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Zircon abundance, size and paragenesis in SiO_2-rich volcanic rocks: Implications for geochronologic studies

Abstract

Textural relationships between different mineral phases in rock (such as grain size, shape, associated minerals, inclusions, overgrowths) may provide information on crystallization conditions. Such relations between zircon and associated mineral phases can affect interpretation of zircon chemical composition and age. The information on the rock texture is best observed in thin sections. However, observations on thin sections are often neglected due to low number of zircon grains in a thin section, and usually only separates from larger rock volume are being analysed. By doing so, the information on occurrence of zircon within the rock is lost and different zircon generations cannot be traced back to a particular textural position in the rock. In this study we analysed thin sections from silicic volcanic rocks in order to characterize the textural position of zircon in the rock and its diversity.

Zircon grains in lava flows and domes samples analysed in this study are rare and usually small. They often occur within the rim of phenocrysts (e.g quartz, plagioclase, feldspar, biotite), which indicates that zircon crystallized during the last stage of magma evolution, probably not long before eruption. Therefore, dating of this zircon provides the age of this last stage, but its chemistry may be affected by crystallization in melt pocket concentrated along mineral boundaries. On the other hand, such zircon is absent from ignimbrite samples, which contain abundant and large grains in the (glassy) matrix. The difference between the zircon appearance in lavas and ignimbrites might be explained by many factors (e.g. the difference in analysed localities, crystallization in volatile-rich magma chamber, zonation within magma chamber prior to eruption, sorting and concentration during pyroclastic deposition).

Streszczenie

Relacje teksturalne i strukturalne (wielkość, wykształcenie ziarna, współwystępowanie z innymi minerałami, inkluzje i przerosty) między różnymi fazami mineralnymi w skale mogą dostarczyć informacji na temat zróżnicowanych warunków krystalizacji. Takie relacje między cyrkonem a fa-

Geoscience Notes 2.1, 2014
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zami towarzyszącymi mogą mieć kluczowe znaczenie, jeśli chodzi o interpretację wieku cyrkonów datowanymi metodą U-Pb. Aby uzyskać informacje na temat teksturalnych relacji między cyrkonem a pozostałymi minerałami głównymi skały (Qtz, Bt, Pl), zalecane są dokładne analizy płytek cienkich próbek skalnych. Bardzo często ten rodzaj badań jest pomijany i bezpośrednio przechodzi się do procesu separacji ziaren. W ten sposób utracone są informacje na temat występowania cyrkonu w skale, co jednoznacznie pozwala wydzielić i rozróżnić poszczególne etapy jego krystalizacji. W artykule przedstawiono wyniki analiz ponad 500 płytek cienkich skał wulkanicznych. Analizy te zostały wykonane w celu opisania występowania cyrkonu oraz potencjalnego zróżnicowania cyrkonu ze względu na sposób jego krystalizacji. Ziarna cyrkonu zidentyfikowane w lawie i kopule lawowej są zazwyczaj małe i wbudowane w brzegi minerałów. Świadczy to o ich krystalizacji podczas ostatniego etapu ewolucji magmy, najprawdopodobniej zaraz przed jej erupcją. Dzięki takim ziarnom uzyskujemy wiek tego etapu, niemniej jednak ich zapis chemiczny najprawdopodobniej odzwierciedla warunki krystalizacji w brzegowej strefie różnych minerałów. W ignimbrytach nie spotyka się małych ziaren zamkniętych w innych minerałach, natomiast występują liczne duże ziarna w szklistym tle skalnym. Taka różnica między występowaniem cyrkonu w lawach i iginmbrytach może być wynikiem analiz konkretnych lokalizacji. Jednak mogą mieć na to wpływ zarówno charakterystyczne warunki krystalizacji magmy (np. w komorach silnie nasyconych gazami), jak i jej stratyfikacja w obrębie komory. Stąd też ziarna mogą być selektywnie gromadzone w osadach wulkanicznych odzwierciedlających części komory magmowej bogate bądź ubogie w kryształy.

Keywords: zircon, volcanic rocks, thin section, paragenesis

Introduction

Zircon in volcanic rocks is widely used for dating of magmatic activity as well as for reconstructing the magma evolution processes (e.g. Breitkreuz and Kennedy 1999; Breitkreuz et al. 2007; Bindeman 2008; Watts et al. 2011; Kryza and Awdankiewicz 2012; Awdankiewicz et al. 2013). Zircon is highly resistant to weathering and alteration, can be analysed for various isotopic systems, e.g. U-Pb, Lu-Hf, $\delta^{18}O$ and can also concentrate many trace elements, such as Hf, U, Th, REE (cf.: Ireland and Williams 2003; Košler and Sylvester 2003; Kinny and Maas 2003). Trace element and isotope composition of zircon can provide information on magma evolution and on proportions of crustal and mantle components that melted to produce magma (e.g. Claiborne et al. 2006; Kemp et al. 2006, 2007; Harley and Kelly 2007; Pietranik et al. 2008, 2011; Bahlburg et al. 2009, 2010; Andersen et al. 2009; Appleby et al. 2010; Gagnevin et al. 2010, 2011; Hawkesworth et al. 2010; Andersson et al. 2011; Nebel et al. 2011; Zhu et al. 2011; Thompson et al. 2012). Also inherited and detrital zircon is often used to identify source rock lithology based on trace element concentration (Belousova et al. 2002). However, zircon REE abundances show little inter-sample variations and there are no systematic differences in normalized pattern shapes, despite different crustal elements in the source region and age. Therefore zircon chemistry is not generally useful as an indicator of zircon provenance (Hoskin and Ireland 2000), unless a wide set of trace elements is used (Belousova et al. 2002) and this might be obtained by investigation of the occurrence and chemistry of inclusions hosted by de-

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trital zircon. In contrast, Belousova et al. (2002) argue that applying a wider number of trace elements gives the distribution of trace elements reflecting host rock composition and crystallization environment.

Dating of Quaternary zircons by U-series shows that zircon crystallization in a magma chamber may be protracted and may span several hundreds of thousand years (e.g. Schmitt et al. 2010 ; Storm et al. 2012). Zircon separated from a volcanic sample may represent only one stage of several stages of the magma evolution of this sample. On the other hand, zircon from older volcanic rocks is dated by U-Pb method for which it is impossible to obtain age uncertainties lower than 1 Ma. Due to these uncertainties it is impossible to recognize separate stages of magma evolution only on the basis of zircon ages. The way forward is to use combined isotope and trace element analyses of zircon to define chemically and/or morphologically different zircon groups that may represent different stages of magma evolution (e.g. Pietranik et al. 2013), which is showed in the discussion.

Additional information may be provided by establishing petrological relations between zircon and other minerals in the rock. However, detailed petrological context is rarely examined in zircon studies, as zircon is separated from the rock to obtain statistically representative number of grains for analyses. In this study we characterize zircon in thin sections from a variety of volcanic rocks of different emplacement types and geotectonic settings. The aim is to show if different groups of zircon, e.g. included in different minerals or in the groundmass, can be identified already by examining thin sections. We also discuss if characterizing zircon in petrological framework may add information on its timing of crystallization.

Analytical methods

For the purpose of this study, more than 520 thin sections were examined under polarizing microscope. The thin sections form part of the collection of the Centre of Volcanic Textures (CVT[1]) in Freiberg (Germany) which hosts over 2000 samples of different types of volcanic rocks from localities worldwide. The aim was to find thin sections representing different emplacement types of silicic volcanic rocks and document the position of zircon in the rock texture. Thin sections containing zircon were chosen for further examination. Characteristic features of zircon in each section were noted including shape, size, abundance, association with other minerals (Table 1). Relations to other rock-forming minerals were defined and abundance of zircon with distinct characteristics was estimated for each rock. The matter of internal textures in zircon as zonation, inheritance, inclusions, hydrothermal overprint was not the subject of this study.

[1] http://tu-freiberg.de/geo/sedi/ausstattung/cvt (access: May 2014).

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Results

The investigated thin sections were taken from previously described volcanic rocks with well-defined emplacement modes (see Table 1 for particular references of each mode). Emplacement types include surge and pyroclastic flow deposits, fluvial conglomerates, lavas, lava domes. Zircon grains were found in three of them: lava, lava dome and ignimbrite samples. Zircon abundance was estimated in four categories: none (no grains were found in several thin sections of the same rock), scarce (a single grain was found in several thin sections), visible (each thin section contained at least one grain), abundant (> 2 grains were visible in each thin section) with respect to thin section views. Zircon groups have been established based on the occurrence of zircon in the rock texture. It was observed that zircon mainly was 1) incorporated into phenocrysts or crystal clasts (quartz, plagioclase, biotite; for definition see Winter et al. 2008), in lavas and ignimbrites respectively; 2) partially overgrown or in the vicinity of plagioclase and biotite in lava domes; 3) situated in the glassy ash matrix of ignimbrites (Table 1).

Table 1. Zircon characteristics in different localities and emplacement types

Emplacement type	Locality [age of formation]	Zircon abundance	Zircon position	Zircon characteristics	Associated minerals**	References for sampled volcanic complex
Lava	New Zealand, Mt. Tarawera [Quaternary] _22/2/96/2_*	scarce grains	incorporated in crystal rims	only small grains (<60 mm), elongated, rarely stubby	Qtz, Pl, Bt	Speed et al. 2002
	Lidy Hot Springs, Snake River Plain Idaho (USA) [Pliocene] _1/8/97/1_*	visible grains				Watts et al. 2011
	Visegrad Mtns, N of Budapest, Hungary [Neogene] _28CI; 28CII_*	scarce grains	surrounded by glass	only small stubby grains (<50 mm)	— (glass)	Harangi et al. 2001
	Tokai Mtns, Hungary [Cenozoic] _TM-4_*	scarce grains	incorporated in crystal rims	small grains (<40 mm) rounded	Pl	Németh et al. 2008
		scarce grains	surrounded by glass	big stubby grains (>100mm)	— (glass)	

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Lava dome	Lassen Peak, California (USA) [eruption in 1915] *26/7/97/1**	visible grains	incorpo-rated into or very close to crystal edges	variable in size and shape (usually stubby, rarely elongated), often rounded	Pl, Qtz, Bt	Clynne 1999
	Visegrad Mtns, north of Buda-pest, Hungary [Neogene] *27A/II*	visible grains				Harangi et al. 2001
	Chao Coulee, N Chile [Quaternary] *15/2/3/1B**	single grain	surround-ed by glass	single grain measures 80mm	— (glass)	de Silva et al. 1994
Ignimbrite	Sardinia, North of Burumini, [Cenozoic] *15/9/99/1**	visible grains	in rims of rock forming minerals	relatively big stubby (up to 150 mm), often rounded, rarely elongated	Bt, Qtz, Pl	Lustrino et al. 2000
	St. Francis Mtn., Missouri (USA) [Proterozoic] *18/3/93/5A*	visible grains	grains in (ex-) glassy matrix			Menuge et al. 2002
	Collio Basin, N Italy [Permian] *19/7/96/1 II**	scarce grains	grains in (ex-) glassy matrix			Cortesogno et al. 1998; Breitkreuz et al. 2001
	Valles Caldera, New Mexico (USA) [< 1Ma] *28/6/89/1**	abundant grains	grains in glassy matrix			Reneau et al. 1996

* names of investigated thin sections from CVT in Freiberg.
**associated minerals hosting zircon in order of frequency.

Eruption mode and description of representative localities

Whether magma erupts effusively (lava flow, dome extrusion) or explosively (e.g. ignimbrite) depends on the efficiency of gas escape during the ascent of magma (Degruyter et al. 2012 and therein). Effusive eruption occurs when the gas can easily get out of the magma or when the magma was volatile-poor from the start. Explosive eruption occurs when the gas stays trapped within the ascending magma and the potential energy, needed for fragmentation of the magma, is created (Degruyter et al. 2012). Furthermore, explosive eruptions can be caused by phreatomagmatic processes. Eruption and emplacement style, duration and in-

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tensity of eruption, vent configuration vary depending on whether the magma is basaltic or silicic in composition (Bryan et al. 2010). Whether magma erupts out of volcanic vent into a flow or a dome depends on a change of boundary conditions (flow rate, viscosity, magnitude of heat lost to the atmosphere — or water for subaqueous flows). All these parameters strongly affect the distribution of gas pressure and stress within the volcanic material (Massol and Jaupart 2009). It has been also suggested that the main control on dome emplacement is not cooling but degassing-induced crystallization, which depends on pressure changes during ascent and spreading at the surface (Sparks et al. 2000). However, a full dynamic framework of dome-forming eruptions is complicated and requires taking into consideration such factors as pore pressures, flow stress, degassing and crystallization development (Massol and Jaupart 2009). In this study we distinguished lava and lava dome emplacement, but, in fact, it is reported that these types may be similar in appearance and composition (Clynne 1999), covering not only silicious but also intermediate magmas (Bryan and Ferrari 2013).

Lava is one of the most commonly investigated emplacement types related to volcanoes (e.g. references in Table 1), due to its spectacular occurrence and high emplacement temperature. However, compared to typical ignimbrite complexes, volume is small. Thin sections from lava flows were examined from Lidy Hot Springs, Snake River Plain, USA; Mt. Tarawera, New Zealand; North California, USA; Northern Islands, New Zealand; Visegrad Mtns., north of Budapest; Cordon de Lila, N Chile, and the Tokai Mtns, Hungary (Table 1). Generally, zircon detection was difficult in lavas from these localities. The grains are generally small (< 50 mm) and enclosed within rims of plagioclase, quartz and feldspar (Figure 1b, c, e, respectively). Only a few grains were found without other minerals overgrowth (Figure 1d, f). Grains above 100 mm are extremely rare and only one such grain was found in all thin sections from lava — the grain (Figure 1f) is elongated, but further polishing of this thin section might show euhedral and fully prismatic crystal. The most interesting occurrence is the one in Figure 1a, where larger zircon is included in the phenocryst and the smaller occur in the glassy matrix. More detailed analytical work (zircon chemistry and cathodoluminescence) should be done to properly interpret this relationship. A speculative interpretation might be that the larger grain is an antecryst (Miller et al. 2007) or that some differences in Zr oversaturation controlled growth of the grains, but without further analyses there is no certain answer.

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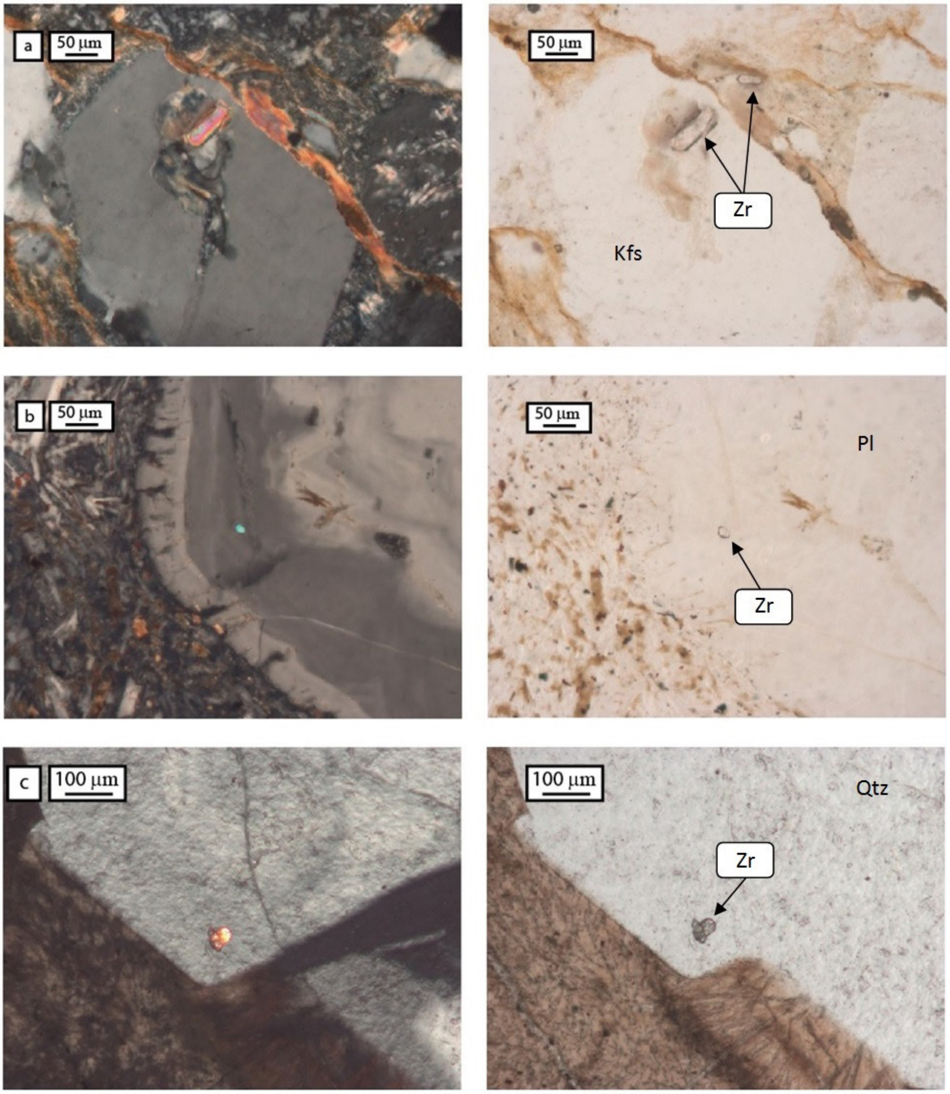

Figure 1a–c. Zircon grains in lava; cross (left) and plane (right) polarized light; (a) two zircon grains in glassy lava, larger zircon is included in the feldspar phenocryst and the smaller occur in the glassy matrix [mass flow deposit related to lavadome collapse — Collio Basin]; (b) small grain incorporated into phenocrysts rim (plagioclase) [dacitic lava Tokai Mountains, Hungary]; (c) zircon grain incorporated into rim area of quartz phenocryst [partially crystallized obsidian lava — Mt. Tarawera, New Zealand]

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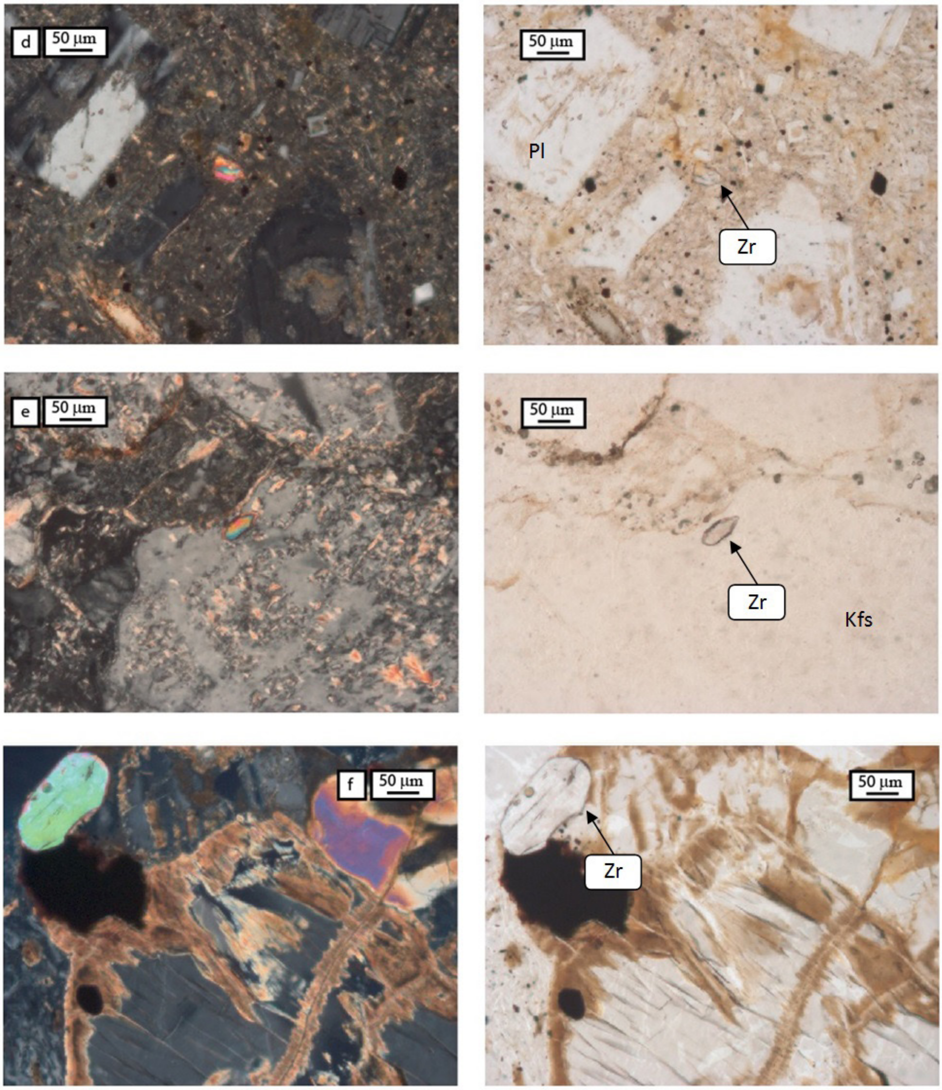

Figure 1d–f. (d) zircon grain within glassy matrix [Visegrad Mtns, N of Budapest, Hungary]; (e) elongated 50 µm zircon grain incorporated into rim of feldspar [mass flow deposit related to lavadome collapse; Collio Basin, Italy]; (f) large rounded grain, probably xenocrystic [dacitic lava, Tokai Mtns, Hungary]

A mound of volcanic rocks that forms lava flows onto the surface and amasses over a vent is called **lava dome** (Sigurdsson et al. 1999). In this emplacement type (thin sections from: Lassen Peak, California; North of Budapest, Hungary; Chao Coulee, N Chile) zircon usually occurs as grains enclosed within plagioclase (< 40 mm in size; Figure 2a, c) or in contact with plagioclase and biotite phenocrysts (> 40 mm in size; Figure 2b, d, respectively). Rare larger grains (> 80 mm) appear usually in contact with phenocrysts (Figure 2e — zircon texturally in

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contact with plagioclase). More rarely, they are visible within a matrix of feldspar crystals (Figure 2f). Generally, the zircon grains are comparable in size and abundance to those from lavas.

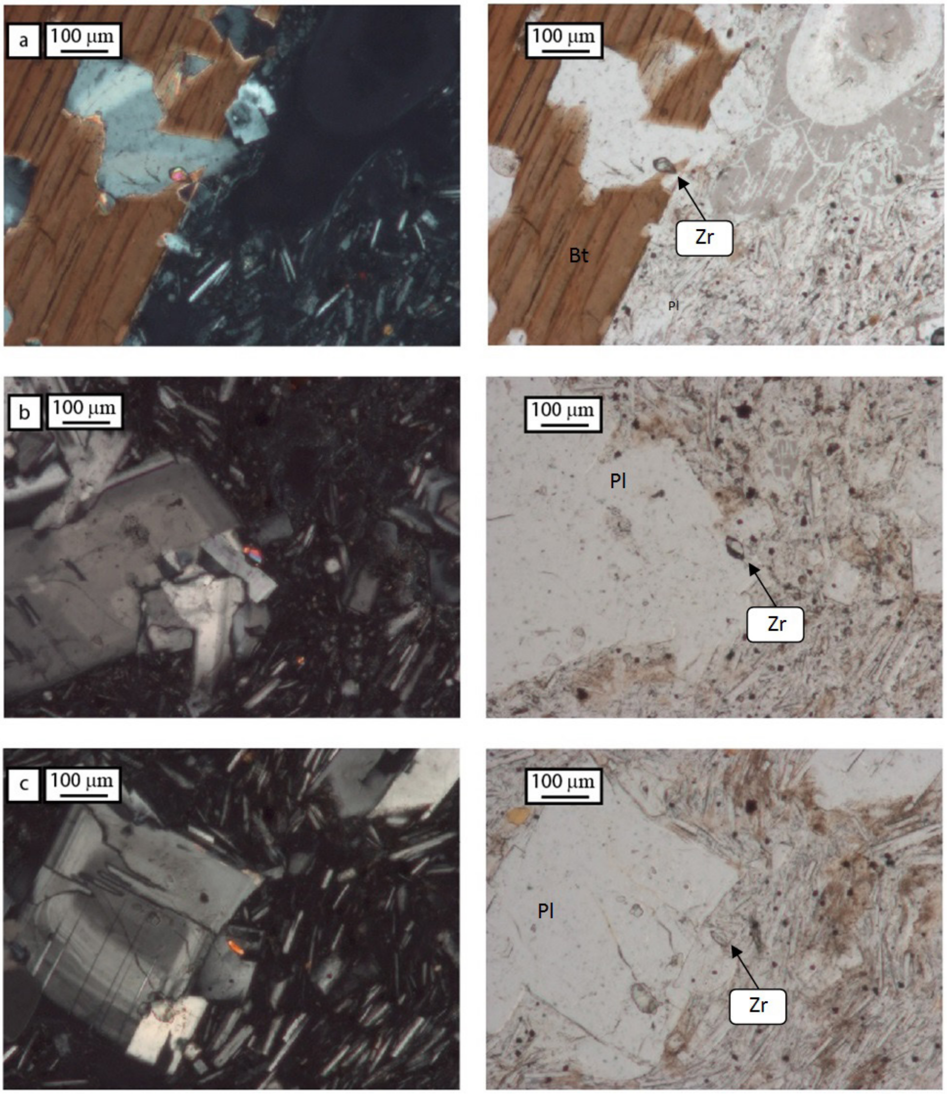

Figure 2a–c. Zircon grains in dacitic lavadome from: (a–e) North of Budapest, Hungary; (f) Chao Coulee, N Chile; crossed (left) and plane (right) polarized light; (a) hypidiomorphic zircon grain incorporated into plagioclase rim; (b) zircon accompanied by grains of plagioclase; note that zircon is not incorporated into phenocrysts but texturally in contact with plagioclase rims; (c) small elongated zircon grain in plagioclase;

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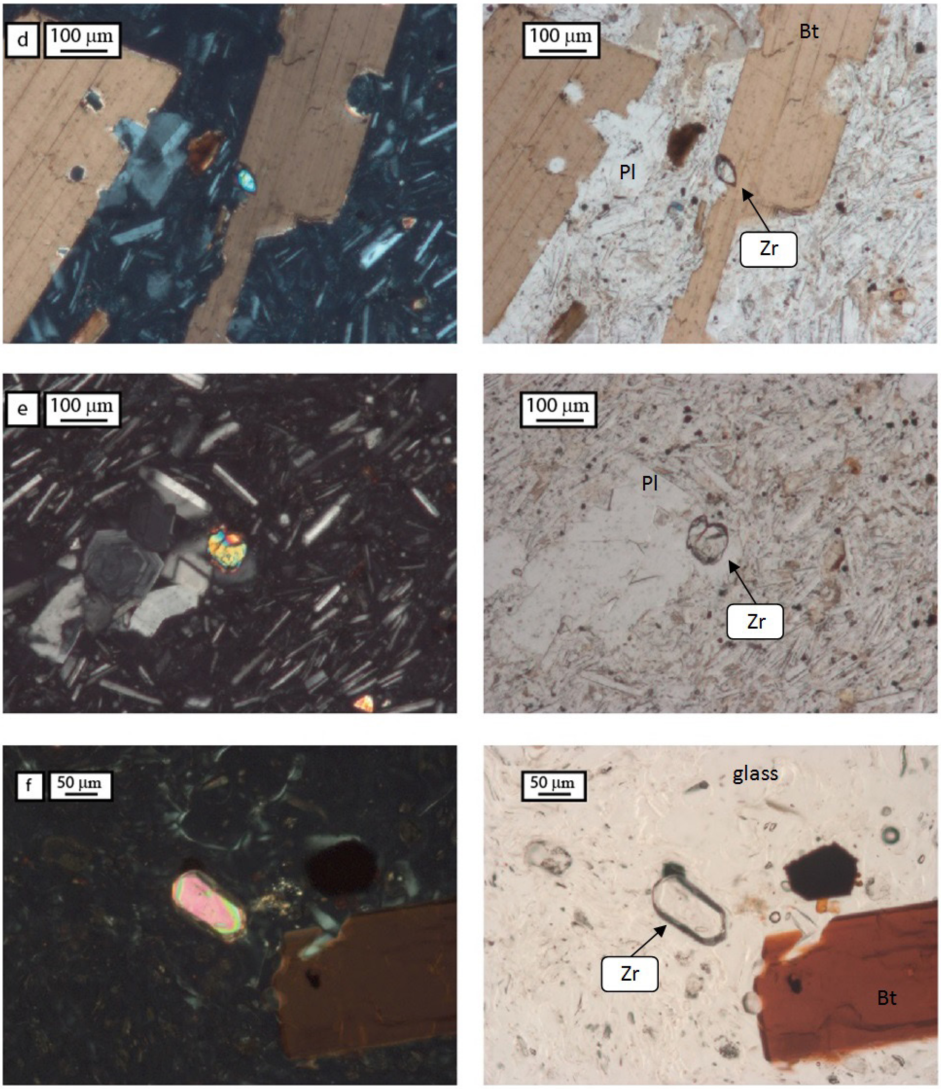

Figure 2d–f. (d) zircon incorporated in biotite rim; (e) zircon grain within glomerocryst of plagioclase, the size of zircon is similar to Pl grains; (f) big zircon grain within glassy matrix

Ignimbrites are pumice-rich pyroclastic flow deposits (composed of glass shards, pumice lapilli, crystals, rock fragments) formed by pyroclastic flows typically originating from large Plinian or caldera-forming eruptions. Ignimbrites may experience welding-compaction depending mainly on emplacement temperature and thickness of the cooling unit (Quane and Russell 2005). Furthermore, variation in texture within the deposits is most likely related to differing eruptive and emplacement temperatures and volatile content of the magma

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(Branneyet al. 2008), whereas variation in composition may reflect chemical zonation of the magma chamber prior to the eruption with the zonation being inversely reflected in the deposit (Bachmann and Bergantz 2008). However, ignimbrite zonation is not a rule and homogeneous deposits are also known (e.g. Bachmann et al. 2002).

In this study both welded and non-welded ignimbrites were investigated. Zircon was found very often in thin sections. It usually occurred in glass (or

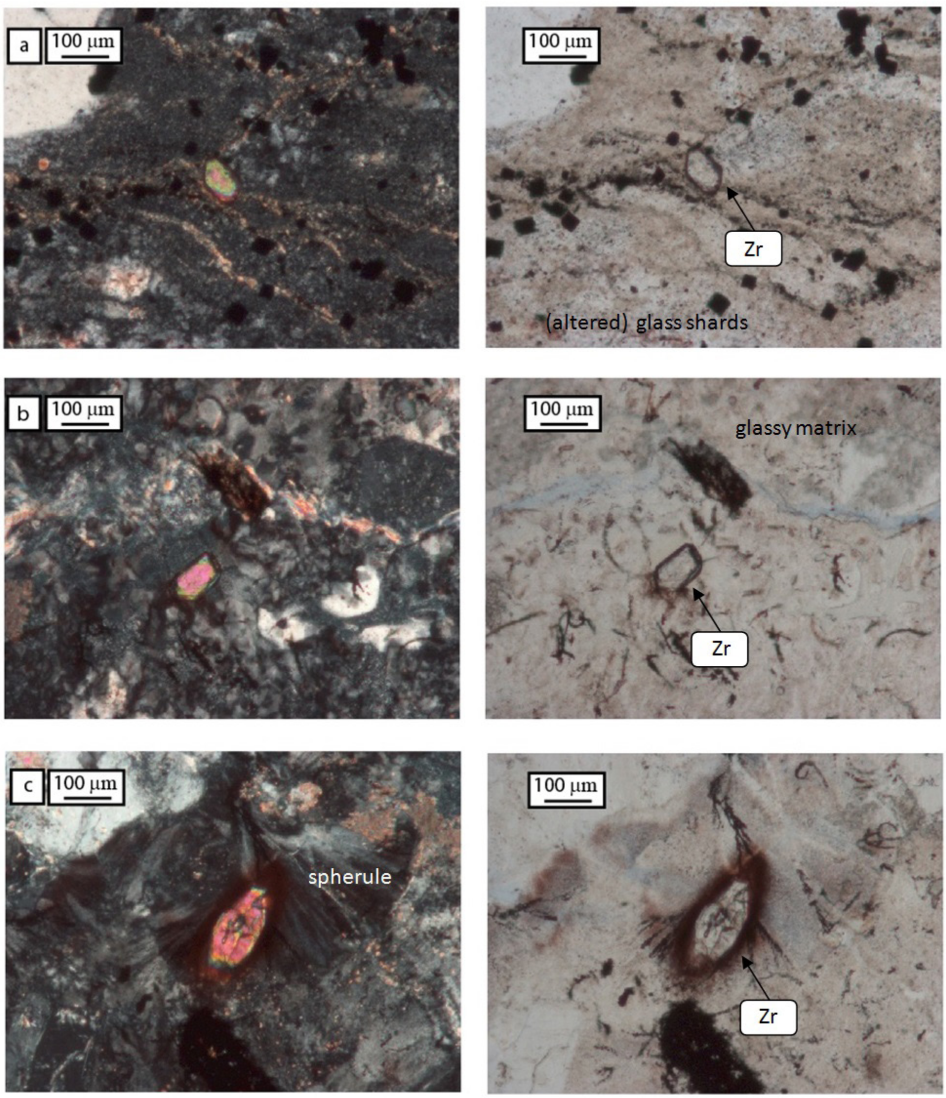

Figure 3a–c. Zircons in ignimbrites; cross (left) and plane (right) polarized light; (a) single zircon grain surrounded by (alterated) glass shards [welded ash-rich ignimbrite, St. Francis Mtn., Missouri]; (b) single zircon grain in glassy matrix; (c) zircon grain surrounded by late stage spherule;

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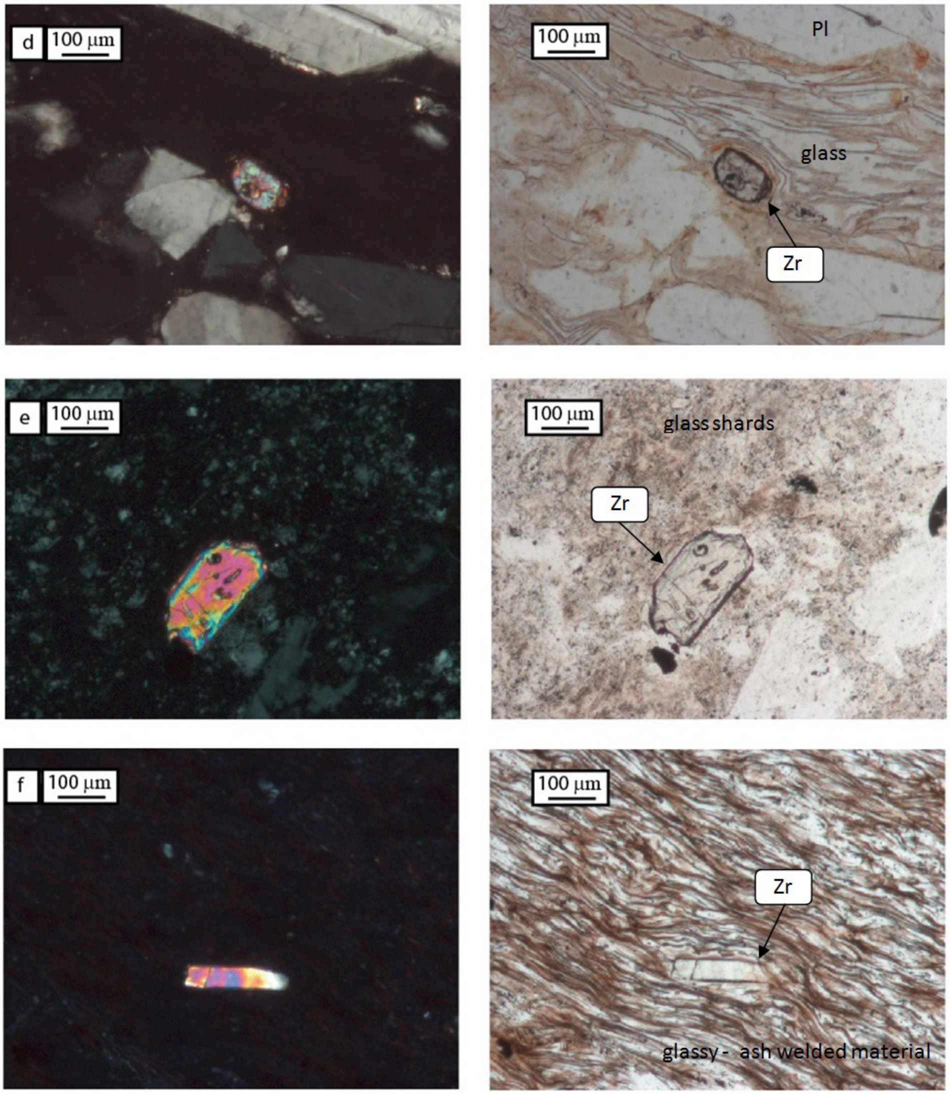

Figure 3d–f. (d) zircon surrounded by glass [b–d: crystal-rich spherulitic welded ignimbrite — Collio Basin, Italy]; (e) big (>100 μm) zircon surrounded by glass shards (now alterated); (f) elongated grain of zircon in glassy-ash material [e–f: welded post caldera ignimbrite, Valles Caldera, New Mexico]

ex-glass; Figure 3a–f) and only rarely was it enclosed or surrounded by other minerals. Zircon in ignimbrite is larger (up to 150 mm) than grains detected in lava (up to 60 mm). The grains appear either sub-rounded (Figure 3a–e) or elongated (Figure 3f).

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Discussion

Pitfalls of mineral separation and advantages of in situ work

Zircon in igneous rocks can originate from a variety of sources (e.g. Miller et al. 2007). It may grow in the magma chamber feeding the volcano (autocrystic grains), but it may also be derived from precursory magmatic stages (antecrystic grains). The latter can be recycled in the magma chamber together with older zircons entrained from the original melt source (inherited zircon) or incorporated from the surroundings (xenocrystic zircon). Zircon preserves information on chemical and chronological evolution of magma (e.g. Košler and Sylvester 2003), therefore, it is important to constrain at which stage of magma crystallization zircon formed. Such information is difficult to obtain if only separates of zircon are analysed, but it may be provided if zircon is analysed in thin sections. However, neither in situ nor separates method is without flaws. In fact, separates are more often used due to the high number of grains they provide. However, it is also possible that larger, probably antecrystic, grains are preferentially separated and analysed due to their size. Also, occurrence of the grains as inclusions in major light minerals, such as plagioclase and quartz, may make them difficult to separate, if they remain attached to their host during crushing and separation using panning or heavy liquids. Thus, small zircons observed as the main zircon phase in lavas and lava domes may be underrepresented in zircon separate and may not be analysed. On the other hand, separates are better to characterize zircon features such as shape and size of grains. While examining sections in this study, it was not always clear what the grain morphology was, since in thin sections morphology is dependent on the orientation of investigated crystals and the depth of the polishing.

Ideally, the most complete dataset should include petrological observations of the rock texture and chemical composition of all phases. In this study we show what information is obtained from petrological observations only. The studied thin sections show important differences in zircon appearance between different emplacement types including zircon position in relation to other minerals, its size and abundance.

Zircon textural position within lava and lava dome

Interpretation of our results and its general application strongly depends on how representative the described samples are. As discussed above, crystallization in magma chambers may be affected by numerous factors and crystallization of zircon may take place at different intervals of magma differentiation. However, the major factor

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controlling zircon appearance is Zr content in magma and this usually decreases with increasing Si content, in response to early zircon saturation and fractionation in more evolved magmas (Figure 4). This general trend is observed for a range of Variscan volcanic rocks (GEOROC database) and the volcanic rocks analysed in this study also fit in this trend (Figure 4). The implication is that our observations were done on relatively typical samples of volcanic rocks in terms of Zr content and, therefore, the timing of zircon saturation, and it is possible that they may be extended for other volcanic rocks with similar Si and Zr concentration.

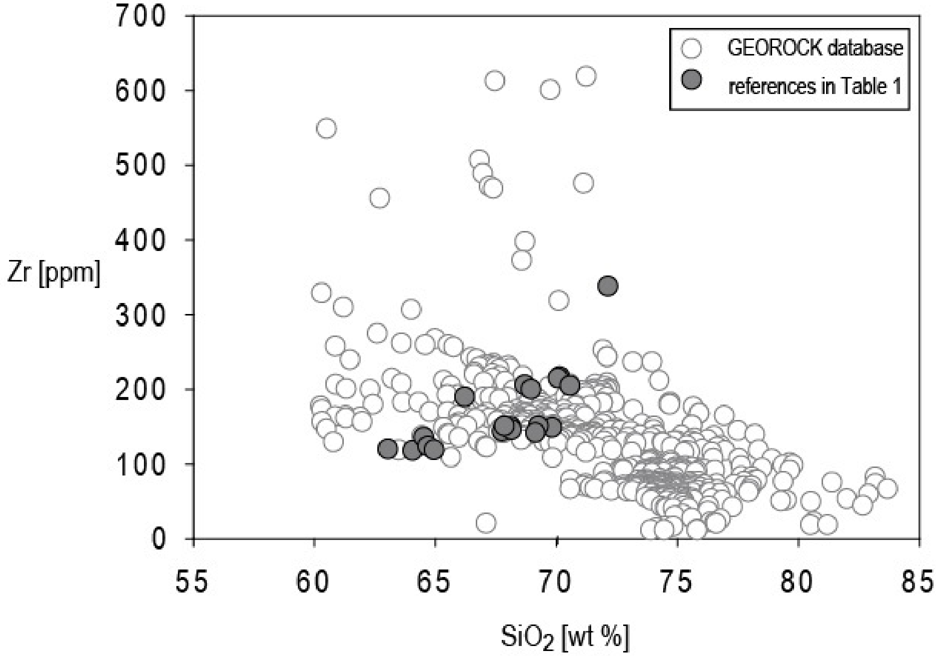

Figure 4. SiO_2 (wt%) vs Zr concentration (ppm) in different Variscan volcanics (trachyte, trachydacite, trachyandesite, rhyolite, rhyodacite, dacite, andesite — open symbol) and data available for location listed in Table 1 (solid symbol). Data from Variscan volcanic were compiled from the GEOROC database (http://georoc.mpch-mainz.gwdg.de/georoc/), data for locations analysed in this study does not represent exactly the same sample from which the thin section was taken, only the products of the same volcanic eruption

Zircon found in lavas and lava domes is usually small and included in the rims of major minerals forming early phenocrysts (Figures 1a, b, c, e, and 2a, c, d, respectively to the lava and lava dome). Such a position suggests that the zircon formation took place relatively late with respect to the hosting phenocryst. Nucleation and initial growth of such zircon might preferentially take place on the edges of preexisting phenocrysts. It is also possible that zircon crystallizes in melt pockets surrounding the phenocrysts which will be locally saturated in Zr (e.g. Hoskin and Schaltegger 2003). As such, zircon can be interpreted as autocrysts (Miller et al. 2007) that crystallized during the last stage of magma evo-

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lution and was not carried in from previous stages (antecrysts). It is important to identify such grains as they would provide an age close to the volcanic eruption (the formation of lava or lava dome), whereas if zircon grains are recycled through several magma chambers they provide a more general age of magmatic activity in the area. Identification of such late grains may be particularly useful for dating young volcanics by U-series method. It was shown in many studies that such volcanics contain zircon with the range of ages of several hundred thousand years (cf. Storm et al. 2012 where zircon crystals record continuity of growth through ~ 34 ka and discontinuous growth ~ 90 ka; Tarawera volcano, New Zealand). It would be interesting to see if there is a correlation between zircon position in the rock texture and the obtained age. In terms of zircon chemistry, the grains included in other phases may grow for a shorter period of time and record only limited chemical changes in the surrounding magma reflecting local saturation in zircon around different phases (Zr is incompatible in major phases and it may accumulate in boundary layers around these phases resulting in zircon saturation close within the layers, but not in the surrounding magma, (Hoskin and Schaltegger 2003 and references therein). For example, zircon in Figure 1a may represent a larger antecrystic grain incorporated in the feldspar phenocryst and a smaller autocrystic grain in the glass or different levels of Zr saturation around growing phenocrysts and in the melt leading to preferential crystallization of zircon next to the mineral. Interpretation of chemistry of those two grains will only make sense when tied to their textural position in the rock. Knowing the exact textural relations we can go further and apply combined isotope and trace element analyses of zircon. The recent study by Pietranik et al. (2013) of magmatic and inherited zircon from ryolitic rocks showed that it is crucial to link both isotopic and trace elements measurements.

Zircon textural position within ignimbrite

Interestingly, zircon appearance in ignimbrites is different to that in lavas and lava domes. Zircon is larger, usually contained in the (ex-)glassy matrix and is also more abundant. Ignimbrites might have higher amount of isolated zircon, compared to lava, possibly because they get isolated during the fragmentation in the conduit (e.g. Best and Christiansen 1997), but that does not explain their larger size and abundance. The larger and more abundant zircon may reflect differences in magma chemistry within magma chamber as well as between localities we analysed. However, all of the localities analysed in this study had similar Zr concentration and ignimbrites had similar composition compared to that of lavas and lava domes (Figure 4).

Most magmatic bodies are reported to be heterogeneous, implying that complex mixing and unmixing processes occur while the magmas interact with each other and the surrounding crust (Huber et al. 2009). Stratification within an upper crustal magma reservoir may develop due to effective crystal-melt

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separation with independent and continuous evolution of the layers after separation (Schmitt 2002). Rhyolitic magma chambers often erupt to form deposits with a wide range of chemistry which reflect zoning in the magma chamber prior to eruption, e.g. compositionally zoned 2200 km^3 of Huckleberry Ridge Tuff that erupted from the Yellowstone volcanic field (Christiansen 1979, 2001) or explosive heterogeneous eruptions in Italy (Mollo and Masotta 2014). This compositional zonation within large silicic deposits might involve a number of different compositional "batches" either injected into, differentiated in situ within, or associated with a larger, dominant magma chamber (Cooper et al. 2012). Interestingly, some magma bodies such as granitic plutons and crystal-rich, dacitic ignimbrites display a remarkable homogeneity in temperature, crystallinity and major-element composition at the hand sample or at the whole rock scale (Bachmann et al. 2002). For instance, the Fish Canyon Tuff (dacitic ignimbrite) is notorious for its thermal and chemical homogeneity at the whole-rock scale. But in contrast, the system is very heterogeneous at the crystal scale, where chemically zoned minerals attest to an open system behaviour (Bachmann et al. 2002).

Therefore, these processes causing homogeneity or heterogeneity of magma and also of later erupted deposits play an important role in developing different chemical and structural characteristics of different phases. The absence or appearance of zircon in different samples is complex and may be related to all of the mentioned magmatic processes.

One feature typical for ignimbrites is that they are derived from magma chambers saturated in volatiles. Zircon textures and composition are refractory records of magmatic volatile evolution (Erdmann et al. 2013). Zircon crystallized from volatile-rich melt has typically larger size and larger length-to-width ratios, which consequently may point towards an increased crystallization rate or a larger crystallization interval (Corfu et al. 2003). Zircon crystallization at volatile-undersaturated versus volatile-saturated conditions is reflected in different zircon morphologies, zoning patterns, and composition (Erdmann et al. 2013). Features such as: large crystal size, large length-to-width ratio (~1–5), weak and wide-scale oscillatory zoning of zircon may indicate a longer crystallization interval, an increased crystallization rate, and/or crystallization from a more evolved, volatile-rich melt (cf. Corfu et al. 2003).

Another option for explaining occurrence of larger zircon within ignimbrite, compared to that from lava and lava dome, is that it is somehow concentrated during pyroclastic flow, probably due to the flow-induced density segregation. Density segregation of crystals from the pyroclastic density may result in detectable variations in the whole-rock chemistry. Some crystal segregation layering may be a reflection of this segregation (Christiansen 2001). Awareness of this process is crucial while sampling material for analyses.

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Small zircon grains included in other minerals, similar to those observed in lavas and lava domes, were not found in the analysed sections of ignimbrite. If the smaller grains representing the last stage of magma evolution are truly lost during deposition of ignimbrites, then dating and analyzing zircons from ignimbrites may not provide information on the latest magmatic episode that led to the eruption.

Conclusions

Research on zircon should be carried out using integrated approach of both thin sections and separates. Zircon characteristics (shape, size, associated minerals), including those observed in thin sections, should be taken into account when making a decision which zircon grains should be chosen for further analysis. This stage of research should be also supported by imaging (CL, BSE) of internal structures to choose the right place for further measurements. The chemical composition of zircon and its age can vary depending on where it occurs texturally. Smaller and elongated zircons from lavas and lava domes are often incorporated in the rims of major phenocrysts. They probably represent crystallization in the lava itself and date this last stage of magma evolution. However, their chemistry may be affected by crystallization within boundary layer of different minerals compared to grains, which grow in the melt and possibly record more comprehensive history of magma evolution. On the other hand, larger grains incorporated within glomerocrysts or included in the main rock forming minerals may represent earlier stages of magma crystallization (antecrysts). In contrast to lava, ignimbrites contain predominately larger, isolated zircon and are characterized by a puzzling lack of small grains included in other phases. The reason for this difference needs further investigation, but may reflect complex magmatic processes affecting different magma chambers, including different volatile concentrations or accumulation of larger grains during flow-induced density segregation. Whatever the reason for the occurrence of larger grains in ignimbrites, such grains may be preferentially analysed from separates, because they are easier to pick and mount, also they may be more easily separated than smaller grains enclosed by other minerals.

Acknowledgements

The present study was supported in parts by a scholarship to one of the authors (E.S.) provided by the German Academic Exchange Service (DAAD). The authors are

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grateful to two reviewers and the editor of *Geoscience Notes*. Inspiration for work and critical comments on the earlier version of the manuscript are greatly appreciated.

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