

could be related to hydrothermal activity associated with intrusion of high level sills now present as large metabasite bodies, or it could be an early manifestation of the extrusive activity which generated the metavolcanic rocks at a higher stratigraphical level.

In east Glen Muick, staurolite persists as a relict phase in upper amphibolite-facies rocks on the verge of anatexis. It survives to these exceptionally high grades as a result of the stabilising influence of zinc, and the low availability of reactant quartz. The paragenesis differs from those previously described in the literature, and is an additional example of the occurrence of staurolite at anomalously high metamorphic grade.

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Sector-zoning of epidote in the Sanbagawa schists and the question of an epidote miscibility gap

IN the controversy over the presence of a miscibility gap in the epidote solid-solution series first proposed by Strens (1965), Raith (1976) used compositional data from a suite of rocks from the southern Tauern Window area, Austria, to sup-

port the concept of a miscibility gap. In our work on the low-grade Sanbagawa schists in central Shikoku, Japan, we have accumulated a large quantity of compositional data for epidotes from a wide range of rock-types and metamorphic

grades, but have not found evidence to support the miscibility gap. More recently, Yoshizawa (1984) described some epidotes that are sector-zoned. We now describe this briefly and discuss the implications for the miscibility problem.

Sector-zoned epidote

Sector-zoned epidotes were observed in basic schists of the Sanbagawa metamorphic belt in central Shikoku. These rocks belong to the chlorite zone of the metamorphic belt which corresponds to the pumpellyite-actinolite facies (Banno and Sakai, 1989). Details of the mode of occurrence of the sector-zoned epidote may be obtained from the paper of Yoshizawa (1984). The sector-zoned epidote coexists with actinolite or magnesio-riebeckite, but not with pumpellyite which occurs only in Fe^{3+} -poor rocks. The growth sectors we recognised are illustrated in Fig. 1. The composition of the sectors, denoted herein in terms of $Y_{\text{Fe}} = \text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Al})$, following the notation of spinal mineralogy, changed as they grew, but the relative Y_{Fe} at the same stage of growth, generally remains the same. The order of Y_{Fe} is as follows $\{100\} \geq \{110\} \geq \{001\} > \{10\bar{1}\}$.

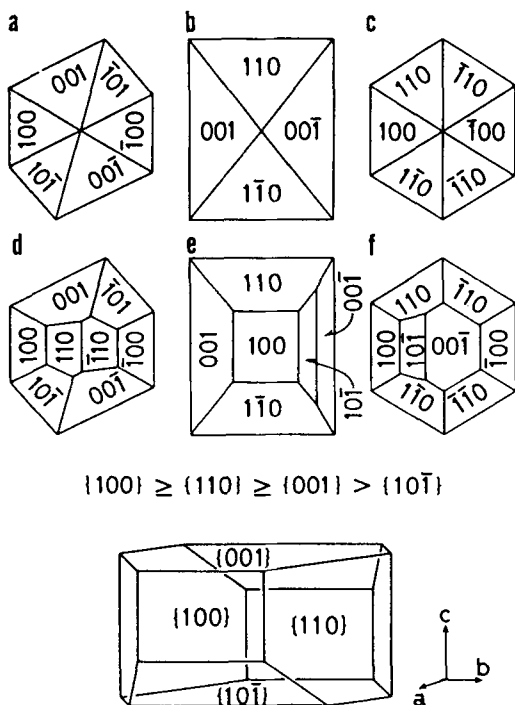


Fig. 1. Sectors recognised for epidote (Yoshizawa, 1984).

Fig. 2 shows a back-scattered electron image (BSI), photomicrograph (OPT), and camera lucid sketches with a stereogram of the orientation (ORI) of two epidotes from the same thin section, grain A near-parallel to (010) and grain B near-parallel to (100). In most of the sector-zoned epidotes examined, the sectorized area is overgrown by a discordant rim of homogeneous composition with the highest Y_{Fe} .

In Fig. 2, the grains A and B are similar to photomicrographs of epidotes from the Tauern Window area of the Austrian Alps as presented by Raith (1976; figs. 4 and 5). Raith has emphasised that the homogeneous core is commonly mantled by near-homogeneous rims and proposed that the cores and rims are separated by a compositional gap. However, the zonal structure of his fig. 4 may be interpreted as a section cut nearly parallel to (010) rimmed by non sector-zoned epidote, because we see that the outermost part of possible $\{10\bar{1}\}$ and $\{001\}$ sectors are in the extinction position, suggesting that the orientation of the 2-fold axis is nearly normal to the section. The distribution of inclusions also seems to be controlled by the 2-fold axis. The crystal in Raith's fig. 5 may be interpreted as near parallel to the (100) section as it resembles the grain B of this paper. The rectangular area of the crystal in the extinction position may correspond to the $\{110\}$ sector.

However, the exact value of the compositional gap across the core-rim boundary differs between the specimens from the Alps and those from Shikoku. The gap in the former is $Y_{\text{Fe}} = 0.18$ to 0.20 – 0.23 , whereas in Shikoku epidotes the rim are rather homogeneous even though their cores are sector-zoned. The compositional gap differs according to the orientation of the crystals. For grain A, the gap in OB direction is from 0.25 to 0.30 and in OC direction 0.20 to 0.30 in Y_{Fe} . This implies that after the formation of sector-zoned epidote, which was the product of metastable crystallisation possibly due to the driving force supplied by distinct overstepping of equilibrium, the rim grew under near-equilibrium conditions because the degree of overstepping was attenuated.

Concluding remarks

Our sceptical view of the miscibility gap may be based too much on the impression of the photographs presented by Raith (1976). Fig. 3 shows the frequency distribution of epidote compositions in terms of the Fe^{3+} atoms p.f.u. against $O = 12.5$ (anhydrous basis), from the Sanbagawa belt, including the chlorite, garnet and albite-

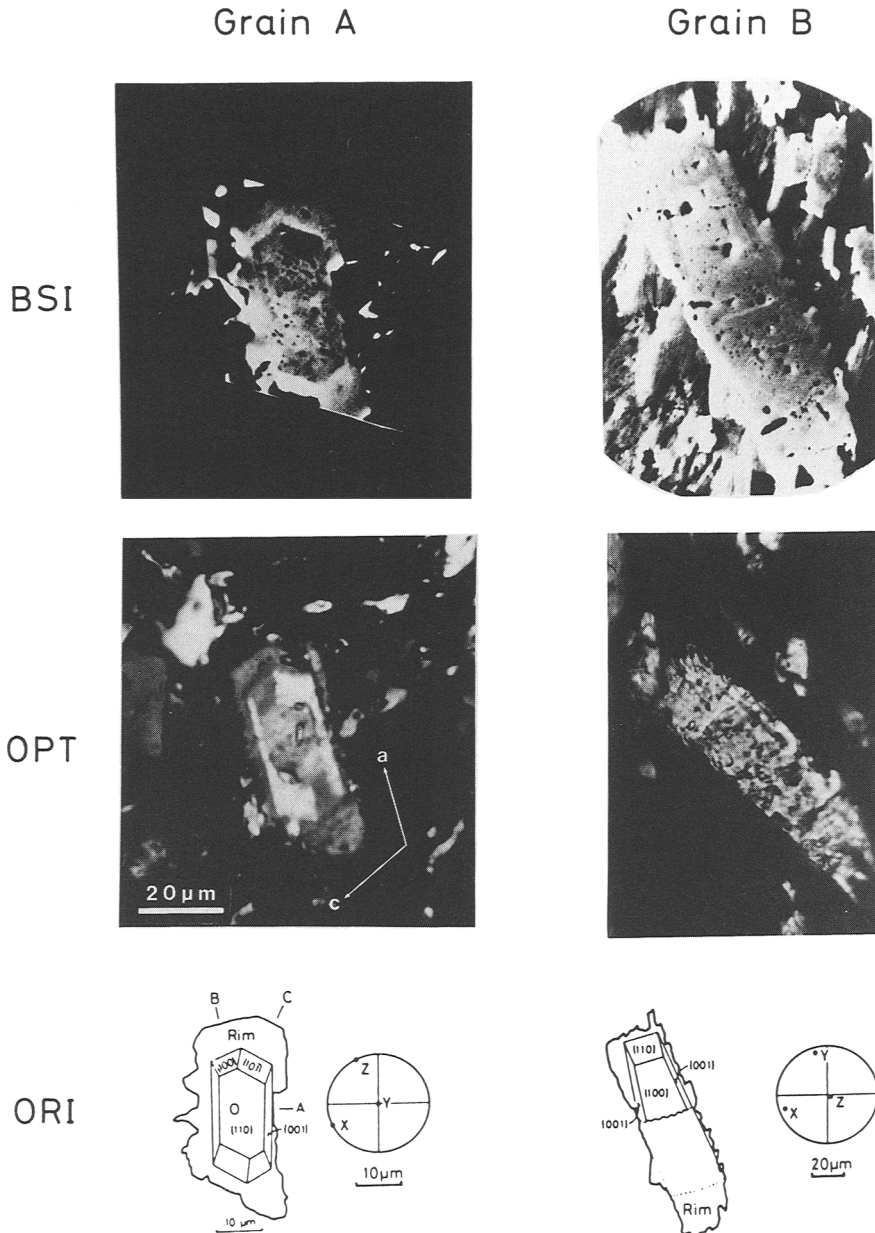


FIG. 2. Backscattered images (BSI), photomicrographs (OPT) and orientations (ORI) of two epidotes from a Sanbagawa green schist (Yoshizawa, 1984).

biotite zones (pumpellyite-actinolite facies to epidote-amphibolite facies), shown separately for hematite-bearing and hematite-free basic schists (Higashino *et al.*, 1982, 1984; Nakajima, 1982; Aiba *et al.*, 1984). Two histograms were drawn to avoid the bimodal Fe^{3+} distribution caused by the frequency of hematite-bearing and

hematite-free basic schists. The approximate range of the compositional gap for the Alpine epidote is shown for comparison. Although some compositions rarely occur, we consider them as depending on the frequency distribution of host rocks of epidotes. The range of epidote compositions of the Sanbagawa schists in the greenschist

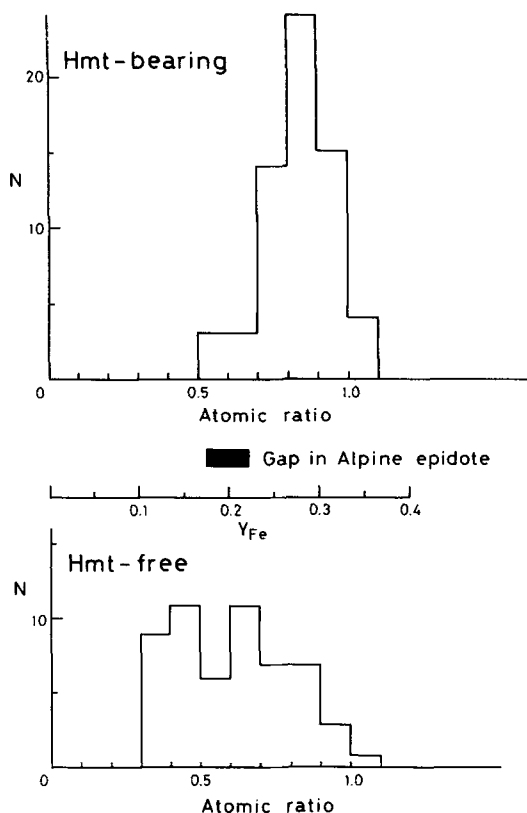


FIG. 3. Frequency distribution of Fe^{3+} values (atomic ratios against $\text{O} = 12.5$, anhydrous basis) from Sanbagawa schists (Higashino *et al.*, 1982, 1984; Nakajima, 1982; Aiba *et al.*, 1982). Frequency of composition of hematite (Hmt)- and hematite-free rocks are shown separately.

and pumpellyite-actinolite facies as shown by Nakajima (1982) in his fig. 8a and Fig. 9, respectively, does not support the existence of the gap in the range $Y_{\text{Fe}} = 0.18$ to 0.23 .

We consider therefore that it is more likely that the compositional gap noted by Raith (1976) and supported by Schreyer and Abraham (1978) is not a miscibility gap but instead a compositional gap between the sector zoned crystals and their rim, the latter having grown at near-equilibrium conditions.

We consider that the apparent miscibility gap reported for epidotes from the southern Tauern Window or part of it can be explained by sector-zoning of epidote. The presence of metastably grown mineral phases such as staurolite, is not uncommon even in regional metamorphism (Hollister, 1970), and zoisite (Enami, 1977). We may expect that the sector-zoning is more common in epidotes of other metamorphic terrains.

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Optical, X-ray, and chemical analysis of four eudialytes from Alaska

FOUR eudialyte samples from Alaska were studied to determine their optical, X-ray, and chemical properties. These data are useful in helping to document the overall correlation between optical properties and crystal chemistry of the chemically complicated eudialyte group. No definite correlations could be found, although an overall trend does exist. This is probably the result of the complicated chemistry and chemical substitutions that occur in this mineral group (Johnson *et al.*, 1990). Positive eudialytes have lower refractive indices than negative eudialytes, sometime referred to as 'eucolite' (a variety name only, which should not be considered a separate mineral, E. H. Nickel, IMA, pers. comm., 1991). ω increases at a faster rate than ϵ ; thus, for a change in optic sign, ω and ϵ must become equal, resulting in near-isotropic eudialytes. This has been observed and is called 'mesoeudialyte'. Recently, Pol'shin *et al.* (1991) also attempted to determine the crystal chemical reasons for positive and negative eudialytes by correlating them to the spectroscopic behaviour of Fe^{2+} .

Three of the eudialyte samples are from the north-central Alaska Range; the other is from southeast Alaska, about 1400 km away (Fig. 1). Of the three Alaska Range samples, two are from the Middle Fork plutonic complex (MFPC) and is one from the Windy Fork plutonic complex, which is about 8 km southeast of the MFPC. Both of these localities are associated with silica-saturated plutons, whereas the fourth sample, from Prince of Wales Island, is from a silica-undersaturated pluton.

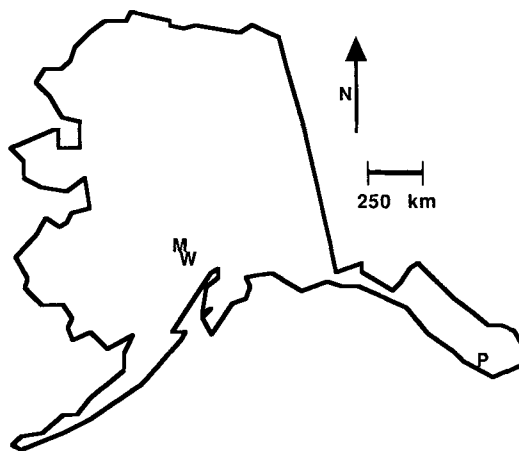


FIG. 1. Map of Alaska showing location of eudialyte samples. 'M' is the Middle Fork plutonic complex, 'W' is the Windy Fork pluton, only 8 km southeast of the Middle Fork, and 'P' is the Prince of Wales Island pluton in southeast Alaska.

Middle Fork Plutonic Complex. The early Tertiary (57 m.y.) MFPC consists of coeval syenite, peralkaline alkali feldspar granite, metaluminous granite, diorite, and gabbro, hosted by thinly bedded Palaeozoic calc-phyllites and marbles (Solie, 1988; Solie and Sinha, 1988; Gilbert *et al.*, 1989). The eudialyte-bearing specimen was found in talus in the contact zone between cogenetic fayalite-hedenbergite-syenite and peralkaline alkali feldspar granite near the southern