Chapter 3

MORPHOLOGICAL AND CHEMICAL FEATURES OF MOUNT ETNA PLAGIOCLASE TEXTURES

Plagioclase phenocrysts embedded in etnean magmas are generally euhedral and twinned, 1–5mm, exceptionally up to 1 cm, in size. Seven main texture types, some of them coexisting in the same hand-sized sample, were found among phenocrysts of both historic and recent eruptions by optical microscope and high-contrast BSE imaging (Table 3.1). According to Tsuchiyama (1985), in the following descriptions, *dissolution* is referred to when rounded edges occur without evident development of sieve- or dusty-textures, whereas *partial dissolution* is used if the crystal is affected by sieve or dusty textures. However, for clarity, the term *resorption* will be used here as synonymous to partial dissolution (Landi et al. 2004)

The recognized textures can be classified as follow:

I Simple zoning textures

- Type 1, oscillatory zoning (Fig. 3.1; Table 3.1);

LAHF: Low Amplitude High Frequency

HALF: High Amplitude Low Frequency

II Complex zoning textures

1. Crystals with complex cores

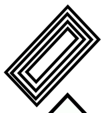
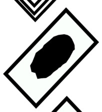
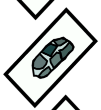
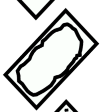
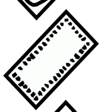
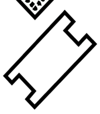
- Type 2, dissolved or resorbed, ovoidal cores (Fig. 3.2a; Table 3.1)
- Type 3, patchy cores (Fig. 3.2b; 270 Table 3.1);
- Type 4, coarsely sieve-like cores (Fig. 3.2c; Table 3.1);

2. Crystals with complex mantles and rims

- Type 5, resorbed dusty rims (Fig. 3.2d; Table 3.1);
- Type 6, stripes of melt inclusions aligned parallel to crystallographic planes (Fig. 3.2e; Table 3.1);
- Type 7, swallow-tailed crystals (Fig. 3.2f; Table 3.1; cf. Shelley, 1992).

Plagioclase crystals may show only one type of texture or, more commonly, a combination of two or three, thereby evidencing a highly complex growth pattern.

In the following paragraphs, the An and FeO profiles are presented for each type of texture. I will refer to concordant behavior when the change of An and FeO observed for each spot analysis occurs in the same direction, independent of the absolute extent of the variation along the profile. The outer rim in most of the crystals is represented by a 20–30 μm thick envelope with a marked decrease in An (up to ΔAn ~40%).

TYPE OF TEXTURE		DESCRIPTION	FREQUENCY		INTERPRETATION
			HISTORIC	RECENT	
TYPE 1		Oscillatory-zoned	40%	40%	LAHF - kinetic effects at the plagioclase/melt interface HALF - crystallization in dynamic regime (i.e., convection, sinking)
TYPE 2		Resorbed Core	10%	20%	High rate of decompression at H_2O-undersaturated conditions in volatile-rich magma
TYPE 3		Patchy Core	20%	0%	Slow rate of decompression at H_2O-undersaturated conditions in volatile-poor magma
TYPE 4		Coarsely sieved	10%	10%	Sudden, limited steps of decompression at H_2O-undersaturated conditions
TYPE 5		Resorbed Rim	10%	20%	Recharge of more primitive, hotter and volatile-rich magma
TYPE 6		Fine melt inclusion trains	5%	5%	Rapid growth due to decompression accompanied by volatile loss
TYPE 7		Swallow-tailed	5%	5%	Skeletal growth due to sin-eruptive fast decompression of degassed magma

Tab. 3.1. Schematic representation of the textures considered and their proposed interpretations. Frequency was estimated on the basis of modal analysis under polarizing microscope.

Type 1 texture consists in oscillatory zoning. As described in Chapter 2, zoning patterns is one of the most spectacular features in crystals, consisting of fine concentric zones of contrasting compositions. Zoning can be easily investigated by optical microscope due to the shifting in extinction angle, and by back-scattered electron microscopy (SEM), revealed as a change in particles energy that is proportional to An content variations. Variations generally range from 1 to over 30 mol% An. Several experimental and theoretical studies have demonstrated the primary role played by kinetics on oscillatory zoning in plagioclase (e.g., Lofgren, 1974a,b; Kirkpatrick et al., 1979; Haase et al., 1980; Lofgren, 1980; Allegre et al., 1981; Lasaga, 1982: Loomis, 1982; Ortoleva, 1990; Cashman, 1990; L'Heureux and Fowler, 1994; Wang and Wu, 1995; L'Heureux and Fowler, 1996a,b).

Two main types of oscillatory zoning, that is small- and large-scale oscillations (cf. Pearce and Kolisnik, 1990), can be frequently observed in plagioclases of Mount Etna. BSE images and chemical profiles highlight two distinct oscillation patterns: a) Low Amplitude–High

Frequency (LAHF) and b) High Amplitude–Low Frequency (HALF). LAHF patterns display little An variation (~ΔAn_5) with zone widths of 5–10 μm, while An variations are higher in HALF patterns (>ΔAn_{10}) with wider zones (20–30 μm) (Figs. 3.1 and 3.3a, 3.5a) and more sodic compositional gradient toward the edges of the crystal. Iron and An variations are almost concordant in both LAHF and HALF zoning patterns (Figs. 3.1 and 3.3a, 3.5a). In few instances, An content and FeO show a slightly discordant behavior. Rims of Type 1 crystals are often characterized by epitaxial growth of plagioclase microlites at the crystal/groundmass interface.

HALF oscillatory zoning is often associated with crenulated edges due to dissolution, angular unconformities and complex dissolution–regrowth patterns (Fig. 3.1 b–c).

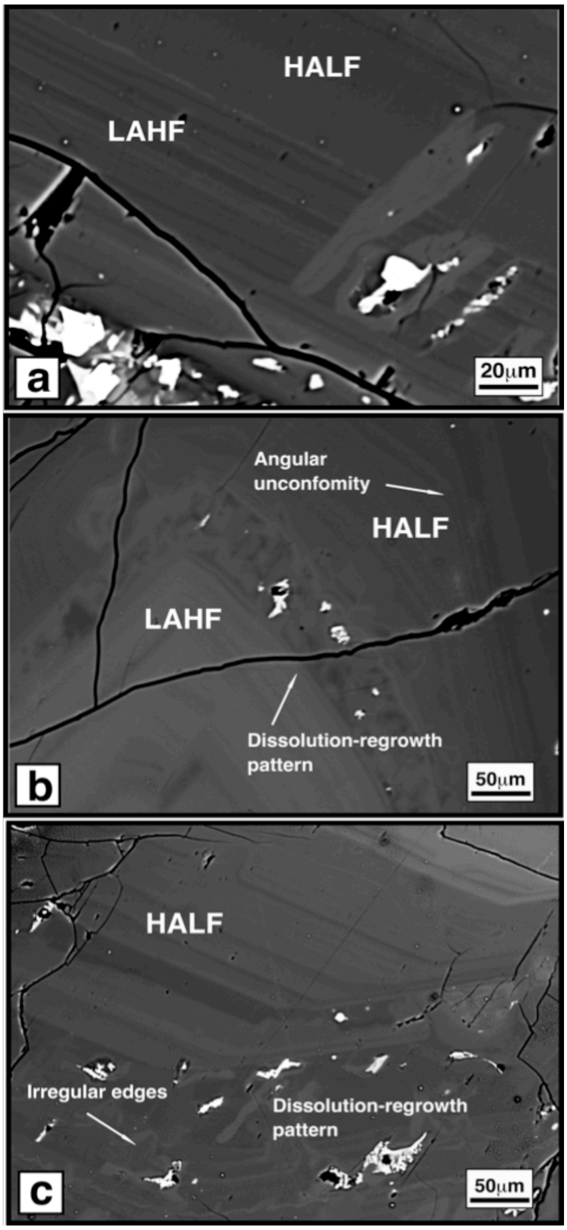


Fig. 3.1. a) Example of coexistent Low Amplitude–High Frequency (LAHF) and High Amplitude–Low Frequency (HALF) oscillatory zoning patterns; **b)** LAHF oscillatory zoning followed by HALF, the latter showing dissolution–regrowth patterns and angular unconformity; **c)** another example of HALF oscillatory zoning characterized by the occurrence of dissolution–regrowth patterns as well as irregular edges due to dissolution events. Photos taken by BSE scanning electron microscope.

Type 2 plagioclases, are coarse crystals with dissolved or resorbed ovoidal cores that enclose μm-sized glass pockets, sometimes interconnected by channels (Fig. 3.2a; Table 3.1). Analyses within these dissolved/resorbed cores evidenced a LAHF zoning pattern (sometimes not evident with BSE imaging), generally followed by an abrupt decrease in An content (Fig. 3.3b and 3.5b). FeO has a pattern fairly discordant with respect to that of An, remaining relatively constant throughout the profile from core to rim. Acicular crystals of diopsidic clinopyroxene, often associated with opaque oxides, are commonly present at the glass pocket edges.

Type 3 crystals display patchy cores (Fig. 3.2b; Table 3.1). This texture is composed by An-rich (~An_{80}) and An-poor (~An_{55}) domains (each extending for about 400 μm2), arranged in irregular patches. FeO variations are generally discordant relative to An (Fig. 3.3c). Within the patchy cores, coarse sieve-textures may occur (see Type 4 texture). It is worth noting that the first envelope coating the patchy cores is always characterized by an abrupt transition to more sodic compositions, sometimes accompanied by FeO decrease. Type 1, 5 or 6 textures (see below) may develop toward the rim.

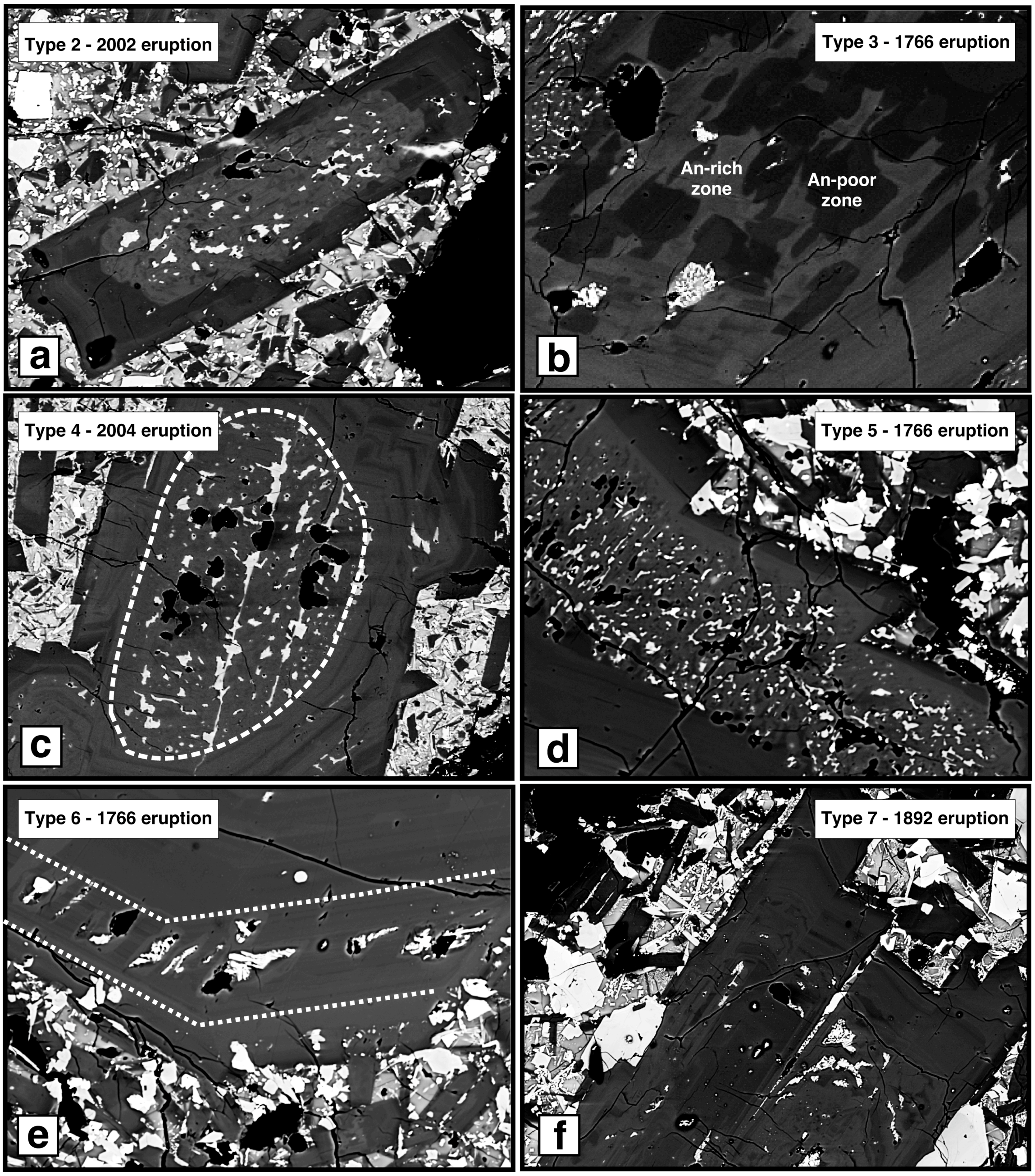


Fig. 3.2 a) Crystal showing a dissolved, ovoidal core and LAHF/HALF oscillatory zoning toward the rim; **b)** detail of patchy texture characterized by the coexistence of An-poor (~An_{55}) and An-rich (~An80) domains; **c)** crystal with coarsely sieve-textured core and LAHF/HALF oscillatory zoning toward the rim; **d)** plagioclase with strongly resorbed, An-rich dusty rim; **e)** example of crystal displaying a stripe of melt inclusions partially re-crystallized in diopsidic clinopyroxene and opaque oxides; **f)** complex plagioclase phenocrysts exhibiting several types of zoning patterns; the main feature, however, is the skeletal, H-shaped texture. Photos taken by BSE scanning electron microscope.

Type 4 plagioclases show coarsely sieve-textured cores (Fig. 3.2c; Table 3.1). In this case, sieve-textures are related to the occurrence of partially re-crystallized glass pockets randomly distributed within the crystal core. Coarsely sieved crystals are characterized by oscillatory zoning with either LAHF or HALF patterns inside the core, generally concordant with FeO (Fig. 3.3d and 3.5c). As for the preceding type of texture, the outer envelopes may develop textures of Type 1, 5 or 6.

Type 5 plagioclases display an oscillatory pattern at the core interrupted by a strongly resorbed zone toward the rim, marked by a thick (~50 μm) dusty envelope (Fig. 3.2d; Table 3.1). This zone is ovoidal in shape, and shows isolated or interconnected pockets of glass, sometimes partly crystallized in acicular diopside and opaque oxides. Noteworthy An (ΔAn15–30) and FeO enrichments mark the inner edge of the resorbed zone, evolving to higher An contents at generally constant FeO concentrations (Fig. 3.4a and 3.6d). Juxtaposed to the dusty envelope, a thin rim (10–30 μm) with a sharp An decrease marks the outer edge of the crystal. Most of Type 5 plagioclases show one resorbed zone toward the rim, although some crystals exhibit two resorbed zones along the profile, spaced by oscillatory zoning.

Type 6 plagioclases are coarse crystals characterized by thin alignments (~5–10 μm wide) of μm-sized glass inclusions with polygonal sections (Fig. 3.2e; Table 3.1), elongated orthogonally to the oscillatory zoning and arranged sub-parallel to the growth direction of each crystal face. Skeletal diopside and opaque oxides are frequently embedded in the glass. BSE images also evidence that these glass inclusions are frequently enclosed in An-rich envelopes. These crystals commonly display LAHF oscillatory patterns along their profiles, with a maximum of two alignments of glass inclusions. Glass inclusion-bearing envelopes generally display abrupt An (Δ10–20%) and FeO decrease, which may be followed in turn by a zone with the pattern changing from LAHF to HALF (Particular in Fig. 3.3c and 3.6a).

Type 7 plagioclases are crystals with H-shaped outer skeletal envelopes (swallow-tailed; Fig. 3.2f; Table 3.1). Although this texture affects some large phenocrysts, it is particularly evident of micro-phenocrysts. Their average compositions along the profiles exhibit no significant An variations, resulting on the whole in LAHF or HALF patterns. A marked An decrease, accompanied by a fairly constant FeO content, occurs next to the outer rim (Fig. 3.4b and 3.6b).

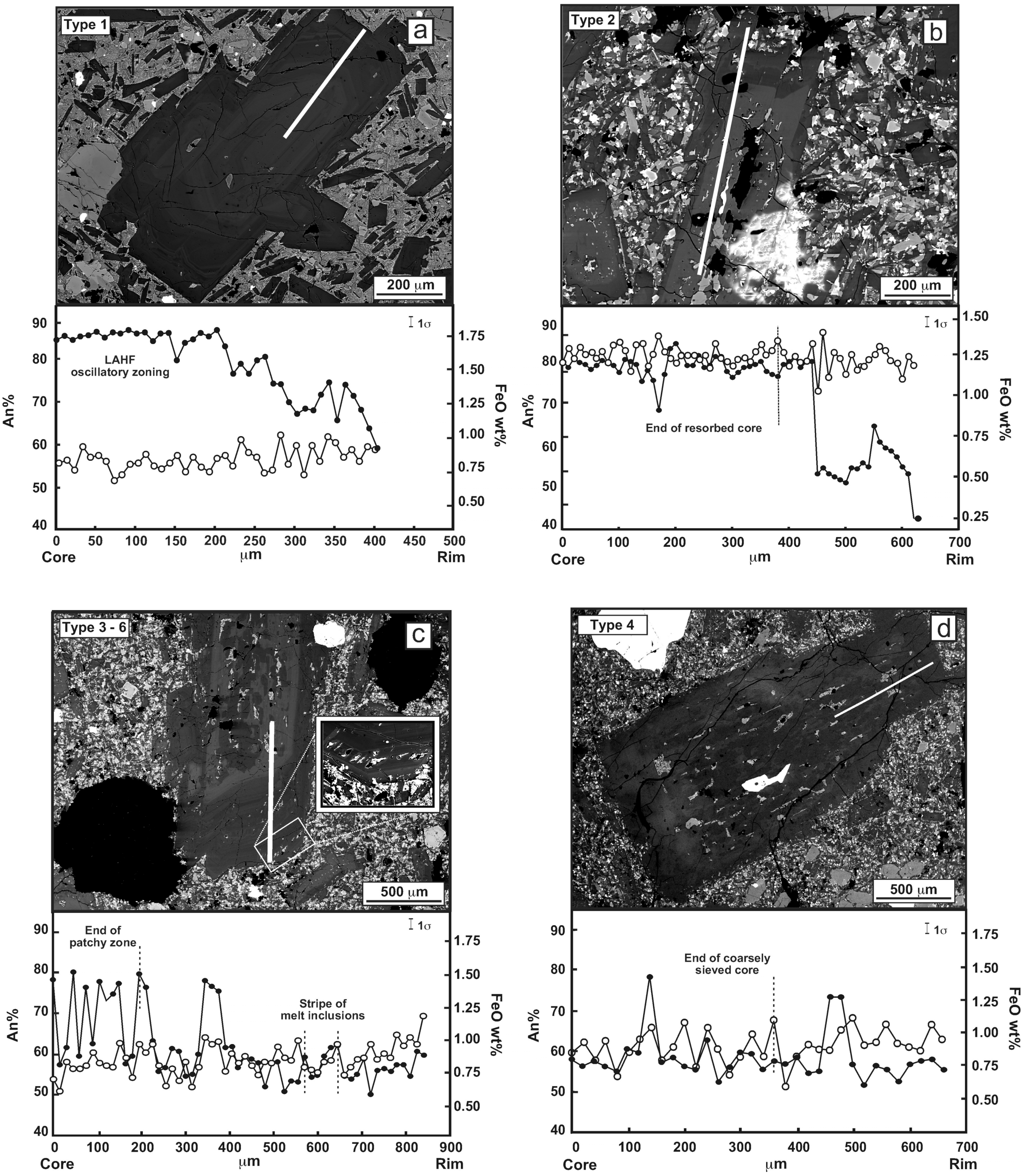


Fig. 3.3. Example of textures and their associated An%–FeO zoning patterns for plagioclase phenocrysts of historic lavas. Filled circles: An%; open circles: FeO wt.%.

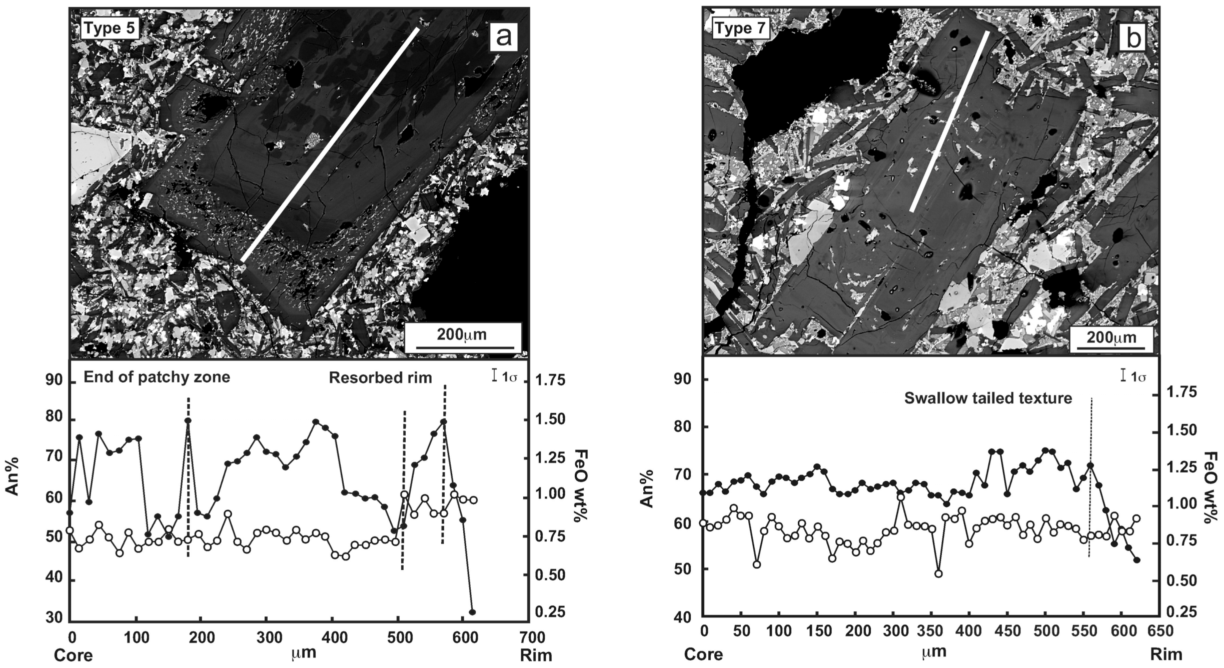


Fig. 3.4. Example of textures and their associated An%–FeO zoning patterns for plagioclase phenocrysts of historic lavas. Filled circles: An%; open circles: FeO wt.%.

3.1 Differences between historic and recent plagioclase phenocrysts

Although plagioclase textures found in both historic and recent lavas are rather similar, some differences occur regarding the lack of patchy cores (Type 3) in recent products and to their higher An content. In fact historic plagioclase are bytownite (An_{89}) to oligoclase (An_{17}) at the outermost rims (An_{66} on average). Plagioclases in recent lavas are more anorthitic (An_{76} on average) varying from anorthite (An_{90}) to andesine (An_{41}). Both historic and recent plagioclases present a thick 20-30 μm rim, marked by a decrease in An (up to $\Delta An \sim 40\%$).

Plagioclase of recent lavas frequently exhibit dissolved or resorbed cores ($An_{75\text{-}80}$) followed by an An drop ($\Delta An \geq 20\%$).

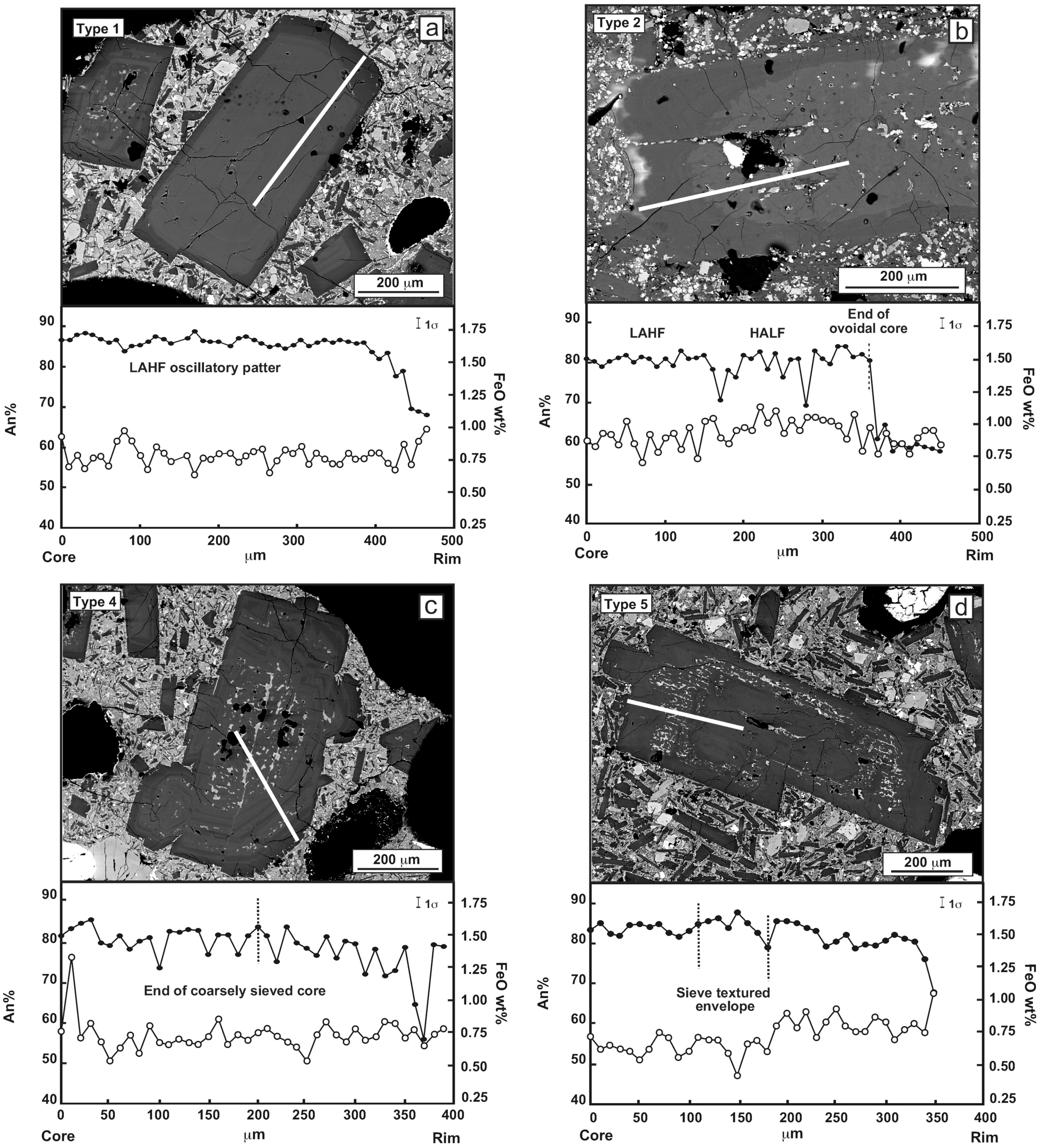


Fig. 3.5. Example of textures and their associated An%–FeO zoning patterns for plagioclase phenocrysts of recent lavas. Filled circles: An%; open circles: FeO wt.%.

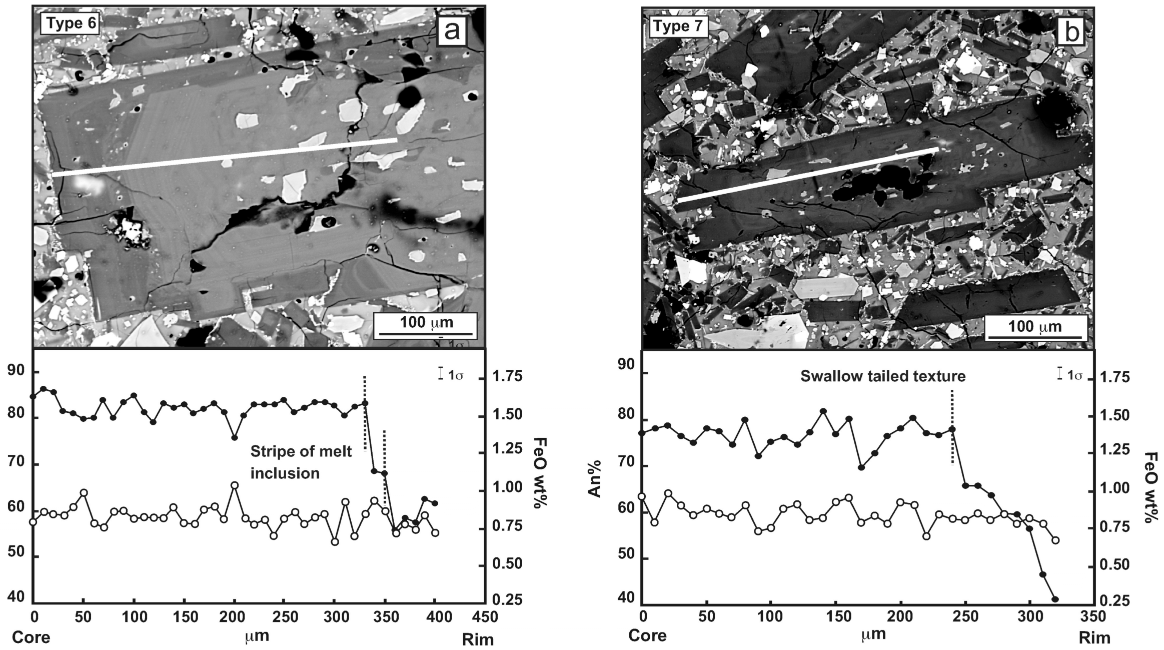


Fig. 3.6. Example of textures and their associated An%–FeO zoning patterns for plagioclase phenocrysts of recent lavas. Filled circles: An%; open circles: FeO wt.%.