Mineralogical Magazine, August 2017, Vol. 81(4), pp. 975–985

Mixing of basaltic and andesitic magmas in the Bazman volcanic field of southeastern Iran as inferred from plagioclase zoning

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[*Received 14 July 2016; Accepted 22 November 2016; Associate Editor: Martin Lee*]

ABSTRACT

Late Cenozoic basalts of the Bazman volcanic field, Makran volcanic arc of southern Iran, contain two types of plagioclase feldspar phenocrysts with significant textural and compositional differences. The most common type is rather homogeneous with only weak zoning and maximum An content of 83 mol.%. The less common type of phenocryst exhibits complex zoning and, other than rims, is close in composition and similar in texture to those of associated andesites. This type of plagioclase phenocryst is characterized by an engulfed core with oscillatory zoning, which is overgrown by sieve-textured, moderately zoned mantle, and a relatively narrow rim. In both rock types, the An content of the core is between 40 and 63 mol.% with abrupt fluctuations. No significant correlation between An content and MgO, FeO, SrO and BaO is apparent in the core of phenocrysts in basalts. Anorthite content of the core of phenocrysts in andesites inversely correlates with SrO and BaO. The mantle of plagioclase phenocrysts in both rock types is characterized by sharp increases of An (up to 41 mol.%), MgO, and FeO, in the contact with the core. Anorthite correlates positively with MgO and FeO in the mantle, but correlation between An and SrO and BaO is not evident. It is assumed that plagioclase phenocrysts originally crystallizing from the host andesitic magma were interrupted by mixing with a hotter, juvenile basaltic magma. The resulting changes in temperature, composition, and H_2O content of the surrounding melt caused compositional zonation, and the development of resorption in the cores and sieve texture in the mantles. As the An contents of the rims of the phenocrysts resemble the average An content of the groundmass plagioclases in both rock types, it is thought that the two involved magmas gained their independent physical identity before the formation of compositionally-distinct rims of plagioclase phenocrysts.

Keywords: plagioclase zoning, magma mixing, sieve texture, resorption, Bazman volcano.

Introduction

Physical and chemical changes during crystal growth in the magma chamber such as change of pressure (Pringle *et al.*, 1974; Nelson and Montana, 1992), temperature (Couch *et al.*, 2001), and water content (Shcherbakov *et al.*, 2010), together with magma mixing (Snyder and Tait, 1996), may lead to the formation of a variety of zoning patterns and dissolution surfaces in plagioclase feldspars. In particular, study of plagioclase texture and composition in volcanic rocks has been of interest in identification of mixing of magma bodies (Anderson, 1976; Eichelberger *et al.*, 2000). The changes of bulk composition of the magma may have a stronger effect on distribution coefficients of Sr, Ba, Mg and Fe in plagioclase than the fluctuations of An content (Ginibre *et al.*, 2002). For this reason, study of Sr, Ba, Mg and Fe as trace elements in plagioclase may be of help in the characterization of the internal and external factors which have affected the evolutionary trends of the

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https://doi.org/10.1180/minmag.2017.081.001

magmas (Churikova *et al.*, 2013; Zhijian *et al.*, 2014).

Basalts and andesites from the Bazman volcanic field of the Makran continental margin volcanic arc of southeastern Iran (McCall, 1997) (Fig. 1*a*) contain large amounts of plagioclase, either as phenocrysts or matrix grains. A rather small proportion of plagioclase phenocrysts in both rock types exhibit complex zoning. The peculiar feature of this type of plagioclase phenocryst is that compositions and types of zoning may differ from one lava to the next, and even from one phenocryst to another in a thin section. Of special interest is that some phenocrysts in basalts have zones with a lower concentration of anorthite (An) than other phenocrysts in the same rock or plagioclase of the groundmass. The composition of the core and mantle of such An-poor phenocrysts seems to be in equilibrium with the whole rock composition of the associated andesites, rather than the host basalt in which the composition of plagioclase phenocrysts are up to An_{83} with no remarkable zoning (Saadat

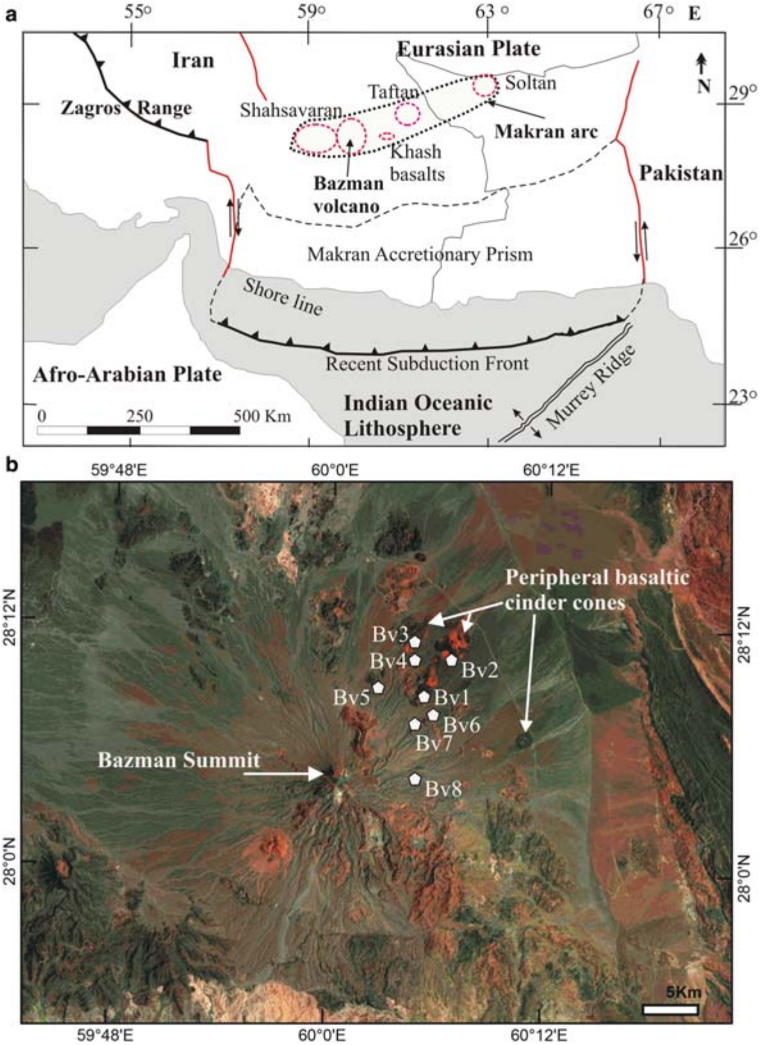

FIG. 1. (*a*) Regional geological map showing the Makran volcanic arc to the north of the Makran accretionary prism and within the overriding Eurasian plate. Some large-scale geotectonic elements of the region such as the downgoing Indian oceanic lithosphere, Afro-Arabian plate, and Zagros range are also shown. (*b*) Processed satellite image of the Bazman volcano, showing the location of the samples studied.

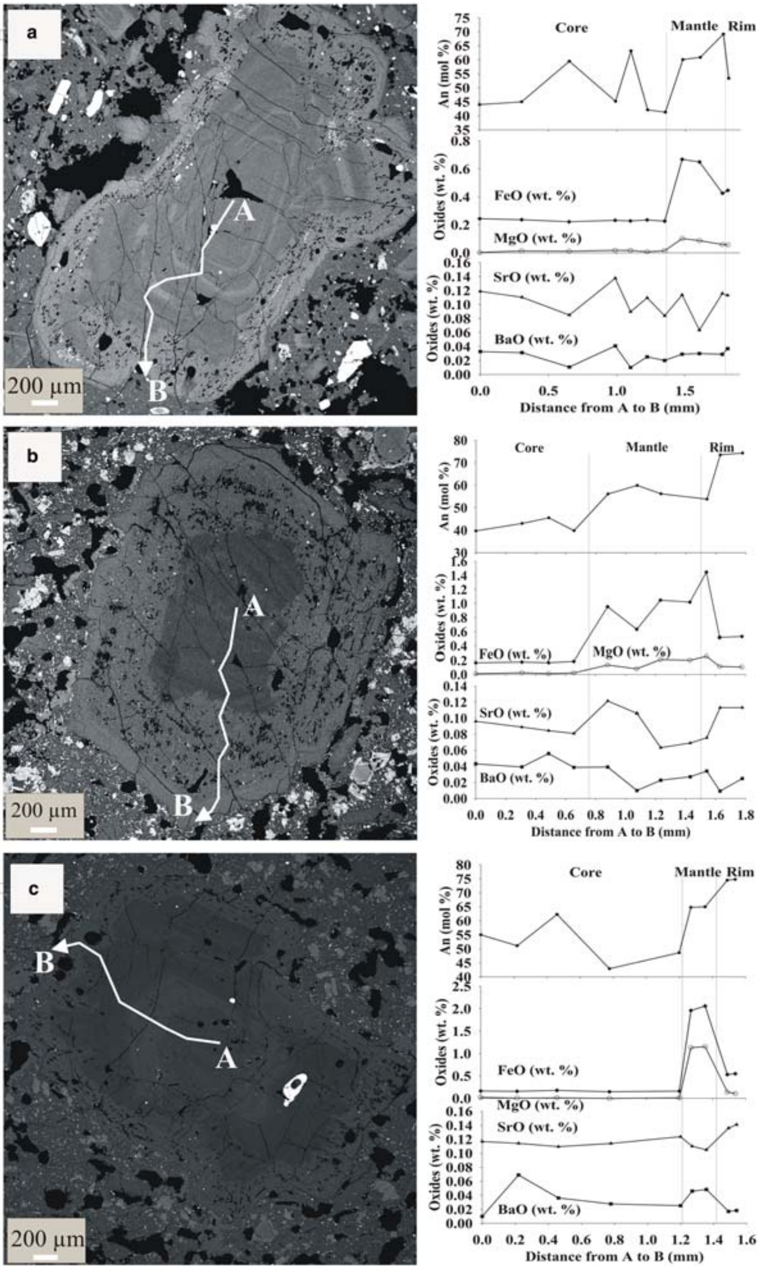

FIG. 2. Back-scattered electron (BSE) images and measured electron microprobe analyses profiles for representative plagioclase phenocrysts from Bazman andesites (*a*) and basalts (*b*,*c*), showing anorthite and trace-element content in plagioclase. Vertical dashed lines on the plots mark the boundary between core, mantle and rim (see text). White spheres on BSE images show the analysed locations. Anorthite content and Fe, Mg, Ba and Sr are shown on the profiles. Weak oscillation of anorthite content in the core is not associated with any considerable changes in trace elements; anorthite jumps (oscillations) in the core to rim dissolution boundary coupled with an abrupt increase in trace-element content and with high anorthite content gradually decreasing towards the rim. The outermost part of this zone is slightly more An-rich in basalts and An-poor in andesites.

and Stern, 2011; the present study). For this reason, it seems that some basaltic rocks have been involved in open-system processes (Streck, 2008; Churikova *et al*., 2013; Lee and Bachmann, 2014) and have been mixed partly with some derivative andesitic magmas.

Here we present microprobe analyses of three representative plagioclase phenocrysts from one andesite and two basalts from the Bazman volcanic field and interpret the compositional and textural data as evidence for magma mixing. Magma mixing is a common phenomenon in active continental margins (Anderson, 1976; Churikova *et al*., 2013; Williamson *et al*., 2016), where water-bearing magmas of mainly calc-alkaline affinity experience changes in pressure, water content, and oxygen fugacity (Kawamoto, 1992). Nevertheless, mixing of two magmas with close composition, and perhaps close physical properties in the Bazman volcanic field is interesting, as the magmas involved have resulted in rocks of homogeneous compositions regardless of having minerals of diverse compositions and textures. The Pleistocene (≤0.7 Ma) ages obtained from the rocks studied (Conrad *et al*., 1981; Pang *et al*., 2014), together with our field studies verify the close temporal and spatial relationships among the rocks.

Geological setting

An outline of the geology of Makran region and Bazman volcanic field is in Fig. 1*a*. Makran is a short segment, ~900 km long, in the Alpine-Himalayan orogenic system that marks a still-active, north-dipping Neotethyan subduction zone (McCall, 1997; Zarifi, 2006). One of the peculiar features of the Makran subducting system is the northern belt of a volcanic arc, commonly termed the Makran arc (Fig. 1*a*). The Makran arc consists of four major volcanic fields, from west to east: Shahsavaran (Dupuy and Dostal, 1978); Bazman (Saadat and Stern, 2011); Khash ("Chah-Shahi" volcanic field of Moinevaziri, 1985); and Taftan (Biabangard and Moradian, 2008; Pang *et al*., 2014) (Fig. 1*a*). These are major stratovolcanoes consisting mainly of andesitic and dacitic lava flows and pyroclastics, and numerous monogenic, mainly peripheral, satellitic, basaltic cinder cones and lava flows (Moinevaziri, 1985).

The Late Miocene-Pleistocene Bazman stratovolano is composed mainly of andesitic to dacitic lava flows and pyroclastics with an age range from ~7.5 Ma (Pang *et al*., 2014) to 0.7 Ma (Conrad *et al*., 1981). There are also numerous peripheral basaltic cinder cones and small lava flows (Saadat and Stern, 2011), and andesite lava flows (Conrad *et al*., 1981). These peripheral occurrences of basalt and andesite are the subject of this study. The age of these rocks was reported by Conrad *et al*. (1981) to be ~0.7 Ma. Field relationships deciphered by us, are consistent with Quaternary ages for the samples studied.

Analytical procedures

Major-element whole-rock analyses were performed using X-ray fluorescence (XRF) spectrometry by the fused disk method at Acme Lab™, Vancouver, Canada (Table 1). Crystalline phases were analysed with a 4-spectrometer JEOL JXA-733 electron microprobe at the University of New Brunswick, Fredericton, Canada, using a 10 kV accelerating voltage and 1 μm beam diameter. The beam current was 10 nA and counting times of 40 s or 60,000 counts (whichever was first) were employed. The standards were analysed periodically to assure the quality of the analyses. The microprobe analyses of the plagioclase phenocrysts studied, the standards used to control the quality of the analyses, and the minimum detection limits, expressed in oxide weight percent, are listed in Table 2.

Rock types

Generally, the basalts studied are porphyritic and the groundmass is commonly subophitic. In these rocks, phenocrysts of plagioclase, olivine, and commonly clinopyroxene are set in a groundmass of plagioclase microlites, fine-grained olivine, clinopyroxene, and glass. The forsterite content of olivine is in the range of 85–78 mol.% with weak normal zoning. Orthopyroxene seems to be absent in the basalts and the composition of clinopyroxene is $En_{47-44}Fs_{13-11}Wo_{44-41}$ mol.%.

The andesites studied are medium- to fine-grained, porphyritic and microporphyritic rocks, with phenocrysts of plagioclase, hornblende, clinopyroxene, and orthopyroxene set in a matrix of the same minerals. Both clinopyroxene and orthopyroxene phenocrysts and microphenocrysts of the andesitic lavas are augite and hypersthene with average compositions of $En_{46}Fs_{11}Wo_{43}$ and $En_{73}Fs_{25}Wo_2$ mol.%, respectively.

Major-element concentrations of the volcanic rocks from Bazman volcano are presented in

TABLE 1. Representative bulk-rock composition of the studied basalts and andesites.

	Basaltic rocks				Andesitic rocks					
Sample	Bv1*	Bv2*	Bv3	Bv4	Bv5	Bv6*	Bv7	Bv8	sd	A
Oxides (wt.%)										
SiO_2	51.50	52.39	50.74	54.28	58.19	61.67	61.00	63.30	0.97	–
Al_2O_3	17.01	17.20	18.16	18.62	16.33	16.69	17.16	17.03	0.70	4.21
Fe_2O_3*	6.92	7.24	8.53	7.59	7.08	5.56	5.10	4.33	0.95	9.38
CaO	10.33	8.88	9.27	7.75	7.27	6.06	5.71	5.41	0.95	9.38
MgO	6.06	6.60	6.48	4.27	4.28	2.42	2.73	2.34	0.95	8.05
Na_2O	3.64	3.74	4.07	4.01	4.10	3.71	4.07	4.20	1.33	4.65
K_2O	0.79	0.67	0.68	0.93	0.79	1.79	1.96	1.36	1.00	5.41
MnO	0.13	0.13	0.15	0.14	0.12	0.09	0.08	0.08	1.25	0.48
TiO_2	0.77	0.78	0.94	0.78	0.76	0.75	0.71	0.47	0.00	0.85
P_2O_5	0.21	0.19	0.25	0.35	0.21	0.23	0.24	0.15	1.95	0.75
Cr_2O_3	0.03	0.04	0.02	0.02	0.01	0.00	0.01	0.01	0.00	22.91
SrO	0.06	0.06	0.09	0.24	0.12	0.04	0.04	0.04	0.00	0.00
BaO	0.03	0.02	0.02	0.06	0.05	0.04	0.04	0.03	0.00	0.00
LOI	2.43	1.34	0.50	0.64	0.60	0.80	0.97	0.96	1.67	–
SUM	99.91	99.28	99.89	99.68	99.92	99.84	99.81	99.71		

sd: 2σ standard deviation on statistical mean.
A: accuracy = (measured-real)/real × 100 (Jenner, 1996).
*Samples with plagioclases analyses in Table 2.

TABLE 2. Representative compositions wt.% of plagioclase phenocrysts.

	Basalts								Andesite									
	m.c.	sd (8)	m.m.	sd (5)	m.r.	sd (4)	m.g.	sd (12)	m.c.	sd (9)	m.m.	sd (2)	m.r.	sd (2)	m.g.	sd (7)	Std	DL%
SiO_2	55.71	2.19	54.13	1.62	50.63	3.65	56.26	5.04	55.35	2.70	53.34	3.66	53.25	2.74	56.99	7.67	Plgbyt	0.019
Al_2O_3	27.83	1.37	28.01	0.74	30.52	2.90	26.41	4.32	27.90	1.56	29.11	2.72	29.51	1.98	26.12	6.63	Plgbyt	0.016
FeO	0.17	0.01	0.97	0.70	0.76	0.46	1.32	0.74	0.27	0.17	0.55	0.17	0.44	0.01	0.93	1.15	HMT	0.031
MgO	0.01	0.01	0.32	0.47	0.15	0.07	0.24	0.22	0.02	0.03	0.08	0.03	0.06	0.00	0.31	0.65	Ol1741	0.012
CaO	10.17	1.72	11.77	1.06	14.22	2.29	10.55	3.43	10.75	1.90	13.17	2.04	12.95	2.35	9.91	4.18	PLGBYT	0.014
Na_2O	5.99	0.92	4.57	0.85	3.37	0.93	4.77	0.92	5.61	1.19	3.64	0.22	4.36	1.25	4.87	1.36	Cpxjad	0.016
K_2O	0.22	0.06	0.39	0.20	0.22	0.29	0.51	0.48	0.25	0.17	0.39	0.43	0.15	0.08	0.77	1.45	Or1	0.012
MnO	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.03	Bust	0.026
SrO	0.10	0.01	0.10	0.02	0.11	0.03	0.10	0.03	0.10	0.02	0.11	0.00	0.11	0.00	0.09	0.03	Cele	0.048
BaO	0.04	0.02	0.03	0.01	0.02	0.01	0.05	0.03	0.03	0.01	0.03	0.00	0.03	0.01	0.08	0.03	Baryte	0.027
Total	6.36	0.32	5.11	0.34	3.73	0.22	100.53	0.92	6.00	0.54	4.19	0.25	4.66	0.25	100.08	0.74		
mol.% An	47.4	8.1	57.2	6.0	69.1	10.2	52.4	13.6	50.3	9.5	64.7	6.4	61.3	11.2	47.8	17.9		
Ab	51.4	7.7	40.5	6.3	29.7	8.5	44.3	10.7	48.3	9.5	33.0	3.7	37.9	10.7	44.9	7.8		
Or	1.2	0.4	2.3	1.3	1.3	1.7	3.3	3.4	1.4	1.0	2.4	2.6	0.9	0.5	7.4	16.3		

m.c, m.m., and m.r. are mean of analyses from core, mantle, and rim, respectively. Sd: 2σ standard deviation on statistical mean. Std = standard used to evaluate the quality of analyses; DL%: the minimum detection limits, expressed in oxides (wt.%). Figures in brackets are the number of analyses.

Table 1, and location of the analysed samples are shown in Fig. 1*b*. The SiO_2 contents of the basaltic rocks, 49.9–54.16 wt.%, are higher than expected from continental–margin basalts. The average MgO contents of the basalts and andesites studied are 5.91 and 3.03 wt.%, respectively, indicative of the evolved nature of the basalts. High Al_2O_3 (>17.01) together with high CaO (on average, 9.26 for basalts and 5.75 for andesites) reflect the abundance of plagioclase, and places the samples among the calc-alkaline suite. The K_2O contents (0.67–1.60 wt.%) are in agreement with the medium-K calk-alkaline nature of the rocks.

Zoning patterns in plagioclase

Although the composition of most of plagioclase phenocrysts in basaltic rocks of Bazman is about An_{83-47} with no, or very weak, zoning, compositions of ~7%–25% of the plagioclase phenocrysts in <15% of basalts are distinctly different, and close to the composition of those of andesites. The zoned phenocrysts in basalts and andesites consist of three distinct parts: oscillatory-zoned core; sieve-textured mantle; and relatively thin rim. Core-to-rim traverses from three representative plagioclase phenocrysts in an andesite and two basaltic lava flows are shown in Fig. 2. It could be concluded from Fig. 2 that the cores of phenocrysts in both rock types are close in composition, regardless of their distinctive bulk chemistry.

The An contents in the cores of plagioclases of andesites and basalts are quite close and generally vary between 40 and 63 mol.%. Oscillation, however, is considerably more developed in the core of plagioclase in andesites (Fig. 2*a*). Changes of An contents in the plagioclase cores of the andesite samples correlate inversely with concentrations of BaO and SrO, however negligible changes are evident from MgO and FeO concentrations. Any relationship between the An content and trace elements in the cores of plagioclases of basalts (Fig. 2*b*,*c*), is not readily discernible, and in cases of minimal evident An changes, the behaviour of trace elements does not match.

The mantle, 200–400 μm wide, is characterized in both rock types by a sieve texture, sharp increase of An content from ~40 to a maximum of 68 mol.% and concomitant elevated FeO and MgO at the contact with the core. A reverse trend in the An content in andesite samples from ~62 close to the core to ~74 mol.% in the vicinity of the rim is evident, although fluctuations of An in the grains from basalts are not that significant. Nevertheless, in both rock types FeO and MgO correlate positively with the An content of the plagioclase. However, there is no correlation between SrO and BaO and the An contents in plagioclase phenocrysts in either type of rock.

The rim of plagioclase phenocrysts is 50–150 μm wide, with distinct compositions in the two rock types. In andesites the An content decreases from ~69 mol.% at the contact with the mantle to ~53 mol.% at the edge of the phenocrysts, apparently in equilibrium with the groundmass plagioclases, which have an average An content of 50 mol.%. In basalts, the An content increases to ~74 mol.% towards the edge, again a value close or even similar to the An content of the matrix plagioclase grains. In both rock types FeO and MgO decrease towards the edge of phenocrysts, which is more strongly developed in basalts. In andesites, BaO and SrO show no significant change in the rim, but in basalts these oxides slightly increase towards the edge of the grains.

Discussion

A proportion of zoned plagioclase phenocrysts in a subset of basalts from the Bazman volcano have the following characteristics: (1) The composition of the core is essentially similar to that of core of plagioclase phenocrysts of associated andesites; (2) resorption of the core is evident; (3) the mantle of the grains is characterized by complex compositional zonation and disequilibrium textures; (4) the margins of the mantles are resorbed; and (5) the rim seems to be in equilibrium with the groundmass of the rock. The reasonable explanation of such features is that these plagioclase crystals encountered compositional and thermal instability in an open-system magma chamber in the course of crystallization. The following interpretations serve to explain the textural and compositional evidence.

Magma mixing: evidence from the core

Oscillatory zoning can be the result of different processes in the magma chamber, such as change in composition, temperature, water content (Perugini *et al.*, 2003; Putirka, 2005; Shcherbakov *et al.*, 2010), and lithostatic pressure (Lange *et al.*, 2010). The coarse-banding zonation of the plagioclase cores, which correspond to changes in An content (Fig. 2), would not be solely kinetically-controlled (Streck, 2008). Rather, they could be a result of dynamic processes (Shore and Fowler, 1996), and changes of water content and/or pressure within the magma body (Rutherford and Devine, 2008), as it has a calc-alkaline, water-saturated nature. In the course of evolution of a magma, the SiO_2 content increases, and An content of plagioclase decreases, causing decrease of Fe and Mg and increase of Ba and Sr distribution coefficients in plagioclase (Arth, 1976; Singer *et al.*, 1995; Ginibre *et al.*, 2002). However, increase of Fe and Mg concentrations can also occur in response to elevated oxygen fugacity (vapor pressure increasing), and magma ascent (Perugini *et al.*, 2003; Putirka, 2005; Lange *et al.*, 2010). Moreover, mixing with geochemically different magma batches could also change the An and Fe, Mg, Ba and Sr content accordingly. As the change in concentrations of FeO, MgO, BaO and SrO in the cores are not as remarkable as changes of An contents, and their fluctuations do not match the oscillatory zoning of An. The slight oscillatory zonation of the core is attributed here to degassing episodes and consequent fluctuations of water contents of the magma chamber.

Magma mixing: evidence from the mantle

Rapid changes in the An content in the early stages of mantle formation in andesites and basalts, associated with sharp increases in MgO and FeO, 10 and 3 times, respectively, may be generated by two mechanisms. These can be either pressure decrease as a result of magma ascent (Nelson and Montana, 1992) or replenishment of the magma chamber by new hotter mafic magma (Snyder and Tait, 1996; Landi *et al*., 2004). Regarding the development of peripheral satellite basaltic cones, local mixing in magma bodies accompanied by convectional flow could be possible. Sudden changes of SrO and BaO patterns, forming a positive correlation between SrO and An contents in the mantle could be better explained by intrusion of Sr-rich and Ba-poor basaltic magma into andesitic host magma; the latter could be generated due to fractional crystallization. This mixing process may increase the Sr distribution in plagioclase (Zellmer *et al*., 1999). Such a condition may also cause an inverse relationship between BaO and An contents in the mantle of plagioclase phenocrysts.

Contact between felsic and hotter, new mafic magma as a result of either magma chamber replenishment (Humphreys *et al*., 2006) or convection (Couch *et al*., 2001), could lead to resorption processes (Viccaro *et al*., 2010). Sieve texture of the mantles and engulfed edges of the cores are considered as pervasive dissolution phenomena (Vance, 1965; Tsuchiyama, 1985; Stewart and Pearce, 2004), and interpreted here a consequence of magma mixing and disequilibrium crystallization (Nakamura and Shimakita, 1998; Ruprecht and Worner, 2007). Dissolution-related textures may also form by rapid decompression where heat loss is lower than the ascending rate of the magma (Nelson and Montana, 1992). Compositional zonation accompanied with resorbed, rounded edges, in some clinopyroxene phenocrysts of some andesite samples may be in support of reheating processes. All of this evidence from the mantles of plagioclase phenocrysts may be the result of periodic injection of juvenile mafic magmas into a differentiated magma chamber beneath the volcano.

Rim-rock matrix equilibrium: evidence from the rims

At Stromboli the decrease in FeO content together with an increase in An at the rim of plagioclase phenocrysts has been attributed to magma mixing processes (Landi *et al*., 2004). This has been reported from other volcanic systems, such as Kuril Islands (Volynets *et al*., 1977), Unzen volcano, Japan (Eichelberger *et al*., 2000), and Kizimen volcano, Russia (Churikova *et al*., 2013). Negative correlation of FeO and MgO with An in the rims of plagioclase phenocrysts in basalts of the Bazman volcano is interpreted here also as due to magma mixing. Nevertheless, this feature has also been attributed to the nonlinear behaviour of the Fe and Mg distribution coefficients in the plagioclase–melt system (Churikova *et al*., 2013). It should be mentioned that most experimental work on the determination of Kd_{Mg} and Kd_{Fe} have been carried out for plagioclases up to An_{85} (Severs *et al.*, 2009), and is applicable to Bazman plagioclase grains.

In the last stages of plagioclase growth, physical changes in the magma reservoir led to the generation of sodic labradorite rims around some andesitic plagioclases, and sodic bytownite rims around some basaltic plagioclases. The composition of the rim in both rock types seems to be a sign of an approach to equilibrium with the host melts, as An content of the rims seem to be close to the An content of the groundmass plagioclases. We suggest, therefore, that the involved andesitic and basaltic melts gained their distinct identity during

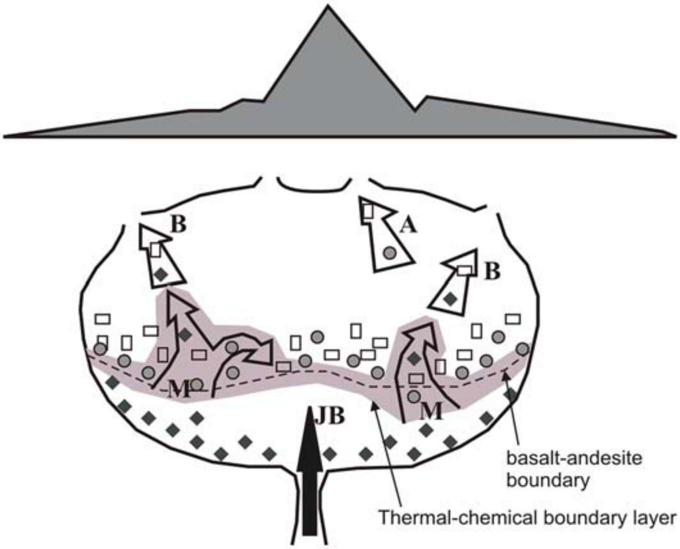

FIG. 3. Schematic depiction of magma mixing in the Bazman magma chamber as proposed in this study. Frequent injections of basaltic magmas into the chamber caused compositional and thermal gradients, and consequently, partial, and possibly local, mixing of the juvenile, hotter basaltic magmas (JB) with the residing, evolved andesitic magma. The mixed portion of magmas (M) erupted mainly from fringes of the magma chamber, and formed a segment of the peripheral basalts (B) and andesites (A). The dashed line marks a hypothetical, turbulent boundary layer. Diamond = olivine; circle = pyroxene; rectangle = plagioclase.

the formation of the rim of the plagioclase phenocrysts. In addition to rim-groundmass equilibrium, positive correlation of An and SrO in basaltic plagioclases, and decreasing of An content of andesitic plagioclases while MgO, SrO, and BaO are almost constant, again are indicative of separation of two distinct magmas, during the formation of the rims.

Petrologic implication

The above constraints suggest replenishment of the magma chamber by basaltic magma and mixing, at least partly, with the residing andesitic magma (Fig. 3). Mixing of basaltic-dacitic or andesitic-dacitic magmas has been previously documented by many studies (Churikova *et al*., 2013 and references therein). Insightful studies have also been undertaken on mixing processes of two mafic magmas (e.g. Landi *et al*., 2004; Ginibre and Worner, 2007). This study focuses on the less-described phenomenon of mixing of basalt and andesite magmas. We contend, however, that the applicability of our model is limited, and may serve as a case study. Nevertheless, this study suggests that in the case of an intimate field occurrence of temporally-close basalts and andesites, mixing between the two through open-system magma chamber processes has been viable. In the Bazman volcano, such mixing is limited, small-scale, and local phenomenon. Acquisition of magma mixing of this type seems not to be readily achievable via study of the bulk rock compositions of the involved rocks.

Concluding remarks

In conclusion: (1) mixing of basaltic and andesitic magmas is a local and small-scale phenomenon within the Bazman volcanic field; (2) it may be difficult to infer magma mixing from whole-rock composition of the involved rocks in the Bazman volcanic field, but interpretations based on zoning and textures of plagioclase phenocrysts are fairly conclusive.

Acknowledgements

Funds for this research were provided to DL via a NSERC Discovery grant. Constructive reviews by two anonymous reviewers improved the manuscript. We are grateful to the Associate Editor, an anonymous Editorial Board Member, and the Production Editor of the *Mineralogical Magazine* for constructive comments. Dr. Douglas Hall from UNB Microscopy and Microanalysis Facility, helped patiently with microprobe analyses.

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