A suggested igneous origin for the banded granular hornfelses within the hypersthene-gabbro of Ardnamurchan, Argyllshire.

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THE hypersthene-gabbro of Centre 2, Ardnamurchan, is intruded largely amongst sedimentary rocks. Despite this fact the majority of the inclusions are, as described by Richey and Thomas (1930), of granulitized basic and ultrabasic igneous rocks. Recently M. K. Wells (1951) studied this problem again, but was only able to find four occurrences in which the xenolith was undoubtedly of sedimentary origin. However, he considered in some detail a problematical group known as the banded granular hornfelses and concluded that, despite four possible modes of origin, the textural and compositional evidence favoured a development through the metasomatism of sediments.

The banded granular hornfelses are, according to Wells, generally characterized by a normal gabbroic suite of minerals, prominent concordant layering—often rhythmic and on a very fine scale, and a relative deficiency in clinopyroxene. These features typify rocks from certain horizons within layered basic intrusions, such as the rhythmically layered allivalites from the Isle of Rhum. Where these allivalites are caught up as inclusions within the later fine-grained gabbros, then the metamorphic sieve-texture of the olivines appears to replace the original poikilitic texture.

One diopside-bytownite-hornfels is described in detail (1951, pp. 731–732), Wells considering that the rock is of sedimentary origin because of its composition. An analysis is given, and though it is not compared directly with that of any other rock it is said to have features which the other hornfelses of this group lack—a composition closer, perhaps, to certain sediments of the marl or calcareous mudstone group than to any normal igneous rock.

A comparison of the chemical analyses of calcium-rich argillaceous sediments (e.g. Pettijohn, 1949) with that of the hornfels reveals certain major discrepancies. Most striking is the $K_2O:Na_2O$ ratio which is 2·5:1 in an average of 78 shales (Goldschmidt, 1954, p. 159) and, due

to its higher value in limestones (6·6:1), increases as the shale becomes more calcareous (e.g. the marl in table I). A further major difference lies in the proportion of Al_2O_3:SiO_2, which is abnormally high (0·52:1) in the hornfels. The average shale has an Al_2O_3:SiO_2 ratio of about 0·25:1, while that of the average limestone is 0·15:1 (Clarke, 1924, pp. 34, 564), the only argillaceous sediments with a much higher value being the residual bauxitic clays which are lime-free. Hence the simple metamorphism of any normal sediment could not produce the hornfels, and Wells, drawing attention to the unusual K_2O:Na_2O ratios (1951, p. 733), suggests metasomatism as a means of explaining the differences in composition of sediment and hornfels.

In order to view the relationship between the composition of the hornfels and that of a normal igneous rock, similar analyses were examined amongst Washington's superior chemical analyses of fresh igneous rocks (1917). Though several similar analyses are to be found amongst the gabbros, an almost identical analysis (table I) is that of the Tertiary olivine-gabbro from the Cuillins, Isle of Skye. The chemical composition of the hornfels is closer to that of the Skye gabbro than to that of any normal sediment. Mineralogically the differences are not great, for the rock analysed by Pollard is better described as an olivine-eucrite, low in olivine and having, in the CIPW norm, 79 % bytownite (An_{81}), 10 % diopsidic pyroxene, and 7 % olivine. The low silica content of the hornfels is, in view of the absence of olivine, probably due not only to the presence of 2·4 % normative ore but also to the epidotization which Wells comments upon.

Texturally the hornfels consists of layers of closely packed clino-pyroxene crystals separated by similar aggregates of bytownite crystals, the width of the layers varying from a millimetre to a centimetre. Such layering is a common feature of the ultrabasic rocks of Hallival and Askival, Isle of Rhum. There the layering, believed to be the product of a rhythmic deposition of crystals separating from a slowly-cooled basic magma, consists of a rapid alternation of crystals of bytownite, olivine, diopsidic pyroxene, and sometimes chrome-spinel. The formation of monomineralic layers is believed to be due to diffusion of material, in the interprecipitate liquid, in response to deposition round primary crystals and the subsequent establishment of a composition gradient (cf. Hess, 1939; Brown, unpublished thesis, 1954). Rocks in which the only minerals to participate in the layering are diopside and bytownite are found in Rhum, though subordinate to the rest. One in which the grain-size and general distribution of the minerals is com-

parable with that of the calc-silicate hornfels (Wells, 1951, fig. 11) is shown in fig. 1. The fine grain-size of the Rhum rock is attributed to granulitization through slumping, whereas in the hornfels it may be due to granulitization by re-heating.

TABLE I. Analysis of the diopside-bytownite inclusion from Ardnamurchan compared with analyses of igneous and sedimentary rocks.

		1.	2.	3.	4.
SiO_2	...	46·26	46·39	48·92	48·12
Al_2O_3	...	24·18	26·34	25·00	12·80
Fe_2O_3	...	1·38	2·02	0·48	1·60
FeO	...	3·96	3·15	0·75	3·25
MgO	...	3·58	4·82	4·30	2·55
CaO	...	17·67	15·29	18·01	10·77
Na_2O	...	1·54	1·63	1·65	0·60
K_2O	...	0·09	0·20	0·09	3·60
H_2O+	...	0·73	0·48	0·19	3·25
H_2O-	...	0·19	0·10	0·15	1·70
TiO_2	...	0·16	0·26	0·19	0·78
P_2O_5	...	nil	trace	nil	0·65
MnO	...	trace	0·14	0·05	0·05
Cr_2O_3	...	n.d.	trace	0·22	-
CO_2	...	nil		n.d.	9·19
Others	...	—			1·37
		99·74	100·82	100·00	100·32

1. Banded calc-silicate hornfels, Sanna Point, Ardnamurchan. Analyst, W. H. Herdsman. (Wells, 1951, table III.)
2. Olivine-gabbro of Cuillin Hills, Isle of Skye. Analyst, W. Pollard. (Harker, 1904, p. 103.)
3. Layered allivalite (H5049) from the Isle of Rhum, recalculated to 100 % after subtracting 20 % olivine. Analyst, G. M. Brown.
4. Marine marlstone (calcareous shale), Ordovician. Analyst, D. Schaaf. (Pettijohn, 1949, table 84.)

Though a pyroxene-felspar accumulation has not been analysed from Rhum, a neighbouring olivine-pyroxene-felspar accumulation has. As the olivine from the rock has also been analysed, the composition of a pyroxene-felspar accumulation has been obtained by subtraction of the composition of an appropriate amount of olivine from the rock analysis. This estimated composition (table I, column 3) compares closely with that of the banded pyroxene-felspar-rock from Ardnamurchan (column 1). Differences are probably due to the absence of epidote and scarcity of ore in the Rhum specimen, and consequent greater SiO_2 content, and to the more ferriferous character of the Ardnamurchan pyroxene. The ore and clinopyroxene in the Rhum specimen are chromiferous, and it would be of interest to know the Cr_2O_3 content of the Ardnamurchan hornfels.

To derive the banded granular hornfels inclusions of Ardnamurchan from sedimentary rocks, as suggested by Wells, would require much metasomatic replacement as well as complete recrystallization. On the other hand, there are varieties of layered ultrabasic or basic igneous

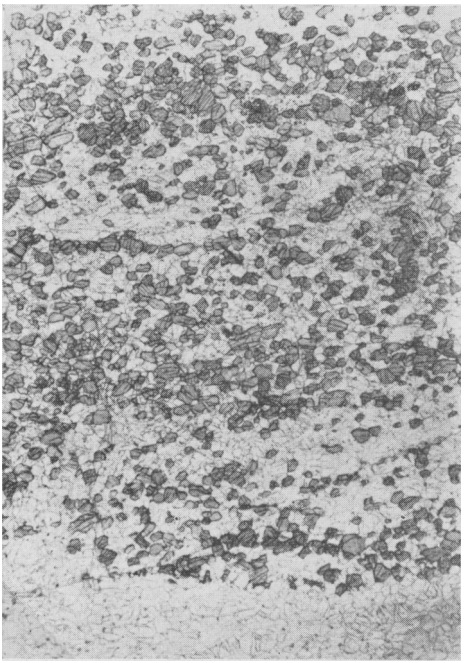

FIG. 1. Photomicrograph of a banded diopside-bytownite-rock (H 5626) from the ultrabasic layered series (unit 10), Hallival, Isle of Rhum. ×11.

rocks, such as found in Skye and Rhum, from which the hornfelses could be derived by simple thermal metamorphism. It seems reasonable to suggest that such rocks exist at some level beneath the Ardnamurchan layered hypersthene-gabbro.

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