the threads during replication (Fig. 3c), however, makes the estimation of their exact size difficult. Figure 3b illustrates also a planar net structure of threads splitting from the surface. The presence of such a net structure may account for the filmy appearance of the gel.

The authors wish to thank Dr. Koji Wada of Kyushu University for many helpful suggestions and for reading the manuscript.

REFERENCES

AOMINE, S. AND N. MIYAUCHI (1965) Imogolite in Imogo-layers in Kyushu. *Soil Sci. Pl. Nutr. (Tokyo)* **11**, 212–219.

FLEISCHER, M. (1963) New mineral names. *Amer. Mineral.* **48**, 434.

MIYAUCHI, N. AND S. AOMINE (1966) Mineralogy of gel-like substance in the pumice bed in Kanuma and Kitakami districts. *Soil Sci. Pl. Nutr. (Tokyo)* **12**, 187–190.

WADA, K. (1966) Deuterium exchange of hydroxyl groups of allophane. *Soil Sci. Pl. Nutr. (Tokyo)* **12**, 176–182.

WADA, K. (1967) A structural scheme of soil allophane. *Am. Mineral.*, **52**, 690–708.

YOSHINAGA, N. AND S. AOMINE (1962a) Allophane in some Ando soils. *Soil Sci. Pl. Nutr. (Tokyo)* **8**, 6–13.

YOSHINAGA, N. AND S. AOMINE (1962b) Imogolite in some Ando soils. *Soil Sci. Pl. Nutr. (Tokyo)* **8**, 114–121.

THE AMERICAN MINERALOGIST, VOL. 53, JANUARY–FEBRUARY, 1968

A STUDY OF GRAIN CONTACTS IN SOME HIGH-GRADE METAMORPHIC ROCKS

SHEILA M. MAHAN AND JOHN J. W. ROGERS, *Department of Geology, Rice University, Houston, Texas.*

PURPOSE AND METHOD

Precise determination of the medium of crystallization of silicate rocks is a classic petrologic problem. In particular, efforts have been made for many years to distinguish rocks formed by crystallization of a melt from those formed by grain growth in an essentially solid medium. The problem clearly hinges on accurate interpretation of textural relationships.

A number of papers have recently attempted to develop a quantitative approach to the study of rock textures. The grain size distribution of individual minerals has been studied, for example, by Kretz (1966*a*) and in a series of papers by K. A. Jones and A. K. Galwey (*e.g.*, Jones and Galwey, 1966). These studies have not been applied specifically to the distinction between solid and liquid media of growth, but they have yielded information concerning the growth process of the minerals and the process of migration of their component elements through the rocks in which they occur. A different line of investigation based on interfacial angles at the contact between several grains and shapes of individual grains has been successful in demonstrating solid-state growth in metamorphic rocks (Kretz, 1966*b*). A very recent paper by Vance and Gilreath (1967) uses the proportions of various grain contacts to demonstrate preferential synneusis of phenocrysts of like minerals in crystal growth from magmas.

The present study of metamorphic rocks is based on an earlier study of granitic rocks by Rogers and Bogy (1958). In that work a ratio was established based on a modal analysis of thin sections and counts of the varieties of grain contacts (*e.g.*, plagioclase-biotite, quartz-quartz, *etc.*) in the same sections. These measurements permitted calculation of the ratio: percentage of total contact length of all grains of mineral A occupied by mineral B/modal percentage of mineral B. A ratio of 1 would indicate that mineral B was in contact with mineral A in direct proportion to the percentage of B in the rock. The principal conclusion of the study of granites was that contacts between adjoining potassium feldspar grains were much less common than contacts between other like minerals or between unlike minerals. This relationship could be explained either on the basis that growth of potassium feldspar prevents nucleation of other potassium feldspar in its neighborhood (Rogers and Bogy, 1958) or, more likely, that a growing potassium feldspar grain causes rapid nucleation of other feldspar lattices in its neighborhood and simply incorporates these into its own structure rather than permitting their formation as separate grains (Rogers, 1961).

RESULTS

On the possibility that the relationships found for potassium feldspar in rocks broadly classified as granitic might not be valid for metamorphic rocks, the writers have investigated a suite of 18 rocks from 12 localities. These rocks are classified as metamorphic on the basis of published field data, and all of them have a modal quartz content (average 45.8 percent) much higher than that of ordinary granites. The rocks studied and number of samples include: Idaho Springs Formation (2) and Mt. Morrison Gneiss (2), Front Range, Colorado; Pellisier Granite, Inyo Mountains, California; Swauk Arkose, Washington; Killarney Granite (2), Ontario; a gneiss east of North Bay, Ontairo; Lebanon Gneiss and Bethlehem Gneiss (2), New Hampshire; Mascoma Quartz Monzonite, New Hampshire; migmatite (?) near contact of Roan Mountain complex, North Carolina; Valley Springs Gneiss (3), Texas; and a metasomatized (?) schist on the east side of Mt. Whitney, California.

In each of the 18 sections, the same ratio of grain contact to modal percentage was measured as in the granite study mentioned above. The

TABLE 1. GEOMETRIC MEANS, AMONG MINERALS OF METAMORPHIC ROCKS, OF THE RATIO: (PERCENTAGE OF CONTACT LENGTH OF MINERAL *A* IN CONTACT WITH MINERAL *B*/(MODAL PERCENTAGE OF MINERAL *B*)

Mineral *A*	Mineral *B*			
	Quartz	Potassium feldspar	Plagioclase	Biotite
Quartz	0.86	1.08	1.18	1.91
Potassium feldspar	1.14	0.83	1.10	1.53
Plagioclase	1.01	0.70	0.78	2.23
Biotite	0.81	0.67	1.25	3.87
Modal %	45.8	24.6	19.7	7.5

results are shown in Table 1. Most of the ratios in Table 1 are close to 1 except for the proportion of contacts of biotite as mineral *B* with other minerals. These same high values with respect to biotite were also found for granites and presumably result from the fact that biotite, being platy, has a much higher surface/volume ratio than the other minerals. With the exception of ratios involving biotite, all ratios in Table 1 are in the range 0.70 to 1.18.

DISCUSSION

The data of Table 1 are quite similar to those of the granites studied earlier with the exception of the high potassium feldspar/potassium feldspar ratio for the metamorphic rocks. The equivalent ratio in the granites was 0.45, significantly lower than the 0.83 of Table 1. This relatively high ratio in metamorphic rocks is presumed to be indicative of crystallization of the potassium feldspar in a comparatively solid medium, in which a growing grain would probably have less effect on its environment and on nucleation in its neighborhood than it would have in a melt.

The above conclusion is clearly based on the prior placement of individual rocks in the categories of metamorphic (formed in the solid state) or igneous (formed from a melt). This placement cannot be made with any assurance in individual cases. It seems significant, however, that rocks assumed in the field to have formed from a melt and having an average modal quartz content of 32.3 percent (Rogers and Bogy, 1958) have demonstrably fewer potassium feldspar-potassium feldspar contacts than rocks designated as metamorphic and having a modal quartz content of 45.8 percent. The conclusions in this paper are drawn on the basis of this distinction.

The major difficulty with the preceding argument is the presumption of a liquid growth medium for the granitic rocks. There is little doubt that the metamorphic textures studied in this paper have formed by solid-state reactions, but it is possible to interpret the granitic textures as representative of solid-state reactions of a higher intensity than those of the obviously metamorphic rocks. It is also possible that any liquid portion of the granitic growth medium is merely an interstitial fluid. In classifying the granitic textures as the products of crystallization from a liquid, the present writers are following conclusions based on textural studies discussed by Whitfield *et al.*, (1959) and Rogers (1961).

The possibility that the relatively high ratio of potassium feldspar /potassium feldspar in metamorphic rocks compared to igneous rocks is caused by the finer grain size of metamorphic rocks has been tested by investigating metacrysts in two sections of the Idaho Springs Formation. Photomicrographs were made of 10 metacrysts, and the percentage of metacryst border occupied by each mineral in the rock was determined by planimeter tracing of the borders. The ratio of grain border of the metacrysts occupied by other potassium feldspar grains/modal percentage of potassium feldspar in the rock outside of each studied metacryst averaged 1.79 for the 10 grains. It appears, therefore, that the increase in the proportion of potassium feldspar-potassium feldspar contacts in metamorphic rocks in comparison with igneous rocks is not caused by the generally smaller grain size of the metamorphic rocks but by a real difference in the medium of growth of the feldspar grains.

The data presented here do not contradict the conclusions of Vance and Gilreath (1967). The high proportion of contacts between adjoining potassium feldspar grains which they attributed to synneusis in melts represented only contacts between phenocrysts. The study of granites by Rogers and Bogy and the present study of metamorphic rocks, however, includes all mineral sizes. In fact, it is noteworthy that a high proportion of potassium feldspar-potassium feldspar metacryst contacts has been found in this study.

ACKNOWLEDGMENTS

The writers have greatly benefitted from discussions and correspondence with Dr. Ralph Kretz and from a review by Dr. F. W. Dickson. The work was supported by Grant C-009 from the Robert A. Welch Foundation to John A. S. Adams and John J. W. Rogers.

REFERENCES

JONES, K. A. AND A. K. GALWEY (1966) Size distribution, composition, and growth kinetics of garnet crystals in some metamorphic rocks from the west of Ireland. *Quart. J. Geol. Soc. (London)* **122,** 29–44.

KRETZ, R. (1966*a*) Grain size distribution for certain metamorphic minerals in relation to nucleation and growth. *J. Geol.* **74,** 147–173.

——— (1966*b*) Interpretation of the shape of mineral grains in metamorphic rocks. *J. Petrology* **7**, 68–94.

Rogers, J. J. W. (1961) Origin of albite in granitic rocks. *Amer. J. Sci.* **259**, 186–193.

——— and D. B. Bogy (1958) A study of grain contacts in granitic rocks. *Science* **127**, 470–471.

Vance, J. A. and J. P. Gilreath (1967) The effect of synneusis on phenocryst distribution patterns in some porphyritic igneous rocks. *Amer. Mineral.* **52**, 529–536.

Whitfield, J. M., J. J. W. Rogers, and M. C. McEwen (1959) Relationships among textural properties and modal compositions of some granitic rocks. *Geochim. Cosmochim. Acta* **17**, 272–285.

THE AMERICAN MINERALOGIST, VOL. 53, JANUARY–FEBRUARY, 1968

STAINING FOR CORDIERITE AND FELDSPARS IN THIN SECTION[1]

Gary M. Boone, *Department of Geology, Syracuse University, Syracuse, N. Y.*

AND

E. P. Wheeler, 2nd, *Department of Geological Sciences, Cornell University, Ithaca, N. Y.*

Introduction

Often in the course of studying cordierite-bearing rocks it is desirable to know where cordierite is concentrated with regard to relict bedding, gneissic layering, or granitic veins or pods. Even within a thin section, different areas may represent different sub-systems; it is therefore critical, in determining phase equilibrium and variance, to observe without ambiguity the bounding relations of cordierite against other pertinent phases.

Cordierite characteristically lacks *diagnostic* habit, color, pleochroism, distinctive relief, radioactively induced halos, and cleavage. Lamellar twinning (Deer, Howie, and Zussman, 1962, p. 268) superficially resembling that of plagioclase is commonly present. These features make staining a desirable petrographic procedure where the presence of cordierite is suspected. Though the stains and relevant procedures described here have been applied with varying success and should be further refined, we hope the methods will aid those who are studying the metamorphism of aluminous rocks.

Wheeler has experimented with amaranth stain described by Laniz, Stevens, and Norman (1964). Boone has been concerned with a more Mg-specific stain, trypan blue, which Professor M. B. Bayly of Rensselaer Polytechnic Institute had successfully applied to rock slabs and

---

[1] Publication No. 48, Department of Geological Science, Cornell University, Ithaca, N. Y.