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研究課題名（和文）Development and application of new methods for calculating magma mixing timescales

研究課題名（英文）Development and application of new methods for calculating magma mixing timescales

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研究成果の概要（和文）：三宅島火山の最近の噴火による溶岩とテフラ中の結晶の化学組成分析を実施した。結晶から得られる時間スケールの制約は、西暦 1874 年の噴火の 1 ～ 5 日前と、西暦 2000 年の噴火の 12 ～ 25 日前に、マグマがマグマだまりから噴火口まで急速に移動したことを示す。 これらの制約は、2 つの噴火前の対応する地震活動の増加に関する報告とよく一致しており、噴出物中の結晶を分析することで噴火前の警告および避難の期間に関する貴重な情報が得られることを示す。

研究成果の学術的意義や社会的意義
将来の火山災害から社会を守るためには、マグマの移動から噴火までの潜在的な期間を知る必要があります。この研究の結果は、三宅島では山腹火口の溶岩噴火は、火山活動開始から数日で発生する可能性があるが、山頂噴火の前には数週間にわたる前兆現象が続く可能性があることを示している。 この研究は、危機管理者に対して、火山噴火に備る際必要な火山活動の時間スケールについての情報を提供するために、マグマ中の結晶の分析が役立つ可能性を示しています。

研究成果の概要（英文）：Chemical data was collected for volcanic crystals in lava and tephra from recent eruptions at Miyakejima volcano, Japan. Time scale constraints from the crystals indicate that magma moved rapidly from its source to the eruption vent over a period of 1-5 days prior to the eruption in 1874 AD, and 12-25 days prior to the eruption in 2000 AD. These constraints closely match reports of corresponding increases in seismicity before the two eruptions, and indicate that volcanic crystals provide valuable information regarding the warning and evacuation time periods before eruptions.

研究分野： Volcanology

キーワード： magma mixing　eruption time scales　volcanic hazards　diffusion chronometry

１．研究開始当初の背景

One of the primary objectives of geoscience research is to improve our ability to recognize the warning signs for volcanic eruptions. Numerous studies have shown that magma mixing is a typical process that commonly occurs immediately prior to eruptions at active arc volcanoes in Japan. The occurrence of magma mixing as an eruption precursor has two major consequences. Firstly, the introduction of new magma induces changes to seismicity, ground deformation and gas chemistry that can be recorded by monitoring equipment. Secondly, the hybridization of two magmas results in chemical zonation of crystals derived from each magma type. Comparing the records provided by monitoring and petrology is necessary to advance our understanding of the types and time scales of processes that trigger volcanic eruptions.

A simplified scenario of magma mixing and the impacts on crystal zonation is outlined in Figure 1. In panels A and B, the changes over time to the zonation of a crystal derived from a relatively Mg-rich magma that mixed with a Fe-rich magma are shown. At t1, prior to mixing, the crystal is in equilibrium with its host magma. Immediately after magma mixing at t2, the crystal grows a rim that reflects the composition of the hybridized magma. The boundary between the core and rim of this crystal is initially sharp (lower B), but becomes diffuse as chemical re-equilibration between the adjacent zones occurs at magmatic temperatures (upper B). Diffusion ceases when the magma is erupted at t3, and the zonation pattern of the crystal is then preserved after this time. The time it takes for the shape of the compositional gradient to change from sharp (at mixing) to diffuse (at eruption) can be determined using a modeling technique, called diffusion chronometry, because we know the rate of chemical diffusion. The modeling process is complicated by the fact that diffusion occurs in an anisotropic manner through volcanic crystals. Therefore, it is essential to measure the crystallographic axes of a crystal relative to the compositional zoning profile that is used to calculate a diffusion time scale.

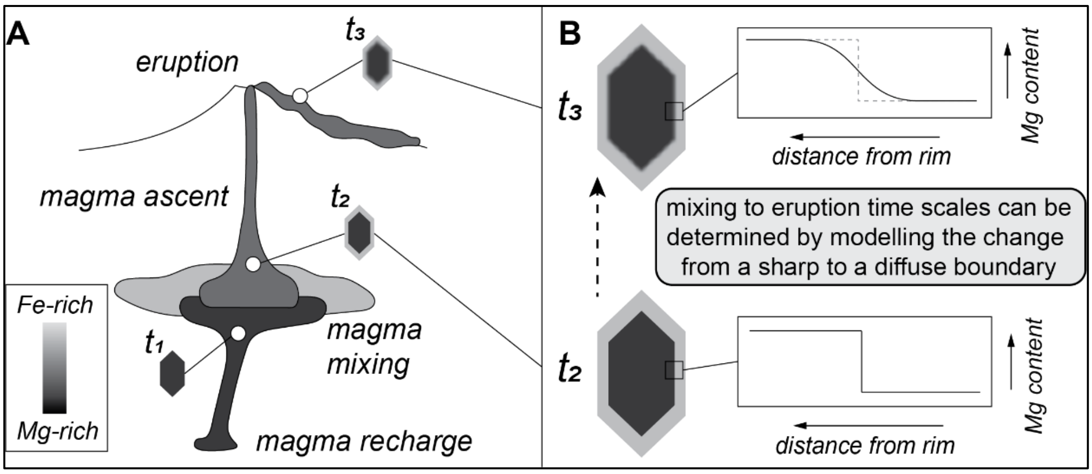

Figure 1. Schematic diagrams of how magma mixing affects chemical zoning in crystals. The volcano cross-section in Panel A shows how the compositional zoning in a crystal records the process of magma mixing. The graphs in Panel B shows how the compositional profile of a crystal can be used to reconstruct the time period between magma mixing (sharp boundary) and eruption (diffuse boundary).

Development and application of diffusion chronometry has become a vital tool in volcanology research. Recent progress within this field has followed two main trends. Firstly, researchers are aiming to apply corrections for anisotropic diffusion within the structure of crystals. Secondly, researchers are testing quantitative comparisons of magma movement signals that are recorded by geophysical tools with the timelines of magmatic processes that are recorded by diffusion chronometry. There have been few studies dedicated to the development and application of diffusion chronometry at Japanese volcanoes, particularly with respect to the trends outlined above.

２．研究の目的

The purpose of this research is to develop and apply new methods for collecting and integrating orientation and chemical composition data from volcanic crystals, in order to enable the accurate calculation of mineral diffusion time scales. The products of recent eruptions at Miyakejima volcano were selected as case studies for this research because they represent a flank-vent effusive lava flow eruption (1874 AD) and a summit-vent explosive ash-forming eruption (2000 AD) that were both preceded by magma mixing and allow two key questions to be addressed. Firstly, is the time period between magma mixing and eruption different for each eruption style? Secondly, how do the diffusion chronometry time scales compare with the time sequences of observed pre-eruption signals, such as seismicity?

There are two major implications if it can be shown that volcanic crystals accurately record magma mixing-to-eruption time scales for modern eruptions. Firstly, expanding the scope of diffusion chronometry studies to pre-historic eruption products will build up comprehensive catalogs of the lead-up times to volcanic eruptions throughout the long-term histories of active volcanoes. Secondly, when precursory seismic signals occur in the future, emergency managers will have valuable information about the likely timelines for response and evacuation before an eruption occurs. Furthermore, publication and distribution of a well-defined methodology to other researchers will allow more studies to be undertaken in the future for the numerous volcanoes in Japan where this approach is applicable and valuable. These represent significant steps forward in our aims to build societies that are resilient to natural hazards.

３．研究の方法

Samples were collected from the 1874 AD and 2000 AD eruption deposits of Miyakejima volcano during field surveys on the island, during which the long-term evolution of the volcano was also investigated. Sample preparation and analysis was undertaken at the Geological Survey of Japan, AIST. Crystallographic axis orientations for compositionally zoned olivine crystals were determined using electron backscatter diffraction (EBSD) methods. Major element compositions across zonation boundaries in crystals were measured using an electron probe microanalyzer (EPMA). A method for integrating crystal orientation and composition data was finalized during this project, using data collected for lava flow samples from Ruapehu volcano in New Zealand (Conway et al. 2020). Data from the samples from Miyakejima were processed using this method and applied to diffusion models to calculate magma mixing-to-eruption time scales. The time scale results were compared to recorded observations and geophysical monitoring data for the eruption sequences. Microanalytical data was also collected for samples from Aira caldera in Kyushu (Geshi et al. 2023) and Popa volcano in Myanmar (Sano et al. 2022) to assist with collaborative studies to understand the magmatic systems in these settings.

４．研究成果

Investigation of the long-term history of Miyakejima revealed that Mg-rich magmas have frequently been injected from deeper regions into the shallower crustal magma storage zone beneath Miyakejima volcano (Geshi et al. 2022). This process has dominated the overall compositional evolution of erupted products during the last 2000 years, and has exerted a direct control on triggering eruptions.

Diffusion chronometry calculations for olivine crystals from samples of lava flows and scoria from the 1874 AD eruption revealed that magma mixing occurred 1 to 5 days prior to the eruption. Recorded observations indicate that intense seismic activity began approximately 4 hours prior to the onset of the eruption. The eruption lasted several days, so the crystal time scales may accurately reflect the timing of the pre-eruption magma mixing if samples were collected from lavas that erupted during the later stages of the event. Moreover, there are no precise geophysical monitoring records available to verify the timing of the pre-eruption seismic signals. Regardless of these complexities, the diffusion chronometry results indicate that the 1874 AD eruption from the flank vent location was initiated rapidly after magma mixing occurred.

Diffusion chronometry calculations for olivine crystals from samples of tephra from the 2000 AD eruption indicate that magma mixing occurred 12 to 25 days prior to the eruption. Monitoring data indicates that seismic activity increased approximately 20 days prior to this eruption, which closely matches the time constraints provided by the volcanic crystals. In this case, there was a relatively complex process of magma migration leading up to the eruption from a vent at the summit of the volcano. When compared with the 1874 AD eruption, it is apparent that flank vent eruptions of lava can be initiated rapidly (within days), whereas explosive eruptions from the summit may have weeks of volcanic unrest preceding an eruption.

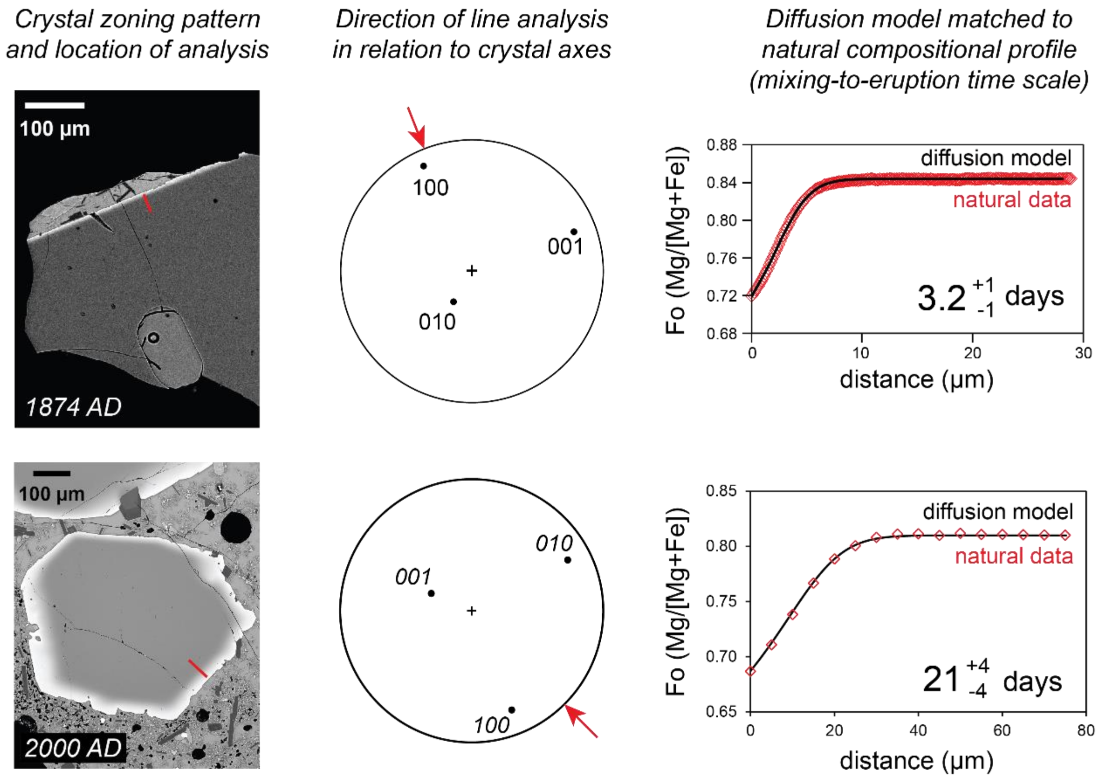

Figure 2. Summary of data and outcomes from diffusion chronometry modeling for olivine crystals from the products of eruptions in 1874 AD (top) and 2000 AD (bottom) at Miyakejima volcano. Left panels show compositional images for olivine crystals and the locations where compositional profiles were analyzed. Middle panels show stereographic projections of the crystal axes and the direction of the line profile analyses. Right panels show the changes in composition with distance from the crystal rims, with modeled diffusion curves that provide the calculated time scales (in days).

This study has outlined new methods for collecting and integrating crystal orientation and composition data from volcanic samples, which can be used to calculate diffusion time sales. These methods can be widely applied in future studies to investigate magma generation and eruption processes at active volcanoes in Japan and around the world. Such studies will continue to advance our ability to recognize and react appropriately to volcanic unrest signals that precede eruptions, which are crucial actions for mitigating volcanic hazards.

５．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　2件／うち国際共著　2件／うちオープンアクセス　2件）

１．著者名 Geshi Nobuo、Oikawa Teruki、Weller Derek J.、Conway Chris E.	４．巻 74
２．論文標題 Evolution of the magma plumbing system of Miyakejima volcano with periodic recharge of basaltic magmas	５．発行年 2022年
３．雑誌名 Earth, Planets and Space	６．最初と最後の頁 1 - 19
掲載論文のDOI（デジタルオブジェクト識別子） 10.1186/s40623-022-01577-7	査読の有無 有
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１．著者名 Conway, C.E., Chamberlain, K.J., Harigane, Y., Morgan, D.J., Wilson, C.J.N.	４．巻 48
２．論文標題 Rapid assembly of high-Mg andesites and dacites by magma mixing at a continental arc stratovolcano	５．発行年 2020年
３．雑誌名 Geology	６．最初と最後の頁 1033 - 1037
掲載論文のDOI（デジタルオブジェクト識別子） 10.1130/G47614.1	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

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２．発表標題 The types and tempos of magmatic processes that preceded historic eruptions at Miyakejima volcano, Japan
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３．学会等名 American Geophysical Union, Annual Meeting（国際学会）
４．発表年 2020年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関