

*The 'pseudodiorites' of Dielette*

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*Summary.* An account is given of the mineralogy and chemistry of the 'pseudodiorites' of Dielette, the hornfelses from which they are derived, and the contaminated granite veins associated with them.

**C**ALCAREOUS sediments, of Devonian age, and thermally metamorphosed by the Flamanville granite, outcrop on the shore just south of the village of Dielette in north-west France. The resulting metamorphic rocks were described by Michel-Lévy (Michel-Lévy, 1894) and, later, by Mme Jérémine (Jérémine, 1931).

The main type is a fine grained pyroxene-garnet-plagioclase hornfels, with varying amounts of these three phases. Chemical analyses given by Mme Jérémine of a typical hornfels, a pyroxenite band, and a garnetite (Jérémine, 1931, p. 44), proved all the rocks to be rich in iron and poor in magnesium. The chemical analysis of a block of relatively coarse-grained pyroxene-plagioclase rock (collected by Prof. A. Lacroix) was also given. This rock, termed 'pseudodiorite' by Mme Jérémine, was also rich in iron, and was considered to be the end term in the alteration of the more normal hornfelses by the granite.

It was thought that a more detailed chemical investigation of the 'pseudodiorite' and the related rocks might prove to be of interest. Typical 'pseudodiorite' was observed at the margins of veins of fine-grained granite,<sup>1</sup> which cut the pyroxene-garnet-plagioclase hornfels, and had clearly formed at the expense of the latter. In the examples found, the band of rock so formed was only a few inches thick at its maximum, and was characterized by the development, in varying degree, of porphyroblasts of plagioclase.

Table I, col. 1, gives the results of a chemical analysis of a large sample of the pyroxene-garnet-plagioclase hornfels, with accessory sphene (fig. 1). Both the garnet (brown in thin section) and the pyroxene (pale green in thin section) vary somewhat in depth of colour from place

<sup>1</sup> These veins would appear to belong to the 'white aplogranite-granite' suite recognized by Martin (1953, p. 324).

TABLE I. Chemical analyses of hornfels and some constituent minerals

		1	2	3	4	5
SiO <sub>2</sub>	...	45.31	37.32	36.57	49.44	48.88
TiO <sub>2</sub>	...	1.11	0.80	0.79	0.42	0.36
Al <sub>2</sub> O <sub>3</sub>	...	16.23	12.78	8.11	1.93	2.07
Fe <sub>2</sub> O <sub>3</sub>	...	5.14	12.54	19.16	1.80	1.86
FeO	...	5.92	1.89	1.79	16.88	18.46
MnO	...	0.26	0.41	0.45	0.47	0.49
MgO	...	1.82	0.12	0.04	5.93	4.97
CaO	...	22.13	33.62	32.60	23.15	23.07
Na <sub>2</sub> O	...	1.62	—	—	0.36	0.36
K <sub>2</sub> O	...	0.10	—	—	0.01	0.01
H <sub>2</sub> O <sup>+</sup>	...	0.52	0.31	0.12	n.d.	n.d.
H <sub>2</sub> O <sup>-</sup>	...	0.03	nil	0.02	nil	nil
P <sub>2</sub> O <sub>5</sub>	...	0.06	—	—	—	—
		100.25	99.79	99.65	100.39	100.53

Analyst: J. H. Scoon.

1. Pyroxene-garnet-plagioclase hornfels, south of Dielette; sp. gr. 3.20.
2. Garnet, paler and lighter fraction, from 1.
3. Garnet, darker and denser fraction, from 1.
4. Clinopyroxene, paler and lighter fraction, from 1.
5. Clinopyroxene, darker and denser fraction, from 1.

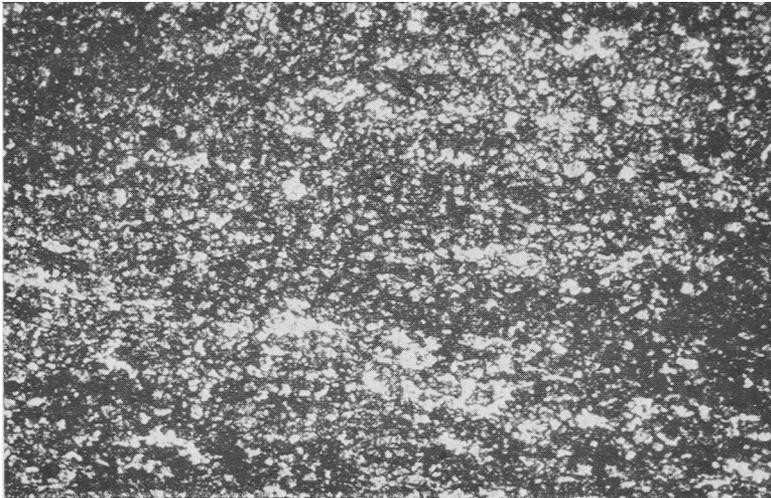


FIG. 1. Fine-grained pyroxene-garnet-plagioclase hornfels, south of Dielette. Ord. light  $\times 40$ .

to place. Chemical analyses of paler and darker garnet and of paler and darker pyroxene will be found in table I, cols. 2 to 5. The garnet is virtually pure grossular-andradite, ranging in composition from  $\text{Gr}_{59}\text{And}_{41}$  to  $\text{Gr}_{37}\text{And}_{63}$ . The pyroxene is feebly aluminous hedenbergite-diopside, ranging in composition from  $\text{Hd}_{64}\text{Di}_{36}$  to  $\text{Hd}_{70}\text{Di}_{30}$ . The composition of the plagioclase feldspar is also variable. Partial chemical analyses show that it ranges from  $\text{An}_{77}$  to  $\text{An}_{45}$ , averaging about  $\text{An}_{66}$  for the rock as a whole.

TABLE II. Trace elements in garnet and pyroxene from pyroxene-garnet-plagioclase hornfels

	2	3	4	5
Ga ... ..	22	22	16	16
Cr ... ..	100	100	80	70
V ... ..	220	220	60	60
Li ... ..	5	5	18	22
Ni ... ..	*	*	45	45
Co ... ..	*	*	32	22
Zr ... ..	100	45	45	22
Y ... ..	22	40	*	*
La ... ..	*	*	*	*
Sr ... ..	*	*	18	18
Ba ... ..	*	*	*	*

An asterisk denotes below limit of sensitivity.  
Spectrographic analyses by R. Allen.  
All values in parts per million.

2. Garnet, paler and lighter fraction (table I, col. 2).
3. Garnet, darker and denser fraction (table I, col. 3).
4. Clinopyroxene, paler and lighter fraction (table I, col. 4).
5. Clinopyroxene, darker and denser fraction (table I, col. 5).

Averaging the compositions of the garnet and the pyroxene, the modal composition of the rock (wt. %) is approximately: garnet 27 %, pyroxene 32 %, plagioclase 39 %, sphene 2 %.

Values for some of the trace elements present in the garnet and the pyroxene of the hornfels are given in table II. The main point of interest here is the discrimination against nickel, cobalt, and strontium shown by the garnet. Turekian has shown recently (Turekian, 1963, p. 845) that garnet associated with pyroxene in eclogites discriminated against both nickel and strontium. Chromium was more equally divided between the two phases, as is the case here, also.

Table III, cols. 1 and 2, provide new chemical analyses of samples of the 'pseudodiorites'. These 'pseudodiorites', coarser grained than the hornfels from which they are derived, carry a pale green pyroxene, and

TABLE III. Chemical analyses of 'pseudodiorite' and contaminated granite

	1	2	3	4	5	6	Norms				
							4	5	6		
SiO <sub>2</sub>	48.59	48.49	48.75	68.99	67.53	66.65					
TiO <sub>2</sub>	0.55	0.75	0.25	0.40	0.45	0.55	qz	20.8	15.6	14.8	
Al <sub>2</sub> O <sub>3</sub>	14.49	15.89	1.04	14.26	14.63	15.20	or	24.5	42.8	37.3	
Fe <sub>2</sub> O <sub>3</sub>	0.84	0.39	0.41	0.15	0.31	0.44	ab	32.0	24.1	28.3	
	12.18	10.98	23.35	2.04	2.06	2.12	an	9.7	5.6	7.8	
MnO	0.35	0.27	0.68	0.03	0.03	0.03	di {	CaSiO <sub>3</sub>	5.0	2.9	2.0
MgO	1.49	1.95	2.60	1.52	1.69	1.83		MgSiO <sub>3</sub>	2.7	1.7	1.2
CaO	18.74	18.11	22.70	4.54	2.71	2.71		FeSiO <sub>3</sub>	2.1	1.1	0.7
Na <sub>2</sub> O	1.82	1.90	0.22	3.76	2.85	3.36	hy {	MgSiO <sub>3</sub>	1.1	2.5	3.4
K <sub>2</sub> O	0.26	0.34	0.02	4.10	7.25	6.34		FeSiO <sub>3</sub>	0.8	1.7	1.9
H <sub>2</sub> O <sup>+</sup>	0.64	0.84	n.d.	0.35	0.44	0.53		mt	0.2	0.5	0.7
H <sub>2</sub> O <sup>-</sup>	0.05	0.08	0.04	0.05	0.06	0.04	il	0.8	0.9	1.1	
P <sub>2</sub> O <sub>5</sub>	0.18	0.13	n.d.	0.16	0.19	0.19	ap	0.3	0.3	0.3	
	100.18	100.12	100.06	100.35	100.20	99.99					

Analyst: J. H. Scoon.

1. 'Pseudodiorite' (clinopyroxene-plagioclase rock), south of Dielette; sp. gr. 3.07.
2. 'Pseudodiorite', a different sample, south of Dielette.
3. Clinopyroxene from 1.
4. Contaminated fine-grained granite, at contact with no. 2.
5. The same fine-grained granite, away from the contact.
6. Another sample of fine-grained granite.

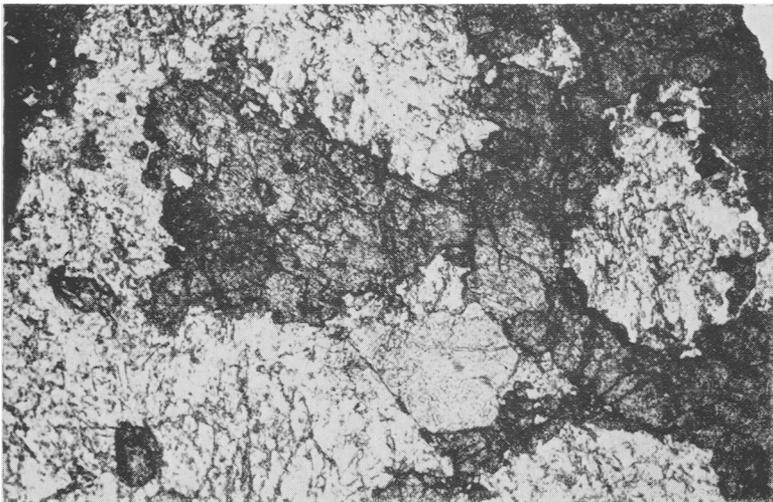


FIG. 2. 'Pseudodiorite' composed of pyroxene and plagioclase, south of Dielette. Note the large apatite crystal. Ord. light  $\times 40$ .

plagioclase which may be somewhat sericitized (fig. 2). The plagioclase occurs partly as porphyroblasts which sometimes have a mottled appearance between crossed nicols (Jérémine, 1931, p. 34). Garnet is absent, but accessory sphene is still present and scattered large, well-formed, dusky apatite crystals make their appearance.

Table III, col. 3, gives the chemical analysis of the pyroxene from one of these rocks (table III, col. 1). The pyroxene is now strongly hedenbergitic ( $\text{Hd}_{85}\text{Di}_{15}$ ). Partial chemical analyses of the plagioclase from the same rock showed it to range in composition from  $\text{An}_{79}$  to  $\text{An}_{62}$ , averaging about  $\text{An}_{67}$ . The modal composition of this rock (wt. %) is approximately: pyroxene 54 %, plagioclase 45 %, sphene and apatite 1 %.

TABLE IV. Comparison of 'pseudodiorite' with pyroxene-garnet-plagioclase hornfels on (a) basis of constant volume, (b) basis of constant  $\text{Al}_2\text{O}_3$

	1	2	3
$\text{SiO}_2$ ... ..	45.3	50.6	54.4
$\text{TiO}_2$ ... ..	1.1	0.6	0.6
$\text{Al}_2\text{O}_3$ ... ..	16.2	15.1	16.2
$\text{Fe}_2\text{O}_3$ ... ..	5.1	0.9	0.9
$\text{FeO}$ ... ..	5.9	12.7	13.6
$\text{MnO}$ ... ..	0.26	0.36	0.39
$\text{MgO}$ ... ..	1.8	1.6	1.7
$\text{CaO}$ ... ..	22.1	19.5	21.0
$\text{Na}_2\text{O}$ ... ..	1.6	1.9	2.0
$\text{K}_2\text{O}$ ... ..	0.10	0.27	0.29
$\text{P}_2\text{O}_5$ ... ..	0.06	0.19	0.20

1. Pyroxene-garnet-plagioclase hornfels (table I, col. 1).
2. 'Pseudodiorite' (table III, col. 1), recalculated on basis of constant volume.
3. 'Pseudodiorite' (table III, col. 1.), recalculated on basis of constant alumina.

The two analyses of 'pseudodiorite' are remarkably similar, but differ considerably from the analysis of a 'pseudodiorite' given by Mme Jérémine (1931, anal. 8, p. 44). In particular, her analysis shows much higher alumina, coupled with lower iron, which includes 2.90 %  $\text{Fe}_2\text{O}_3$ . Comparing the two new analyses with that of the original hornfels (table I, col. 1), it can be seen that only comparatively small changes have to be made to convert the hornfels to the 'pseudodiorite'. There is a small increase in silicon, in total iron, in alkalis and in phosphorus. These are offset by an appreciable decrease in calcium and small decreases in aluminium and titanium.

Calculations based on assumptions of constant volume, or of constant alumina, during the change from hornfels to 'pseudodiorite' (table IV), give essentially the same result except, of course, for no loss of aluminium in the second case. Of the two, the change at constant volume is perhaps the more likely.

The small additions are such as could have been provided by the neighbouring granitic magma in the vein, and the lime is to be found

largely in the contaminated margin of such a vein, as will be detailed below. The most striking feature of the change, however, is the conversion of practically all the original ferric oxide in the hornfels to the ferrous state. This is borne out mineralogically by the low ferric oxide of the clinopyroxene and the absence of iron-ore in the 'pseudodiorite'.

This conversion of the iron to the ferrous state is in harmony with conditions in the magma of the veins responsible for the change. The rocks which crystallized from this magma have low  $\text{Fe}_2\text{O}_3/\text{FeO}$  ratios (0.07, 0.15, 0.21, as compared with 0.04 and 0.07 for the 'pseudodiorite') and are virtually devoid of iron-ore.

Mme Jérémine observed that the hornfels were cut by leucocratic veinlets, often several centimetres wide, which resemble neither the Flamanville granite nor the later microgranite dykes. They were composed mainly of quartz and microperthite with the large plates of potash feldspar enclosing little rounded grains of quartz, small crystals of oligoclase bordered by albite, lamellae of biotite, and sphene. There were also larger isolated crystals of oligoclase ( $\text{An}_{18}$ ), finely twinned and anti-perthitic. Myrmekite is developed in places between potash feldspar and plagioclase. Some colourless pyroxene was disseminated through the rock, often bordered by green hornblende. Apatite (dusky with inclusions) and sphene are accessory constituents. She compared these veins with the dissogenites of Lacroix, and there is no doubt that they owe their content of pyroxene to slight assimilation of lime.

Such a description applies (with the addition of accessory zircon) to the fine-grained granite veins whose analyses are given in table III, cols. 5 and 6. The rock represented by col. 6 is the least contaminated. The rock represented by col. 5 has somewhat more clinopyroxene with less abundant hornblende and biotite. Where such a vein has 'pseudodiorite' at its contact, there is a narrow zone where the assimilation process has gone further.

Here, the clinopyroxene is dominant over hornblende and biotite, plagioclase is more abundant than usual and, indeed, for a few millimetres at the actual contact the rock is composed essentially of almost colourless clinopyroxene, plagioclase ( $\text{An}_{27}$ ), and quartz. There is the usual accessory sphene and apatite, and an occasional grain of orthite. It is interesting to find that the apatite in all these contaminated veins has the same dusky appearance as that introduced into the 'pseudodiorite'. A chemical analysis of such a more highly contaminated zone is given in table III, col. 4, and reflects the mineralogical changes noted above. The main features are the increase in lime, released to the

magma during the conversion of hornfels to 'pseudodiorite'; and decrease in potash, which makes its appearance as increased potash feldspar in the rest of the vein (compare table II, cols. 5 and 6).

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