Canadian Mineralogist
Vol. 31, pp. 459-466 (1993)

PLAGIOCLASE ZONATION IN A BASALT TO RHYODACITE ERUPTIVE SUITE, SEGUAM ISLAND, ALASKA: OBSERVATIONS BY NOMARSKI CONTRAST INTERFERENCE

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Abstract

Plagioclase zoning in lavas from the Seguam volcanic center, Aleutian arc, has been studied using the Nomarski Differential Interference Contrast (NDIC) imaging technique on etched polished sections. Plagioclase in basalts records a complex history including periods of oscillatory euhedral growth interrupted repeatedly by patchy cellular growth, and less commonly, by dissolution events, whereas andesites, dacites, and rhyodacites crystallized oscillatory euhedral zoned plagioclase with only rare evidence of subtle dissolution events. The complexity of plagioclase in basalts and the simplicity of plagioclase in the evolved lavas at Seguam contrast with NDIC observations from previously studied orogenic lavas. These first-order observations suggest that the intensive parameters T, P, and *X* of equilibrium crystallization for the basaltic magmas may have been disturbed by thermal effects of magma mixing or convection, or by decompression during magma ascent. Andesitic to rhyodacitic magmas apparently were less strongly affected by thermal, baric, or compositional shifts. The contrasts in plagioclase zoning between Seguam and other orogenic volcanic centers reflect the difference between systems dominated by closed-system fractionation (Seguam) and more typical open systems where magma mixing may be common.

Keywords: plagioclase, interferometry, Nomarski method, Aleutian island arc, Seguam Island, Alaska.

Sommaire

Nous avons analysé la zonation des cristaux de plagioclase du centre volcanique de Seguam, dans les Îles Aléutiennes, en Alaska, en utilisant la technique de contraste par interférence différentielle de Nomarski sur des sections polies traitées à l'acide. Dans les basaltes, le plagioclase témoigne d'une évolution complexe, dont les périodes de croissance oscillatoire du cristal idiomorphe sont interrompues de façon répétée par des zones de croissance cellulaire en taches et, moins couramment, par des événements de dissolution. Par contre, dans les andésites, dacites et rhyodacites, le plagioclase idiomorphe est zoné de façon oscillatoire; très exceptionnellement seulement voyons-nous des signes subtils d'événements de dissolution. La complexité du plagioclase des basaltes et la simplicité du plagioclase des laves plus évoluées diffèrent des caractéristiques des suites de laves orogéniques étudiées antérieurement. Ces observations font penser que les paramètres intensifs T, P et *X* qui régissaient la cristallisation des magmas basaltiques à l'équilibre ont probablement été dérangés, soit par effets thermiques dus au mélange de magmas ou à la convection, soit par décompression au cours de l'ascension du magma. Les magmas andésitique et rhyodacitique auraient été moins fortement affectés par de tels changements de température, pression, ou composition. Le contraste dans les détails de zonation entre les laves de Seguam et celles d'autres centres volcaniques orogéniques reflète la différence entre un fractionnement en système fermé surtout (Seguam), et une évolution en système ouvert, probablement avec mélange de magmas, ce qui semble être plus courant.

(Traduit par la Rédaction)

Mots-clés: plagioclase, interférométrie, méthode de Nomarski, arc insulaire des Aléutiennes, île de Seguam, Alaska.

Introduction

Plagioclase zoning in volcanic rocks has received a great deal of attention because patterns of zoning reflect the physical and chemical history of the magmatic liquids from which the crystals formed. Several recent studies have sought to relate zoning patterns in natural plagioclase to phenomena such as magma mixing (Kuo & Kirkpatrick 1982, Sakuyama 1981, Nixon & Pearce 1987, Stamatelopoulou-Seymour *et al.* 1990), phenocryst recycling (Blundy & Shimizu 1991), stratification of the magma chamber (Kawamoto 1992), tidally driven periodic crystal–liquid motions (Anderson 1984), and plagioclase resorption during magma ascent

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(Pearce *et al.* 1987a). In addition, experimental studies have produced textures of plagioclase dissolution and reaction similar to those in lavas considered to preserve evidence of magma mixing (Tsuchiyama 1985), rapid isothermal decompression (Nelson & Montana 1989), and isochemical heating (Sunagawa 1992). In light of these studies, some features in plagioclase phenocrysts, such as sieve textures or bimodal compositions of phenocrysts, have become widely accepted indicators of open-system magma mixing.

Our purpose here is to present initial Nomarski Differential Contrast Interference (NDIC) observations of plagioclase phenocrysts in lavas from the Seguam volcanic center, central Aleutian arc, Alaska. In contrast to many calc-alkaline volcanic centers in the Aleutians, which are dominated by lavas of intermediate composition (53–63% SiO_2), with an origin by open-system magma mixing (*e.g.*, Conrad *et al.* 1983, Brophy 1987, 1990), Seguam is composed of tholeiitic basaltic to rhyodacitic lavas (49–71% SiO_2) that evolved by episodic closed-system crystal fractionation from a basaltic parent (Singer *et al.* 1992a, c).

These initial NDIC observations complement a more comprehensive study using NDIC, laser interferometry, and results of electron-microprobe analyses intended 1) to correlate the fine-scale structures of plagioclase phenocrysts to compositional changes within the crystals, and 2) to infer changes in magma composition or intensive parameters (Singer *et al.* 1993). The overall aim is to constrain, in some detail, the dynamic behavior of magmas within the Pleistocene subvolcanic plumbing system beneath Seguam Island. In volcanic systems where geochemical evidence indicates that intermediate and silicic magmas formed by closed-system crystal fractionation, plagioclase zoning can be expected to be distinct from that formed in more common open-system magma chambers.

Geology, Petrography, and Petrology

Seguam Island is a 205-km^2 Mid-Pleistocene to Recent central Aleutian volcanic center. Unlike adjacent volcanic centers in the oceanic portion of the arc, Seguam grew atop strongly extended crust. This local tectonic difference is reflected in the unusual suite of low-K, high-Al basaltic and basaltic andesitic lavas and subordinate andesitic to rhyodacitic lavas that compose the island (Singer & Myers 1990). The eleven samples examined in this study were selected from a suite of 50 samples collected from the 1.07 to 0.07 Ma Turf Point Formation (TPF), which comprises the oldest subaerial lavas on Seguam (Singer *et al.* 1992a). The samples (Table 1) contain phenocrysts of plagioclase (Pl), clinopyroxene (Cpx), ± olivine (Ol), ± orthopyroxene (Opx), ± titanium-rich magnetite (Mag). Groundmass pigeonite and rare ilmenite also occur.

TABLE 1. SUMMARY OF PETROGRAPHY, LAVAS OF THE TURF POINT FORMATION

	Basalt	Basaltic Andesite	Andesite	Dacite & Rhyodacite
wt.% SiO_2	49-52	52-56	56-63	63-71
number of samples	(n=21)	(n=13)	(n=8)	(n=8)
plagioclase	20.1-42.1	19.6-45.0	0.2-21.8	4.5-7.1
olivine	0.4-9.3	0.4-5.0	0-0.5	none
clinopyroxene	0.3-5.8	0.1-7.3	tr-7.2	0.5-2.0
orthopyroxene	0-tr	0-3.0	0-1.8	0-0.3
magnetite	rare	rare	rare	rare
Σ phenocrysts	22-47	23-58	<1-31	6-9
texture	porphyritic intergranular gm, with rare pigeonite	porphyritic seriate intersertal-hyalopilitic gm	porphyritic vitrophyric intersertal-hyalopilitic gm	vitrophyric hyalopilitic gm

Numbers are volume % of crystals greater than 0.03 mm in diameter. tr = trace, gm = groundmass.

The petrology and geochemistry of the TPF lavas are thoroughly described in Singer *et al.* (1992a, b) and are only briefly summarized here. Mg-numbers [$100Mg/(Mg+Fe^{2+})$] of mafic phenocrysts decrease from basalt to rhyodacite with increasing whole-rock FeO^*/MgO. Reverse zoning was not observed in olivine, clinopyroxene and orthopyroxene; however, the range in anorthite (An) content of plagioclase and the Mg-numbers of olivine and clinopyroxene are greater in basalts and basaltic andesites than in andesites or dacites. Plagioclase phenocrysts in basalt and basaltic andesite typically range from An_{93} to An_{55}, with most phenocryst cores between An_{70} and An_{93}. Most plagioclase cores in andesites and dacites are between An_{70} and An_{45}. The An content of plagioclase generally decreases with increasing whole-rock SiO_2; however, several andesite and rhyodacite samples contain a small percentage of plagioclase phenocrysts with a sieve-textured calcic core (An_{75}) overgrown by more sodic inclusion-free zones. A thin (<50 μm), relatively sodic rim is common to all plagioclase phenocrysts.

On the basis of major- and trace-element variations and Sr, Nd, Pb and O isotope compositions, Singer *et al.* (1992a, c) concluded that TPF basaltic andesites, andesites, dacites, and rhyodacites can be related to a typical Seguam basaltic parent magma by closed-system fractional crystallization. In contrast to the evolved lavas, the basalts and some basaltic andesites (49–54% SiO_2) have heterogeneous compositions in terms of major and trace elements that cannot be related to one another by crystal fractionation or sorting; this may reflect variable degrees of partial melting of the source and possibly some mixing of slightly evolved and more primitive basaltic magmas (Singer *et al.* 1992b).

NOMARSKI DIFFERENTIAL INTERFERENCE CONTRAST ANALYSIS

Polished sections of five samples of basalt (49–52% SiO_2), two of basaltic andesite (54.4 and 55.1% SiO_2), two of andesite (58.3 and 62.7% SiO_2), one of dacite (67.5% SiO_2), and one of rhyodacite (71.0% SiO_2), which represent the spatial, temporal, textural and geochemical range of TPF lavas, were etched in fluoboric acid, HBF_4, for 30–600 seconds, then neutralized in a saturated solution of Na_2CO_3. Zones containing a higher Ca content are etched more deeply than those containing less Ca. The resulting microtopographic relief (± 0.5 μm) is visually enhanced by utilizing reflected-light Nomarski differential interference contract (DIC) microscopy (for details see Anderson 1983, 1984, Clark *et al.* 1986). Although the Nomarski technique does not directly yield chemical composition, it dramatically improves the resolution of oscillatory zoning, patchy or sieve-textured zones, truncated zoning, and other features that may otherwise go unnoticed during routine petrographic or microprobe studies (*e.g.*, Pearce & Clark 1989). To emphasize salient characteristics of plagioclase zoning in the Seguam samples, NDIC images of plagioclase from other orogenic lavas also are discussed.

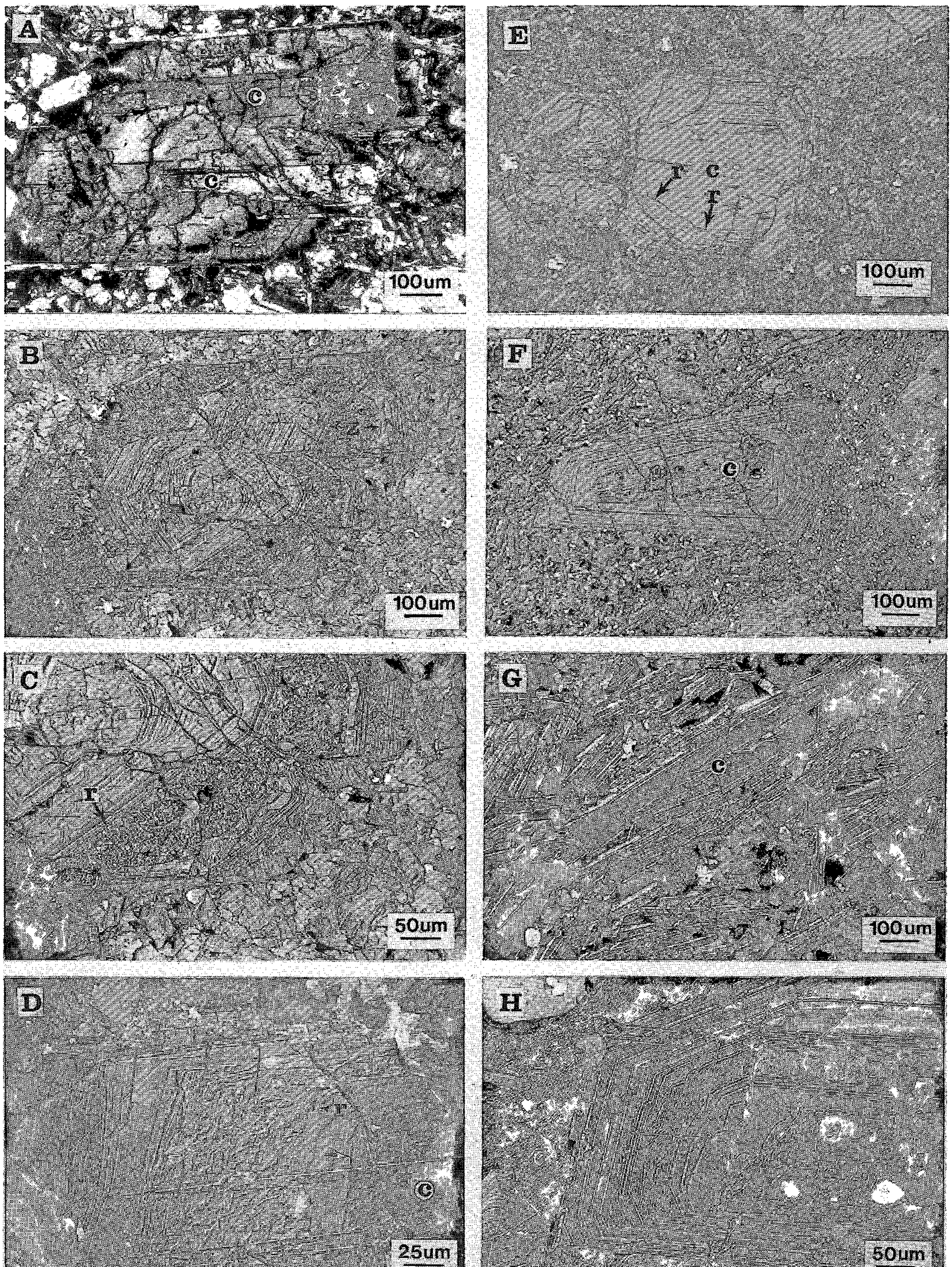
OBSERVATIONS

TPF basalts contain plagioclase phenocrysts with complex patterns of zoning (Fig. 1). Most commonly, phenocrysts in basalt contain zones alternating between oscillatory euhedral and patchy or sieve-textured zones (Figs. 1B, C, D). Patchy zones 10–100 μm wide commonly grew on planar, locally fritted, surfaces bounding oscillatory euhedral zones (Fig. 1C). The internal structure of the patchy zones may be very fine and chaotic (Fig. 1C) or coarser, and exhibit a more ordered, "hieroglyphic" texture (Figs. 1D, E), previously described by Pearce & Kolisnik (1990) in andesitic lavas. The coarser patchy zones commonly contain elongate inclusions of glass 10–35 μm in diameter, some containing two-phase fluid inclusions. Although rare, unequivocal cross-cutting relations in which euhedral oscillatory zones are truncated and overgrown by younger euhedral zones occur in plagioclase in the basalts (Figs. 1C, E). Many basaltic andesites have plagioclase phenocrysts with the same alternating zoning noted in the basalts; however, several also contain phenocrysts with a sieve-textured core surrounded by a euhedral oscillatory-zoned mantle (Fig. 1F). Phenocrysts with a morphology similar to that in Figure 1F also occur in several andesite to rhyodacite samples. Despite the textural complexity of plagioclase phenocrysts in the basalts, virtually no shifts in composition accompany changes in texture or in the dissolution surfaces (Singer *et al.* 1993).

In contrast to the basalts and their texturally complex, but compositionally simple plagioclase phenocrysts, the andesites, dacites, and rhyodacites contain plagioclase that is remarkably free of textural complexity. These intermediate to silicic lavas are dominated by plagioclase phenocrysts with fine-scale euhedral oscillatory zoning from core to rim (Figs. 2A, B, C). Although not illustrated here, many crystals, similar to those in Figures 2B and 2C, exhibit one or more very subtle dissolution surfaces in which the corners of underlying euhedral zones are slightly rounded. Whether or not dissolution surfaces are present, compositionally, phenocrysts in the andesites, dacites, and rhyodacites exhibit virtually no gradual zoning or abrupt shifts. The only exceptions are uncommon crystals similar to those in Figure 1F where the sieve-textured phenocryst core is calcic and probably a xenocryst overgrown by less calcic (>10% An lower) zones (see discussion below).

Complex patterns of plagioclase zoning in basaltic lavas had not previously been detected in NDIC (*e.g.*, Pearce & Kolisnik 1990, Fig. 1G). Kuo & Kirkpatrick (1982) used petrographic and electron-microprobe techniques to document complex zoning in plagioclase from MORB; however, the features they observed are quite different than those in the Seguam basalts. Specifically, Kuo & Kirkpatrick (1982) identified skeletal glass-rich phenocryst cores and reversely zoned mantles, the likes of which are absent in TPF basalts. Plagioclase phenocrysts in the Seguam basalts do, however, exhibit zoning and resorption features similar to many of the basaltic andesites and andesites studied with Nomarski techniques (Figs. 1H, 2D and 2E; Pearce & Kolisnik 1990, Pearce *et al.* 1987a, Nixon & Pearce 1987, Anderson 1984). Previously studied calc-alkaline andesites are invariably complex and display alternating euhedral oscillatory and patchy zones or are characterized by multiple features of dissolution (*e.g.*, Figs. 2D, E) associated with large (>10% An) shifts in composition. This is in marked contrast to the Seguam andesites, which display no such complex features (Figs. 2A, B). Many examples of calc-alkaline rhyodacite and rhyolite exhibit simple oscillatory euhedral zoning (Fig. 2F), and the andesite, dacite, and rhyodacite from Seguam are very similar to these (*e.g.*, Figs. 2A, B, C).

In summary, plagioclase phenocrysts in TPF basalts and some basaltic andesites record a complex history, including periods of oscillatory euhedral or cellular patchy growth, punctuated infrequently by cross-cutting surfaces reflecting dissolution and resorption. It is common to find two or more sieve-textured zones, each bounded by euhedral oscillatory zones in phenocrysts in basalt. Except for the uncommon calcic-plagioclase-cored xenocrysts, plagioclase in TPF andesite, dacite, and rhyodacite reveals a much less complex history, usually implying uninterrupted oscillatory euhedral growth. Many previously studied basalts exhibit plagioclase zoning less complex than at Seguam, whereas plagioclase in most calc-alkaline andesites displays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prominent textural features and compositional zoning that reflect complex phenomena of growth and dissolution.

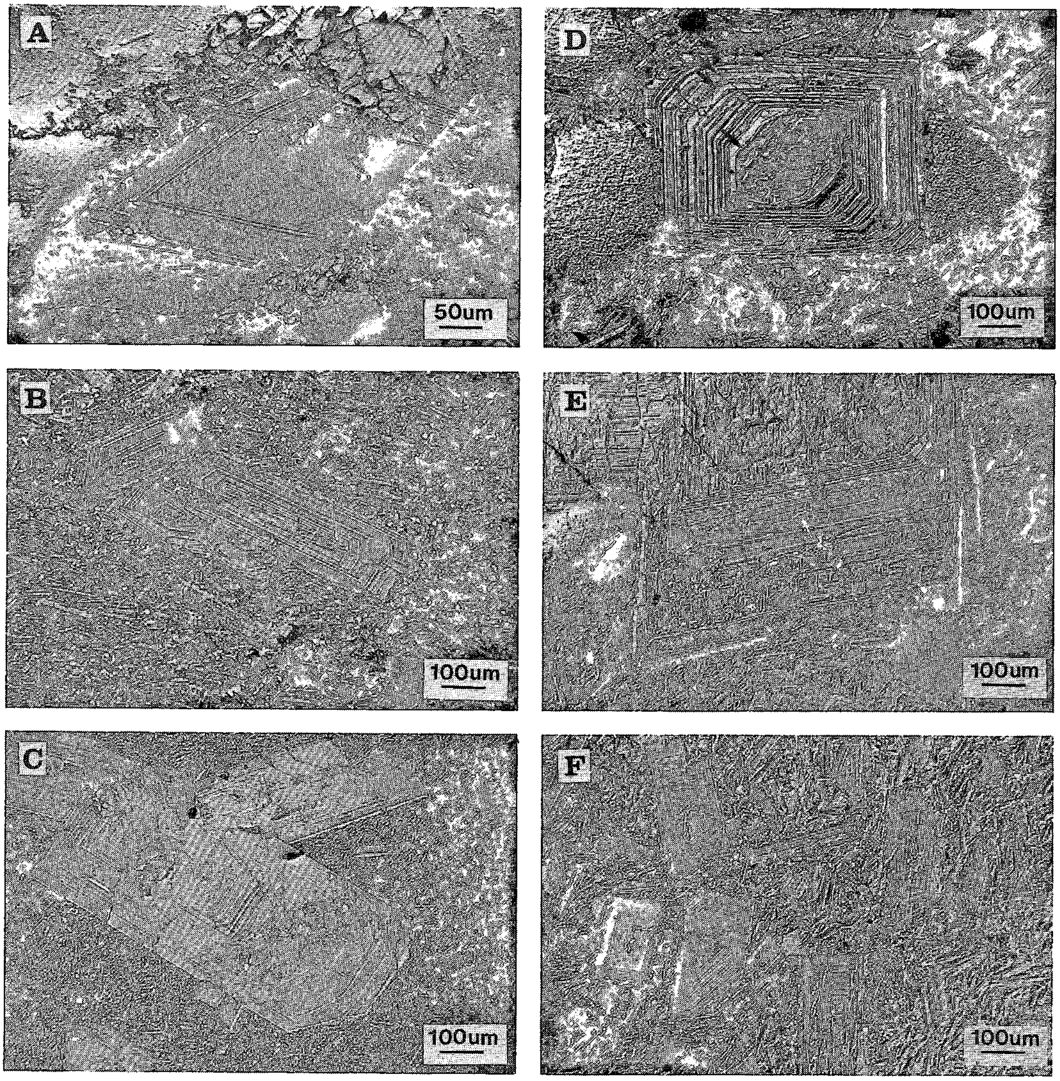
Discussion

Wiebe (1968) suggested that "plagioclase zoning is a stratigraphic record of magmatic events occurring during crystallization". Wiebe's notion of plagioclase stratigraphy coupled with experimental results (Tsuchiyama 1985, Nelson & Montana 1989, Sunagawa 1992) provide tools for unraveling in some detail the physicochemical history of the magmas from which plagioclase crystallized (Pearce & Kolisnik 1990, Pearce *et al.* 1987b). Although the precise origin of oscillatory zoning remains problematic, it is probably safe to say that at Seguam as at other volcanoes, it reflects crystal growth affected by small-scale perturbations from equilibrium in melt locally surrounding a crystal (*e.g.*, Pearce & Kolisnik 1990). In contrast, patchy or sieve-textured zoning and cross-cutting features related to dissolution most likely reflect the response of plagioclase crystals to changes of the intensive parameters P, T, and *X*, affecting a larger extent of the magmatic system (Pearce & Kolisnik 1990).

The viable mechanisms responsible for patchy zoning with or without resorption fall into two categories, thermally induced or decompression-induced (Vance 1965). Anderson (1984) suggested that decompression was reponsible for cellular growth of sieve-textured zones in basaltic andesites erupted from Fuego volcano, Guatemala in 1974 (Fig. 1H). On the basis of NDIC and laser interferometry, Pearce *et al.* (1987a) suggested that several populations of phenocrysts in dacite erupted from Mt. St. Helens on May 18, 1980 suffered resorption, leading to rounded simple dissolution-surfaces similar to those observed in some samples of basalt at Seguam (Fig. 1E). More recently, Nelson & Montana (1989) experimentally demonstrated that rapid isothermal decompression of basaltic andesite magma over a range of 2 kbar results in partial resorption and sieve textures similar to textures commonly attributed to magma mixing.

Tsuchiyama (1985) recognized simple and partial dissolution of plagioclase in his experimental studies of magma mixing and determined that both types are related to temperature and compositional contrasts between plagioclase crystals and their surrounding melt. Tsuchiyama (1985) proposed that simple dissolution without cellular growth results from mixing high-temperature melt unsaturated with plagioclase with a plagioclase-saturated melt. The result is dissolution and rounding of plagioclase crystals similar to what is observed in some Seguam basalts (Fig. 1E). Alternatively, mixing of two melts both saturated with plagioclase at different temperatures may result in a reaction between the more sodic crystals and melt, partial dissolution of these crystals, and growth of sieve-textured mantles surrounding the more sodic plagioclase (Tsuchiyama 1985). Although similar textures occur in many plagioclase phenocrysts in the Seguam basalts (Figs. 1B, C, D), no compositional shifts (to more calcic sieve-textured zones), as observed by Tsuchiyama, occur in the Seguam samples (Singer *et al.* 1993). An important set of recent

FIG. 1. Internal features and zoning characteristics of plagioclase phenocrysts from Seguam basalt and basaltic andesite (A–F), Columbia River basalt (G), and Fuego basaltic andesite (H). A. Complexly zoned phenocryst in Seguam basalt (J87–79) under crossed polars. Two cores forming a synneusis texture (c: core in this and following figures), with relatively simple patterns of concentric zoning, are surrounded by an inclusion-riddled mantle. B. NDIC image of the same crystal as A. The cores exhibit simple patterns of oscillatory euhedral zoning interrupted by minor convolute zoning. The cores are mantled by a fine-grained sieve-textured zone (Z) with a convolute outer margin, which is in turn overgrown by alternating simple oscillatory euhedral and convolute zones. A second narrow (<20 μm), sieve-textured zone is present just inside the euhedral zones that bound the crystal faces. C. Enlarged NDIC image of the crystal in B. The inner boundary of zone Z forms a very weakly resorbed fritted interface on the euhedral planar zones bounding the core (r: resorption or dissolution surface in this and later figures). Zone Z was superseded by a thin set of oscillatory euhedral zones, a narrow (10–20 μm), convolute to sieve-textured zone and an outer margin of euhedral zones. D. NDIC image of phenocryst from Seguam basalt (B87–29). The patchy zoned core has an irregular margin (arrow), overgrown by a set of wavy convolute zones, which in turn are superseded by a thick patchy zone (Z) that resembles "hieroglyphic" textures reported by Pearce & Kolisnik (1990). This patchy zone grew from an irregular dissolution surface and is bounded by euhedral zones, with minor convolute zones, extending to the rim. E. NDIC image of phenocryst in Seguam basalt (B87–32). Around most of the unzoned core are simple oscillatory euhedral zones; however, these zones and part of the core are truncated by a surface (arrows) interpreted to reflect dissolution of the underlying euhedral zones. Outside this surface, the crystal displays simple oscillatory zoning. F. NDIC image of a phenocryst in Seguam basaltic andesite (B87–9). The sieve-texured core is mantled by more sodic oscillatory euhedral zones. G. NDIC image of Columbia River basalt (from the Kimberly dikes). Note the simple oscillatory euhedral zones surrounding a nearly unzoned core. This simple pattern of zoning contrasts markedly with the complex zoning in Seguam basalts. H. NDIC image of phenocryst in basaltic andesite from Fuego volcano, Guatemala (see Anderson 1984). The alternation of oscillatory euhedral and complex sieve-textured zoning is similar to that in many Seguam basalts, although clear evidence of dissolution or reaction at the base of the sieve-textured zones is lacking.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experiments enabled Sunagawa (1992) to record *in situ* observations of isochemical dissolution of crystal surfaces when the crystals convected through silicate liquids possesing local gradients in temperature, demonstrating that mixing of magmas is not required to provide the thermal energy to cause simple dissolution of plagioclase.

In many cases, plagioclase phenocrysts in TPF basalts contain two or more patchy cellular zones mantled by oscillatory euhedral zones (Figs. 1C, D). These features indicate that plagioclase records a complex history of relatively simple near-equilibrium growth repeatedly interrupted by thermal or baric disturbances of the basaltic magmatic system, which caused the sieve-textured zones and unconformable dissolution-surfaces. It has been proposed that such features in calc-alkaline andesites result from mixing during convective overturn of a magma chamber (Nixon & Pearce 1987, Tsuchiyama 1985). Pearce & Kolisnik (1990) appealed to cyclic convective overturn as a mechanism capable of explaining the repetitive occurrence of sieve-textured zones. Similarly, repeated injection of relatively hot basaltic melt into a pre-existing chamber of more evolved lower-temperature basalt, as suggested by Kuo & Kirkpatrick (1982) for mid-Atlantic MORB, also could explain some textural features characteristic of plagioclase in the Seguam basalts. Alternatively, decompression during ascent of the basaltic magmas from depths of 10–15 km (3–5 kbar; Singer & Myers 1990, Singer *et al.* 1992a) could have affected plagioclase phenocrysts in TPF basalts.

Since no shifts in An content accompany the sieve-textured zones or the dissolution surfaces in the Seguam plagioclase, and since reverse zoning in clinopyroxene, orthopyroxene and olivine is absent, the role of mixing of compositionally distinctive magmas appears to have been limited. We suggest instead that a combination of episodic decompression and convective cycling in thermally zoned but compositionally uniform basaltic magma-chambers contributed to the complexity of plagioclase zoning in the TPF basalt. In contrast to plagioclase in the basalts, phenocrysts in the TPF andesite, dacite, and rhyodacite record histories of relatively simple crystallization, uninterrupted by patchy growth or dissolution. Apparently, plagioclase crystalization was not disturbed once a liquid line of descent began to evolve from a basaltic parental magma. We suggest that this reflects crystal growth in relatively small magmatic systems unaffected by magma mixing, pronounced convection, or rapid decompression. The sieve-textured calcic-plagioclase-cored xenocrysts (*e.g.*, Fig. 1F) in the evolved magmas are interpreted as xenocrysts re-entrained into silicic liquids from mafic cumulates in the marginal parts of the chamber, complementary to the large extent of crystal fractionation required to generate the dacite (Singer *et al.* 1993). These observations are in marked contrast to complex zoning and dissolution features reported in many calc-alkaline andesites and dacites erupted from stratovolcanoes (*e.g.*, Figs. 2D, E; Pearce & Kolisnik 1990, Nixon & Pearce 1987, Pearce *et al.* 1987b, Stamatelopoulou-Seymour *et al.* 1990) and are consistent with the hypothesis of closed-system evolution of the andesite and dacite at Seguam, in small shallow dikes fed from deeper independently evolving basaltic magma-chambers (Singer *et al.* 1992b).

ACKNOWLEDGEMENTS

This work was supported by the Natural Sciences and Engineering Research Council of Canada, operating (A8709) and infrastructure (A0656) grants. A.M. Kolisnik prepared the samples used in this study. Reviews of an early version of this manuscript by K.V. Cashman

FIG. 2. NDIC images of internal features and zoning characteristics of plagioclase phenocrysts in andesite and dacite from Seguam, Popocateptl (Mexico), and St. Kitts (Lesser Antilles). A. Fragment of a euhedral plagioclase phenocryst in Seguam andesite (B87–50). The core is unzoned, and the entire crystal contains only a few simple euhedral zones. B. Phenocrysts in Seguam andesite (B87–49). Euhedral plagioclase in this sample displays uninterrupted oscillatory euhedral zoning. C. Phenocrysts in Seguam rhyodacite (B87–56). Most plagioclase grains in this sample display uninterrupted oscillatory euhedral zoning, although in several crystals (not shown) very subtle rounding and truncation of underlying zones may be present. D. Phenocryst in andesite from Popocateptl, Mexico (Kolisnik 1990). The rounded core and several irregular zone boundaries (arrows) indicate multiple resorption-dissolution events. Compare this complex crystal to those in andesite from Seguam (Figs. 2A, B). E. Phenocryst in St. Kitts Island andesite (Round Hole, Mt. Misery). The patchy zoned "hieroglyphic" core was succeeded by oscillatory euhedral zones interrupted by a prominent dissolution-surface (arrow). A second period of patchy growth also truncates euhedral zones (arrow), and a third dissolution-surface marks the inner boundary of a very fine sieve-textured zone near the rim. Compare the morphology of this complex phenocryst to those in andesite from Seguam (Figs. 2A, B). F. Phenocrysts in rhyodacite from the north end of St. Kitts Island. Most crystals display simple oscillatory euhedral zoning and are morphologically similar to those in dacite and rhyodacite from Seguam (Fig. 2C). The principal contrast between the Seguam samples and previously studied intermediate to silicic lavas is the simple growth-history preserved in the andesite from Seguam and the complex history, including multiple dissolution or resorption events, preserved in most other examples of andesite. Also note the more simple zoning preserved in the evolved lavas from Seguam (A, B, and C above) compared to the basalt (Figs. 1A–E).

and M.J. Hibbard and comments by two anonymous reviewers and R.F. Martin helped us to substantially improve the content and presentation.

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Received April 15, 1991, revised manuscript accepted July 23, 1992.