An extreme form of poikiloblastic texture in Rogaland – Vest-Agder, SW Norway

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Some samples from the amphibolite/granulite facies terrain of SW Norway show an extreme form of poikiloblastic texture: a group of at least three sections of the same mineral, generally orthopyroxene and clinoamphibole with the same optic orientation and separated by a fabric consisting of other minerals. The nucleation energy for this texture seems to be relatively high, but once a nucleus was formed, it must have grown very rapidly. High temperature and low pressure seem to favour this extreme type of poikiloblastic texture. Similar textures are found in the contact metamorphosed Biwabik and Gunflint Iron Formation of Minnesota, U.S.A.

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Recent studies in the high-grade metamorphic Precambrian of the Sirdalen–Ørsdalen area, Rogaland – Vest-Agder, SW Norway (Hermans et al. 1975) showed that in some cases the mafic rock constituents may exhibit an extreme form of poikiloblastic texture (Gary et al. 1973).

This texture is defined as a group of at least three sections of the same mineral, with the same optic orientation and separated by a fabric consisting of other minerals.

The minerals under discussion are orthopyroxene, clino-amphibole, and garnet, although clinopyroxene, biotite, and olivine also may show this texture.

The isolated areas in optical continuity often have straight boundaries; the total-crystal outline may tend to a euhedral from. In rare cases thin connections between the isolated parts can be seen. Orthopyroxene and clino-amphibole are the main minerals to show this texture.

The size of the individual sections is usually about equal to the average grain size, rarely somewhat larger; the size of the whole poikiloblast may vary from some millimeters to some centimeters, but is always larger than the average grain size of the rock. Within one hand specimen several minerals may exhibit this texture. The mineral fabric separating the sections usually consists of feldspars and eventually some quartz, though all other mineral constituents may be present in minor quantities (Fig. 1.) In outcrop or hand specimen the poikiloblasts generally do not show any preferred orientation. Therefore the parallel arrangement of the composing sections of the texture cannot be due to schistosity. The texture should be distinguished from that due to extreme resorption: here the isolated remnants invariably display rounded boundaries. This is especially true for orthopyroxene and garnet in the charnockitic and garnetiferous migmatites of the Sirdalen–Ørsdalen area.

Regional distribution

About ten thousand samples have been studied from the area covered by Fig. 2. The samples seem to be representative for the area. The texture here described is only present in a small portion of these samples. They are plotted in Fig. 2. The most important mineral to display this texture is orthopyroxene and, to a lesser extent, clino-amphibole.

The bulk of the orthopyroxene poikiloblasts occurs in the upper part of the Bjerkreim–Sokndal lopolith (Hermans et al. 1975); more rarely in the 'antorthosito-leuconoritic and noritic phase', and completely absent in the upper part of the monzonitic- and quartz-monzonitic phase, where fayalitic olivine plus quartz occur instead of low-calcium pyroxene (Duchesne 1972). Outside the lopolith, orthopyroxene poikiloblasts occur mainly in the area west of the so-called 'hyperstene line' from Hermans et al. (1975:54).

The clino-amphibole poikiloblasts are mainly

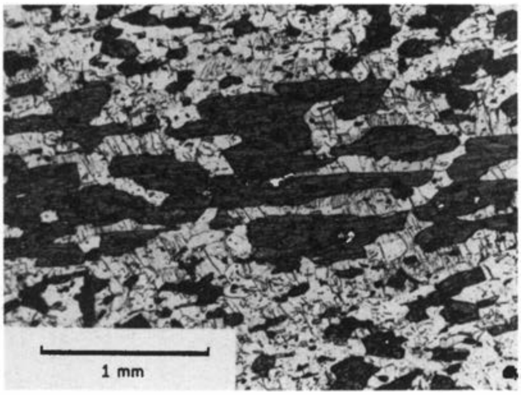

Fig. 1. Extreme amphibole poikiloblast. Length of poikiloblast: ±4 mm.

restricted to the monzonitic- and quartz-monzonitic phases of the lopolith. Clinopyroxene, biotite, and olivine showing this texture are too scarce as to justify any conclusion on their distribution and origin. Therefore it seems reasonable to restrict this study to the orthopyroxene and clino-amphibole, the latter only from the lopolith.

Orthopyroxene

The orthopyroxene showing this texture contains abundant lamellae parallel to (100), and domains of lens-shaped lamellae of a Ca-rich clinopyroxene phase. Within one domain, the lamel-

Table 1

	R 312[1]	R 247[2]
host-phase	$En_{25.9}Fs_{71.9}Wo_{2.2}$ (denuded zone around lens-shaped lamellae)	
	$En_{24.9}Fs_{72.4}Wo_{2.7}$ ('between' (100)-lamellae)	$En_{19.6}Fs_{79.3}Wo_{1.1}$
lens-shaped lamellae	$En_{21.7}Fs_{34.0}Wo_{44.3}$	$En_{17.1}Fs_{39.1}Wo_{43.8}$
lamellae // $(100)_{opx}$	$En_{22.1}Fs_{34.8}Wo_{43.1}$	$En_{17.9}Fs_{41.7}Wo_{40.4}$
initial composition[3]	$En_{24.5}Fs_{62.7}Wo_{12.8}$	$En_{19.3}Fs_{72.8}Wo_{7.9}$
Fe/(Fe + Mg) opx-host	0.73–0.74	0.80
$K_D{}^{opx\text{-}cpx}_{Fe\text{-}Mg}$		
	R 312	R 247
opx vs. lens-shaped lamella	0.83	0.87
opx vs. lamella // $(100)_{opx.}$	0.83	0.89
T° C (Wood/Bano 1973)		
opx vs. lens-shaped lamella	1013	1002
opx vs. lamella // $(100)_{opx.}$	1017	

From K_D-values it seems clear that R 247 equilibrated at higher temperature as did R 312. The Wood/Banno temperatures should be regarded with caution and may only indicate 'high temperatures' for the samples.

[1] R 312 (monzonorite): 54% plag. (25% An), 20% K-feldspar, 2% Quartz, 12% inverted Pig. 4% Cpx., 1% Amf., 3% Ap., 4% ore-minerals, zirc.acc.

[2] R 247 (hypersthene-monozonite): 36% plag. (24% An), 46% K-feldspar, 1% Quartz, 10% inverted Pig., 3% Cpx., 4% ore minerals, Accessories: Amf., Bi., Ap., Zirc.

[3] Recalculated from thin sections.

Electron microprobe analyses: Si, Fe, Mg, Ca, Al, Ti, Mn, Na.

Analyst: F. J. M. Rietmeijer.

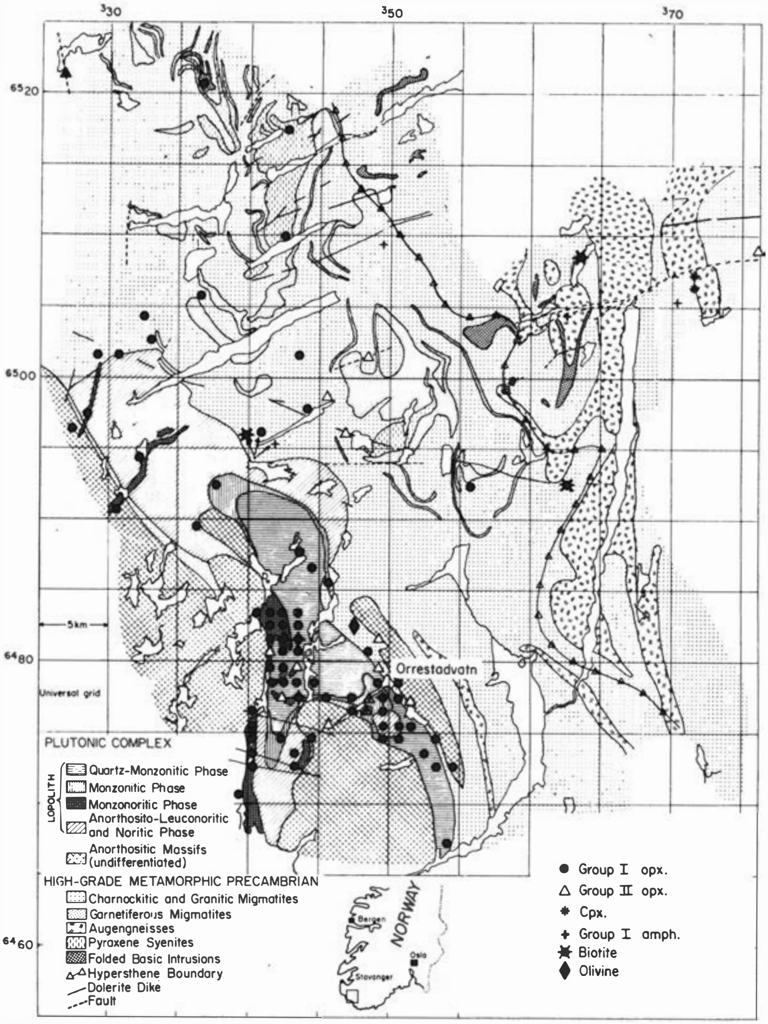

Fig. 2. **Geological map of the Sirdalen-Ørsdalen area in Rogaland–Vest-Agder (after Hermans et al. 1975), showing the distribution of extreme poikiloblasts in this area. Each symbol indicates the presence of at least one occurrence per square kilometer. Group II-amphiboles are of general occurrence in the monzonitic- and quartz-monzonitic phases of the lopolith, and therefore not indicated in this figure.**

lae are parallel. Within one orthopyroxene crystal several domains may be present. Each domain can have a different crystallographic orientation with respect to the host phase. The domains seem to represent original pigeonite phases with (001) lamellae. There is no systematic relationship between the crystallographic axes of the pre-existing pigeonites and the orthopyroxene phase (Universal-stage measurements). All separate sections of one orthopyroxene poikiloblast show the same orientation for the clinopyroxene lamellae parallel to (100) opx.

Optically these orthopyroxenes closely resemble the inverted pigeonites from the Biwabik and Gunflint Iron Formation, Minnesota, U.S.A. (Bonnichsen 1969, figs. 11 and 14, Simmons et al. 1974).

Some pyrozenes from this group were analysed by electron microprobe. The results are given in Table I. It can be seen that the initial wollastonite content of these pyroxenes varies from 5–15% – the range commonly observed for pigeonite.

In Fig. 2 these orthopyroxenes are indicated

Table 2

Chemical analyses					*Amphibole structural formula*				
	Whole rock[1]		Amphibole[2]			R 227		E 167	
	R 227	E 167	R 227	E 167		5	6	7	8
SiO_2	52.66	67.80	43.2	40.8	Si	6.67	6.56	6.59	6.49
TiO_2	3.02	0.72	1.71	2.01	Al^{IV}	1.33	1.44	1.41	1.51
Al_2O_3	12.83	13.58	9.1	8.8	Al^{VI}	0.32	0.19	0.26	0.14
Fe_2O_3	1.75	2.12	n.a.[3]	7.0	Ti	0.20	0.20	0.25	0.24
FeO	12.01	3.76	23.0[4]	24.3	Fe^{2+}	2.96[9]	2.92[9]	4.13[9]	0.84 Fe_3^+ 3.23 Fe^{2+}
MnO	0.17	0.08	0.18	0.54	Mn	0.02	0.02	0.08	0.08
MgO	2.75	0.26	7.4	2.00	Mg	1.69	1.67	0.48	0.47
CaO	5.64	1.81	10.4	9.7	Ca	1.72	1.70	1.68	1.65
Na_2O	4.30	3.87	1.80	2.02	Na	0.54	0.53	0.64	0.63
K_2O	2.67	5.22	1.27	1.35	K	0.25	0.24	0.27	0.27
P_2O_5	1.85	0.12	n.a.	n.a.	OH	–	–	–	1.73
H_2O^+	0.44	0.37	n.a.	1.63	F	–	–	–	0.17
H_2O^-	0.11	0.07	n.a.	n.a.	Z	8.00	8.00	8.00	8.00
CO_2	0.37	0.00	n.a.	n.a.	Y	5.19	5.00	5.20	5.00
F	0.41	0.08	n.a.	0.34	X + A	2.51	2.47	2.59	2.55
					mg.	0.36	0.36	0.11	0.11
Sum	100.98	99.86	98.1	100.53	Atomic				
–F = O	0.17	0.03	n.a.	0.14	Proportions				
Total	100.81	99.83	98.1	100.4	$\frac{Fe}{Fe+Mg}$	.64	.64	.90	.90

[1] Rapid rock analysis, mostly based upon the methods of Shapiro (1962), under supervision of K. Stephan, Leiden.

[2] Microprobe anlysis by A. G. C. Dekker (Si, Al, Ti, Fe-tot, Mn, Mg, Ca, Na, K). Fe_2O_3, F, and OH, other methods see Dekker, 1978).

[3] n.a. = not analysed.

[4] All Fe-oxides calculated as FeO.

[5] Calculated on 23 O, according to Deer, Howie & Zussman (1974).

[6] *Idem* 5, recalculated to Z + Y = 13 (see Dekker 1978).

[7] *Idem* 5, not including Fe_2O_3, F and H_2O.

[8] Calculated on 24 O, including Fe_2O_3, H_2O, and F.

[9] All Fe calculated as Fe^{2+}.

as Group I opx. A somewhat different texture is found in very fine-grained rocks, and indicated as Group II opx. in Fig. 2. Here the separate sections of the orthopyroxene poikiloblasts are clearly rounded. A beautiful sequence of changing rock structure shows the development of this texture; in the field a light-coloured medium-grained mangerite gradually changes into a dark, dike-like, fine-grained body several meters in thickness. In thin section, the medium-grained mangerite shows a mortar structure (thin rims around medium-sized mesoperthite crystals). In these fine-grained rims, clino-amphibole, ortho- and clinopyroxene, and olivine are present, exhibiting no peculiar texture. Closer to the dark, fine-grained rocks, the mortar rims become thicker, and the remaining mesoperthite crystals are less frequent. In the dark 'dike', the whole rock is granulated, only rarely are coarser mesoperthite crystals present. Orthopyroxene exhibits beautiful archipelago-like poikiloblasts with rounded faces for the individual sections; amphibole and olivine have disappeared. The light-mineral bulk mineralogy of the samples remains essentially the same; first of all only the grain size diminishes and finally the dark minerals re-organize.

Clino-amphibole

On morphological grounds the clino-amphibole can be divided into two groups:

1. Clino-amphibole occurring in very fine-grained rocks of more or less monzonoritic composition (Table 2, sample R227). The grain size is smaller than 1 mm, sometimes much smaller.

The poikiloblasts vary from several mm to about 1 cm. Type locality is Orrestadvatn (Fig. 2). The host rock contains, besides amphibole, a variable amount of alkalifeldspar and plagioclase, ortho- and clinopyroxene, disperse ilmenite and magnetite, apatite, little or no quartz, and sometimes a little zircon, biotite, and carbonate. Apatite occurs abundantly enclosed in all minerals. In a few specimens, larger feldspar crystals are found, giving the rock a porphyritic appearance. These fine-grained rocks are in sharp contact with coarser grained, lighter coloured syenites. In the type locality the contact is vertical. A zone approximately 20 cm in thickness exhibits a very strong almost vertical macroscopic lineation, due to the parallel arrangement of amphibole prisms. Further inside the fine-grained rock, the lineation seems to disappear; the amphiboles here occur in a pattern of scattered spots without specific orientation. Microscopically, the fine-grained monzonorites show a distinct lineation, mainly indicated by apatite; often the orthopyroxene and clino-amphibole have the same orientation. Some larger amphibole poikiloblasts have grown athwart the lineation (Fig. 3). There is no banding and the rock is homogeneous. This microscopical lineation is not restricted to the 20 cm contact zone. At the contact this lineation is sometimes irregular.

According to Leake (1968), the amphibole should be termed ferro-hornblende; its chemical composition and structural formula are given in Table 2. Optical properties are n_n: light brownish yellow; n_y: brownish green; n_z: dark green; $-2V = 61° \pm 2°$; $n_z \Lambda c = 12° \pm 2°$ (universal stage); elongation is +, $\Delta = \pm 0.024$. Some simple twins according to (100) can be found; inclusions of ore and apatite are abundant. The outline of each poikiloblast tends to be a euhedral form. Only the marginal fragments may contain some pyroxene.

2. The second type is restricted to coarse-grained rocks in the monzonitic- and quartz-monzonitic phases of the lopolith (see Table 2, sample E 167; Fig. 2, the Group II amphiboles are not marked because of their abundance). The size of the poikiloblasts is normally about 10 × 10 cm, with extremes up to 50 × 100 cm.

Macroscopically the amphiboles show the above-mentioned texture: they look like separate sections with the same crystallographic orientation. These amphiboles are all more or less related to quartz-bearing, coarser-grained veinlets and pockets. They can be found inside the veinlets or at the contact in the host rock. In thin section, the amphibole fragments are large and of irregular shape, often clearly connected with each other and enclosing other minerals in a normal poikiloblastic way. Mostly there is a direct relationship with quartz (sometimes as a symplectitic intergrowth, sometimes just in contact). The assemblage amphibole + quartz is probably the product of the reaction $\text{opx} \pm \pm \text{cpx} + \text{plag.}^1 + \text{k.feldspar} + H_2O \rightarrow \text{amph} + \text{plag.}^2 + + \text{qu.}$ (plag.^1 having a higher An-content than plag.^2) (Beach 1974). The water could derive from the final stage of a magmatic period, without being necessarily related to the formation of pegmatites (e.g. Harker 1968:23–24). The quartz sometimes cuts straight through the original rock fabric. It may round off and enclose the feldspars. It often separates pyroxene from amphibole and plagioclase. The large amphibole frag-

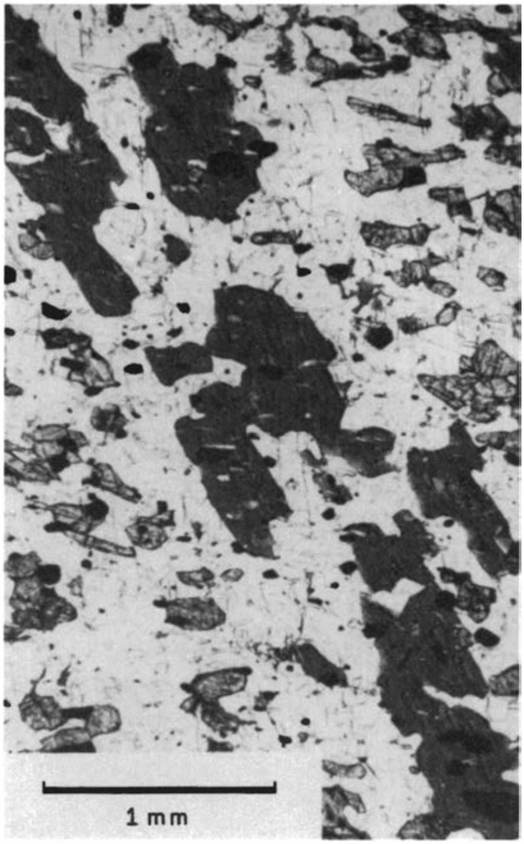

Fig. 3. Group I-amphibole grown athwart the lineation indicated by apatite.

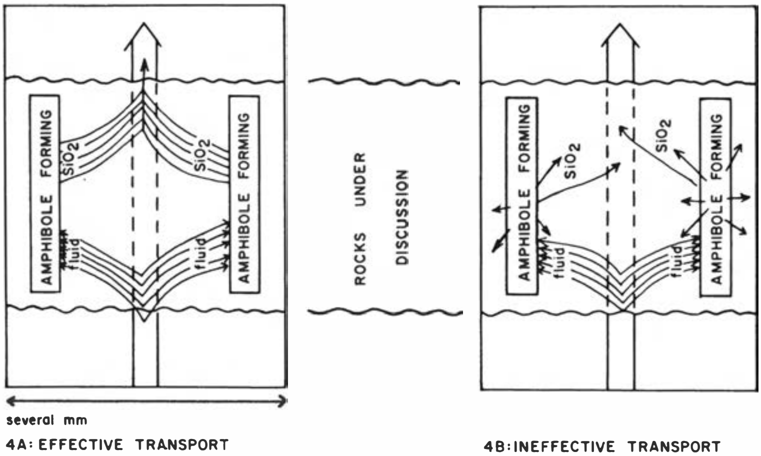

Fig. 4. A and B. Schematic representation of the possibilities of quartz behaviour after the amphibole formation.

ments do not contain plagioclase and pyroxene together. Incidentally they may contain small crystals of the other minerals. The alkalifeldspar is little affected by the reaction. In the matrix some ortho- and clinopyroxene may still remain, if separated from plagioclase by a quartz-rim or because of a spatial separation. The quartz in this rock will be the reaction product which is leaving the 'system' and traversing the rock, presumably by means of the fluid channels that introduced the H_2O needed for the reaction. Depending on the effectivity of the transporting agent and on the activity of SiO_2, the quartz can be removed from the rock system (Fig. 4A) or it can remain in the surroundings of the newly formed amphibole (Fig. 4B). We like to see these amphiboles as transitional between normal poikiloblasts and the extreme form discussed above. The ratio 'amphibole versus other minerals' is smaller than for the normal poikiloblastic texture; the amphibole only fills the speca between these minerals, so that often no connections can be seen. But in places where there was more pyroxene and plagioclase in direct contact, and sufficient fluid, large poikiloblasts of amphibole were formed. These large poikiloblasts are only found in the upper part of the lopolith, where alkalifeldspar is available for the reaction. The pyroxene and plagioclase contain too little potassium to account for K-content of the amphibole. The chemical composition, which can be the same or may differ slightly from Group I, depends on the position in the magmatic sequence of the lopolith. The difference between Group II sample E 167 and Group I sample R 227. (Table 2) can be explained in this way: E 167, a hastingsitic hornblende, is located in the very top of the lopolith, R 227 comes from a relatively lower position.

Discussion

The orthopyroxene poikiloblasts form disproportionally large crystals with respect to the coexisting silicates and can be compared to the orthopyroxenes inverted from pigeonite as described by Bonnichsen (1969) and Simmons et al. (1974). Both Bonnichsen and Simmons et al. suggest that the orthopyroxene nucleates only with difficulty, but once a nucleus is formed, it grows very rapidly, disregarding pigeonite grain boundaries. The nucleii form at widely spaced points within the rock. This behaviour can be related to the reconstructive nature of the pigeonite $\rightleftharpoons$ orthopyroxene transition. The difficulty of orthopyroxene to nucleate has been demonstrated experimentally by Simmons et al. (1974) and Lindsley et al. (1973). Bonnichsen (1969) suggests a relationship between the nucleation energy of orthopyroxene, at given temperature, and the Fe/(Fe + Mg) ratio of the orthopyrozene. The nucleation energy should increase with increasing ratio. As can be inferred from Table 1, the orthopyroxenes from this study have fairly high ratios. Hermans et al, (1976) and Brons (1975) analysed orthopyroxenes, not exhibiting the extreme poikiloblastic texture, from the Rogaland – Vest-Agder area, and they found repectively bronzitic and hypersthenitic (Fe/(Fe + Mg) = .40–.48) compositions.

The amphiboles of the first group – the clinopyroxene-, biotite, and olivine poikiloblasts – invariably form crystals which are also disproportionally greater than the coexisting silicates. Dekker (1978) shows that amphiboles displaying the extreme poikiloblastic texture have high Fe/(Fe + Mg) ratios (table 2) with respect to the other amphiboles (Fe/(Fe + Mg) ratios smaller than .55). Therefore it seems possible that the relation between the Fe/(Fe + Mg) ratio and the nucleation energy of orthopyroxene, as suggested by Bonnichsen (1969), is also applicable to the amphibole poikiloblasts. By analogy with the orthopyroxenes we suggest that these crystals nucleated with great difficulty at widely spaced points in the host rock.

The texture under discussion suggests 'dendritic' crystallization from *one* nucleus, implying that growth dominated nucleation. The rate of growth (growth velocity) should be intermediate between that leading to the formation of poikiloblasts (low) and of dendrites (high). To quote Spry (1974): 'dendritic crystals can be produced experimentally by rapid precipitation from gas or liquid under strong supersaturation gradients around a limited number of nucleii'. The influence of the cooling rate and the amount of supercooling on crystal morphologies have been established experimentally, e.g. Lofgren et al. (1974) and Donaldson (1976). The latter established textures for olivine, similar to the texture under discussion.

P-T conditions: from the studies of Bonnichsen (1969) and Simmons et al. (1974) the physical conditions in the Biwabik and Gunflint Iron Formation can be summarized as follows: $T_{minimum}$ 700–750°C. The primary assemblages could have formed at $T >/ 800°C$; $P_{total} >/ 2$ kb.; $P_{H_2O} < P_{total}$ and f_{O_2} slightly below the FMQ-buffer. P_{total} from experimental work, coincides very well with the P_{total} estimates on stratigraphical basis: $2 < P_{tot} < 4$kb (French 1968).

The samples discussed in this study are mainly from the Bjerkreim–Sokndal lopolith and its surroundings. One sample is from the Faurefjell Formation (Hermans et al. 1975). The granulite facies terrain has been characterized by Hermans et al. (1976) as high T, low P granulite facies (the pressure probably close to 4kb). Hermans et al. (1976) established for the metamorphism of the Faurefjell Formation a temperature around 900°C, and a pressure of 3–6 kb. Very likely $P_{H_2O} < P_{total}$. Data for the lopolith coincide very well with these data: $T \pm 950°C$ and $P_{total} \pm 5$ kb. (Table 1). P-T conditions as can be suggested from the amphibole stability (e.g. Gilbert 1966, Ernst 1968, Eggler 1972, Lambert & Wiley 1968, Dekker 1978) do not seem to contradict the data of Hermans et al. (1976).

A similar texture is shown by clinohumite in a contact-metamorphosed dolomitic marble in the French Pyrenees (Struwe 1959). Contact metamorphism suggests rather high temperature and relatively low pressure. We also like to compare the texture of biotite in a cordierite-bearing hypersthene-quartz-monzonite porphyry described by Ford (1964). The authors would greatly appreciate any comments on other occurrences unknown to them.

Conclusions

The extreme poikiloblastic texture, described in this paper, can form during recrystallisation in 'high temperature, low pressure' environments. The requirements to be met are:

High nucleation energy at given temperature for the new stable phase.

High cooling rate and strong supersaturation.

The Group II orthopyroxenes and Group I amphiboles are only present in granulated rocks. There seems to be a relationship between the recrystallisation to the extreme poikiloblastic, archipelago-like, texture of these orthopyroxenes and clino-amphiboles and the process of granulation.

We like to regard, as extreme poikiloblasts, the sets of small orthopyroxene grains, which in local areas have nearly parallel crystallographic orientations, and which were reported by Bonnichsen (1969) to be due to the breaking down of larger orthopyroxene grains.

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Note added in proof: Comparable Group I orthopyroxenes have been described from the Bushveld Complex by von Gruenewaldt & Weber-Diefenbach (1977), from the Kiglapait Layered Intrusion by Morse (1969), and from the Dufek Intrusion by Himmelberg & Ford (1976).

References

Beach, A. 1974: Amphibolitisation of Scourian ganulites. *Scott. J. Geol. 10,* 35–45.

Bonnichsen, B. 1969: Metamorphic pyroxenes and amphiboles in the Biwabik Iron Formation, Dunka river area, Minnesota. *Min. Soc. Am., Spec. Pap. 2,* 217–233.

Brons, J. H. 1975: Berekende evenwichts-temperatuur en -druk relaties uit de geanalyseerde Fe-Mg verhoudingen in de drie fasen orthopyroxeen, granaat en cordieriet uit Rogaland, zuidwest Noorwegen. *Internal Report, Univ. Utrecht.*

Deer, W. A., Howie, R. A. & Zussman, J. 1974: *An Introduction to the Rock-Forming Minerals.* London, Longman, 7th impression.

Dekker, A. G. C. 1978: Amphiboles and their host rocks in the high-grade metamorphic Precambrian of Rogaland/Vest-Agder, SW. Norway. *Geologica Ultraiectina, 17,* XII + 277 p. Rijksuniversiteit Utrecht.

Donaldson, C. H. 1976: An experimental investigation of olivine morphology. *Contr. Mineral Petrol. 57,* 187–213.

Duchesne, J. C. 1972: Pyroxènes et olivines dans le massif de Bjerkreim-Sokndal (Norvège méridionale). Contribution à l'étude de la série anorthosite-mangérite. *24th I.G.C., section 2,* 320–329.

Eggler, D. H. 1972: Amphibole stability in H_2O-undersaturated calcalkaline melts. *Earth Planet. Sci. Lett. 15,* 28–34.

Ernst, W. G. 1968: *Amphiboles. Minerals, Rocks, and Inorganic Materials.* Sub-series: Experimental Mineralogy, Vol. 1. Springer, Berlin–Heidelberg–New York.

Ford, A. B. 1964: Cordierite-bearing hypersthene-quartz-monzonite porphyry in the Thiel Mountains and its regional importance, 429–441. In Adie, R. J. (ed.) *Antarctic Geology.* Proceedings of the first international symposium on Antarctic Geology, Cape Town, 1963. North Holland Publishing Company.

French, B. M. 1968: Progressive contact metamorphism of the Biwabik Iron Formation, Mesabi Range, Minnesota. *Min. Geol. Survey Bull. 45.*

Gary, M., McAfee Jr., R. & Wolf, C. L. (eds.) 1973: *Glossary of Geology.* American Geological Institute, Washington D.C.

Gilbert, M. C. 1966: Synthesis and stability relations of the hornblende ferropargasite. *Am. J. Sci. 264,* 698–742.

Gruenewaldt, G. von & Weber-Diefenbach, K. 1977: Coexisting Ca-poor pyroxenes in the Main Zone of the Bushveld Complex. *Contr. Mineral. Petrol. 65,* 11–18.

Harker, A. 1968: *Petrology for Students.* Cambridge, University Press, 8th edition.

Hermans, G. A. E. M., Tobi, A. C., Poorter, R. P. E. & Maijer, C. 1975: The high-grade metamorphic Precambrian of the Sirdal-Ørsdal Area, Rogaland/Vest-Agder, Southwest Norway. *Nor. Geol. Unders. 318,* 51–74.

Hermans, G. A. E. M., Hakstege, A. L., Jansen, J. B. H. & Poorter, R. P. E. 1976: Sapphirine occurrence near Vikeså in Rogaland, SW Norway. *Nor. Geol. Tidsskr. 56,* 397–412.

Himmelberg, G. R. & Ford, A. B. 1976: Pyroxenes of the Dufek Intrusion, Antarctica. *J. Petrol. 17,* 2, 219–243.

Lambert, I. B. & Wiley, P. J. 1968: Stability of hornblende and a model for the low-velocity zone. *Nature 219,* 1240–1241.

Leake, B. E. 1968: A catalog of analyzed calciferous and subcalciferous amphiboles together with their nomenclature and associated minerals. *Geol. Soc. Amer., Spec. Pap. 98.*

Lindsley, D. H., Grover, J. E. & Calabro, C. E. 1973: Subsolidus phase relations of Ca-Mg-Fe pyroxenes with Fe/Fe + Mg near 0.75 at pressures from 1–5 kbar and temperatures from 600–800°C. *G. S. A. Abstracts with Programs 5,* no. 7, 713–714.

Lofgren, G., Donaldson, C. H., Williams, R. J., Mullins Jr., O. & Usselman, T. M. 1974: Experimentally reproduced textures and mineral chemistry of Apollo 15 quartz normative basalts. *Proc. 5th Lunar Conf. 1,* 549–567.

Morse, S. A. 1969: The Kiglapait Layered Intrusion, Labrador. *Geol. Soc. Am. Mem. 112.*

Shapiro, L. & Brannock, W. W. 1962: Rapid analyses of silicate, carbonate, and phosphate rocks. *U.S. Geol. Surv. Bull. 1144-A.*

Simmons, E. C., Lindsley, D. H. & Papike, J. J. 1974: Phase relations and crystallization sequence in a contact metamorphosed rock from the Gunflint Iron Formation, Minnesota. *J. Petrol. 15,* 539–565.

Spry, A. 1974: *Metamorphic Textures.* Pergamon Press. Oxford, New York, Toronto, Sydney.

Struwe, H. 1958: Data on the mineralogy and petrology of the dolomite-bearing northern contact zone of the Quérigut Granite, French Pyrenees. *Leidse Geol. Med. 22,* 237–351.

Wood, B. J. & Banno, S. 1973: Garnet-Orthopyroxene-Clinopyroxene relationships in simple and complex systems. *Contr. Mineral. Petrol. 42,* 109–124.