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講演要旨 - Abstract

噴火準備過程の岩石学的解析に関する国際ワークショップ（PAPEMP）発表概要*

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Akihiko Tomiya (2017) The International Workshop on Petrological Analysis of Pre-eruptive Magma Processes (PAPEMP) abstracts. *Bull. Geol. Surv. Japan*, vol.68 (4), p.177–182.

噴火準備過程（マグマ蓄積や噴火トリガー等）に関する岩石学的研究は，微小領域分析手法の発展に伴って近年急速に進みつつある．こうして得られた最新の知見の共有と，関連研究者間の相互交流等を目的とし，国際ワークショップ“International Workshop on Petrological Analysis of Pre-eruptive Magma Processes (PAPEMP)”［噴火準備過程の岩石学的解析に関する国際ワークショップ］を，活断層・火山研究部門主催で行った．ワークショップは，所内 34 名・所外 42 名・合計 76 名を集め，活発な議論が行われた．以下では，国内外から招聘した 5 名の招待基調講演（30 分），および総合討論の要旨を報告する．それ以外のショートトーク（5 分）・ポスター発表については，タイトルと著者名のみを挙げる．なお，発表は全て英語で行われたが，利便性を考え，各発表の英文タイトルに和訳を付けるとともに，国内招待講演者の要旨の一部は日本語で掲載する．

Keywords: magma process, magma system, time scale, pre-eruptive magma condition, magma decompression

セッション 1：Deep magma processes（深部マグマプロセス）

［招待基調講演］Multiple lines of evidence for the dominance of antecrysts in arc eruptive products, and a study of crystal mushes from the Mexican Volcanic Belt（島弧噴出物がアンテクリストに富むといういくつかの証拠 – メキシコ火山帯の結晶マッシュの研究）

Georg F. Zellmer[†]

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Volcanic hazard mitigation at subduction zones critically depends on knowledge of magma generation and ascent processes and timescales. Multiple lines of evidence are presented that point to crystal uptake as the principal process by which arc melts acquire their crystal cargo: (i) variable ^{234}U-^{238}U disequilibria in mineral separates; (ii) hydrous mineral rims with amorphous alteration textures; and (iii) two-pyroxene pseudo-decompression paths; cf. Zellmer *et al.* (2014a, *Geol. Soc. London Spec. Pub*., vol. 385, p. 161–184; 2014b, *Geol. Soc. London Spec. Pub*., vol. 385, p. 185–208) and Zellmer *et al.* (2015, *Geol. Soc. London Spec. Pub*., vol. 410, p. 219–236). These observations point to a scarcity of true phenocrysts in arc magmas, and thus indicate rapid decompression of aphyric melts that take up their crystal cargo during ascent. The crystal cargo may thus be used to gain insights into present-day intrusive magmatic compositions and processes. For example, the Trans-Mexican Volcanic Belt (TMVB) is known for the chemical diversity in its erupted products. We have analysed the mineral chemistry of 30 geochemically well-characterized mafic eruptives from Isla Maria at the western end of the arc to Palma Sola in the east. A combination of plagioclase antecryst chemistry and MELTS thermodynamic modelling of H_2O-saturated isobaric fractional crystallization was employed to develop a pressure sensor aimed at determining the ponding depths of the co-genetic magmas from which the erupted plagioclase crystal assemblage originates. We show that the depth of magma-mush reservoirs increase eastwards along the TMVB. Magma-mush ponding depth variations fully explain the observed westward increase of average surface heat flux along the TMVB, supporting a new model of mafic arc magma ascent, where rapidly rising, initially aphyric melts pick up their antecrystic crystal cargo from a restricted crustal depth range, in which small unerupted batches of previously risen co-genetic magmas typically stall and solidify. We suggest that magma ponding is triggered by degassing-induced crystallization during magma ascent, and

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that the pressure sensor can also be regarded as a degassing sensor, with more hydrous melts beginning to degas at greater depths. Modelled initial magma H_2O contents at the Moho range from ～ 4 to ～ 9 wt%. This implies that globally, mafic arc magmas may be used to constrain the depths of degassing and mush zone formation, as well as the amount of H_2O in the primary melts. Cf. Zellmer *et al*. (2016, *Amer. Mineral*., vol. 101, p. 2405-2422).

Keywords: antecryst, plagioclase, magma mush, ponding depth, Trans-Mexican Volcanic Belt

Snapshot of hydrous arc magma differentiation at deep crust: constraints from melt inclusion in amphibole-bearing gabbroic xenoliths (Ichinomegata maar, Northeast Japan)（東北日本・一ノ目潟マールに産する角閃石斑れい岩中のメルト包有物から制約する深部地殻領域における含水島弧マグマの分化過程）

柳田泰宏[†]

（[†]東北大学）

Thermodynamic modeling of hydrous melts: Density, seismic velocity and olivine-hydrous basalt equilibrium（含水マグマの熱力学数値モデル：密度，地震波速度と，カンラン石ー含水玄武岩間の平衡）

上木賢太[†]

（[†]東京大学）

セッション 2：Evolution of magmatic systems（マグマ供給系の進化）

[招待基調講演] Temporal signals and magmatic histories of mushy silicic magma systems revealed by zircon chronochemistry: implications for catastrophic caldera-forming eruptions（ジルコン年代から見たマッシュ状珪長質マグマシステムの時間的シグナルとマグマ履歴および破局的カルデラ形成噴火）

Shanaka de Silva[†]

（[†]CEOAS, Oregon State University, USA）

Several different pre-eruptive timescales need to be considered that characterize different stages of silicic magma system: 1) Formation of parental "mush" and associated plutonic complex (10^5 – 10^6 years); 2) Extraction of crystal-poor rhyolite (10^3 – 10^2 years); and 3) Eruption timescales that describe the transition from storage to eruption (years, months, days). Three case studies will be presented that provide valuable insight into the magmatic history and intrusive to extrusive ratios of large silicic systems.

At the 3.64 Ma Pastos Grandes caldera in SW Bolivia, Kaiser *et al*. (2017, *Earth Planet. Sci. Lett*., vol. 457, p. 73–86) show that zircon crystallized continuously for over at least 1.1 Ma while magma accumulated, erupted and eventually solidified. Such longevity is also evidenced at five Pleistocene domes in the same volcanic region. Tierney *et al*. (2016, Geology, vol. 44, p. 683–686) found essentially continuous zircon crystallization for 3.5 Ma prior to eruption. This requires time-integrated recharge rates and extremely high intrusive to extrusive ratios of 75: 1. A similar conclusion is drawn from the U–Th in zircon systematics at Unzen volcano, Shimabara peninsula in Kyushu, Japan. Murphy *et al*. (in prep) show that while eruptive activity at Unzen is episodic over its 500 ka history, zircon crystallization was continuous, supporting the disconnect between eruptive and intrusive fluxes.

The longevity recorded in these magmatic systems supports the predictions of theoretical models that emphasize the thermomechanics of calderas (Jellinek and DePaolo, 2003, *Bull. Volcanol*., vol. 65, p. 363–381; Gregg *et al*., 2012, *Jour. Volcanol. Geotherm. Res*., vol. 241–242, p. 1–12). A thermomechanical division of calderas into smaller "brittle" systems that are triggered internally (bottom-up) while larger "ductile" systems are triggered externally (top-down) is proposed.

Keywords: pre-eruptive timescale, zircon, U–Th dating, large silicic magma reservoir, thermomechanical feedback

Relationship between temporal changes of magma-discharge rate and magmatic compositions（マグマ噴出率の時間変化とマグマ組成変化の関係）

山元孝広[†]

（[†]活断層・火山研究部門）

Long-term evolution of the andesite-dacite magma system of Ruapehu volcano, New Zealand（ルアペフ火山の安山岩 - デイサイトマグマ供給系の長期的進化）

Chris Conway [†]

（[†]国立科学博物館）

Evolution of magma plumbing system of Aso volcano, SE Japan（阿蘇火山のマグマ供給系の進化）

金子克哉[†]

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Age, petrology and chemistry of volcanic products from Omine volcano, a precursory event of Aso-4 eruption（阿蘇 -4 前駆噴火として特徴づけられる大峰火山噴出物の年代，岩石と化学組成）

長谷中利昭[†]

（[†]熊本大学）

Collapse calderas and their magma chambers（陥没カルデラとそのマグマたまり）

下司信夫[†]

（[†]活断層・火山研究部門）

セッション 3：マグマプロセスのタイムスケール（Timescales of magma processes）

[招待基調講演] Timescales of magma injection and triggering processes（マグマ注入と噴火トリガー過程の時間スケール）

Fidel Costa [†]

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Openly degassing volcanoes are among the most active on earth (e.g., Llaima, Etna, Stromboli, Mayon, Arenal), producing mildly explosive eruptions (VEI 1–3) every few months or years. During quiescence they deliver thousands of tones of gas per day to the atmosphere. Many of these volcanoes erupt similar bulk magma composition for decades and their deposits tend to be crystal-rich. Petrological and geochemical studies show that crystals are strongly zoned (e.g. Fe/Mg in olivine and pyroxenes), which can be interpreted as evidence for shallow crystallization and partial dissolution by intrusion of a volatile-rich primitive melt in a crystal-rich shallow reservoir/conduit. However, the time scales between the first intrusion and eruption can vary significantly: at Stromboli and Etna intrusion times are days to months, whereas in Mayon or Llaima they are months and years. There seems to be a correlation between volcanoes with longer repose periods showing longer times since the first intrusions and eruption. The mass and pressure balance of open vent volcanoes suggests that magma intrusions could be induced by pressure instabilities driven by the gradual loss of mass occurring during quiescent degassing. We propose that during quiescence the shallow magma cools, degasses and crystallizes. This leads to an increase in viscosity and density of the resident magma, which becomes stiffer with time. Thus, volcanoes with longer repose times may need more magma replenishment before eruption, either through multiple intrusion episodes or larger intrusion volumes. The eruption frequencies or repose times of openly degassing volcanoes are the combined result of intrusion times (which depend on degassing fluxes) and the crystallization kinetics which depend on initial volatile contents and on heat diffusivity.

Keywords: pre-eruptive timescale, degassing, magma viscosity, repose period

Petrologic features of the magma reservoir around beginning of the Goshikidake activity, Zao volcano（蔵王火山五色岳形成開始前後の噴出物のマグマ溜まり）

西　勇樹[†]

（[†]山形大学）

Pre-eruptive process and timescale of basaltic eruption: A case study of the 2.5 ka subplinian eruption at Fuji volcano（玄武岩質噴火の噴火準備過程と時間スケール：富士山の 2.5 ka の準プリニー式噴火の例）

菅野拓矢[†]

（[†]静岡大学）

Pre-eruptive process and timescale of the 60 ka caldera-forming eruption at Hakone volcano, Japan: A preliminary results（箱根火山の 60 ka カルデラ形成噴火の噴火準備過程と時間スケール：予察的結果）

石橋秀巳†

（†静岡大学）

セッション 4：Pre-eruptive conditions of magma reservoirs（噴火直前のマグマ供給系）

[招待基調講演] Pre-eruptive structure of the magma system of a caldera-forming eruption: Case studies for Shikotsu and Kutcharo volcanoes, Japan（カルデラ形成噴火前のマグマ系の構造：支笏および屈斜路火山の事例研究）

中川光弘†

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巨大噴火におけるマグマ系の形成過程と噴火過程について，複数の事例研究を積み重ね，それらの共通点と相違点を明確にすることが重要である．そのような観点から，42 kaの支笏火山と120 kaの屈斜路火山でのカルデラ形成噴火について検討した．2つの噴火では，主要なマグマは斑晶に乏しい（CPタイプ）流紋岩で，それに加えて少量のデイサイト～安山岩質のマフィックマグマが認められる．支笏ではそれらに加えて，噴火活動終盤に斑晶に富む（CRタイプ）デイサイト～安山岩質マグマも共存した．鉱物組成および全岩化学組成を検討すると，CPタイプ珪長質マグマは珪長質2端成分マグマの混合の産物であること，また鉱物の累帯構造から，その混合は噴火の数百年前から起こっていることが明らかになった．そして2つの噴火では，この混合珪長質マグマに，噴火前の数年～ 10年程度の間，マフィックマグマの貫入が噴火直前まで続いたことが明らかになった．大規模な珪長質マグマは地殻物質の部分溶融によって生じると考えられ，その場合，初期の状態では溶融で生じた結晶とメルトの混合物（マッシュ）に，地殻物質の不均質を反映した多様性が存在する可能性が高い．このことから２つのカルデラ噴火では，まず不均質マッシュから多様な珪長質メルトが集積・混合して大型のCPタイプメルト溜まりを形成し，そこにマフィックマグマが繰り返し貫入して巨大噴火に至ったと考えられる．このプロセスは珪長質巨大噴火で共通する可能性が高い．一方，支笏で認められるCRタイプマグマは，全岩組成や同位体比組成を考えると，CPタイプメルトが分離した残存マッシュの可能性が高い．屈斜路の場合には，CPメルトの噴出だけで噴火が終了したが，支笏の場合には最後にはマッシュの結晶主体の部分もCRタイプマグマとして噴出したと考えられる．このマグマ噴火過程の違いは，両者のカルデラ陥没深度の差に反映されていると考えられる．

Keywords: caldera-forming eruption, silicic magma,phenocryst content, magma mixing, mushy magma chamber

Melt inclusion constraints on pre-eruptive storage, evolution, and eruption of catastrophic caldera-forming（CCF）magma systems（メルト包有物から見たカルデラ形成マグマシステム（CCF）の噴火前マグマ蓄積・進化そして破局的噴火）

Shanaka de Silva†

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Large caldera system and small caldera system（大カルデラシステムと小カルデラシステム）

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Conditions of the magma chamber and eruptive process of Ofunato scoria in Ofunato stage, Miyakejima volcano（三宅島火山大船戸期のマグマ溜まり条件と大船戸スコリアの噴出過程）[ポスターのみ]

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セッション 5：Magma ascent and eruption（浅部マグマ上昇～噴火過程）

[招待基調講演] Shallow level bifurcation of eruption styles: petrographical and experimental constraints（火道浅部での噴火様式の分岐：岩石記載と実験からの制約）

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Once magmatic unrest starts, we presume a wide variety of outcomes. If we understand the mechanisms behind the branching of events, then we can utilize the results of geophysical monitoring for prediction and forecast of eruption styles effectively. A growing consensus formed in recent years is that explosive–effusive transitions often occur in shallow volcanic conduits, as evidenced by the hybrid explosive–effusive activities in which explosive and effusive eruptions occurred simultaneously (e.g. Castro *et al*., 2014, *Earth Planet. Sci. Lett*., vol. 405, p. 52–61). In this sense, the "pre-eruptive" period continues until the last minute before we see magmas in the Earth's surface. Such transitions in eruption style have been hardly distinguishable by using only microlite petrography. As reported by Mujin and Nakamura (2014, *Geology*, vol. 42, p. 611–614) for the 2011 Shinmoedake activity, eruption styles may be discriminated by assemblages of nanolites, i.e., groundmass minerals exhibiting a kink (break) in their CSD slopes at a few micrometers to hundreds of nanometers. The nanolite and ultrananolite are considered to have crystallized in a nearly closed, non-steady state system, because the CSD analyses in this scale are made in very small areas of dehydrated viscous melts with small turbulence within a short duration. The increase in crystal number density in a sub-micron size range should thus have been driven by accelerated increase in effective undercooling owing to extensive degassing in a shallow conduit. We additionally discovered a gap from ～ 100 to 30 nm in the size distribution of pyroxene in a dense juvenile fragment of the 2011 Vulcanian explosion, and defined the finer-sized crystals (～30–20 nm) as "ultrananolites." Besides, Fe–Ti oxide ultrananolite ~1–2 nm in diameter was recognized with a ～10 nm gap from titanomagnetite nanolites. These nucleation hiatuses in the late stage of groundmass crystallization are considered to have been caused by increased interfacial energy and decreased melt diffusivity in a dehydrated melt. Experimental determination of crystallization conditions of the nanolite and ultrananolite will lead to constrain bifurcation conditions of eruption styles such as minimum magma ascent rates for the sub-Plinian eruptions and maximum magma residence time in a shallow conduit for the vulcanian explosions in the Shinmoedake activity.

Keywords: explosive–effusive transition, groundmass crystallization, nanolite, ultrananolite, degassing

Evolution of magma ascent during the climactic phase of 2011 eruption of Shinmoe-dake, Japan, in view of groundmass microlite textures（石基マイクロライト組織から見た 2011 年新燃岳噴火最盛期におけるマグマ上昇過程の進化）

鈴木由希[†]

([†] 早稲田大学)

On progress and rate of the peritectic reaction of olivine to pyroxene, with implications for the growth rates of microlites at the onset of eruption（かんらん石 - 輝石の包晶反応の進行と速度：噴火開始時のマイクロライト成長速度への影響）

Georg F. Zellmer[†]

([†] IAE, Massey University, New Zealand)

Magma ascent process of the 2000 eruption at Miyakejima volcano deduced from melt inclusion analyses（メルト包有物からみた三宅島火山 2000 年噴火のマグマ上昇過程）

斎藤元治[†]

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Temporal change in microstructure of volcanic ashes from Aso Nakadake 2014–2015 eruption（阿蘇中岳 2014–2015 年噴火で噴出した火山灰の微細組織の時間変化）[ポスターのみ]

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General discussions（総合討論）

Summary of the general discussions（総合討論の概要）

Shanaka de Silva[†]（moderator）

（[†]CEOAS, Oregon State University, USA）

1) Deep magma processes — what do we think we know?
- Crystal cargo from deep offers an opportunity to probe plutonic system (Zellmer)
- Crystal extract is within melt of much more evolved composition (Yanagida)
- Water content of melts controls seismic velocities (Ueki)

2) Evolution of magma systems — what do we think we know?
- Variable time scales for different parts of the system (de Silva)
- Variable eruptive fluxes at different volcanoes (Yamamoto)
- Progressive magma fluxes can erode fertility (Conway)
- Deep melting can produce silicic magmas (Kaneko)
- Omine volcano might be a precursor and trigger to Aso 4 (Hasenaka)
- Mixing and unmixing of magmas during Aira caldera evolution (Geshi)

3) Timescales — what do we think we know?
- Different time scales for different stages of the system (de Silva)
- Cause and effect? — temporal relationships don't always mean a causations (Costa)
- Need to look at processes leading to eruption rather than focus on a trigger (Costa)
- Degrees of mixed magma development control eruptive style (Nishi)

4) Pre-eruptive magma conditions — what do we think we know?
- Recharge, hybridization and depth of extraction explains the difference between Shikotsu and Kutcharo (Nakagawa)
- Melt inclusion data - shallow storage and evolution of CCF magma systems; may control eruptive transition from explosive to effusive (Grocke/de Silva)
- Petrological forensics using experimental and MELTS approach allows geophysical parameters of magma chambers to be developed (Miyagi)

5) Magma Ascent and Eruption — what do we think we know?
- Discovery of nanolites and ultrananolites requires us to think about what CSD’s are telling us about conduit processes — volcanic glass may not be glass (Nakamura)
- Decompression experiments are critical to resolving this (Nakamura)
- Same magma may follow divergent decompression paths (Suzuki)

6) What do we know that we don't know?
- What controls the variable histories of similar volcanoes?
- Time scales
  - Arrhenius relationship: Diffusion coefficients, Temperature
  - Nature of recharge — continuous vs step-wise recharge
- What do we mean by “trigger” ?
  - What are the triggers?
  - How do we know what is important? Recharge as a universal trigger?
- CSD’s, nucleation/growth
  - Decompression rate recorded in microlites
  - Where divergence of decompression occurs

Keywords: magma process, magma system, time scale, pre-eruptive magma condition, magma decompression

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