McConnell, D. (1964) Refringence of garnets and hydrogarnets. *Can. Mineral.* 8, 11–22.

Nissen, A. L. (1969) A new Norwegian occurrence of scheelite. *Norges Geol. Unders.* 258, 116–123.

Pistorius, C. W. F. T., and G. C. Kennedy (1960) Stability relations of grossularite and hydrogrossularite at high temperatures and pressures. *Amer. J. Sci.* 258, 247–257.

Pringsheim, P. (1949) *Fluorescence and Phosphorescence.* Interscience Publishers, New York.

———, and M. Vogel (1946) *Luminescence of Liquids and Solids and its Practical Applications.* Interscience Publishers, New York.

Winchell, H. (1958) The composition and physical properties of garnet. *Amer. Mineral.* 43, 595–600.

Yoder, H. S. (1950) Stability relations of grossularite. *J. Geol.* 58, 221–253.

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HORNBLENDE–ACTINOLITE AND HORNBLENDE–CUMMINGTONITE ASSOCIATIONS FROM CUYUNI RIVER, GUYANA, SOUTH AMERICA

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Abstract

Fine-grained proterozoic metagreywackes from Matope Falls, Cuyuni River, contain abundant actinolite rimmed by green hornblende. Both amphiboles also coexist in the matrix—apparently due to a miscibility gap between the two. At the intrusive contact of a granodiorite the rocks have been further metamorphosed to hornblende hornfelses in which hornblende has exsolved cummingtonite lamellae. Optical and unit-cell data are given.

Introduction

Parageneses of coexisting amphiboles have been frequently reported in which two amphiboles not only occur as discrete grains but also one of them is found to be rimmed by the other. The most commonly observed association is that of actinolite with hornblende rims, and the sharp demarcation of the two has been taken as an indication of a miscibility gap. Electron microprobe analyses of such amphiboles by Klein (1969) and by Cooper *et al.* (1970) lend support to this idea of immiscibility. Another feature of amphibole immiscibility is the occurrence of exsolution lamellae analogous to those in pyroxenes in calcic and Mg–Fe amphiboles. Recently, attention has been drawn to amphibole exsolution by Jaffe *et al.* (1968), Klein (1969), and Ross *et al.* (1968, 1969). Rimmed amphiboles and exsolved amphiboles are spatially closely associated in the fine–grained metagreywackes from Cuyuni River and are described here.

Geology

Proterozoic rocks of the Blue Mountains Formation (unpublished report by R. T. Cannon, 1962) are exposed in the Cuyuni River, some 90 miles (144 km) southwest of Georgetown; the location of Matope Falls where metamorphosed sedimentary rocks belonging to this formation occur is shown in the sketch map in Figure 1. The rocks at the falls are dark grey mafic metagreywackes which have been intruded by a late tectonic hornblende–biotite granodiorite. At sharp intrusive contacts the country rocks have been hornfelsed, and further up–river large xenoliths are enclosed in the granodiorite.

Petrography

Matope Metagreywackes

The metagreywackes are fine–grained rocks varying in grain size from 0.1 to 0.3 mm, with a fine schistosity in some cases. Actinolite,

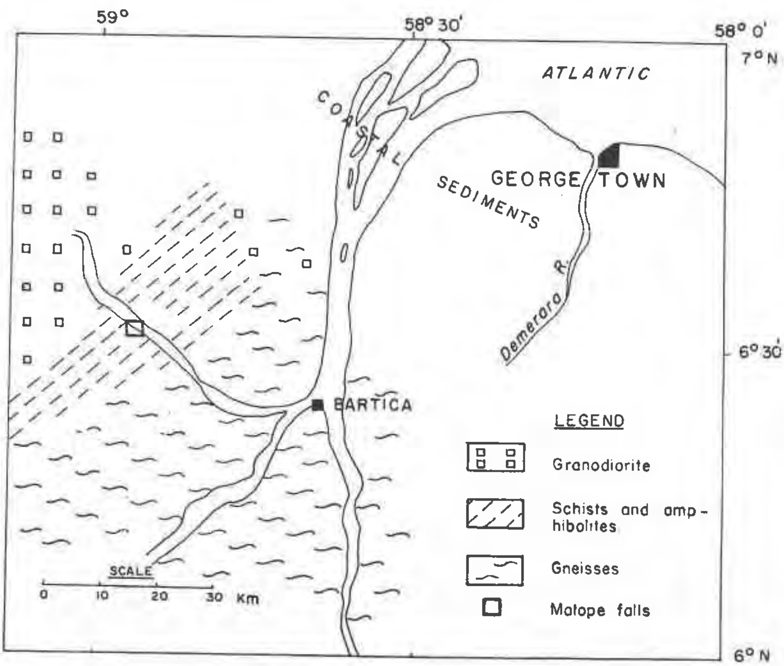

Fig. 1. Sketch map showing location of Matope Falls with respect to Georgetown.

green hornblende, quartz, and biotite make up the major minerals in the rocks; other minerals are untwinned oligoclase, epidote, and opaques. Metagreywackes containing clastic actinolite, albite, and oligoclase with chlorite and epidote in the matrix occur to the south, and appear to be of lower metamorphic grade (J. N. Punwasee, pers. comm.). All these rocks are possibly derived from intermediate to basic volcanic detritus, but it is not certain whether they were originally tuffaceous. The possibility that the original sediments were volcanogenic is also suggested by the reported occurrence of greywackes from the northwest of Guyana that are derived from andesites (A. R. Westerman, pers. comm.).

In the hornblende–actinolite metagreywackes the detrital, colorless-to-pale green actinolite grains (0.08–0.3 mm) are rimmed by green hornblende, and are often haphazardly arranged with regard to the microschistosity. The actinolite porphyroclasts are set in a finer matrix consisting mainly of quartz, actinolite, hornblende, and biotite; the hornblende in the matrix is the same as that which forms the rims on the actinolite. The hornblende rim is sharply demarcated from the core actinolite and there is a well defined Becke line between the two (Fig. 2). The absorption of the hornblende is α = pale yellow, β = green, and γ = light blue-green; the refractive indices of the amphiboles are given in Table 1. Some of the acicular blue-green hornblende of the matrix is in continuity with the hornblende

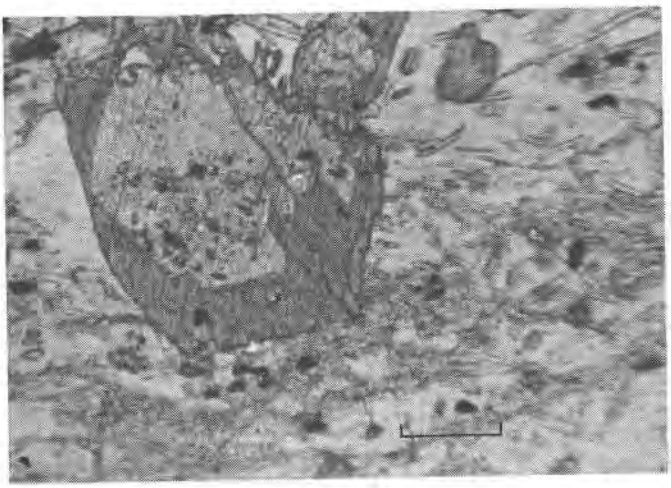

FIG. 2. Basal section of amphibole showing pale green actinolite sharply demarcated by green hornblende rim. Scale 0.1 mm.

rims of the porphyroclasts, whereas the fine fibrous actinolite of the matrix is not. It is possible that the latter represents newly–formed actinolite that appeared before hornblende and persists with it because of a miscibility gap between the two.

Hornblende Hornfelses

A few hundred meters away from the rocks described above, hornblende hornfelses occur at the contact of granodiorite; these hornfelses belong to the same series of metagreywackes. Texturally they are fine–grained, equigranular, and granoblastic, and consist of interlocking grains of hornblende, quartz, andesine (An_{35-40}), ± biotite, ± cummingtonite; the mineralogy changes over short distances depending on the presence or absence of the latter two minerals. There is, however, no actinolite in these rocks which here belong to the hornblende hornfels facies. Any actinolite which may have been present was apparently used up in reactions giving hornblende.

An interesting feature of the hornfelses is the occurrence of exsolved hornblende with or without coexisting cummingtonite. The hornfelses (AC–164) consists of coexisting green hornblende and colorless cummingtonite in idioblastic to hypidioblastic grains with andesine (An_{40}) and quartz. Besides separate amphibole grains there are numerous hornblende hosts with colorless cummingtonite lamellae and vice versa. Exsolution lamellae parallel both ($\bar{1}01$) and (100) in the amphiboles. These directions are referred to the $C2/m$ cell for clinoamphiboles; the ($\bar{1}01$) of this cell is (001) of the $I2/m$ cell (Jaffe *et al.*, 1968). The ($\bar{1}01$) lamellae vary in thickness from 3 to 15 μm, and at times form herringbone texture in cummingtonite twinned on (100). Basal sections of amphiboles clearly show (100) exsolution with a Becke line between cummingtonite and hornblende, as well as very faint and fine lamellae also parallel to (100). The pleochroic scheme of hornblende is α = pale yellow, β = light olive green, and γ = light blue-green. Refractive indices and unit cell dimensions of the amphiboles are given in Table 1.

Another hornfels (AC–158) consists of hornblende, andesine (An_{35}), quartz, and brown biotite. Hornblende shows fine ($\bar{1}01$) exsolution of cummingtonite of about 1 to 5 μm thickness (Fig. 3). It seems that in the presence of K_2O, biotite is formed in preference to cummingtonite, which occurs only as exsolved lamellae in the hornblende in contrast to hornfels AC–164. The hornblende in this case has the paler colors α = pale yellow, β = pale yellow–green, and γ = pale yellow–green. Deeper green hornblende with exsolved cummingtonite lamellae occurs in the hornfels AC–39, which has hornblende, quartz, and andesine without separate crystals of biotite or cummingtonite.

Table 1. Refractive indices and unit cell dimensions of the amphiboles

	Metagreywacke		Hornfels		
	AC - MV		AC - 164		AC - 158
	Actinolite	Hornblende	Hornblende	Cummingtonite crystals	Hornblende
α	1.642	1.652	1.645	1.645	1.638
β	1.650	1.668	1.650	1.648	1.644
γ	1.660	1.672	1.672	1.668	1.660

	Hornfels			
	AC - 164		AC - 39	
	Hornblende host	($\bar{1}01$) Cummingtonite lamellae	Hornblende host	($\bar{1}01$) Cummingtonite lamellae
a	9.85	9.51	9.84	9.50
b	18.08	18.08	18.05	18.05
c	5.33	5.34	5.33	5.33
β	104°45′	102°15′	104°45′	102°25′

Refractive indices of amphiboles probably within ± 0.003. Fe/Fe + Mg ratios for actinolite and cummingtonite are 0.42 and 0.50, based on optical data from Deer et al. (1965) and Klein (1964) respectively.

Unit cell dimensions in Angstrom units by J.J. Papike.

Metamorphic Facies

According to Ernst (1968), the miscibility gap of actinolite and hornblende is probably due to the intersection of a "hornblende solvus" under relatively low-pressure regional metamorphism. This appears to have been the case in the Matope metagreywackes in which green hornblende forms rims on detrital actinolite and also coexists with actinolite in the matrix. It is possible that the actinolite in the matrix is newly formed before the formation of hornblende and has not been entirely consumed for the formation of the latter; provided, however, that the two amphiboles are in equilibrium, the rocks would then belong to the low-pressure upper greenschist facies of Winkler (1967). This upper greenschist facies association gives way to the typical hornblende hornfels facies paragenesis, hornblende + cummingtonite + andesine (An_{40}) + quartz, in hornfeleses which have formed as a result of contact metamorphism of the metagreywackes at the contact of a granodiorite.

Conclusions

An examination of the fine-grained metamorphosed sediments of the Blue Mountains Formation at and around Matope Falls, Cuyuni River, reveals that the rocks are metagreywackes with innumerable clastic actinolite grains which probably had their origin as volcanic detritus. These rocks were subjected to greenschist facies metamorphism and subsequently contact metamorphosed, so that the actinolite–hornblende metagreywackes of the upper greenschist facies described above gave rise to hornblende hornfelses with coexisting hornblende and cummingtonite, or with hornblende as the only amphibole. Hornblendes formed at high contact temperatures subsequently cooled and exsolved cummingtonite. In the case of hornfelses in which hornblende and cummingtonite coexist both these amphiboles formed in the hornblende hornfels facies and later exsolved.

Fig. 3. Pale yellow green hornblende with exsolution lamellae of colorless cummingtonite oriented parallel to ($\bar{1}01$) of the host. Scale 0.1 mm.

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REFERENCES

COOPER, A. F., AND J. F. LOVERING (1970) Greenschist amphiboles from Haast River, New Zealand. *Contrib. Mineral. Petrology,* 27, 11–24.

DEER, W. A., R. A. HOWIE, AND J. ZUSSMAN (1965) *Rock forming minerals.* 2, Longmans, London.

ERNST, W. G. (1968) *Amphiboles.* Springer Verlag, New York.

JAFFE, H. W., P. ROBINSON, AND C. KLEIN (1968) Exsolution lamellae and optic orientation of clinoamphiboles. *Science,* 160, 776–778.

KLEIN, C. (1964) Cummingtonite-grunerite series: a chemical optical and X-ray study. *Amer. Mineral.* 49, 963–982.

——— (1969) Two amphibole assemblages in the system actinolite–hornblende–glaucophane. *Amer. Mineral.* 54, 212–237.

ROSS, M., J. J. PAPIKE, AND P. W. WEIBLEN (1968) Exsolution in clinoamphiboles. *Science,* 159, 1099–1102.

———, ———, AND K. W. SHAW (1969) Exsolution textures in amphiboles as indicators of subsolidus thermal histories. *Mineral. Soc. Amer. Spec. Pap.* 2, 275–299.

WINKLER, H. G. F. (1967) *Petrogenesis of metamorphic rocks.* 2nd edition. Springer Verlag, Berlin-Heidelberg-New York.

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THE CRYSTAL STRUCTURE OF YAVAPAIITE: A DISCUSSION

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ABSTRACT

The crystal structure of yavapaiite, recently determined by Graeber and Rosenzweig (1972), is shown to be similar to those of $FeSO_4$ and Na_2SO_4 (III). Crystal data and atomic parameters determined in this study are presented.