An anorthite-epidote-garnet-hornfels from Namaqualand, South Africa.

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THE present communication deals with a calc-silicate hornfels of uncommon mineralogical and chemical composition. It may be tentatively referred to the deep-seated metamorphism of a marl, and on account of the shortage of analytical data pertaining to metamorphosed sediments of the calcareo-argillaceous type, a detailed investigation of a variety of this group seems justified.

Field Occurrence.

Intercalated bands of anorthite-epidote-garnet-hornfels bordered bilaterally by pyroxene-bearing gneisses occur on the farms Zandfontein, Pella, and Klein Pella in the north-eastern part of the division of Namaqualand, South Africa (cf. geological map[1]). On Klein Pella small exposures also extend intermittingly for approximately 1·5 miles due WNW.–ESE. of the amphibolite koppie situated on the northern boundary of the farm area. The bands exhibit a gentle pinch and swell structure with maximum widths of 15 to 41 inches, and the contact with the host rock is commonly marked by an epidotic fringe $\frac{3}{4}$ inch in thickness. In some cases the anorthite-epidote-garnet-rock is penetrated by parallel lenticles of pure quartz which may attain maximum breadths of 0·8 inch.

The compound xenoliths (Kheis series?) occur in the younger Namaqualand granite-gneiss, which, in the present state of our knowledge, is best regarded as a later phase of the ancient basement granite-gneiss complex of the Union, South-West Africa, and the Rhodesias.[1]

[1] C. B. Coetzee, The petrology of the Goodhouse–Pella area, Namaqualand, South Africa. Trans. Geol. Soc. S. Africa, vol. 44 (for 1941).

Petrography and Mineralogy.

The texture is granoblastic and the absolute grain-size variable. The following data were obtained for the mode on a rather fine-grained homogeneous specimen (fig. 1):

Anorthite ...	57·8	Sphene ...	2·2
Epidote ...	20·2	Apatite ...	0·9
Garnet ...	18·3	Rest ...	0·6

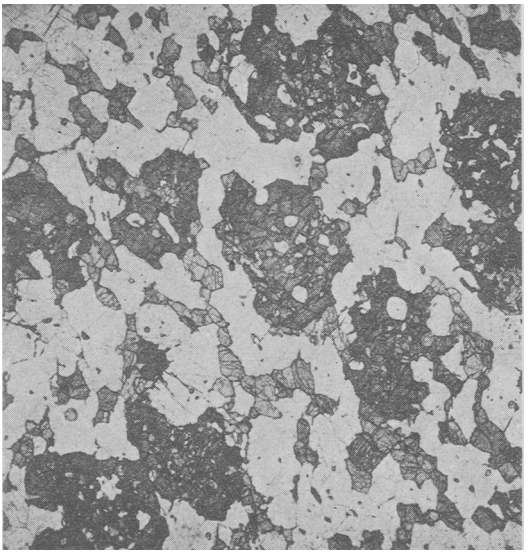

FIG. 1. Anorthite-epidote-garnet-hornfels. The garnet porphyroblasts are traversed by irregular cracks and include anhedra of plagioclase and epidote. The latter is of a lighter colour and its distribution does not suggest a wholesale derivation from the garnet poeciloblasts. Ordinary light. ×16.

Garnet.—Reddish poeciloblastic garnet (average diameters 2·0× 1·3 mm.) includes pools of basic plagioclase, anhedra of epidote, and crystals of sphene and apatite. The specific gravity and the percentages of FeO and MnO were determined on a 3·3 gm. concentrate, which, in the final stages, was separated by centrifuging in Clerici solution.

n 1·832±0·002	FeO 2·66 %
Sp. gr. 3·78±0·01	MnO 1·33

According to Winchell's graphs[1] the garnet is of the grossular-

[1] A. N. Winchell, Elements of optical mineralogy. New York and London, 3rd edit., 1933, pt. 2, p. 176.

andradite group with andradite : grossular = 6 : 4, and almandine (6·14 %) dominant over spessartine (1·33 %).

Epidote.—A small portion of the epidote (±1 %) arises from the alteration of garnet; the remainder occurs as subhedra (average diameters 0·3 × 0·2 mm.) whose distribution suggests a primary metamorphic mineral, since there is not the clustering which would be indicative of pseudomorphs after the garnet porphyroblasts.

α 1·732 β 1·755 γ 1·764 ±0·002	β = γ yellowish-green α colourless
γ−α 0·032	β ≥ γ > α
$2V_\alpha$ 76°	

Clinozoisite 76%, $HCa_2Fe_3Si_3O_{13}$ 24 %.

Plagioclase.—Lime-felspar builds equigranular grains (average diameters 0·5 × 0·4 mm.) which often have a low twin frequency and the mineral consequently appears as simple crystals.

α 1·570 β 1·578 γ 1·584 ±0·002	Composition, $Ab_{10}An_{90}$.

The remaining constituents comprise greyish sphene ($2V_\gamma$ 31°±3°, α 1·91±0·01) and colourless apatite.

Chemical Analysis and Genesis.

The chemical analysis of the anorthite-epidote-garnet-rock (table 1, column I) compares excellently with the composition of a para-pyroxenite ('grenatite feldspathique') believed to have been produced by the transformation of a marl and described by Lacroix from Madagascar. These para-pyroxenites are part of the crystalline basement of Madagascar and belong to Lacroix's gneissic series. This series is of unknown age, but is thought to have been produced by the general metamorphism (sometimes preceded by mechanical deformation) of schistose rocks.

The sedimentary origin of these rocks is not confirmed by plotting *al*, *alk*, and *c*+*fm* in the standard diagrams devised by Niggli, since the points fall in the eruptive fields corresponding to the particular *c*/*fm* values. But this observation alone, cannot conclusively establish an igneous derivation, because a similar position is assumed by the Niggli values of the Houston marl[1]—a typical sedimentary rock.

The characters suggestive of a sedimentary parentage are: (i) the mode of occurrence, (ii) the chemical composition which is unlike that

[1] Sir John Flett, Thomsonized inclusion from the Blackness sill. Summ. Prog. Geol. Surv. Great Britain, 1934, for 1933, pt. 2, pp. 85–90. [M.A. 6–24.]

of known eruptives and orthogneisses, and (iii) the composition of the garnet, in which connexion Wright[1] has recently shown that 'grossularite and andradite represent over 90 % of the garnet molecules in calcareous contact rocks.' The constitution of the original sediment, calculated by Rosenbusch's formula,[2] indicates a ferriferous marl with approximately 40 % carbonates, and 60 % silicates+quartz+titania (table 1, column III).

TABLE 1.

		I.	II.	III.			Niggli values. I.	II.
SiO_2	...	41·63	40·04	32·22	*al*	...	32·6	32·8
TiO_2	...	0·96	0·39	0·74	*fm*	...	14·3	12·7
Al_2O_3	...	25·32	27·02	19·60	*c* ...	...	51·8	53·8
Fe_2O_3	...	6·33	2·87	—	*alk*	...	1·2	1·0
FeO	...	1·50	4·75	5·57	*c*/*fm*	...	3·62	4·21
MnO	...	0·15	—	0·11				
MgO	...	0·28	0·06	0·22				
CaO	...	22·06	24·24	17·07				
Na_2O	...	0·46	0·29	0·36				
K_2O	...	0·17	0·28	0·13				
P_2O_5	...	0·36	0·07	0·28				
H_2O+	...	0·92	0·23	6·66				
H_2O-	...	nil	0·05					
CO_2	...	trace	—	17·10				
Total	...	100·14	100·29	100·06				

I. Anorthite-epidote-garnet-hornfels, Klein Pella. Analyst, W. H. Herdsman.
II. Para-pyroxenite ('grenatite feldspathique'), Ambatonalihala, Madagascar. (A. Lacroix, Minéralogie de Madagascar. Paris, 1922, vol. 2, p. 570.)
III. Composition of original sediment as calculated from analysis I.

By virtue of the three component mineral associations and the absence of micas and potash-felspar, the rock would appear readily adaptable to Goldschmidt's classification of the hornfelses where it falls in class 8, as represented by the anorthite-diopside-grossular triangle.[3] Diopside appears to be proxied by epidote, and this raises the question whether the assemblage, anorthite-epidote-garnet represents a stable equilibrium association which is not accommodated in the classification, and whether in an aqueous environment in the katazone epidote may be generated in lieu of pyroxene.

[1] W. I. Wright, The composition and occurrence of garnets. Amer. Min., 1938, vol. 23, p. 445. [M.A. 7–183.]

[2] H. Rosenbusch, Elemente der Gesteinslehre. Stuttgart, 1910, p. 615.

[3] V. M. Goldschmidt, Die Kontaktmetamorphose im Kristianiagebiet. Skrifter Videnskapsselskapet, I, Mat.-Naturvid. Kl. Kristiania, 1912, vol. 1 (for 1911, no. 11, p. 192.

The Nature of the Host Rocks.

The anorthite-epidote-garnet-hornfels is always symmetrically enclosed by recrystallized sediments of the lime-silicate type, e.g. pyroxene-epidosite, pyroxene-amphibolite, plagioclase-amphibolite, which attain maximum breadths of over 100 feet and dip from 25° to 40° north. The activity of the surrounding granite is exemplified by the introduction of quartz and potash-felspar into the ultrabasic metamorphics, and sometimes this activity takes the form of lit-par-lit injection, as in the case of the hybrid analysed in table 2, column I.

TABLE 2.

	I.	II.		Norms. I.	Norms. II.	Mode (I).	
SiO_2 ...	65·24	65·69	Q ...	26·82	20·52	Microcline ...	13·2
TiO_2 ...	0·58	0·57	or ...	15·57	16·68	$Ab_{45}An_{55}$ ...	39·3
Al_2O_3 ...	15·41	16·11	ab ...	15·72	31·44	Quartz ...	30·3
Fe_2O_3 ...	1·10	1·76	an ...	25·85	18·90	Amphibole ...	10·1
FeO ...	2·92	2·68	c ...	—	—	Pyroxene ...	4·3
MnO ...	0·04	0·07	di wo ...	4·87	1·04	Rest	2·8
MgO ...	1·56	1·93	di en ...	2·60	0·60		
CaO ...	7·70	4·47	di fs ...	2·11	0·40		
Na_2O ...	1·83	3·74	hy en ...	1·30	4·20		
K_2O ...	2·64	2·78	hy fs ...	1·19	2·24		
P_2O_5 ...	0·18	0·20	mt ...	1·62	2·55		
H_2O+...	0·78	—	il ...	1·22	1·06		
H_2O-...	0·10	—	ap ...	0·34	0·34		
			H_2O ...	0·88	—		
Total	100·08	100·00	Total	100·09	99·97		

I. Migmatized amphibole-pyroxene-gneiss, Klein Pella. Analyst, W. H. Herdsman.
II. Average of 40 granodiorites. (R. A. Daly, Igneous rocks. New York and London, 1933, p. 15.)

From the analysis it is evident that the sediment is converted to a bulk composition corresponding to that of a granodioritic gneiss, and the calcareous nature of the clastic parent is indicated only by a high percentage of lime and a relatively low percentage of soda.

The pyroxene displays all degrees of conversion to hornblende, and as the granite is approached the former shows a tendency to recrystallize as large well-sieved porphyroblasts. A peculiar feature in some of these calc-silicate rocks is the formation of large idioblastic crystals of magnetite (up to 1 inch diameter), but whether this is merely due to the high position of the mineral in the crystalloblastic series, or to the transfusion

of iron from the granite into the sediment there is no evidence to indicate.

The Younger Namaqualand Granite-gneiss.

The affinities of the granite which induced the metamorphism have been investigated in some detail (C. B. Coetzee, loc. cit.): it constitutes a homogeneous coarse to medium grained granite-gneiss which grades into aplitic, but not into granodioritic or more basic differentiates. The average of four chemical analyses and 15 modes are appended in table 3.

TABLE 3.

Average of four chemical analyses.		Norm.		Average of 15 modes.	
SiO_2	72·09	Q	30·06	Quartz	34·2
TiO_2	0·41	or	29·47	Microcline	30·5
Al_2O_3	13·77	ab	26·20	$Ab_{71}An_{29}$	27·3
Fe_2O_3	1·28	an	8·90	Biotite	5·3
FeO	1·27	hy(en	1·30	Hornblende	0·3
MnO	0·01	hy(fs	0·66	Sphene	0·5
MgO	0·51	mt	1·86	Iron-ore	1·2
CaO	1·97	il	0·76	Rest	0·7
Na_2O	3·12	ap	0·34		
K_2O	5·02	H_2O	0·53		
P_2O_5	0·09				
H_2O+	0·40	Total	100·08		
H_2O-	0·13				
Total	100·07				

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