



Interpretation of the Magma Chamber Processes with the Help of Textural Stratigraphy of the Plagioclases (Konya-Central Anatolia)

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Abstract

The variations in the chemical composition and micro-texture of a mineral from the core to the rim allow the sequencing of the formation of the magma chamber processes and the interpretation of which texture might have been formed by which process. In this contribution, the textural and chemical zoning of the plagioclases, which are a significant recorder of magma chamber processes, from some enclave-containing andesites (calc-alkaline) and basalts (calc-alkaline) from the Karapınar-Karacadağ Volcanic Units, were examined and their textural mineral stratigraphies were investigated to enlight the magma chamber processes. Plagioclases from the andesitic host-rock and their enclaves generally exhibit different composition from core to rim. The composition in the enclave ranges from oligoclase to labradorite (core:An₂₅₋₇₂), however, in the host rock it ranges from andesine to labradorite (core:An₄₆₋₆₄). It is noteworthy that the plagioclases in the host-rock are mostly rounded, and reverse and oscillatory zoned with Anorthite, Fe, Mg, Sr, and Ba. However in the enclaves they display generally fine sieve and dusty sieve textures. The cores of the plagioclase micro-phenocrysts in calc-alkaline basalts are andesine-labrador (An₃₂₋₆₆) in composition. Remarkably, plagioclases in basalts show reverse and oscillatory zoning with An, Fe, Mg, Sr, and Ba, and as well as exhibit coarse-grained sieve texture with glass and microlitic inclusions, and spongy cellular textures. Combined with their An, Fe, Mg contents it is suggested that some of the plagioclases from the basalts may be xenocrysts rather than phenocrysts. Considering the textural and chemical properties of the plagioclases, in the formation of reverse and oscillatory zoning in the basaltic rocks, the decompression processes in addition to the magma mixing processes (magma mixing/self-mixing) also have an impact on the genesis of the basalts. However, in the formation of andesitic rocks, the magma replenishment processes have a key role rather than decompression or temperature-pressure change.

Keywords: Decompression, Magma Mixing, Micro-Texture, Plagioclase, Xenocryst.

Plajiyoklazların Dokusal Stratigrafisi ile Magma Odası Süreçlerinin Yorumlanması (Konya-Orta Anadolu)

Öz

Çekirdekten kenara bir mineralin kimyasal bileşimindeki ve mikro dokusundaki varyasyonlar, magma odası süreçlerinin oluşumunun sıralanmasına ve hangi dokunun hangi süreçle oluşmuş olabileceğinin yorumlanmasına olanak tanır. Bu çalışmada, Karapınar-Karacadağ Volkanik Birimleri'nden bazı anklav içeren andezit (kalk-alkalen) ve bazaltlardan (kalk-alkalen) alınan, magma odası süreçlerinin önemli bir kaydedicisi olan plajiyoklazların dokusal ve kimyasal zonlanması incelenmiştir ve dokusal mineral stratigrafileri magma odası süreçlerini aydınlatmak için oluşturulmuştur. Anklav içeren andezitler ve anklavları içindeki plajiyoklazlar genellikle çekirdekten kenara farklı bir bileşim sergilemektedir. Anklavda bileşim oligoklaz-labradorit (çekirdek:An₂₅₋₇₂) arasında değişirken, ana kayada andezinden labradorite (çekirdek:An₄₆₋₆₄) kadar değişmektedir. Ana kayadaki plajiyoklazların çoğunlukla yuvarlaklaşmış ve Anortit, Fe, Mg, Sr ve Ba ile ters ve salınımlı zonlu olması dikkat çekicidir. Ancak anklavlarda yer alan plajiyoklazlar genellikle ince elek ve kirli yüzeyle elek dokusu sergilerler. Kalk-alkalen bazaltlardaki plajiyoklaz mikro-fenokristalleri, çekirdekten kenara bileşimde andezin-labrador (An₃₂₋₆₆) bileşimindedir. Dikkat çekici bir şekilde, bazaltlardaki plajiyoklazlar, An, Fe, Mg, Sr ve Ba ile ters ve salınımlı zonlanma gösterirler ve ayrıca cam ve mikrolitik kapanımlarla iri taneli elek dokusu ve süngerimsi hücresel dokular sergilerler. An, Fe, Mg içerikleri ile birlikte incelendiğinde bazaltlardaki bazı plajiyoklazların fenokristalden ziyade ksenokristal olabilecekleri ileri sürülmektedir. Plajiyoklazların dokusal ve kimyasal özellikleri göz önüne alındığında, bazaltik kayalarda ters ve salınımlı zonlanma oluşumunda, magma karışımı işlemlerinin (magma karışımı/kendi kendine karışma) yanı sıra dekompresyon süreçleri de bazaltların

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oluşumunu etkilemektedir. Bununla birlikte, andezitik kayaların oluşumunda, magmanın yeniden beslenmesi süreçleri, dekompresyon veya sıcaklık-basınç değişiminden daha ziyade anahtar bir role sahiptir.

Anahtar Kelimeler: Dekompresyon, Ksenokristal, Magma Karışımı, Mikro-Doku, Plajiyoklaz.

1. Introduction

Although it is known that magmatic systems are commonly recharged in tectonic environments associated with subduction, collision or rifting, the character and frequency of recharging events, thermal and compositional effects on the primary magma are not fully understood. By using the whole-rock geochemical data only, we may not solve the complex magmatic history of the rocks, and evaluate the relative roles of fractional crystallization or mixing processes on the rock genesis. Since the minerals can be highly susceptible to gradual or sudden variations in the volcanic system, their textural and compositional zoning patterns, and also resolution and dissolution textures are generally utilized to determine the magma chamber processes (i.e. Ginibre et al. (2002); Renjith (2014); Streck (2008); Ustunisik and Kilinc (2011); Viccaro et al. (2009); Viccaro et al. (2010)). The presence of the (repeated) recharging events can be interpreted by the chemistry of the crystals. For example, plagioclases can be used as an important recorder mineral showing the recharging events and fractional crystallization processes occurring during their evolution (Ginibre et al., 2002; Singer et al., 1995; Streck, 2008). The major and minor element contents of the crystals is related to the melt composition. For example, variations in Fe, Sr, Ba, and Mg in plagioclase may result from both changes in coefficients of separation and change in melt composition, whereas changes in anorthite (An) content depend largely on temperature, pressure, oxygen fugacity (fO_2), and water content (Ginibre et al., 2007). The partition between plagioclase and silicate melt is predominantly dependent on the Ca content of plagioclase. If an An-rich increase in plagioclase is due to a large change in melt composition (superheating/recharging by processes such as magma mixing/self mixing), this growth zone will also be different from the previous zone with Fe, Sr, Ba, and Mg contents (Ginibre et al., 2007). Conversely, changes in temperature, pressure, oxygen fugacity, and H_2O content will affect An content but cause little change in Fe, Sr, Ba, and Mg. This is because the overall compositional change of the host magma is more robust (Ginibre et al., 2007). The progressive P_{H_2O} increase may affect the crystallization of the composition richer in anorthite. The decrease in anorthite content may be attributed to the decrease in both pressure and water content and/or the melt may change compositionally to more albitic composition during crystallization. The changes in the An content of plagioclases (reverse-oscillatory zoning) represent the changes in the crystallization conditions. Many researchers report that magma mixing causes that variations (Table 1). Since the convection in the magma chamber causes the changes in the temperature and the pressure at regular intervals, oscillatory zoning can be generated by convection in the magma chamber or by repeated replenishment processes. Nixon and Pearce (1987) reported that early-crystallized plagioclases can be resorbed into the magma chamber by repeated hot and basaltic magma inputs. Gill (1981), Pearce (1994); Singer et al. (1995) suggested that oscillatory zoning may occur with diffusion rate-controlled compositional gradients at the crystal-melt interface or with rhythmic changes in petrological variables such as pressure and P_{H_2O} (Table 1). In addition, the position of the liquidus-solidus curves of plagioclase changes depending on the water content of the magma. Water can

reduce the value of liquidus-solidus curves by a few hundred °C. Thus, the rising and dropping in the water content of the magma bring about changes in the crystallization conditions and cause variations in the An content. Recent studies indicate that FeO and An contents are discordant under constant fO_2 , whereas they become concordant when the fO_2 has a significant modification (Viccaro et al., 2010). Therefore, to detect the most effective process (water content, P_{H_2O} , fO_2 of the magma, decompression and/or repeated replenishments of more primitive and hotter magma) on the evolution of both textural and chemical modifications of the plagioclase, the concordant or discordant relationships of the major and minor elements such as An, Fe, Mg, Sr, Ba spot by spot should be evaluated together. The convection in the magma chamber gives rise to the replenishment of the more evolved magma by the more primitive, fresh and hotter magma. The replenishment of the magma can be executed by (1) cryptic mixing, (2) self mixing and (3) magma mixing. In cryptic mixing, the magma with the same composition but with different oxygen fugacity and water content must make repetitive involvements as small inclusions. Also, self mixing means an environment advanced by the replenish of a hotter magma at the base of the magma chamber (Couch et al., 2001; Huppert et al., 1982; Renjith, 2014). In magma mixing process, more primitive and more hotter magma introduces into the more evolved magma. The absence of enclaves, ocellar textures, acicular-quenched-bladed biotite-amphibole minerals, and the reaction of olivine rims explain other superheating phenomena rather than magma mixing.

The Neogene-Quaternary aged Karapınar-Karacadağ Volcanic Units (southwest extension of the Cappadocia Volcanic Province), which has a complex petrogenetic story associated with the opening and closure process of the Neotethys ocean, crops out in a wide area extending to Karapınar-Emirgazi-Ereğli in the SE of Konya (Figure 1). Neogene lava flows/domes with calc-alkaline; intermediate-acidic composition in the study area are named as "Karacadağ volcanites". On the other hand, Quaternary aged mafic-intermediate volcanites with mildly alkaline-calc-alkaline character crop out as scoria cones and lava flows are named as "Karapınar volcanites". Recent studies indicate that basaltic and dacitic rocks from the Karacadağ volcanites yielded ^{40}Ar - ^{39}Ar ages ranging between 5.65-5.45 Ma (Gençoğlu Korkmaz et al, under review) and basaltic rocks from the Karapınar volcanites yielded the maximum age of 2.5 Ma (Dogan-Kulahci et al., 2018; Reid et al., 2017). Some of the Karacadağ andesites and Karapınar basalts contain enclaves (magma segregation, magma mixing and xenolith) with different types and compositions (Gençoğlu Korkmaz et al. under review). Here, we present the assimilation-contamination and magma recharging processes, which are open system processes, by utilizing mineralogical records. Since the textural properties and chemical compositions of the minerals can indicate open system processes (Streck, 2008), especially the texturally different plagioclase minerals of the enclave-containing (magma mixing and magma segregation) andesites and basalts (xenocryst-bearing) examined in this study to explain these processes. In this study, Fe, Mg, An, Sr, and Ba contents of the plagioclase minerals and their relationships with each other were investigated, and the different recharging events were tried to be understood by mineral

chemistry and petrographic analysis. Mineral-textural stratigraphies of the plagioclases have been presented in different tables and the recharging events were tried to be understood by mineral chemistry and petrographic analysis. The symbol D in the tables represents the textural domain, and the display from the first textural area (bottom) to the last textural area (top) is D1-D4, respectively.

2. Material and Method

Around 700 samples were randomly compiled from domes, lava flows, block flows, and scoria cones from Central Anatolian Volcanism (Neogene-Quaternary aged Karapınar-Karacadağ Volcanic Units). Approximately 180 thin sections were made in Ankara University Earth Sciences Application and Research Center (YEBİM) and petrographic observations especially for micro-textures in plagioclase were executed in detail under a

polarizing microscope in Konya Technical University Geological Engineering Microscope Laboratory. Several micro-textures are identified for plagioclase minerals and they are illustrated in both microphotographs as well as schematic diagrams. Representative nine plagioclase grains showing maximum micro-textural diversity were chosen for the interpretation and the determination of the relationship between microtextures and the chemical composition of them. Thin sections were polished and coated with carbon to conduct electron micro-probe analysis (EPMA) Backscattered electron (BSE) images were taken, and EPMA analyzes were executed using JEOL brand JXA 8230 device under 20 kV voltage and 15 nA current at Ankara University YEBİM. The detailed procedure for performing the analysis has been reported in detail in Deniz and Kadioğlu (2019). Micro-probe analysis data are presented in Supplementary data (S1).

Table 1. Based on several researchers, growth-resorption-dissolution textures and their definitions observed in the investigated plagioclases.

Texture-Symbol	Interpretation	References
Oscillatory zoning 1) Fine banding-FOZ 2) Coarse banding-COZ	a. Compositional gradients with diffusion rate control at the crystal-melt interface b. It may occur with rhythmic changes (P or P _{H2O}) in environmental variants. c. It can occur with repeated supersaturation and crystallization in anhydrous melt d. Thin layer: Kinetic controlled: small-scale compositional fluctuations (1-10 μm) Thick layer: Dynamic magmatic process controlled: growth zone, mantled growth zone.	a. Gill (1981); Pearce (1994); Singer et al. (1995); Brophy et al. (1996) b. Gill (1981) c. Vance (1965) d. Streck et al. (2008); Duda and Schmincke (1985)
Patchy zoning-PZ	a. It can happen when a crystal is in the re-equilibration process by diffusion. b. Areas with sodic patches in some crystals may possibly reflect water-saturated decompression proceeding with crystallization and gas removal at shallow depth. c. If the compositional change associated with the transition from a patch to a neighboring patch is sharp, crystal growth probably occurs. d. If there is a progressive transition from a patch to a neighboring patch, there is diffusional re-equilibration.	a. Streck (2008) b. Ginibre and Wörner (2007) c. Stewart and Pearce (2004) d. A. Tomiya and E. Takahashi (2005); Streck et al. (2007)
Sieve texture: Cellular texture (A,B) 1) Fine sieve-FS 2) Coarse sieve-CS A) Spongy cellular-SC B) Boxy cellular-BC	Sieve texture is also known as cellular texture and pitted texture. It can be classified by various researchers according to the size and shape of the pits on the surface of the mineral. a. A prolonged and intense dissolution by interaction with a more primitive magma. b. Pitted texture; They can be examined in two categories as spongy cellular and boxy cellular and can be observed as glass-containing or depression pits/craters. a. Sodic plagioclase-rich melt can be realized by the equilibration reaction with a more calcic plagioclase-rich melt. b. Can occur with rapid decompression (temperature under constant falling pressure) c. May be occurred by partial dissolution/resolution due to reaction with a more calcic melt. d. Usually can occur with diffuse dissolution a. Sodic crystal can be realized by equilibration reaction with more calcic melt. b. It may occur by dissolution-resolution caused by the change in the adiabatic decompression rate of undersaturated magma c. Can occur with rapid growth (such as skeletal growths) d. Resorption (experimentally interpreted square and zigzag-shaped melt inclusions as boxy-shaped cellular texture)	a. Renjith (2014) b. Lunney (2002) a. Nelson and Montana (1992); Pearce (1994); Singer et al. (1995); Tsuchiyama (1985) b. Nelson and Montana (1992) Singer et al. (1995) c. Renjith (2014) d. Streck (2008) a. Nakamura and Shimakita (1998) b. Renjith (2014) c. Hibbard, 1995 d. Nakamura and Shimakita (1998)
Broken crystals-B	a. It may occur with decompression caused by strong aerial volcanic eruptions.	a. Renjith (2014)
Synneusis crystals - S	a. It can occur by convection related to magmatic turbulence in the magma chamber. b. It is a process in which microliths drift together and bind to large phenocrysts, indicative of magmatic turbulence.	a. Renjith (2014) b. Vance (1969)
Glomerocrystals-G	Suturing of spatially closer resorbed crystals by the convection in the magma chamber	Renjith (2014)
Dentritic texture-D	a. Extreme undercooling b. Water exsolution	a. Logfren (1974) b. Castro (2001)

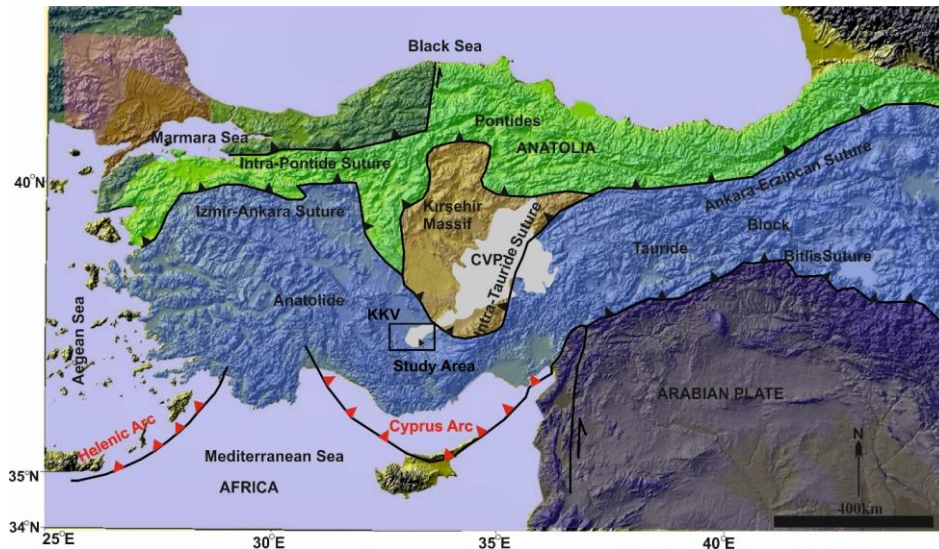


Figure 1 Location map of the investigated area in Turkey tectonic units map (Okay & Tüysüz, 1999). KKV: Karapınar-Karacadağ Volcanics, CVP: Cappadocia Volcanic Province. Solid lines represent major suture zones (black lines with black triangles), arc systems (black lines with red triangles) separating continental blocks in Turkey. The map is taken from Gençoğlu Korkmaz et al (under review).

3. Results and Discussion

3.1 Results

3.1.1. Textural properties of plagioclases

Plagioclases in the investigated andesitic host-rock are generally rounded at the core and more angular at the rims. Some of the plagioclases display repeated oscillatory zoning in growth zones from the core to the rim (Figure 2 a, b, d, e). Dendritic texture (D) and patchy zoning (PZ) are also observed in the cores of plagioclases from the same rocks. However in the enclaves from the andesites, plagioclases generally exhibit fine-grained sieve texture (FS) and coarse-grained sieve texture CS (Figure 2 c, f). In the plagioclases from the basalts have dominantly spongy cellular SC and CS with glass and microlitic inclusions, and rarely FS and boxy cellular textures (BC) (Figure 2 g-i, m). While some andesites contain broken olivines (Figure 2j), some basalts include especially synnesis (S) crystals (Figure 2.l), glomerocrysts (G) (Figure 2.l), and accompanying broken (B) olivines (Figure 2k).

3.1.2 Mineral chemistry of plagioclases

Generally in andesites, plagioclase cores are andesine in composition. Plagioclases from the andesitic host-rock and their magma segregation enclaves generally exhibit different composition from core to rim. In the enclave they range between oligoclase- labradorite (core:An₂₅₋₆₇, rim: An₂₇₋₃₄) in composition. However in the host rock they are andesine-labradorite (core:An₅₆₋₆₀, rim: An₄₂₋₅₂). Plagioclases from the magma mixing enclaves are labradorite (An₆₁₋₇₂) in thier cores. However in the host rock plagioclase cores range from andesine to labradorite in composition (core:An₄₆₋₆₄)Also, plagioclases in some enclaves are

enriched with Ca at the rims and are bytownite in composition (Figure 3). On the other hand, plagioclase micro-phenocrysts cores in basalts range in composition between andesine and labradorite (An₃₂₋₆₆). Also, plagioclase microliths from the same basalts are anorthite. Alkali feldspar also occurs in the groundmass of the basalts, ranging anorthoclase to sanidine in composition.

Plagioclases in the andesitic host rock generally display oscillatory and inverse zoning and they have Fe, Mg enriched growth zones. One of the texturally investigated plagioclase from the andesitic host rock contains 59.7% An, 1336 ppm Sr, 394.09 ppm Ba, 4060.45 ppm Fe, 84.43 ppm Mg, in the core. However, in the magma segregation enclave, the core of the plagioclase phenocryst contains lower An (25%), Sr (617.32 ppm), and Ba (116.43 ppm), higher Fe (5048.33 ppm), and Mg (247.27 ppm) compositions. All plagioclases from the magma mixing enclave from the andesites are completely sieved, hence, we acquired a few meaningful results (Supplementary data S1). The plagioclase cores contain 6000-7000 ppm Fe, 60-70% An, while the core of plagioclase phenocrysts from the host-rock include lower Fe (3000-3900 ppm) and An (45-65%) than those of enclave. In the basalts, we observed 2 different types of plagioclase micro-phenocrysts except for microlites. One of them contains lower An, Sr, Ba, but higher Fe, Mg contents in the core (An:66-32 %; Sr: 169-1057 ppm; Ba: 0-214 ppm; Fe: 9093-23600 ppm; Mg: 500-747 ppm). The other one contains An, Fe, Mg values as lower as to not be formed in the basaltic magma (An:32-43 %; Sr: 1268-1440 ppm; Fe: 1641-1711 ppm; Mg: 0-205 ppm; Ba: 438-609 ppm).

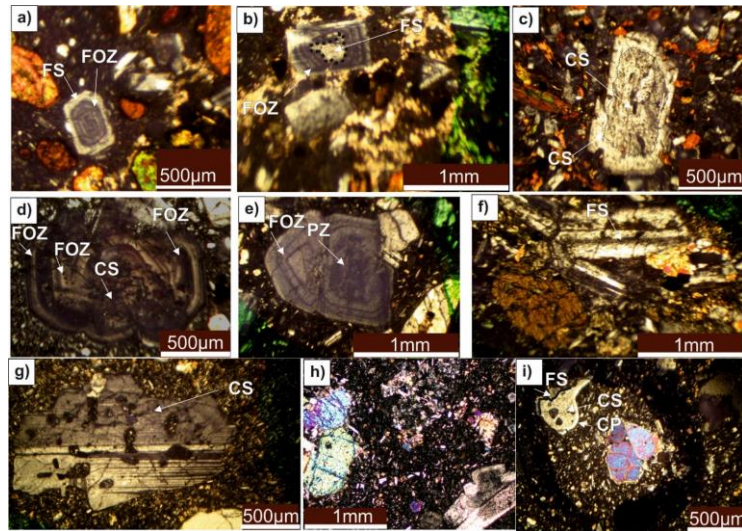


Figure 2 Microphotographs of plagioclases showing distinct textural zoning and sieve texture of the investigated rocks. (a)-(b) FS and FOZ in plagioclases from the andesites, (c) CS in plagioclases from the magma mixing enclave, (d) CS and repeated FOZ and (e) FOZ and PZ in the plagioclases from the andesitic host rock, (f) FS plagioclases from the magma segregation enclave, (g) SC textured plagioclase, (h) FS and (i) FS, DS, and CP textures in plagioclases from the Karapınar basalts. CP: Clear Plagioclase; CS: Coarse Sieved; DS: Dusty Sieve; FS: Fine sieve; FOZ: Fine oscillatory zoning; SC: Spongy Cellular; PZ: Patchy zoning.

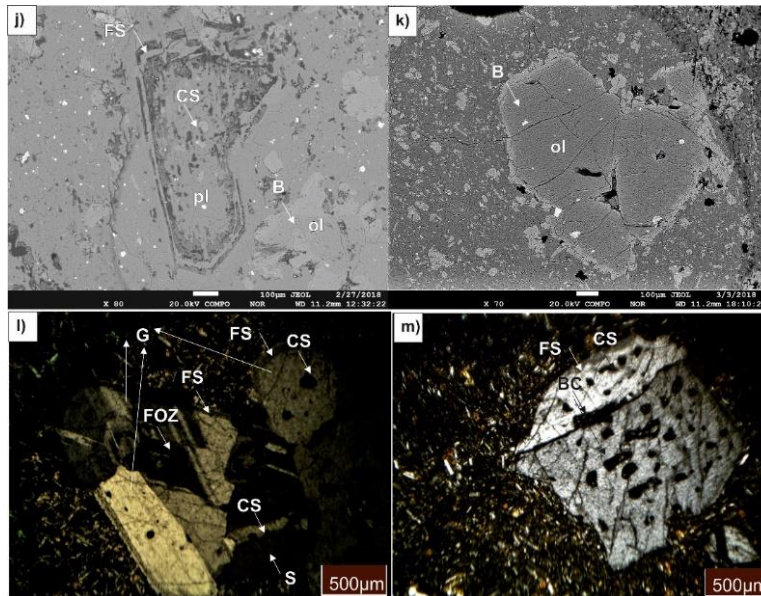


Figure 2 cont. BSE images of the plagioclases (j) from the andesites and (k) basalts (l)-(m) Microphotographs of the plagioclases showing distinct textural zoning and sieve textures from the basalts. B: Broken crystals; BC: Boxy Cellular; G: Glomerocrysts; S: Synneusis crystals. pl: plagioclase; ol: olivine.

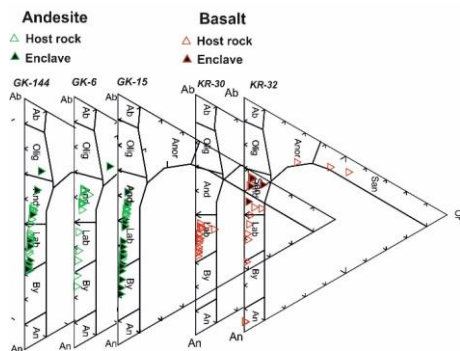


Figure 3 Ab-An-Or classification diagram (Deer et al., 1963) of the feldspars from the investigated rocks.

3.2 Discussion

3.2.1. Relationships between Textures and Trace Element Distributions of Plagioclases

In plagioclases, Sr is a compatible element and generally has a concordant relationship with the An content. With the differentiation of the melt, the Sr and An contents decrease in plagioclases. The Ba element also conforms to Sr and decreases with differentiation. Mg element is rare found in plagioclases relative to Fe element. Fe, Mg and calcic composition increasing at the rims together with the sieve textures may indicate that the magma is resorbed and recharged by a more mafic magma (Ginibre & Wörner, 2007; Streck, 2008; Streck et al., 2005; Streck et al., 2002; Akihiko Tomiya & Eiichi Takahashi, 2005). During

recharging, resorption surfaces may develop between growth zones, depending on the level of temperature and composition difference. Patchy zoning shows that the crystal is resorbed by a more mafic magma (Ginibre & Wörner, 2007), which is supported by the increase in Fe, Mg in growth zones. If there is little or no compositional change in minor element contents, patchy zonings suggests that the crystals may have been subjected to undersaturated decompression (Ginibre & Wörner, 2007). Fine oscillatory zoning could be formed by small-scale Physico-chemical perturbation created by convection at the crystal-melt interface. FOZ occurs in two way as dynamic (with rhythmic changes in water pressure, temperature, or composition if the amplitude of changes in An is > 2%; Humphreys et al. (2006); Ginibre et al. (2002)) and kinetic (close to equilibrium condition; Pearce (1994); Ginibre et al. (2002)) models. Intermittent dissolution-regrowth properties, high amplitude (> 2%) in An changes, and wavy growth zone margins are evidence that strongly supports the dynamic model (Ginibre et al., 2002). Sieve textures (FS, CS, SC, BC) may be originated from dissolution, resorption, or decompression as mentioned in table 1. Generally prolonged and dense interaction with more primitive magma gives rise to the formation of the FS textures. The dense pits may seem as dusty surface and generally is known as dusty sieve texture (DS). Investigated plagioclases in andesites generally have a significant resorption surface, repeated FOZ, and CS. They have (multiple) enrichment in major oxides (FeO, CaO) and minor elements (S1) in their growth zone and their rims. However, plagioclases from the magma segregation enclaves display commonly FS. Plagioclases from the magma segregation enclaves have a more primitive composition relative to those from their host (S1). It is suggested that plagioclases from the magma mixing enclaves have been exposed to recharging events by more calcic and more mafic magma (S1) because of showing rounded,

interconnected-widespread-dense sieve texture. Subhedral-euhedral and normal zoned crystal growth (CP-clear plagioclase) has occurred in the equilibrium magmatic condition in the rims of some plagioclases. Some of the plagioclases from the basalts have enriched in Fe, Mn contents in their growth zones and/or rims, however, others display the fluctuating relationship in chemical content (S1). Combined with their widespread spongy cellular and coarse sieved textures, it could be inferred that decompression and the recharging events had a key role in their genesis. Combined with the major-minor element distributions (Figure 4-12), the textural characteristics of the most representative plagioclases could help to make their textural stratigraphy (Table 2-10). According to chemical and textural zoning patterns we propose the textural stratigraphy of the most representative plagioclase grains from the investigated rocks at below.

Table 2 Textural stratigraphy of the plagioclase from the Andesitic Host-rock (GK-144-C1)

Domain	Texture	Process
D4	FOZ	Repeated and multiple interaction with more calcic, more primitive and more hotter magma. An content variation in the zone is (> 2%) (Figure 4). FOZ is existed by dynamic model.
<i>RS (Resorption Surface): Interaction with hotter Fe-Mg-Sr-An-FeO-Ca-rich Ba depleted magma: Major RS developed.</i>		
D3	FOZ	Interaction with more hotter and more primitive magma. FOZ growth zones are rather flat than wavy (Figure 4). FOZ is existed by dynamic model.
<i>RS (Resorption Surface): Interaction with hotter Fe-Mg-Sr-An-FeO-Ca-rich Ba depleted magma: Major RS developed.</i>		
D2	FOZ	Repeated and multiple interaction with more calcic, more primitive and more hotter magma. An content variation in the zone is (> 2%) (Figure 4). FOZ is existed by dynamic model.
<i>Ambiguous resorption surface: Minor RS developed.</i>		
D1	CS D	Interaction with the hotter, and Fe-Mg-An-Sr rich magma. Fe-Mg-An-Sr content from the core to the growth zone firstly decreases slightly and then increases regularly (Figure 4). The main process is recharging by a hotter and primitive magma. The presence of the enclave may be an indicator of self mixing. In the CS-formed core, dendritic texture is widely observed.

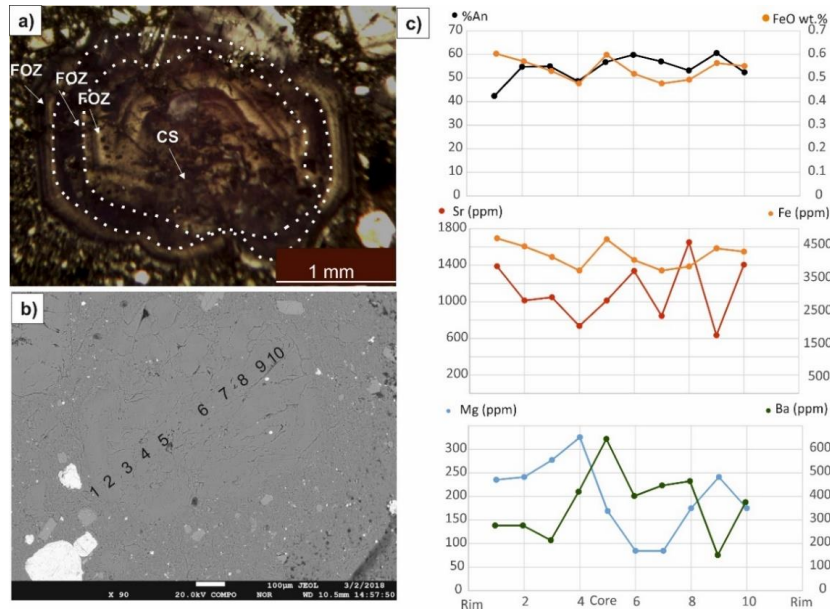


Figure 4. (a) Microphotograph, (b) BSE image of the plagioclase from the andesitic host rock (GK-144-C1) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the rim to the rim.

Table 3 Textural stratigraphy of the plagioclase from the Magma Segregation Enclave (GK-144-C5)

Domain	Texture	Process
D1	FS	Interaction with the hotter, Fe-Mg-An-Sr-Ba rich magma. An content of the core shows a concordant relationship with Fe-Mg, except for the core. Sr, Ba, Fe have a completely positive correlation. The diagrams display the fluctuation in An-Fe-Mg contents (Figure 5). The quite low An content in the core may be due to the change in the water content and oxygen fugacity of the magma. The plagioclase phenocryst is more primitive than those of host rock, and has higher Fe-Mg content. It may be crystallized at an early stage in the magma chamber, and has been brought into the andesitic host-rock by convection in the magma chamber. During this process, it has interacted with the more primitive magma.
	DS	

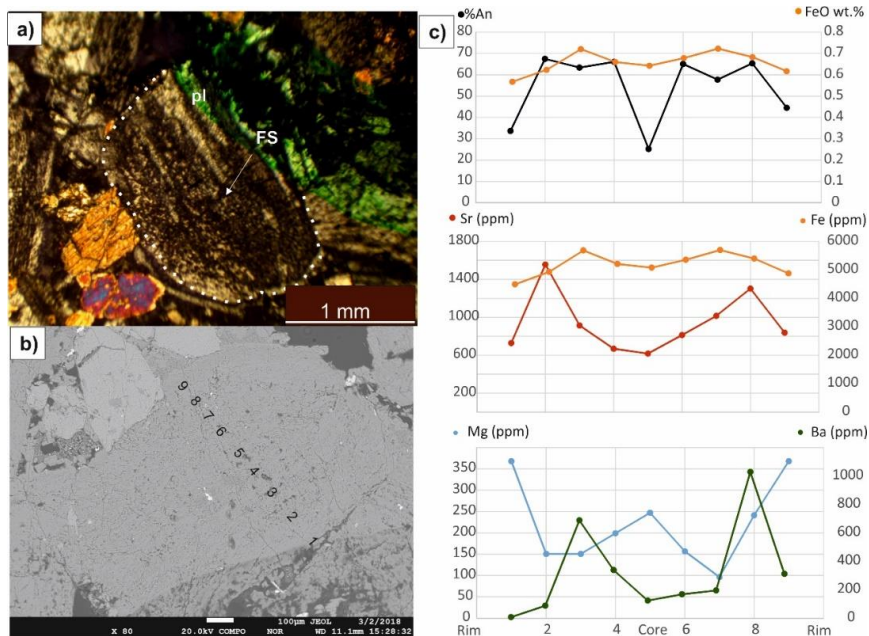


Figure 5. (a) Microphotograph, (b) BSE image of the plagioclase from the magma segregation enclave of andesite (GK-144-C5) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the rim to the rim.

Table 4 Textural stratigraphy of the plagioclase from the Andesitic Host (GK-6-C3)

Domain	Texture	Process
D4	CP	Subhedral- Euhedral and clear surface crystal growth
D3	FS	Interaction with the Fe-Mg-FeO-Ba rich, An-Sr depleted magma (Figure 6). The discordant relationship of the An content with Fe-Mg can be explained by the variations in oxygen fugacity and water pressure.
<i>RS (Resorption Surface) : Interaction with Fe-Mg-FeO rich, An-Sr-Ba depleted magma: Major RS developed.</i>		
D2	CS	Interaction with hotter and Fe-Mg-Sr-Ba-Ca enriched magma (Figure 6). The formation of interconnected and large-sized pits is associated with intense and prolonged dissolution.
<i>RS (Resorption Surface) : Interaction with hotter and Fe-Mg-Sr-Ba-Ca rich magma: Major RS developed.</i>		
D1	FS	Interaction with hotter and Fe-Mg-Sr-Ca-An enriched magma (Figure 6). There is an enrichment with An, Fe, and Mg from the core to the growth zone.

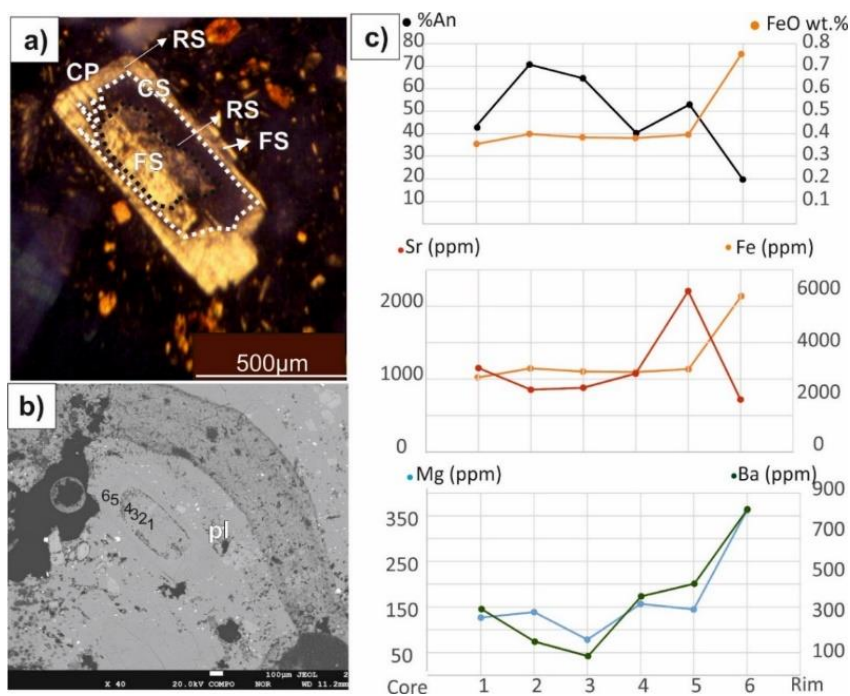


Figure 6. (a) Microphotograph, (b) BSE image of the plagioclase from the andesitic host rock (GK-6-C3) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the core to the rim.

Table 5 Textural stratigraphy of the plagioclase from the Andesitic Host (GK-6-C6)

Domain	Texture	Process
D4	CP	Subhedral- Euhedral and clear surface crystal growth
<i>RS (Resorption Surface): Interaction with hotter Fe-Mg-Sr-An-FeO rich Ba depleted magma: Major RS developed.</i>		
D2	CS	Interaction with the hotter, Fe-Mg-Sr-An-FeO-Ca-rich and Ba depleted magma. The formation of interconnected and large-sized pits is associated with intense and prolonged dissolution (Figure 7).
<i>RS (Resorption Surface): Interaction with hotter Fe-Mg-Sr-An-FeO rich Ba depleted magma: Major RS developed.</i>		
D2	CS	Interaction with the hotter, Fe-Mg-Sr-An-FeO-Ca-rich and Ba depleted magma. Interconnected and large size sieves show intense or prolonged dissolution (Figure 7).
<i>Significant resorption surface is not developed.</i>		
D1	CS SC	Interaction with hotter magma. There is no significant composition change in An, Fe. Heat transfer is faster during overheating than chemical change by diffusion (Self-mixing) (Figure 7).

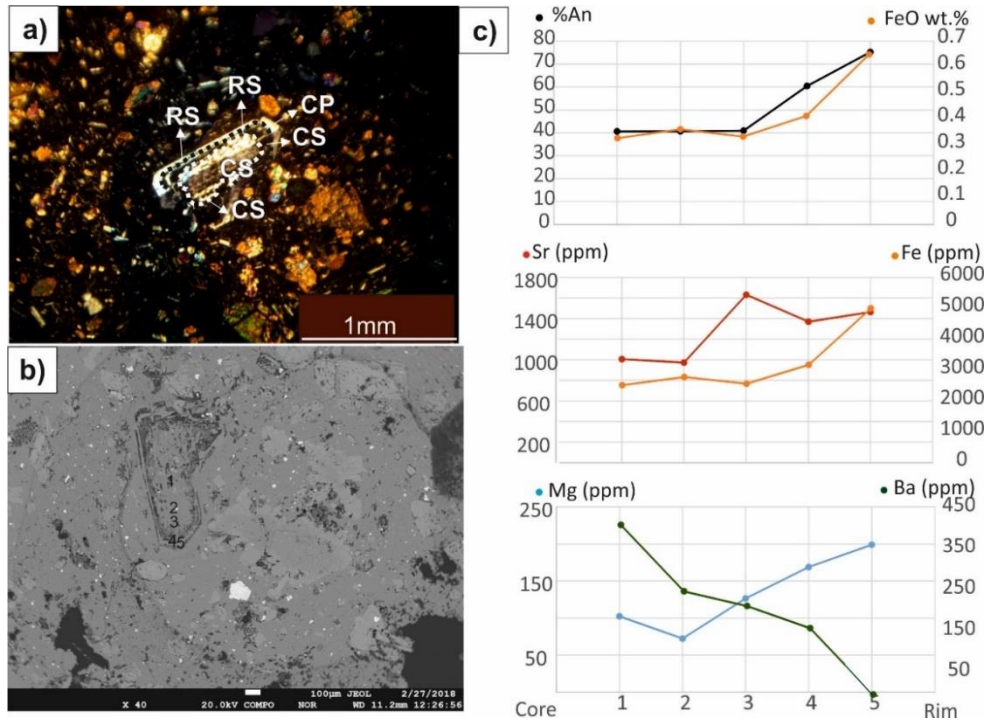


Figure 7. (a) Microphotograph, (b) BSE image of the plagioclase from the andesitic host rock (GK-6-C6) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the core to the rim

Table 6 Textural Stratigraphy of the plagioclase from the Magma mixing Enclave (GK-15-C5)

Domain	Texture	Process
D2	CS	Interaction with hotter magma. There is no significant composition change in An, Fe. Heat transfer is faster during overheating than chemical change by diffusion (Figure 8).
<i>RS (Resorption Surface): Interaction with more hotter and more enriched in Fe-Mg-FeO and more depleted magma in Sr, Ba: Major RS developed.</i>		
D1	FS (with rounded core) DS	Interaction with the hotter Fe-Mg-FeO rich and Sr-Ba depleted magma. Glass inclusions, interconnected and small pits indicate an intense or prolonged dissolution. Significantly resorbed, rounded core shows dense-dusty sieve texture (Figure 8). The low An content in the core may be related to the water content of the magma. Although FeO-An contents generally show a concordant relationship from the core to the rim, An significantly peaks in the middle-growth zone where the pits are concentrated and FeO is decreased. The oscillatory changing in Fe-Mg-Sr-Ba contents from the core to the rim may be due to repetitive, intense and prolonged interaction.

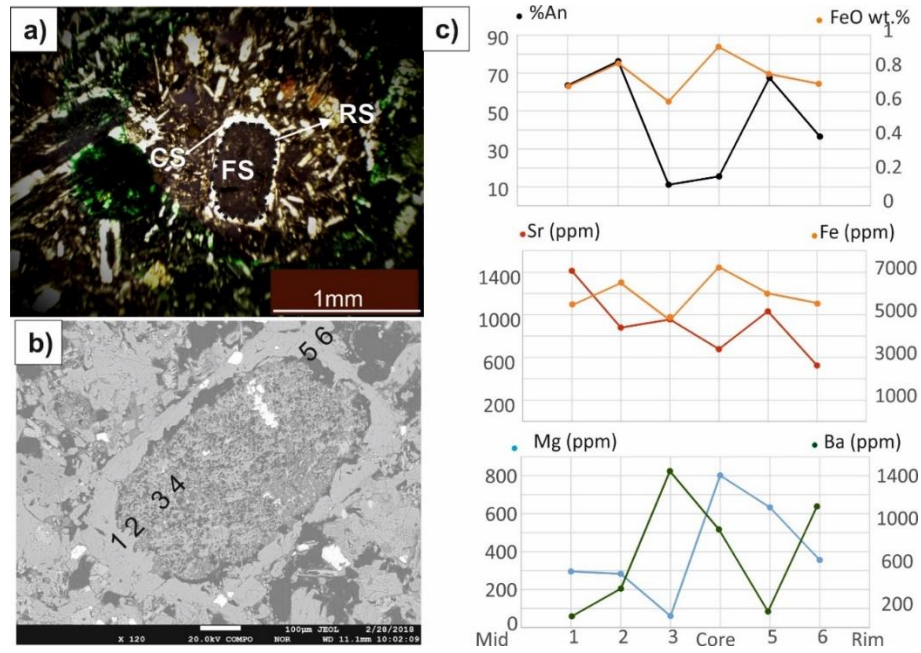


Figure 8. (a) Microphotograph, (b) BSE image of the plagioclase from the magma mixing enclave of the andesitic host rock (GK-15-C5) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the mid to the rim.

Table 7 Textural Stratigraphy of the plagioclase from the Magma mixing Enclave (GK-15-C6)

Domain	Texture	Process
<i>RS (Resorption Surface) : Interaction with hotter Fe-Mg-Sr-An-FeO-Ca-rich Ba depleted magma: Major RS developed.</i>		
D3	CS	Interaction with hotter and more primitive magma
D2	G	Suturing of closely resorbed /absorbed crystals. After the microcrysts came together, CS developed again (Figure 9). The rim is rounded due to the long and intense interaction.
<i>RS (Resorption Surface) : Interaction with hotter, Fe-Mg-Sr-An-FeO-Ca-rich Ba depleted magma: Major RS developed.</i>		
D1	CS	Interaction with the hotter, Fe-Mg-Sr-An-FeO-Ca-rich and Ba depleted magma. Rounded core, interconnected and large sized sieves show intense or prolonged dissolution (Figure 9).

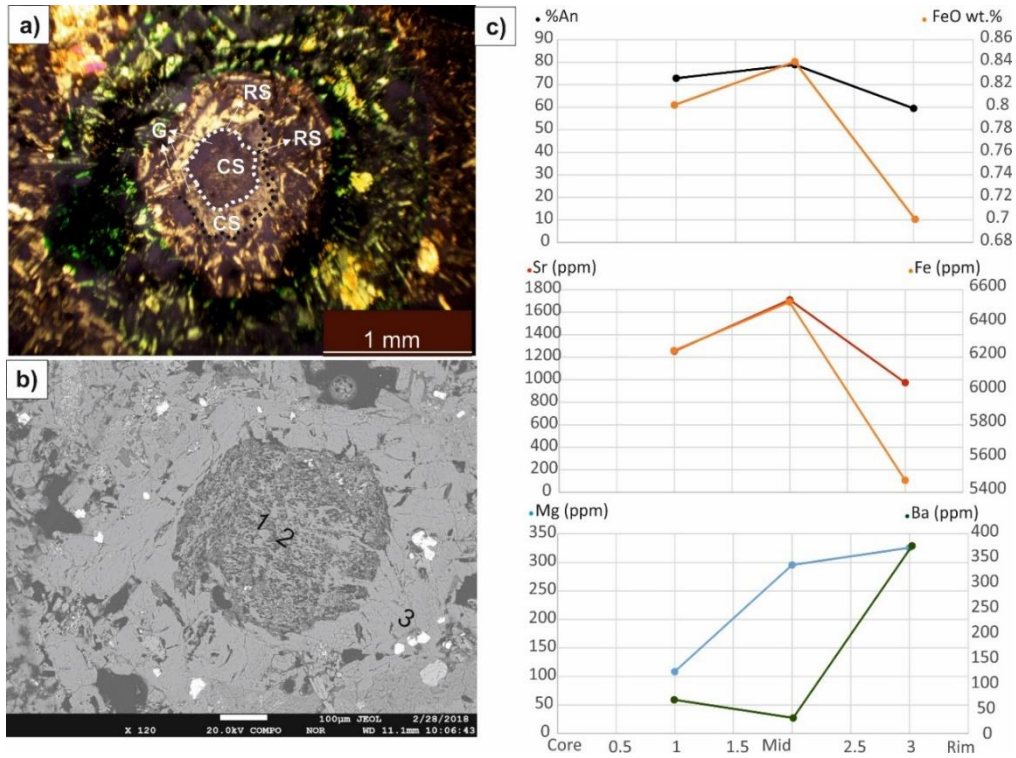


Figure 9. (a) Microphotograph, (b) BSE image of the plagioclase from the magma mixing enclave of the andesitic host rock (GK-15-C6) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the core to the rim.

Table 8 Textural Stratigraphy of the plagioclase from the Basaltic Host rock (KR-30-C3)

Domain	Texture	Process
D3	CP	Subhedral- Euhedral, normal zoned crystal growth (Figure 10).
D2	FS	Decompression (Continue). The size of the large pits have decreased from the core to the rim, and small-sized pits concentrated in the rims (Figure 10).
<i>Ambiguous resorption surface: Minor RS developed.</i>		
D1	CS	Decompression. An enrichment in Mg-An-Sr content and a depletion in Fe content from the core to the growth zone. The irregular relationship between Fe-Mg-An is perhaps due to changes in the water content and oxygen fugacity of the magma. An and Sr generally tend to be compatible with each other (Figure 10). CS may be formed by rapid decompression.

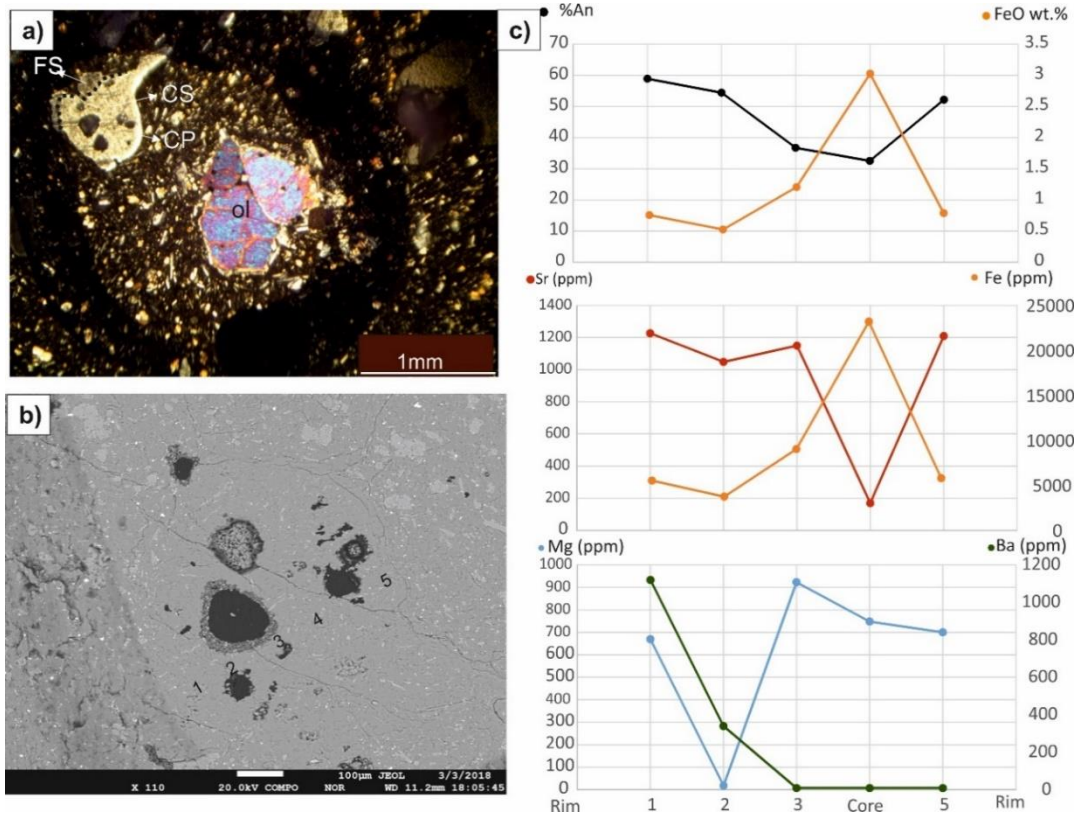


Figure 10. (a) Microphotograph, (b) BSE image of the plagioclase xenocryst from the basaltic host rock (KR-30-C3) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the rim to the rim.

Table 9 Textural Stratigraphy of the plagioclase from the Basaltic Host rock (KR-32-C4)

Domain	Texture	Process
D3	CP	Subhedral and clear-surfaced crystal growth
<i>Significant resorption surface is not developed.</i>		
D2	FS DS	Interaction with hotter, Fe-Mg-FeO rich magma. Dense fine sieves indicate intensive or prolonged dissolution. During the heating, smaller but very dense FS texture forms from the large pits in the core. From the core to the rim oscillatory and irregular variations in Fe-An contents can be explained by water content and oxygen fugacity (Replenishment process cannot explain that due to Mg (0) content) (Figure 11).
<i>Ambiguous resorption surface: Minor RS developed.</i>		
D1	CS	Interaction with more primitive magma. Due to the significant increase in Fe-Mg content from the core to the growth zone, it may be heated by a Fe-Mg rich source. An-Sr contents decrease regularly, show normal zoning and a concordant relationship with each other from the core to the growth zone. Fe-Mg contents, on the other hand, increase regularly and show a negative relationship with An composition (Figure 11). Therefore, it may be reheated and recharged by a Fe-Mg rich source. The irregular variations in An content can be explained by changes in water content and oxygen fugacity. Also, their An, Fe, Mg values in the core are too low to be occurred in a basaltic rock. Therefore they are probably xenocrysts plucked from the wall rock during magma arising.

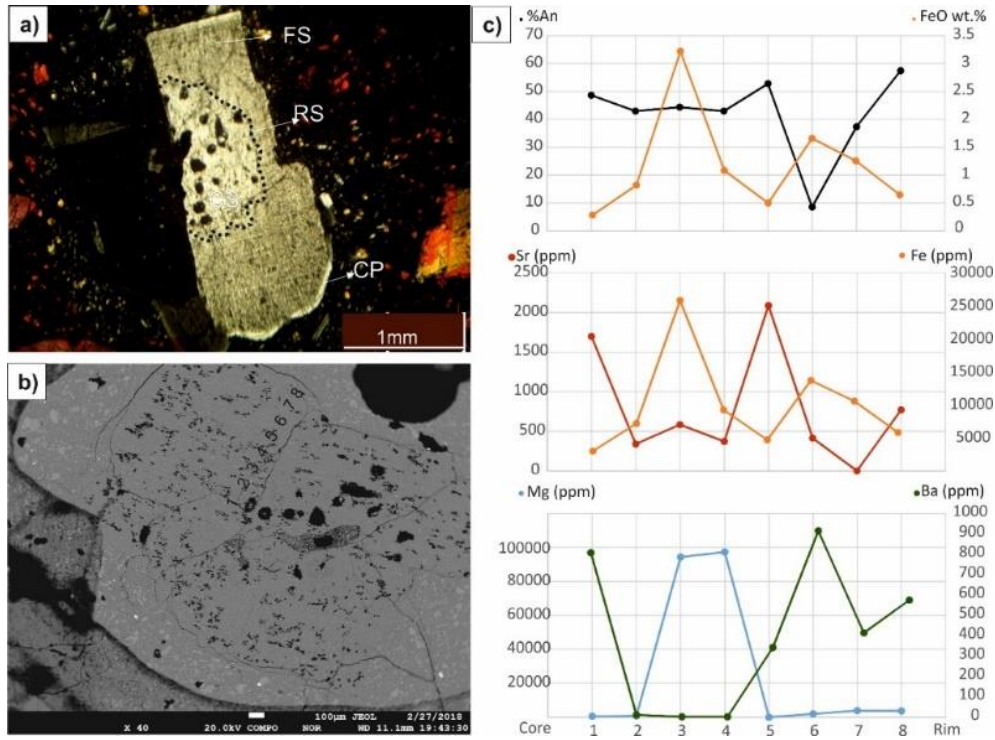


Figure 11. (a) Microphotograph, (b) BSE image of the plagioclase xenocryst from the basaltic host rock (KR-32-C4) and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the core to the rim.

Table 10 Textural Stratigraphy of the plagioclase from the Basaltic Host rock (KR-32-C7)

Domain	Texture	Process
D5	CP	Euhedral and clear-surfaced crystal growth
<i>Significant resorption surface is not developed.</i>		
D4	FS DS	Interaction with the hotter, Fe-Mg-FeO rich magma. During reheating, smaller but very dense pits have formed FS texture (Figure 12). The irregular variations in An and Fe content can be explained by changes in water content and oxygen fugacity
<i>Ambiguous resorption surface: Minor RS developed.</i>		
D3	CS	During heating, the size of the pits decreases from the core to the rim (Figure 12).
<i>Significant resorption surface is not developed.</i>		
D2	PZ	Wide and widespread patchy zoning indicates widespread resorption.
<i>Significant resorption surface is not developed.</i>		
D1	CS SC	Decompression. An-Sr compositions decrease regularly, show normal zoning and a concordant relationship with each other from the core to the growth zone. Fe-Mg contents, on the other hand, shows a negative trend with An (Figure 12). Therefore, it may be reheated and recharged by a Fe-Mg rich source. The irregular variations in An content can be explained by changes in water content and oxygen fugacity. Large-sized SC may be formed by rapid decompression. Also, their An, Fe, Mg values in the core are too low to be occurred in a basaltic rock. Therefore they are probably xenocrysts plucked from the wall rock during magma arising.

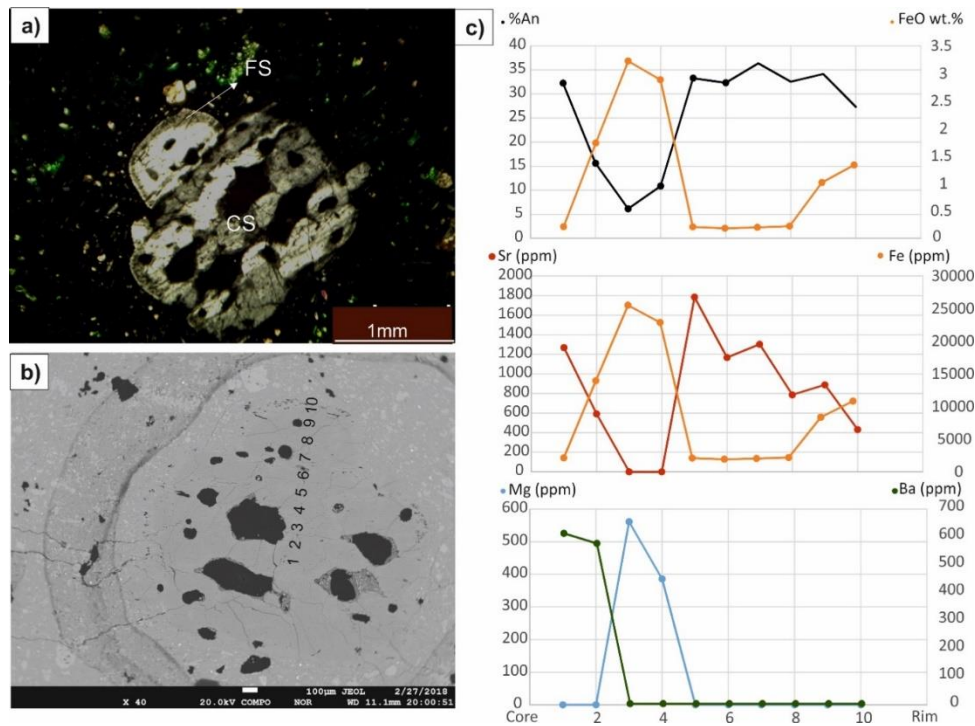


Figure 12. (a) Microphotograph, (b) BSE image of the plagioclase from the basaltic host rock (KR-32-C7), and (c) An-Fe-Mg-Sr-Ba variation diagrams of the same plagioclase from the core to the rim.

3.2.2. The importance of textural properties and chemical changes of plagioclases

The shallow magma chamber is dynamically active by convection or by new magma pulses or a combination of both. Repeated fine-grained sieve occurrence and oscillatory zoning in a single plagioclase crystal may indicate that multiple superheating events have occurred (Renjith, 2014; Viccaro et al., 2010). Crystals in the shallow magma chamber may encounter self-mixing or magma mixing which occurs when the magma chamber is recharged with hotter magma at the bottom through convection or turbulence (Couch et al., 2001; Huppert et al., 1986). Magmatic processes in the shallow magma chamber are not uniform to produce a homogeneous crystal assemblages. For instance magma mixing (self-mixing) process can generate textural heterogeneity (Perugini et al., 2004). Thus, fresher, more primitive magma comes into the shallow magma chamber from the deep magma chamber, and multiple recharge events may take place and heterogeneous crystal assemblages may coexist. It shows that phenocrysts with different textural sequences may occur in the rock. It indicates that the lava units may be heterogeneous in terms of more than one crystal assemblage.

Sieve and cellular textures can be formed by the reaction of sodic plagioclase with more calcic melts (Nakamura & Shimakita, 1998; Nelson & Montana, 1992; Pearce, 1994; Singer et al., 1995; Tsuchiyama, 1985), or the result of rapid decompression (adiabatic decompression). Fine and/or coarse-grained sieve texture, spongy texture, reverse, and/or oscillatory zoning are frequently observed in the plagioclases from the investigated volcanites. Combined with chemical compositions from the cores to the rims, we report that these textures observed in plagioclases may have been caused by interaction with a more primitive melt (magma mixing) and self-mixing in andesites, while in basalts it

may be caused by rapid decompression and repetitive self-mixing events. The fact that some of the Karapınar basalts contain plagioclase glomerocrysts and the presence of broken olivine crystals proves the decompression effect accompanied with the recharge events in the formation of sieve textured plagioclases (Renjith, 2014).

4. Conclusions and Recommendations

Regarding Fe-Mg content, plagioclase phenocrysts from the magma segregation enclaves are more primitive than those from the andesitic host rock. They may be crystallized at an early stage in the magma chamber, and have been brought into the andesitic host-rock by convection in the magma chamber. Moreover, in basaltic rocks, some of the plagioclase phenocrysts have very low Anorthite, Fe, Mg, Ca contents showing that they could not be formed in a mafic magma. They are probably xenocrysts plucked from the wall rock during magma arising. Reverse and oscillatory zonings are common in plagioclases belonging to both the host-rock and their enclaves. However, in some plagioclases showing reverse and oscillatory zoning, disequilibrium textures such as fine/coarse-grained sieve textures, dusty sieve texture indicating long-term dissolution are apparently observed. Moreover, the coexistence of the crystals with different textures cannot be explained by a unique disequilibrium process. All this suggests the existence of complex processes in the magma chamber. Considering the textural and chemical properties of the minerals from the Karacadağ Karapınar Volcanic Units, the formation of reverse and oscillatory zoning (repeated or not), and the presence of the different type of the sieve textures are generated by dominantly repeated and multiple recharging processes (magma mixing/self-mixing) in the magma chamber combined with decompression. Open system magmatic processes (i.e. recharging/assimilation) seem to play an important role in the evolution of the investigated volcanic rocks

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