Significance of the cumulate mineralogy of the Belhelvie mafic–ultramafic intrusion—comments on: Silicate mineralogy of the Belhelvie cumulates, NE Scotland, by W. J. Wadsworth

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Abstract

New data on the composition of cumulus phases in the Belhelvie intrusion presented by Wadsworth (1991) are discussed in the light of existing data and of knowledge on the form and internal structure of the intrusion. The relevance of the Rustenburg Layered suite of the Bushveld Complex as a model for the 'single intrusion' hypothesis for the layered basic intrusions in NE Scotland is examined: current knowledge of the Rustenburg Layered Suite and related intrusions suggests that similar crystallisation sequences of cumulus phases and ranges of cryptic variation do not give any case *for* a single intrusion hypothesis.

KEYWORDS: cryptic variation, cumulates, Belhelvie, Scotland.

Introduction

THE Belhelvie layered mafic–ultramafic intrusion is situated astride the coast of NE Scotland, 8 to 16 km north of Aberdeen (Fig. 1). Aeromagnetic data (IGS, 1968) indicate that a large part of the intrusion lies offshore, much of the offshore extension probably consisting of ultramafic rocks (Ashcroft and Boyd, 1976). The northernmost part of the landward extension of the intrusion consists of a sequence of cumulates—ultramafic, troctolitic, gabbroic and noritic—which is repeated to the east of a thin septum of country rocks, and with a thin unit of norite along the western margin of the body (Ashcroft and Boyd, 1976). The Belhelvie intrusion has been the topic of numerous papers, i.e. Stewart (1946), Wadsworth *et al.* (1966), Ashcroft and Boyd (1976), and Boyd and Munro (1978); the most comprehensive published description is in the BGS Memoir for sheet 77 (Munro, 1986). The most recent paper on Belhelvie (Wadsworth, 1991) has prompted this communication.

Cryptic variation and internal structure

Wadsworth *et al.* (1966) presented chemical, optical and X-ray data on the composition of the major cumulate phases; olivine, plagioclase, clinopyroxene and orthopyroxene. The results showed 'slight cryptic layering', viewed in the context of the form of the body as shown on Fig. 1 of the paper, i.e. without the country-rock septum and repetition of the cumulate sequence demonstrated by Ashcroft and Boyd (1976). Wadsworth *et al.* (1966) divided the intrusion from its westernmost to its easternmost contact into three units: A, ultrabasic; B, troctolite and C, olivine- and hypersthene gabbro.

As reported by Munro (1986), Boyd (1972) carried out microprobe and optical investigations which showed broadly comparable patterns of cryptic variation in the two cumulate sequences. Mineral compositions based on 33 microprobe analyses were presented by Munro (1986); the data gave a slight extension of the total range of cryptic variation in all four major cumulate phases

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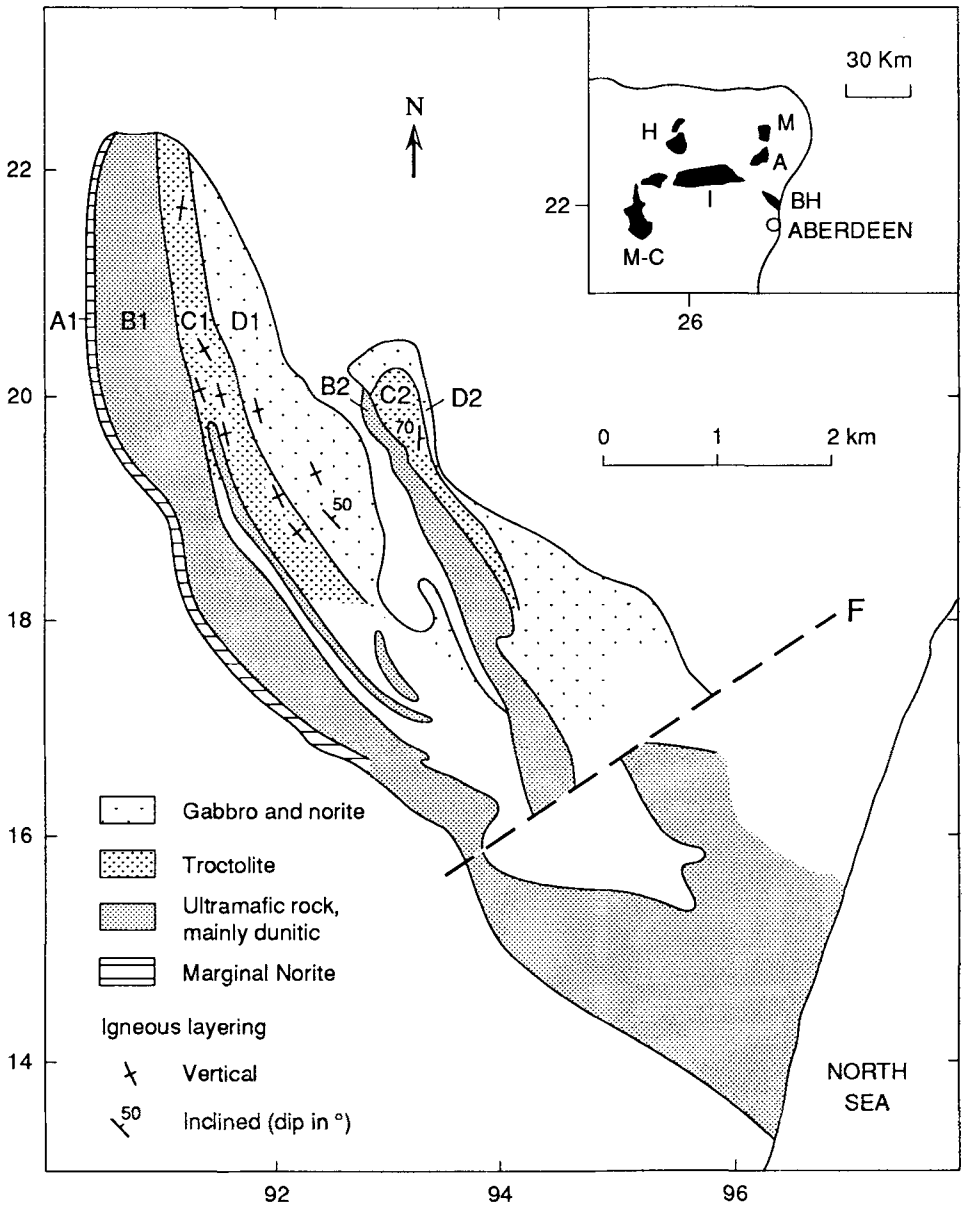

FIG. 1. Geological map of the Belhelvie intrusion: A1, B1, C1 and D1 refer to the major lithological units within the complex, the uppermost three of which are repeated east of a septum of country rock. The inset shows the Belhelvie Mass (BH) in relation to other mafic intrusions of similar age in north-east Scotland (H: Huntly, M-C: Morven-Cabrach, I: Insch, M: Maud, A: Arnage), simplified from Ashcroft and Boyd (1976).

documented by Wadsworth *et al.* (1966), but viewed the results in the context of a different understanding of the form and internal structure of the body.

Wadsworth (1991) presents microprobe data from seven samples from Belhelvie. His Fig. 1 shows the location of the samples in relation to geological boundaries that are attributed to the work of Wadsworth *et al.* (1966) in the caption, but which in fact are clearly those shown on Fig. 3 of Ashcroft and Boyd (1976).

The analyses presented by Wadsworth (1991)

extend the range of orthopyroxene compositions already documented in the intrusion from En_{81-76} to En_{87-76} and extend the range of clinopyroxene compositions slightly, but do not add to the ranges already shown for olivine and plagioclase (Boyd, 1972; Munro, 1986). They reaffirm the picture of modest cryptic variation at Belhelvie documented by Wadsworth *et al.* (1966), Boyd (1972), and Munro (1986), and confirm the similarity of the crystallisation orders of cumulus phases and of their compositions at Belhelvie and in the southeasternmost part of the Insch intrusion to the NW (Ashcroft and Munro, 1978).

The 'single layered intrusion' hypothesis

Wadsworth (1970) interpreted the layered mafic-ultramafic intrusions of NE Scotland as 'having originated as a single layered intrusion of Bushveld type'. This concept, originally suggested by Read (1923), has been the subject of some controversy; its advocates include Shackleton (in discussion of Read and Farquhar, 1956) and Stewart and Johnson (1960), while its opponents include Ashcroft and Munro (1978) and Munro (1986) who felt that the intrusions had been emplaced and had evolved separately.

Wadsworth (1991) argues that 'similar cumulate successions, in terms of both phase and cryptic layering, would obviously favour the disrupted sheet hypothesis, and any minor differences could be explained as due to local variations . . . within a single large magma chamber' and uses his new data to support this model. He cites Eales *et al.* (1988) as describing this type of variation in 'the Bushveld intrusion'; the paper, however, is specifically concerned with variations within the Western Bushveld Complex.

Cousins (1959) demonstrated that the Rustenburg Layered Suite of the Bushveld Complex does not form a single, sheet-like intrusion and that it probably consists of separate bodies, each having its own feeder. Von Gruenewaldt (1979) states that 'the complex should be seen in terms of seven shallow, cone-like intrusions'; elsewhere in the same paper, he cites several authors, including Willemse (1969) and Vermaak (1976), as support for the view that 'the complex consists of a number of essentially separate and only partly overlapping intrusions'. A tectonic model for the location of the feeders to the Rustenburg Layered Suite, and which also encompassed the location of the related satellite intrusions such as Losberg, was given by Sharpe *et al.* (1981). Clearly, the Rustenburg Layered Suite and related intrusions, as seen by many authors in the light of the voluminous studies conducted of them in recent years, thus provides a strong argument for the view that similar crystallisation sequences of cumulus phases and ranges of cryptic variation do not give any case *for* a single intrusion hypothesis; such similarities are compatible with both single and multiple intrusion hypotheses. The obverse is also, within certain limits, the case. It has been demonstrated, within the last decade that both the various parts of the Rustenburg Layered Suite (Sharpe, 1981; Sharpe and Irvine, 1983; von Gruenewaldt *et al.*, 1985) and the Stillwater Complex (Todd *et al.*, 1982; Irvine *et al.*, 1983) formed from multiple magma pulses of at least two distinct magma types, of respectively olivine boninitic and tholeiitic affinities (Irvine and Sharpe, 1982; Sharp and Irvine, 1983; von Gruenewaldt *et al.*, 1985). This suggests that care would have to be exercised in drawing from hypothetical divergences in sequences of crystallisation of cumulus phases in the intrusions in NE Scotland, the implication that this necessarily supported the hypothesis that they were emplaced as separate intrusions rather than as a single sheet. Further complications would be introduced by the potential presence of lateral cryptic variation of the type shown in the Fongen–Hyllingen intrusion to reach up to 62% forsterite along the strike of modal layering (Wilson and Larsen, 1985). The similarity of cumulate successions is no more evidence *for* the origin of the basic bodies in NE Scotland as a single intrusion than the presence of subtle differences in the successions, be it phase or cryptic layering, would be evidence *against* such an origin.

The magmatic 'event' which includes the Rustenburg Layered Suite of the Bushveld complex and its satellite intrusions has subsequently been shown to include the Malopo Farms Complex in Botswana (Gould *et al.* 1986): the lithologies of the Malopo Farms Complex are comparable with, but not identical to those found in the Rustenburg Layered Suite (von Gruenewaldt *et al.*, 1989). There is thus a great deal of evidence for a regional magmatic event leading to the emplacement of several intrusions at a roughly similar level in the crust. A much 'simpler' example of a complex located in a zone of crustal weakness and consisting of individual magma chambers separated at depth but connected at present erosion level, is provided by the Great Dyke (Wilson and Prendergast, 1989). The, in parts, roughly linear string of intrusions extending from the innermost part of the Gulf of Bothnia across northern Finland and into Russia (Alapieti, 1982; Alapieti *et al.*, 1990) has some similarities to the Great Dyke: two of the complexes, the block-faulted

Koillismaa complex, and the Näränkävaara complex on the Finnish–Russian border, have a concealed connection which does not reach the present erosion surface but which is interpreted to be dyke-formed on the basis of geophysical data (Alapieti, 1982).

All three intrusive suites cited above illustrate areally very extensive magmatic events, during which several feeder channels, the location of which had a tectonic control, were exploited. The extent to which the magma chambers fed from the separate feeders overlapped or became connected depended on magma volume and tectonic factors: our current view on this is influenced by whether geophysical data are available to aid us, but also by the fortuitous impression given by present-day-, and possibly also palaeo-erosion surfaces. All three intrusive suites are emplaced into stable cratons, in the second case along a linear zone of weakness, and in the third case at least partly so. It is questionable whether even the simplest of these, the Great Dyke, can be regarded as a single intrusion in the normal sense of the expression. It would seem even less probable, particularly if one regards the layered mafic–ultramafic intrusions of NE Scotland as being synorogenic sensu strictu rather than intraorogenic, that they should ever have been part of a single intrusion. Ashcroft *et al.* (1984) have demonstrated that the intrusions are largely enveloped in a regional system of vertical anastomosing shear zones which were active late in the Caledonian orogeny, but which are deep-seated and may have had a long history. While there can be little doubt that the mafic–ultramafic intrusions form a single magmatic 'event', the evidence indicates that each represents a separate tapping of the source(s) at depth with subsequent emplacement as several individual bodies in the tectonically complex environment which now forms the Dalradian in Buchan.

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