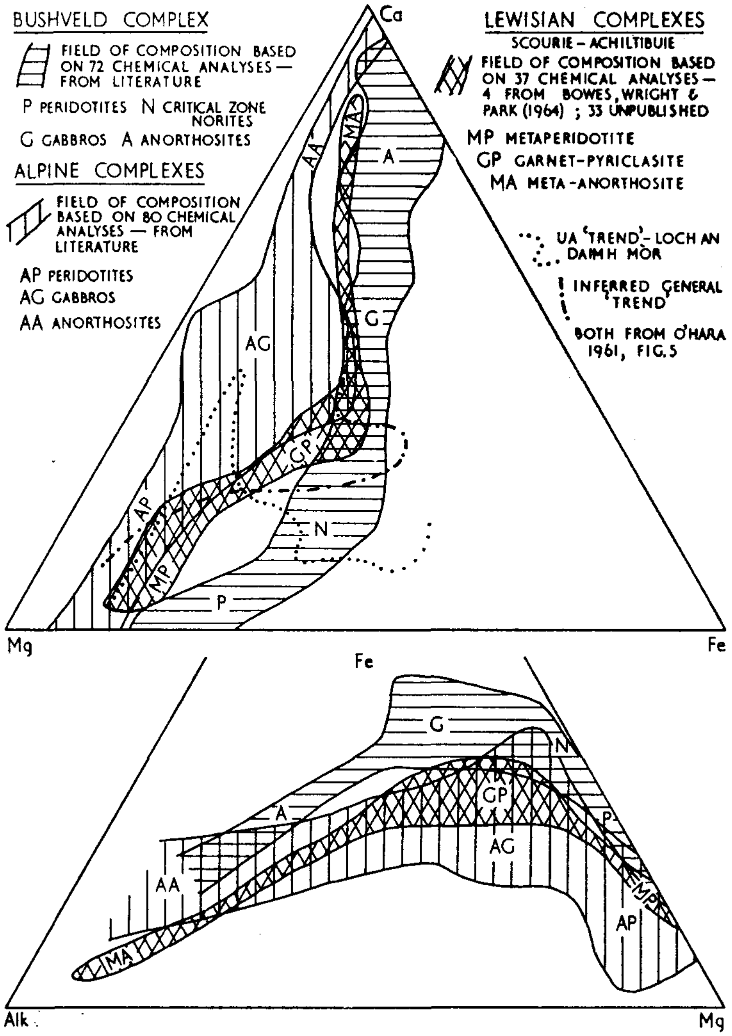
CORRESPONDENCE

ORIGIN OF ULTRABASIC AND BASIC MASSES IN THE LEWISIAN

SIR,—In a recent issue of *Geological Magazine* (1965, 102, 296–314) Dr. M. J. O'Hara has criticized extensively our paper on layered intrusive rocks in the Lewisian (Bowes, D. R., A. E. Wright, and R. G. Park, 1964, *Q.Jl. geol. Soc. Lond.*, 120, 153–192). However, a significant feature of his contribution is the agreement revealed on a number of matters with our conclusions based on work over a much wider area. The ultimate igneous origin of the ultramafic rocks, the tectonic emplacement of the masses, and the subsequent granulite facies metamorphism with the development of the gneissosity (as distinct from the layering) after the emplacement of the ultrabasic intrusions are all mutually agreed. The impression of general disagreement given by O'Hara's abstract (1965) is not borne out by the paper itself as the conclusions reached do not differ from ours except in relation to the origin of the banding in these masses, the origin of the basic rocks, and the possibility of the existence of relict igneous features. The recognition by Dr. O'Hara (1965, p. 299) of the importance of layering in the ultrabasic—basic masses represents a change in his previously expressed views.

The four possible modes of origin of the layering listed by O'Hara (1965, pp. 299–300) as alternatives to our conclusion (viz. recrystallization of original igneous layering) we consider to be unsatisfactory. (i) One relates only to variations in the proportion of amphibole present and does not appear to explain the varying proportions of olivine, ortho- and clinopyroxene and chrome spinel in the bands. Until a fuller explanation of " mechanical sorting of existing metamorphic minerals during deformation " is available, we are unable to see the relevance of this mode of origin to rhythmic banding of olivine and pyroxene at granulite facies. (ii) A second alternative involves metamorphic differentiation as the process responsible for the compositional banding. Whilst this process is capable of producing banded rocks, there is evidence that the compositions of individual bands so formed do not, in general, correspond to igneous compositions (see Bowes, D. R., and R. G. Park, 1966, *J. Petrol.*, 7 (2). In the case of the Lewisian banded ultrabasic—basic rocks, the compositional trends of the bands and the masses correspond and follow an igneous trend (Text-fig. 1). (iii) Metasomatic introduction of material from the country rock—the mechanism favoured by O'Hara (1961, pp. 273–4)—has yet to be demonstrated to apply to the major *banding* in these masses, even on the scale of a few centimetres. Where a metaperidotite contact can be observed, as inland from the first inlet west of Pairc a' Cladaìch, the metaperidotite shows no systematic variation away from the contact. The adjacent rock, a variable hornblende gneiss, corresponds with country rock unconnected with metaperidotite or garnet-pyriclasite which occurs in many places in the Scourie district, and south towards Kylesku. (iv) There remains the possibility that the banding was formed by some non-magmatic and possibly tectonic process prior to the granulite facies metamorphism. If so, it represents an earlier event than any identified so far in the country rocks.

O'Hara considers the basic masses to be zoned around the ultrabasic rocks and disputes our evidence to the contrary (1965, pp. 296–9). However the new maps presented by him are either generalized or interpretive at crucial localities. We purposely used the term garnet-pyriclasite in our paper to distinguish it from " garnetiferous basic gneiss " which is common in the Scourian country rocks. Those parts of the Loch an Daimh Mor mass recorded by O'Hara (1965, Text-fig. 1) as being " garnetiferous basic gneiss " consist of a variety of lithologies corresponding to those of the country rocks. Because of this variation in lithology and the presence of much tectonized and retrograded bands (? slices) of garnet-pyriclasite which here has a gneissosity produced during this retrogression, we recorded the composite assemblage



TEXT-FIG. 1.—Fe : Ca : Mg and Mg : Fe : Alk plots (Cation per cent) of analyses of rocks from the Bushveld complex, alpine complexes, and Lewisian complexes (Scourie-Achiltibuie).

as "gneiss" (Bowes, Wright, and Park 1964, Fig. 6)—not "acid gneiss" as O'Hara (1965, Text-fig. 1) incorrectly indicates. The juxtaposition of thin bands of deformed igneous rock and varieties of country rock in an area of very indifferent exposure is a very unfavourable situation for geochemical work on which to base a postulation of the zoned nature of the complex (O'Hara, 1961) not apparent from the field relations (cf. O'Hara, 1965, Text-fig. 1). It would, however, explain the unusual and erratic geochemical

" trend " plotted by O'Hara (1961, Fig. 5), a trend which bears no relation to the metaperidotite-garnet-pyriclasite-anorthosite fields of composition shown by the rocks of the ultrabasic—basic masses occurring from Scourie to Achiltibuie (Text-fig. 1) or to the field of composition of the rocks of the metaperidotite-garnet-pyriclasite masses at Scourie.

The zones depicted by O'Hara in the mass north of Scourie House (1965, Text-fig. 2) cannot be substantiated and the figure is incorrect in indicating that " ultrabasic gneiss " (metaperidotite) crops out continuously immediately west of the sheepfold. Evidence here, vital for his hypothesis of zoning, is lacking, as there is an expanse of grass at the north-eastern end of the main " garnetiferous basic gneiss " outcrop between the outcrops of metaperidotite on its north-western and south-eastern sides. Without this evidence the map presented by O'Hara is clearly an interpretation which the parallelism of the banding from end to end thoughout the mass does not support.

We agree with O'Hara (1965, pp. 298–9) that garnet-pyriclasite is found both underlying and overlying metaperidotite in a number of complexes (O'Hara incorrectly ascribes a contrary view to us). However, it does not form a zone surrounding metaperidotite, the greater repetition of units is in the smaller masses, and flat lenticular masses of hornblendic and acid gneisses and granulites of the country rock are found within may of the complexes. In addition not only is metaperidotie found as isolated lenses within the country rock, but in a number of places between Scourie and Kylesku, garnet-pyriclasite occurs as separate lenses in the country rock with no metaperidotite anywhere nearby. Garnet-pyriclasite and metaperidotite are not systematically associated as claimed by O'Hara (1961, p. 272 ; 1965, p. 313), and such an association would seem to be essential for Dr. O'Hara's interpretation, but not for ours. These relationships and the outcrop patterns within the complexes such as near Loch an Daimh Mor and Scourie House (O'Hara, 1965, Text-figs. 1 and 2) can be interpreted as the result of tectonic slicing of a layered ultrabasic-basic complex(es) during the intense deformation associated with the prominent tectonic banding of the country rocks of the " Scourian block " with the insertion of slices of country rock between slices of igneous rock. The larger slices would act as discrete units in the continuing deformation, while the smaller slices would show more intense tectonic effects behaving in the same way as lithological layers in the country rock.

Since O'Hara (1965) gives the impression that the presence of folds in the ultrabasic—basic masses weakens our case, it is important to explain the relationship between the folds, the foliation and the compositional layering. In the country-rock gneisses, the early folds are tight or isoclinal and are cut, parallel to their axial planes, by the dominant foliation. The minerals within the bands are aligned parallel to the lineation developed on the foliation planes. On the other hand where folds of the same orientation, style, and presumed age occur in the layered masses it is the compositional banding (= the layering) that is folded (Bowes, Wright, and Park, 1964, Fig. 5*a*). In both cases the granulite-facies metamorphism is either coeval or post-dates the folds. While tectonic structures are present in some of the ultrabasic masses, and are more common than the emphasis of our paper suggests, the discordance of axial plane and banding (cf. O'Hara, 1965, Text-fig. 3) and the overall regularity and parallelism of the banding suggest that tectonic deformation of bands within individual masses has been minimal. Obviously, where layering is folded and cut by a foliation, structures simulating current bedding, etc., will result but sedimentation-type structures in places where the layering is unfolded are difficult to explain by tectonic agenies. The granulite facies metamorphism has obscured many of the original features of these masses but despite the metamorphism, the existence in the Lewisian rocks of olivine-pyroxene-spinel bands and anorthosite bands, the latter a feature not mentioned by O'Hara (1965), strongly supports an igneous origin for the banding.

Some basic rocks containing garnet, which may have formed by reaction between ultrabasic rocks and the country rock do occur, such as those beneath the metaperidotite at Loch Culag, Lochinver (Bowes, Wright, and Park, 1964, mass 17). However, the amount of these rocks is small and we consider them to be quite different from the garnet-pyroxene-plagioclase rocks.

We agree with much of the criticism of O'Hara (1965) concerning both the presentation and paucity of our geochemical data. The emphasis in our paper being on field evidence, the geochemical (and mineralogical) sections were, of necessity, very restricted. O'Hara (1965, p. 307) points out that the rapid alternation of chemical composition shown by our analyses (D 1–4) does not support an igneous origin for the banding. However, the relevance of comparing normative mineral compositions of bands in rocks which have undergone a granulite-facies metamorphism with reaction at band boundaries (Bowes, Wright, and Park, 1964, p. 178) and at least one subsequent amphibolite-facies metamorphism may be doubted particularly as calculations of normative Fa per cent of feldspar-rich rocks and normative An per cent of mafic rocks are likely to be unreliable, even in igneous suites. Variation in metamorphosed masses are found which show the inverse relationship of Fa : An per cent which Dr. O'Hara thought unlikely (1965, p. 307) in our much more segregated bands. For the Bay of Islands complex (Cooper, J. R. 1936, *Bull. geol. Sect. Dep. nat. Resour. Newfoudld*, 4) troctolite has 80 per cent An, 21 per cent Fa, gabbro 73 per cent An, 28 per cent Fa and metagabbro 89 per cent An, 46 per cent Fa (our calculations) with modal variation in An per cent An_{66}—An_{82}—An_{70}. Until much more is known of the nature of individual bands in layered rocks of alpine and stratiform type, it is difficult to assess the evidence obtained so far. We agree that Dr. O'Hara's reasoning in the matter seems logical, but when relatively unmetamorphosed and undeformed rocks show apparently anomalous results, we are not surprised at the variations present in the Lewisian rocks. O'Hara (1965, p. 307 and 312) also implies that we considered that igneous differentiation actually took place within the small bodies as now seen. We had assumed that our references to alpine-type intrusions were sufficient to imply the solid intrusion of fragments of a pre-existing large layered complex(es). We do not consider that any of the basic masses were necessarily originally adjacent to the ultrabasic rocks now seen with them. Thus the present position of the basic rocks may be misleading when trying to discover the original sequence of chemical variation.

A detailed structural and geochemical study of the Achiltibuis ultrabasic–basic mass is in progress, this being the largest and apparently least deformed of the masses and the one in which anorthosite bands are well-developed. This follows a geochemical study relating to the ultrabasic–basic masses in the " Scourian block " which will be published shortly along with a discussion of the geochemistry of the various bands and a comparison with the geochemistry of some stratiform and alpine igneous masses. The results indicate a considerable similarity in both fields and trends with two undoubted igneous suites (Text-fig. 1), but it would appear that the Lewisian bodies are not unequivocally assignable to either stratiform or alpine-type. This conclusion corresponds with that drawn on the basis of field evidence (Bowes, Wright, and Park, 1964, p. 189). In contrast, the "trends" of O'Hara (1961, Fig. 5.) can be seen to bear little relation to those derived from a much more comprehensive sample.

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Sir,—I am glad that Bowes *et al.* (1966) now observe the agreement on three principal points between Bowes *et al.* (1964) and O'Hara (1961, pp. 272–275). Much of the remaining field of conflict between our views concerns contradictory reading of the field evidence and cannot be resolved by further discussion, but Bowes *et al.* (1966) have raised three points worthy of remark.

(i) Their comments on the occurrence of isolated masses of ultrabasic or garnetiferous basic gneiss in the country rocks are covered by my earlier remarks (O'Hara, 1961, p. 272, l. 26–33 and p. 275, l. 4–9).

(ii) They suggest that data in Cooper (1936) throw doubt on the usefulness of criteria for composition variation in *adjacent* layers of igneous complexes used by O'Hara (1965). The three samples in question were gathered at three different localities up to five miles apart, and I doubt if they are relevant to discussions of the chemistry of adjacent layers.

(iii) The ten analysed samples from the Loch an Daimh Mhor mass (O'Hara, 1961, table 3, and figs. 3, 4, 5) came from successive layers of two contiguous specimens collected from a well exposed lower contact of the lower serpentinite layer (location given by O'Hara (1961, p. 249) and deducible from O'Hara (1965, fig. 1B and p. 297). Neither indifferent exposure nor alleged juxtaposition of igneous rocks and country rocks can explain away the geochemical sequence, the principal features of which (rapid increase of Fe/Mg ratio at relatively low Ca/Ca + Mg + Fe ratio) is reproduced by 8 analyses of materials from five different masses (these samples being chosen as representing good samples of the principal petrographic types involved in the masses). The dissimilarity between these trends and those revealed by alpine-type ultrabasic masses and a layered igneous complex (Bowes *et al.* 1966, fig. 1) strengthens my case that the basic gneisses are not related to the ultrabasic gneisses by an igneous mechanism. The fact that data collected by Bowes *et al.* (1966, fig. 1) over a much wider area define a composition " field " which does not include 8 out of 18 samples chosen for analysis by O'Hara (1961) suggests that Bowes *et al*'s. sampling is less, not more, comprehensive than mine.

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April, 1966.

CLOUDED FELSPAR

Sir,—The recent demonstration that clouded felspar in the dykes from the Scourie district contains more water than unclouded felspar from the same rocks (Burns, 1966) is of considerable interest, and would appear to have a petrogenetic significance outside the metamorphosed rocks in which it has been described.

Black felspars occur in several geological environments in South Greenland, as constituents of charnockites, as primary minerals in andesitic dykes formed under regional metamorphic conditions, and as primary plagioclases in unmetamorphosed alkali gabbros of the Gardar igneous province. Only the black felspars from the last environment have been investigated in any detail.

Black felspars occur in the Gardar alkali gabbro dykes as giant megacrysts, some of which reach 30–40 cm. in length. They are commonly rimmed by clear felspar which has apparently formed from the black felspar by loss of colour during interaction with their basic hosts. It is thought significant that black felspars taken from hosts in which primary hornblende crystallized do not show the clear rims. The black and clear felspars show very similar properties except for colour; they are integral parts of the same crystals, twin planes crossing from one part of the crystal to another with no break at the border between the two colour varieties. The chemical composition of the two types is identical with respect to the major elements. However, water is significantly more abundant in the black felspar than in the clear.