with fractional crystallization to account for such changes, as in the widely applied model of DePaolo (1981). It may be possible to apply this model satisfactorily to the geochemical variations in the Loch Doon pluton (there are no published attempts), but such a geochemical model would be inconsistent with the field evidence that the rocks requiring the greatest degree of assimilation are the innermost granites, those most isolated from the likely source of contamination. (It should be noted that the outcrops at the GCR site do not include the volumetrically less important ‘Trend 1' and ‘Trend 3' of Tindle and Pearce (1981) and thus have not been included in this discussion).

There is no model for the origin of the concentric zonation in the Loch Doon pluton that is consistent with all of the data. Isotopically, there is a requirement for two components in the magma generation, involving a primitive mantle-like component with another source which resembles the average of Southern Uplands Lower Palaeozoic crust (Halliday *et al.*, 1980). Where and how these components interacted is not known, but there is also strong evidence for the operation of fractional crystallization as proposed by Stephens and Halliday (1979) and Tindle and Pearce (1981).

In regional terms the Loch Doon pluton is the most southerly large pluton of the South of

Scotland Suite. The relatively unevolved I-type granites of this suite have little evidence of significant crustal contamination. Farther south, plutons of the Galloway Suite are more complex with evidence for greater incorporation of Lower Palaeozoic metasedimentary rocks during their genesis (Halliday *et al*., 1980) (see Clatteringshaws Dam Quarry, Lea Larks and Lotus quarries to Drungans Burn GCR site reports). One feature in common with many of the larger South of Scotland Suite granites is the presence of marginal pyroxene-mica diorites. Isotopic studies have shown that this facies is not the universal parental magma for the Caledonian granites as suggested by Nockolds (1941) and Nockolds and Mitchell (1948). Nevertheless it is important, as relatively anhydrous dioritic facies are not widely represented in granitic rocks of other orogens.

Conclusions

The Loch Dee GCR site was chosen as representing a key segment of the Loch Doon pluton, which has made important contributions to international studies of when and where compositional variation is developed in the history of a granitic pluton. Possible sites are *in situ*, by accumulation of crystals against the walls of the pluton and squeezing out of remaining magma towards the centre (filter pressing), or by fractionation in a feeder magma chamber beneath the pluton. Other possible factors include contamination during ascent, and heterogeneities in the original source. Presently no single model fully accounts for the variations within the Loch Doon pluton; it is expected that the Loch Dee GCR site will continue to provide new and valuable constraints in developing a fully consistent model, and that this will have implications for many plutons elsewhere in the world that show similar concentric petrological zonation.

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