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"ZONE PERTHITE" FROM SOUTHERN BRITISH COLUMBIA

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Abstract

Perthite specimens from a syenite dyke, part of a syenite complex at Mt. Fleet, near Kamloops, B.C., are strikingly zoned. Each zone consists of two sub-zones, one rich in albite and the other rich in microcline. Some specimens show more than 75 zones. The two components of the perthite have compositions near $Ab_{95}Or_5$ and $Ab_{22}Or_{78}$, and its bulk composition is $Ab_{56}Or_{42}An_2$. It is concluded that the zonal pattern is pseudomorphous after an original magmatic zoning. Two alternate hypotheses of origin are proposed: one invokes two episodes of exsolution controlled by two solvi; the other makes use of alkali ion exchange followed by exsolution.

Sommaire

Des spécimens de perthite d'un dyke syénitique du complexe du mont Fleet, près de Kamloops (C.B.) sont zonés de façon frappante, contenant jusqu'à 75 zones. Chaque zone comporte deux sous-zones: l'une dans laquelle l'albite domine ($\simeq Ab_{95}Or_5$), l'autre où le microcline est prépondérant ($\simeq Ab_{22}Or_{78}$). La composition globale est $Ab_{56}Or_{42}An_2$. On conclut que cette zonation résulte de la pseudomorphose d'une zonation magmatique originelle. Deux hypothèses génétiques sont émises: l'une invoque deux épisodes d'exsolution chacun selon un solvus différent; l'autre fait appel à un échange d'ions alcalins suivi d'exsolution.

(Traduit par la Rédaction)

Introduction

A perthite of unusual type occurs in a syenite complex at Mount Fleet, some 13 km northeast of Kamloops, B.C. Although similar perthite has been briefly described before, little attempt has been made to account in detail for its development.

The regional geology at Mount Fleet has been described by Cockfield (1948), and the area of immediate interest, by Kwak (1964). Argillite, limestone and greywacke of the late Paleozoic Cache Creek Group are intruded by a syenitic complex, approximately elliptical in plan view, some 9 by 5 km. The complex (Kwak 1964) consists of a discontinuous quartz syenite rim that surrounds a variety of syenitic rocks including garnetiferous syenite, shonkinite, and nepheline- and natrolite-bearing varieties. Syenite dykes intrude both the adjacent Cache Creek strata and the syenite complex; one of these dykes contains the perthite that is the subject of this paper.

The syenite dyke, about 3 m thick, occurs near the 1130 m level on the southeast side of Mount Fleet. It is strikingly porphyritic (Fig. 1), with closely crowded zoned feldspar phenocrysts up to 2.5 cm across, averaging about 1.5 cm. These are set in a matrix that in some specimens forms as little as 15% of the rock. This matrix is composed of perthite, albite, zoned aegirine-augite, strongly pleochroic amphibole, sphene, magnetite and unusually coarse apatite.

Description

The phenocrysts are anhedral. Many are subspherical or roughly ovoid, and some have a sheaf-like (bow-tie or crude hourglass) outline. In hand specimen, cleavage surfaces are strikingly curved.

Zoning can be seen on weathered and on sawn surfaces and is made obvious by staining with sodium cobaltinitrite. In thin section, some crystals are zoned almost throughout (Fig. 2) but many show areas or sectors that are zoned and others that consist of patch perthite (Fig. 3). Innermost zones are commonly eccentric with respect to the outlines of ovoid crystals, the zonal pattern suggesting that the crystal grew more easily in the crystallographic direction *a* than in other directions. Zoning rather than patch perthite is commonly better developed in sectors that include the *a* direction as a radial bisector than in others, but some sectors show both zone perthite and patch perthite (Fig. 3). Many crystals are composed of domains that are bounded by more or less radial discontinuities. At growth discontinuities, zoning may be deflected towards the middle of the crystal (Figs. 3, 4). At other discontinuities,

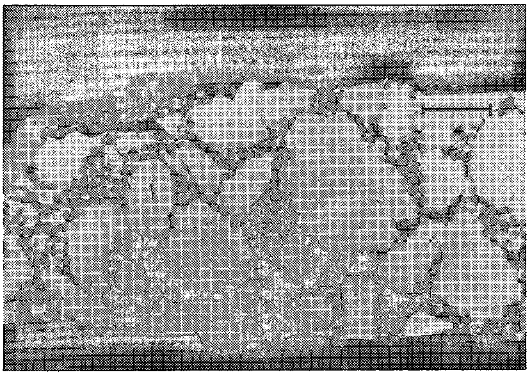

FIG. 1. Polished and stained slab of syenite porphyry showing shapes of zoned phenocrysts and scanty matrix. Zoning can be seen in some crystals (largest crystal and one at bottom right). Bar scale is 1 cm long.

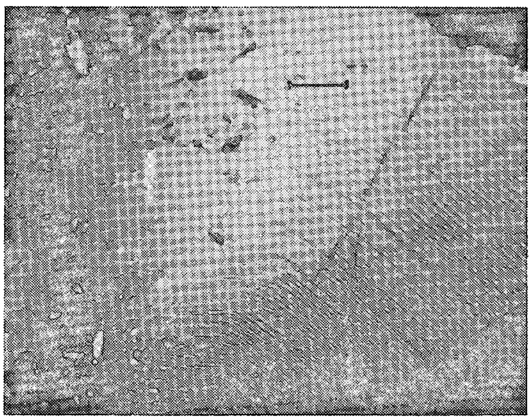

FIG. 2. Zoned feldspar, showing more or less radial discontinuities and changes in extinction position. Zones convex towards rim of crystal. Crossed nicols; bar scale is 1 mm long.

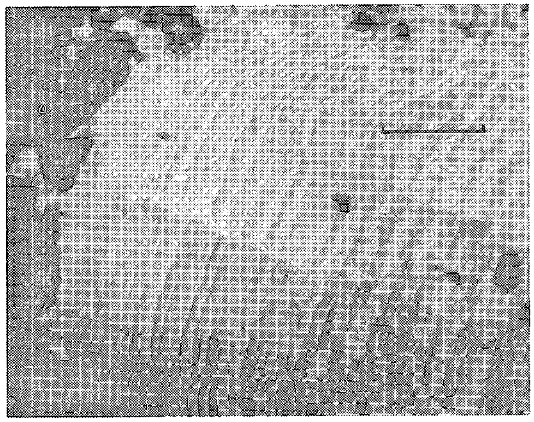

FIG. 3. Zoning interrupted by radial discontinuities, at which extinction positions change. "Zone perthite" gives way to patch perthite. Light colored areas are albitic, dark areas are rich in microcline. Exsolution lamellae and zones in middle part of photo are nearly parallel to (100). Crossed nicols; bar scale is 0.5 mm long.

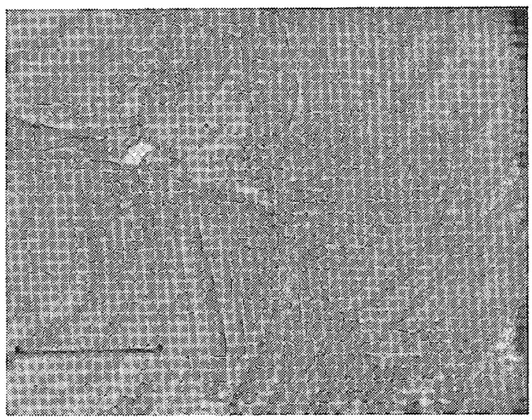

FIG. 4. Radial discontinuities due to growth, marked by re-entrants, truncated at an "unconformity". Zones are cut at a low angle, and therefore diffuse in appearance. Light colored areas are albitic, dark areas are rich in microcline. Crossed nicols, bar scale is 0.5 mm long.

cleavage directions and extinction angles change by a degree or two (Fig. 3), zones change slightly in thickness, show a slight offset over a small length of discontinuity, or exhibit a local development of patch perthite. Some of the latter discontinuities do not extend to the edges of the crystals but where they do, the matrix shows no obvious strain. The strain within the phenocrysts may have been acquired before the matrix of the rocks crystallized, and, in some crystals, before the outermost zones were formed. Extinction angles change in very small steps across areas lacking abrupt discontinuities; crystals do not seem to have elastic strain. Zones generally are parallel to the outer curved surfaces of the crystals, and can be traced around subspherical crystals; however, they are truncated at some exterior surfaces, *e.g.*, in sheaf-like crystals. "Unconformities", at which outer zones overlie truncated inner zones, were seen in several crystals (Fig. 4). Some crystals show more than 150 zones (*i.e.*, 75 couplets, each consisting of an albitic part and an intergrown microcline–albite part). Inclusions of weakly zoned sodic plagioclase are locally abundant and randomly oriented.

Typical couplets are shown in Figure 5. The

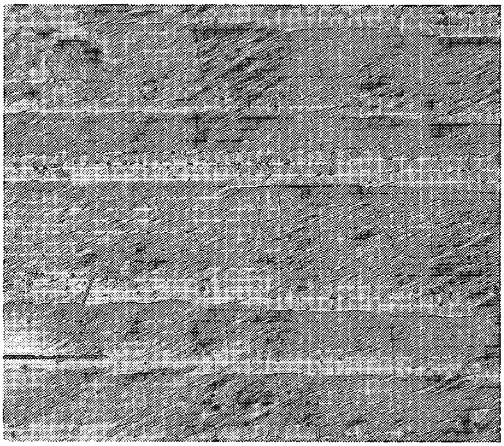

FIG. 5. Typical couplets. White parts are albitic, grey areas are microcline-rich. The fine lamellae are approximately parallel to (100). The rim of the crystal is towards the top of the photo. Crossed nicols; the bar scale is 200 μm long.

albite part, towards the core of the crystal, is generally nearly optically homogeneous, occasionally contains lamellae of K-feldspar, and commonly shows albite twinning. Generally the albitic part forms about ⅓ of the 0.15 mm average thickness of a couplet. It is succeeded by a zone of lamellar perthite, with lamellae about 2 μm thick; this part gradually becomes richer in microcline as the number of albitic lamellae diminishes, and may grade into a narrow zone of non-perthitic microcline, with characteristic twinning. The fine lamellae of the outer part of the couplet are oriented near (100); U-stage tests gave a range of about 20° in orientation, probably due to difficulties in orienting optical axes, cleavages and lamellae in such fine intergrowths.

X-ray tests, using the method of Wright (1968) show that albite lies near the maximum microline – low albite series and the microcline near maximum microcline but slightly displaced towards the orthoclase series (Wright 1968, p. 91). Peaks on diffractograms are sharp; there is no suggestion that more than two feldspar species are present.

Zoning was studied in detail using an A.R.L. electron microprobe with beam diameter of 20 μm, specimen current 50 nA and accelerating voltage 15 kV. A traverse was made across three couplets (at about 60° to the zoning to avoid inclusions, fractures, *etc.*) with analyses at intervals of 10 μm (Fig. 6). The average composition of these three couplets is almost identical to the average composition obtained by traverses made with a moving beam across many zones. Marginal parts of crystals seem to have the same bulk compositions as interior parts. The average compositions of the zoned crystals lies close to $Ab_{56}Or_{42}An_2$. BaO ranges between 0.1 and 0.2%. The most albitic subzone is near $Ab_{95.5}$ and the subzone richest in microcline, near Or_{78}. Anorthite ranges from 0.2% in microcline to about 4.5% in albite.

The most typical couplet of Figure 6 is "C"; note the sharply delineated basal albitic zone, succeeded outwards by a wide zone of intermediate composition and fine perthitic intergrowth, and lastly, the microcline-rich zone. The asymmetry of the couplets is clearly shown. These features are shown also in Figure 7, an X-ray image made by scanning electron microscope; the randomly distributed patches of sodic or potassic feldspar probably account for most of the minor fluctuations in the curves of Figure 6.

ORIGIN

There seems no reason for doubting that the finely lamellar perthite (Fig. 5) formed

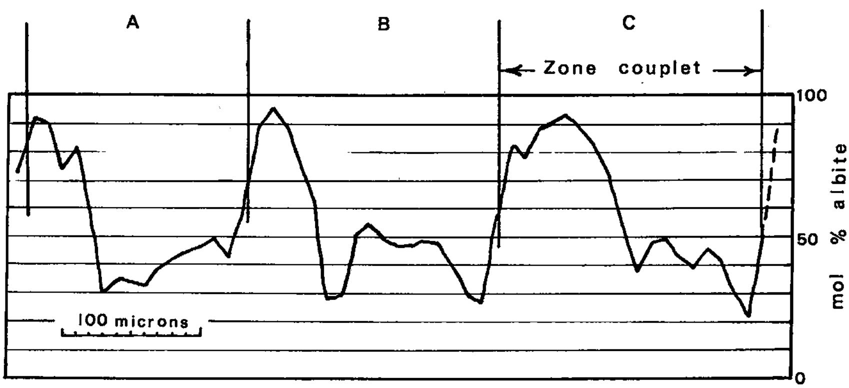

FIG. 6. Electron microprobe analysis of three zone couplets.

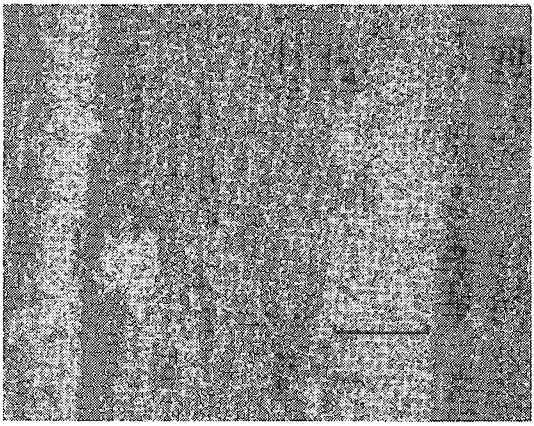

FIG. 7. S.E.M. X-ray image of a zone couplet. Light areas, Na-rich; dark areas, K-rich. Lamellae and zones are approximately parallel to (100). The bar scale is 40 μm long.

by exsolution (hereafter referred to as Stage II exsolution). It is inferred that before this exsolution occurred, the compositions of the zones were much like those shown in Figure 6 because the beam of the electron microprobe used was large enough to span several perthite lamellae, thus smoothing out the fine alternations in composition. The general nature of the zoning before Stage II exsolution is shown in Figure 8B, with the zones alternating between about Ab_{90} and Ab_{40}.

Kwak (1964) noted the same pattern of zoning in many rocks from the Mount Fleet pluton but the zoning he described seems not to have been as strikingly developed as that discussed here. He ascribed the zoning to Harloff's (1927) diffusion-supersaturation mechanism. Although this mechanism or others that depend on crystal–melt equilibrium may explain the common short-ranging oscillatory zoning in plagioclase or alkali feldspar, it seems impossible to apply them to feldspars where the zones alternate between such widely ranging compositions as Ab_{90} and Ab_{40}, particularly as these compositions lie on opposite sides of the minimum in the system Ab–Or.

Although the observed zoning is not truly primary, *i.e.*, magmatic, the clear relation of the zones to growth patterns and to crystal borders and the presence of cross-cutting relations at "unconformities" suggest that the *pattern* of zoning is magmatic. The compositions of the zones are thus probably the result of modification of primary oscillatory zoning by an early (Stage I) perthitic unmixing. This view is supported by the fact that the compositions of the feldspar phases, Ab_{90} and Ab_{40}, correspond approximately to those dictated by accepted solvi in the system Ab–Or. Therefore, the crystals were probably originally sanidine with oscillatory zoning. Moreover, the fact that at "unconformities" the albitic part invariably forms the basal unit suggests that the couplets represent original zone units.

In relating this Stage I perthite to the assumed original oscillatory zoning, it seems simplest to assume that the original zoning was in the same sense as that preserved after Stage I exsolution and that during Stage I, the compositional range was simply enlarged. It therefore would follow that the original zoning was something like that shown in Figure 8A. It may be noted here that the bulk composition lies on the orthoclase side of the minimum and that feldspars with this sort of reverse zoning *within zones* have been synthesized by Lofgren (1974). Two hypotheses for the origin of the "zone perthite" are outlined below.

The first hypothesis makes use of two different solvi. The strain-free solvi for sanidine-high albite and for microcline-low albite are shown in Figure 9 for a pressure of one atmosphere. Increasing pressure will raise the maxima of the solvi. With slow cooling, the hypothetical weakly zoned sanidine unmixes

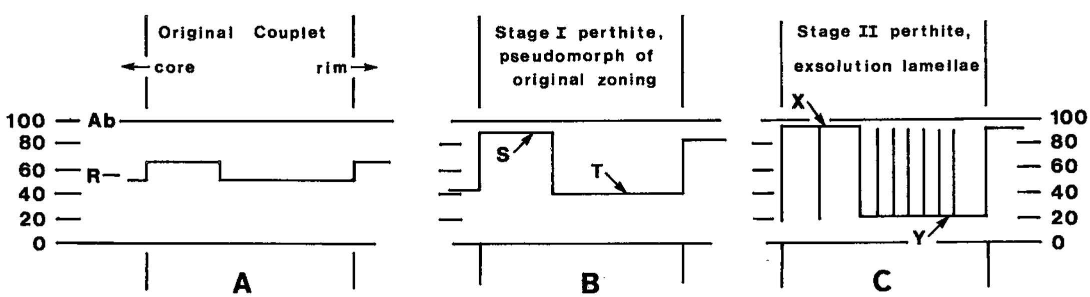

FIG. 8. Two-stage unmixing of "zone perthite". (A) Original magmatic zone couplet in sanidine. *R* is the bulk composition. (B) The first unmixing produces pseudomorphs of the original zoning. (C) Second unmixing, with development of lamellae about parallel to (100).

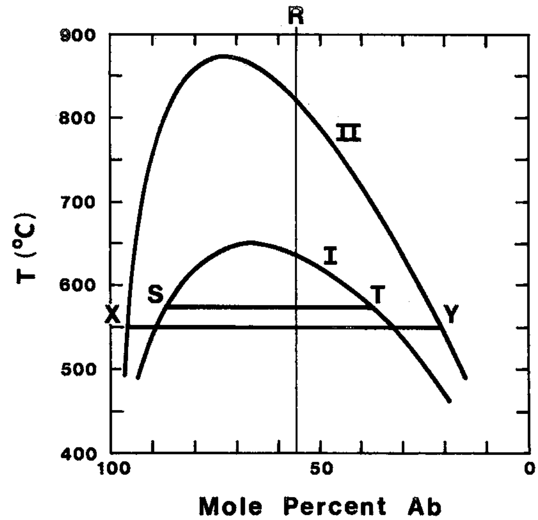

FIG. 9. Curve I is the strain-free solvus (Waldbaum & Thompson 1969) for sanidine–high albite; curve II is the strain-free solvus (Bachinski & Müller 1971) for the microcline–low albite series. *R* is the average composition of the Mount Fleet perthite.

(Stage I), in response to the appropriate solvus, to compositions *S* and *T*. The physical surfaces that controlled the unmixing were those of the primary magmatic zones; these surfaces would promote nucleation. Thus, exsolution seems to have been accompanied or closely followed by extensive diffusion and coarsening because the product at the completion of Stage I was a pseudomorph of the original zoning, with no lamellar perthite (Fig. 8B). Phase I exsolution was terminated, perhaps, by intrusion and cooling of the crystal mush. After intrusion, prolonged exposure to moderate temperatures promoted inversion to more ordered crystals, and Stage II exsolution, controlled by the microline–low albite solvus, yielded lamellar perthite or patch perthite, compositions *Y* and *Z*. Limited diffusion of sodium, leaving microcline-rich subzones adjacent to the succeeding albite subzone seems to be required (Figs. 6, 7). Pressure and temperature variations during formation of the feldspars have not been established; the compositions *S*, *T*, *Y* and *Z* (Fig. 9) are to be considered qualitative rather than quantitative. Their general correspondence, however, with the measured compositions supports the general hypothesis. The strained nature of the feldspars is ascribed to cataclastic action, perhaps during intrusion. It seems impossible to relate deformation or strain to coherent exsolution at Stage I because the diffusion and coarsening process postulated would probably relieve strain as it accumulated.

An alternative hypothesis of origin depends on alkali-ion exchange. Orville (1963) has shown that below 680°C at 2 kbar, homogeneous Na–K feldspar will, by alkali-ion exchange with an appropriate alkali-rich vapor phase, be replaced by two alkali feldspars of perthite-like compositions. A temperature–composition diagram showing one- and two-feldspar fields outlined by his experiments closely resembles a solvus. It seems possible that the stage I perthite could be produced at relatively high temperatures from a mildly zoned sanidine by exchange with an interstitial vapor phase, the difference in original composition of the zones being increased, producing a "perthite" pseudomorph of the original zoned crystal. This mechanism might be more effective in producing the pseudomorph than the nucleation and coarsening appealed to in the first hypothesis. Stage II unmixing would ensue at lower temperatures, controlled finally by the low albite–microcline strain-free solvus.

Richardson (1968) described somewhat similar perthite from a metamorphosed syenite in Scotland and concluded "that at one time the large perthites were homogeneous monoclinic alkali-feldspars and have since unmixed into a monoclinic K-feldspar and a triclinic plagioclase member" (1968, p. 14). Specimens from the Duckling Creek syenite of northern British Columbia (Armstrong 1949) contain "zone perthite" but in the examples available to the author it is not as spectacularly developed as in the Mount Fleet syenite dyke. The margins of the Poplar Creek and McKain Creek alkalic granite stocks contain perthitic microcline in which occasional albite stringers partly outline euhedral shapes and are probably pseudomorphs of original zones (Read 1973; pers. comm.).

Why is "zone perthite" not more common? The best examples known to the writer are from alkalic syenites. According to the hypotheses of origin outlined above, the magmas from which these rocks formed must have been hypersolvus and their sanidines zoned. It may be that a combination of the high initial temperatures of crystallization of syenitic magmas with a particular cooling regime leads to the development and preservation of "zone perthite". In the Mount Fleet specimens, many crystals show sectors with perfectly developed "zone perthite", but other sectors show only ghostly zoning, barely discernible in patch perthite, and other sectors of the same crystal are of completely random patch perthite. These observations suggest that "zone perthite" is a transient type and that the usual fate of zoned sanidines in intrusive rocks is to unmix to form perthite which does not pseudomorph original zoning.

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