The reaction of fayalite and ilmenite or fayalite and ulvospinel with a sodium-rich liquid to give aenigmatite, as proposed by Carmichael (1962), is the corresponding reaction for Ca-free systems.

Titanomagnetites rimmed with aenigmatite have been observed in several trachytes from the Nandewar Mountains. This indicates a possible reaction of titanomagnetite with a peralkaline sodium silicate liquid to yield aenigmatite under conditions of low oxygen fugacity. The breakdown products of aenigmatite under controlled conditions of oxygen fugacity are to be further investigated.

Acknowledgments

My thanks are due to Dr. A. J. R. White for help in the separation of the aenigmatite and for critically reading the manuscript. This work was part of a larger study of the Nandewar volcanic province, which was supported by an A.N.U. Research Scholarship.

References

Abbott, M. J. (1965) *A petrological study of the Nandewar volcano.* Ph.D. Thesis, Aust. Nat. Univ., Canberra.

Carmichael, I. S. E. (1962) Pantelleritic liquids and their phenocrysts. *Mineral. Mag.* **33,** 86–113.

Deer, W. A., R. A. Howie and J. Zussman (1963) *Rock-forming minerals. Vol. 2. Chain silicates,* Longmans, London.

Ernst, W. G. (1962) Synthesis, stability relations, and occurrence of riebeckite and riebeckite-arfvedsonite solid solutions. *J. Geol.* **70,** 689–736.

Fleischer, M. (1936) The formula of aenigmatite. *Amer. J. Sci.* **32,** 342–348.

Kelsey, C. H. and D. McKie (1964) The unit-cell of aenigmatite. *Mineral. Mag.* **33,** 986–1001.

Mitrofanov, F. P. and L. I. Afanas'eva (1966) Enigmatite from alkaline syenites of the Eastern Sayan Mountains. *Dokl. Akad. Nauk. SSSR* **166,** 444–446 [*Chem. Abs.* **64,** 10932].

Washington, H. S. (1913) The volcanoes and rocks of Pantelleria. *J. Geol.* **21,** 653–670, 683–717.

Zies, E. G. (1960) Chemical analyses of two pantellerites. *J. Petrology* **1,** 304–308.

——— (1966) A new analysis of cossyrite from the Island of Pantelleria. *Amer. Mineral.* **51,** 200–205.

THE AMERICAN MINERALOGIST, VOL. 52, NOVEMBER–DECEMBER, 1967

NUCLEI OF PLEOCHROIC HALOS IN BIOTITES OF SOME SIERRA NEVADA GRANITIC ROCKS

Kenneth G. Snetsinger, *Space Sciences Division, Ames Research Center, NASA, Moffett Field, California.*[1]

The concentric ring structure of pleochroic halos in biotite has been studied in very great detail (Hirschi, 1920; Kerr-Lawson, 1927, 1928;

[1] This work was done while the writer was a Ph.D. candidate in the Department of Geology, Stanford University.

TABLE 1. NUCLEI OF PLEOCHROIC HALOS IN BIOTITES OF SOME SIERRA NEVADA GRANITES

Sample	Nuclei	Remarks
Sample 1–6[a] (adamellite)	Monazite, zircon	Apatite occurs in the biotite, but is not surrounded by halos. Xenotime is not present in the rock.[b]
Sample t–2 (Taft adamellite, Yosemite Valley)	Monazite, zircon, xenotime	Of fourteen nuclei determined, nine are monazite (with $\alpha=1.792$, $\gamma=1.840$); four are partly-metamict zircon (ω close to 1.91 and $\epsilon=1.94$); and one nucleus is xenotime ($\omega=1.720$). Apatite is not present in the rock.[a]
Sample t–1 (Taft adamellite, Yosemite Valley)	Monazite, zircon, xenotime	Fourteen nuclei determined, of which eight are monazite, five are zircon and one is xenotime. No apatite occurs in this rock.[b]
Sample 1–4 (adamellite)	Zircon	Twenty determinations: all are partly-metamict zircon ($\epsilon=1.965$, $\omega=1.925$). Apatite is present in the biotite, but produces no darkening of the mica. Neither monazite nor xenotime is present in the rock.[b]
Sample 1–9 (adamellite)	Monazite, zircon	Ten determinations: monazite and zircon produce halos in equal amounts. No apatite occurs in this rock.[b] A very small amount of xenotime is present in this sample, but the mineral was not noted during halo study.
Sample 3–9 (tonalite)	Apatite, zircon	Sixteen determinations: ten nuclei are apatite, the rest zircon. Thirty other samples of this unit contain apatite, but in no other instance does the mineral produce pleochroic halos. Monazite and xenotime are not present in the rock.[b]
Sample 2–9 (granodiorite)	Apatite, zircon	Xenotime and monazite are absent from the rock.[b]

[a] Unless otherwise noted, samples are from the northwest part of the Bass Lake quadrangle, Madera and Mariposa Counties, California.
[b] Not found in a heavy concentrate from the sample.

Hoppe, 1959; Gentry, 1966),[1] but in only a few instances has precise identification of the nuclear mineral grains been attempted. Hutton (1947) separated nuclei to pleochroic halos from biotite in a New Zealand migmatite and, upon identification by the immersion method, found these were monazite, xenotime and sometimes apatite, but never zircon, although the latter mineral was occasionally present in the mica. Laemm-

[1] See Rankama, 1954, p. 129, for many other references.

lein (1945) found only monazite as a nucleus of halos in some quartz crystals. It appears that prior to these studies morphological characteristics were mainly depended upon as a means of identification, a procedure which may be misleading, particularly in the case of small grains. Ramdohr (1957), however, argues that zircon, monazite, allanite, xenotime, sphene, apatite and uranium minerals have all been correctly identified as halo nuclei by previous workers.

Study of halos in some Sierra Nevada granites (Snetsinger, 1965) has provided data regarding nuclei in biotite of these rocks (Table 1). Separatory procedures were much the same as employed by Hutton, with the exception that each nucleus was broken out of the biotite with a sharp pin while the mica plate was immersed in a refractive index medium. Zircon is a common nucleus in these examples, and it is difficult to account for this because, as Hutton (1947) has pointed out, the small radius of the zirconium ion should allow only limited substitution of large uranium and thorium ions. Conceivably the Sierran zircons crystallized at temperatures sufficiently elevated as to allow easier entry of the large radioactive metals (*cf.* Murthy, 1958). On the other hand, inclusions are common in these zircons, and a good part of the uranium or thorium could be present in such impurities. Hutton (1961) has, for example, identified metamict samarskite as inclusion material in metamict zircon. But whatever the source of the radioactivity, zircons in the halos studied may be of unusually high activity, because the writer has in a number of instances seen yellow halos surrounding zircons enclosed in plagioclase: Ramdohr (1957) and McAndrew (1957) find halos in plagioclase only about strong emitters (*e.g.*, pitchblende). Hoppe (1959) has actually discounted the possibility of zircon producing halos in plagioclase, owing to zircon's theoretically low content of radioactive cations.

References

Gentry, R. V. (1966) *Appl. Phys. Lett.* **8,** 65–67.

Hirschi, H. (1920) *Vierteljahresschrift der Naturforschenden Gesellschaft Zürich* **65,** 209–247. [Oak Ridge Nat. Lab. Transl. 702].

Hoppe, G. (1959) *Geol. Fören. Förhandl.* **81,** 485–494. [Oak Ridge Nat. Lab. Transl. 756].

Hutton, C. O. (1947) *Amer. J. Sci.* **245,** 154–157.

——— (1961) *Trans. Royal Soc. New Zealand* **88,** 639–653.

Kerr-Lawson, D. E. (1927) *Contrib. Can. Mineral. Univ. Toronto Stud., Geol. Ser.,* **24,** 54–71.

——— (1928) *Contrib. Can. Mineral. Univ. Toronto Stud., Geol. Ser.,* **27,** 15–27.

Laemmlein, G. G. (1945) *Nature* **155,** 724–725.

McAndrew, J. (1957) *Amer. J. Sci.* **255,** 715–723.

Murthy, M. V. N. (1958) *Can. Mineral.* **6,** 260–263.

Ramdohr, P. (1957) *Abhandl. Deut. Akad. Wiss. Berlin Kl. Chem., Geol. Biol* **2,** 1–17.

Rankama, K. (1954) *Isotope Geology.* Pergamon Press, New York. 535 pp.

Snetsinger, K. G. (1965) Ph.D. thesis, Stanford University.