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Eruptive History and Magmatic Evolution of a Subduction Zone
Volcano: Geology, Petrology and Geochemistry of Akita-Komagatake
Volcano, Northeast Japan Arc

(沈み込み帯火山の噴火史とマグマ進化：
東北日本弧，秋田駒ヶ岳火山の地質学・岩石学・地球化学)

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Abstract

Subduction-zone volcanoes are characterized by producing eruptive products with diverse chemical compositions through complex mantle-to-crust processes. Clarifying the structure and temporal evolution of magma plumbing system requires a highly resolved edifice formation history, which is difficult, particularly in terms of inserting a temporal axis into the edifice stratigraphy. This study aimed to (1) propose a new, high-precision method for constructing the formation history and (2) combine it with petrological/geochemical data to elucidate the evolution of magma plumbing system. I selected Akita-Komagatake volcano in the Northeast Japan Arc because it mainly erupted mafic magmas, spans the Late Pleistocene–Holocene (allowing ^{14}C dating), and remains one of the most active volcanoes in the Tohoku region (Chapter 1).

Chapter 2 revealed the formation history of this volcano. First, this study conducted topographical analysis and field survey to clarify the stratigraphy of the edifice deposits (lava flows, pyroclastic cones and pyroclastic flow deposits). In addition, this study reexamined the facies and stratigraphy of tephra fall deposits and obtained eruption ages for all tephra fall deposits using radiocarbon (^{14}C) dating. After establishing the stratigraphy of both edifice deposits and tephra fall deposits, these were correlated, and the ages obtained from the tephra fall deposits were incorporated into the edifice formation history. In previous studies, tephra fall deposits and edifice deposits have generally been correlated on a one-to-one basis based on chemical similarity. In contrast, this study proposes an alternative approach. In this study, eruptive products that form the same compositional trends in a suite of variation diagrams, such as Harker diagrams, are defined as a single “magma type.” The diversity and temporal variations of magma types were then identified by conducting multiple geochemical analyses, and deposits attributed to the same magma type were correlated with one another. As a result, the thirteen tephra fall deposits were classified into five magma types based

on Sr and Nd isotopic ratios and the abundances of large ion lithophile (LIL) elements. Furthermore, the same magma type classification established for the tephra fall deposits can also be applied to the edifice deposits. Therefore, by correlating tephra fall deposits and edifice deposits belonging to the same magma type, a comprehensive formation history of the volcano was reconstructed, incorporating eruption ages, erupted volumes, and eruption styles for each eruptive event. The results indicate that this volcano underwent a three-stage evolution: (1) an initial phase characterized by voluminous magma discharge through explosive eruptions, (2) a subsequent stage dominated by effusive lava flows that constructed the volcanic edifice, and (3) a final stage marked by a gradual decline in eruption rate. These results suggest that magma types changed systematically through time, reflecting the temporal evolution of the magma plumbing system associated with the growth of the volcano.

Chapter 3 discussed the generation mechanisms of the magma types identified at this volcano and the evolution history of its magma plumbing system. Based on Sr–Nd–Pb isotopic ratios, the rocks of this volcano can be classified into three main magma type. All three types share several common characteristics: (1) each magma type includes mafic rocks with SiO₂ contents of approximately 50–54 wt.%, from which compositional trends extend toward andesitic to dacitic compositions; (2) irrespective of SiO₂ content, petrographic observations reveal the presence of both texturally homogeneous samples and samples exhibiting disequilibrium features; and (3) isotopic ratios systematically shift toward relatively more enriched compositions from mafic to felsic rocks within each magma type. These results indicate that assimilation–fractional crystallization (AFC) was the dominant intra-crustal process. And this process occurred in two phases: first, magmas differentiated to SiO₂ contents of 50–54 wt.% through fractional crystallization (Phase 1), and then assimilated with surrounding crustal materials before erupting (Phase 2). it is considered that all three main magma types were generated as primary magmas

by the supply of aqueous fluids from the subducting slab to the mantle wedge. However, the volume and composition of these fluids varied for each main magma type, which led to the formation of three distinct magma types with different isotopic ratios. Combined with the eruptive history, it is known that the main magma types changed at intervals of several thousand years, and that each transition was invariably preceded by a period of dormancy. This suggests that slab-derived fluids are not supplied at a steady rate but rather in a pulse-like manner. This implies that the active periods of subduction zone volcanoes are controlled by the timing of these pulse-like supplies of slab-derived fluids.

The correlation method between tephra fall deposits and edifice deposits proposed in this study enabled the construction of a detailed eruptive history that integrates both explosive eruptive activity and edifice formation. This approach is expected to be applicable to many volcanoes worldwide that have erupted multiple magma types. Furthermore, the generation mechanism of magma types with distinct isotopic compositions is explained by a simple model based on differences in the amount of slab-derived fluid added to the mantle source. In the Northeast Japan Arc, many volcanoes are known to have erupted multiple magma types throughout their eruptive histories. Therefore, the magma-type generation mechanism proposed in this study can be regarded as a general model for the generation of diverse magma types in the Northeast Japan Arc.

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Chapter 1. Introduction

1-1. Significance of Clarifying the Evolution History of Subduction Zone Volcano

In subduction zones, complex magmatism occurs involving subducting slab, mantle wedge and crust (Kimura and Yoshida, 2006). A common model for magma plumbing system in subduction zone is as follows: fluids released from the subducting plate are added to the mantle wedge, thereby triggering partial melting (Tatsumi et al., 1986). The primary magmas generated through this process then ascend into the crust, where they undergo various differentiation processes—such as fractional crystallization, magma mixing, and assimilation-fractional crystallization (AFC)—before ultimately erupting at the surface (Forni et al., 2013; Mokitkanana et al., 2024).

Elucidating the structure and temporal evolution of “magma plumbing system”, which includes magma generation in mantle, differentiation process in crust, and eruption, provides important insights for both volcanology and modern society. For example, volcanoes are considered to play a key role in global material recycling. Therefore, discussions on the mechanisms of magma generation in the deep subsurface contribute to understanding the material circulation within the Earth's interior (Hirschmann, 2006; Xing et al., 2024). Specifically, Xing et al. (2024) demonstrated that Potassium isotopic compositions of eruptive products from intraplate volcanoes in Northeast China revealed that surficial water, once subducted, was transported into the mantle transition zone and subsequently returned to the Earth's surface as volcanic products. (Fig. 1-2). In addition, information on intra-crustal magma plumbing systems is indispensable for understanding the compositional evolution of magma and is expected to contribute to applied geological fields such as ore deposit formation and geothermal development (Barber et al., 2021; Akatsuka et al., 2022). Barber et al. (2021) explained the ‘Cu paradox’—the observation that

magmas with high Sr/Y ratios and high water contents, which are indicative of porphyry Cu-forming potential, exhibit the lower copper concentrations—through the process of amphibole fractionation. Specifically, they demonstrated that extensive amphibole fractionation reduces the Fe content of the melt, thereby lowering the sulphur content at sulphide saturation (SCSS). This promotes the segregation of sulphide phases from the melt; since Cu has a high partition coefficient into sulphide phases, it is effectively extracted from the melt, ultimately resulting in the formation of Cu-depleted magmas (Fig. 1-3). Furthermore, fundamental data such as the ages, styles, and transitions of past eruptive events are essential for understanding the processes that occurred within magma chambers immediately before and during eruptions, as well as for elucidating eruption dynamics (e.g., Pioli et al., 2008; Mujin and Nakamura, 2020; Lerner et al., 2021).

Moreover, such fundamental information is also valuable for volcanic hazard mitigation (Andreastuti et al., 2000; Andronico and Cioni, 2002; Orsi et al., 2004). Constructing a high-resolution eruptive history is expected to significantly contribute to volcanic hazard mitigation on both short-term (days to years) and medium- to long-term (decades or longer) timescales. In the short-term perspective, eruptive history allows us to estimate the eruption frequency of a volcano, thereby enabling approximate forecasts of the timing of future eruptions. Furthermore, compiling detailed information on the progression of past eruptions—including geophysical observation data—helps identify eruption patterns characteristic of each volcano, which in turn facilitates forecasting how an eruption may evolve once it begins. Such information contributes to the development of “volcanic event tree,” providing a quantitative framework for eruption forecasting (Fig. 1-4; Wright et al., 2019). In addition, increasing the number of well-documented eruptive events generally improves the reliability of these forecasts, highlighting the value of constructing the most precise eruptive history possible. From a medium- to long-term

perspective, quantitative indicators such as the eruptive volume and eruption rate allow us to evaluate and forecast how eruption magnitude and frequency have changed over timescales of several decades or more. These datasets also contribute to improving the accuracy of the magma discharge-step diagram (Nakamura, 1964), which is currently being refined (Fig. 1-5; Nakagawa et al., 2024).

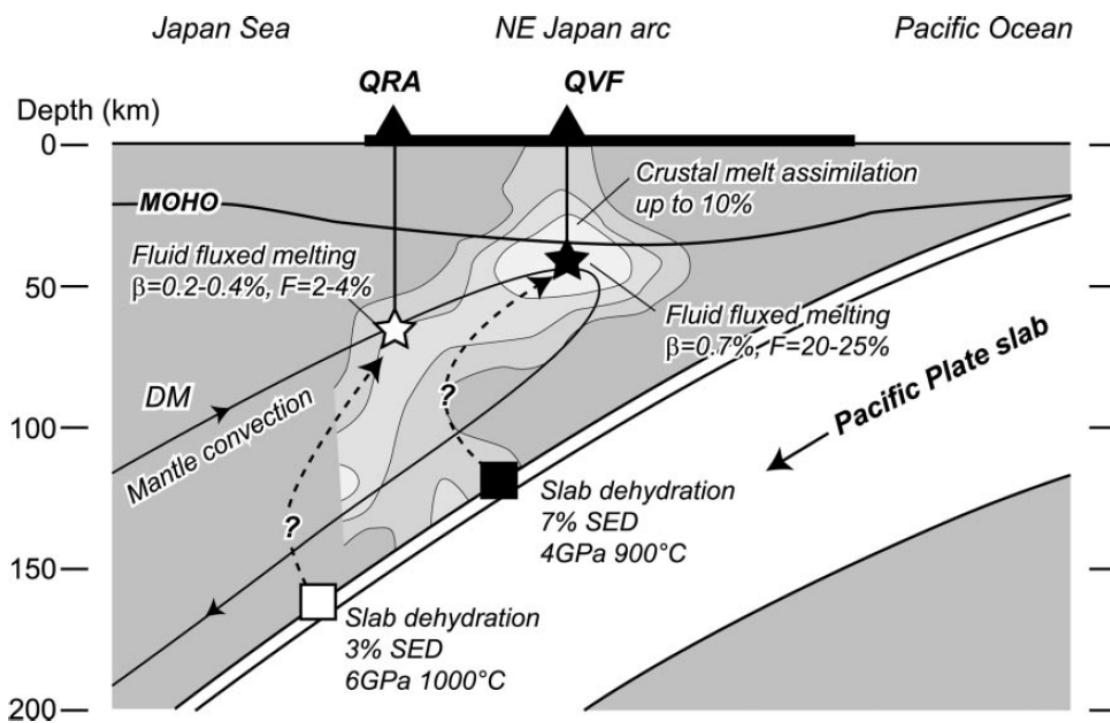


Figure 1-1 Conceptual diagram of a subduction zone (from Kimura and Yoshida, 2006). In a subduction zone, fluids released from the subducting slab are supplied to the overlying mantle, inducing partial melting. Primary magma generated in mantle then ascend into crust, where they undergo various differentiation processes. Thus, magma in a subduction zone experienced a complex and diverse series of processes from their generation to eruption.

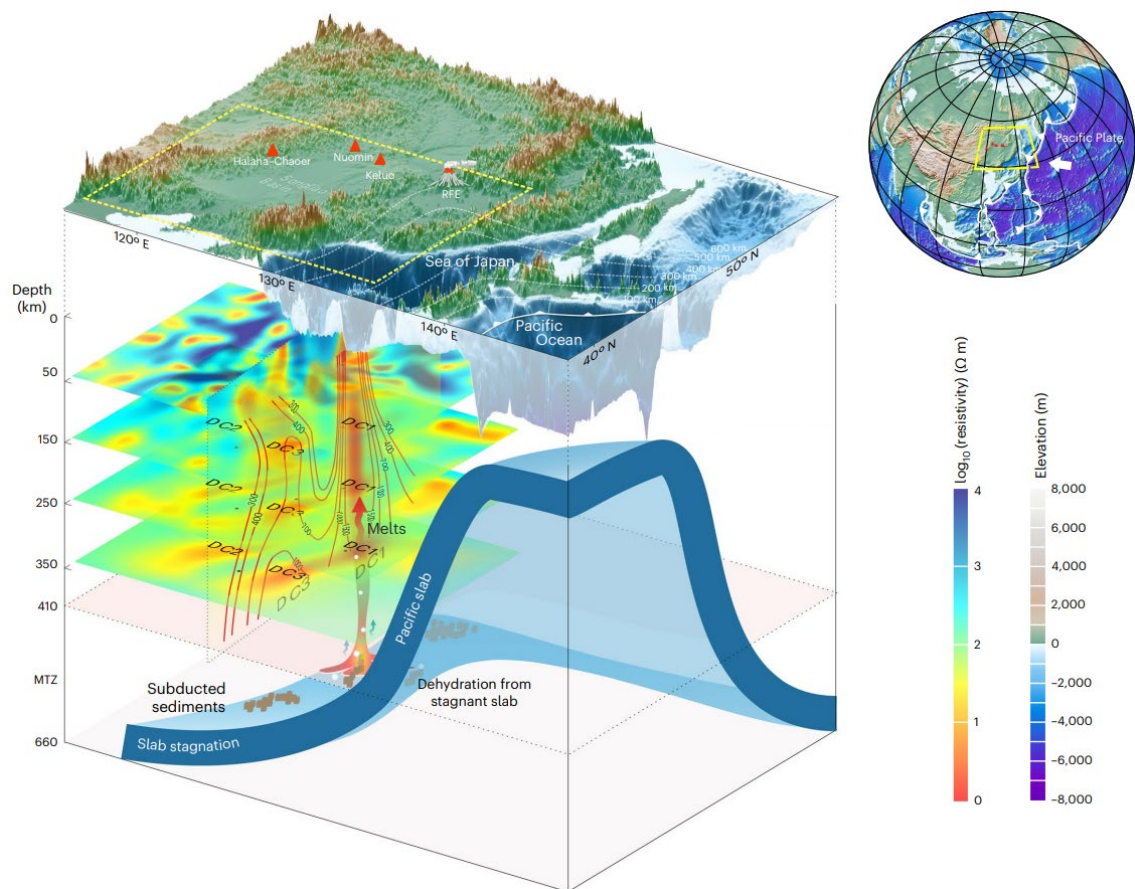


Figure 1-2 Three-dimensional schematic diagram of the distribution of Cenozoic volcanism in Northeast Asia (from Xing et al., 2024). Xing et al. (2024) clarified that water once subducted into the mantle transition zone by subduction can subsequently be recycled to the Earth's surface through intraplate volcanic activity.

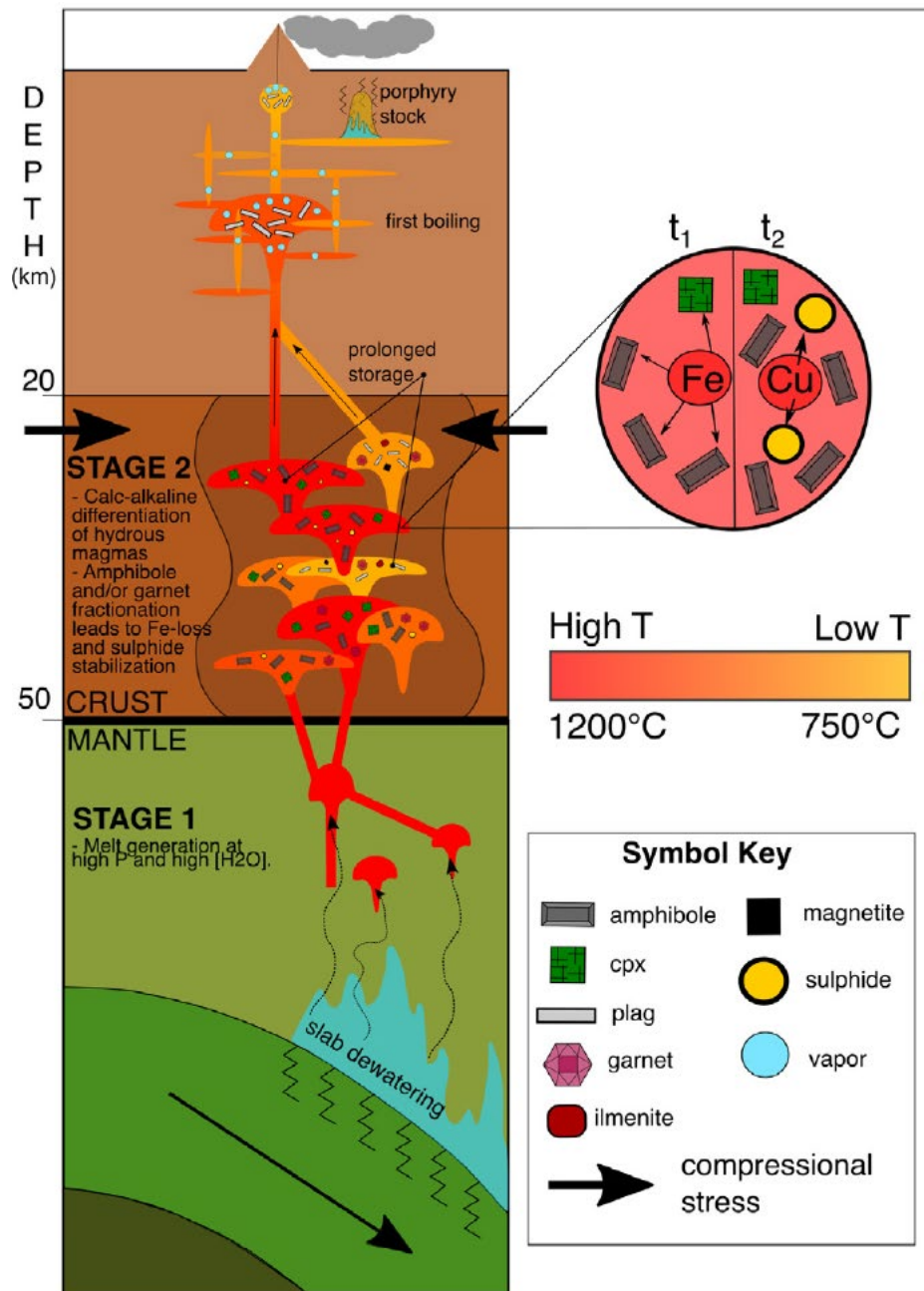


Figure 1-3 A schematic illustration of the mechanisms responsible for the formation of porphyry copper deposits (from Barber et al., 2021). Within the crust, fractional crystallization of amphibole decreases the FeO content of the magma, promoting the stabilization of sulphides. As a result, Cu in the magma is sequestered into sulphide phases and removed from the silicate melt. The segregated Cu ultimately forms porphyry copper deposits, which account for over 70% of global Cu ore production.

Sinabung 11-07-13 for the period 11-07-13 to 11-21-13

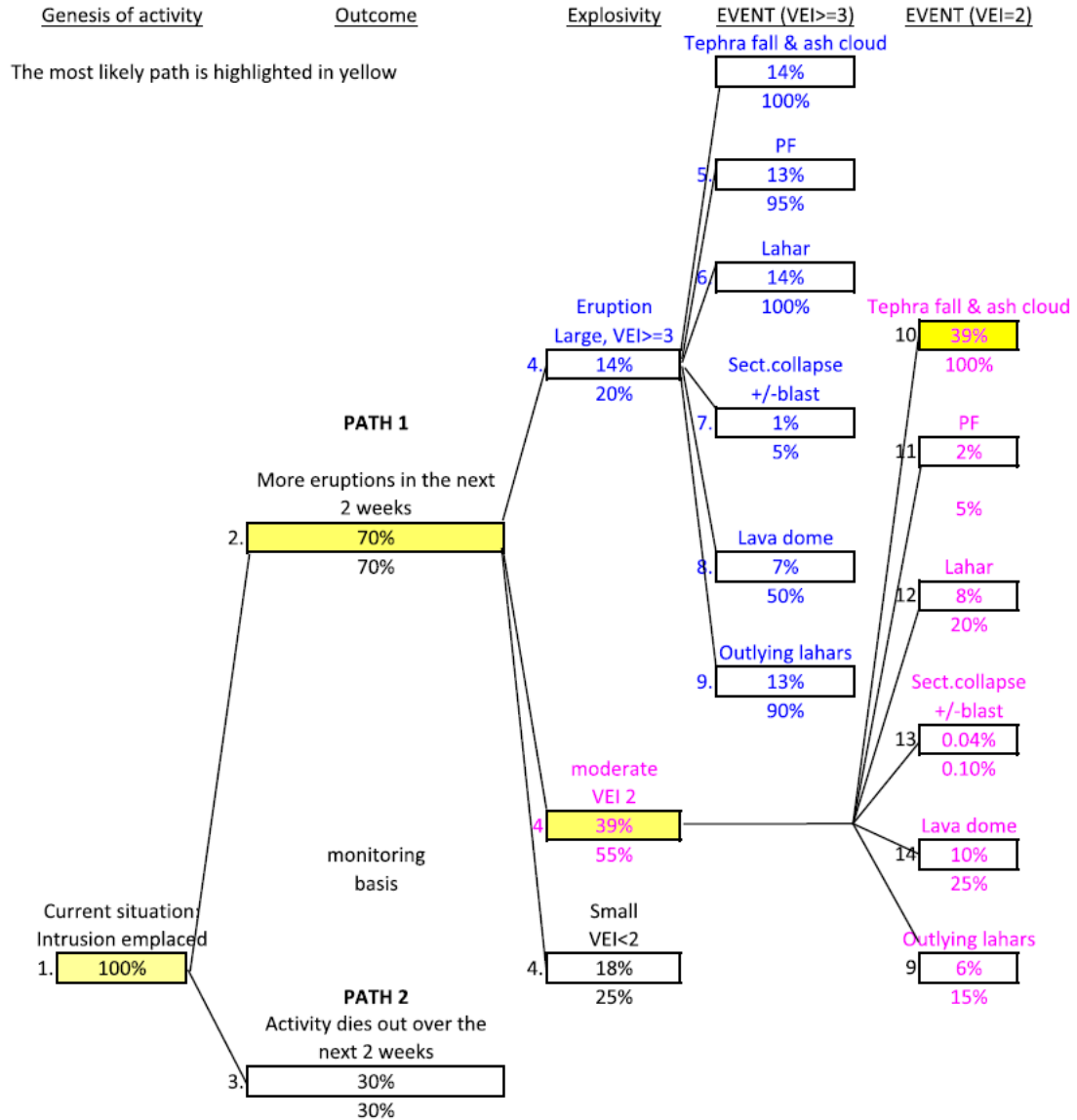


Figure 1-4 A volcanic event tree of Sinabung volcano (from Wright et al., 2019). The probabilities assigned to each branch of the event tree are determined based on its past eruptive history and recent geophysical monitoring data. Thus, elucidating the past eruptive history plays a crucial role in constructing more reliable eruptive event tree and therefore serves as an important component of volcanic hazard mitigation.

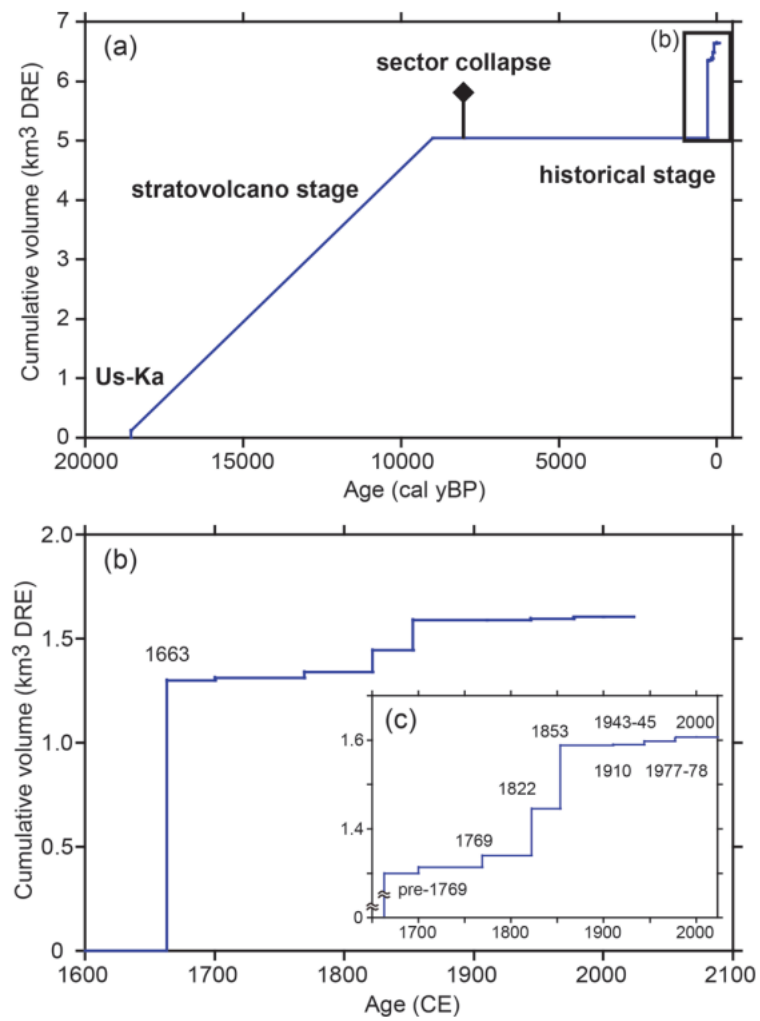


Figure 1-5 The magma discharge step-diagram for Usu volcano (from Nakagawa et al., 2024). (a): Long-term step-diagram showing magma discharge from the initial and present stage of the volcano. (b) and (c): Short-term step-diagrams focusing on magma discharge during the historical period. By constructing these diagrams, it becomes possible to predict the medium- to long-term evolution of volcanic activity based on parameters such as erupted volume and eruption rate.

1-2. Background and Challenges in the Study of Subduction Zone Volcanoes

Subduction zone is characterized by the production of eruptive materials with diverse chemical compositions, resulting from their complex magma generation mechanisms. Such variations are observed not only on a regional scale—both across and along arc transects (Cembrano and Lara, 2009; Ancellin et al., 2017; Till et al., 2019)—but also within individual volcanoes distributed along subduction zone (Grenada: Thirlwall et al., 1996; Merapi: Gertisser and Keller, 2003; Montserrat: Cassidy et al., 2012). Although numerous studies have reported the chemical diversity of eruptive products from individual volcanoes, there has been little discussion on the mechanisms underlying such diversity based on detailed chronological frameworks (Wibowo et al., 2022). Consequently, the evolution process of the entire magma plumbing system in subduction zone volcanoes remain poorly understood.

There are two main reasons why only a few studies have traced the structure and temporal evolution of magma plumbing system. The first is that subduction-zone volcanoes are generally dominated by intermediate to felsic eruptive products. These magmas are strongly influenced by crustal processes, making it difficult to obtain information, especially about processes occurring in the mantle. The second reason is that constructing a detailed “edifice formation history”, which is essential as a prerequisite for such discussions, is often difficult. If a detailed formation history with a well-constrained chronological framework have been established, the temporal resolution of magma plumbing system evolution would be significantly improved, allowing for a more precise reconstruction of its evolution processes. However, elucidating such a high-resolution formation history remains challenging. This comes from two main factors: (1) the difficulty of carrying out comprehensive surveys of an entire volcanic edifice, and (2) the difficulties of inserting reliable age constraints into the edifice evolution process. Regarding (2), radiometric dating methods such as K–Ar and Ar–Ar dating have long been

established and have been applied to construct edifice evolution histories (e.g. Martínez et al., 2018; Zhou et al., 2021; Santamaria et al., 2022). However, these methods have relatively large analytical uncertainties and are less suitable for dating young eruptive products, such as those erupted in Holocene. Alternatively, if organic material can be identified beneath or within edifice deposits—such as lava flows, pyroclastic cones, and pyroclastic flows—it is possible to estimate the emplacement age of the edifice deposit using radiocarbon (^{14}C) dating. Radiocarbon dating provides smaller uncertainties than K–Ar or Ar–Ar methods and can be applied to the deposits erupted in late Pleistocene to Holocene. However, because organic material is often difficult to find beneath edifice deposits, obtaining comprehensive age data throughout the edifice’s evolution history is challenging.

On the other hand, tephrostratigraphy—in the sense of the history of large explosive eruptions—allows organic material to be more readily identified immediately above or below tephra fall deposits. Consequently, tephrostratigraphy has been widely applied as an effective means to introduce a chronological framework into volcanic activity, and its stratigraphy have been reconstructed for many volcanoes (e.g., Fuji: Yamamoto et al., 2023; Tarumae: Furukawa and Nakagawa, 2010; Yōtei: Uesawa et al., 2016; Colima: Crummy et al., 2019; Campi Flegrei: Smith et al., 2011; Arenal: Soto et al., 2006; Etna: Coltelli et al., 2000; Agung: Fontijn et al., 2015). However, tephrostratigraphy does not capture small-scale explosive eruptions or mild eruptions such as lava flow emissions. Therefore, to construct the evolution history of magma plumbing system with a high-resolution chronological framework, it is necessary to establish a new method for integrating precise chronological information into the volcanic edifice formation.

1-3. Volcanological Background of the Northeast Japan Arc

The Northeast Japan Arc is a subduction zone where the Pacific Plate is subducting

beneath the North American Plate. This arc is one of the most extensively studied subduction zones in the world, with numerous studies have been conducted across various academic field, including geophysical studies (e.g., Zhao et al., 2011; Diba et al., 2023; Usui et al., 2024; Nishimura et al., 2025), geological studies (e.g., Yamamoto et al., 2018; Ohba et al., 2022; Hasegawa et al., 2023; Kudo, 2024), petrological studies targeting the entire arc (e.g., Nakagawa et al., 1988; Kimura and Yoshida, 2006; Yoshida et al., 2013; Shimaoka et al., 2016), and petrological studies focused on individual volcanoes (e.g., Towada volcano, Hunter and Blake, 1995; Ichinomegata volcano, Sato and Ozawa, 2023; Zao volcano, Ban et al., 2022; Hijiori volcano, Miyagi et al., 2017). Meanwhile, the arc is dominated by volcanoes erupted mainly intermediate to felsic products, and most petrological and geochemical studies focused on these volcanoes. To discuss the structure and evolution of magma plumbing system, including processes in the deep mantle, it would be preferable to study volcanoes dominated by mafic eruptions, where the influence of shallow crustal processes is considered minimal. However, for mafic-dominated volcanoes in the Northeast Japan Arc, no studies have addressed the structure or evolution of their magma plumbing system.

1-4. Overview of Akita-Komagatake volcano

Akita-Komagatake is a volcano located in the Northeast Japan Arc (Fig. 1-6). In the central part of the arc lies a volcanic zone known as the Sengan volcanic field (Kimbara and Matsunaga, 1985). Volcanic activity in this area has continued for at least the past 2 million years, formed numerous volcanic groups and edifices, including the Iwate volcanic group and the Hachimantai volcanic group (Suto and Ishii, 1987). In addition, deposits of Tamagawa welded tuff, a pyroclastic flow deposit, are distributed around this volcanic zone, suggesting that caldera (es) once existed in the central to western part of the field. Furthermore, geothermal activity

occurs in the central part of this field, and the Kakkonda geothermal power plant is currently in operation.

Akita-Komagatake volcano locates at the southernmost end of the Sengan volcanic field and represents one of the youngest volcanoes within the field. There are three main reasons for selecting this volcano. First, Akita-Komagatake is dominated by mafic eruptive products, which is rare in the Northeast Japan Arc, making it suitable for investigating the series of processes from the mantle to the crust. Second, the volcano is relatively young, having been active from the late Pleistocene to the Holocene (Itaya et al., 1987), with well-preserved topography and the potential for precise ^{14}C dating. Third, clarifying the evolution history of the volcano has important implications for volcanic hazard assessment. This volcano has two documented eruptions in the 20th century (1932 and 1970-71 CE; Kosaka and Hirabayashi, 1971), with the 1970–71 CE eruption being the only magmatic eruption in Honshu during the 20th century (Fig. 1-7). Furthermore, volcanic earthquakes have continued to occur beneath the volcano in recent years (Japan Meteorological Agency, 2013). For these reasons, Akita-Komagatake, together with neighboring volcanoes such as the Iwate and Akita-Yakeyama volcanoes, is designated as a constantly-monitored volcano.

Several geological and petrological studies have been conducted on Akita-Komagatake. Regarding the tephrostratigraphy, earlier studies focused mainly on relatively large-scale tephra deposits (Nakagawa et al., 1963; Ōgami and Doi, 1978; Inoue, 1978; Inoue, 1980; Ōgami et al., 1980; Doi et al., 1983). A more detailed study by Wachi et al. (1997) recognized 13 tephra units from the late Pleistocene to the present. Several studies have also addressed the formation history of the edifice, and Fujinawa et al. (2004) correlated the edifice deposits and tephra fall deposits. However, correlations based on whole-rock chemical compositions and descriptive petrography have not yet been conducted using clear and consistent criteria.

Petrological and geochemical studies have also been carried out (Nakagawa et al., 1985; Kuritani et al., 2019). Kuritani et al. (2019) focused on a single mafic eruptive deposit to infer the generation conditions of its primary magma. Nevertheless, the structure and temporal evolution of the magma plumbing system of Akita-Komagatake, based on its eruptive history, have not yet been investigated.

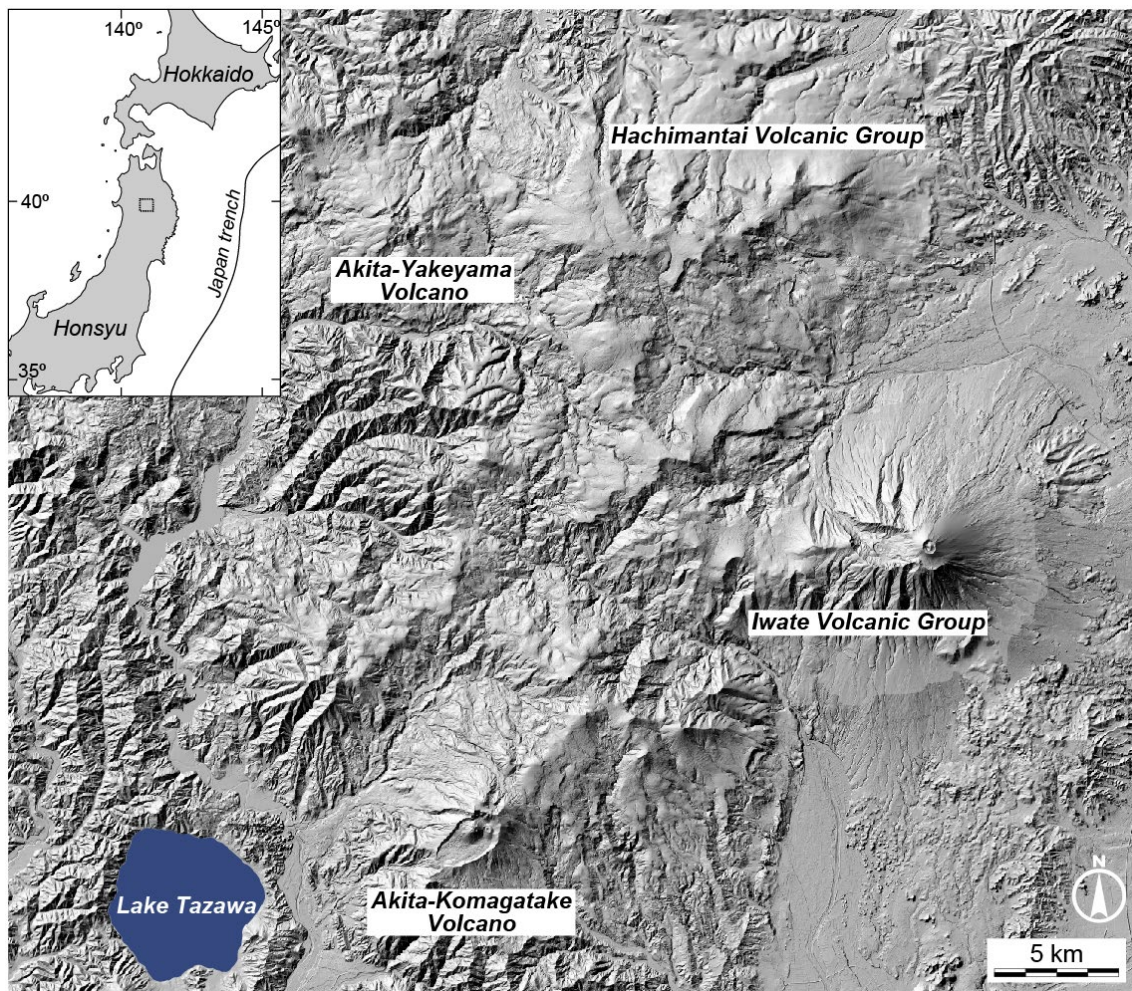


Figure 1-6 Index map of Northeast Japan Arc and shaded relief map around Sengan Volcanic area. In this area, volcanic activity has continued for more than two million years. Akita-Komagatake volcano locates at the southern part of it.

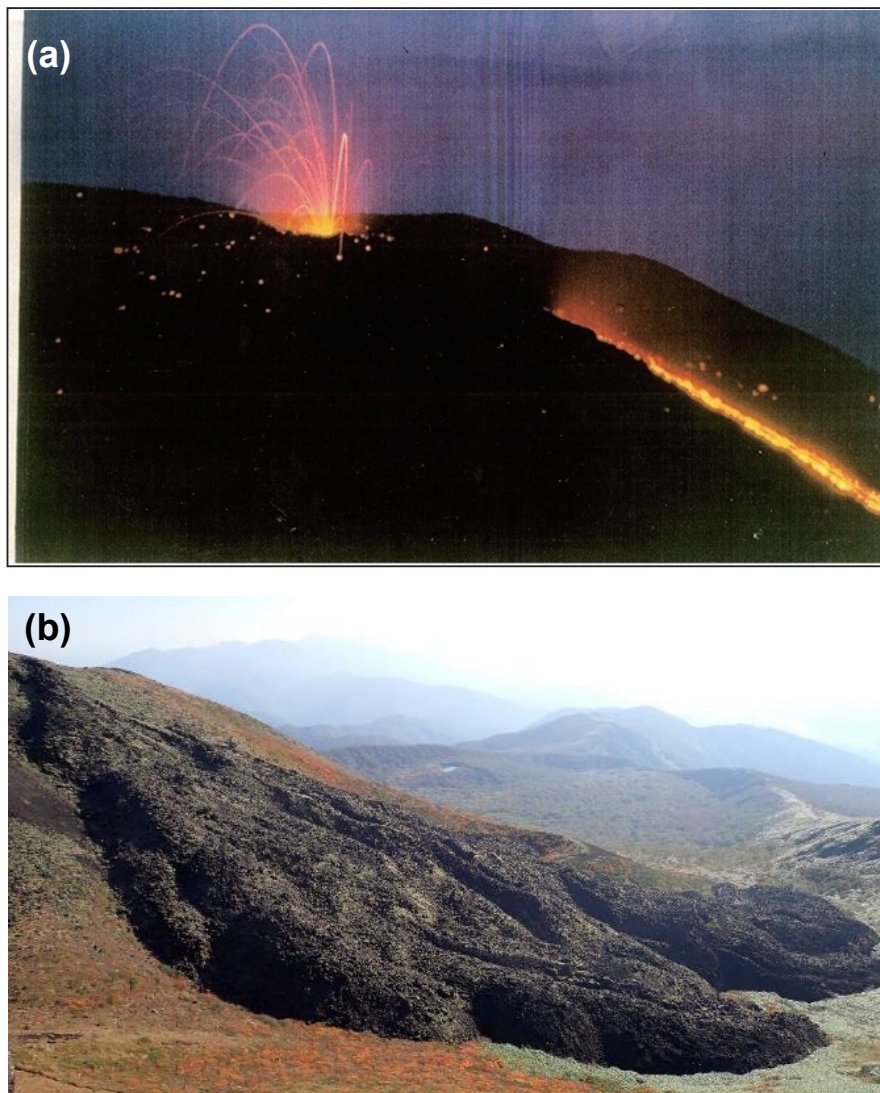


Figure 1-7 (a) Photograph of the 1970–71 CE eruption at Akita-Komagatake volcano (from JMA, 2013). (b) Photograph of the lava flow of 1970–71 CE eruption. The eruption was accompanied by lava effusion. In addition to two eruptions in the 20th century, this volcano has exhibited persistent seismic and geothermal activity in recent years. These observations indicate that Akita-Komagatake is one of the most active volcanoes in the Tohoku region.

1-5. Objectives of This Study

The objectives of this study are: (i) to propose a new method for constructing edifice formation history and apply it to Akita-Komagatake in order to elucidate its formation history; and (ii) to clarify the structure and temporal evolution of the magma plumbing system from the mantle to the crust, based on the constructed eruptive history and petrological and geochemical analyses of erupted products.

1-6. Outline of This Study

The outline of this study is as follows. Chapters 2 and 3 constitute the main body, and Chapter 4 provides the overall conclusion. Chapter 2 proposes a new method for constructing the edifice formation history and demonstrates its application to Akita-Komagatake. Since a variety of magma types erupted throughout the activity of this volcano, Chapter 3 discusses the origins and temporal evolution mechanisms of these diverse magma types. Chapter 4 presents the overall conclusions of this study.

Chapter 2. Formation History of Akita-Komagatake volcano

Abstract

Reconstructing a formation history of a volcano with a detailed temporal axis is crucial for understanding magma processes and eruption mechanisms beneath the volcano. To reveal this, it is necessary to clarify the relationship between tephra stratigraphy, which provides information about eruption age, and edifice deposits (lava flows, pyroclastic cones and pyroclastic flow deposits). In this study, instead of correlating tephra fall deposits and edifice deposits on a one-to-one basis based on chemical similarity, I propose an alternative approach in which (1) identify the diversity and temporal variations of magma types by conducting multiple geochemical analyses, and (2) correlate these deposits that attributed to the same magma type. I applied this method to Akita-Komagatake volcano located Northeast Japan arc to re-examine its formation history. As a result, the thirteen tephra fall deposits were classified into five magma types based on Sr and Nd isotopic ratios and the abundances of LIL elements. Furthermore, the edifice deposits were divided into nine units that are identified by vent location, eruption style, and stratigraphic relationships, and I confirmed that the same magma type classification as that of the tephra can be applied to the edifice deposits. Therefore, by correlating tephra fall deposits and edifice deposits that belong to the same magma type, I reconstructed the formation history that comprehensively includes a complete set of information such as the eruption ages, volumes, and styles of each eruptive event. As a result, Akita-Komagatake volcano underwent a three-stage evolution: (1) an initial phase of voluminous magma discharge through explosive eruptions, (2) subsequent effusive lava flows forming the volcanic edifice, and (3) a gradual decline in eruption rate. These results suggest that the magma types changed over time, reflecting an evolution of the magma plumbing system associated with the volcano's growth.

2-1. Introduction

A high-precision chronological framework for the formation history of a volcano is essential for understanding magma processes and eruption mechanisms occurring beneath the volcano. It also provides fundamental data for assessing volcanic activity and forecasting future eruptions. Accordingly, tephrostratigraphy has been widely applied as an effective means of introducing a temporal framework into volcanic activity, since organic material can often be identified immediately above or below each tephra unit (Fig. 2-1). Tephrostratigraphy has thus been constructed for many volcanoes (e.g., Fuji—Yamamoto et al., 2023; Tarumae—Furukawa and Nakagawa, 2010; Yōtei—Uesawa et al., 2016; Colima—Crummy et al., 2019; Campi Flegrei—Smith et al., 2011; Arenal—Soto et al., 2006; Etna—Coltelli et al., 2000; Agung—Fontijn et al., 2015). However, studies based on tephra stratigraphy in the medial to distal regions focus on deposits from relatively large explosive eruptions, which may overlook small-scale eruptions or mild eruptions dominated by lava flows that do not produce tephra. To address this limitation, it is important to conduct geological investigations in the vicinity of the vent, directly examining the internal structure and formation history of the volcanic edifice. Near the vent, in principle, all eruptive deposits are preserved. However, especially in young volcanic edifices, erosion is limited and the deposits are often covered by more recent eruptives, making it difficult to identify older eruptive deposits. Additionally, dating lava flows poses a challenge, particularly for deposits from the late Pleistocene onward, due to the lack of high-resolution chronological methods. Unlike tephra stratigraphy, where soil carbon dating can be applied, there is no equivalent technique for lava-flow-dominated sequences, making it difficult to construct their stratigraphy with comparable precision (Fig. 2-1).

Against this background, efforts have been made to correlate medial to distal tephra fall deposits with edifice deposits, leveraging the advantages of both vent-proximal geological

investigations and tephrostratigraphical studies while compensating for their respective limitations. Such comparisons have been conducted not only by examining the stratigraphy of tephra fall deposits and edifice deposits and the petrography of the juvenile materials, but also based on petrological characteristics, particularly the whole-rock major-element compositions (Allan et al., 2008; Tomlinson et al., 2014; Zawalna-Geer et al., 2016; Matsumoto and Nakagawa, 2019).

This approach correlates tephra fall deposits and edifice deposits from the perspective of “chemical similarity”. As a result, it can be applied when a volcanic event exhibits a distinctive chemical signature. However, in many volcanoes, the periods dominated by tephra eruptions and those dominated by lava flows often differ within a single eruptive sequence (e.g., El Reventador 2002 eruption—Samaniego et al., 2008; Tungurahua 2006 eruption—Samaniego et al., 2011; Kirishima 2011 eruption—Nakada et al., 2013). Moreover, the chemical composition of eruptive products commonly changes within a single eruption event (e.g., St. Helens 1980–1986 eruption—Cashman, 1988; Redoubt 2009 eruption—Coombs et al., 2012; La Soufrière 2020–2021 eruption—Weber et al., 2024). Therefore, when using major-element chemical composition, correlation based on whether tephra fall deposits and edifice deposits match chemically are inherently uncertain. Consequently, studies that directly correlate tephra fall deposits with edifice deposits to construct the long-term and high-precision formation history of a volcanic edifice remain extremely rare.

In this study, rather than correlating tephra fall deposits and edifice deposits on a one-to-one basis according to exact chemical similarity—as has been done in previous studies—I propose a new method for correlating these units. First, I define “magma type” as a group of eruptive products that form similar compositional trends on a set of variation diagrams (such as Harker diagrams); in other words, these products share similar primary magmas or differentiation

processes. Subsequently, I correlate the tephra fall deposits and edifice deposits that belong to common magma type.

In many volcanoes worldwide, the physicochemical properties of magma change as activity progresses, and specific magma types are known to be active during particular period (for example, Fig. 2-2). Furthermore, changes in magma type often correspond to shifts in vent location or eruption style (e.g., Mount Mazama—Bacon and Lamphere, 2006; Santorini—Fabbro et al., 2013; Antuco—Sierra Velluda—Martínez et al., 2018; Vulcano—Astis et al., 2013; Stromboli—Francalanci et al., 2013; Sundoro—Haryo et al., 2022; Sakurajima—Kuritani et al., 2025). Therefore, by elucidating the temporal and spatial evolution of magma types at a given volcano, individual tephra fall deposits and edifice deposits can be correlated based on their respective magma types. In this study, magma types were defined and identified using multiple petrological parameters, including major-element compositions, trace-element compositions, and isotopic ratios, and the resulting classifications were used to correlate tephra fall deposits with edifice deposits.

In this study, I focused on Akita-Komagatake, a volcano located in the Northeast Japan Arc (Fig. 1-6). This volcano has been active since the Late Pleistocene (Itaya et al., 1984; Suto and Ishii, 1987) and has been the subject of numerous studies on tephrostratigraphy (e.g., Wachi et al., 1997). First, I examined the characteristics and temporal evolution of magma types for individual tephra units. As a result, the tephra could be divided into several groups corresponding to different magma types. I then investigated the structure and development of the volcanic edifice, defining unit divisions with attention to the supply vent and edifice structure. The magma types of all edifice units were also examined and correlated with tephra fall units based on magma type classifications. Consequently, I successfully introduced a temporal framework based on tephrochronology to reconstruct the detailed formation history of this volcano from the Late

Pleistocene to the present.

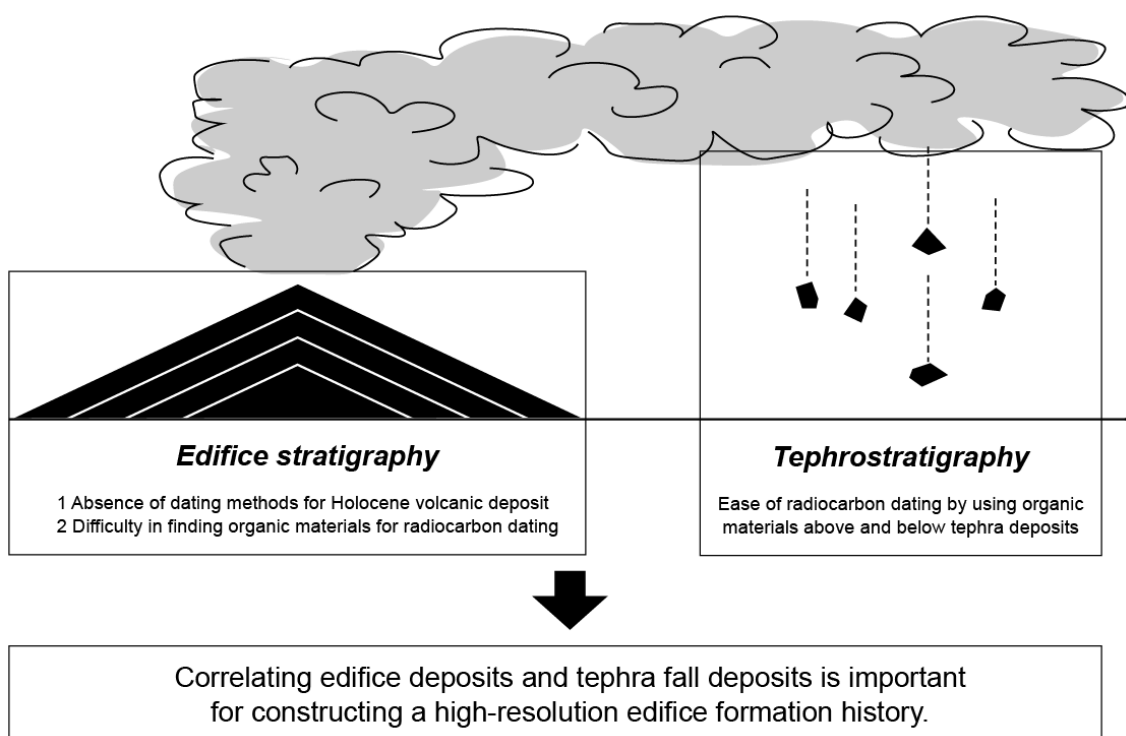


Figure 2-1 Schematic illustration highlighting the challenges in previous studies of eruptive histories and the key aspects addressed in this study.

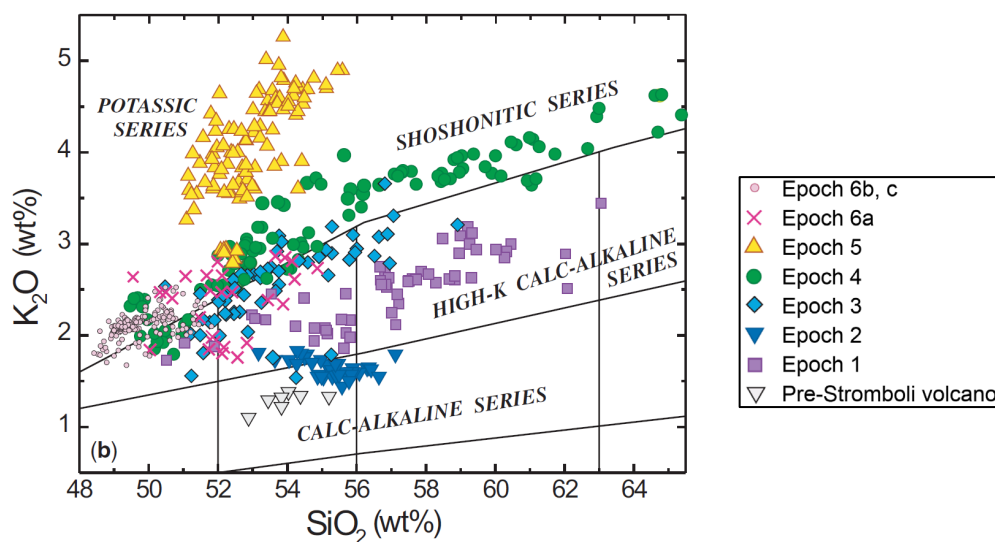


Figure 2-2 Whole-rock chemistry of the eruptive deposits of Stromboli volcano (from Flancalanci et al., 2013). In many volcanoes worldwide, the physicochemical properties of magma change as activity progresses, and specific magma types are known to be active during particular period. In this study, groups of samples that define a single compositional trend on a suite of variation diagrams are defined as a “magma type,” and tephra fall deposits and edifice deposits are correlated on a magma-type basis. In the case of Stromboli volcano, the SiO_2 – K_2O diagram shows distinct compositional trends for each of Epochs 1–6; therefore, each epoch is considered to represent a single magma type.

2-2. Geological Overview of Akita-Komagatake

Akita-Komagatake locates in the southwestern part of the Sengan volcanic area (Kimbara and Matsunaga, 1985), forming the southern end of a northeast–southwest-trending volcanic chain. This volcano is one of the youngest volcanoes in the region. The volcanic edifice is a stratocone with Otake at its summit (Fig. 2-3). Calderas are recognized on both the northern and southern slopes, referred to as the Northern Caldera and Southern Caldera, respectively (Suto and Ishii, 1987). Post-caldera edifices have formed within each caldera: Katakuradake and Onamedake within the Northern Caldera (Figs. 2-4a, b), Kodake and Medake within the Southern Caldera (Fig. 2-4c). These post-caldera volcanic bodies are referred to as the Northern Edifice and Southern Edifice, respectively. Activity within the Southern Caldera has been recorded since the late 19th century (Suwa, 1971), with eruptions occurring near Medake in 1932 CE and 1970–71 CE. The 1970–71 CE eruption, in particular, involved repeated Strombolian eruptions and produced lava flows extending several hundred meters downslope (Kano, 1971; Suwa et al., 1971; Oosaka and Hirabayashi, 1971).

Numerous studies have been conducted on the eruptive history of this volcano. Regarding the edifice structure, Suto and Ishii (1987) clarified its overall features and identified the structures of the Northern and Southern Calderas. Studies on the tephrostratigraphy of this volcano have primarily focused on areas distant from the edifice (Nakagawa et al., 1963; Ogami and Doi, 1978; Inoue, 1978, 1980; Ogami et al., 1980; Doi et al., 1983). Later, Wachi et al. (1997) re-examined the tephra stratigraphy at medial sites and identified 13 units from the Late Pleistocene to the present (Fig. 2-5). Furthermore, Fujinawa et al. (2004) attempted to correlate these units with the edifice deposits based on whole-rock major-element compositions and petrographic characteristics (Fig. 2-6). However, because the volcanic rocks are dominated by basalt to basaltic andesite with similar major-element compositions, clear correlation criteria have

not yet been established.

Both the Northern and Southern Calderas were originally thought to have been formed by large-scale eruptions (Suto and Ishii, 1987). However, Doi et al. (1997) suggested that the Northern Caldera is associated with debris avalanche deposits distributed in the northern part of the edifice (Ui et al., 1986), reporting ^{14}C ages of approximately 22 ka from wood fragments within these deposits. This indicates that the Northern Caldera represents a collapse scarp formed by edifice collapse, which is considered to have occurred after 22 ka.

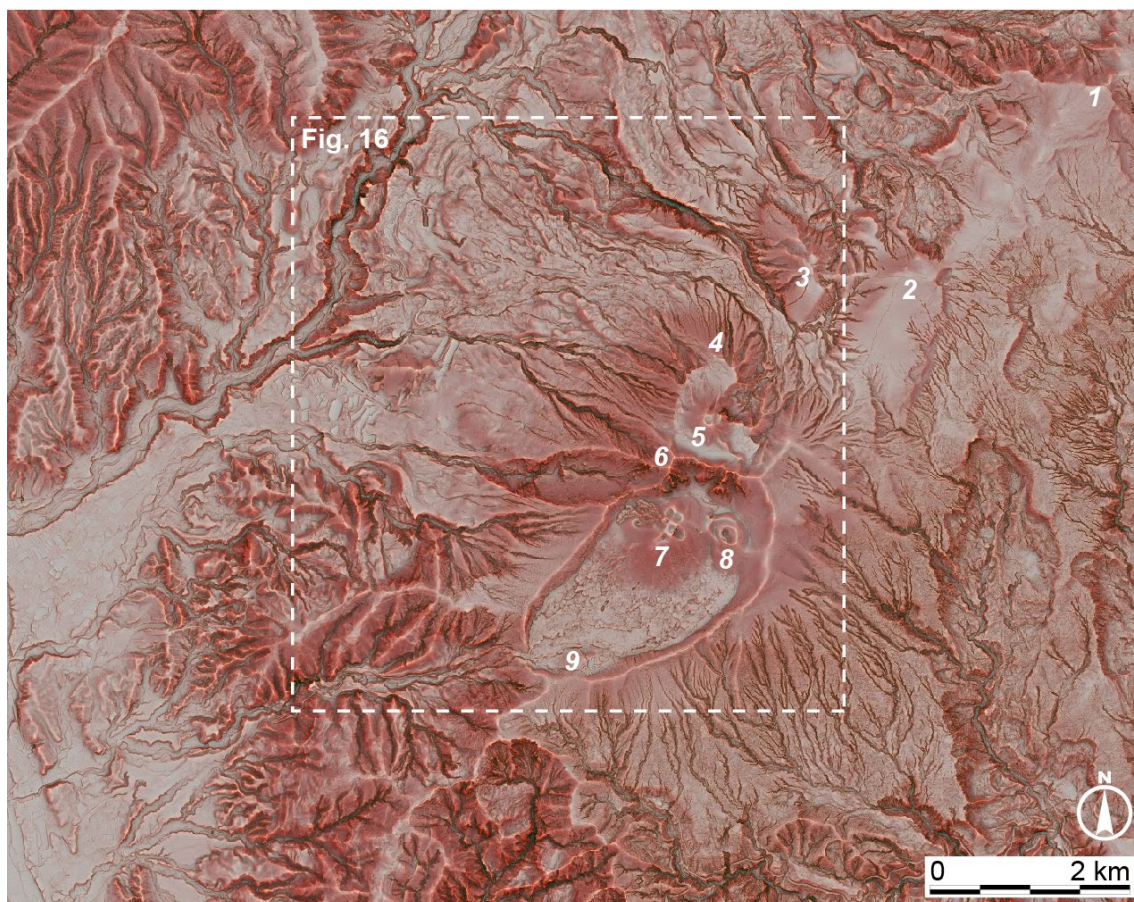


Figure 2-3 Red relief image map around Akita-Komagatake. Numbers 1 to 8 indicate the locations of the edifices mentioned in the text: 1, Zarumori; 2, Yunomori; 3, Sasamori; 4, Katakuradake; 5, Onamedake; 6, Odake; 7, Medake; 8, Kodake; 9, Minamidake.

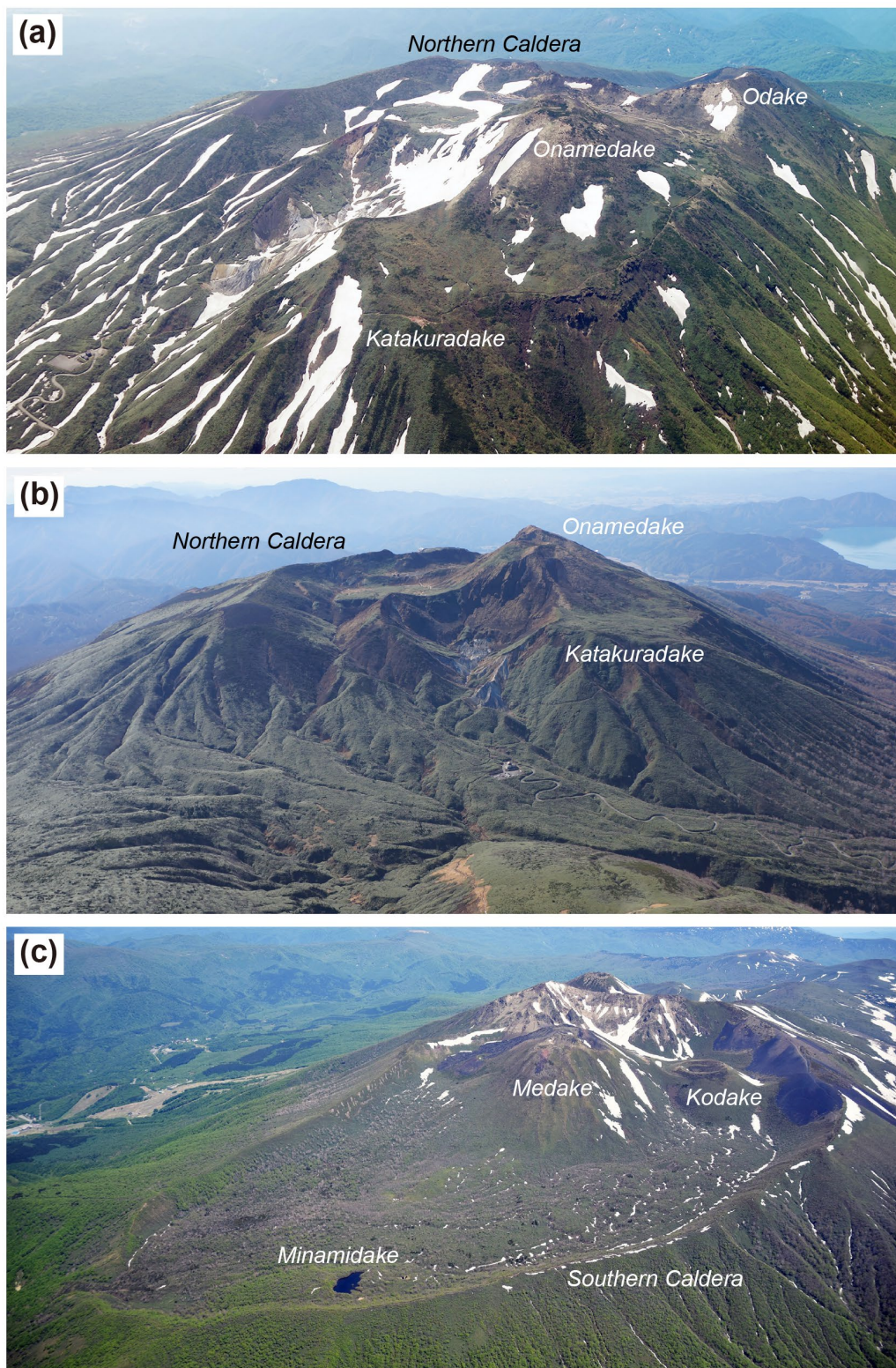


Figure 2-4 Aerial photographs of the (a, b) Northern edifice and the (c) Southern Edifice of Akita-Komagatake volcano. The photographs (a) and (b) are provided from the Akita-Komagatake Sabo Branch Office and (c) is from the Morioka Local Meteorological Observatory.

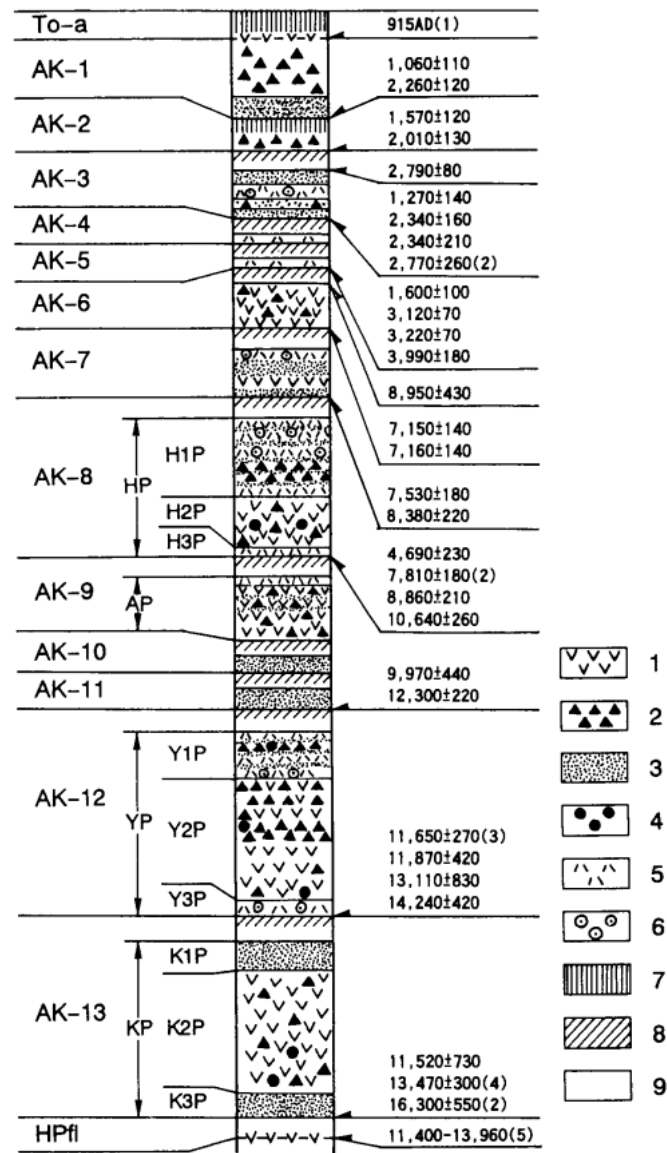


Figure 2-5 Schematic columnar section of tephra erupted from Akita-Komagatake volcano (From Wachi et al., 1997). 1, pumice; 2, scoria; 3, sandy ash; 4, accidental rock fragment; 5, fine-grained ash; 6, accretionary lapilli; 7, black to dark brown buried soil; 8, brown buried soil; 9, loess.

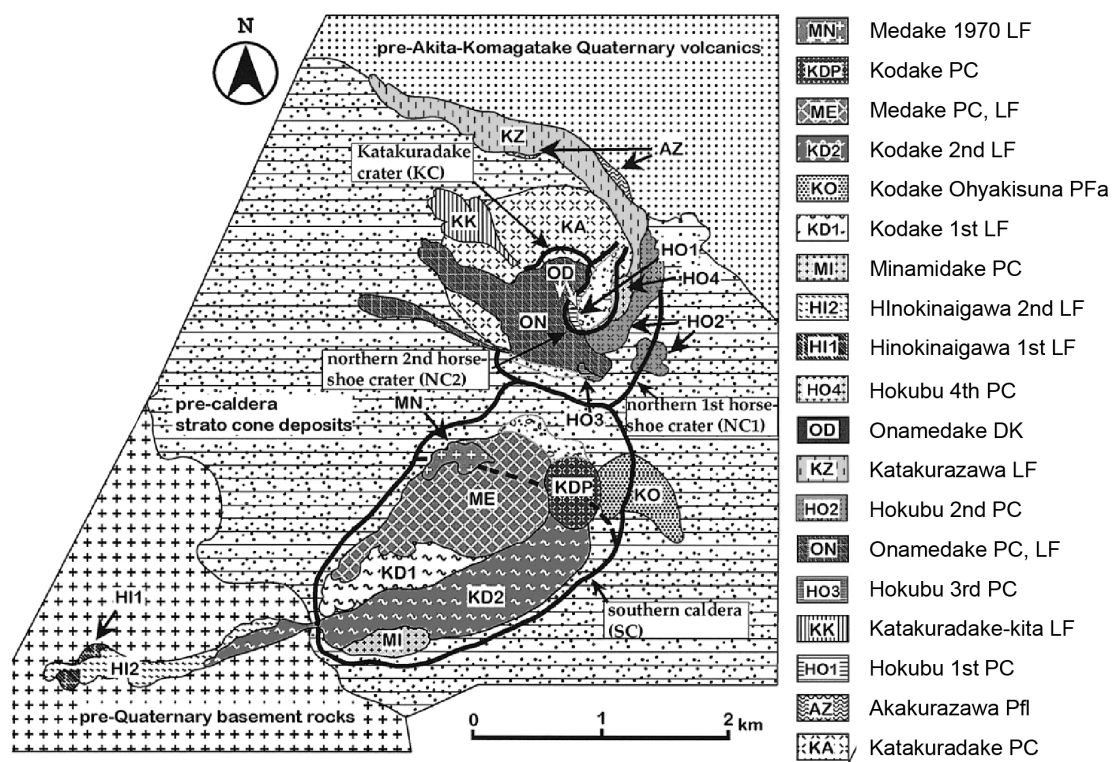


Figure 2-6 Geologic map showing the eruptive deposits of the Akita-Komagatake volcano (after Fujinawa et al., 2004). Abbreviations: LF, lava flow; PC, pyroclastic cone; PFa, pyroclastic fall; Pfl, pyroclastic flow, DK, dyke.

2-3. Method

In this study, I reconstructed the tephra stratigraphy and, based on multiple petrographic and geochemical datasets, clarified the diversity of magma types in the tephra fall deposits and their temporal evolution. For the volcanic edifice, I examined the structure and formation sequence of edifice deposits. Petrographic and geochemical data were also obtained for the edifice deposits to characterize the diversity of magma types and their coverage relationships. Using magma type as a correlation criterion, I then attempted to correlate tephra fall deposits with edifice deposits. The overall workflow of these procedures is summarized as follows.

(1) Tephrostratigraphy

I conducted field investigations at medial to distal sites and re-examined the tephra stratigraphy of each unit reported by Wachi et al. (1997). In addition, by documenting tephra deposits in proximal areas, this study provides more detailed descriptions for several tephra fall units. Samples were collected from each unit, and soil layers between tephra fall units were also sampled for ^{14}C dating. Additionally, the thicknesses of each tephra unit were newly measured at sites ranging from proximal to distal locations, and, together with the descriptions by Wachi et al. (1997), the isopach maps for each unit were revised or newly constructed. Fig. 2-7 shows the locations where the tephra stratigraphy and thickness were investigated in this study.

(2) Volcanic Edifice Stratigraphy

For the structural analysis of the volcanic edifice, I used a red relief image map created from a 1 m resolution DEM (Chiba et al., 2007). Using this, vent topography, edifice morphology, and the distribution of edifice deposits such as lava flows and pyroclastic deposits were identified, and their coverage relationships were inferred. In this study, edifice deposits were not subdivided into individual units; instead, they were broadly categorized based on the state of vent preservation and microtopography, corresponding to either the time of activity or the supplying

vent. Subsequently, field surveys were conducted. During the surveys, the coverage relationships and stratigraphy of the eruptive deposits were confirmed, and samples were densely collected from Akita-Komagatake and surrounding edifices to capture the diversity of their petrological characteristics. Fig. 2-7 also shows the locations where edifice deposit samples were collected in this study. In addition, in the northern and northwestern slopes of the volcano, borehole drilling has been carried out by the Japan Meteorological Agency and the Ministry of Land, Infrastructure, Transport and Tourism. Samples from these two boreholes were also used in this study to examine the coverage relationships among the edifice deposits.

(3) ^{14}C dating

Radiocarbon (^{14}C) dating was performed on 23 soil samples collected immediately above and below tephra fall deposits, as well as on 3 charcoal samples from beneath lava flows and within pyroclastic flow deposits. All measurements were commissioned to the Accelerator Mass Spectrometry Laboratory, using a dedicated ^{14}C -AMS instrument (NEC). Soil samples were treated with acid, whereas charcoal samples underwent acid–alkali–acid pretreatment; the resulting residues were diluted with ultrapure water to neutrality, dried, and then measured. Radiocarbon ages were calculated using the Libby half-life of 5,568 years, and $\delta^{13}\text{C}$ values were applied to correct for isotopic fractionation. The calibration of ^{14}C ages to calendar years was performed using the IntCal20 calibration curve (Reimer et al., 2020) and the OxCal v4.4 calibration program (Bronk Ramsey, 2009). In cases where multiple radiocarbon measurements were conducted on a single unit, the mean of the calibrated age was adopted as the age of that deposit.

(4) Eruptive Volume

In this study, the eruptive volumes of tephra fall deposits and each edifice deposits were calculated. The volume of tephra fall deposits was estimated following Pyle (1989). For

edifice deposits, different calculation methods were applied depending on the deposit type: scoria cones, lava flows, and pyroclastic flows. Scoria cones were approximated as cones or truncated cones to calculate their volumes. For lava flows, representative outcrops were selected for each unit, and the areal extent of the lava flow was multiplied by the thickness measured at the representative outcrop to estimate the volume. Pyroclastic flows were calculated using a similar procedure to that for lava flows. In cases where a pyroclastic flow had multiple distribution areas, representative outcrops were selected for each area, and volumes were calculated separately.

After calculating the volumes of tephra fall deposits and edifice deposits, Dense Rock Equivalent (DRE) conversions were performed. For the DRE conversion, bulk densities derived by Fujiwara et al. (2007) were used: pumice and scoria in tephra fall deposits, 1.2 g/cm³; scoria in pyroclastic flow deposit, 1.8 g/cm³; pumice in pyroclastic flow deposit, 1.4 g/cm³; agglutinate, 1.5 g/cm³; lava flows, 2.4 g/cm³. The density of dense rock was assumed to be 2.7 g/cm³.

(5) Microscope observation

250 samples were examined under a polarizing microscope using thin sections, and 44 representative samples were subjected to modal composition analysis. Modal compositions were determined using a point counter, with 3,000 points counted per thin section.

(6) Geochemical analyses

Whole-rock major and trace element (Sc, V, Cr, Co, Ni, Rb, Sr, Y, Zr and Ba) analyses were performed on 577 samples of Akita-Komagatake volcanic products, including both tephra fall deposits and edifice deposits, as well as on 14 samples of Sasamori, Yunomori, and Zarumori volcanic products, using X-ray Fluorescence (XRF). Sr, Nd, and Pb isotopic analysis were carried out on 73 selected samples using a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). All the petrological and geochemical analyses were conducted at the Faculty of Science, Hokkaido University.

For edifice deposits, the samples were first cut into chip-sized pieces several millimeters thick using a rock cutter, and any weathered or altered portions were removed. They were then rinsed with deionized water in an ultrasonic bath for at least 2 hours until the supernatant became clear. The washed chips were dried in an oven at 120 °C for more than 48 hours and subsequently powdered. For tephra fall deposits, particles larger than 1.5 cm were treated as individual samples for powdering, while particles 1.5 cm or smaller were combined in multiple pieces to create a single powdered sample. For XRF analyses, powdered samples were kept at 850°C for >8 hours in a muffle furnace to remove structural water and to oxidize the ferrous iron. The whole-rock compositions of the major and trace elements were obtained by XRF on glass beads containing an alkali flux consisting of a 4:1 mixture of $\text{Li}_2\text{B}_4\text{O}_7$ and LiBO_2 (2:1 sample dilution) using Spectoris MagiX PRO (major elements) and Malvern Panalytical Zetium instruments (trace elements). For Sr–Nd–Pb isotopic analyses, the procedures for chemical separation followed the methods of Pin et al. (1994) and Noguchi et al., (2011) for Sr; of Pin et al. (1994) and Pin & Zalduegui (1997) for Nd; and of Kuritani & Nakamura (2002) for Pb. Isotopic analyses were conducted using a MC–ICP–MS (Thermo Fisher Scientific Neptune Plus). Mass fractionation was internally corrected using $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ for Sr and $^{143}\text{Nd}/^{144}\text{Nd} = 0.7219$ for Nd, and that for Pb was corrected using Tl as an external standard ($^{205}\text{Tl}/^{203}\text{Tl} = 2.3871$; Dunstan et al., 1980). The corrected Sr, Nd, and Pb isotopic ratios were finally normalized to $^{87}\text{Sr}/^{86}\text{Sr} = 0.710240$ for NIST SRM 987, $^{143}\text{Nd}/^{144}\text{Nd} = 0.512117$ for JNdi-1, and $^{206}\text{Pb}/^{204}\text{Pb} = 16.9424$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.5003$, and $^{208}\text{Pb}/^{204}\text{Pb} = 36.7266$ for NIST SRM 981 (Kuritani & Nakamura, 2003), by applying a standard bracketing method. One standard deviation uncertainties on the Sr, Nd, and Pb isotopic ratios of the JB-3 standard measured in this study are 0.003% for $^{87}\text{Sr}/^{86}\text{Sr}$, 0.002% for $^{143}\text{Nd}/^{144}\text{Nd}$, 0.009% for $^{206}\text{Pb}/^{204}\text{Pb}$, 0.010% for $^{207}\text{Pb}/^{204}\text{Pb}$, and 0.011% for $^{208}\text{Pb}/^{204}\text{Pb}$. The results of the replicate analyses of the reference material JB-3

(obtained from the Geological Survey of Japan; Imai et al., 1995) and the reference values are shown in Appendix.

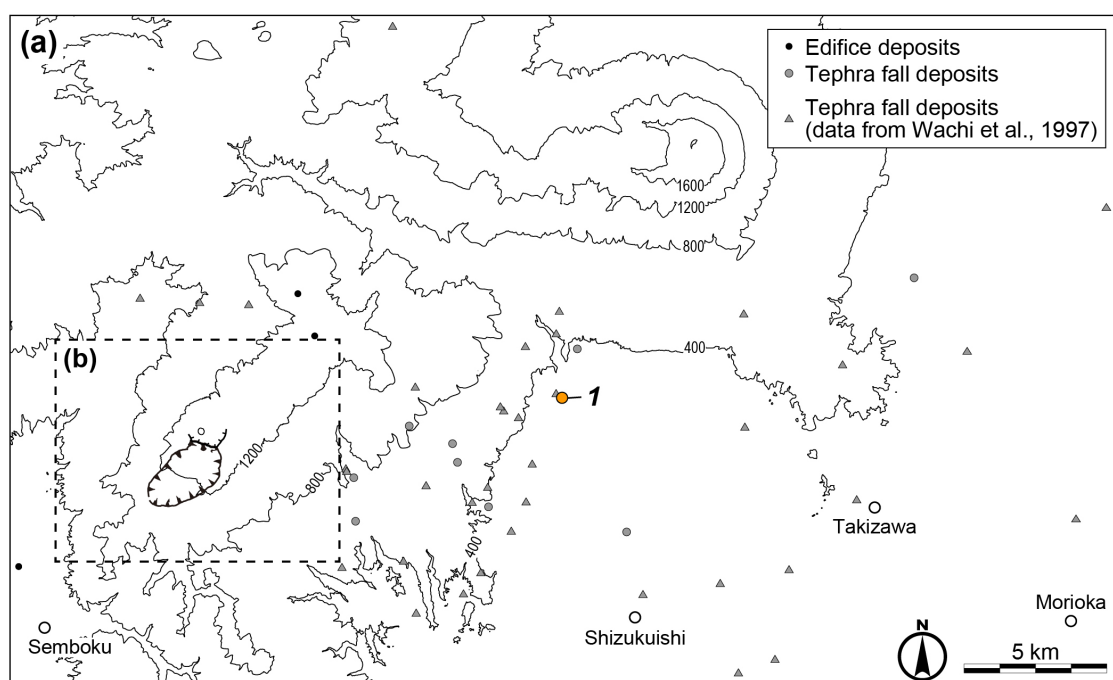


Figure 2-7 Topographic map showing the survey localities conducted in this study. (a) indicates the sites in the distal area, and (b) indicates the sites in the proximal to medial areas, respectively. The contour interval is 400 m for (a) and 200 m for (b). In both figures, localities shown by gray circles and black circles are the survey locations for tephra fall deposits and edifice deposits (lava flow, pyroclastic cone, and pyroclastic flow deposits), respectively. The localities assigned a locality number (1 to 24) are indicated by orange circles, encompassing both the tephra description sites and the edifice deposits survey sites. The stars (☆) represent past boring excavation sites, where JMA stands for the Japan Meteorological Agency and MLIT stands for the Ministry of Land, Infrastructure, Transport and Tourism, indicating the respective agencies that carried out the excavation. The localities shown by triangles are those described in Wachi et al. (1997), and the description results from these sites were also incorporated when revising the isopach maps in this study.

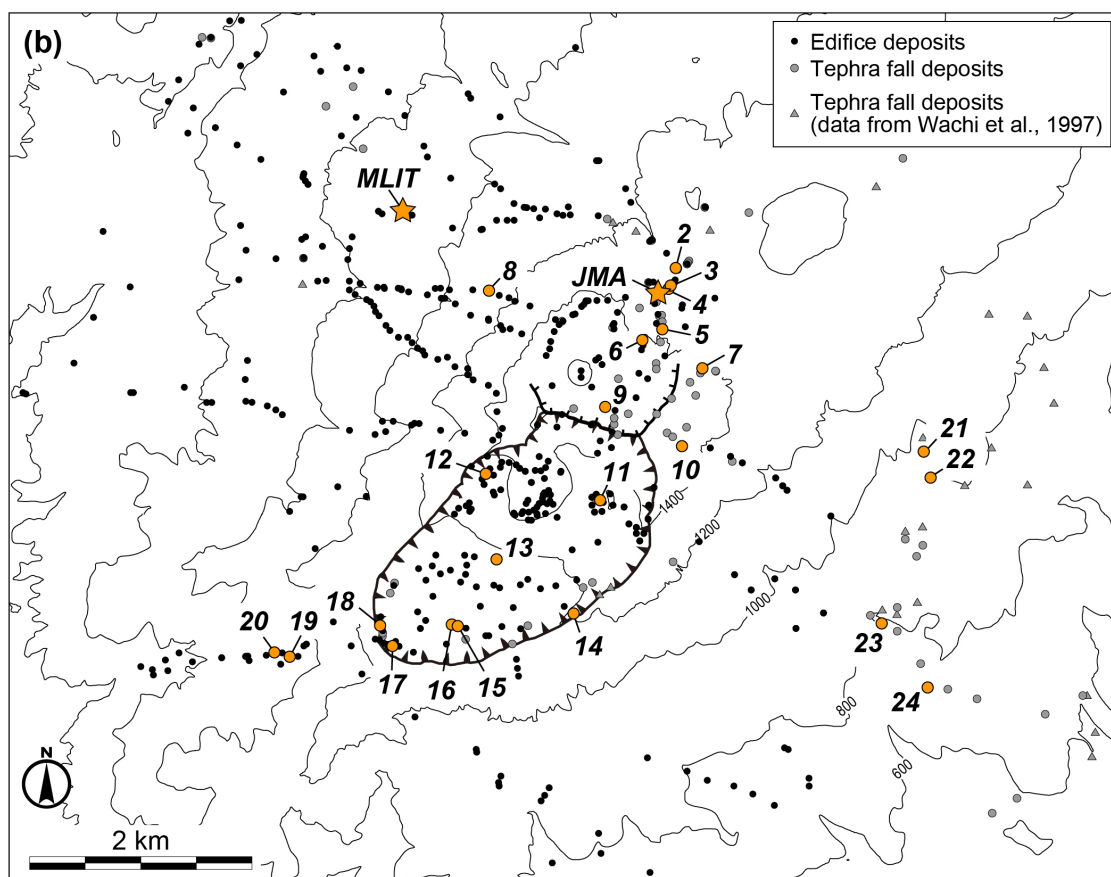


Figure 2-7 (continued)

2-4. Topography

Fig. 2-3 shows a red relief image map of the area surrounding Akita-Komagatake. The volcano is a stratocone with Otake as its peak (Otake stratocone), and it is flanked by two calderas on its northern and southern slopes, referred to as the Northern Caldera and Southern Caldera, respectively. The Northern Caldera opens to the north and forms a ridge extending eastward from Otake. This caldera is considered a collapse scar formed by a sector collapse that occurred around 22 ka, which generated the Sendatsugawa debris avalanche deposit on the northwestern foot of the volcano (Doi et al., 1997; Geospatial Information Authority of Japan, 2018). The Southern Caldera is an elliptical depression approximately 3 km in its long axis and 1.5 km in its short axis, elongated in the NE–SW direction (Fig. 2-8). The caldera floor slopes upward from the southwest to the northeast. The caldera rim is not perfectly circular; rather, it appears to consist of two or three adjoining depressions aligned from southwest to northeast (Fig. 2-8).

Within both the Northern and Southern Calderas, post-caldera edifices have formed. In the Northern Caldera, multiple edifices such as Katakuradake and Onamedake have formed, filling the caldera interior. Lava flows sourced from these edifices extend down to the northern and northwestern slopes. In the Southern Caldera, the edifices of Minamidake, Kodake, and Medake are distributed, with lava flows from Kodake and Medake nearly filling the caldera interior, and some flows spilling over the caldera rim to reach the southwestern slopes. Compared to the Otake stratocone, the post-caldera edifices exhibit remarkably well-preserved topography, and lava microtopography, such as lava channels and levees, remains clearly visible.

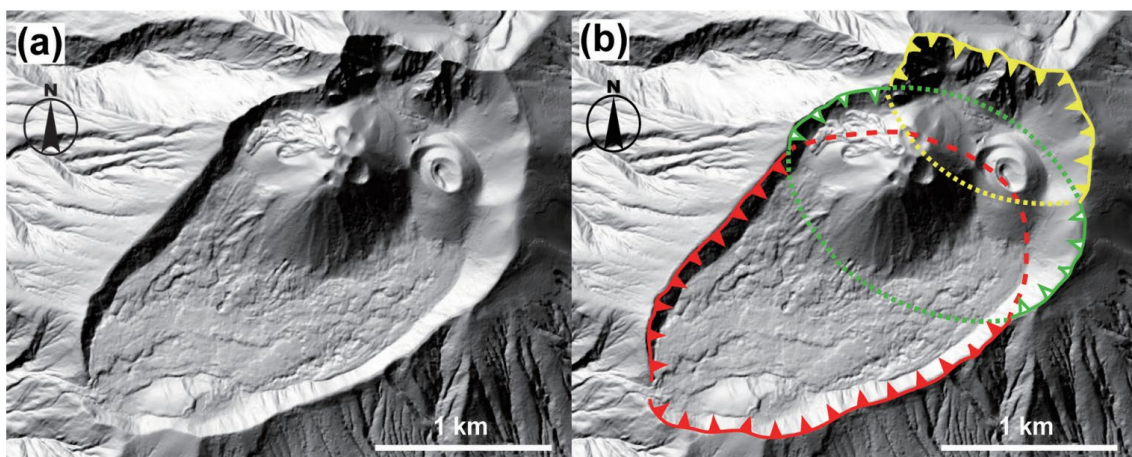


Figure 2-8 (a) Shaded digital elevation model (DEM) of the southern caldera of Akita-Komagatake volcano. Source: Geospatial Information Authority of Japan (GSI) web site. (b) Annotated map showing the three craters that might contribute the caldera formation.

2-5. Tephrostratigraphy

2-5-1. Overview

Wachi et al. (1997) defined tephra fall deposits bounded by soils as individual units and recognized 13 tephra units derived from Akita-Komagatake from the late Pleistocene to the present, naming them AK13 to AK1 in ascending order. In this study, I re-examined its stratigraphy and their tephra stratigraphy was confirmed to be essentially correct. Furthermore, examinations of facies at proximal localities in this study provided more detailed descriptions of AK13, AK12, AK4 and AK1 than those reported by Wachi et al. (1997). A schematic column of the tephra fall deposits reconstructed in this study is shown in Fig. 2-9. The thickness of each tephra fall units at the described localities are presented in Fig. 2-10, and the isopach maps constructed based on these thickness data are shown in Fig. 2-11. The descriptions of each tephra fall unit at the type localities are summarized in Table 2-1, and all ^{14}C dating results obtained in this study are listed in Table 2-2.

Fujinawa et al. (2004) proposed a new tephra fall unit, AK3.5, between AK4 and AK3. However, they described AK3.5 at only a single locality, and that site is situated within a landslide area where large amounts of colluvial deposits are present. In contrast, although this study examined the stratigraphy of this stratigraphic order at multiple localities, no tephra fall deposit corresponding to AK3.5 was identified. Therefore, AK3.5 is interpreted in this study to represent a secondary deposit, such as colluvium, rather than a primary tephra fall unit, and we conclude that such a tephra does not exist.

2-5-2. Individual Tephra Fall Unit

AK13 (Wachi et al., 1997)

This unit was originally named the Koiwai Pumice (Nakagawa et al., 1963), but Wachi et al. (1997) described its stratigraphy from medial to distal sites and newly designated it as AK13. This unit originates from the central to southern part of the Southern Caldera and has a main dispersal axis extending toward the east and northeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality was set at locality 23 (Fig. 2-7), approximately 5 km east of Otake. At the type locality, this unit overlies the widespread tephra To-HP from the Towada volcano (15,500 cal. BP; Machida and Arai, 2003) with a 2-cm-thick soil layer in between, and is in turn overlain by AK12. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.24 DRE km³, and its eruption age is estimated at 13,950 cal. BP.

At the type locality, the thickness of this unit is 215 cm. Based on its stratigraphy, the unit is divided into three subunits from the bottom: K3P to K1P (Wachi et al., 1997). The lowermost subunit, K3P, is 90 cm thick and consists of poorly vesiculated bluish-black scoria in a clast-supported, well-sorted scoria fall deposit (Fig. 2-12a). Overall, it shows upward coarsening. The scoria is somewhat rounded, with an average grain size of about 0.5 cm in the lower part and increasing to ~1 cm in the upper part, with a maximum grain size of 2.5 cm. The middle subunit, K2P, is approximately 100 cm thick and consists of clast-supported, well-sorted black to bluish-black scoria fall deposit (Fig. 2-12a). K2P also shows upward coarsening. The scoria is more vesiculated than those in K3P, with an average grain size of 1.5 cm in the lower part, increasing upward to ~2 cm, and a maximum grain size of 5.5 cm. The uppermost subunit, K1P, is 25 cm thick and consists of clast-supported, well-sorted blackish-gray scoria fall deposit (Fig. 2-12a). Compared to the lower subunits, it exhibits a slightly more compact texture. The scoria is poorly vesiculated, with an average grain size of ~1.2 cm and a maximum grain size of 3 cm.

The juvenile material of this unit is olivine-bearing orthopyroxene-clinopyroxene

basaltic andesite or olivine-bearing clinopyroxene-orthopyroxene basaltic andesite.

AK12 (partially redefined from Wachi et al., 1997)

This unit was originally named the Yanagisawa Pumice (Nakagawa et al., 1963) or Ak-g (Inoue, 1980) but Wachi et al. (1997) described its stratigraphy from medial to distal sites and newly designated it as AK12. The unit originates near the northern part of the Southern Caldera and has a main axis of distribution toward the east-northeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, same as AK13, the type locality of AK12 was set at locality 23 (Fig. 2-7), located approximately 5 km east of Odake. At the type locality, the unit overlies AK13, separated by a soil layer approximately 6 cm thick. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.40 DRE km³.

The thickness of this unit at the type locality exceeds 510 cm. Based on lithofacies, the unit was previously divided into three subunits from the base: Y3P to Y1P (Wachi et al., 1997). In this study, a distinct tephra fall deposit was recognized beneath Y3P, which was newly designated as subunit Y4P. In addition, Y2P was further subdivided into Y2P-L and Y2P-U based on differences in the types of juvenile materials. The newly identified Y4P consists of a gray-white, clay-rich ash layer less than 1 cm thick, exhibiting poor continuity and occurring in patchy distributions (Fig. 2-12b). No juvenile material was observed within Y4P. Y3P has a thickness of approximately 35 cm and consists of a fine-grained, pinkish-brown, sandy volcanic ash layer with moderately poor sorting and showing cross-stratification (Fig. 2-12b). Based on its lithofacies, it is interpreted as a pyroclastic surge deposit. Y3P contains accretionary lapilli, as well as pumice and lithic fragments. Several thin layers (a few millimeters to ~2 cm thick) of pumice-bearing volcanic ash, volcanic sand, and lithic-rich concentrations are intercalated within the unit. The pumice is yellowish-brown, highly vesicular, and some fragments show fibrous volcanic glass.

The average pumice clast diameter is approximately 1 cm, but clasts exceeding 10 cm are occasionally present, with a maximum diameter of 17 cm. Y2P is a clast-supported, well-sorted fall deposit (Fig. 2-12b). The juvenile material of Y2P-L is predominantly pumice, whereas Y2P-U consists mainly of scoria, with subordinate pumice and banded or gray pumice. The thicknesses are approximately 115 cm for Y2P-L and 140 cm for Y2P-U. In Y2P-L, the lower part is primarily clast-supported, with fine volcanic ash filling the gaps between pumice clasts, while the middle to upper parts contain almost no fine ash. The pumice is highly vesicular and shows upward coarsening (lower part: mean clast diameter ~1.5 cm, maximum ~4 cm; middle to upper part: mean ~2.5 cm, maximum ~6.5 cm). At the type locality, the top of Y2P-L includes two layers: a coarse, sandy pumice fall layer (~5 cm thick) and an overlying pumice layer (~11 cm thick) coated with brown volcanic ash (mean clast diameter ~1.8 cm). In Y2P-U, the juvenile material is composed of pumice as well as prominent banded and gray pumice and black scoria. These clasts have a mean diameter of ~2.5 cm and a maximum of ~9 cm. Compared with pumice in Y3P and Y2P-L, pumice in Y2P-U is less vesicular and slightly grayish. The banded/gray pumice and scoria are even less vesicular than the pumice. Y1P consists of interbedded brown to yellowish-brown fine volcanic ash and clast-supported, well-sorted fall deposits (Fig. 2-12c), with volcanic lapilli also present within the ash layers. At the type locality, Y1P has a thickness of over 220 cm. The juvenile material and its characteristics are similar to those of Y2P-U, with pumice being most abundant, followed by banded/gray pumice and scoria. All of these clasts are less vesicular than the pumice in Y2P-L. The juvenile clasts have an average grain size of about 2.5 cm and a maximum of about 4 cm in the coarse part.

Pumice is clinopyroxene–orthopyroxene andesite to dacite, banded/gray pumice and scoria are olivine–orthopyroxene–clinopyroxene andesite to basaltic andesite.

AK11 (Wachi et al., 1997)

This unit, together with the overlying AK10 and AK9, was grouped as AK-f by Inoue (1980). However, Wachi et al. (1997) identified soil layers between them and subdivided AK-f into three distinct tephra units. The isopach map of this unit was constructed for the first time in this study (Fig. 2-11), and it revealed that the unit originated around the Northern Caldera and has its main dispersal axis toward the east. In this study, locality 21 (Fig. 2-7), located about 3.5 km east of Otake, is designated as the type locality. At the type locality, the unit overlies AK12 with an intervening 18 cm-thick soil and is overlain by AK10, described later. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.026 DRE km³, and its eruption age is 11,640 cal BP.

At the type locality, this unit consists of a dark bluish-gray, coarse-grained, sandy volcanic ash layer with a thickness of 17 cm. This unit commonly contains a layer enriched in reddish-brown scoria, which serves as one of the criteria for distinguishing it from AK10, a similar sandy scoria deposit. The scoria, which is the essential material of this unit, is highly vesiculated, and its maximum grain size at the type locality is about 8 mm. The juvenile material of this unit is olivine–clinopyroxene–orthopyroxene basaltic andesite.

AK10 (Wachi et al., 1997)

As mentioned above, the deposit previously referred to as AK-f was subdivided into three units—AK9, AK10, and AK11—based on the presence of intervening soil layers (Wachi et al., 1997). The isopach map of this unit was constructed for the first time in this study (Fig. 2-11), and it revealed that the unit originated around the Northern Caldera and has its main dispersal axis toward the east. In this study, locality 21 (Fig. 2-7), located approximately 3.5 km east of Otake, is designated as the type locality. At the type locality, the layer overlies AK11 with a 4 cm-thick soil layer in between and is overlain by AK9. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.022 DRE km³, and the eruption age is 11,420

cal BP.

At the type locality, this unit consists of dark bluish-black to bluish-gray coarse-grained sandy volcanic ash with a thickness of approximately 16 cm. The essential material is dark bluish-black scoria with good vesicularity, and the maximum grain size at the type locality is about 5 mm. The juvenile material is a clinopyroxene–orthopyroxene andesite.

AK9 (Wachi et al., 1997)

As mentioned above, the deposit previously referred to as AK-f was subdivided into three units—AK9, AK10, and AK11—based on the presence of intervening soil layers (Wachi et al., 1997). This unit originates from around the Northern Caldera and extends mainly toward the northeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality is defined at locality 21 (Fig. 2-7), approximately 3.5 km east of Otake. At the type locality, this unit overlies AK10 with an intervening 4 cm-thick soil layer and is overlain by AK8, described later. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.053 DRE km³, and the eruption age is 9,390 cal. BP.

At the type locality, this unit is 53 cm thick. The lower 35 cm consists of a clast-supported, well-sorted scoria fall deposit composed of highly vesiculated dark bluish-black scoria. The scoria fragments are moderately rounded, with an average grain size of 0.7 cm and a maximum grain size of 1.9 cm. The overlying 13 cm also comprises a clast-supported, well-sorted dark bluish-black scoria fall deposit, within which several thin, silt- to sand-sized layers of the same composition are intercalated. The uppermost 5 cm consists of a grayish-brown, clayey volcanic ash layer containing scattered scoria fragments of the same type. The juvenile material of this unit is an olivine-bearing orthopyroxene–clinopyroxene basaltic andesite.

AK8 (Wachi et al., 1997)

This unit was originally named the Horikiri Pumice (Nakagawa et al., 1963) or Ak-e (Inoue, 1980) but Wachi et al. (1997) described its stratigraphy from medial to distal sites and newly designated it as AK8. The unit originates near the Northern Caldera and has a main axis of distribution toward the east (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality of AK8 was set at locality 21 (Fig. 2-7), located approximately 3.5 km east of Odake. At the type locality, the unit overlies AK9, separated by a soil layer approximately 5 cm thick. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.057 DRE km³, and the eruption age is 9,300 cal. BP.

At the type locality, this unit is 169 cm thick and is subdivided into three subunits, H3P to H1P, based on lithofacies. The lowermost subunit, H3P, is a 4.5 cm thick milky-white, clayey volcanic ash layer containing sparsely distributed, poorly vesiculated black scoria with a maximum grain size of 1.2 cm. H2P is a 110 cm thick, well-stratified, clast-supported, and well-sorted black scoria fall deposit. The lower part of H2P is dominated by scoria, whereas the middle part mainly consists of lithic fragments—including lava, altered rock, and tuff clasts—and the upper part again becomes scoria-dominant. The vesicularity of scoria is generally low, with an average grain size of ~1.7 cm in the lower part and ~0.7 cm in the upper part. H1P, more than 55 cm thick, is a strongly consolidated, well-stratified, clast-supported, and well-sorted brownish scoria fall deposit. In addition to the black scoria, H1P contains abundant lithic fragments such as lava, altered rock, and tuff. The scoria in this subunit is poorly vesiculated and slightly rounded, with an average grain size of 1.0 cm and a maximum grain size of 1.5 cm. The juvenile material of this unit is an olivine-bearing clinopyroxene andesite.

AK7 (Wachi et al., 1997)

This unit was originally named AK-e (Inoue, 1980), but Wachi et al. (1997) described

its stratigraphy from medial to distal sites and newly designated it as AK7. The unit originates near the Northern Caldera and has a main axis of distribution toward the east-northeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality of AK7 was set at locality 21 (Fig. 2-7), located approximately 3.5 km east of Otake. At the type locality, the unit overlies AK8, separated by a soil layer approximately 15 cm thick. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.030 DRE km³, and the eruption age is 8,050 cal BP.

The cumulative thickness of this unit at the type locality is 38 cm. The lower 20 cm consists of a weakly indurated, well-sorted, sandy scoria layer, with the lower 9 cm being overall dark bluish-black and the upper 11 cm reddish-brown. The scoria in the upper and lower parts is of the same type, with a maximum clast size of 0.5 cm. The uppermost 18 cm is a strongly consolidated bluish-gray, silt-rich volcanic ash layer, containing no essential clasts. The juvenile material of this unit is augite–olivine basaltic andesite.

AK6 (Wachi et al., 1997)

This unit was originally named AK-d (Inoue, 1980), but Wachi et al. (1997) described its stratigraphy from medial to distal sites and newly designated it as AK6. The unit originates near the Northern Caldera and has a main axis of distribution toward the east (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality of AK6 was set at locality 21 (Fig. 2-7), located approximately 3.5 km east of Otake. At the type locality, the unit overlies AK7, separated by a soil layer approximately 7 cm thick. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.020 DRE km³, and the eruption age is 7,290 cal BP.

The cumulative thickness of this unit at the type locality is 48 cm. The lower 5 cm consists of a reddish-brown silt-rich volcanic ash layer with scattered black scoria. The overlying

43 cm is a clast-supported, well-sorted scoria fall deposit composed of highly vesicular dark brown scoria. The scoria clasts are angular, with a mean diameter of 1.2 cm and a maximum diameter of 2.5 cm. The juvenile material of this unit is augite–olivine basalt.

AK5 (Wachi et al., 1997)

This unit, together with the overlying AK4, was grouped as AK-c by Inoue (1980). However, Wachi et al. (1997) identified soil layers between them and subdivided AK-c into two distinct tephra units. The isopach map of this unit was constructed for the first time in this study, and it revealed that the unit originates near the Onamedake and has a main axis of distribution toward the east-northeast (Fig. 2-11). In this study, the type locality of AK5 is set at locality 4 (Fig. 2-7), located approximately 1.5 km northeast of Odake. At the type locality, the unit overlies Onamedake 1st edifice, separated by a soil layer approximately 14 cm thick. According to the procedures described in Section 2-3, the eruption age is 3,340 cal BP.

At the type locality, this unit is a 2.5 cm thick white, clay-rich volcanic ash layer. Although it contains lithic clasts such as lava fragments and altered rock fragments, no scoria or other juvenile material is present, indicating that the deposit originated from a phreatic eruption.

AK4 (Wachi et al., 1997)

As mentioned above, the deposit previously referred to as AK-c was subdivided into two units—AK4 and AK5—based on the presence of intervening soil layers (Wachi et al., 1997). The isopach map of this unit was constructed for the first time in this study, and it revealed that the unit originates near the Onamedake and has a main axis of distribution toward the east (Fig. 2-11). In this study, the type locality of AK4 is set at locality 4 (Fig. 2-7), located approximately 1.5 km northeast of Odake. At the type locality, the unit overlies AK5, separated by a soil layer approximately 2 cm thick. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.0066 DRE km³, and the eruption age is 2,220 cal BP.

The cumulative thickness of this unit at the type locality is 76 cm (Fig. 2-13). The lowermost 10 cm of this unit consists of a strongly consolidated reddish-brown silt-rich volcanic ash layer, overlain by a 37 cm thick white to yellowish-brown clay-rich volcanic ash layer. These layers contain abundant lithic clasts, such as lava and altered rock fragments, but no scoria or other juvenile material is present, indicating that they were deposited by phreatic eruptions. The uppermost 29 cm is a well-stratified, clast-supported, well-sorted brown fallout scoria layer. In addition to brown scoria, this layer contains numerous lava fragments, altered rock fragments, and tuff clasts (Fig. 2-14). The scoria exhibits moderately high vesicularity, with some show fractured surfaces and cauliflower-shaped textures. The scoria has an average grain size of 0.7 cm and a maximum of 1.6 cm. The juvenile material of this unit is olivine-augite-plagioclase basaltic andesite.

AK3 (Wachi et al., 1997)

This unit was originally named AK-b (Inoue, 1980), but Wachi et al. (1997) described its stratigraphy from medial to distal sites and newly designated it as AK3. The unit originates in the northern part of the Southern Caldera and has a main axis of distribution toward the east-southeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality of AK3 was set at locality 24 (Fig. 2-7), located approximately 4.0 km southeast of Otake. At the type locality, a soil layer approximately 25 cm thick has developed, and the unit is overlain by AK2, as described below. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.022 DRE km³, and the eruption age is 2,110 cal BP.

The cumulative thickness of this unit at the type locality is 28 cm. The lowermost 4 cm consists of a well-sorted bluish-black sandy scoria layer, and the overlying 5 cm is a well-sorted brownish sandy scoria layer with well-stratified. Both layers contain compositionally

homogeneous scoria, and in the upper layer, lithic clasts such as lava fragments and altered rock fragments are also abundant. The overlying 7 cm is a strongly consolidated light brown silty volcanic ash layer, within which accretionary lapilli approximately 2 mm in diameter are present. The uppermost 12 cm is a weakly consolidated, grayish-brown to bluish-black fine sandy volcanic ash layer. The juvenile material of this unit is olivine–clinopyroxene–orthopyroxene basaltic andesite.

AK2 (Wachi et al., 1997)

This unit, together with the overlying AK1, was grouped as AK-a by Inoue (1980). However, Wachi et al. (1997) identified soil layers between them and subdivided AK-a into two distinct tephra units. The unit originates in the northern part of the Southern Caldera and has a main axis of distribution toward the southeast (Fig. 2-11; the isopach map reconstructed in this study exhibits the same pattern as that of Wachi et al. (1997)). In this study, the type locality of AK2 was set at locality 24 (Fig. 2-7), located approximately 4.0 km southeast of Odake. At the type locality, the unit overlies AK3, separated by a soil layer approximately 6 cm thick, and the unit is overlain by AK1, as described below. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.0029 DRE km³, and the eruption age is 1,510 cal BP.

At the type locality, this unit has a thickness of 9 cm and consists of a well-sorted, clast-supported scoria fall deposit composed of highly vesicular dark brown scoria. The scoria is angular, with an average grain size of 0.3 cm and a maximum grain size of 0.6 cm. The juvenile material of this unit is an olivine basalt.

AK1 (partially redefined from Wachi et al., 1997)

As mentioned above, the deposit previously referred to as AK-a was subdivided into two units—AK1 and AK2—based on the presence of intervening soil layer (Wachi et al., 1997). The unit originates in the northern part of the Southern Caldera and has a main axis of distribution

toward the southeast (Fig. 2-11; in this study, the proximal thickness distribution was clarified in detail compared with Wachi et al. (1997)). In this study, the type locality of AK1 was set at locality 24 (Fig. 2-7), located approximately 4.0 km southeast of Otake. At the type locality, the unit overlies AK2, separated by a soil layer approximately 4 cm thick, and the unit is directly overlain by To-a tephra (915 CE; Machida and Arai, 2003), a widespread tephra derived from the Towada Volcano. According to the procedures described in Section 2-3, the calculated volume of this unit is 0.011 DRE km³, and the eruption age is 1,250 cal BP.

The cumulative thickness of this unit at the type locality is 345 cm (Fig. 2-15). Based on lithofacies, the unit is divided into three subunits from the base: AK1-3, AK1-2, and AK1-1. The lowermost subunit, AK1-3, is 115 cm thick and consists of a well-stratified, clast-supported, well-sorted brown scoria fall deposit. In addition to scoria, AK1-3 contains numerous lithic clasts, including lava fragments, altered rock fragments, and tuff fragments. This subunit shows general upward fining: the average grain size is 1.5 cm (maximum 3.5 cm) at the base and 0.4 cm (maximum 0.8 cm) at the top. The scoria exhibits poor vesicularity, with abundant fractured and cauliflower-shaped clasts, and tuff fragments occur universally as xenoliths. AK1-2, 130 cm thick, is a well-stratified, clast-supported, well-sorted dark brown to black scoria fall deposit dominated by scoria with almost no lithic fragments. Scoria in AK1-2 is highly vesicular and free of xenoliths, with an average grain size of 1.0 cm and a maximum of 2.3 cm. The uppermost subunit, AK1-1, is 100 cm thick and comprises a well-stratified, weakly consolidated dark scoria fall deposit. The scoria is of similar composition to that in AK1-2, with an average grain size of 0.8 cm and a maximum of approximately 1.5 cm. The juvenile material of this unit is olivine–clinopyroxene basaltic andesite or clinopyroxene–olivine basaltic andesite.

2-5-3. Tephra Chronology

(1) Eruption Age

Previous ages of the tephra fall deposits were reported by Wachi et al. (1997). However, all of these ages were measured more than 25 years ago, and thus the error ranges of the individual age were relatively large. Furthermore, even for the same tephra fall deposit, there was considerable variability among reported ages, and the precise eruption ages remained unclear. The ages obtained in this study are consistent with the stratigraphy and show no contradictions with the stratigraphic relationships to widespread tephra (Table 2-2). Therefore, the ages obtained in this study are adopted as the eruption ages of the respective tephra fall deposit.

(2) Dormancy

This study identified five stratigraphic intervals in which thick soil are often developed: (i) beneath AK13, (ii) between AK12 and AK11, (iii) between AK8 and AK7, (iv) between AK6 and AK5, (v) above AK1. In contrast, the other stratigraphic intervals contain only thin soil a few centimeters thick, and the age differences between the overlying and underlying units are at most several hundred years (Fig. 2-9). On the other hand, in the stratigraphic intervals where thick soil are intercalated (ii–iv), age differences of more than 1,000 years are recognized between the bounding tephra fall units. As shown in Fig. 2-16, which plots cumulative soil thickness from surface on the vertical axis against radiocarbon ages obtained immediately beneath each tephra fall units on the horizontal axis, all data points are well approximated by a linear trend corresponding to a soil development rate of 0.098 mm/year. The coefficient of determination (R^2) for this regression is as high as 0.987, indicating extremely small scatter. This result demonstrates that estimating soil development duration based on the loesschronometry (Hayakawa, 1991) is valid in this study area.

In this study, the loesschronometry was applied to stratigraphic intervals (i) to (v) to estimate the duration of soil development between tephra fall deposits and to evaluate whether these intervals correspond to dormancy period. Here, stratigraphic interval in which volcanic

activity was judged to be absent for a prolonged time—namely, period lacking tephra deposit or historical eruption record—are regarded as interval of low eruptive activity and are defined as dormancy periods. Because stratigraphic intervals containing only thin soil generally correspond to age differences of several hundred years, interval with estimated age differences exceeding 1,000 years are classified as dormancy period. Based on the results of loesschronometry, radiocarbon dating, and stratigraphic relationship with widespread tephra of known age, this study concluded that all five stratigraphic intervals represent dormancy periods. Details of each dormancy period are described below.

(i) Beneath AK13

In this stratigraphic interval, soil more than 75 cm thick is developed, with an estimated formation period of 7,653 years. In this study, radiocarbon dating was performed on soil collected 75 cm beneath AK13, yielding an age of 19,750 cal. BP (Fig. 2-17a). This age is approximately 6,000 years older than that of AK13 (13,950 cal. B). It should be noted that, in reality, soil development extends even deeper than the sampled depth. Based on these results, this study concluded that a dormancy period of at least 6,000 years existed prior to the deposition of AK13.

As noted in the topographical section, the Otake stratocone is clearly less well preserved than the post-caldera edifices (the Northern and Southern Edifices). Although this may partly reflects the effects of tephra deposition associated with post-caldera activity, it may also indicates a substantial temporal gap between the construction of the stratovolcano and the caldera-forming and post-caldera activities. As described later, AK13 was produced by the Southern Caldera-forming eruption. Therefore, the possibility that a dormancy existed prior to AK13 is also supported by the state of topographical preservation. Based on these results, a long-term age gap is inferred between the activity that formed the Otake stratocone and the subsequent eruptions.

Therefore, in this study, the activity of the Otake stratocone is defined as that of the “Otake volcano,” whereas the Southern Caldera-forming eruption and the subsequent activity are defined as the “Akita-Komagatake volcano” in the narrow sense.

(ii) Between AK12 and AK11

In this stratigraphic interval, soil approximately 18 cm thick is developed, with an estimated formation period of 1,837 years. Radiocarbon ages of 13,400 cal. BP and 11,640 cal. BP have been obtained for AK12 and AK11, respectively, yielding an age difference of approximately 1,810 years. Based on these results, this study concluded that a dormancy period of approximately 1,800 years existed between AK12 and AK11.

(iii) Between AK8 and AK7

In this stratigraphic interval, soil approximately 15 cm thick is developed, with an estimated formation period of 1,531 years. Radiocarbon ages of 9,300 cal. BP and 8,050 cal. BP have been obtained for AK8 and AK7, respectively, yielding an age difference of approximately 1,250 years. Based on these results, this study concluded that a dormancy period of approximately 1,250 years existed between AK12 and AK11.

(iv) Between AK6 and AK5

In this stratigraphic interval, soil approximately 37 cm thick is developed, with an estimated formation period of 3,776 years. Radiocarbon ages of 7,290 cal. BP and 3,340 cal. BP have been obtained for AK6 and AK5, respectively, yielding an age difference of approximately 3,950 years. Based on these results, this study concluded that a dormancy period of approximately 3,700 years existed between AK12 and AK11. In this study, radiocarbon dating was conducted on soil collected immediately above AK6, yielding an age of 5,830 cal. BP (Fig. 2-17b). This age is consistent with the radiocarbon ages of AK6 (7,290 cal. BP) and AK5 (3,340 cal. BP).

(v) Above AK1

Immediately above AK1, the Towada-a tephra (915 CE) derived from Towada volcano is recognized. Above the Towada-a tephra, a surface soil of approximately 25 cm thick is developed, within which no tephra derived from this volcano is identified. Based on these observations, this study interpreted the interval of approximately 1,000 years between AK1 and the historically documented 1932 eruption as a dormancy period.

2-5-4. Overview of the Formation History Based on Tephra Fall Deposit

Based on the isopach maps of each tephra fall deposits (re)constructed in this study (Fig. 2-11), it can be inferred that AK13 and AK12 originated from the southern edifice, AK11–AK4 from the northern edifice, and AK3–AK1 again from the southern edifice. Among these, AK13 and AK12 are large-scale deposits from the southern edifice and are thus considered to have resulted from the Southern Caldera-forming eruptions. Therefore, the volcanic activity of this volcano can be summarized as occurring sequentially from the southern edifice (Southern Caldera-forming eruptions) to the northern edifice, and then back to the southern edifice.

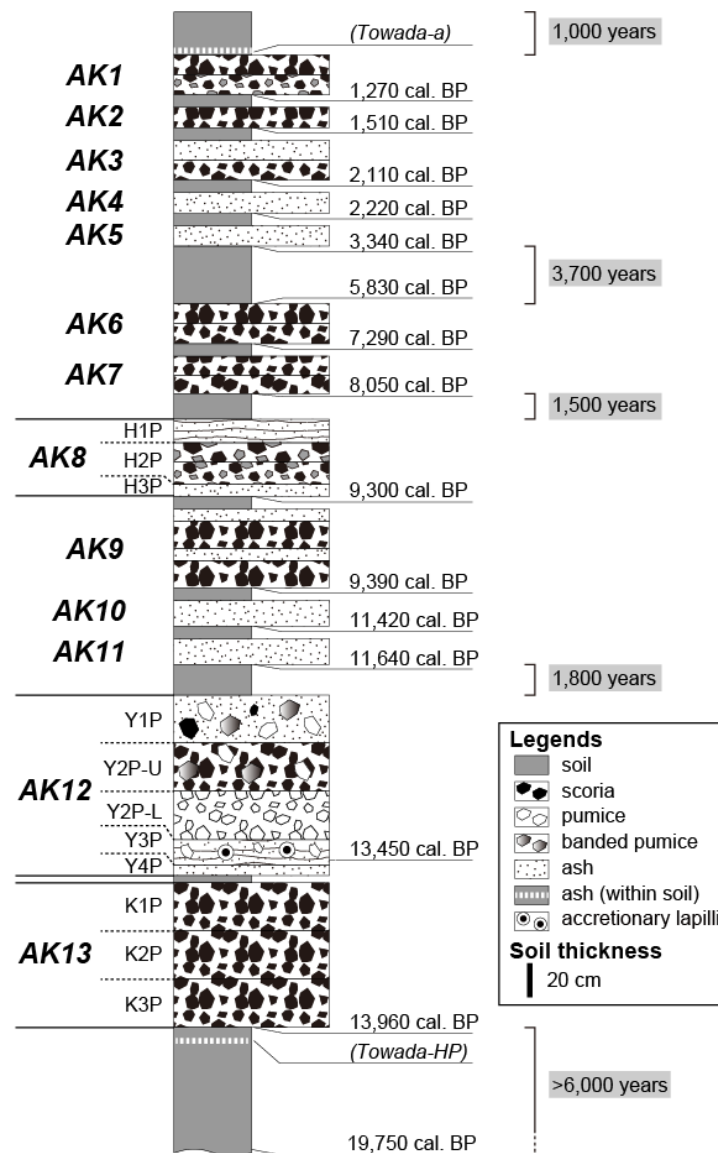


Figure 2-9 Schematic columnar section of the tephra fall deposits. In this study, as in Wachi et al. (1997), thirteen tephra fall units (AK1 to AK13) were identified, and more detailed descriptions were obtained for AK1, AK4, AK12, and AK13 (for details, see text). In addition, all age data were newly acquired. The ages shaded in gray represent the duration of the dormancy periods estimated from soil thickness based on loesschlonometry.

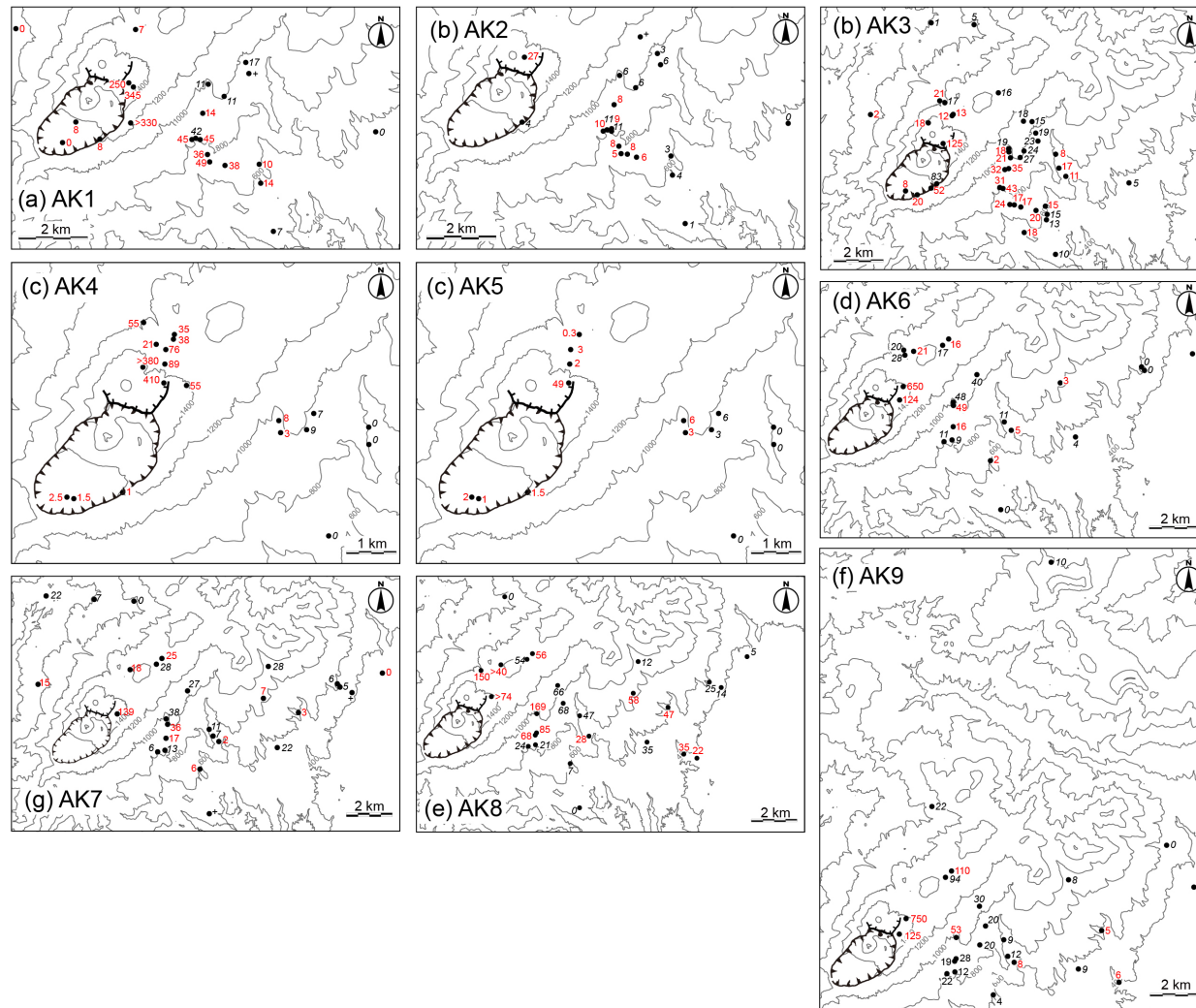


Figure 2-10 Thicknesses of tephra fall deposits at each site. Red labels indicate results (re)described in this study.

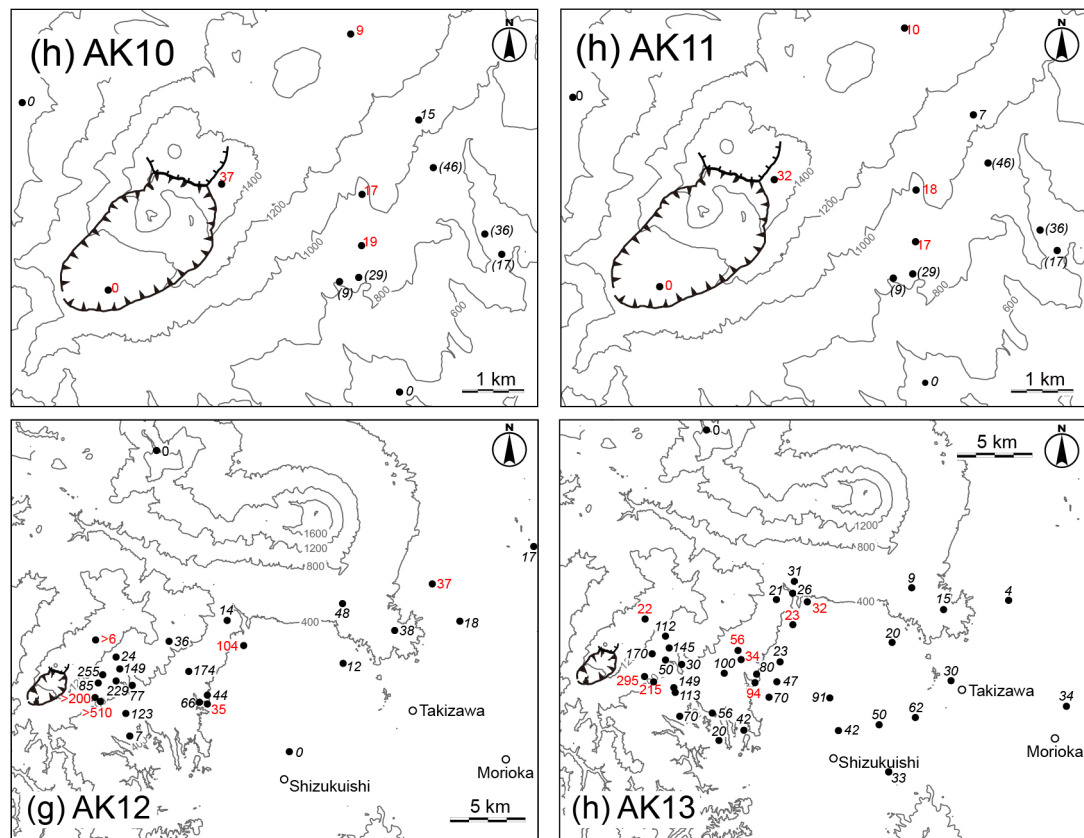


Figure 2-10 (continued)

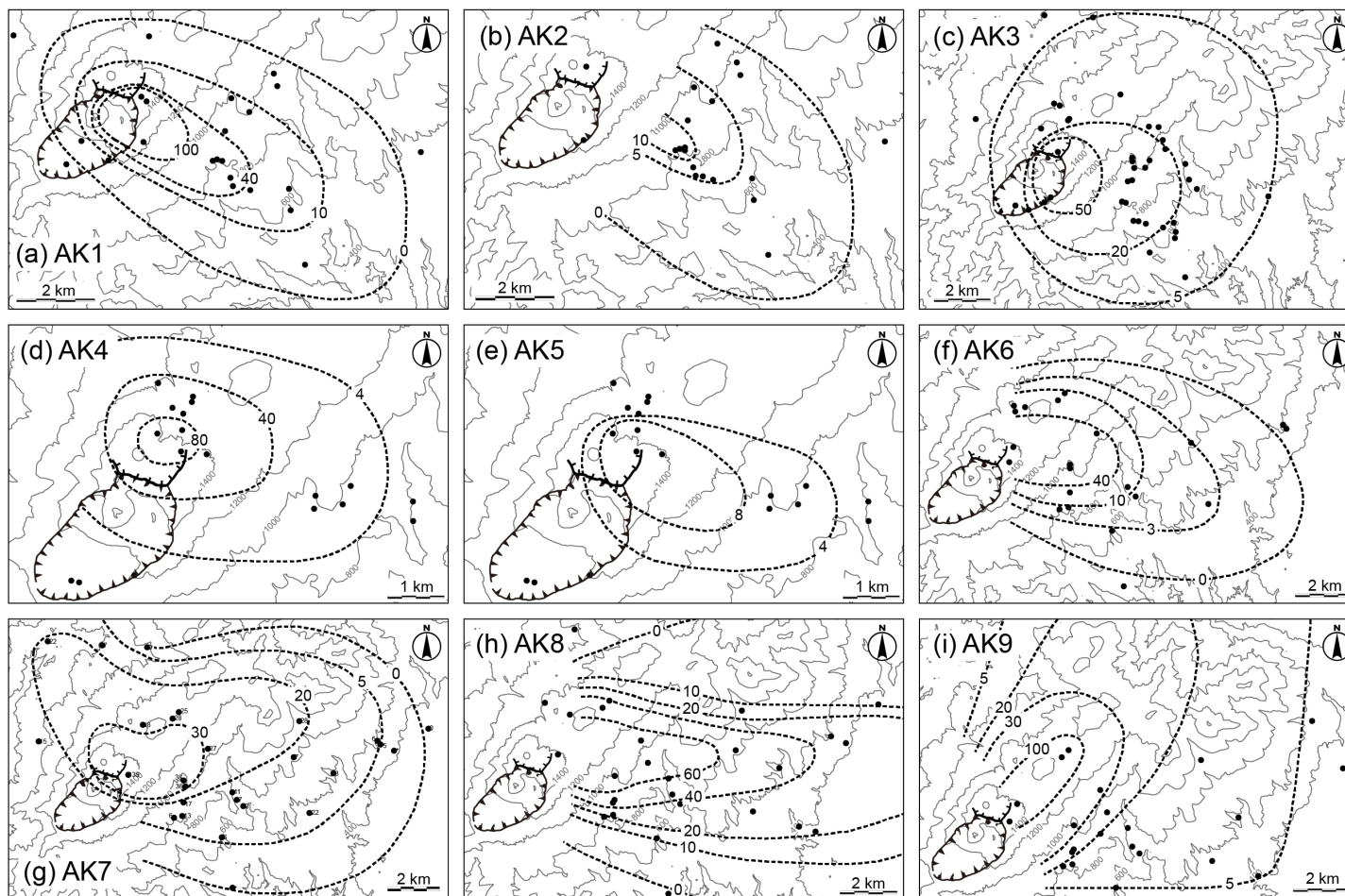


Figure 2-11 Isopach maps constructed in this study. The maps for AK4, AK5, AK10, and AK11 were newly produced in this study, and a more detailed proximal isopach map for AK1 was also generated compared with Wachi et al. (1997).

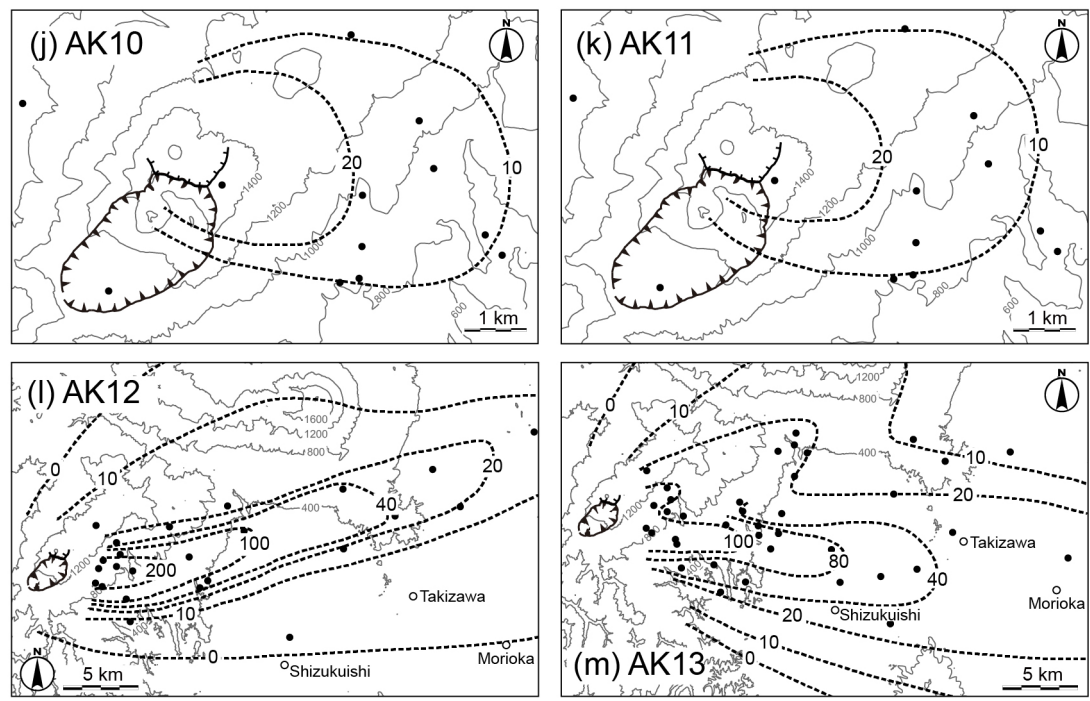


Figure 2-11 (continued)

Table 2-1 Description of tephra fall deposits at type localities. The type localities are shown in Fig. 2-7. Abbreviations: Pfa, Pyroclastic fall deposit; Afa, Ash fall deposit; Sc, Acoria; Gp, Gray pumice; Pu, Pumice; Lf, lava fragment; Al, Altered fragment; Se, Sedimentary rock fragment; Pl, Plagioclase; Ol, Olivine; Cpx, Clinopyroxene; Opx, Orthopyroxene; Opq, Opaque minerals.

Stage	Substage	Unit	Subunit	Dispersal axis	Type locality	Facies	Characteristics at the type locality		Type of juveniles	Phenocryst assemblage	Volume (km ³ DRE)
							Thickness (cm)	Maximum juvenile fragment diameter (cm)			
III	III-1	AK1	AK1-1	ESE	10	Pfa/Afa	3.0	0.8	Sc	Pl+Ol+Cpx	0.011
			AK1-2			Pfa	8.0	1.9	Sc		
			AK1-3			Pfa/Afa	36	2.1	Sc		
		AK2	SE	24	Pfa	9.0	0.6	Sc	Pl+Ol	0.0029	
		AK3	E	24	Pfa/Afa	28	0.3	Sc	Pl+Ol+Cpx+Opx+Opq	0.022	
II	II-4		AK4	E	4	Pfa/Afa	76	1.6	Sc	Pl+Ol+Cpx+Opx+Opq	0.0066
			AK5	E~ESE	4	Afa	2.5	-	-	0 (ph)	
			AK6	E	21	Pfa	48	2.5	Sc	Pl+Ol+Cpx	0.020
	II-3		AK7	ENE	21	Pfa	38	0.5	Sc	Pl+Ol+Cpx	0.030
				H1P			Pfa	>55	1.5	Sc	
	II-2	AK8	H2P	E	21	Pfa	110	3.6	Sc	Pl+Ol+Cpx+Opx+Opq	0.057
			H3P			Afa	4.5	1.2	Sc		
						AK9	NE	21	Pfa		
	II-1		AK10	E	21	Pfa	17	0.7	Sc	Pl+Cpx+Opx+Opq	0.022
			AK11	E	21	Pfa	16	0.6	Sc	Pl+Cpx+Opx+Opq	0.026
I			Y1P			Pfa/Afa	>220	4.0	Sc, Gp, Pu		
			Y2P-U			Pfa	140	9.5	Sc, Gp, Pu		
		AK12	Y2P-L	E~ENE	23	Pfa	115	6.5	Pu	Pl+Ol+Cpx+Opx+Opq	0.40
			Y3P			Pfa/Afa	35	17	Pu		
			Y4P			Afa	~1	-	-		
			K1P			Pfa	25	3.2	Sc		
		AK13	K2P	E~ESE	23	Pfa	100	5.5	Sc	Pl+Ol+Cpx+Opx+Opq	0.24
			K3P			Pfa	90	2.5	Sc		

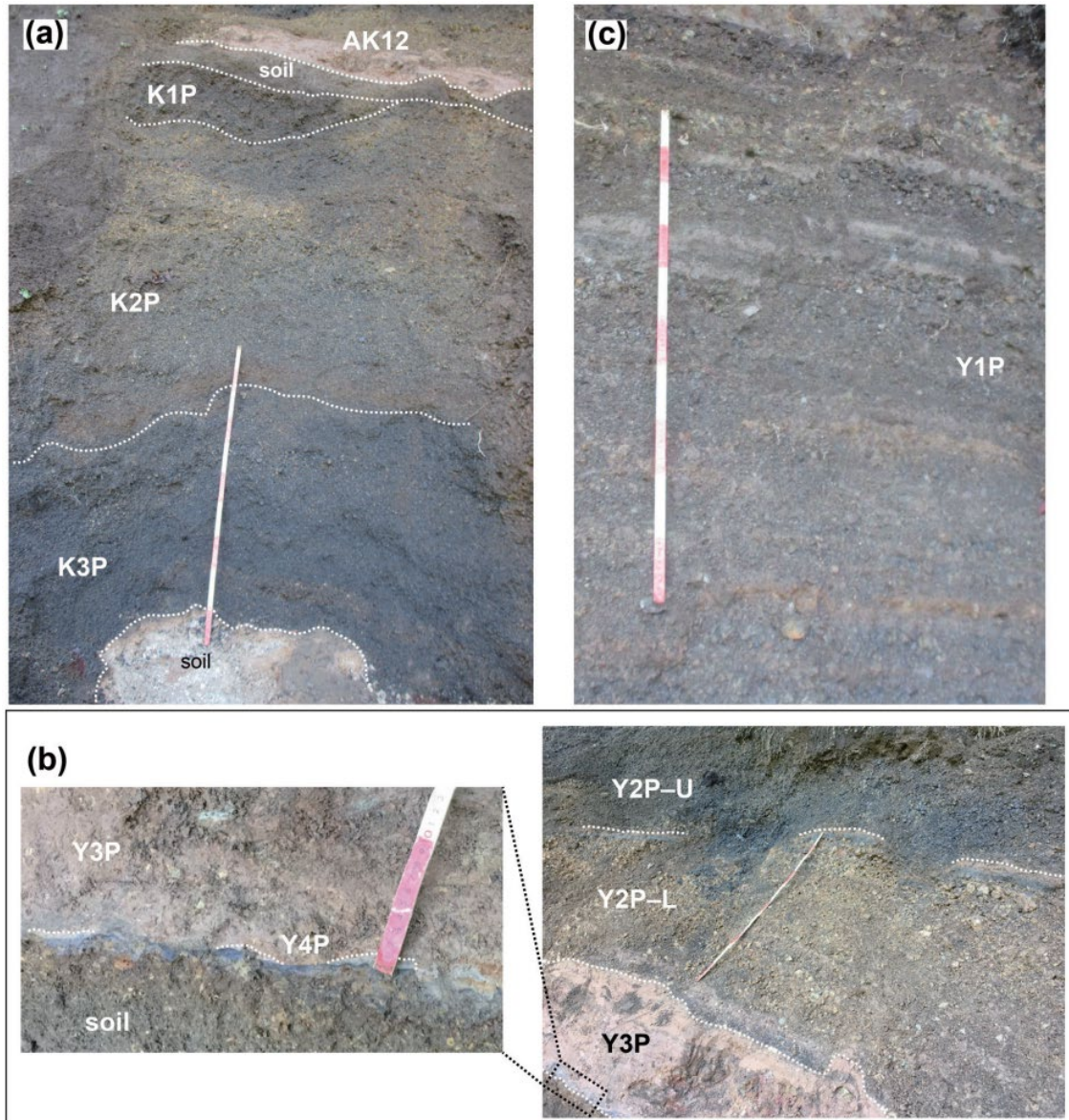


Figure 2-12 Photographs of the AK13 and AK12 tephra units at locality 23 in Fig.2-7. Scale bar is 1 m. (a) Scoria fall deposits K1P, K2P and K3P are the subunits composing the AK13 tephra separated by a soil layer from the underlying AK12 tephra. The lighter color of K2 P reflects the greater proportion of accessory and accidental materials in the unit. (b) Subunits Y2P-U, Y2P-L and Y3P in the lower part of the AK12 tephra. Unit Y2 P, defined by Wachi et al. (1997), is divided here into Y2P-U and Y2P-L; Y2P-U contains scoria and banded pumice and Y2P-L is mainly composed of pumice clasts. Unit Y3P is composed of stratified fine ash with occasional accretionary lapilli. The enlargement at left shows the newly recognized ash layer Y4P. (c) Subunit Y1P in the upper part of the AK12 tephra, consisting of alternating ash and lapilli tuff layers.

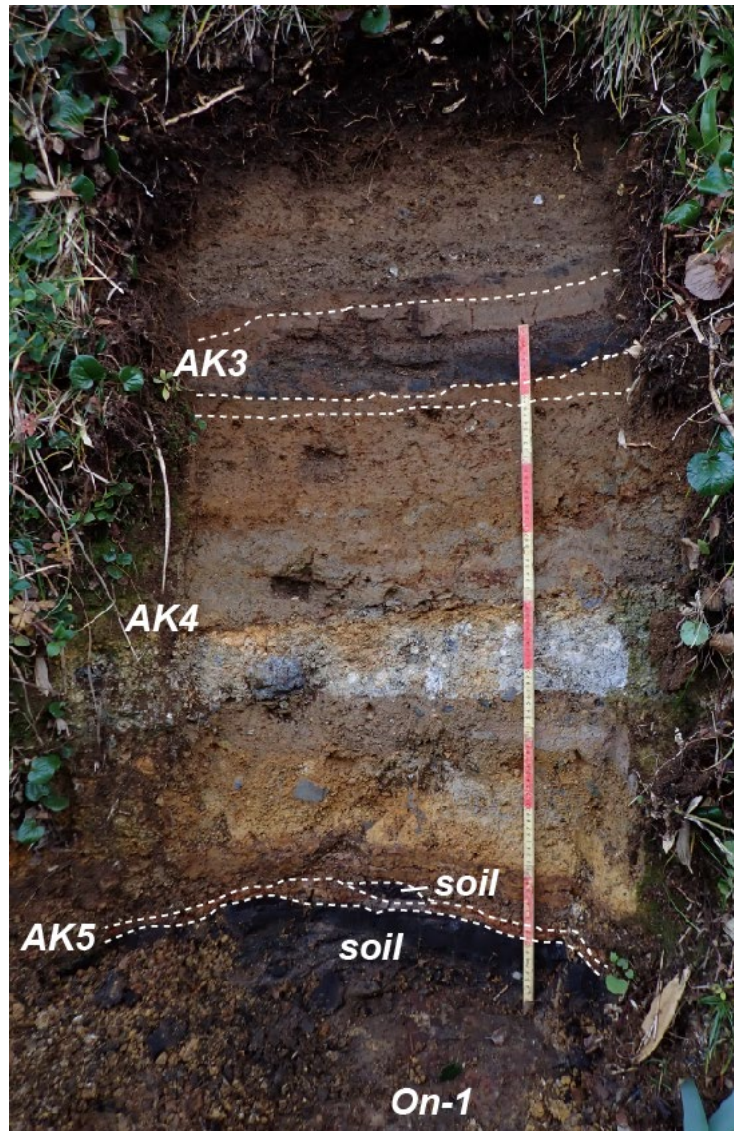


Figure 2-13 Photograph of the AK3–5 tephra units at locality 4 (Fig. 2-7). AK4 is underlain by a consolidated reddish-brown phreatic deposit, and above it occurs a milky-white to pale bluish-white phreatic deposit. A white mudflow deposit is intercalated between these deposits. The uppermost unit consists of a brownish phreatomagmatic deposit containing dark brown scoria as its juvenile material.



Figure 2-14 Photograph of the components of AK4. AK4 is composed of four types of lithic fragments: scoria, lava fragments, tuff fragments, and altered lithic fragments. The scoria fragments are angular and exhibit a fresh glassy appearance; therefore, they are interpreted as juvenile material in this study. Accordingly, this study concluded that AK4 is a phreatomagmatic eruptive deposit that involved scoria as a juvenile material.

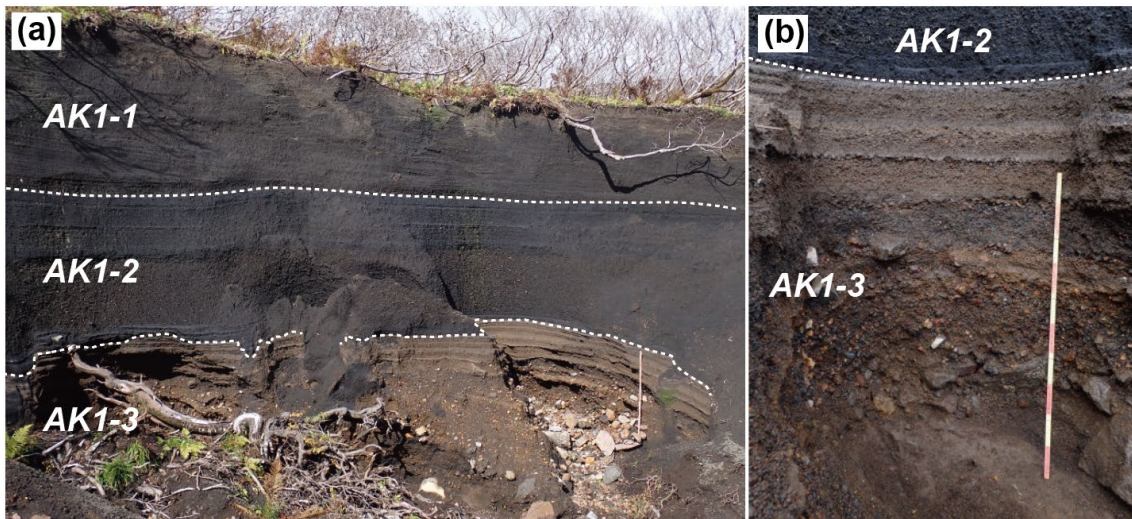


Figure 2-15 Outcrop photographs of AK1 tephra at locality 10 (Fig. 2-7). (a) Overview of the outcrop. The AK1 tephra is divided into three subunits (AK1-3 to AK1-1 in ascending order) based on its lithofacies. (b) Outcrop photograph of AK1-3. AK1-3 is richer in accidental fragments than AK1-1 and AK1-2.

Table 2-2 ^{14}C dating results obtained in this study. Locality numbers are from Fig. 2-7.

Sample	Locality	Stratigraphic order	Material	Method	Lab. No	^{14}C age (y BP)	Calendar ^{14}C age (2 σ) (cal. BP)
22AK100 D-3	24	beneath AK1	Paleosol	AMS	IAAA-221184	1,390 $\pm$ 20	1,345 – 1,285
22AK101 D-3	23	beneath AK1	Paleosol	AMS	IAAA-221187	1,280 $\pm$ 20	1,284 – 1,176
22AK100 D-2	24	beneath AK2	Paleosol	AMS	IAAA-221183	1,580 $\pm$ 20	1,523 – 1,398
22AK101 D-2	23	beneath AK2	Paleosol	AMS	IAAA-221186	1,660 $\pm$ 20	1,689 – 1,420
22AK100 D-1	24	beneath AK3	Paleosol	AMS	IAAA-221182	2,020 $\pm$ 20	2,038 – 1,889
22AK101 D-1	23	beneath AK3	Paleosol	AMS	IAAA-221185	2,260 $\pm$ 20	2,342 – 2,157
24AK-12 S-8	22	beneath AK4	Paleosol	AMS	IAAA-241031	2,000 $\pm$ 20	1,995 – 1,844
AK2-s-1	3	beneath AK4	Paleosol	AMS	IAAA-200571	2,430 $\pm$ 20	2,696 – 2,354
AK2-s-2	3	beneath AK5	Paleosol	AMS	IAAA-200572	3,200 $\pm$ 20	3,466 – 3,375
19AK117D-1	14	beneath AK5	Paleosol	AMS	IAAA-191105	2,720 $\pm$ 20	2,859 – 2,763
19AK119D-1	15	beneath AK5	Paleosol	AMS	IAAA-191106	3,780 $\pm$ 20	4,239 – 4,013
22AK78 D-1	4	beneath AK5	Paleosol	AMS	IAAA-221188	3,280 $\pm$ 20	3,563 – 3,451
24AK-12 S-7	22	beneath AK5	Paleosol	AMS	IAAA-241030	2,740 $\pm$ 20	2,871 – 2,770
25-24AK-12-S3	22	above AK6	Paleosol	AMS	IAAA-250625	5,080 $\pm$ 30	5,909 – 5,747
24AK-12 S-4	22	beneath AK6	Paleosol	AMS	IAAA-241028	6,360 $\pm$ 30	7,417 – 7,168
24AK-12 S-2	22	beneath AK7	Paleosol	AMS	IAAA-241026	7,200 $\pm$ 30	8,158 – 7,937
24AK-11 S-4	21	beneath AK8	Paleosol	AMS	IAAA-241024	8,320 $\pm$ 30	9,459 – 9,144
24AK-11 S-3	21	beneath AK9	Paleosol	AMS	IAAA-241023	8,380 $\pm$ 30	9,483 – 9,296
24AK-11 S-2	21	beneath AK10	Paleosol	AMS	IAAA-241022	9,930 $\pm$ 40	11,602 – 11,239
24AK-11 S-1-2	21	beneath AK11	Paleosol	AMS	IAAA-241021	10,110 $\pm$ 40	11,875 – 11,403
24AK-13 S-1	1	beneath AK13	Paleosol	AMS	IAAA-241032	12,120 $\pm$ 40	14,099 – 13,811
25-24AK-13-S3	1	80 cm below AK13	Paleosol	AMS	IAAA-250626	16,400 $\pm$ 50	19,921 – 19,582
24AK4 W-1	19	beneath Me	Charcoal	AMS	IAAA-240083	1,890 $\pm$ 20	1,867 – 1,731
24AK5 W-1	15	beneath Me	Charcoal	AMS	IAAA-240084	1,700 $\pm$ 20	1,692 – 1,537
AK21-21-c	17	in Ku PFI	Charcoal	AMS	IAAA-210539	11,570 $\pm$ 40	13,571 – 13,335

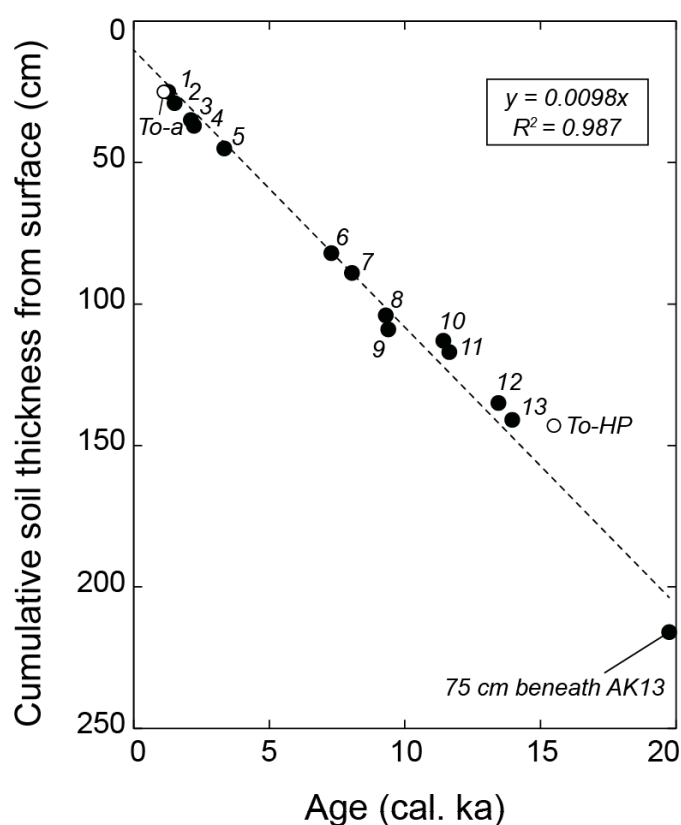


Figure 2-16 Relationship between cumulative soil thickness from the surface and radiocarbon ages obtained in this study. In this figure, filled circles represent ^{14}C ages obtained from soils immediately underlying tephra fall deposits of Akita-Komagatake volcano, where numbers from 13 to 1 correspond to AK13 to AK1, respectively. Open circles indicate the Towada-Hachinohe pumice (HP) and Towada-a (a) tephra observed at the study area. These data points fit well to a linear trend corresponding to a soil development rate of 0.098 mm/year ($R^2 = 0.987$). Based on this result, the presence of relatively thick soil (>15 cm) beneath AK13, between AK12 and AK11, between AK8 and AK7, between AK6 and AK5, and above AK1 suggest prolonged periods of dormancy.

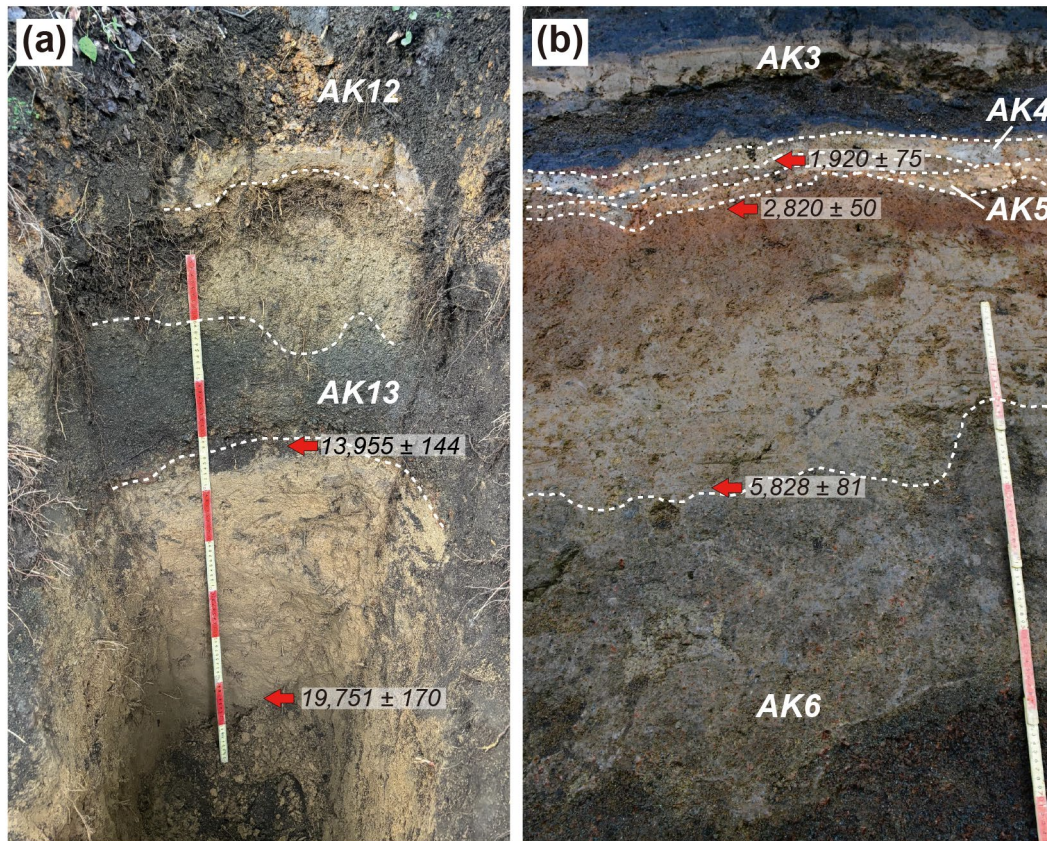


Figure 2-17 Outcrop photographs of the localities where radiocarbon dating was conducted. The results of ^{14}C dating (cal. BP) are also shown. (a) Outcrop photograph at Locality 1 (Fig. 2-7). Radiocarbon dating was performed on loam samples collected immediately below AK13 and 75 cm beneath AK13, revealing an age difference of approximately 6,000 years. (b) Outcrop photographs at Locality 22 (Fig. 2-7). Thick soil between AK6 and AK5 yielded an age difference of approximately 2,500 years between its upper and lower parts.

2-6. Edifice stratigraphy

2-6-1. Overview

At the base of this volcano, Neogene sedimentary rocks, pyroclastic rocks, and lava flows (the Obonai and Kunimitoge formations) are exposed. Overlying these are Quaternary volcanic deposits from Sasamori and Yunomori edifices. Otake volcano also began its activity concurrently with Sasamori and Yunomori volcanoes, formed a stratocone.

After the formation of Otake stratocone, the volcano entered a long period of dormancy (>6,000 years) before the activity of Akita-Komagatake started. In this study, based on the locations of activity, timing, and petrological characteristics of the erupted products, the activity of Akita-Komagatake volcano was divided into three stages: Stage I to Stage III. Stage I corresponds to the Southern Caldera-forming stage, during which multiple explosive eruptions created the Southern Caldera. Stage II represents activity of the Northern Edifice and is further subdivided into Substage II-1 (Katakuradake formation substage), Substage II-2 (Katakuradake explosive eruption substage), Substage II-3 (Onamedake formation substage) and Substage II-4 (Onamedake hydrothermal substage). Stage III corresponds to renewed activity of the Southern Edifice and continues to the present. Stage III is also subdivided into Substage III-1 (Pre-915 CE substage) and Substage III-2 (Historical activity substage). The following sections describe the geological characteristics for each stage. The geological map made in this study is shown in Fig. 2-18, and Fig. 2-19 summarizes the revisions to the edifice stratigraphy identified by comparing previous studies (Fujinawa et al., 2004; Yanagisawa et al., 2021) with the results of this study.

2-6-2. Individual Edifice Deposit

(1) Stage I (Caldera formation stage)

In the previous study (Fujinawa et al., 2004), Stage I was considered to consist only

of the Obonai pyroclastic flow deposit (Fig. 2-19). However, this study newly identified the Minamidake pyroclastic cone, located in the southern part of the Southern Caldera, as an additional Stage I unit. Furthermore, this study clarified that the Kunimi pyroclastic flow deposit that newly recognized in this study belongs to Stage I. Fig. 2-20 shows generalized geological map of the Stage I of Akita-Komagatake volcano.

Obonai pyroclastic flow deposit (OboPfl: Suto and Ishii, 1987)

This pyroclastic flow deposit was first described by Inoue (1979) and later redefined by Suto and Ishii (1987). Its distribution has previously been reported in the Hinokinaigawa River area (western flank) and southern foothills (Inoue, 1979), as well as near the Mizusawa Onsen area on the western foothills (Suto, 1982) (Fig. 2-20). The unit consists of a blackish-gray, sandy volcanic ash matrix containing subrounded, poorly vesicular scoria and lava fragments. The erupted volume of this unit, calculated using the procedures described in Section 2-3, is 0.04 DRE km³. The essential material of this unit is olivine-bearing clinopyroxene-orthopyroxene basaltic andesite.

In this study, new insights were obtained around the Hinokinai River, the results of the investigation in this area are described below. A topographic map and outcrop photographs of area A (Fig. 2-20) are shown in Fig. 2-21. In the Hinokinai River basin, the valley floor formed by the basement rocks is occupied by the Hinokinaigawa Second Lava Flow (Fujinawa et al., 2004), and flat surfaces interpreted as being formed by the Oonai pyroclastic flow deposits remain on the north and south valley slopes (Fig. 2-21a, b). At locality A-1 within area A in Fig. 2-20, the boundary between the Obonai pyroclastic flow deposit and the Hinokinaigawa Second Lava Flow is exposed (Fig. 2-21a). At this locality, the Obonai pyroclastic flow deposit exceeds 10 m in thickness, with scoria having an average clast size of approximately 2 cm and a maximum of about 20 cm, and they overlie a dense lava flow more than 1.4 m thick (Fig. 2-21c, d). This lava

flow is an olivine-bearing hypersthene andesite with a SiO₂ content of approximately 59.0 wt.%, showing petrological characteristics similar to those of the Hinokinaigawa Second Lava Flow (Fujinawa et al., 2004). Therefore, the Obonai pyroclastic flow deposit is considered stratigraphically above the Hinokinaigawa Second Lava Flow. Considering the topography and stratigraphy of the deposits in area A, the sequence can be interpreted as follows: first, the Hinokinaigawa Second Lava Flow flowed along the valley floor, after which the Obonai pyroclastic flow filled the valley and deposited over the lava flow. Over time, erosion of the pyroclastic flow exposed the underlying Hinokinaigawa Second Lava Flow in the valley floor, leaving remnants of the Obonai pyroclastic flow deposit along the valley margins.

Minamidake pyroclastic cone (Mi: redefined from Suto and Ishii, 1987)

This unit locates at the southern end of the Southern Caldera floor. Fujinawa et al. (2004) previously assigned this unit to Stage III; however, since it has been found to be overlain by the Kunimi pyroclastic flow (described below), it is here redefined as a Stage I unit. The cone extends approximately 600 m east–west and 300 m north–south at its base, with a maximum relative height of about 70 m. The summit is flat, and near the top lies a crater lake called Sugatami Pond, which measures 100 m north–south and 50 m east–west. Although the cross-section of this unit cannot be observed, the surface deposits consist predominantly of volcanic blocks with very little fine material. Although the surficial deposit is rich in altered and lava fragments, small amount of black glassy juvenile clasts are also present. Considering the flat shape of the cone, the lithofacies of the deposit, and the presence of dense glassy juvenile material, this unit is interpreted to have formed by phreatomagmatic eruptions. The erupted volume of this unit, calculated following the procedures described in Section 2-3, is 0.0029 DRE km³. The juvenile material of this unit is olivine-bearing clinopyroxene–orthopyroxene andesite.

Kunimi pyroclastic flow deposit (KuPfl; newly defined)

This study identified a previously undescribed pyroclastic flow deposit and named it the Kunimi pyroclastic flow (Fig. 2-20). This unit is recognized in the southern part of the Southern Caldera floor, on the outer rim of the eastern caldera, and along the hiking trail on the southern slope; the most distal occurrence is approximately 2 km south from the Southern Caldera wall (Fig. 2-20). At locality B-1 (Fig. 2-22a) in the southern part of the Southern Caldera floor, this unit is exposed on the river floor and the southern bank (Fig. 2-22b). The thickness at this locality exceeds 5 m and exhibits a matrix-supported texture, with pale brown fine silty volcanic ash containing subrounded light brown pumice clasts. The pumice shows areas of relative concentration and sparsity (Fig. 2-22b), indicating that thin layers of pyroclastic flow are superposed to a thickness of several tens of centimeters. The maximum pumice clast size is approximately 20 cm. At locality B-2, also in the southern caldera floor, the unit directly overlies the Minamidake pyroclastic cone (Fig. 2-22c). At locality B-3, situated on the southern slope of the outer caldera rim (approximately 300 m south of the 1175 m point), this unit has a thickness of 1–2 m and shows a matrix-supported structure in yellow-brown silty volcanic ash containing subrounded light brown pumice with a maximum size of 4.5 cm (Fig. 2-22e). The juvenile pumice is orthopyroxene-clinopyroxene andesite to dacite (Fig. 2-22d).

From the deposits at locality B-1 (Fig. 2-22a), one charcoal sample was collected and subjected to radiocarbon dating. The obtained ^{14}C age is $11,570 \pm 40$ y BP, corresponding to a calibrated age of $13,425 \pm 64$ cal. BP (Table 2-2). Based on the procedure described in Section 2-3, the calculated volume of this unit is 0.023 DRE km^3 .

(2) Stage II (Northern edifice)

After the formation of the Southern Caldera, volcanic activity shifted to the Northern Edifice. Northern Edifice consists of Katakuradake, which has a large summit crater, and multiple pyroclastic cones (main one is Onamedake), formed within the crater of Katakuradake (Fig. 2-

23a, b).

In this study, the overall sequence of edifice construction—namely, the formation of Katakuradake followed by the development of Onamedake and other edifices—agrees with Fujinawa et al. (2004). However, for many of the individual eruptive events, this study reached different interpretations (Fig. 2-19). In this study, Stage II is subdivided into four substages (Substages II-1 to II-4). Substages II-1 and II-2 correspond to the activity of Katakuradake. Substage II-1 consists of an early phase involving the initial construction of Katakuradake and associated lava effusion (Katakuradake 1st edifice), and Substage II-2 is characterized by explosive eruptions that produced pyroclastic flows (Katakuradake 2nd edifice). Substages II-3 and II-4 correspond to the activity of Onamedake. Substage II-3 consists of the activity of multiple pyroclastic cones, including Onamedake, involving lava effusion and explosive eruptions accompanied by a pyroclastic flow (Onamedake 1st edifice). Substage II-4 consists of a pyroclastic deposit within the crater formed during Substage II-3 (Onamedake 2nd edifice). A schematic development diagram of the northern edifice is shown in Fig. 2-26.

Katakuradake-1st edifice (Kt-1; newly defined)

This unit corresponds to the part of the Katakuradake pyroclastic cone of Fujinawa et al. (2004) and to the part of the Katakurazawa 1st, 2nd, and 3rd lava flows, which were assigned to the Otake stratocone by Yanagisawa et al. (2021) (Fig. 2-19). Notably, it has already found that these lava flow units overlie the Sendatsugawa debris avalanche deposit generated by the formation of the Northern Caldera (Yanagisawa et al., 2021). In addition, red-relief image map shows that these lava flows preserve their original morphology well (Fig. 2-24a). Furthermore, each unit can be traced both topographically and petrologically to the Katakuradake edifice (Fig. 2-24b). Based on these results, these units are interpreted to belong to this unit.

This unit consists of a stratocone formed within the Northern Caldera and lava flows

that descended northwestward concomitant with the construction of the edifice (Fig. 2-24c). The stratocone has a basal diameter of 1.9 km and a relative height of approximately 250 m, with a summit crater about 700 m in diameter (Fig. 2-23c). The stratocone is composed of alternating layers of dense rocks, such as agglutinate and lava flows, and unconsolidated pyroclastic deposits. The lava flows comprise multiple flow units and extend as far as ~3.8 km northwest from Odake (Fig. 2-24c). According to the procedure described in Section 2-3, the calculated volume of this unit is 0.049 DRE km³ for the lava flows and 0.36 DRE km³ for the stratocone. The rocks of this unit are olivine-bearing clinopyroxene-orthopyroxene bearing basaltic andesite and clinopyroxene-orthopyroxene andesite.

Katakuradake 2nd edifice (Kt-2; newly defined)

This unit corresponds to part of the Katakuradake pyroclastic cone and the lower part of the Akakurasawa pyroclastic flow deposit described by Fujinawa et al. (2004) (Fig. 2-19). In this study, these units are treated as a single unit based on their petrographic similarities. This unit consists of agglutinate capping the Katakuradake 1st edifice and a pyroclastic flow deposit. The agglutinate is observed on the northern slope of Katakuradake, and near the summit, it forms a strongly welded deposit over 5 m thick, composed of well-sorted black scoria. The scoria exhibits poor vesicularity, with an average grain size of approximately 5 cm. The pyroclastic flow deposit is observed along the Akakurasawa on the northern flank of the edifice.

In this study, new findings were obtained at locality C (Fig. 2-23b), which lies within the distribution area of the Akakurasawa pyroclastic flow deposit (Fujinawa et al., 2004). At this site, a lava flow derived from the Sasamori volcano occurs at the base, overlain by a 13 m thick, poorly sorted pyroclastic flow deposit. Above this, a scoria fall deposit approximately 60 cm thick is interbedded, and this is followed by another poorly sorted pyroclastic flow deposit about 15 m thick. At the top of the sequence, a lava flow accompanied by clinker is present, with a thickness

of approximately 5 m (Fig. 2-25a). Both pyroclastic flow deposits contain scoria as their juvenile material; however, the scoria in these pyroclastic flow deposits exhibit different petrological characteristics. The scoria in the lower deposit has SiO₂ contents of approximately 54–57 wt.%. In contrast, the scoria in the upper deposit has SiO₂ contents of 50–52 wt.% and exhibits petrological characteristics identical to those of the Onamedake 1st edifice described later. The scoria fall deposit interbedded between the two pyroclastic flow deposits can be identified as AK8 based on its facies—well-developed stratification, strong consolidation, and abundant lava fragments and altered clasts in addition to scoria—and on the petrological characteristics of the scoria. These results show that the Akakurasawa pyroclastic flow deposit, previously regarded as a single pyroclastic flow deposit (Fujinawa et al., 2004; Suto and Ishii, 1987), is actually composed of two pyroclastic flow deposits emplaced at different times, with AK8 intercalated between them.

This unit corresponds to the lower pyroclastic flow deposit. This pyroclastic flow deposit consists of poorly sorted dark-brown scoria, with the interstitial spaces between scoria clasts filled by a matrix of homogeneous volcanic ash (Fig. 2-25b). The scoria has a maximum grain size of about 20 cm and contains tuff fragments as xenoliths. According to the procedure described in Section 2-3, the calculated volumes of this unit is 0.014 DRE km³ for the agglutinate and 0.012 DRE km³ for the pyroclastic flow deposit. The rock of this unit is olivine-bearing orthopyroxene-clinopyroxene basaltic andesite.

Onamedake-1st edifice (On-1; newly defined)

This unit corresponds to the Onamedake dyke, the Katakurazawa lava flow, the Hokubu 2nd pyroclastic cone, the Onamedake pyroclastic cone and lava flow, the Hokubu 3rd pyroclastic cone, and the upper part of the Akakurasawa pyroclastic flow described by Fujinawa et al. (2004). All these units are distributed around the summit of the Katakuradake edifice and

share similar petrological characteristics. Therefore, they are interpreted to have formed during a similar period and are grouped in this study (Fig. 2-19).

This unit consists of multiple pyroclastic cones, the lava flows and the pyroclastic flow deposit derived from these edifices. Each of the pyroclastic cones has a basal diameter of ~500 m and a height of approximately 200 m. Each pyroclastic cone has an explosive crater at its summit, with the largest crater has approximately 500 m in diameter (Onamedake explosive crater; Fig. 2-23c). Pyroclastic flow deposit was observed along the Akakurasawa on the northern flank. At Locality C (Fig. 2-23b), pyroclastic flow deposit is found above AK8, with a thickness of approximately 15 m, consisting of poorly sorted dark brown scoria, and the interstices between scoria clasts are filled with a homogeneous volcanic ash matrix (Fig. 2-25c). The scoria has an average grain size of 5 cm, with a maximum of about 30 cm. Lava flows extend toward the northern and northwestern slopes, comprising multiple flow units. Each flow unit consists of aa lava with clinker both at the top and bottom. At Locality C, the pyroclastic flow deposit of this unit is overlain by lava flow with a thickness of about 5 m (Fig. 2-25c). According to the procedures described in Sections 2-3, the calculated volumes of this unit are 0.024 DRE km³ for lava flows, 0.018 DRE km³ for pyroclastic cones, and 0.0089 DRE km³ for pyroclastic flows. The rocks of this unit is clinopyroxene–olivine basalt or orthopyroxene-clinopyroxene-olivine basaltic andesite.

Onamedake-2nd edifice (On-2; newly defined)

This unit is relevant to Hokubu 4th pyroclastic cone of Fujinawa et al. (2004) (Fig. 2-19). This unit consists of pyroclastic deposit derived from Iwo-Mining crater (Fig. 2-23c) that opens in the Onamedake explosion crater. It is composed of poorly consolidated, highly vesicular black scoria. Although the unit forms a topographic high of approximately 50 m in relative height, no distinct volcanic landform such as a pyroclastic cone is preserved. According to the procedures

described in Sections 2-3, the calculated volume of this unit is 0.00052 DRE km³. The rocks of this unit is olivine–clinopyroxene-orthopyroxene andesite.

(3) Stage III (Southern edifice)

After the activity of the Northern Edifice, volcanism shifted to the Southern Edifice. Fujinawa et al. (2004) reported that Minamidake, Medake, and Kodake were active during Stage III (Fig. 2-19), and they proposed that, in chronological order, the Hinokinaigawa 1st and 2nd lava flows, the Minamidake pyroclastic cone, the Kodake Ohyakisuna pyroclastic fall, the Kodake 1st and 2nd lava flows, the Medake lava flow and pyroclastic cone, the Kodake pyroclastic cone, and the Medake 1970 lava flow were formed (Figs. 2-6, 2-19). However, as noted above, the Hinokinaigawa 2nd lava flow underlies the Obonai pyroclastic flow, indicating that both the Hinokinaigawa 1st and 2nd lava flows are products of the Odake stratocone. In addition, the Minamidake pyroclastic cone has been identified as a Stage I edifice; therefore, only Medake and Kodake were active during Stage III.

In this study, Stage III is subdivided, based on topography, stratigraphic relations, and petrological characteristics, into Old-Kodake, Medake, New-Kodake (these units are defined as Substage III-1), and the historical eruptive deposits of the 1932 CE pyroclastic deposit and the 1970 CE lava flow (Substage III-2). A schematic development diagram of the southern edifice is shown in Fig. 2-31.

Old-Kodake (OKo; newly defined)

Kodake, located in the northeastern part of the Southern Caldera, is topographically composed of multiple pyroclastic cones (Fig. 2-27a, b). In the previous study (Fujinawa et al., 2004), Kodake was treated as a single unit (Kodake pyroclastic cone). However, the lower pyroclastic cone that constitutes Kodake is overlain by Medake, whereas the upper cone overlies Medake (Fig. 2-27c). Therefore, in this study, the cone overlain by Medake is newly defined as

Old-Kodake, and the cone that overlies Medake is newly defined as New-Kodake.

Based on these stratigraphic relationship, Old-Kodake is the earliest formed unit in Stage III. This unit has a basal diameter of 500 m and a height of approximately 30 m, with a crater at the summit about 300 m in diameter, which is large relative to the basal diameter. No lava corresponding to this unit have been identified (Fig. 2-28b). According to the procedures described in Sections 2-3, the calculated volume of this unit is 0.013 DRE km³. The unit is entirely covered by New-Kodake, so rocks of this unit is unknown.

Medake (Me, newly defined)

Fujinawa et al. (2004) described the volcanic activity at Kodake as having begun with eruptions of basaltic andesitic magma (the Kodake 1st lava flow and the Kodake Ohyakisuna pyroclastic fall), followed by basaltic eruptions at Medake and Kodake (the Medake pyroclastic cone and lava flow, and the Kodake 2nd lava flow; Fig. 2-19). However, examination of the stratigraphic relationships between these lava flows revealed that the lava previously identified as the Kodake 1st lava flow clearly overlies the basaltic Medake lava flow and the Kodake 2nd lava flow (Fig. 2-28). In addition, the Kodake Ohyakisuna pyroclastic fall can be assigned to a edifice deposit of AK1 based on its facies and the petrological features of the scoria. These results indicate that the activity following Old-Kodake was basaltic eruptions of Medake. In this study, these successive basaltic eruptions are therefore grouped together and redefined as the Medake unit. Furthermore, since the Kodake 1st lava flow occurs stratigraphically above the Medake unit, it is reasonable to interpret that Medake-derived lava flowed southward within the Southern Caldera. Consequently, the basaltic lava flow previously referred to as the Kodake 2nd lava flow is also considered to have been derived from Medake (Fig. 2-28).

This unit consists of pyroclastic cone and lava flows. The pyroclastic cone have a basal diameter of approximately 1 km and a height of about 300 m, with multiple craters ranging 50–

150 m in diameter opening at their summits and on the western flank. The lava flows have a thickness of ~3 m and are aa lavas characterized by clinker layers on both upper and lower parts. The lava flows broadly filled the Southern Caldera, with some overflowing the caldera and descending the southwestern slopes (Fig. 2-28b). In this study, charcoal samples collected directly beneath the lava flows of this unit, distributed within the Southern Caldera and the northwestern slopes, yielded an age of 1,710 cal. BP (Table 2-2). According to the procedures described in Sections 2-3, the calculated volume of this unit is 0.029 DRE km³. The rocks of this unit is orthopyroxene-bearing clinopyroxene-olivine basalt and olivine basalt.

New-Kodake (NKo, newly defined)

Following the activity of Medake, volcanic activity at Kodake resumed. This unit consists of pyroclastic cone and lava flows (part of the Kodake pyroclastic cone and the Kodake 1st lava flow of Fujinawa et al., 2004; Fig. 2-19) and covers Old-Kodake and Medake (Fig. 2-27c). The pyroclastic cone has a basal diameter of 300 m and a height of 50 m, with multiple craters at the summit, the largest of which is approximately 200 m in diameter. The lava flows originated from the base of the pyroclastic cone and flowed down to the southern to central parts of the Southern Caldera (Fig. 2-28). In this study, it was confirmed that the Towada-a tephra from Towada volcano directly overlies both the pyroclastic cone and the lava flows (Fig. 2-27d). According to the procedures described in Sections 2–3, the calculated volume of this unit is 0.0092 DRE km³ for the lava flows and 0.0012 DRE km³ for the pyroclastic cone. The rocks of this unit is clinopyroxene–olivine basaltic andesite.

1932 CE pyroclasts (Otuka, 1932)

This unit consists of pyroclastic deposit erupted by the 1932 CE eruption, as described by Yoshiki (1933), Otuka (1932a), and Otuka (1932b). The 1932 CE eruption began after 1:00 PM on July 21 and continued for several days (Yoshiki, 1933; Kitsunozaki, 2013). This activity

was considered to have been a phreatic eruption (Wachi et al., 1997), and it formed 11 craters aligned in a northeast–southwest direction on the southwestern flank of Medake (Fig. 2-27b). From these craters, volcanic blocks, lapilli, and ash were ejected, distributed primarily near the craters and to the east over a limited area. Near the craters, the maximum thickness of the deposit reached 3 m. To the east, at the rim of the Southern Caldera, the ash layer was up to 5 cm thick. In areas about 5 km east, the ashfall was enough to bend leaves of Fuki and Itadori plants, and the ashfall was recorded as far as approximately 15 km east in Nishiyama Village (present-day Shizukuishi Town) (Otsuka, 1932; Otuka, 1932; Yoshiki, 1933).

At present, this unit is only observed around the 1932 CE craters (Fig. 2-29). In this study, a massive deposit of agglomeratic tuff breccia was observed directly beneath 2–3 cm of surface soil, in which gaps between volcanic blocks and lapilli are filled with brown to bluish-gray, silt-sized volcanic ash (Fig. 2-29b-e). This deposit has a thickness of more than 2–3 m, and its base could not be observed. Its components consist of highly vesicular black scoria, basaltic lava fragments, and reddish-brown altered rock fragments, with basaltic lava fragments being the most abundant (Fig. 2-30). The scoria has an average grain size of ~3 mm and a maximum size of ~1.5 cm, showing subangular to angular shapes, with volcanic ash adhering to both the surfaces and the inner walls of vesicles. As described below, the scoria in this unit shares the same petrological characteristics as the scoria of AK1. However, according to the isopach map of AK1, thickness is only a few centimeters, and the particle size is expected to be in the ash size near the 1932 CE craters. In contrast, the scoria in this unit is significantly coarser, indicating that it is not accessory lithic derived from AK1. Therefore, the scoria in this unit represents juvenile material, and based on the depositional characteristics described above, the 1932 CE eruption is interpreted as a phreatomagmatic eruption. According to the procedure described in Sections 2–3, the calculated volume of this unit is 0.00017 DRE km³. The rocks of this unit is clinopyroxene–

olivine basaltic andesite.

1970 CE lava flow (Suto and Ishii, 1987)

This unit consist of lava flows erupted during the 1970–71 CE eruption (corresponds to Medake 1970 lava flow of Fujinawa et al., 2004). Several studies have addressed this eruption, including its chronology (Suwa et al., 1971; Osako et al., 1972), petrology (Yagi et al., 1971; Aramaki, 1971; Aramaki and Katsura, 1971), seismic activity (Tanaka, 1971; Shimozuru et al., 1971; Tanaka, 1971), and aeromagnetic surveys (Mishina, 1971). The eruption occurred at the summit of Medake from September 18, 1970, to late January 1971. During this eruption, repeated Strombolian and Vulcanian eruptions produced lava flows descending along the western slope of Medake. The lava flows extended approximately 500 m southwest from the vent, with the distal parts forming massive flows with a thickness of about 15 m. According to the procedures described in Sections 2–3, the calculated volume of this unit is 0.0014 DRE km³. The rocks of this unit is clinopyroxene–orthopyroxene andesite.

2-6-3. Reexamination of Existing Borehole Samples

Fig. 2-32 shows the columnar diagrams of borehole core samples obtained by the Japan Meteorological Agency (JMA) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The locations of these borehole drillings are shown in Fig. 2-7.

(1) Description of JMA borehole core

From the top, the sequence is as follows: surface soil (0–0.3 m), AK4 (0.3–2.8 m), secondary deposits (2.8–4.8 m), AK6 (4.8–7.0 m), Onamedake 1st edifice (lava: 7.0–16.1 m, pyroclastic flow: 16.1–24.8 m), AK8 (24.8–33.5 m), Katakuradake 2nd edifice (pyroclastic flow: 33.5–39.2 m), and Katakuradake 1st edifice (interbedded lava and pyroclasts: 39.2–100 m).

(2) Description of MLIT borehole cores

From the top, the sequence is as follows: surface soil (0–0.26 m), AK4 (0.26–0.31 m),

soil (0.31–0.73 m), Onamedake 1st edifice (lava: 0.73–10.21 m), AK8 (10.2–10.4 m), Katakuradake 1st edifice (lava: 10.4–29.8 m), Sendatsugawa debris avalanche deposit (29.8–58.9 m), and lavas erupted during the development of Otake stratocone (58.9–100 m).

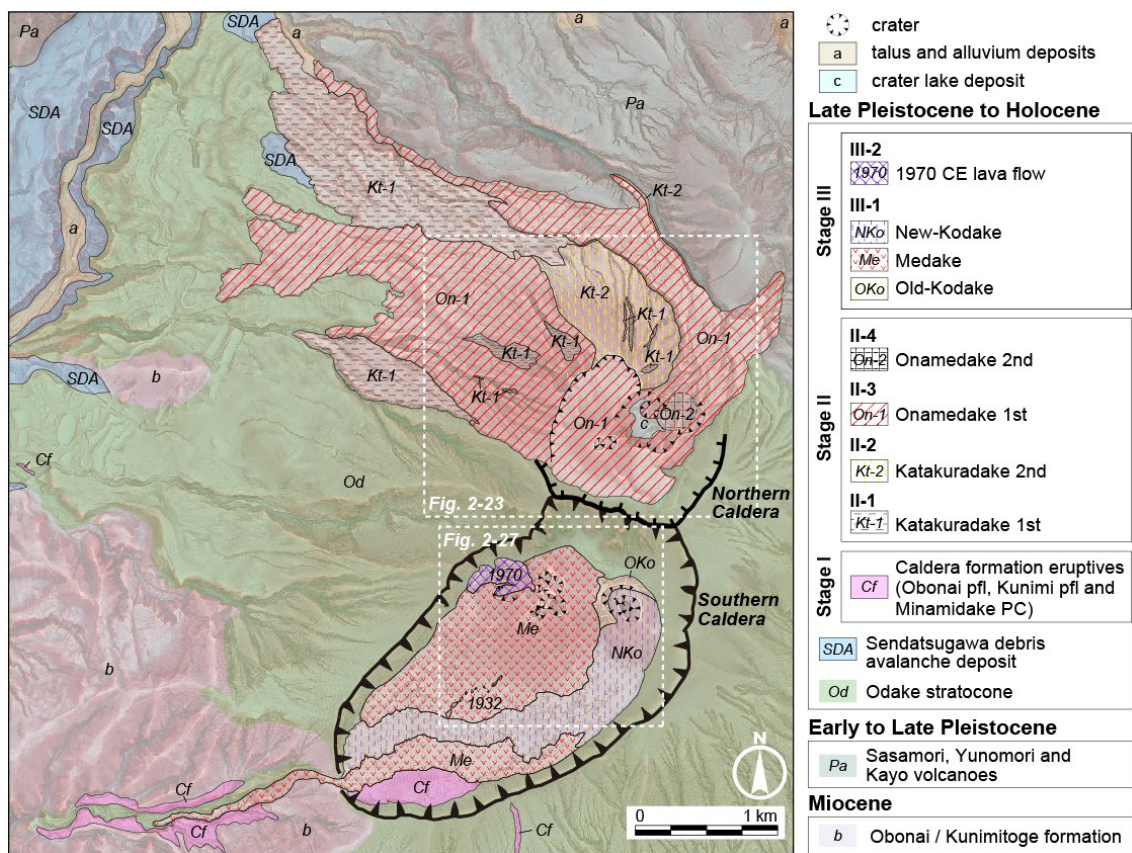


Figure 2-18 Geological map around Akita-Komagatake. The areas shown in Fig. 2-23 (b) and Fig. 2-27 (b) are indicated by white dashed rectangles.

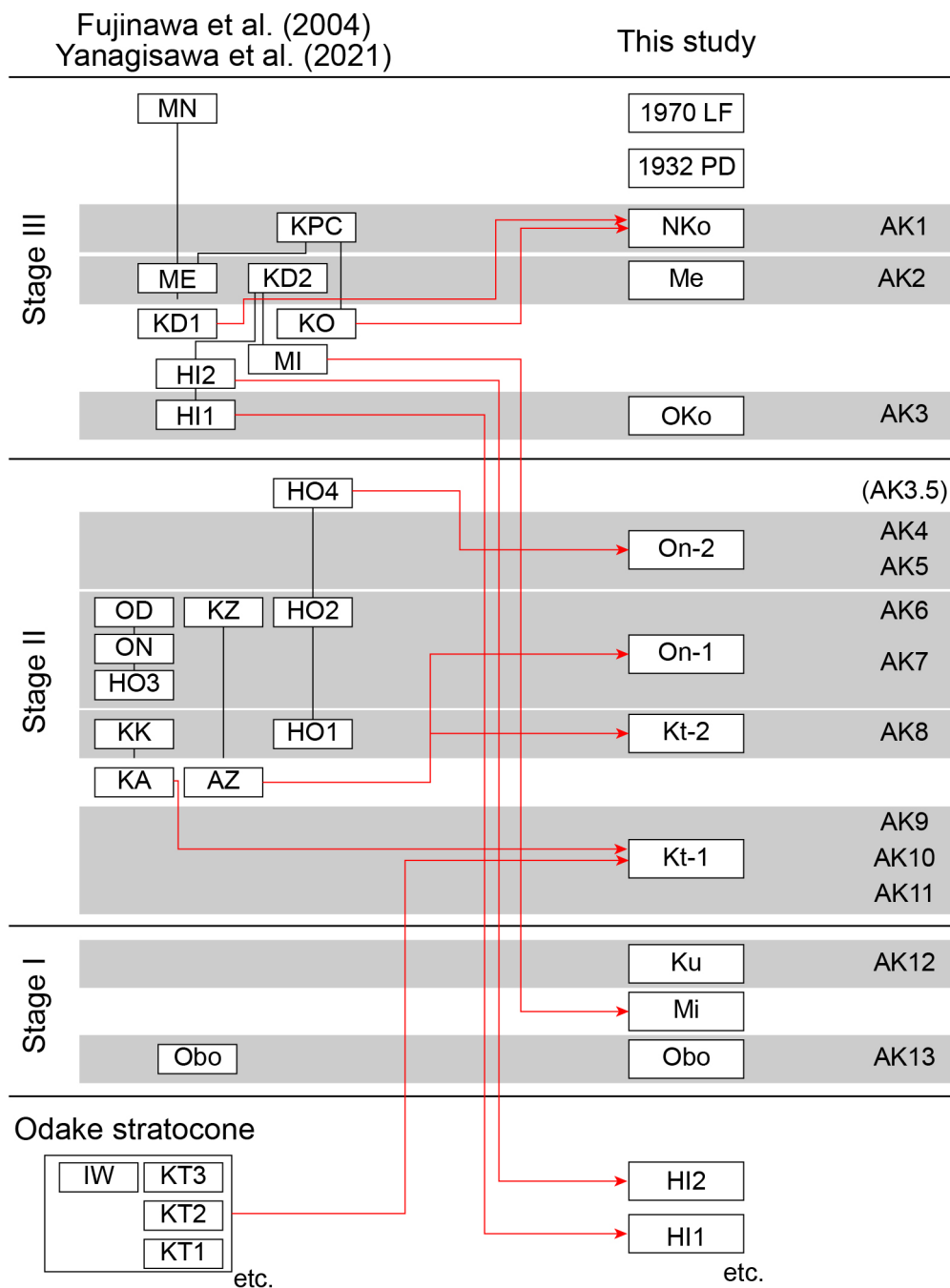


Figure 2-19 Comparison of the edifice stratigraphy proposed by previous studies (Fujinawa et al., 2004; Yanagisawa et al., 2021) and this study. Red arrows indicate units whose stratigraphic assignments differ from those in previous studies.

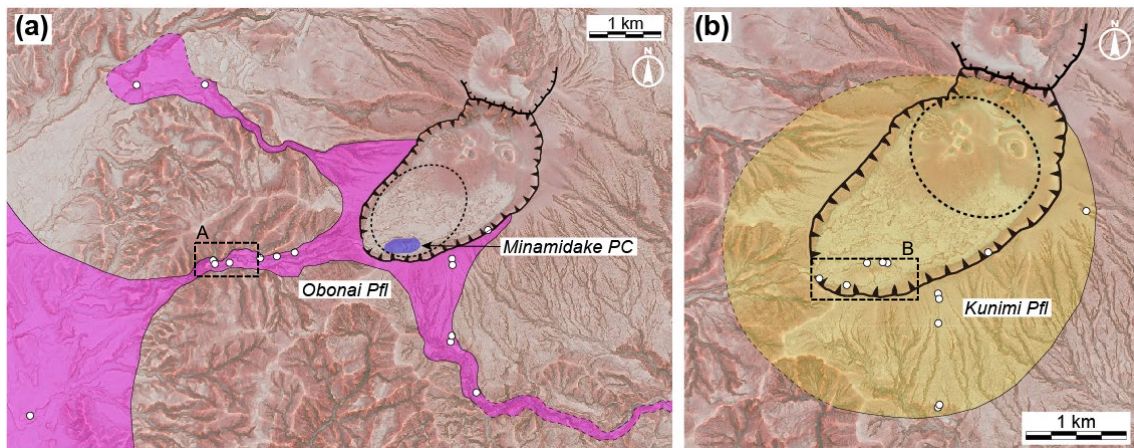


Figure 2-20 (a) and (b) show the distribution of the eruptive deposit of the Stage I of Akita-Komagatake volcano. The open circle in these figures indicate the locations of outcrops where these deposits are recognized. Areas A and B indicate the extents of the topographic maps shown in Fig. 2-21 and 2-22, respectively.

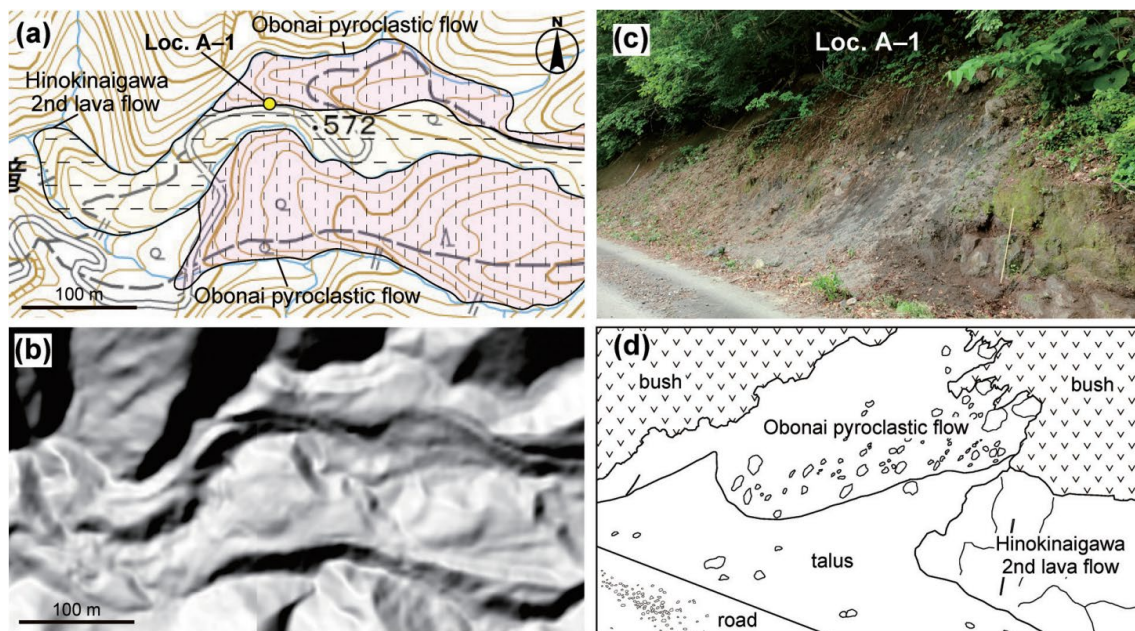


Figure 2-21 Stratigraphic relationship between the Obonai pyroclastic flow (Suto and Ishii, 1987) and the Hinokinaigawa 2nd lava flows (Suto and Ishii, 1987) in area A in Fig. 2-20. (a) Geological map of area A showing the distributions of the Hinokinaigawa 2nd lava flow and the Obonai pyroclastic flow. Contour interval is 10 m. The topography is from the 1: 25,000 map “Kunimi Onsen” published by GSI. (b) Shaded DEM of area A (from GSI). The relatively flat surface of the Obonai pyroclastic flow is apparent on the northern and southern sides of the valley. Locality A-1 is at the boundary of the pyroclastic flow and lava flow. (c) Photograph and (d) annotated sketch of the outcrop at locality A-1 showing that the lava flow (Hinokinaigawa 2nd lava flow of Fujinawa et al., 2004) is overlain by the Obonai pyroclastic flow.

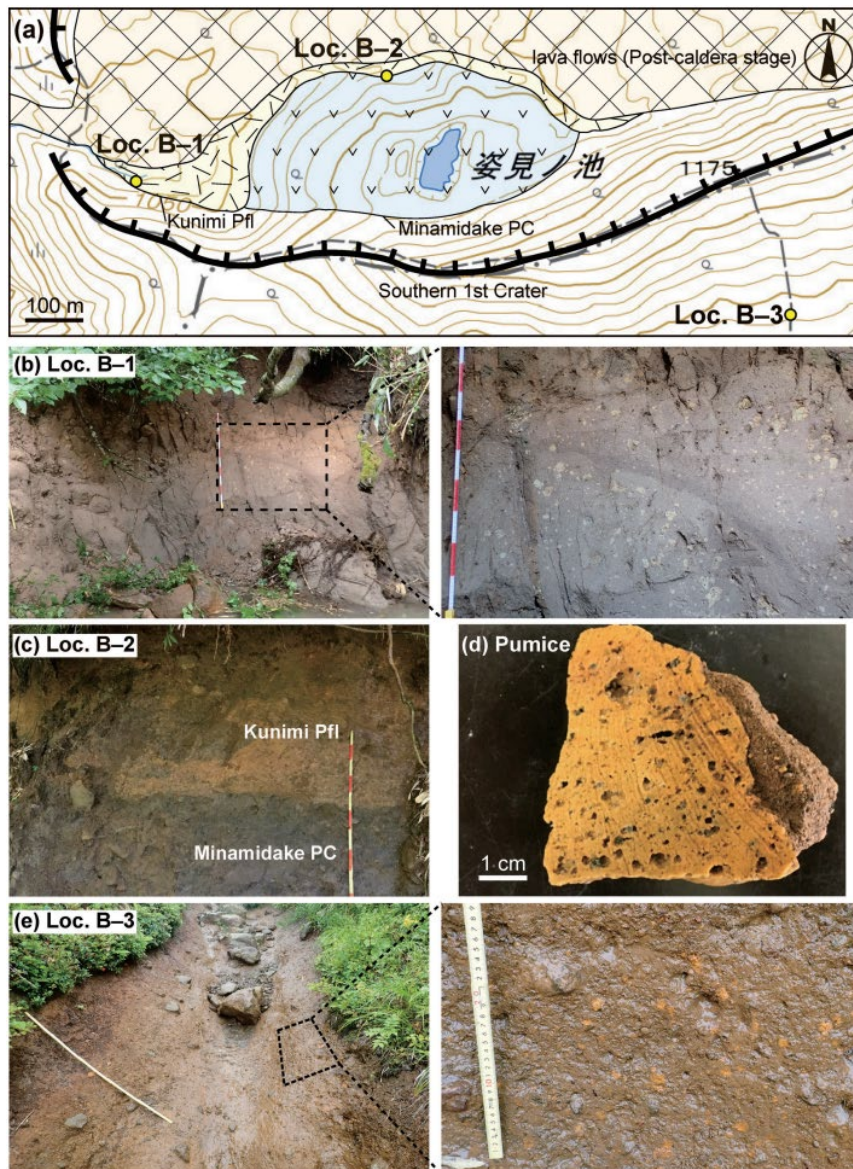


Figure 2-22 (a) Enlarged geological and structural map of area B in Fig. 2-20, showing the volcanic units at the southern rim of the southern caldera. Contour interval is 10 m. Topography is from the 1: 25,000 map “Kunimi Onsen” published by the GSI. (b) Photographs of the Kunimi pyroclastic flow deposit at locality B-1. Close-up at right shows the matrix supported structure and included pumice clasts. Each colored (red and white) segment of the scale bar represents 10 cm. (c) Photograph of locality B-2, showing the Kunimi pyroclastic flow (Pfl) overlying the Minamidake pyroclastic cone (PC). (d) Cut section of a pumice clast in the Kunimi pyroclastic flow collected at locality B-1. (e) Photographs of the Kunimi pyroclastic flow along a mountain trail at locality B-3 on the southern slope of Akita-Komagatake. Close-up at right shows yellow-orange pumice clasts scattered in brown silty matrix.

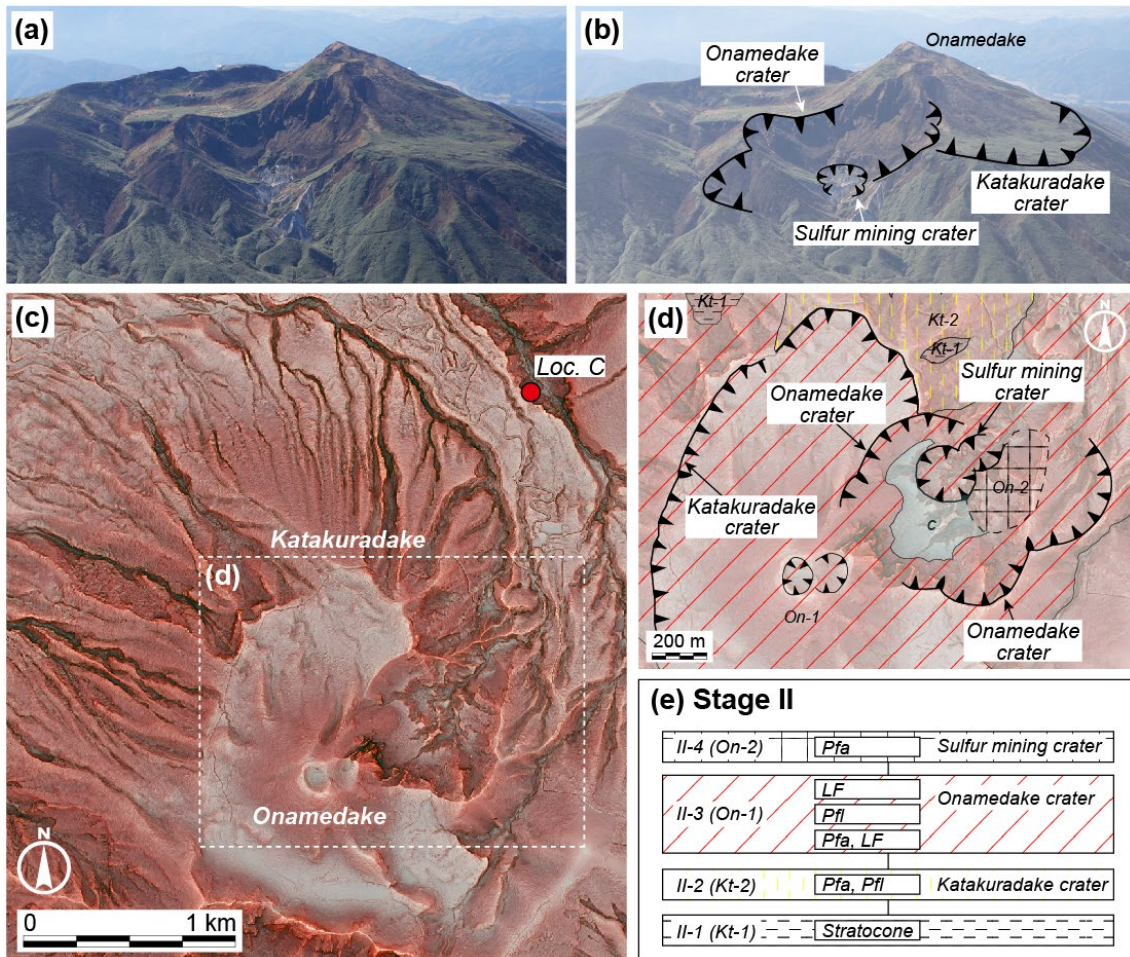


Figure 2-23 (a) and (b) are aerial photographs of the Northern Edifice taken from northeastern part of it. (c) Red relief image map and (d) geological map of the Northern Edifice. In the northern edifice, Katakuradake was formed, filling the northern caldera, and several volcanic edifices, including Onamedake, were subsequently built in the Katakuradake crater. A roughly 500 m-diameter explosion crater (Onamedake Explosion Crater) is observed and Sulfur mining crater was made in the Onamedake Explosion Crater. (e) Block diagram of the Northern Edifice.

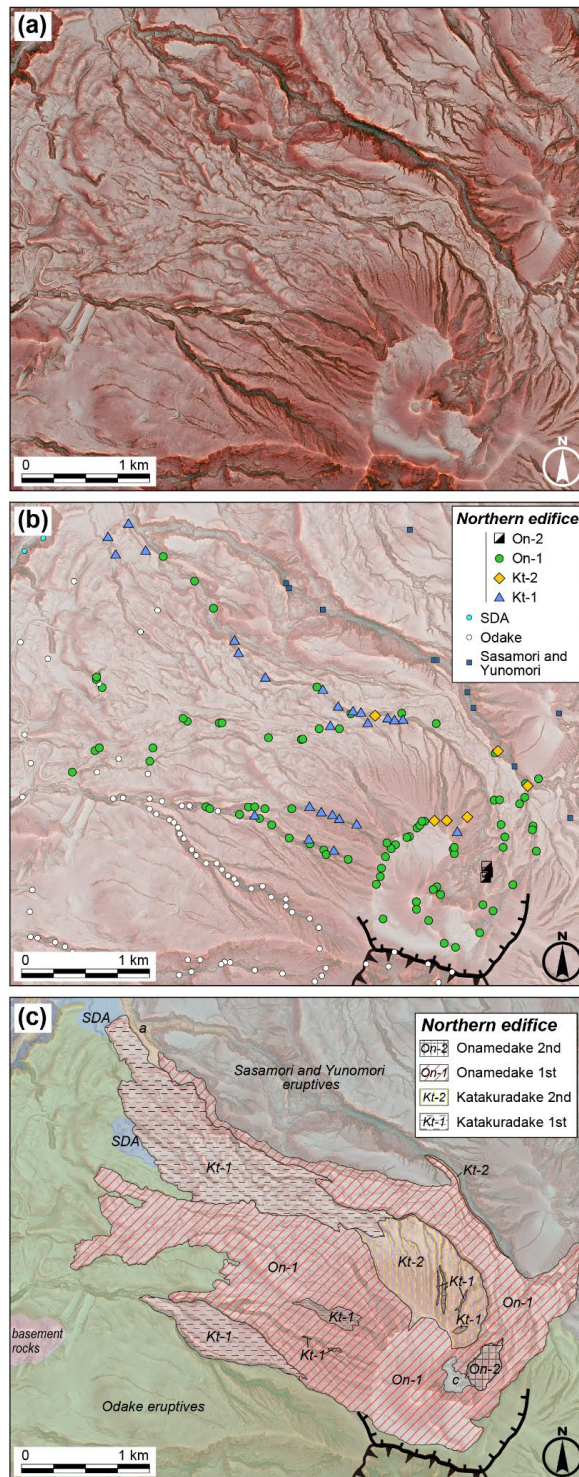


Figure 2-24 (a) Red relief image map around the northern edifice of Akita-Komagatake. (b) Map showing the attribution of the edifice deposits sampled in this study. The attribution of each sample was determined based on topography, stratigraphic relationships, and petrological characteristics. (c) Geological map of the northern edifice compiled based on the topography and distribution of each unit.

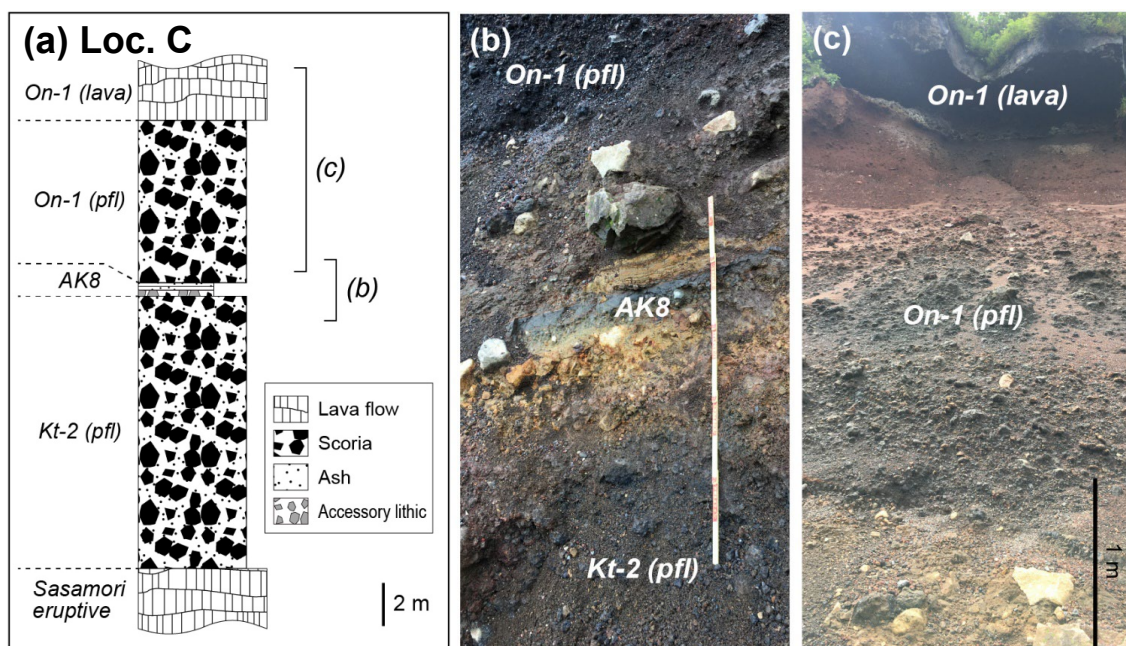


Figure 2-25 (a) Columnar section at locality C (Fig. 2-23). (b) and (c) Outcrop photographs at the locality. At this site, two pyroclastic flow deposits and an overlying lava flow are identified. The lower pyroclastic flow deposit is assigned to Kt-2, whereas the upper pyroclastic flow deposit and the lava flow are attributed to On-1. The AK8 occurs between the Kt-2 and On-1 pyroclastic flow deposits.

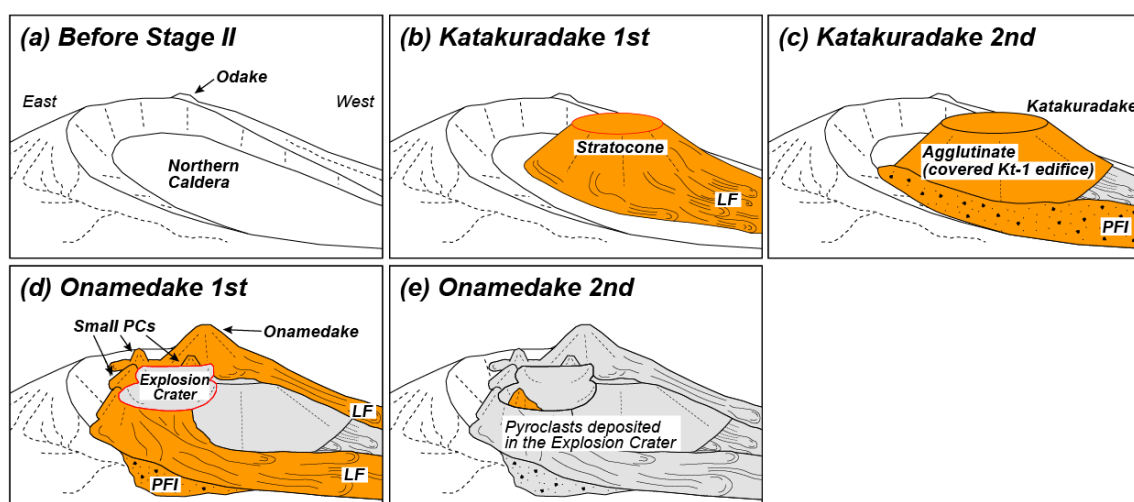


Figure 2-26 Schematic diagram showing the development of Northern Edifice. (a) Before Stage II, the Northern Caldera, characterized by a horseshoe shape, opened toward the north. (b) In Stage II, the stratovolcano of the Katakuradake 1st edifice was first formed. Concurrently with this activity, lava flows descended to the northwestern foot of the edifice. (c) Subsequently, an explosive eruption accompanied by pyroclastic flows occurred. Agglutinate covered the surface of the Katakuradake 1st edifice, and pyroclastic flows descended to the foot of the edifice (Katakuradake 2nd unit). (d) After Katakuradake, multiple pyroclastic cones, including Onamedake, were formed on the upper part of Katakuradake (Onamedake 1st edifice). This activity involved not only lava effusion but also explosive eruption, which led to the formation of the explosion crater and the descent of pyroclastic flows. Furthermore, even after this explosive eruption, mild eruption continued, lava effusion occurred. (e) Small-scale pyroclastic deposit (Onamedake 2nd unit) was formed in the explosion crater formed during the activity of Onamedake 1st edifice.

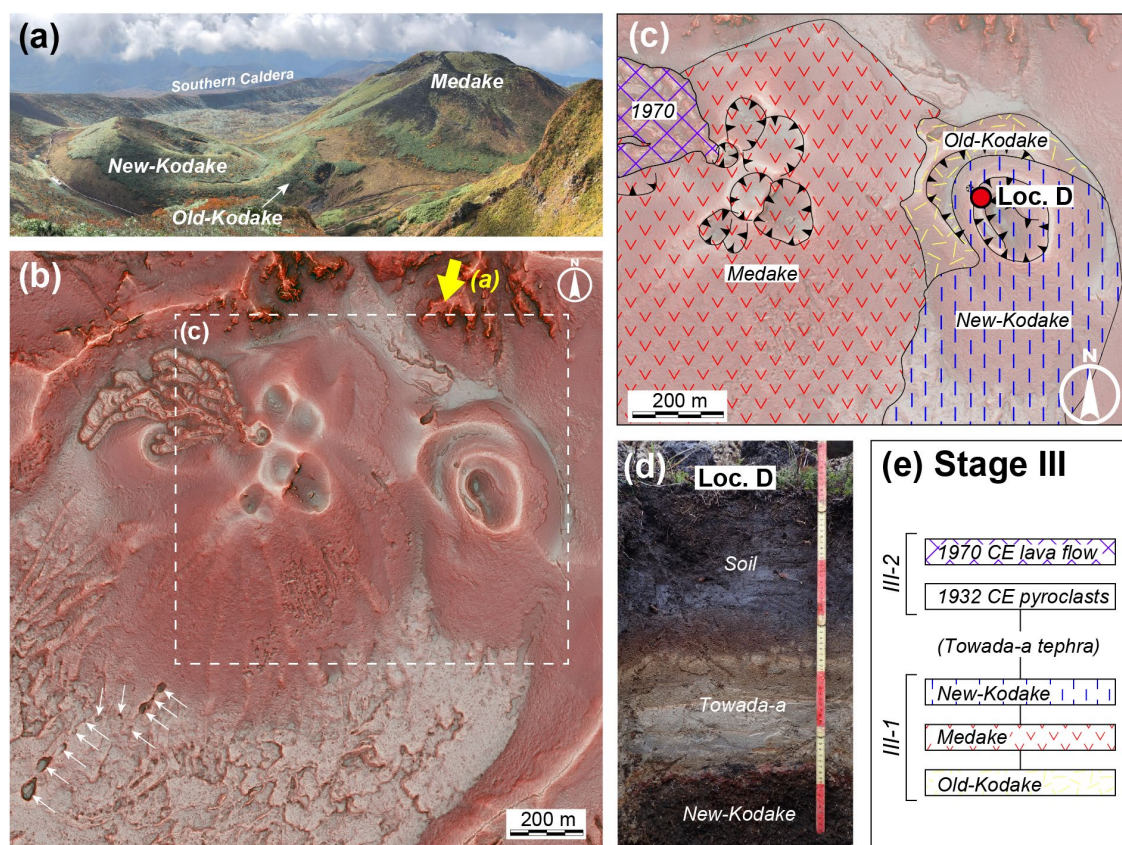


Figure 2-27 (a) Photograph of Medake and Kodake. (b) Red relief image map around Medake and Kodake. The thick yellow indicates the orientation of photograph (a), and the craters of 1932 CE eruption are emphasized by the thin white arrows. The area of (c) is also shown. (c) Geological map around Kodake and Medake. Based on its topography, Kodake can be divided into Old-Kodake and New-Kodake. Considering their stratigraphic relationship with Medake, the Substage III-1 edifices are inferred to have formed in the order of Old-Kodake, Medake, and New-Kodake. (d) Outcrop photograph of locality D in (c). The New-Kodake directly overlie the Towada-a tephra. (e) Block diagram of the Southern Edifice.

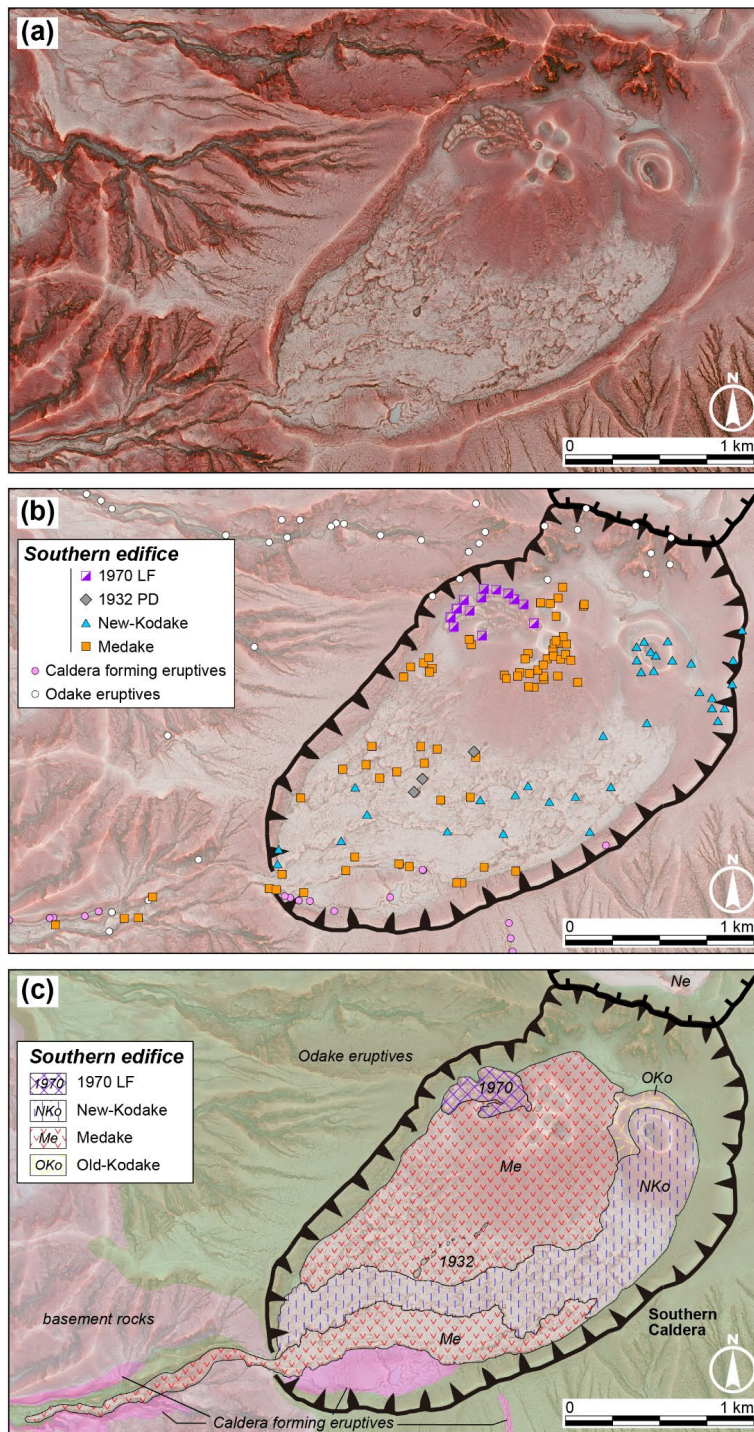


Figure 2-28 (a) Red relief image map around the southern edifice of Akita-Komagatake. (b) Map showing the attribution of the edifice deposits sampled in this study. The attribution of each sample was determined based on topography, stratigraphic relationships, and petrological characteristics. (c) Geological map of the southern edifice compiled based on the topography and distribution of each unit.

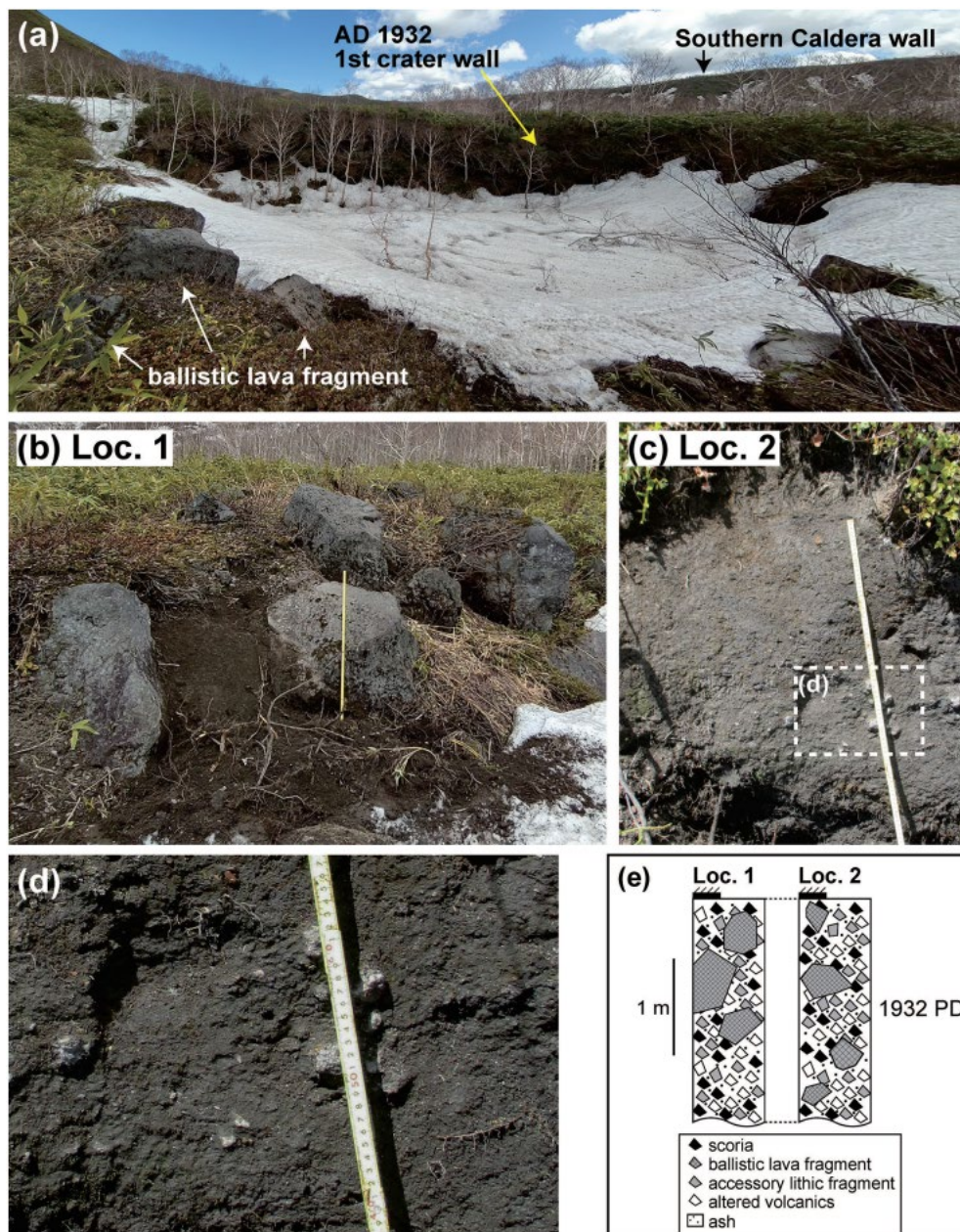


Figure 2-29 (a) A photograph of the Crater rim of the 1932 CE eruption. The eastern rim of the crater and the caldera wall of the southern caldera of Akita-Komagatake volcano are shown. Large ballistic blocks are scattered on the crater rim. (b) A photograph showing top of the western crater rim of the Crater I (Loc. 1). The scale bar is 1 m. Large ballistic blocks are scattered in the 1932 CE eruptive deposit. (c) A photograph showing the southwestern rim of the Crater II (Loc. 2). The scale is about 80 cm. The dotted area is magnified in (d). (d) The enlarged photograph showing the 1932 CE eruptive deposit. The deposit is tuff breccia, containing silty, wet volcanic ash that coats scoria and lithics. (e) Schematic columnar sections of Loc. 1 and 2. Abbreviation: PD, pyroclastic deposit.

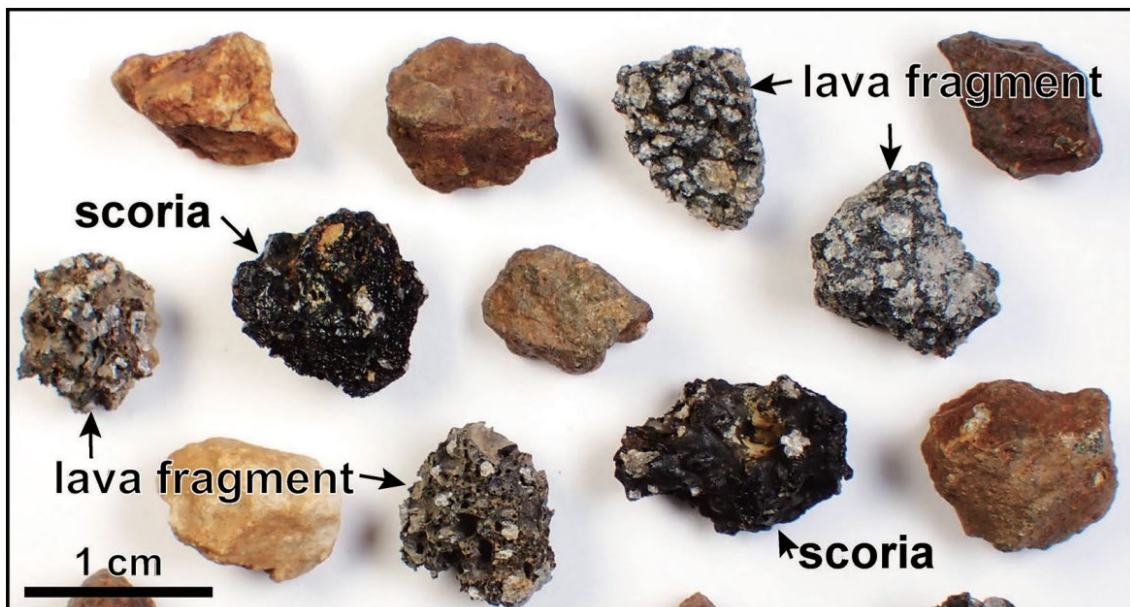


Figure 2-30 Lithic fragments from the 1932 CE eruptive deposit. Three types of fragments are recognized, such as scoria (essential material), lava and altered lithic.

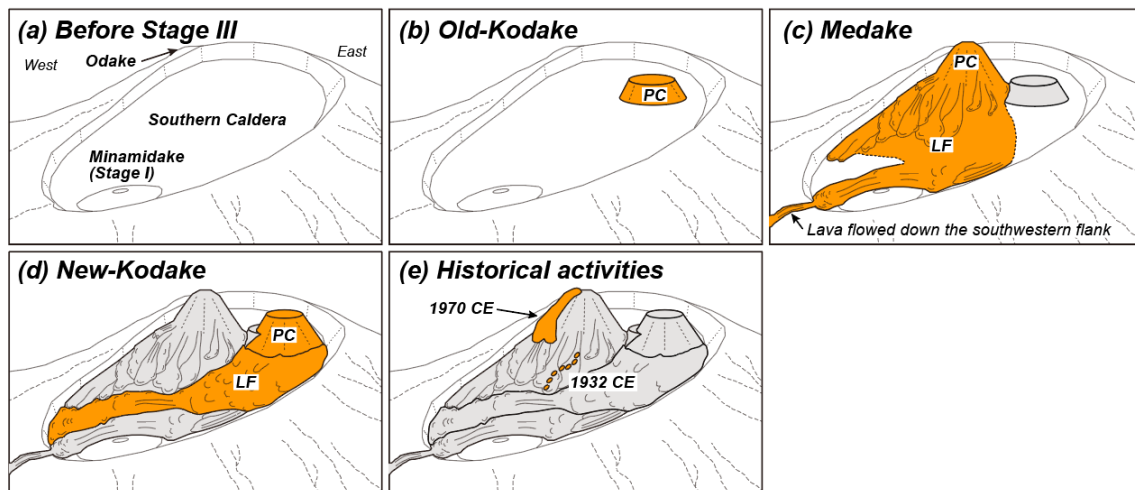


Figure 2-31 Schematic diagram showing the development of Northern Edifice. (a) Before the activity of Stage III, only Minamidake pyroclastic cone existed within Southern Caldera. (b) The activity of Stage III began with Old-Kodake. (c) Subsequently, Medake commenced activity, formed a pyroclastic cone and effused lavas. (d) After Medake, New-Kodake commenced activity, formed a pyroclastic cone and effused lavas. This activity concluded at least by A.D. 915. (e) In the 20th century, eruptions occurred in 1932 and 1970–71 CE.

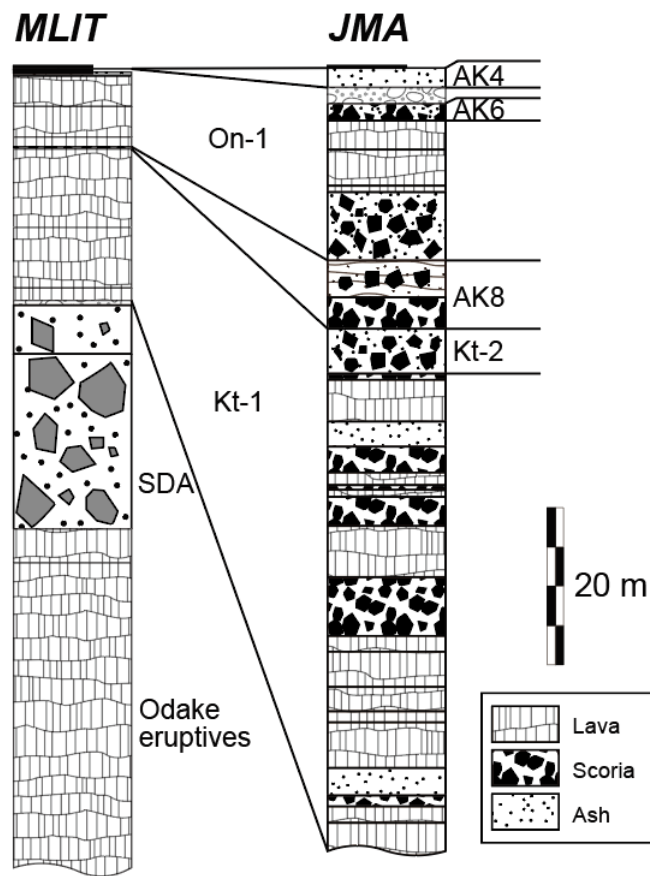


Figure 2-32 Columnar sections of borehole cores. JMA and MLIT indicate the borehole samples obtained by the Japan Meteorological Agency and the Ministry of Land, Infrastructure, Transport and Tourism, respectively. The locations of the boreholes are shown in Fig. 2-7.

2-7. Petrology and Geochemistry of Eruptive Products

2-7-1. Petrography

The eruptive deposits of this volcano range mainly from basalt to andesite with SiO₂ contents of approximately up to 60 wt.%, although dacite also occurs during Stage I (Southern Caldera formation stage). All samples exhibit porphyritic textures characterized by abundant plagioclase phenocrysts, with modal abundances generally ranging from 4.7 to 49 vol.% (Table 2-3).

In basaltic rocks, olivine phenocrysts are the most abundant (~5.3 vol.%), accompanied by minor clinopyroxene phenocrysts (~0.4 vol.%). In some samples, trace amounts of orthopyroxene phenocrysts are also present. In basaltic andesites, the modal abundance of olivine phenocrysts decreases sharply (~2.5 vol.%), while clinopyroxene (~4.2 vol.%) and orthopyroxene (~7.8 vol.%) phenocrysts become the dominant mafic mineral. Olivine phenocrysts frequently exhibit reaction relationships with orthopyroxene phenocrysts, forming reaction rims or coronas. Opaque minerals (~1.1 vol.%) also begin to appear in this compositional range. In andesites to dacites, clinopyroxene (~2.7 vol.%), orthopyroxene (~3.0 vol.%), and opaque minerals (~0.9 vol.%) constitute the principal mafic minerals, although trace olivine phenocrysts are observed in some samples. Throughout all examined samples, quartz and hydrous minerals such as amphibole phenocrysts are absent.

2-7-2. Whole-rock Chemistry and Sr–Nd–Pb Isotopic Ratios

Fig. 2-33 shows some Harker diagrams for representative elements (the analytical results of all samples are shown in Appendix). The rocks of this volcano range in composition from basalt to dacite, with SiO₂ contents spanning 49.8 to 66.4 wt.%. Most samples from this volcano belong to the Tholeiitic series, which is characterized by an increasing FeO/MgO ratio

with increasing SiO_2 content. However, some samples also plot within the field of the Calc-Alkaline series (Miyashiro, 1978). In most Harker diagrams, the volcanic products appear to define multiple compositional trends rather than a single one. Similarly, in the Sr, Nd, and Pb isotope ratio diagrams shown in Fig. 2-34, the volcanic products also appear to form multiple compositional trends.

Table 2-3 The results of modal composition analysis. Abbreviations: Gm, groundmass; Pl, plagioclase; Cpx, clinopyroxene; Opx, orthopyroxene; Ol, olivine; mt, magnetite.

Stage	Substage	Sample	Unit	Subunit	Type	SiO ₂ (wt.%)	Gm (vol.%)	Phenocryst (vol.%)				
								Pl	Cpx	Opx	Ol	mt
III	III-2	AK19-9	1970		Lava	59.1	77.4	17.1	1.5	3.0	tr	0.9
		22AK19-3-1	1932		Scoria	53.6	84.7	13.1	0.9	nd	1.3	nd
	III-1	19AK7	NKo		Lava	54.0	87.3	10.3	0.4	nd	2.0	nd
		45	NKo		Scoria	53.7	83.6	14.2	1.3	nd	1.0	nd
		AK102-102	AK1	AK1-1	Scoria	53.2	88.0	8.9	0.6	nd	2.5	nd
		AK102-101	AK1	AK1-2	Scoria	53.4	90.7	7.4	0.5	nd	1.5	nd
		19AK102-2	AK1	AK1-3	Scoria	55.3	95.3	3.3	1.3	nd	0.2	nd
		AK19-1	Me		Lava	51.1	57.3	41.4	nd	nd	1.3	nd
		AK119-8	Me		Lava	50.9	67.2	32.7	tr	nd	0.1	nd
		6	Me		Agglutinate	50.9	64.8	32.3	0.4	nd	2.4	0.1
		AK50-1	AK2		Scoria	50.7	71.1	28.4	nd	nd	0.5	nd
		20AK37-2	AK3		Scoria	56.7	83.1	15.4	0.4	0.8	0.1	0.2
II	II-4	nak61-2	On-2		Scoria	56.9	73.6	18.7	2.2	3.8	0.6	1.1
		22AK84-1	AK4		Scoria	57.0	72.6	19.8	2.2	3.7	1.4	0.4
	II-3	1006-13	On-1		Lava	51.8	72.5	22.0	0.2	tr	5.3	nd
		20AK3-7-1	On-1		Scoria	51.6	76.8	18.3	0.1	nd	4.8	nd
		19AK116-6	AK6		Scoria	50.9	74.5	22.5	0.6	nd	2.4	nd
		AK26-14	AK7		Scoria	53.7	73.4	21.8	0.1	nd	4.7	nd
	II-2	kt-1	Kt-2		Agglutinate	57.9	78.0	19.5	1.4	0.2	nd	0.9
		20AK3-3-2	Kt-2		Scoria	57.5	87.9	10.5	0.6	0.5	0.5	0.1
		19AK86b-2	AK8		Scoria	56.1	95.0	3.9	0.8	nd	0.1	0.1
	II-1	915-9	Kt-1		Lava	57.2	56.0	38.1	2.7	2.8	nd	0.4
		22AK46	Kt-1		Agglutinate	54.9	89.3	9.6	0.4	0.5	0.1	0.1
		915-7	Kt-1		Lava	60.6	89.3	8.6	0.8	0.7	nd	0.6
		19AK86a	AK9		Scoria	54.5	87.9	10.8	0.7	0.5	0.1	nd
I		AK21-21-pm2	KuPF1		Pumice	66.5	91.6	6.0	0.8	1.4	nd	0.2
		114s	Mi		Scoria	53.3	64.5	27.0	0.5	7.8	0.2	nd
		AK93-3	OboPF1		Scoria	57.2	76.1	17.5	3.3	2.0	tr	1.1
		19AK111-32	AK12	Y1P	Gray pumice	58.1	87.3	7.9	1.3	1.5	1.1	0.8
		19AK111-32	AK12	Y2P-U	Pumice	61.1	89.4	8.0	0.4	1.5	0.1	0.5
		19AK111-24hk	AK12	Y2P-U	Scoria	54.6	75.4	15.7	4.2	1.8	2.3	0.6
		19AK111-23aks	AK12	Y2P-U	Gray pumice	56.4	84.9	9.8	2.0	1.5	1.2	0.7
		19AK111-101	AK12	Y2P-L	Pumice	64.3	92.8	6.2	0.4	0.4	nd	0.2
		19AK111-13	AK13	K1P	Scoria	55.5	79.9	14.5	1.6	2.4	0.6	1.1
		19AK111-11s	AK13	K2P	Scoria	54.2	77.1	15.3	4.2	1.6	0.5	1.2
		19AK111-3	AK13	K3P	Scoria	55.1	77.9	17.3	1.5	2.5	0.1	0.7

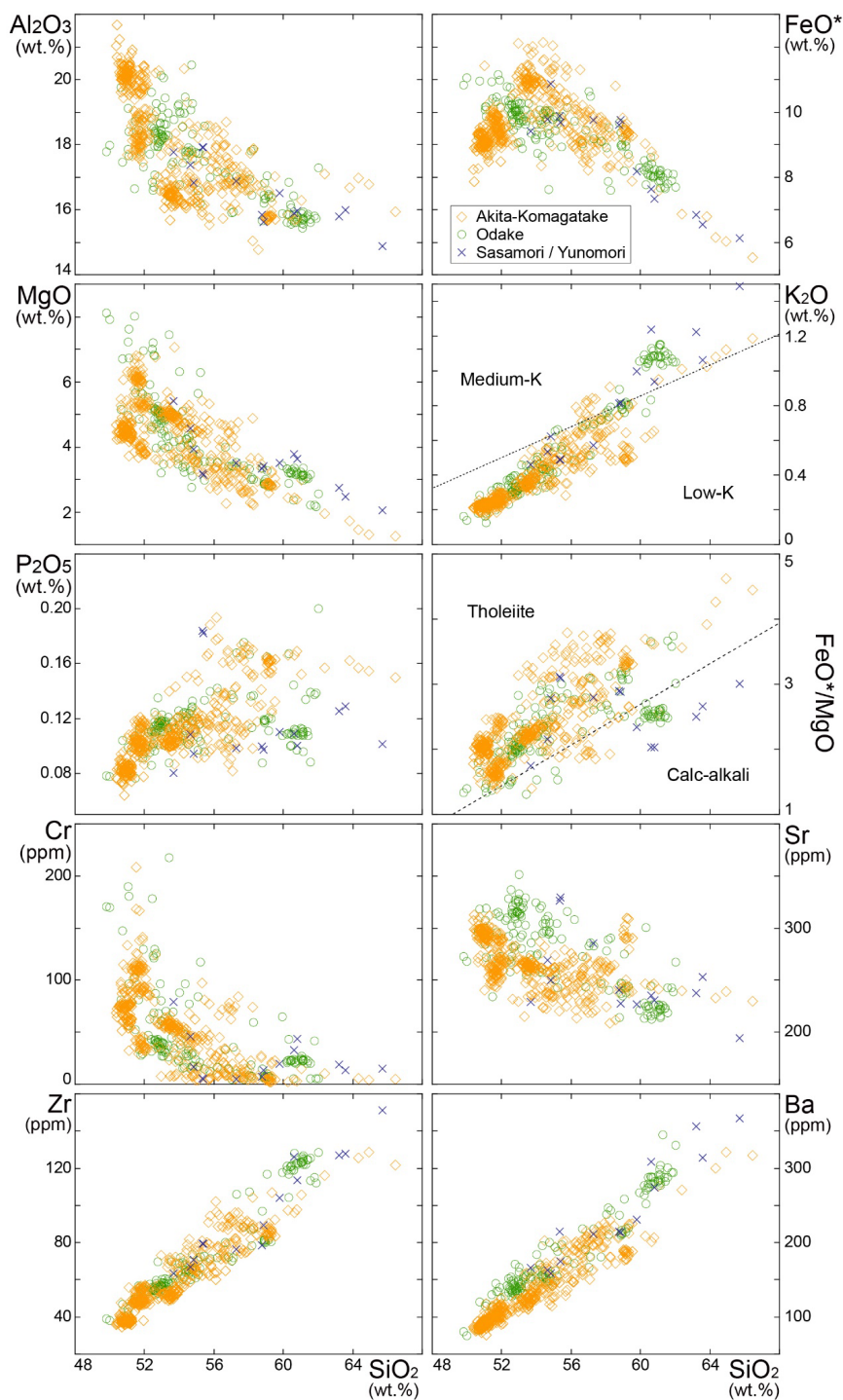


Figure 2-33 Harker diagrams for representative elements created in this study. Based on these Harker diagrams, it is inferred that the volcanic products form multiple compositional trends in many of the diagrams.

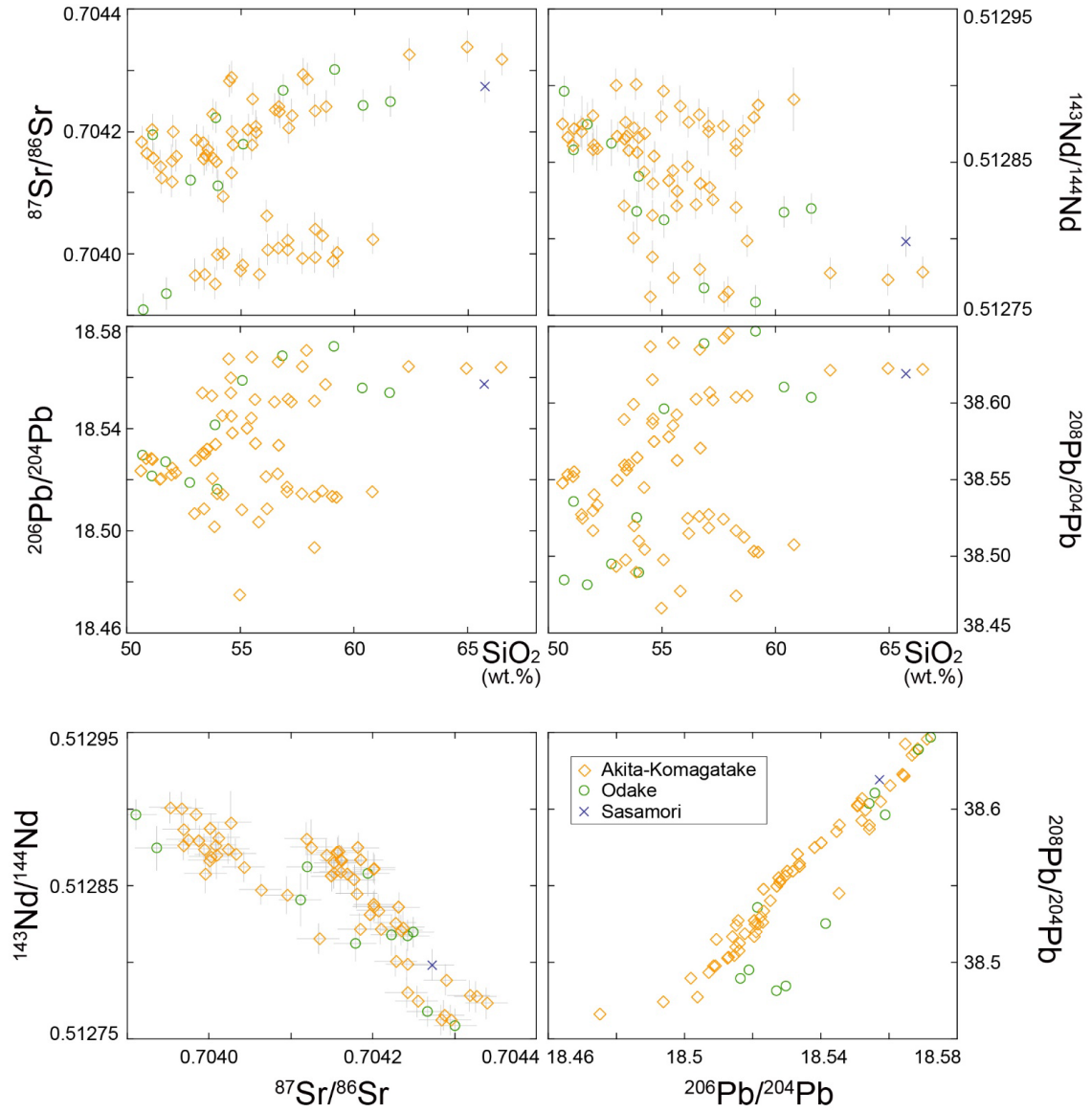


Figure 2-34 Silica variation diagrams for $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$, $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $^{143}\text{Nd}/^{144}\text{Nd}$, $^{206}\text{Pb}/^{204}\text{Pb}$ vs. $^{208}\text{Pb}/^{204}\text{Pb}$ diagrams. These graphs also generally show that the volcanic products exhibit multiple compositional trends, similar to Fig. 2-33. Furthermore, a clear bifurcation into two compositional trends is particularly recognized in the SiO_2 vs. $^{87}\text{Sr}/^{86}\text{Sr}$ diagram.

2-8. Discussion

2-8-1. Correlation of Tephra Fall Deposits and Edifice Deposits

Based on the chemical compositions mentioned before, the magma types classified using the $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios of tephra fall deposits (Fig. 2-35a). The isotope data show that the units fall into three distinct compositional fields, which are defined in this study as A, B, and C types. The characteristic features of these magma types are summarized in Table 2-4. A type is characterized by higher Sr isotope ratios (0.70409–0.70433) and the lowest Nd isotope ratios (0.51276–0.51284). C type exhibits the lowest Sr isotope ratios (0.70395–0.70406) and the highest Nd isotope ratios (0.51284–0.51290). B type shows Sr isotope ratios comparable to those of Type A (0.70412–0.70423), whereas its Nd isotope ratios fall between those of A and C types (0.51282–0.51288). Each tephra unit belongs to a single magma type, and no tephra unit exhibits multiple magma types. Conversely, stratigraphically continuous tephra fall deposits may sometimes belong to the same magma type. Consequently, when the 13 tephra units erupted since the caldera-forming stage are arranged chronologically, they are classified into the following magma types (excluding the phreatic eruption AK5): AK13–12 belong to A type, AK11–8 belong to C type, and AK7, AK6, AK4, and AK3–1 belong to B type (Fig. 2-35a).

Focusing further on the Large Ion Lithophile (LIL) element content such as K_2O and Ba, B and C types could each be subdivided into two subtypes: a Low-LIL (B-1 and C-1) type poor in K_2O and Ba, and a High-LIL (B-2 and C-2) type rich in these elements. Specifically, among the C type unit (AK11–AK8), AK11–AK9 belong to the C-1 subtype, while AK8 belongs to the C-2 subtype. Similarly, among the units of B type (AK7–AK1), AK4 belongs to the B-2 subtype, and the remainder belong to the B-1 subtype (Fig. 2-35b, c). In summary, the tephra fall deposits derived from this volcano could be classified into five distinct magma types based on a

combination of Sr-Nd isotope ratios and LIL element contents (Table 2-4).

The edifice deposits were also examined in terms of Sr and Nd isotopic ratios and K₂O, Ba contents to classify magma types. It was found that the same five magma types identified for the tephra fall deposits can also be applied to the edifice deposits (Fig. 2-36). Accordingly, the following discussion compares magma types for each activity stage.

The edifice deposits of Stage I, namely the Obonai and Kunimi pyroclastic flow deposits and Minamidake pyroclastic cone, are of the A type and can be correlated with AK13 and AK12, which are the same magma type. Since AK13 and AK12 are considered to have originated from the Southern Caldera based on these isopach maps, this correlation is considered reliable. In the Harker diagrams of MgO and Al₂O₃ (Fig. 2-37), AK13 and AK12 form distinct compositional trends, and the Obonai pyroclastic flow plots along the same compositional trend as AK13. Therefore, the Obonai pyroclastic flow is correlated with AK13. Within AK13, the subunits show variations in phenocryst proportions: the lowest subunit, K3P, contains fewer and smaller olivine phenocrysts than the upper subunits K2P and K1P. The scoria within the Obonai pyroclastic flow deposit shows similar olivine phenocryst abundance and grain size to K3P. Hence, the Obonai pyroclastic flow is correlated with K3P of AK13. Regarding the Kunimi pyroclastic flow, both it and AK12 consist exclusively of pumice as essential material, and their pumice lithofacies are two-pyroxene andesites to dacites with low phenocryst abundance. These features suggest that the Kunimi pyroclastic flow corresponds to Y3P or Y2P-L of AK12. Among these, Y3P is characterized by multiple pumice- and lithic-rich layers interbedded within pinkish-brown fine ash, showing strong similarity to the stratigraphy of the Kunimi pyroclastic flow deposit. Furthermore, in the Harker diagrams of MgO and Al₂O₃ (Fig. 2-37), the pumice from both deposits fall along the same compositional trend. Therefore, the Kunimi pyroclastic flow is correlated with Y3P of AK12.

In Stage II (Northern Edifice), Substage II-1 (Katakuradake formation substage) and II-2 (Katakuradake explosive eruption substage) corresponds to C type, Substage II-3 (Onamedake formation substage) and II-4 (Onamedake hydrothermal activity substage) corresponds to B type. Therefore, Substages II-1 and II-2 can be correlated with AK11–AK8, and Substages II-3 and II-4 with AK7–AK4 (AK5 represents a phreatic eruption). This correlation is also consistent with the shapes of the isopach maps. Furthermore, based on LIL element compositions, the Katakuradake 1st edifice is characterized by low-LIL contents, while the Katakuradake 2nd edifice is high-LIL, corresponding to AK11–AK9 and AK8, respectively. Similarly, the Onamedake 1st edifice is low-LIL, and the Onamedake 2nd edifice is high-LIL, corresponding to AK7, AK6, and AK4, respectively.

The AK3–AK1 can be attributed to the Southern Edifice based on these isopach maps (Fig. 2-11). From the Sr–Nd isotopic ratios and LIL element contents, AK3–AK1 and the Southern Edifice are both classified as the B type with low LIL contents, showing consistent geochemical characteristics. Furthermore, based on the lithological difference—AK2 being basalt and AK1 being basaltic andesite—AK2 can be correlated with Medake, and AK1 with New-Kodake. No edifice deposits correlated with AK3 have been identified; however, the isopach map of AK3 suggests that its source is in the northeastern part of the Southern Caldera, near the present Kodake. The present Kodake consists of New-Kodake, which corresponds to AK1, and the underlying Old-Kodake, which is overlain by Medake (corresponding to AK2). Therefore, Old-Kodake is most likely correlated with AK3 based on the stratigraphy of the edifice deposits. In addition, AK3 is inferred to have originated from a phreatomagmatic eruption based on its lithofacies. Given that Old-Kodake exhibits topographical characteristics typical of phreatomagmatic eruption—such as a large crater and a low height-to-diameter ratio—it is also likely to have formed through a phreatomagmatic eruption. Thus, AK3 and Old-Kodake can also be correlated

based on their similar eruptive style.

2-8-2. Formation History and Magma Transition

(1) Overview

Based on the procedure described above, the tephra fall deposits and edifice deposits of this volcano were successfully correlated (Fig. 2-38), allowing the reconstruction of a high-temporal-resolution volcanic edifice evolution from the late Pleistocene to the present. The results are illustrated as a block diagram in Fig. 2-39, and a summary of each eruptive activity is provided in Table 2-5. The characteristics of each stage of activity are described below.

(2) Stage I (Southern Caldera Formation Stage)

After the formation of Otake stratocone, volcanic activity ceased for more than 6,000 years before Stage I began at around 14 ka. During this stage, two large explosive eruptions (AK13 and AK12) occurred at 14.0 and 13.5 ka, accompanied by the formation of the Minamidake pyroclastic cone between them. Each of these major eruptions produced a pyroclastic flow: the Obonai pyroclastic flow extended toward the southern to western flanks, while the Kunimi pyroclastic flow flowed near the caldera. Stage I was characterized by the activity of A type magma, which is not recognized in the subsequent stages.

As described in the topographical section, the Southern Caldera exhibits an elliptical shape elongated in the northeast–southwest direction, and the topography of the caldera wall suggests that multiple craters are joined together (Fig. 2-8). According to the isopach map, AK13 is inferred to have a source in the southern part of the Southern Caldera (Fig. 2-11). Consistent with this interpretation, the Obonai pyroclastic flow is thickly distributed on the southwestern flank (Fig. 2-20). These observations indicate that the first large explosive eruption (AK13)

formed the southern part of the Southern Caldera. In contrast, the isopach map of AK12 indicates a source in the northern part of the Southern Caldera (Fig. 2-11). The Kunimi pyroclastic flow, which is correlated with AK12, is distributed in the southern area of the caldera (Fig. 2-20). Therefore, the second large explosive eruption (AK12) is interpreted to have formed the northern part of the Southern Caldera. Consequently, the Southern Caldera is interpreted as a compound caldera, whose southern and northern parts were formed by the first (AK13) and second (AK12) large explosive eruptions, respectively. The Minamidake pyroclastic cone was formed prior to the explosive eruption of AK12, within the crater produced by the preceding AK13 eruption.

(3) Stage II (Northern Edifice Formation Stage)

After a dormancy period of 1,800 years following Stage I, the Northern Edifice became active. During this activity, Katakuradake first began its activity (Substages II-1 and II-2), and after another dormancy of 1,500 years, multiple pyroclastic cones, including Onamedake, were formed (Substage II-3). Subsequently, after a further dormancy of 3,700 years, hydrothermal activity initiated within the explosion crater formed during Substage II-3 (Onamedake explosion crater), leading to repeated small-scale magmatic–phreatomagmatic eruptions (Stage II-3).

(i) Substage II-1

After 11.6 ka, mild eruptions such as Strombolian eruptions occurred repeatedly (AK11 and AK10), forming the stratovolcano of Katakuradake, accompanied by frequent lava flows that extended toward the northwest flank. At around 9.4 ka, an explosive eruption (AK9) took place, creating a crater approximately 1.2 km in diameter at the present summit of Katakuradake. These activities largely constructed the present edifice of Katakuradake and filled the floor of the Northern Caldera (Figs. 2-18, 2-26). Substage II-1 was characterized by the

activity of C-1 subtype magma, producing eruptive products with compositions ranging from basaltic andesite to dacite.

(ii) Substage II-2

At around 9.3 ka, another explosive eruption (AK8) occurred. During this eruption, agglutinate covered the surface of the Katakuradake 1st edifice, and a pyroclastic flow was also generated (Fig. 2-25). Based on the distribution of these agglutinate and pyroclastic flow deposit, this eruption is inferred to have formed a crater on the northern part of the Katakuradake edifice. Substage II-2 was characterized by the activity of C-2 subtype magma, producing eruptive products with compositions ranging from basaltic andesite to andesite.

(ii) Substage II-3

At around 8.1 ka, activity resumed in the summit area of Katakuradake. The activity began with mild eruptions, such as Strombolian eruptions (AK7), forming several pyroclastic cones including Onamedake. Lava flows were also emitted during this activity, filling the summit crater of Katakuradake and descending along the northwestern and western flanks of the edifice. Subsequently, at around 7.3 ka, an explosive eruption (AK6) occurred, formed Onamedake explosion crater approximately 500 m in diameter on the northwestern slope of Onamedake. This explosive eruption was accompanied by a pyroclastic flow that extended down the northern flank (Fig. 2-25). The activity then continued, producing lava flows that filled the explosion crater and descended along the northern slope (Fig. 2-26). Substage II-3 was consistently characterized by the activity of B-1 subtype magma.

Crater lake deposit was identified within the Onamedake explosion crater (Figs. 2-18, 2-23c). Therefore, a lake is considered to have once existed inside this crater. However, this lake

was likely breached and drained by the subsequent Substage II-4 activity.

(iv) Substage II-4

After a 3,700 years of dormancy, activity resumed at the Sulfur mining crater (located inside the Onamedake explosion crater). A phreatic eruption (AK5) occurred at around 3.3 ka, followed by eruptions at around 2.2 ka (AK4). The AK4 eruption began with multiple phreatic eruptions and then shifted to phreatomagmatic eruptions containing scoria as a juvenile material. These eruptions made the Onamedake 2nd edifice around the Sulfur mining crater. This activity marked the end of eruptive events in the Northern Edifice, after which the activity shifted to the Southern Edifice.

Substage II-4 produced the same B type magma as Substage II-3. However, whereas Substage II-3 is characterized by the B-1 subtype with low LIL contents, Substage II-4 shifted to the B-2 subtype, which is characterized by higher LIL contents.

(4) Stage III

At around 2.1 ka, the Southern Edifice became active. Multiple phreatomagmatic eruptions (AK3) first formed Old-Kodake in the northeastern part of the Southern Caldera. Subsequently, Medake became active at around 1.5 ka, producing AK2 as well as forming a pyroclastic cone and lava flows. From around 1.2 ka, Kodake (New-Kodake) resumed activity, emitting AK1 and formed a pyroclastic cone and lava flows. This activity ceased by 915 CE (Fig. 2-27d).

After the activity of New-Kodake, the volcano experienced a dormancy of approximately 1,000 years before eruptive activity resumed in the late 19th century (Suwa, 1971). In the 20th century, eruptions occurred in 1932 CE and 1970–71 CE. The 1932 CE eruption was

identified in this study as a phreatomagmatic eruption, whereas the 1970–71 CE eruption involved effusion of lava accompanied by repeated Strombolian eruptions.

During Stage III, the activity from 2.1 ka to the 1932 CE eruption was characterized by B type magma with Low-LIL contents, whereas the 1970–71 CE eruption abruptly shifted to C type magma with Low-LIL characteristics. This suggests that the volcano may have entered a new stage of activity after 1970 CE.

2-8-3. Magma Discharge Step-Diagram

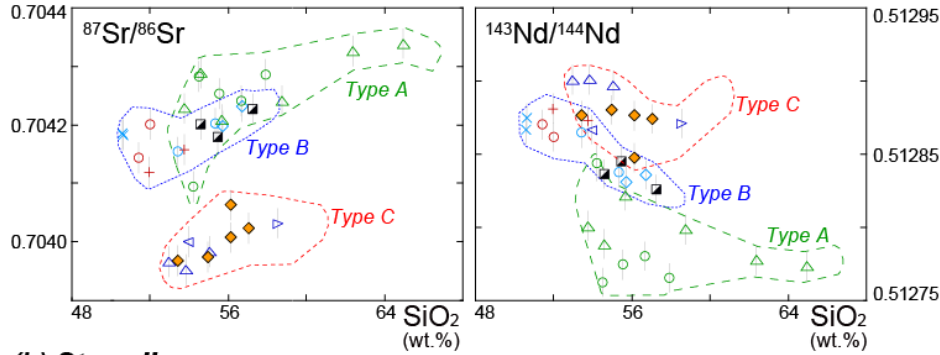
The magma discharge step-diagram, which illustrates the relationship between eruption age and cumulative erupted volume (Nakamura, 1964), has been widely used to quantitatively evaluate temporal variations in volcanic activity (Bacon, 1982; Burt et al., 1994; Aki and Ferrazzini, 2001; Bebbington, 2008; Nfomou et al., 2019). In particular, step-diagrams based on tephra fall deposits have been constructed for many volcanoes and have proven effective in revealing the characteristics of their eruptive histories (Uesawa et al., 2016; Kudo, 2023). However, to evaluate actual eruptive behavior, it is necessary to consider not only tephra fall deposits but also edifice deposits, such as lava flows and pyroclastic cones. In many cases, these deposits are not accompanied by widely dispersed tephra fall deposits, and their eruptive ages are often uncertain. Consequently, step-diagrams that integrate both tephra fall and edifice deposits have rarely been constructed (Maeno et al., 2019; Nakagawa et al., 2024).

In this study, a detailed correlation between the tephra fall deposits and the edifice deposits enabled the estimation of the eruption ages of individual edifice deposits within a certain temporal range. As a result, a magma discharge step-diagram that incorporates both tephra fall units and edifice deposits was successfully constructed (Fig. 2-40).

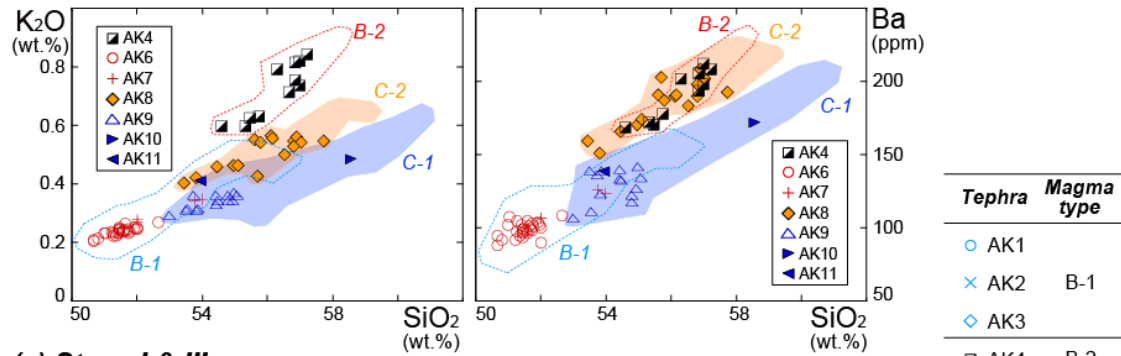
For Akita-Komagatake, Wachi et al. (1997) constructed a step-diagram based solely on tephra deposits. Their results showed that the volume was greatest during Stage I (Southern

Caldera formation stage) and markedly decreased thereafter. In contrast, the step-diagram reconstructed in this study indicates that, in addition to Stage I, Substage II-1 also exhibited a large volume and a relatively high eruptive rate. These results indicate that volcanic activity at Akita-Komagatake since the late Pleistocene can be divided into three characteristic phases: (1) a large discharge of magma during the initial explosive eruptions, (2) subsequent edifice growth through mild eruptions such as lava eruptions, and (3) a decline in the eruptive rate during the later stages. Furthermore, the step-diagram constructed in this study suggests that multiple dormancy of approximately 1,000–3,000 years occurred throughout the eruptive history of Akita-Komagatake. In particular, changes in magma type are recognized across the dormancies between Stage I and Substage II-1, between Substage II-2 and II-3. These observations indicate that the magma plumbing system and magma generation processes of Akita-Komagatake have evolved over time.

(a) All Tephra



(b) Stage II



(c) Stage I & III

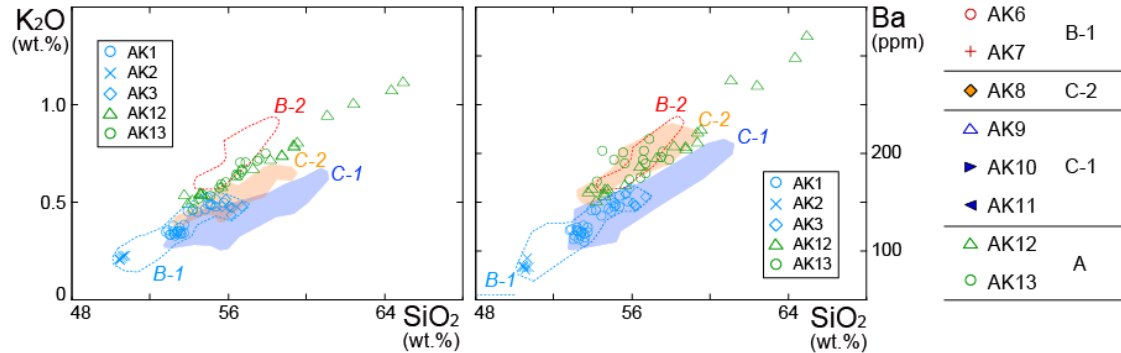
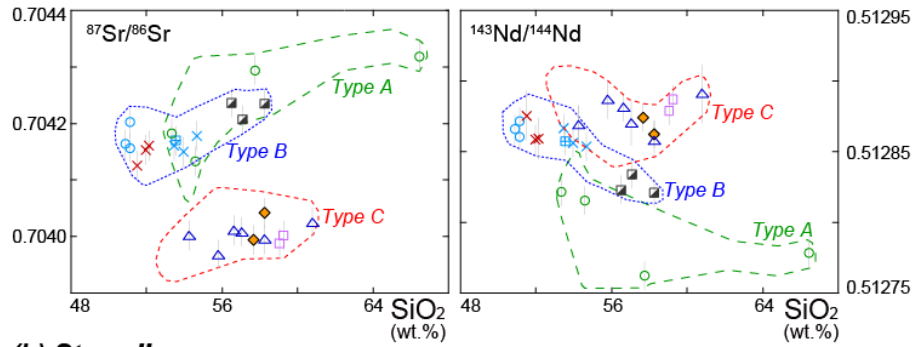
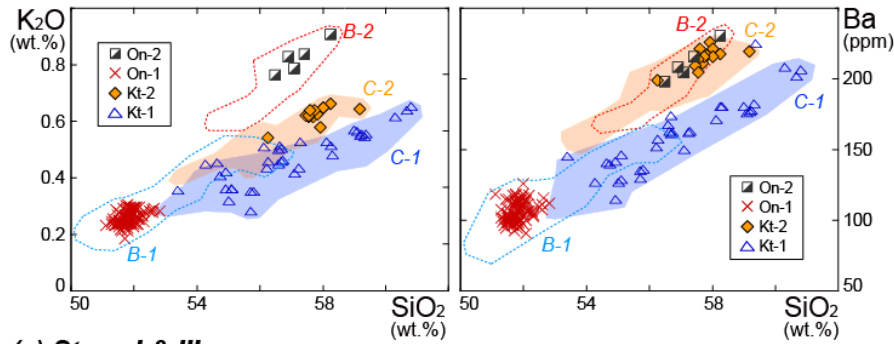


Figure 2-35 Silica variation diagrams of tephra fall deposits. (a) SiO_2 vs. $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ for all tephra fall deposits. Based on these diagrams, the deposits are categorized into three magma types: A type, high Sr and low Nd isotope ratios; B type, high Sr and intermediate Nd isotope ratios; C type: low Sr and high Nd isotope ratios. (b) and (c) show SiO_2 vs. K_2O and Ba for Stage II and Stages I and III, respectively. B and C types were further subdivided into two subtypes each, based on high and low LIL element abundances. Consequently, based on these diagrams, the tephra fall deposits are classified into five distinct magma types: A, B-1, B-2, C-1, C-2.

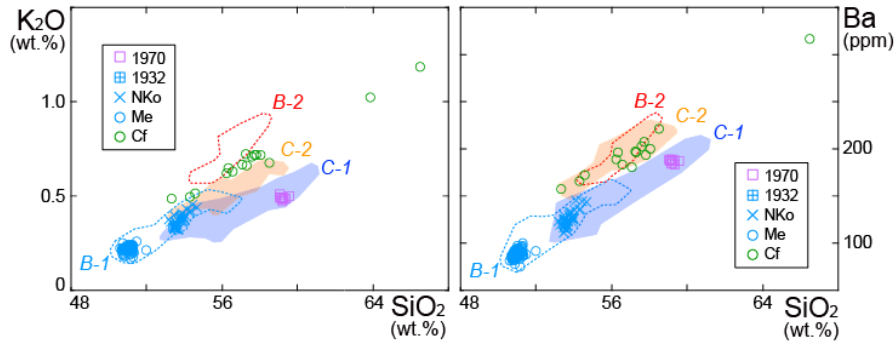
(a) Edifice-forming deposits



(b) Stage II



(c) Stage I & III



Stage	Edifice	Magma type
III-2	1970	C-1
	1932	B-1
	NKo	B-1
III-1	Me	B-1
II-4	On-2	B-2
II-3	On-1	B-1
II-2	Kt-2	C-2
II-1	Kt-1	C-1
I	Cf	A

Figure 2-36 Silica variation diagrams of edifice deposits. (a) SiO_2 vs. $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ for all edifice deposits. (b) and (c) show SiO_2 vs. K_2O and Ba for Stage II and Stages I and III, respectively. The edifice deposits also belong to one of the same five magma types as the tephra fall deposits, and no single unit spans multiple magma types.

Table 2-4 Characteristics and definition of the magma types recognized at Akita-Komagatake

Type	Subtype	SiO ₂	MgO	K ₂ O	⁸⁷ Sr/ ⁸⁶ Sr	¹⁴³ Nd/ ¹⁴⁴ Nd	LILE
A	-	53.32–66.46	1.24–7.04	0.46–1.18	0.70409–0.70434	0.51276–0.51284	High
B	B-1	50.41–56.71	3.32–6.80	0.16–0.53	0.70412–0.70424	0.51282–0.51288	Low
	B-2	54.59–58.25	4.18–5.41	0.60–0.91			High
C	C-1	52.96–60.78	2.21–4.57	0.28–0.65	0.70395–0.70406	0.51284–0.51290	Low
	C-2	53.40–59.16	2.58–4.13	0.40–0.66			High

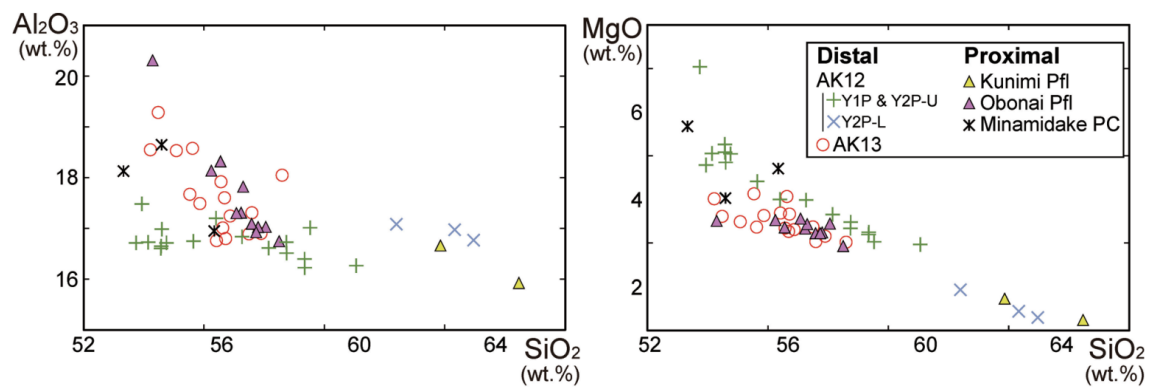


Figure 2-37 Silica variation diagrams for samples of proximal pyroclastic deposits and distal tephra deposits from Stage I of Akita-Komagatake volcano. Samples from Obonai and Kunimi pyroclastic flows show the similar compositional variations to AK13 and Y2P-L of AK12, respectively. The basaltic andesites of Minamidake pyroclastic cone and AK13 can be distinguished in the SiO_2 - MgO diagram.

<i>Tephra fall deposits</i>						<i>Edifice deposits</i>					
Type	A	B-1	B-2	C-1	C-2		A	B-1	B-2	C-1	C-2
						1970					
						1932					
AK1						NKo					
AK2						Me					
AK3						OKo		(no data)			
AK4						On-2					
AK5	(phreatic eruption)										
AK6						On-1					
AK7											
AK8						Kt-2					
AK9						Kt-1					
AK10											
AK11											
AK12						Cf					
AK13											

Figure 2-38 Diagram illustrates the magma type transition of the tephra fall deposits and edifice deposits. Because both deposits exhibit the same sequence of magma type changes, units belonging to the same magma type were correlated according to the color scheme shown.

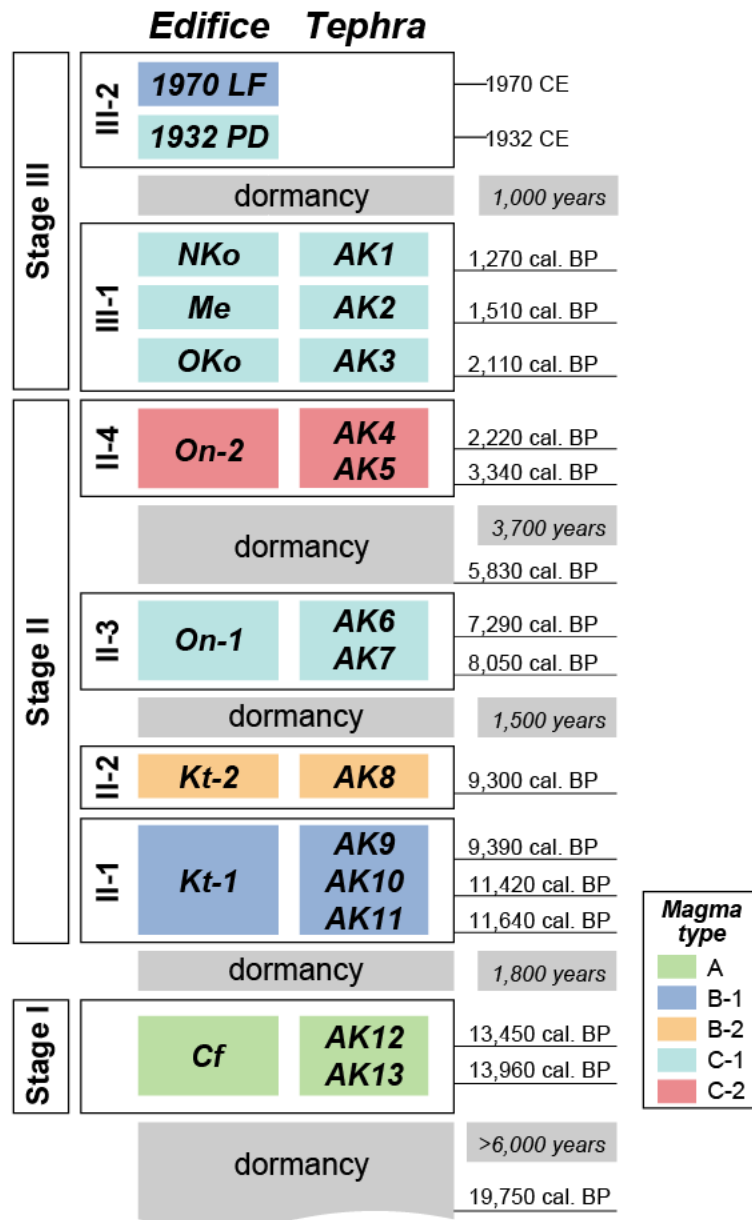


Figure 2-39 Block diagram illustrating the formation history of Akita-Komagatake. In this study, the activity of Akita-Komagatake was divided into three stages, Stage I-III. Stage I corresponds to the Southern Caldera formation stage, during which two large explosive eruptions at 13.9 and 13.5 ka formed the Southern Caldera. Stage II represents activity of the Northern Edifice. Stage II is subdivided into four Substages, Substage II-1 to II-4. Stage III corresponds to activity of the Southern Edifice. This stage is also subdivided into two substages. Substage III-1 is pre-915 CE activity substage, and Substage III-2 is historical activity substage. By correlating edifice deposits with tephra fall deposits, it was possible to integrate the ages obtained from tephra fall deposits into the formation history of the volcanic edifice.

Table 2-5 Overview of the volcanic activity of Akita-Komagatake.

Stage	Substage	Proximal	Tephra	Magma Type	Volume (km ³ DRE)		Total	Remarks
III	III-2	1970		B-1	0.0014	-	0.0014	Lava effusion
		1932		C-1	0.00017	-	0.00017	Phreatomagmatic eruption
	III-1	NKo	AK1	C-1	0.0104	0.011	0.0214	Multiple pyroclastic cones activity
		Me	AK2	C-1	0.041	0.0029	0.043	
		Oko	AK3	C-1	0.0013	0.022	0.023	
II	II-4	On-2	AK4 AK5	C-2	0.00052	0.0066 0 (ph)	0.0071	Onamedake hydrothermal activity
	II-3	On-1	AK6 AK7	C-1	0.054	0.02 0.03	0.1039	Onamedake stratocone formation
	II-2	Kt-2	AK8	B-2	0.026	0.057	0.083	Katakuradake explosive eruption
	II-1	Ki-1	AK9	B-1	0.4	0.053	0.5	Katakuradake stratocone formation
			AK10 AK11			0.022 0.026		
I		Kupfl	AK12	A	0.023	0.4	0.71	Southern Caldera formation
		Mi			0.0029			
		Obopfl	AK13		0.040	0.24		

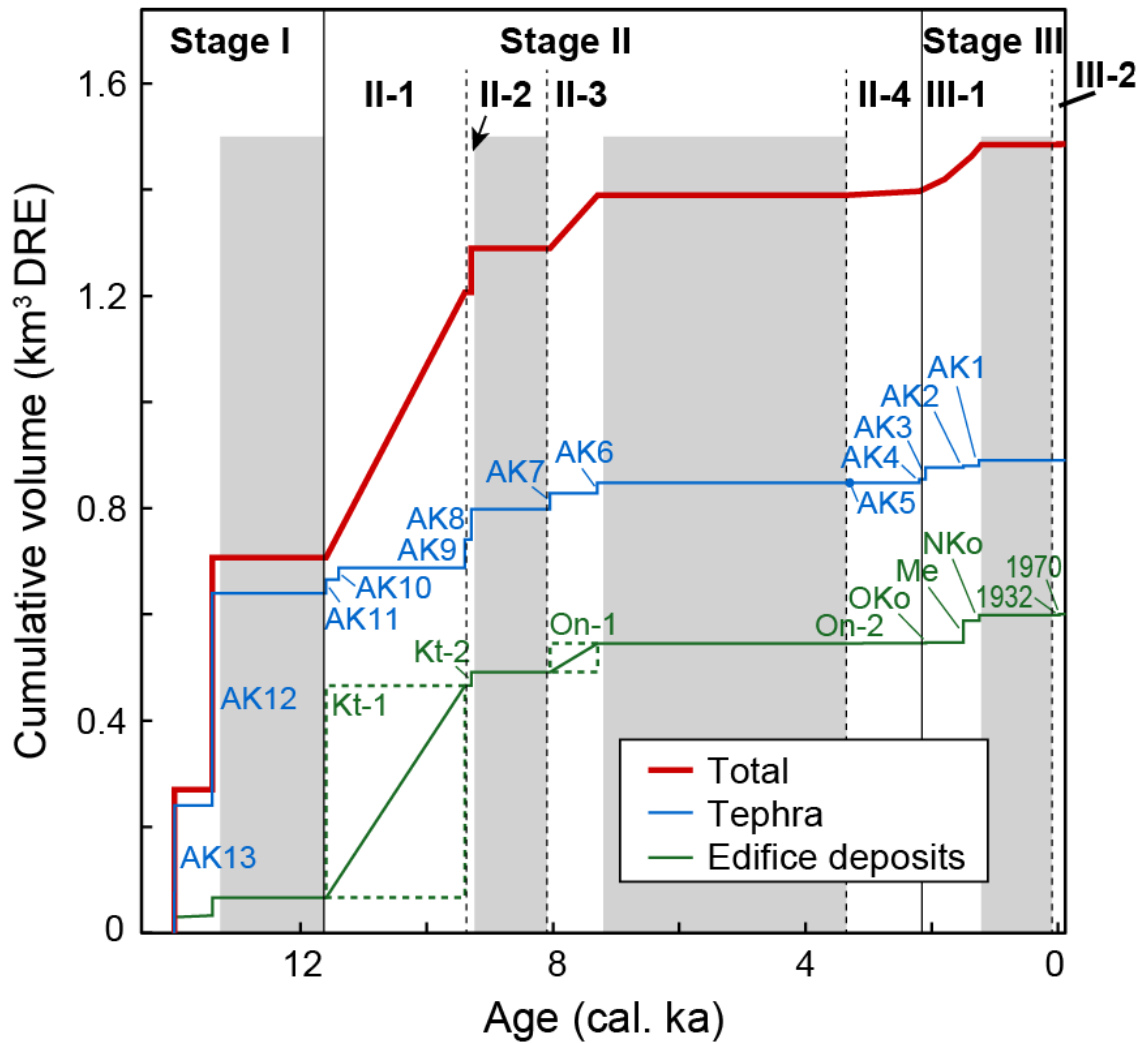


Figure 2-40 Magma discharge step-diagram of Akita-Komagatake. The periods shaded in gray indicate dormancy. Previously, Wachi et al. (1997) constructed a magma discharge step-diagram for this volcano using only tephra fall deposits. In their diagram, volcanic activity was interpreted as having a high discharge rate only during Stage I, followed by lower rates thereafter. In contrast, a magma discharge step-diagram based on both the edifice deposits and tephra fall deposits reveals that Substages II-1 and II-2 also had a high discharge rate, while only Substages II-3, II-4 and Stage III were characterized by lower discharge rates. Thus, by comparing tephra fall deposits with edifice deposits and incorporating the temporal axis into the formation history of the edifice, a more accurate eruptive history was reconstructed. Note that in creating the step-diagram, the eruption age for the tephra fall deposits was adopted as the age of the underlying soil. As for the edifice deposits, the accumulated volume was represented by a diagonal line, assuming that the eruption was emplaced during the period between the eruption age of the correlated tephra fall deposit and the age of the subsequent eruption.

2-9. Conclusion

In this study, in order to construct the formation history of Akita-Komagatake, I correlated the tephra fall deposits with the edifice deposits, focusing on the magma types. To define and identify the magma types, this study utilized petrological and geochemical data from multiple parameters. As a result, the following points were revealed:

(1) The activity of Akita-Komagatake from the Late Pleistocene to the present can be divided into three stages: the Southern Caldera Formation Stage (Stage I), the Northern Edifice Activity Stage (Stage II), and the Southern Edifice Activity Stage (Stage III). Furthermore, Stage II and Stage III can be subdivided into four and two substages, respectively, based on differences in eruptive locations, eruption style, and magma type.

(2) Thirteen units of tephra fall deposits originating from the volcano, designated AK13 to AK1 in order of age, have been identified. Based on the isopach maps of each tephra fall unit, AK13 and AK12 are considered to originate from Stage I activity, AK11 to AK4 from Stage II activity, and AK3 to AK1 from Stage III activity.

(3) Based on Sr-Nd isotope ratios and the concentrations of LIL elements such as K₂O and Rb, the tephra units can be classified into five magma types, with each tephra unit belonging to a single magma type. Moreover, the same magma type classification could be applied to the edifice deposits. Therefore, by correlating units of the same magma type, I was able to insert age data obtained from the tephra fall deposits into the formation history of the volcano.

(4) A magma discharge step-diagram was created based on correlation results, the activity of the volcano was as follows: (i) Massive magma release due to an initial large-scale explosive eruption. (ii) Subsequent edifice formation resulting from vigorous mild eruptions. (iii) A decrease in the eruption rate thereafter.

(5) This study successfully demonstrated that a highly accurate edifice formation history can be

reconstructed through the "correlation of tephra fall units and the edifice deposits based on magma type." Many subduction zone volcanoes are known to produce multiple magma types throughout their activity. Therefore, this method proposed in this study is expected to be applicable to other volcanoes around the world.

Chapter 3. Long term Evolution of Magma Plumbing System of Akita-Komagatake

Abstract

To elucidate the generation and evolution processes of magma in subduction zone, detailed geochemical studies of an individual volcano is important in addition to regional-scale geochemical studies. I have constructed the formation history of Akita-Komagatake volcano located in the Northeast Japan arc and have revealed that multiple types of magma have had erupted through the volcanic activity (Chapter 2). In this chapter, I revealed the formation mechanism of these magma types recognized on the volcano.

Based on Sr–Nd–Pb isotopic ratios, the rocks of this volcano can be classified into three main magma type. All three types share several common characteristics: (1) each magma type includes mafic rocks with SiO₂ contents of approximately 50–54 wt.%, from which compositional trends extend toward andesitic to dacitic compositions; (2) irrespective of SiO₂ content, petrographic observations reveal the presence of both texturally homogeneous samples and samples exhibiting disequilibrium features; and (3) isotopic ratios systematically shift toward relatively more enriched compositions from mafic to felsic rocks within each magma type. These results indicate that assimilation–fractional crystallization (AFC) was the dominant intra-crustal process. And this process occurred in two phases: first, magmas differentiated to SiO₂ contents of 50–54 wt.% through fractional crystallization (Phase 1), and then assimilated with surrounding crustal materials before erupting (Phase 2). it is considered that all three main magma types were generated as primary magmas by the supply of aqueous fluids from the subducting slab to the mantle wedge. However, the volume and composition of these fluids varied for each main magma type, which led to the formation of three distinct magma types with different isotopic ratios.

Combined with the eruptive history, it is known that the main magma types changed at intervals of several thousand years, and that each transition was invariably preceded by a period of dormancy. This suggests that slab-derived fluids are not supplied at a steady rate but rather in a pulse-like manner. This implies that the active periods of subduction zone volcanoes may be controlled by the timing of these pulse-like supplies of slab-derived fluids. Furthermore, given that Phase 1 of AFC process serves as a preparation stage to assimilate crustal materials in Phase 2, this volcano likely renewed its intra-crustal magma plumbing system at each transition between magma types.

This study provides the first example in the Northeast Japan Arc in which the structure of a mantle-to-crust magma plumbing system and its temporal evolution have been reconstructed. Furthermore, the origins of the diverse magma types erupted at Akita-Komagatake are attributed to both mantle and crustal processes. The magma-generation model developed in this study may also be applicable to other volcanoes in the Northeast Japan Arc.

3-1. Introduction

In subduction zones, complex magmatism occurs involving subducting slab, mantle wedge and crust (Kimura and Yoshida, 2006). A common model for magma plumbing system in subduction zone is as follows: fluids released from the subducting plate are added to the mantle wedge, thereby triggering partial melting (Tatsumi et al., 1986). The primary magmas generated through this process then ascend into the crust, where they undergo various differentiation processes—such as fractional crystallization, magma mixing, and assimilation-fractional crystallization (AFC)—before ultimately erupting at the surface (Forni et al., 2013; Mokitikanana et al., 2024).

Subduction zone is characterized by diverse chemical compositions of erupted

products, reflecting their complex magma generation processes. Such compositional variations are observed not only on a regional scale—both across and along a volcanic arc (Till et al., 2019; Ancellin et al., 2017; Cembrano and Lara, 2009)—but also within an individual volcano (Montserrat: Cassidy et al., 2012; Grenada: Thirlwall et al., 1996; Merapi: Gertisser and Keller, 2003). Although numerous studies have documented the chemical diversity of erupted products from an individual volcano, few have discussed the mechanisms responsible for this diversity based on detailed temporal evolution within a single volcanic edifice (Wibowo et al., 2022). Consequently, the evolution of magma plumbing system in a subduction zone volcano—from the mantle to the crust—remain poorly understood.

The Northeast Japan arc is one of the most intensively studied subduction zones in the world, with numerous petrological and geochemical investigations conducted both on a regional scale (e.g. Nakagawa et al., 1988; Kimura and Yoshida, 2006) and on individual volcanoes. Studies focusing on individual volcanoes, however, have been limited to those dominated by intermediate to felsic eruptive deposits (e.g., Towada volcano, Hunter and Blake, 1995; Ichinomegata volcano, Sato and Ozawa, 2023; Zao volcano, Ban et al., 2022; Hijiori volcano, Miyagi et al., 2017). In contrast, for volcanoes dominated by mafic eruptive deposits, the influence of crustal processes is expected to be relatively minor, allowing discussions on the evolution of magma plumbing system, including their source material. However, such volcanoes are rare in the Northeast Japan arc, and no detailed case studies have been reported.

This study selected Akita-Komagatake volcano, which locates on the central part of the Northeast Japan Arc, mainly erupted mafic eruptive deposits. Furthermore, in Chapter 2, a comprehensive eruptive history of the volcano has been established. Therefore, the volcano can be regarded as an ideal volcano for precisely discussing the structure and evolution of the magma plumbing system from the mantle to the crust. This volcano has been shown to have periodically

produced multiple types of eruptive products with distinct Sr–Nd–Pb isotopic ratios throughout its history. Here, based on its formation history and whole-rock geochemical compositions, I constructed the evolution of the magma plumbing system and discussed the mechanism responsible for generating multiple magma types with different isotopic signatures. The result indicate that temporal variations in magma types were primarily controlled by changes in the relative amount and composition of slab-derived fluid added to the wedge mantle at the time of primary basaltic magma generation. The primary basaltic magma generated in the wedge mantle ascended into the crust, where they underwent assimilation and fractional crystallization (AFC) process and subsequently erupted at the surface.

3-2. Method

In this study, in addition to the petrological and geochemical data obtained in Chapter 2, additional whole-rock trace element (Nb, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th and U) analysis was carried on 73 samples (same samples as Sr-Nd-Pb isotopic analysis were carried). The concentrations of these elements were obtained by inductively coupled plasma mass spectrometer (ICP-MS; Thermo Fisher iCAP RQ) at the faculty of Science, Hokkaido University. Using the same powdered samples prepared for the XRF analysis, an acid digestion method was adopted for all samples, following the procedures described by Yokoyama et al. (2017). Trace element concentrations were analyzed with a dilution factor (DF) of $\sim 10^5$. Same as Chapter 2, the results of the replicate analyses of the reference material JB-3 (obtained from the Geological Survey of Japan; Imai et al., 1995) and the reference values are shown in Appendix.

3-3. Outline of Formation History and Magma Transition

The activity of this volcano over the last 14,000 years has been divided into three stages, from oldest to youngest: Stage I to Stage III. The initial Stage I (14.0–13.5 ka) was the Southern Caldera Formation Stage. During this stage, the volcano conducted the two largest explosive eruptions in its history, formed the composite Southern Caldera. Stage II and Stage III represent the post-caldera activity. The earlier Stage II involved activity of the northern edifice. Stage II is further subdivided into four substages: Substage II-1 (Katakuradake formation substage, 12.0–9.4 ka), Substage II-2 (Katakuradake explosive eruption substage, 9.3 ka), Substage II-3 (Onamedake formation substage, 8.1–5.8 ka) and the Substage II-4 (Onamedake hydrothermal activity substage, 3.3–2.2 ka). Stage II was characterized by repeated mild eruptions, including explosive eruptions and lava effusions, which filled the Northern Caldera. Stage III is the activity of the Southern Edifice. Stage III is also subdivided into two substages: Stage III-1 (Pre-915 CE activity substage, 2.1–1.3 ka) and Stage III-2 (20th-century activity substage). During Stage III-1, Kodake and Medake in the northern part of the Southern Caldera became active. After a dormancy of approximately 1,000 years, eruptions occurred around Medake in 1932 and 1970–1971 CE (Stage III-2).

The eruptive products of this volcano can be categorized into three magma types (A, B and C types; these isotopically distinguished types call “main magma type”) based on their Sr, Nd and Pb isotope ratios, and these types erupted alternately throughout its activity. Specifically, Stage I erupted the A type, Substages II-1 and II-2 erupted the C type, and Substages II-3 and II-4 erupted the B type. Stage III continued to erupt the B type, but the 1970–71 CE eruption distinctly switched to the C type.

Furthermore, focusing on the Large Ion Lithophile (LIL) element content, B and C types could each be subdivided into two “subtypes”: a Low-LIL (B-1 and C-1 subtypes) subtype

poor in K₂O and Ba and a High-LIL (B-2 and C-2) subtype rich in these elements. Basically, for both the B and C magma types that comprise two subtypes, the Low-LIL subtype erupts first, followed by the High-LIL subtype.

3-4. Petrography

3-4-1. General characteristics

The rocks of this volcano range mainly from basalt to andesite with SiO₂ contents of approximately up to 60 wt.%, although dacite also occurs during only Stage I (Southern Caldera formation stage). All samples exhibit porphyritic textures characterized by abundant plagioclase phenocrysts, with modal abundances generally ranging from 4.7 to 49 vol.% (Table 2-3). The petrographic characteristics of each main magma type are described below.

3-4-2. A type

Some samples are homogeneous (Fig. 3-1a), whereas others show banded structures characterized by variations in vesicularity and groundmass texture (Fig. 3-1b). The modal abundance of A type samples range from 7.2~36 vol.%, with mafic samples have higher phenocryst content (22~36 vol.%) and felsic samples have lower phenocryst content (7.2~8.4 vol.%). All A type samples share a common phenocryst assemblage consisting of clinopyroxene, orthopyroxene, plagioclase, and opaque minerals, with olivine additionally present in the mafic samples. The olivine phenocrysts (~0.6 vol.% in modal abundance; ~1.5 mm in size; modal abundance and maximum size are given in parentheses hereafter) have euhedral to anhedral shapes. Some olivine phenocrysts have a reaction rim of orthopyroxene (Fig. 3-1c, d). The clinopyroxene (0.4~4.2 vol. %; ~1.6 mm in size) and orthopyroxene (0.4~7.8 vol. %; ~1.6 mm in size) phenocrysts have euhedral to anhedral shapes. The plagioclase phenocrysts (6.0~27 vol. %;

~3.5 mm in size) are euhedral to anhedral; some are clear, whereas others exhibit dusty zones and zoning (Fig. 3-1e). The opaque minerals (0.2~1.1 vol.%, ~1.3 mm in size) have euhedral to anhedral shapes.

3-4-3. B type

Most of the mafic samples are homogeneous (Fig. 3-2a), some basaltic andesite to andesite samples show banded structures characterized by variations in vesicularity and groundmass texture (Fig. 3-2b). The modal abundance of B type samples range from 4.7~43 vol.%, with mafic samples have higher phenocryst content (23~43 vol.%) and felsic samples have lower phenocryst content (4.7~17 vol.%). All B type samples share a common phenocryst assemblage consisting of clinopyroxene and plagioclase. Mafic samples additionally contain olivine phenocrysts, and samples with SiO₂ contents of approximately 55 wt.% or higher also contain opaque minerals. The olivine phenocrysts (~5.3 vol. %; ~2.1 mm in size) have anhedral to subhedral shapes. The olivine phenocrysts are clear in the basalts (Fig. 3-2c), whereas in the basaltic andesites they commonly possess thick reaction rims of orthopyroxene (Fig. 3-2d, e). The clinopyroxene phenocrysts (0.4~2.2 vol. %; ~1.3 mm in size) have euhedral to anhedral shapes. The orthopyroxene phenocrysts (~3.8 vol. %; ~2.3 mm in size) occur in samples with SiO₂ contents of approximately 52 wt.% or higher, but in samples with SiO₂ contents of 52–53 wt.%, they commonly form coronas around clinopyroxene (Fig. 3-2f, g). The plagioclase phenocrysts (3.3~41 vol. %; ~4.1 mm in size) are euhedral to anhedral; some are clear, whereas others exhibit dusty zones and zoning (Fig. 3-2h). The opaque minerals (~1.1 vol.%, ~0.4 mm in size) have euhedral to anhedral shapes.

3-4-4. C type

Some samples are homogeneous (Fig. 3-3a), whereas others show banded structures characterized by variations in vesicularity and groundmass texture (Fig. 3-3b). The modal abundance of C type samples range from 5~43 vol.%. All C type samples share a common phenocryst assemblage consisting of clinopyroxene, orthopyroxene, and plagioclase. Mafic samples additionally contain olivine phenocrysts, and samples with SiO₂ contents of approximately 54 wt. % or higher also contain opaque minerals. Olivine phenocrysts (~0.5 vol.%; ~1.6 mm in size) have euhedral to anhedral shapes. Some olivine phenocrysts are clear (Fig. 3-3c, d), others possess thick reaction rims of orthopyroxene (Fig. 3-3e). The clinopyroxene (0.2~2.8 vol. %; ~2.2 mm in size) and orthopyroxene (0.3~4.7 vol. %; ~2.9 mm in size) phenocrysts have euhedral to anhedral shapes. The plagioclase phenocrysts (3.9~20 vol. %; ~2.4 mm in size) are euhedral to anhedral shapes. Plagioclase phenocrysts in some samples are composed almost entirely of clear, whereas in other samples, most of the phenocrysts exhibit dusty zones and zoning. The opaque minerals (0.1~1.1 vol.%, ~0.4 mm in size) have euhedral to anhedral shapes.

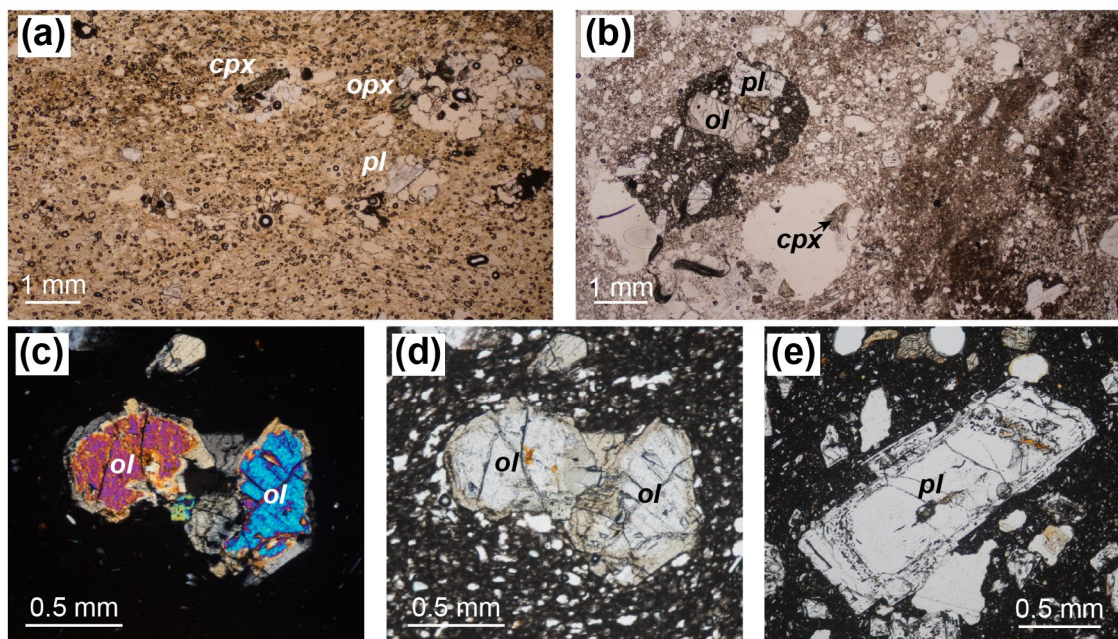


Figure 3-1 Photomicrographs of A type samples. (a) Dacitic pumice. Dacitic A type samples exhibit low phenocryst abundances and generally homogeneous textures. (b) Banded pumice (basaltic andesite). Basaltic andesite to andesite samples occasionally show heterogeneous groundmass textures. (c) and (d) Olivine phenocrysts with thick orthopyroxene reaction rims. (e) A plagioclase phenocryst showing a dusty zone along its rim.

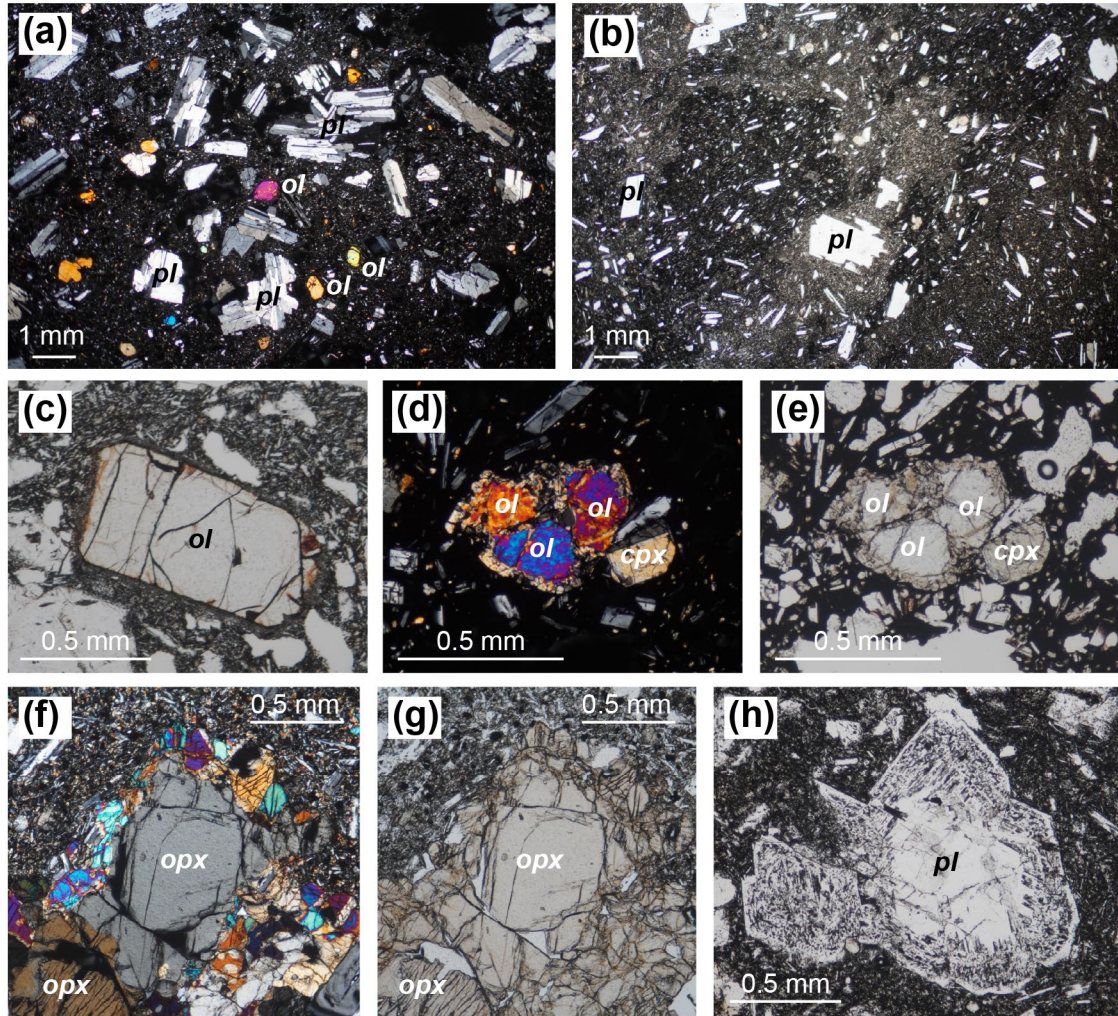


Figure 3-2 Photomicrographs of B type samples. (a) Basaltic lava. Basaltic B type samples show high phenocryst abundances and generally homogeneous texture. (b) Basaltic andesite scoria. Basaltic andesite to andesite samples occasionally show heterogeneous groundmass textures. (c) An olivine phenocryst in a basalt sample, showing a clear appearance without a reaction rim. (d) and (e) Olivine phenocrysts in basaltic andesitic scoria with thick orthopyroxene reaction rims. (f) and (g) Orthopyroxene phenocrysts in basaltic andesitic lava. Orthopyroxene phenocrysts occasionally form coronas around clinopyroxene. (h) A plagioclase phenocryst showing a dusty zone along its rim.

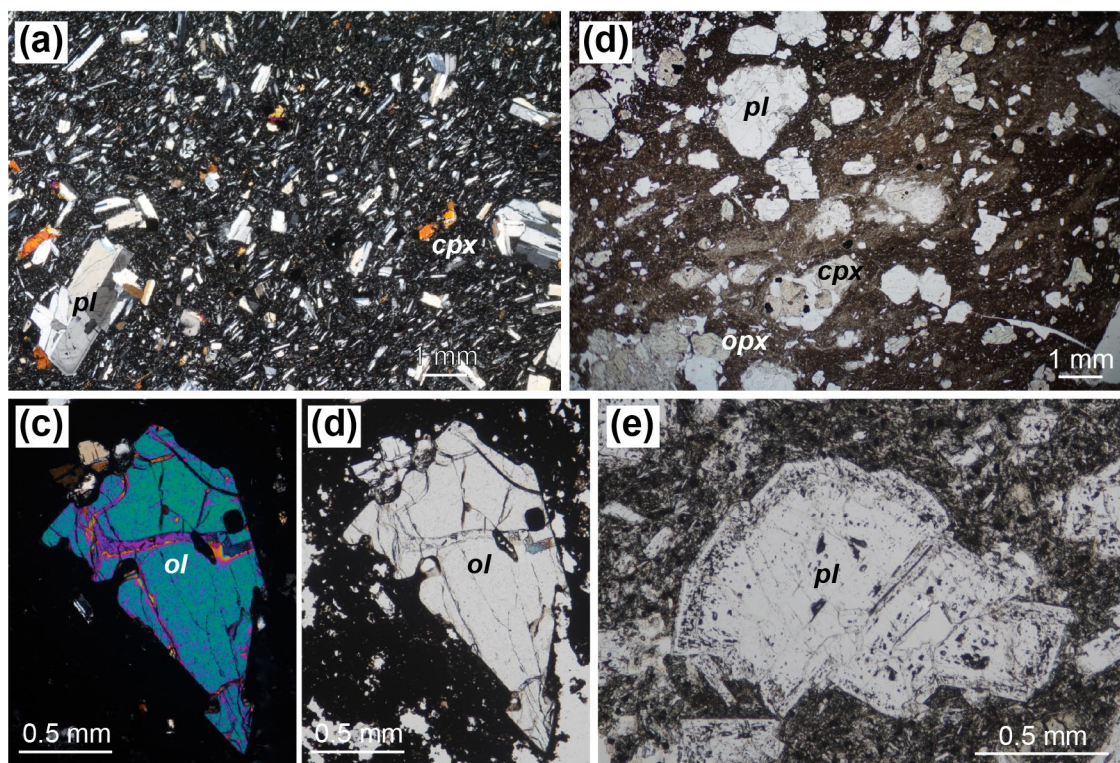


Figure 3-3 Photomicrographs of C type samples. (a) Andesitic lava with a homogeneous texture. (b) Andesitic scoria. Some samples show heterogeneous groundmass textures. (c) and (d) An olivine phenocryst in a basaltic andesitic sample, showing a clear appearance without a reaction rim. (e) A plagioclase phenocryst showing a dusty zone along its rim.

3-5. Geochemical characteristics

3-5-1. Whole-rock Major and Trace Elements composition

Some Harker diagrams with legends categorized by magma types are shown in Fig. 3-4. The rocks of this volcano range in composition from basalt to dacite, with SiO₂ contents spanning 49.8 to 66.4 wt.%. Most samples from this volcano belong to the Tholeiitic series, which is characterized by an increasing FeO/MgO ratio with increasing SiO₂ content. However, some samples also plot within the field of the Calc-Alkaline series (Miyashiro, 1978).

All three main types have mafic rocks with SiO₂ contents of 54 wt.% or less. From these mafic compositions, their trends extend toward more felsic compositions. In particular, A type (53.3–66.5 wt.% SiO₂) spans a wider range toward felsic compositions compared to B and C types (50.4–58.3 and 53.0–60.8 wt.%, respectively). In both the B and C main types, the High-LIL subtypes form compositional trends that start from slightly more silicic compositions than those of the Low-LIL subtypes belonging to the same main type. In addition, the High-LIL subtypes define trends with higher concentrations of LIL elements, such as K₂O and Ba.

Fig. 3-5 shows the REE patterns of the five magma types (primitive-mantle values used for normalization are taken from Sun and McDonough, 1989). All samples exhibit gently decreasing trends from LREE to HREE, and the felsic rocks tend to display higher LREE/HREE ratios than the mafic rocks. Overall, the REE patterns do not show marked differences among the three main magma types. Most samples exhibit a negative Eu anomaly; however, only the mafic samples of Type B (SiO₂ < 51.5 wt.%) show a positive Eu anomaly. Regarding differences among the subtypes, the High-LIL subtypes tend to show a more pronounced Eu negative anomaly than the Low-LIL subtypes within the same main type. In addition, the High-LIL subtypes display higher La/Yb ratios compared with the corresponding Low-LIL subtypes.

3-5-2. Whole-rock Sr-Nd-Pb Isotope Ratios

Figs. 3-6, 3-7 show representative diagrams of Sr-Nd-Pb isotope ratios. The compositional distributions of the three main magma types are clearly distinguishable based on their isotopic ratios. For Sr isotope ratios, the A and B types show high Sr isotope ratios (0.70409–0.70434 and 0.70412–0.70424, respectively), whereas the C type shows a low Sr isotope ratio (0.70395–0.70406). For Nd isotope ratio, the A type shows a low isotope ratio (0.51276–0.51284), the C type shows a high isotope ratio (0.51285–0.51290), and the B type shows an intermediate isotope ratio (0.51282–0.51288). For Pb isotope ratio, the A type shows a high Pb isotope ratio (18.54–18.57), the C type shows a low Pb isotope ratio (18.48–18.52), and the B type shows an intermediate isotope ratio (18.52–18.55). In both the B and C types, the two subtypes plot generally along the same isotopic compositional trends within error.

The isotope ratios of each magma type change systematically with increasing SiO₂ content. Specifically, for Sr and Pb isotope ratios, the felsic products of each magma type have higher isotope ratios than the mafic products. Conversely, as the composition becomes more felsic, the Nd isotope ratio changes to a lower value.

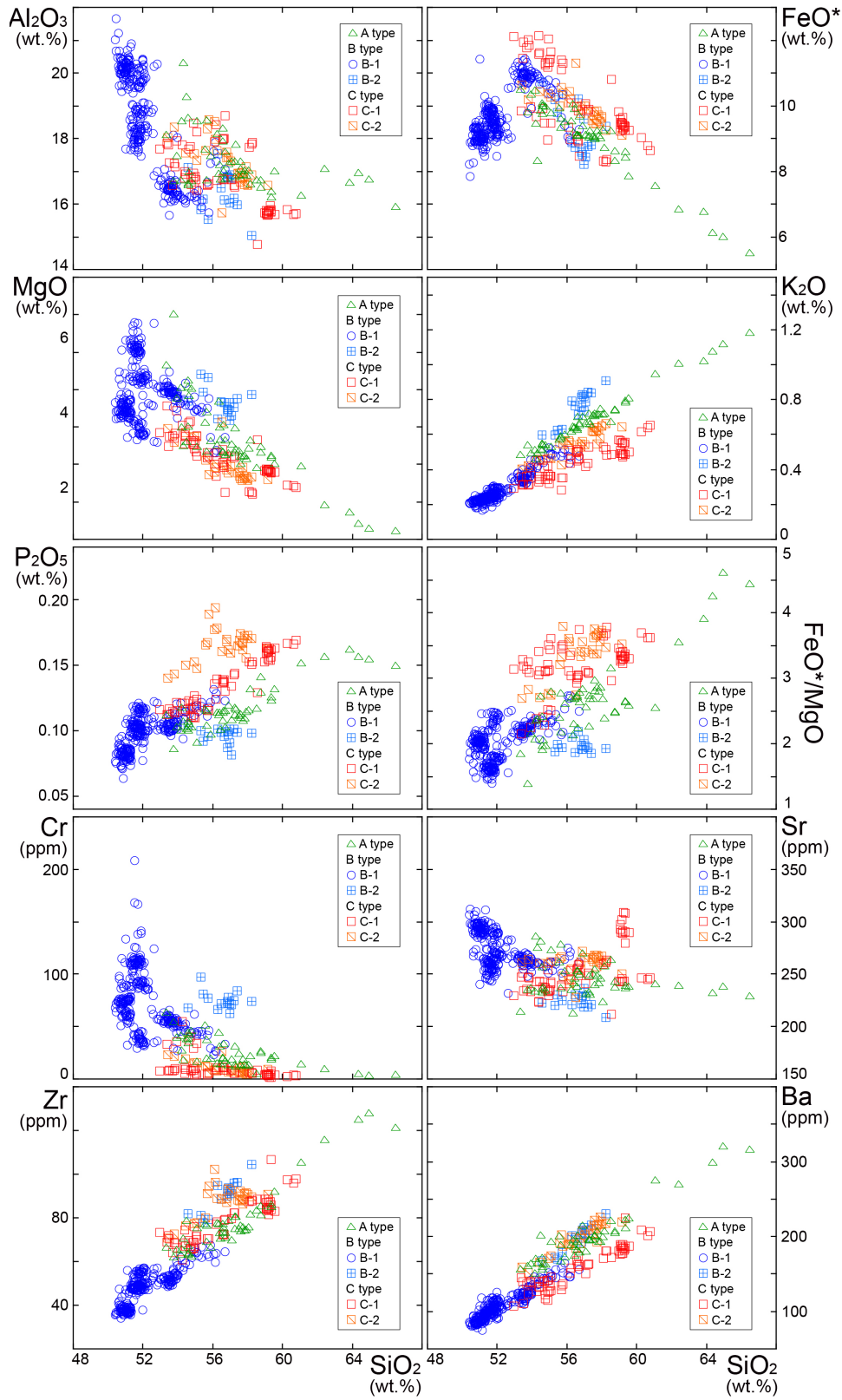


Figure 3-4 Silica variation diagrams for Akita-Komagatake volcano.

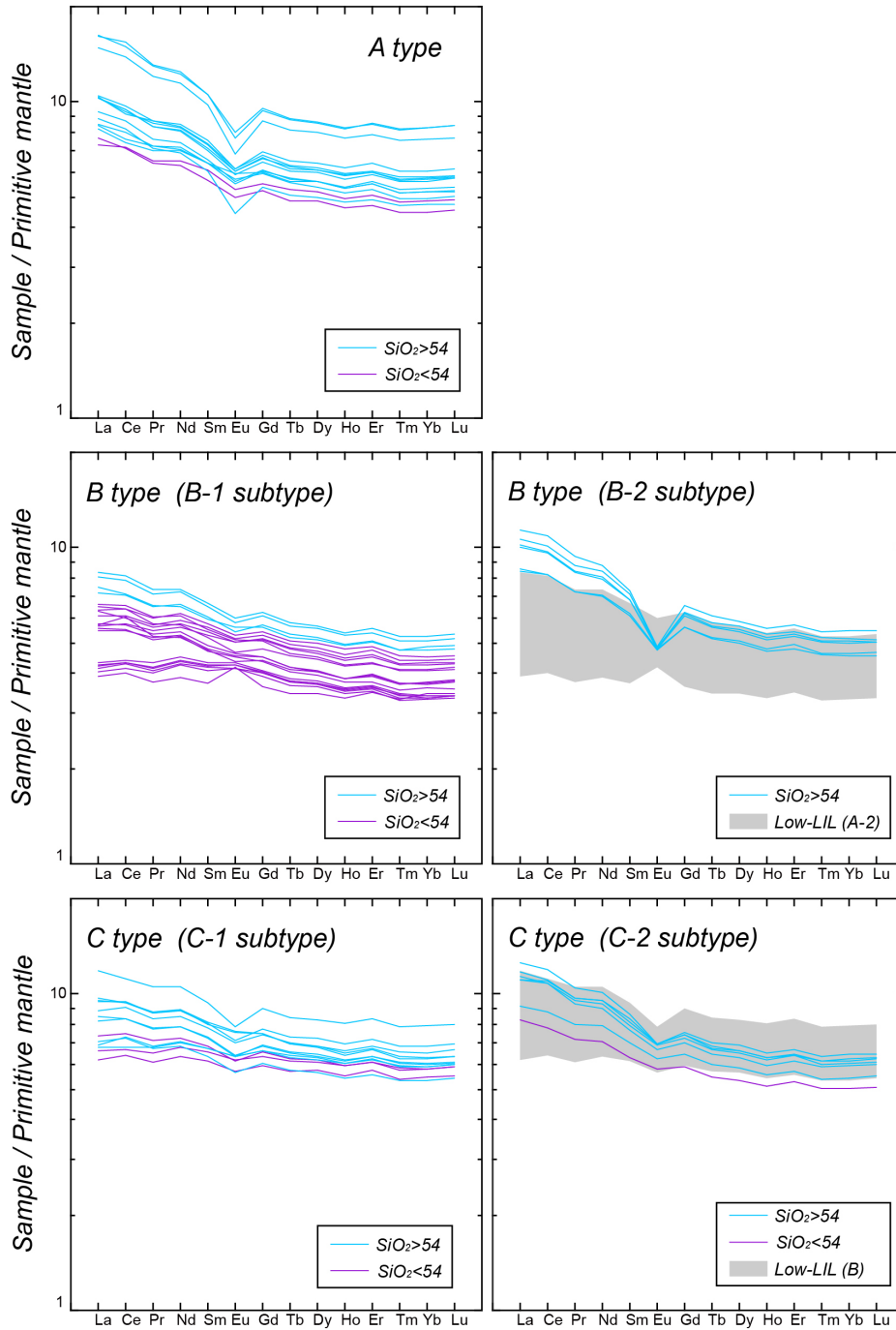


Figure 3-5 REE pattern diagrams for A-1, A-2 (Low-LIL and High-LIL subtypes) and B (Low-LIL and High LIL subtypes) types. In each main and sub-types, REE abundances increase with increasing SiO_2 content. However, because the LREE increase more strongly than the HREE, the more felsic rocks exhibit REE patterns with higher LREE/HREE ratios. Between the two subtypes of the A-2 and B types, the High-LIL subtype tend to show higher LREE/HREE ratios and a greater degree of Eu negative anomaly than the Low-LIL subtype.

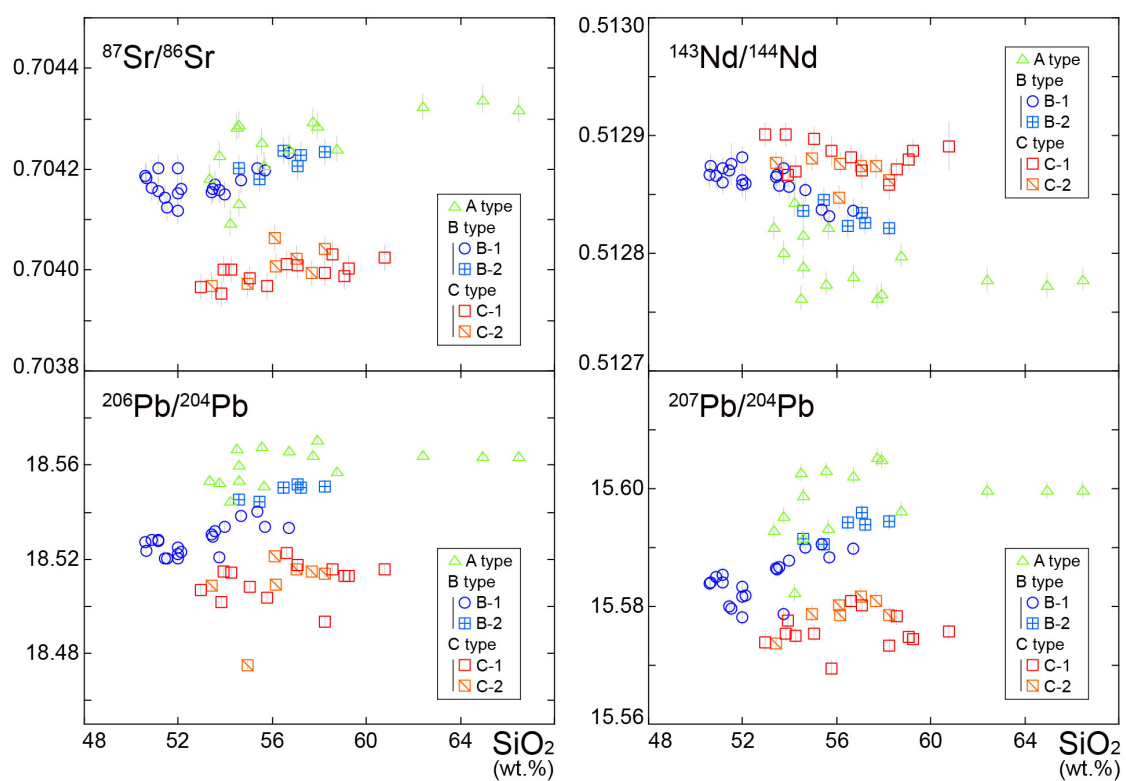


Figure 3-6 Silica variation diagrams of $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$, $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$ of Akita-Komagatake volcano. Each magma type exhibits a systematic shift toward more enriched isotopic signatures in correlation with increasing SiO_2 content.

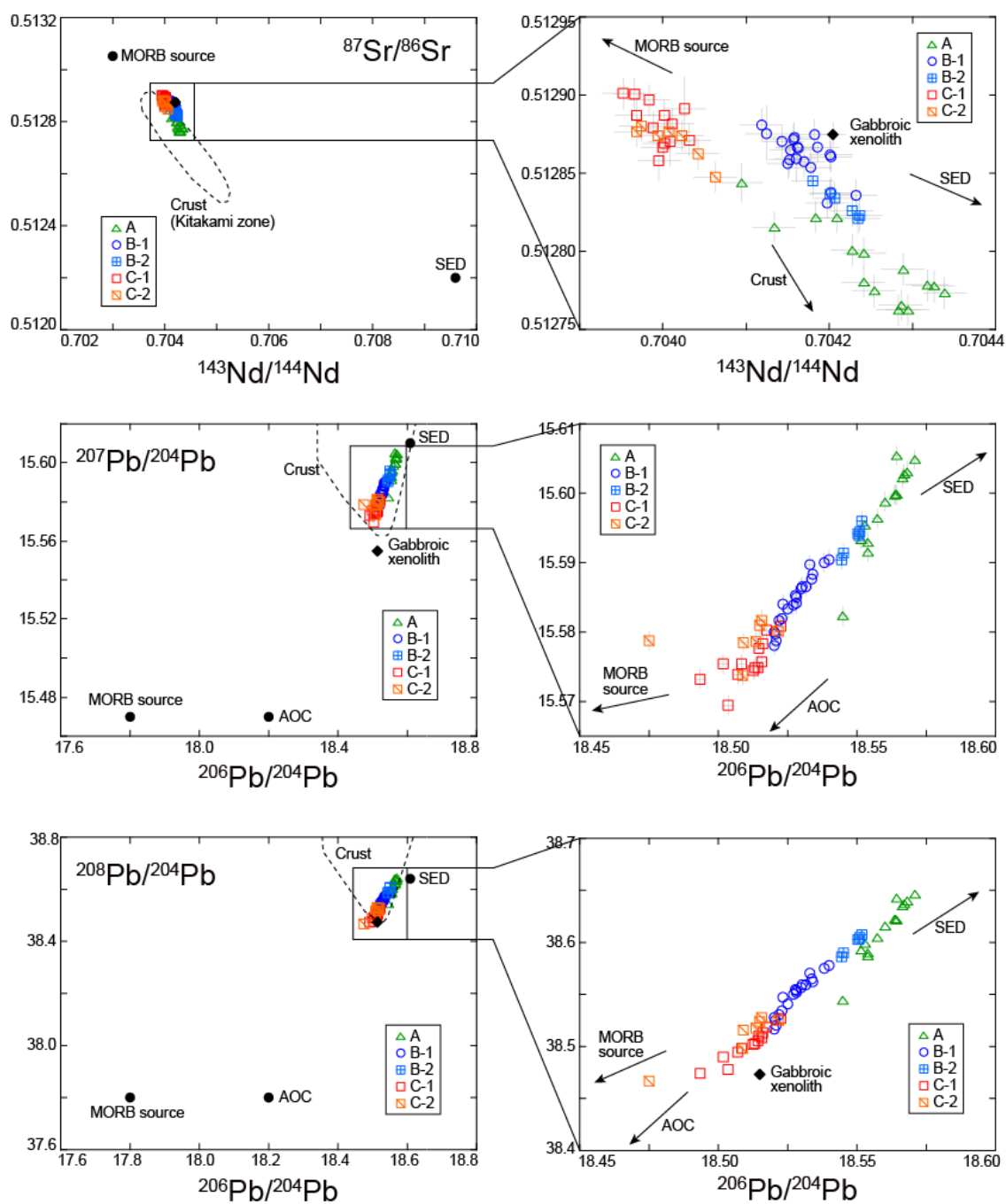


Figure 3-7

Figure 3-7 Representative diagrams of Sr-Nd-Pb isotopic ratios of Akita-Komagatake volcano. In these diagrams, the compositions of MORB source, Pacific sediment (SED) and altered oceanic crust (AOC) used for the calculation of the generation model of the main magma type are shown. In addition, the compositions of Gabbroic xenolith (data from Kuritani et al., 2016) collected at Megata volcano, located 90 km west of Akita-Komagatake volcano, are also shown. The compositional area of Crust is from Kagami et al. (1992) and Kagami et al. (2005) for the $^{87}\text{Sr}/^{86}\text{Sr}$ vs $^{143}\text{Nd}/^{144}\text{Nd}$ diagram, and from the GEOROC database for Pb isotopic diagrams. Particularly in the $^{87}\text{Sr}/^{86}\text{Sr}$ vs $^{143}\text{Nd}/^{144}\text{Nd}$ diagram, since it is observed that the compositional trend of each magma type extends toward the upper crustal material, it was estimated that the crustal material contributed by AFC was the upper crustal material. Also, the gabbroic xenolith, which is considered to be derived from the lower crust, shows isotopic ratios closer to the mantle component than any of the eruptive products of this volcano. From this, it was judged that the contribution of the lower crust was not a main factor in the generation of the compositional variations of the main magma type.

3-6. Discussion

3-6-1. Differentiation Process

In subduction zones, complex and diverse differentiation processes occur within the crust. Consequently, eruptive products in subduction zone volcanoes worldwide are known to exhibit a wide range of chemical compositions through these processes. This section discusses the crustal processes responsible for the compositional diversity of the eruptive products of Akita-Komagatake.

The main process that commonly occurs beneath a volcano (within the crust) is one of the following three: (1) fractional crystallization, (2) mixing of magmas with different chemical compositions, and (3) assimilation and fractional crystallization (AFC). As mentioned above, some samples contain heterogeneous phenocrysts, such as plagioclase with dusty zone and olivine with reaction rim. In all three main magma types, the slope of the REE patterns change with increasing SiO_2 content (i.e. LREE/HREE ratios increase), and the isotopic ratios also show systematic variations as SiO_2 increase. Furthermore, incompatible/incompatible element ratios, such as Ba/Rb and K/Zr, vary with increasing SiO_2 content and incompatible element concentrations (Fig. 3-8). These features cannot be explained by simple fractional crystallization. In addition, the compositional trends of each magma type can be approximated by a mixing trend between mafic and felsic rocks within each type (Figs. 3-8, 3-9). Therefore, the process responsible for the compositional variations within each magma type is considered to be either (2) magma mixing of two end-members or (3) AFC.

If (2) magma mixing was the dominant process, all samples should universally contain phenocrysts that exhibit petrographic evidence of heterogeneity (e.g. dusty zones and zoning in plagioclase phenocrysts and/or reaction rims on olivine phenocrysts). However, in many mafic

rocks, such heterogeneous phenocrysts are rare. Moreover, even among andesitic rocks, there are some samples that lack phenocrysts showing these textures. These observations suggest that simple magma mixing was not the primary process responsible for the compositional variations. On the other hand, in all magma types, the felsic rocks have relatively more enriched isotopic ratios than the mafic ones. Notably, the felsic products of the A and B types show even more enriched isotopic ratios than any mafic samples from Akita-Komagatake. These observations suggest that (3) AFC is the most plausible process responsible for the compositional variations within the crust beneath this volcano. Accordingly, the mafic magmas ascending from deeper levels likely underwent mixing and assimilation with felsic components, such as crustal materials or crustal melts. The petrographic evidence further supports this interpretation. Rocks that lack textural heterogeneity—such as dusty zones, pronounced zoning in plagioclase phenocrysts, or reaction rims on olivine—are considered to have evolved predominantly through fractional crystallization. In contrast, samples that exhibit such heterogeneous textures are interpreted to have been influenced more strongly by assimilation or mixing. The coexistence of these two kinds of rocks ultimately produced the overall AFC-type compositional trends observed for each magma type.

Based on these results, I concluded that AFC was the main differentiation process for all three main magma types. In all of the main types, the presence of a negative Eu anomaly indicates that plagioclase fractionation must have occurred. In contrast, the basaltic samples of Type B ($\text{SiO}_2 < 51.5$ wt.%) exhibit a positive Eu anomaly. In addition, the basaltic samples of Type B show elevated Al_2O_3 contents in the SiO_2 vs. Al_2O_3 diagram (Fig. 3-4). Together, these features suggest that plagioclase accumulation also occurred in B type magma at mafic compositions.

3-6-2. Generation Mechanism of the Three Main Magma Types

As discussed above, the differentiation process of the three main magma types with distinct isotopic compositions are mainly controlled by AFC (plagioclase accumulation was also occurred in the mafic composition of the B-type magma). Therefore, the factors responsible for generating these three main magma types can be attributed to (a) the diversity of crustal materials contributed to AFC, and (b) the diversity of the primary magmas.

(a) Diversity of Crustal Materials Contributed to AFC

Fig. 3-7 shows the isotopic compositions of the upper crust of the Northeast Japan arc (data from Kagami et al., 1992, 2005 and GEOROC database). In these diagrams, particularly in the $^{87}\text{Sr}/^{86}\text{Sr}$ vs $^{143}\text{Nd}/^{144}\text{Nd}$ diagram, the compositional trends of the rocks of this volcano extend toward the upper crustal materials. Additionally, a hornblende gabbroic xenolith (data from Kuritani et al., 2016) collected from Megata volcano, located approximately 95 km west-northwest of Akita-Komagatake is also shown in these diagrams. This xenolith is considered to be derived from lower crust, and exhibits isotopic ratios closer to the mantle component than any of the rocks of this volcano. Therefore, it is difficult to explain the isotopic diversity of the main magma types based on the isotopic ratios of this xenolith. These observations suggest that the material that contributed to AFC was primarily upper crustal material. Furthermore, since there are no distinct differences among the main magma types in the direction of their trends toward felsic compositions, it is inferred that similar upper crustal materials were assimilated across all main magma types. Consequently, it is concluded that the crustal material involved in AFC was not a primary factor in generating the distinctions between the main magma types.

(b) Diversity of Primary Magmas

As discussed above, the material assimilated during the AFC process was identified as upper crustal material, and all three main magma types likely assimilated the same upper crustal

component. Furthermore, the contribution of lower crustal material was found to be inconsistent with the generation of the main magma types at this volcano. Therefore, it is concluded that each main magma type already possessed distinct compositions at the stage of primary magma generation.

Focusing on trace element ratios of mafic rocks is one effective approach to clarifying the origin of primary magma diversity. As previously discussed, primary magma in a subduction zone mantle are generated by the partial melting of the wedge mantle, triggered by the influx of fluids from the subducting slab (e.g., Tatsumi et al., 1986). The subducting slab consists of oceanic sediment, altered oceanic crust (AOC), and lithospheric mantle; among these, the fluids supplied to the wedge mantle are considered to be released from the oceanic sediment and AOC (Fig. 3-10). Depending on the temperature and pressure conditions at the time of release, these components may be released either as melts or as aqueous fluids through dehydration (e.g., Hanyu et al., 2006). Since trace elements exhibit specific behaviors in each of these processes, analyzing their concentrations is considered key to understanding the slab-to-wedge mantle processes.

Fig. 3-11 shows the Ba/La vs. Th/Yb diagram. Large-ion lithophile (LIL) elements, such as barium, are abundant in both AOC and oceanic sediments and are readily partitioned into both melts and aqueous fluids. On the other hand, thorium and light rare earth elements (LREEs), including lanthanum, are highly enriched in oceanic sediments; while they are easily partitioned into melts, they are characterized by their difficulty in entering aqueous fluids. Therefore, an increase in the Ba/La ratio suggests that the wedge mantle was supplied with "aqueous fluids" via dehydration from the subducting slab, whereas an increase in the Th/Yb ratio suggests a supply in the form of "melts."

Fig. 3-11 shows the compositions of mafic rocks of this volcano with SiO₂ content of 53–54 wt.% (while more mafic eruptive products have been identified, samples with similar SiO₂

contents were selected to ensure a consistent degree of differentiation across each magma type). These are plotted alongside the compositions of mafic volcanic rocks of the Northeast Japan arc reported by Hanyu et al. (2006). In their study, high-magnesian andesites (collected from Choshi) exhibit high Th/Yb and low Ba/La ratios, which were interpreted as indicating a supply of "melts" from the slab to the wedge mantle. Conversely, other mafic rocks showing low Th/Yb and high Ba/La ratios were interpreted as having been supplied with "aqueous fluids." Since the mafic rocks of this volcano also exhibit low Th/Yb and high Ba/La ratios, it can be concluded that the slab components beneath this volcano were primarily supplied as "aqueous fluids".

Focusing on the individual magma types of this volcano, there is a tendency to increase Ba/La ratios in the order of A, B, and C types. This suggests that the differences among the primary magmas of each main magma type originated from variations in the volume and/or composition of the aqueous fluids supplied from the subducting slab to the mantle wedge. Specifically, the trace element ratios imply that either the volume of slab-derived fluid increased, or a fluid more enriched in Ba was added, in the order of A, B, and C types.

3-6-3. Modeling the Formation Process of Main Magma Types

As discussed above, the formation mechanism of the main magma types is attributed to the diversity of their primary magmas, which likely originated from variations in the volume and/or composition of slab-derived fluids supplied to the mantle wedge. In this section, I conduct model calculation using assumed parameters to test the validity of it.

Such model calculations have been conducted in several subduction zones (e.g., Wibowo et al., 2022), as well as for Northeast Japan arc (e.g. Hanyu et al., 2006; Kimura and Yoshida, 2006). In these studies, a three-component mixing model involving the mantle wedge, oceanic sediment, and oceanic crust is commonly employed. However, the parameters assigned

to these end-members vary between models due to the inherent heterogeneity and uncertainties of these components.

In this study, model calculations were performed basically following the method of Hanyu et al. (2006). The various parameters used in this study are summarized in Table 3-1. First, the mantle wedge was assumed to be similar to the Philippine Sea MORB source (Hickey-Vargas, 1991; Hochstaedter et al., 2001), which is slightly enriched in trace element compositions. Furthermore, the Pb isotopic ratios were assumed to have an Indian MORB affinity. Regarding the oceanic sediment and oceanic crust, this study adopted the compositions of Pacific Plate sediments and oceanic crust, respectively (Hauff et al., 2003; Straub et al., 2004; Hochstaedter et al., 2001). The compositions of the aqueous fluids released from the oceanic sediment and oceanic crust were then calculated based on the mobility of each element (Kogiso et al., 1997 for oceanic crust; Aizawa et al., 1999 for sediment).

The results of the model calculations performed using the aforementioned values are shown in Fig. 3-12 and Table 3-2. These calculations indicate that the amount of added slab-derived fluid increases in the order of Types A, B, and C, with the fluid-to-mantle ratios estimated at approximately 1.0–2.0%, 1.5–2.0%, and 2.0–3.0%, respectively. Furthermore, the compositions of the added fluids also differ; the estimated ratios of AOC fluid to sediment fluid for A, B and C types are 40:60, 50:50 and 60:40, respectively. These results are consistent with the previous discussion based on trace element ratios. Therefore, it is concluded that the generation mechanism of the main magma types in this study is controlled by "variations in the volume and composition of slab-derived fluids added to the same mantle source."

3-6-4. Generation Mechanism of the Sub Magma Types

As mentioned before, the B type and C types are subdivided into two subtypes—Low-

LIL and High-LIL—based on differences in LIL element contents. The two subtypes belonging to the same main type show an identical compositional trend in Sr–Nd–Pb isotopic ratios. This indicates that the source mantle material and the assimilated (mixed) crust derived material were common between the two subtypes.

In contrast, even within a single main type, clear differences are observed between the High-LIL and Low-LIL subtypes in the contents of LIL elements such as K₂O and Ba, as well as in indicators such as the La/Yb ratio and the degree of Eu negative anomaly (the High-LIL subtype exhibits higher La/Yb ratios and stronger Eu negative anomalies than the Low-LIL subtype). Two mechanisms may account for these differences: (1) variations in the degree of partial melting during the generation of the primary basaltic magma, or (2) variations in the proportion of crustal material involved. However, in both the B and C types, the Low-LIL subtype consistently erupted earlier than the High-LIL subtype, suggesting that mechanism (2) is more plausible. That is, after the eruption of the Low-LIL subtype, the magma remaining within the crust continued to undergo AFC process. The residual basaltic magma evolved into basaltic andesite with SiO₂ contents of 54–55 wt.% through further fractional crystallization. Continued plagioclase fractionation increased the degree of the Eu negative anomaly, while assimilation (mixing) of crust derived material enhanced the abundances of LIL elements and elevated the La/Yb ratio, ultimately leading to the formation of the High-LIL subtype.

3-6-5. Long-term Evolution of the Magma Plumbing System

Based on the results of the discussions before and the eruptive history clarified in Chapter 2, this study examines the evolution process of the magma plumbing system of Akita-Komagatake volcano. Fig. 3-13 shows a schematic diagram illustrating the evolution of the magma plumbing system over the past 14,000 years. The following discussion is divided into two

parts: (1) intra-mantle magma process and (2) intra-crustal magma process.

(1) Intra-Mantle Magma Process

As discussed in Chapter 2, A type magma erupted during Stage I, followed by C type during Substages II-1 and II-2, and B type during Substages II-3 and II-4. Stage III also erupted B type magma, whereas the most recent 1970-71 CE eruption reverted to C type magma. These shifts indicate that the erupted main magma types have shifted over a relatively short timescale of several thousand years. Furthermore, it has been revealed that a dormant period of over 1,000 years consistently preceded each change in the main magma type. This suggests that the supply of slab-derived fluids from the subducting Pacific slab to the mantle wedge is not continuous, but rather episodic or "pulse-like." Primary magmas are thought to be generated by partial melting of the mantle wedge only at these specific timings. Slab-derived fluids were supplied at intervals of several thousand years, coinciding with the changes in the main magma types, and their volume and composition varied with each supply event. Therefore, it is considered that the three main magma types with distinct isotopic ratios were generated and erupted sequentially within a short period of time.

Possible mechanisms for the pulse-like supply of slab-derived fluids and the accompanying variations in their volume and composition include (1) changes in the plate subduction rate or the slab dip (Jones et al., 2014) and (2) the subduction of seamounts or igneous provinces (Ishikawa and Tera, 1999; Straub et al., 2015). However, as pointed out by Wibowo et al. (2022), changes in the main types of primary magmas caused by process (1) occur over timescales of millions of years or more and are expected to affect magmatism across a broad area of the subduction zone. In contrast, variations in the volume and composition of slab-derived fluids caused by process (2) can occur relatively locally and over shorter timescales, which is considered more plausible. Around Sundoro volcano (Java arc), the subject of Wibowo et al.

(2022), the Roo Rise submarine plateau province is distributed, and they suggested the possibility of short-term changes in the composition and volume of slab-derived fluids due to the subduction of such seamounts. In the Northeast Japan arc, the Joban Seamount Chain (Masalu et al., 2001) is distributed on the Pacific Plate. The subduction of such seamounts may have caused the pulse-like release of slab-derived fluids on a short timescale of several thousand years, while also varying their volume and composition each time.

In summary, it is inferred that slab-derived fluids are supplied in a pulse-like manner beneath this volcano, potentially originating from the subduction of seamounts. In other words, this suggests the possibility that the timing of these pulse-like supplies of slab-derived fluids is the primary factor controlling the timing of volcanic activity in subduction zones.

(2) Intra-Crustal Magma Process

The primary basaltic magmas of each magma type, generated through the processes described above, underwent AFC process before reaching the surface. The compositional trends of each magma type start at SiO₂ contents of 50–54 wt.%, suggesting that a certain degree of differentiation had already occurred before they began to mix &/or assimilate crust derived material through AFC. These observations indicate that the AFC process took place in two phases (Fig. 3-13). In Phase 1, the primary basaltic magma generated in the mantle wedge ascended and intruded into the crust, where it differentiated while thermally and chemically modifying the surrounding crustal materials. In the case of the B type, this phase was also accompanied by plagioclase accumulation within the mafic magma. In Phase 2, the mafic magma, which had differentiated to 50–54 wt.% SiO₂, mixed with or assimilated the crust derived materials produced during Phase 1 and then erupted at the surface.

Notably, the observation that the intra-crustal process consistently initiates with Phase 1—meaning that the primitive magma does not directly assimilate or mix with the crust—suggests

that the surrounding crust is not yet thermally or chemically matured enough to undergo immediate assimilation upon the arrival of new magma. In other words, Phase 1 serves as a "preparation stage" in which the primitive magma thermally heats and modifies the surrounding crust, thereby facilitating subsequent assimilation processes. This model implies that the intra-crustal magma plumbing system is systematically renovated on a millennial timescale, coincided with each transition to a new main magma type.

The following discussion proceeds in chronological order. Stage I, the initial phase of activity at this volcano, was the largest-scale eruptive period and was characterized by the activity of the most felsic dacitic magma. This occurred because, during this earliest stage, the magma assimilated a large volume of easily meltable crustal material. The massive melting of this crustal component led to the generation of large volumes of magma, resulting in the maximum scale of eruptive activity and differentiation into dacitic compositions. Because these easily meltable crustal materials were largely exhausted during Stage I, subsequent activity from Stage II onward may have been dominated by more mafic magmas.

In Stage II, the activity began with C-1 magma, and its residual magma further mixed with (assimilated) the crust to form the C-2 subtype, which erupted during Substage II-2. Subsequently, after a dormancy of approximately 1,500 years, B-1 magma was generated and ascended, erupting during Substage II-3 after differentiation. Following a further 2,500 years dormancy, the B-2 subtype erupted during Substage II-4. Notably, Stage III activity commenced at the southern edifice only about 100 years after this eruption. Given this chronological sequence, it is considered that the residual B-1 magma from Substage II-3 remained stagnant over a long period, allowing a hydrothermal system to develop. The subsequent ascent and emplacement of new B-1 magma associated with Stage III supplied heat and/or volatiles to the pre-existing system. This input reactivated the residual magma (or hydrothermal) chamber, triggering the phreatic to

phreatomagmatic eruptions of the B-2 subtype during Substage II-4.

In the subsequent Stage III, activity initially involved B-1 magma during Substage III-1. Following a dormancy of approximately 1,000 years, Substage III-2 commenced with a small-scale phreatomagmatic eruption of B-1 magma in 1932 CE. Only 38 years later, in 1970 CE, the activity shifted abruptly to C-1 magma. Similar to the transition from Substage II-3 to II-4, this chronological sequence suggests that the residual magma chamber from Substage III-1 was reactivated by the supply of heat and/or volatiles from the subsequently ascending C-1 magma. This process likely triggered the initial eruption of B-1 magma in 1932 CE, followed by the eruption of the C-1 magma itself just 38 years later.

3-6-6. Implications of Constructing the Structure and Temporal Evolution of the Magma Plumbing System

In the Northeast Japan Arc, numerous volcanoes remain active, and many of them are known to have erupted multiple magma types (e.g. Sato and Ozawa, 2023; Ban et al., 2022). However, because volcanic products in this arc are predominantly intermediate to felsic in composition, they tend to be strongly influenced by crustal processes. As a result, it is difficult to obtain information especially about mantle processes.

This study provides the first example in the Northeast Japan Arc in which the structure of a mantle-to-crust magma plumbing system and its temporal evolution have been reconstructed. Furthermore, the origins of the diverse magma types erupted at Akita-Komagatake are attributed to both mantle and crustal processes. In particular, this study explained the primary factor controlling main magma type during the generation of primary basaltic magmas in the mantle using a simple mechanism—the amount and composition of slab-derived fluid in the mantle. Because this mechanism is simple and I expect that the magma generation model proposed in this

study may be applicable to other volcanoes in the Northeast Japan Arc.

Furthermore, by integrating these results with the eruptive history clarified in Chapter 2, this study demonstrated that slab-derived fluids are supplied to the mantle wedge beneath this volcano in a pulse-like rather than steady-state manner. This suggests that the timing of this fluid supply is the primary factor controlling the timing of volcanic activity. Such an insight was made possible only by the high-resolution eruptive history established in Chapter 2. By increasing similar case studies at other volcanoes, it will be possible to evaluate whether the findings of this study represent a general phenomenon or a site-specific case.

This study also has important implications for volcanic hazard assessment. As mentioned before, this volcano erupted twice in the 20th century, in 1932 CE and 1970–71 CE. The scoria from the 1932 CE eruption is classified as B type, the same as the rocks of Stage III, whereas the most recent 1970–71 CE eruption produced C type magma. Thus, the volcano changed its erupted magma type from B to C within a period of only 38 years between 1932 and 1970 CE.

This volcano has changed its magma type with each transition between stages, and it has also altered its eruption area and style accordingly. Both the 1932 and 1970–71 CE eruptions occurred around Medake, indicating that the eruption site did not change significantly between the 1970–71 CE eruption and the preceding Stage III activities. Nevertheless, the fact that the magma type changed suggests that the volcano may have entered a new stage of activity.

In recent years, an increase in geothermal activity has been observed particularly around Medake, and volcano monitoring has been intensified in preparation for future eruptions (Japan Meteorological Agency, 2013). If the volcano has indeed entered a new stage, its future eruptive style and eruptive sequence may differ from those of previous eruptions, particularly those of Stage III. Therefore, at this volcano, careful monitoring of its ongoing activity from both

geochemical and geophysical perspectives is of critical importance for volcanic hazard mitigation.

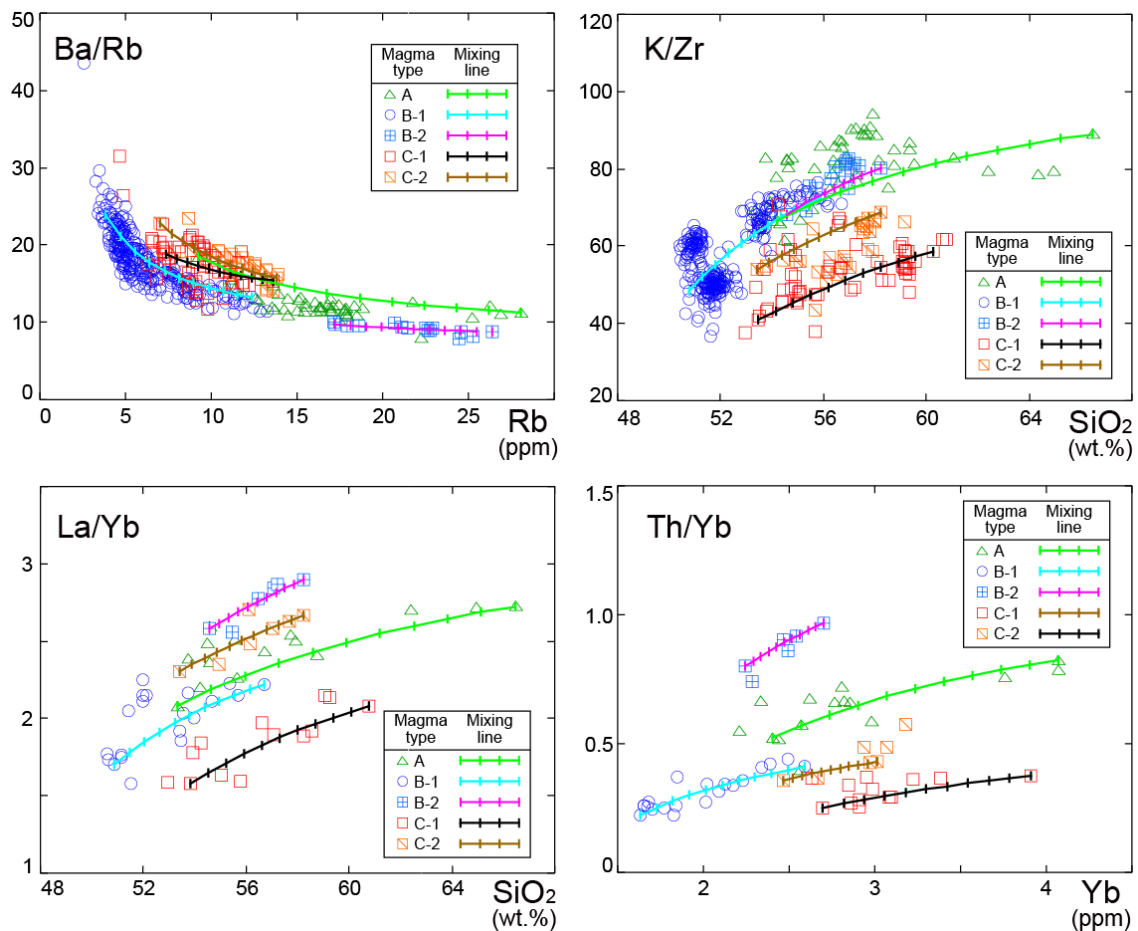


Figure 3-8 Variations in trace element ratios (Ba/Rb, K/Zr, La/Yb and Th/Yb) plotted against SiO₂, Rb and Yb. For each magma type, Ba/Rb decreases with increasing Rb. This trend cannot be explained by simple fractional crystallization alone. In each magma type, incompatible element ratios vary with increasing SiO₂ and trace element concentrations. This characteristic cannot be explained by simple fractional crystallization alone. The compositional trends of each magma type are well-approximated by the solid lines, which represent mixing lines between mafic and felsic rocks. Therefore, the differentiation process of each magma type in these diagrams is considered to have been formed by either magma mixing or assimilation-fractional crystallization (AFC). Ultimately, considering petrographic features as well, I concluded that the AFC was the main differentiation process.

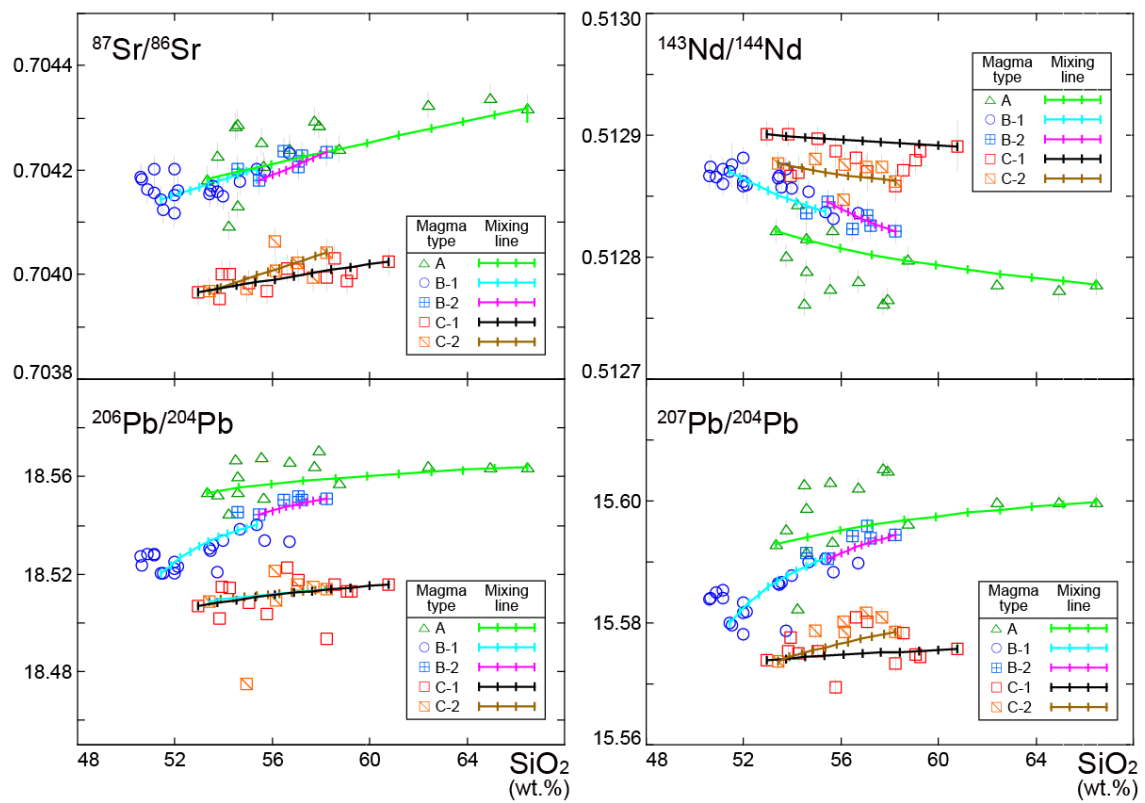


Figure 3-9 Silica variation diagrams of $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$, $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$. The compositional trends of each magma type can be approximated by mixing trends between their respective mafic and felsic rocks, as indicated by the solid lines. Furthermore, each magma type shifts toward more enriched isotopic ratios with increasing SiO_2 content. These observations lead to the conclusion that the differentiation process for each magma type is governed by assimilation and fractional crystallization (AFC).

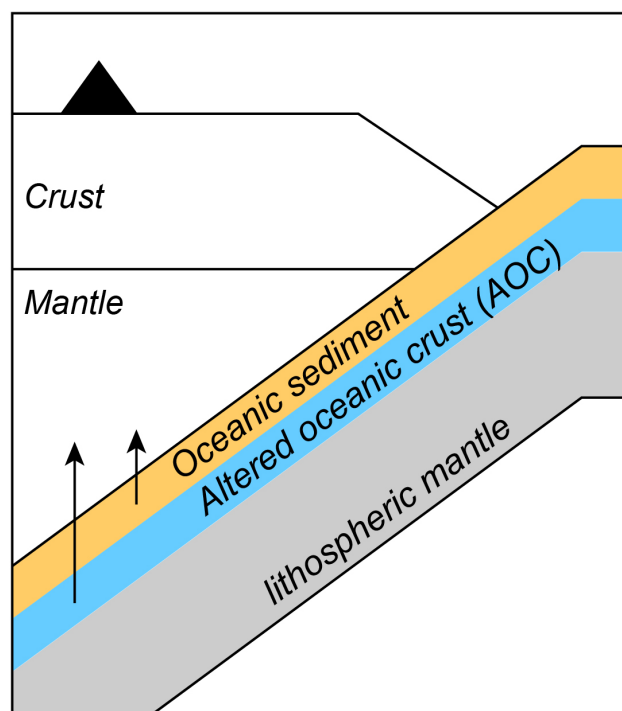


Figure 3-10 Conceptual model of a subducting slab. A subducting slab consists of oceanic sediment, altered oceanic crust and lithospheric mantle. Among these, slab-derived components are mainly supplied from oceanic sediment and AOC (shown by black arrows).

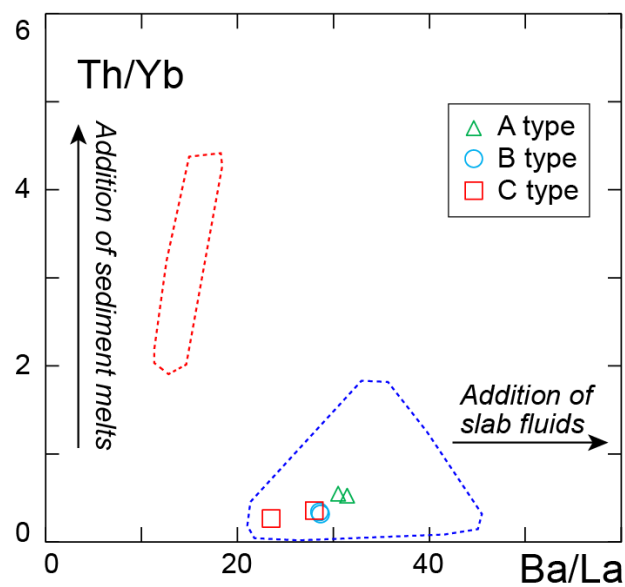


Figure 3-11 Ba/La vs Th/La diagram. The red and blue dashed areas indicate the compositional ranges of volcanic rocks where fluids were supplied from the slab to the wedge mantle as melts and as aqueous fluids, respectively, during primary magma generation (data from Hanyu et al., 2006). Since the mafic rocks of Akita-Komagatake volcano exhibit low Th/La and high Ba/La, I consider that the slab-derived components were released as “aqueous fluids”.

Table 3-1 Isotopic and some elemental compositions used for the mixing model. The parameters and derivation methods are based on Hanyu et al. (2006).

Elements	MORB source ^a	Sediment			Altered Oceanic Crust (AOC)		
		source rock ^b	mobility ^{c, e}	fluid composition	source rock ^b	mobility ^{d, e}	fluid composition
Concentrations (ppm)							
Rb	0.75	130	0.02	170	27	0.63	1100
Ba	5.9	500	0.08	2700	410	0.53	15000
Th	0.06	13	0.03	26	5.2	0.38	130
Pb	0.13	28	0.65	1200	3.9	0.85	220
Sr	25	240	0.12	1900	560	0.41	15000
Nd	1.7	40	0.03	80	17	0.31	350
Zr	15	160	0.005	54	2.5	0.005	35
Isotopic ratios							
⁸⁷ Sr/ ⁸⁶ Sr	0.7030	0.7096			0.7040		
¹⁴⁴ Nd/ ¹⁴³ Nd	0.5129	0.5123			0.5131		
²⁰⁶ Pb/ ²⁰⁴ Pb	17.80	18.61			18.20		
²⁰⁷ Pb/ ²⁰⁴ Pb	15.47	15.61			15.47		
²⁰⁸ Pb/ ²⁰⁴ Pb	37.80	38.64			37.80		

^a After Hickey-Vargas (1991) and Hochstaedter et al. (2001).

^b After Hochstaedter et al. (2001), Hauff et al. (2003), Tatsumi and Hanyu (2003) and Straub et al. (2004).

^c Aizawa et al. (1999)

^d Kogiso et al. (1997)

^e H₂O content during dehydration is 0.015 wt. %

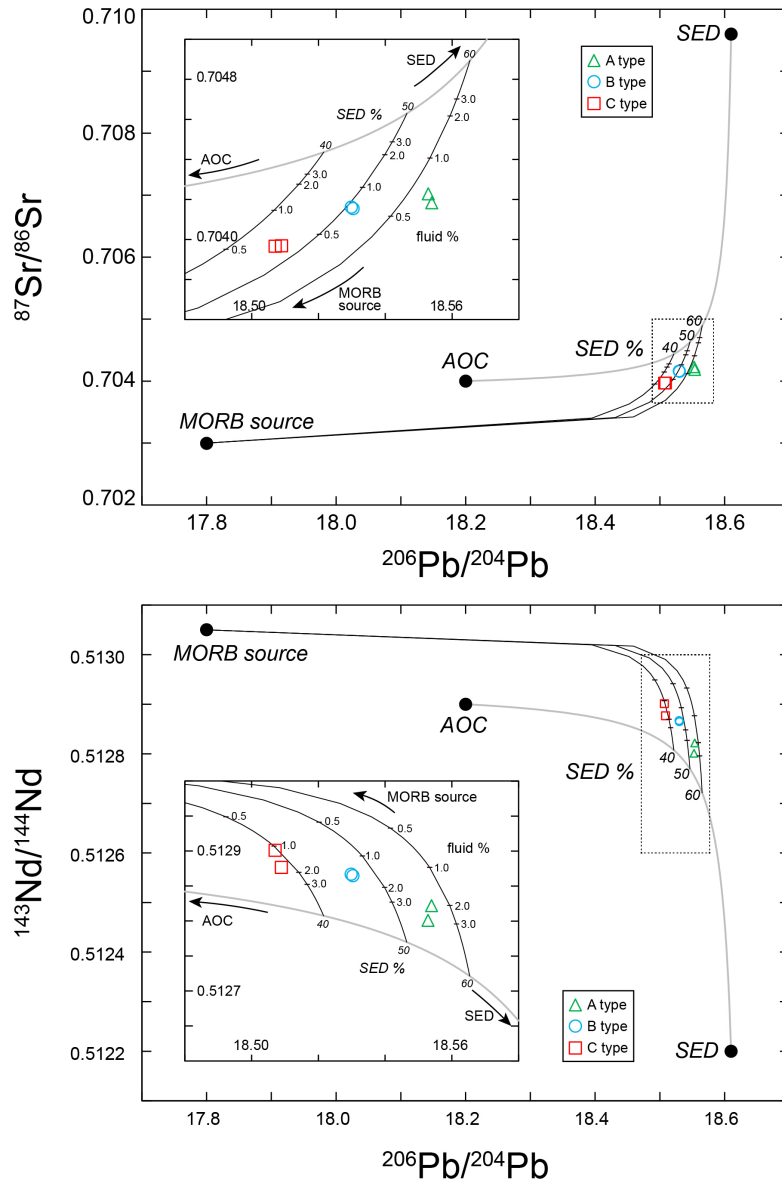


Figure 3-12 $^{206}\text{Pb}/^{204}\text{Pb}$ vs $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ diagrams showing the results of model calculations. The compositions of mafic rocks for A, B, C types are plotted in these diagrams. Based on these results, I concluded that the amount of slab-derived fluid increases in the order of $A > B > C$ type. Furthermore, the ratio of sediment-derived fluid relative to AOC-derived fluid within the slab component also increases in the same order ($A > B > C$).

Table 3-2 Summary of the results of estimation of slab contributions to the magma genesis beneath Akita-Komagatake volcano.

Magma type	AOCf : SEDf	Addition portion of slab-derived fluids	Erupted age
A	40 : 60	2.0 - 3.0 %	14.0 - 13.5 ka
B	50 : 50	1.5 - 2.0 %	8.0 - 7.3 ka, 3.3 - 1932 CE
C	60 : 40	1.0 - 2.0 %	11.6 - 9.3 ka, 1970 CE

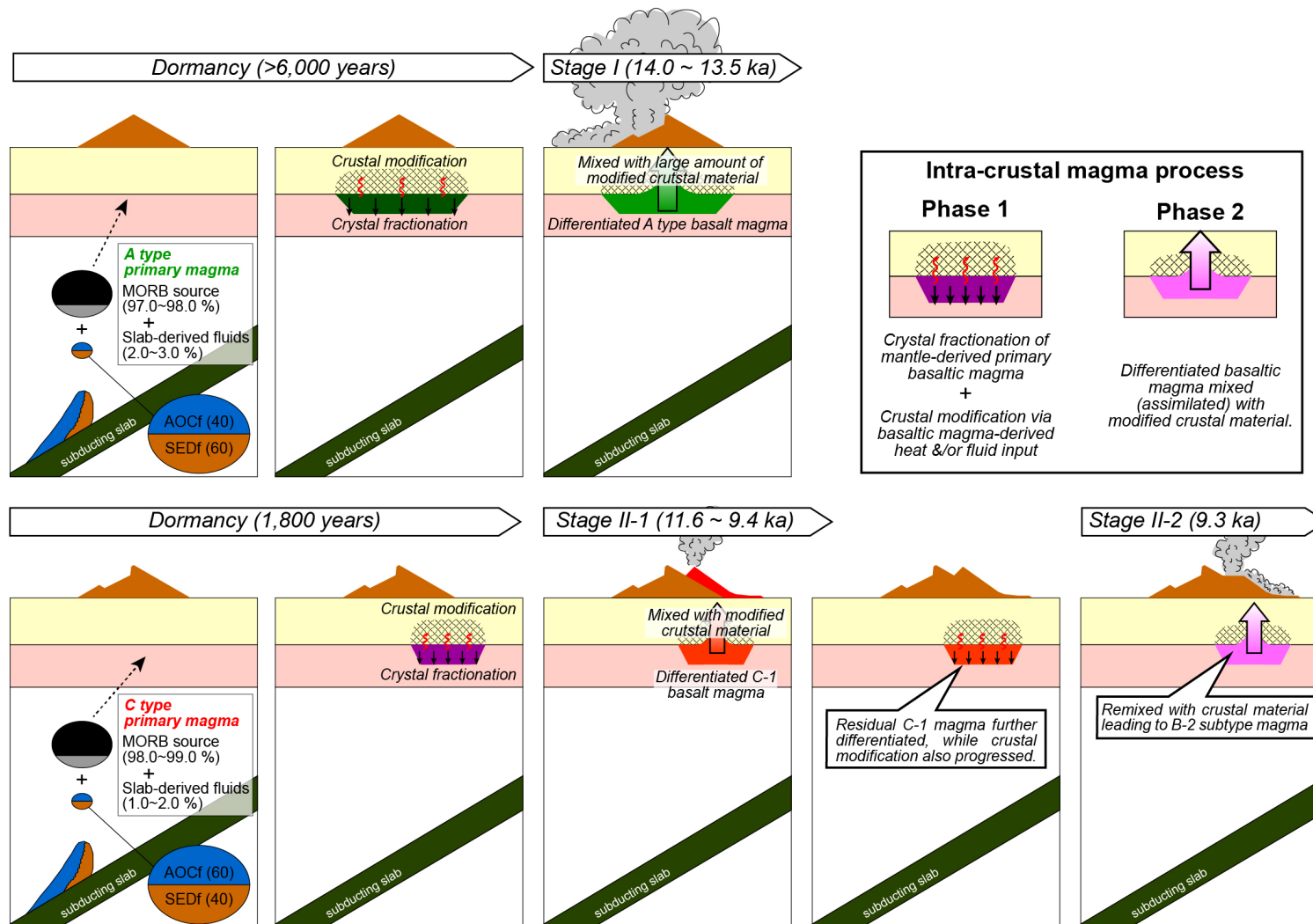


Figure 3-13

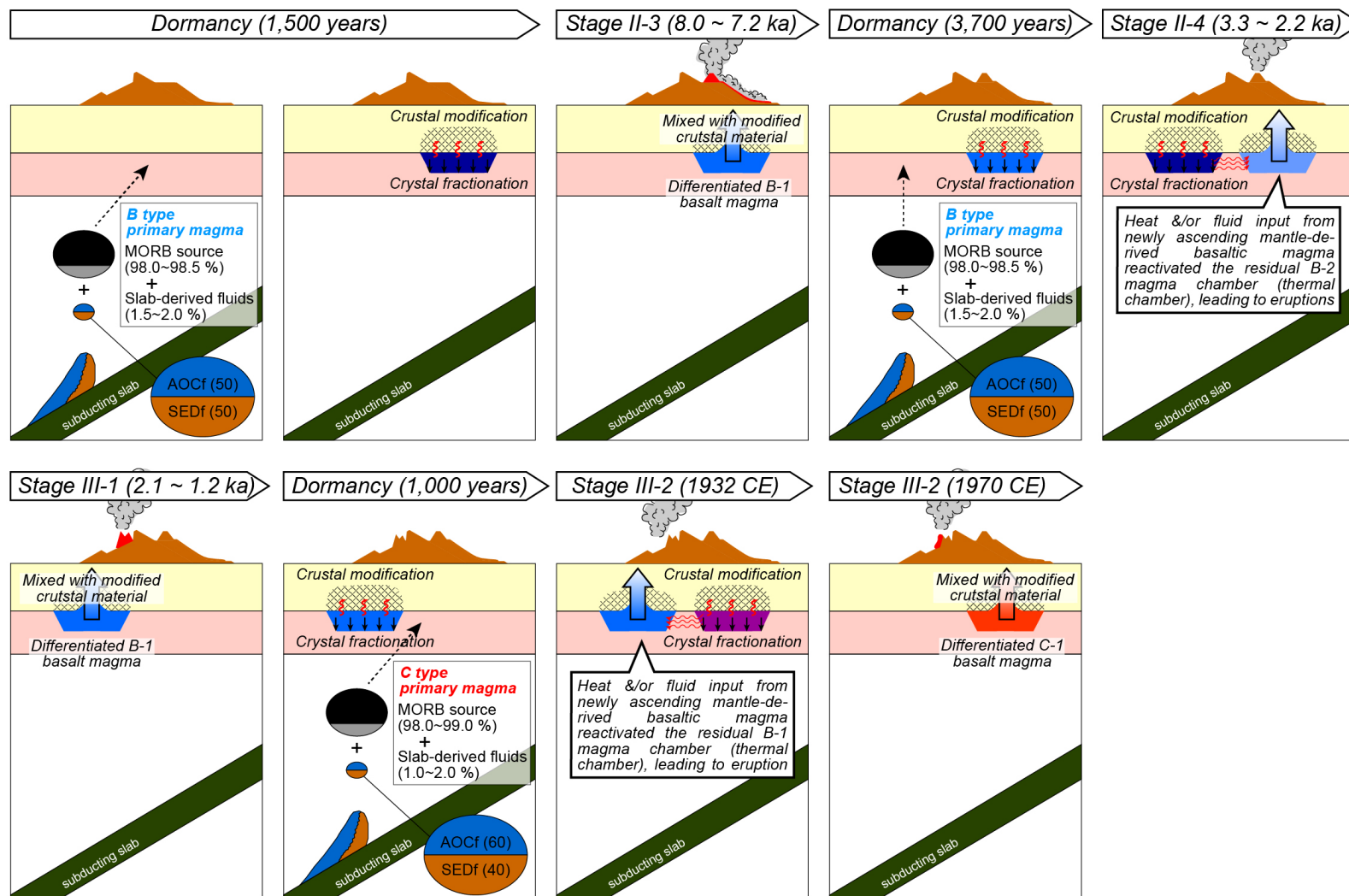


Figure 3-13

Figure 3-13 Schematic model for the evolution of the magma plumbing system at Akita-Komagatake volcano. Fluids are released from the subducting Pacific slab in pulses at intervals of several thousand years, triggering partial melting of the wedge mantle. The quantity and composition of these slab-derived fluids vary over time, leading to the generation of multiple types of primary magmas with distinct isotopic ratios. Upon ascending into the crust, the primary magmas undergo differentiation via the Assimilation-Fractional Crystallization (AFC) process. This process occurs in two stages: in Phase 1, the magmas differentiate while modifying the surrounding crustal materials. In the subsequent Phase 2, the differentiated mafic magmas mix with (assimilate) the modified crustal materials before erupting at the surface.

3-7. Conclusion

In many subduction zone volcanoes, a variety of eruptive products, differing in chemical characteristics such as whole-rock major and trace element compositions and isotopic ratios, are produced throughout their activity. In this study, to elucidate the mechanisms producing chemically diverse eruptive products in a subduction zone volcano, I investigated Akita-Komagatake volcano in the Northeast Japan arc and clarified the structure and temporal evolution of its magma plumbing system from the mantle to the crust.

(1) The rocks of this volcano can be classified into three main magma types (A, B and C) with distinct Sr–Nd–Pb isotopic ratios.

(2) The differences in isotopic ratios among the mafic rocks of the three magma types can be explained by variations in the volume and the composition of slab-derived fluids added to a common mantle source. Specifically, the results show that the amount of slab-derived fluid added to the mantle wedge during primary magma generation increases in the order of A, B, and C types, and the proportion of oceanic sediment components in the fluid also increases in the same order. Thus, it is inferred that the three magma types already possessed distinct isotopic signatures at the stage of primary basaltic magma.

(3) Each magma type exhibits a wide range of SiO₂ contents, from basalt to andesite (dacite). Based on the shapes of the compositional trends, this compositional variation is interpreted to have mainly formed through assimilation and fractional crystallization (AFC).

(4) The main magma type of the eruptive products has changed every few thousand years, and each transition was invariably preceded by a period of dormancy. This observation suggests that slab-derived fluids are not supplied to the mantle wedge at a steady rate but rather in a pulse-like manner. In other words, this implies that the timing of these fluid pulses may be the primary factor controlling the timing of volcanic activity in subduction zone volcanoes.

(5) This study provides the first example in the Northeast Japan Arc in which the structure of a mantle-to-crust magma plumbing system and its temporal evolution have been reconstructed. Furthermore, the origins of the diverse magma types erupted at Akita-Komagatake are attributed to both mantle and crustal processes. The magma-generation model developed in this study may also be applicable to other volcanoes in the Northeast Japan Arc.

Chapter 4. Conclusion

In this study, geological, petrological, and geochemical investigations were conducted on Akita-Komagatake volcano, located in the Northeast Japan arc, to elucidate the structure and evolution history of the magma plumbing system from the mantle to the crust in a subduction-zone volcano.

(1) In Chapter 2, a new approach for constructing the formation history of a volcano was proposed, in which tephra fall units and edifice deposits were correlated based on magma type, and the ages obtained from tephrostratigraphy were integrated into the formation history of the volcano. By applying this method to Akita-Komagatake, a high-temporal-resolution reconstruction of its formation history was successfully achieved.

(2) Chapter 3 revealed that magma type diversity observed in Akita-Komagatake resulted from processes in both mantle and crust. Three isotopically distinct magma types are derived from a common mantle source, and their isotopic differences can be explained by differences in the volume and the composition of slab-derived fluids added during primary magma generation. These magmas subsequently underwent AFC (Assimilation–Fractional Crystallization) within the crust.

(3) The main magma type of the eruptive products has changed every few thousand years, and each transition was invariably preceded by a period of dormancy. This observation suggests that slab-derived fluids are not supplied to the mantle wedge at a steady rate but rather in a pulse-like manner. In other words, this implies that the timing of these fluid pulses may be the primary factor controlling the timing of volcanic activity in subduction zone volcanoes.

(3) Using the method proposed in this study for constructing the volcanic edifice evolution, a high-precision chronological framework obtained from tephrostratigraphy was successfully

incorporated into the formation history of the volcano. As a result, it became possible to construct a comprehensive eruptive history integrates both the explosive eruptions and the edifice formation, including all relevant state variables such as eruption ages, volumes of erupted material, and eruption sequences. In addition, this method effectively eliminated the “uncertainty of correlation” that may arise from conventional correlation approaches based on “chemical similarities”. Since many subduction-zone volcanoes worldwide are known to have erupted diverse magma types throughout their activity, the reconstruction approach presented in this study is expected to be applicable to a wide range of other subduction zone volcanoes.

(4) The diversity of parameters such as whole-rock major and trace element compositions and isotopic ratios observed in the eruptive products of Akita-Komagatake is also recognized in other volcanoes of the Northeast Japan Arc. However, many volcanoes in this arc are dominated by intermediate to felsic eruptive deposits. As a result, information on intra-mantle process is generally not preserved, making it difficult to discuss the structure and temporal evolution of magma plumbing system extending from mantle to crust. This study presents the first comprehensive elucidation of the structure and evolution of the magma plumbing system from the mantle to the crust in the Northeast Japan arc. Furthermore, the mechanisms responsible for generating each magma type were attributed to processes operating within both the mantle and the crust. The processes identified in this study may also be applicable to explain the magma type diversity observed in other volcanoes of the Northeast Japan arc.

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Appendix (whole-rock chemical compositions)

Appendix (whole-rock chemical compositions)

Sample	7	8	11	12	26	38	41	AK2-2-1
Latitude (°N)	39°45'8"	39°45'8"	39°45'13"	39°45'14"	39°45'7"	39°45'1"	39°45'4"	39°45'11"
Longitude (°E)	140°47'37"	140°47'19"	140°47'22"	140°47'26"	140°47'27"	140°48'1"	140°48'1"	140°47'36"
Stage	III	III	III	III	III	III	III	III
Unit	1970 LF	1970 LF	1970 LF	1970 LF	1970 LF	1970 LF	1970 LF	1970 LF
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Bomb	Bomb	Lava
<i>Major elements, wt. %</i>								
SiO ₂	59.54	59.03	58.62	59.61	58.77	57.95	59.04	58.77
TiO ₂	1.10	1.10	1.10	1.11	1.10	1.09	1.12	1.11
Al ₂ O ₃	15.81	15.70	15.50	15.70	15.56	15.42	15.73	15.57
Fe ₂ O ₃	10.43	10.23	10.40	10.29	10.49	10.04	10.29	10.37
MnO	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
MgO	2.81	2.77	2.85	2.81	2.83	2.77	2.87	2.84
CaO	7.21	7.19	7.21	7.11	7.23	7.33	7.30	7.20
Na ₂ O	3.61	3.61	3.56	3.62	3.63	3.62	3.60	3.59
K ₂ O	0.49	0.48	0.48	0.50	0.49	0.50	0.47	0.48
P ₂ O ₅	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Total	101.37	100.48	100.10	101.12	100.47	99.09	100.80	100.30
LOI	-0.47	-0.32	-0.28	-0.41	-0.51	-0.22	-0.45	-0.43
<i>Trace elements, ppm (XRF)</i>								
Sc	36.9	38.4	36.8	36.2	36.4	36.6	38.9	35.7
V	194	189	191	192	192	186	197	196
Cr	5.2	1.6	3.0	4.1	4.6	4.5	4.7	4.7
Co	19.6	21.6	23.5	21.2	20.8	18.7	19.3	20.9
Ni	1.2	0.9	1.7	1.2	1.1	1.3	0.8	0.7
Rb	9.3	9.6	8.7	10.2	9.2	9.5	9.6	8.9
Sr	291	309	302	290	290	297	291	289
Y	25.9	26.6	25.9	25.0	25.9	25.4	26.1	25.5
Zr	74.3	76.4	75.1	73.8	74.8	75.2	73.8	72.4
Ba	184	188	184	187	187	189	187	189
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	AK9-1	10	22AK19-3-1	22AK19-3-2	AK6	AK6-2	AK6-3	AK7-1
Latitude (°N)	39°45'14"	39°45'12"	39°44'47"	39°44'47"	39°44'27"	39°44'27"	39°44'27"	39°44'29"
Longitude (°E)	140°47'34"	140°47'20"	140°47'25"	140°47'25"	140°46'41"	140°46'41"	140°46'41"	140°46'41"
Stage	III	III	III	III	III	III	III	III
Unit	1970 LF	1970 LF	1932 PD	1932 PD	Nko	Nko	Nko	Nko
Subunit								
Type	Lava	Lava	Scoria	Scoria	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	58.46	59.03	53.61	53.27	53.51	53.91	53.69	54.08
TiO ₂	1.11	1.10	1.05	1.02	1.02	1.03	1.03	1.03
Al ₂ O ₃	15.54	15.76	16.69	16.43	16.01	16.36	16.18	16.30
Fe ₂ O ₃	10.36	10.31	12.28	12.09	12.35	12.09	12.23	12.09
MnO	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20
MgO	2.84	2.82	5.04	5.07	4.94	4.77	4.77	4.94
CaO	7.27	7.22	9.54	9.98	9.59	9.73	9.66	9.69
Na ₂ O	3.59	3.59	2.45	2.46	2.57	2.56	2.55	2.57
K ₂ O	0.49	0.49	0.34	0.33	0.39	0.38	0.39	0.38
P ₂ O ₅	0.16	0.16	0.11	0.10	0.11	0.11	0.11	0.10
Total	100.03	100.68	101.33	100.96	100.69	101.14	100.78	101.39
LOI	-0.46	-0.34	1.01	-0.43	-0.56	-0.52	-0.53	-0.51
<i>Trace elements, ppm (XRF)</i>								
Sc	35.2	38.4	45.3	44.2	42.3	42.7	42.8	40.7
V	192	187	325	321	313	307	311	313
Cr	3.5	1.7	55.5	58.3	51.2	50.8	49.8	54.0
Co	19.5	21.1	32.5	32.2	31.2	33.6	33.4	33.8
Ni	1.1	0.6	8.2	10.2	9.7	8.4	9.1	9.2
Rb	9.2	9.9	8.5	7.3	8.7	8.2	9.3	8.6
Sr	292	309	258	261	261	264	266	261
Y	26.7	25.3	18.3	17.9	19.7	19.4	19.5	19.1
Zr	74.2	75.4	43.9	41.1	46.6	46.1	45.6	45.8
Ba	188	185	117	121	133	125	126	127
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.44	2.41	1.76			1.88		
Cs	0.52	0.51	0.52			0.48		
La	6.65	6.58	4.32			4.45		
Ce	16.7	16.6	10.6			11.4		
Pr	2.42	2.41	1.54			1.65		
Nd	12.1	12.0	7.80			8.35		
Sm	3.62	3.56	2.41			2.56		
Eu	1.28	1.27	0.84			0.88		
Gd	4.45	4.46	3.07			3.24		
Tb	0.75	0.75	0.52			0.55		
Dy	5.02	4.99	3.46			3.67		
Ho	1.07	1.05	0.73			0.78		
Er	3.22	3.19	2.20			2.33		
Tm	0.47	0.46	0.32			0.34		
Yb	3.10	3.08	2.13			2.23		
Lu	0.47	0.47	0.32			0.34		
Hf	2.29	2.32	1.39			1.49		
Ta	0.13	0.13	0.10			0.10		
Pb	4.78	4.88	3.63			3.84		
Th	0.90	0.90	0.73			0.79		
U	0.31	0.32	0.24			0.24		
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.703988	0.704002	0.704169			0.704150		
2SE	0.000026	0.000026	0.000026			0.000026		
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512879	0.512887	0.512858			0.512856		
2SE	0.000010	0.000010	0.000010			0.000010		
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5132	18.5128	18.5318			18.5339		
2SE	0.0018	0.0018	0.0018			0.0018		
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5748	15.5745	15.5866			15.5877		
2SE	0.0014	0.0014	0.0014			0.0014		
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5028	38.5023	38.5593			38.5644		
2SE	0.0044	0.0044	0.0044			0.0044		

Appendix (whole-rock chemical compositions)

Sample	22AK9	22AK11	731-4	22AK14	22AK1	22AK10	22AK15	22AK24
Latitude (°N)	39°44'41"	39°44'31"	39°44'27"	39°44'32"	39°44'33"	39°44'35"	39°44'38"	39°44'40"
Longitude (°E)	140°46'58"	140°46'55"	140°46'41"	140°47'31"	140°47'19"	140°47'0"	140°47'26"	140°47'34"
Stage	III	III	III	III	III	III	III	III
Unit	Nko	Nko	Nko	Nko	Nko	Nko	Nko	Nko
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	53.48	53.75	52.54	53.41	53.14	53.19	53.45	52.30
TiO ₂	1.04	1.03	1.02	1.02	1.03	1.02	1.02	1.03
Al ₂ O ₃	16.65	16.04	15.88	16.20	16.00	16.20	16.14	15.85
Fe ₂ O ₃	11.83	12.00	11.81	12.15	11.95	12.02	11.99	12.10
MnO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21
MgO	4.76	4.73	4.81	4.77	4.80	4.95	4.77	4.88
CaO	9.60	9.45	9.69	9.52	9.69	9.66	9.63	9.72
Na ₂ O	2.48	2.51	2.48	2.43	2.50	2.43	2.47	2.44
K ₂ O	0.39	0.41	0.38	0.38	0.40	0.37	0.39	0.39
P ₂ O ₅	0.11	0.09	0.10	0.11	0.11	0.10	0.11	0.11
Total	100.54	100.20	98.92	100.19	99.80	100.15	100.17	99.02
LOI	0.72	-0.38	-0.22	-0.02	-0.49	-0.43	-0.53	0.04
<i>Trace elements, ppm (XRF)</i>								
Sc	44.8	42.0	42.6	45.0	42.5	45.0	42.4	42.3
V	306	302	313	311	313	312	313	308
Cr	53.0	51.1	52.9	56.7	57.5	54.1	52.5	52.1
Co	32.3	32.5	31.2	30.4	31.4	30.5	32.3	29.0
Ni	7.6	9.2	9.2	10.5	10.8	10.3	8.7	10.2
Rb	8.1	8.8	8.5	11.3	9.0	7.8	8.6	8.8
Sr	259	261	269	257	262	263	263	263
Y	19.9	19.4	19.1	18.3	19.0	19.0	19.9	18.9
Zr	47.1	48.0	45.8	46.0	46.5	45.3	46.0	45.6
Ba	127	135	130	125	132	132	135	130
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	22AK26	22AK31	22AK27	22AK28	22AK25	22AK29	22AK30	33
Latitude (°N)	39°44'38"	39°44'33"	39°44'39"	39°44'40"	39°44'41"	39°44'51"	39°44'49"	39°45'5"
Longitude (°E)	140°47'41"	140°47'51"	140°47'47"	140°47'55"	140°47'37"	140°48'3"	140°47'53"	140°48'8"
Stage	III	III	III	III	III	III	III	III
Unit	Nko	Nko	Nko	Nko	Nko	Nko	Nko	Nko
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	50.33	52.99	51.75	52.06	53.07	52.85	53.14	53.40
TiO ₂	0.99	1.01	1.02	1.01	1.02	1.03	1.03	1.02
Al ₂ O ₃	15.37	16.27	15.65	15.91	16.32	15.85	15.99	16.47
Fe ₂ O ₃	11.77	12.02	12.22	12.11	12.14	12.52	12.45	12.04
MnO	0.20	0.20	0.21	0.21	0.20	0.20	0.20	0.20
MgO	4.80	4.96	4.99	4.88	4.86	4.84	4.89	4.98
CaO	9.85	9.85	9.86	9.91	9.78	9.68	9.59	9.95
Na ₂ O	2.40	2.43	2.42	2.38	2.41	2.40	2.45	2.46
K ₂ O	0.36	0.36	0.36	0.35	0.34	0.35	0.37	0.33
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10
Total	96.18	100.19	98.58	98.91	100.24	99.82	100.21	100.95
LOI	-0.19	-0.56	-0.57	-0.41	0.01	-0.53	-0.41	-0.12
<i>Trace elements, ppm (XRF)</i>								
Sc	43.1	41.5	42.5	40.8	46.3	46.9	45.1	43.7
V	313	309	310	318	317	326	318	322
Cr	55.9	53.8	53.1	55.1	56.6	56.3	55.5	57.6
Co	30.4	32.0	30.4	30.0	30.1	27.8	30.9	34.7
Ni	9.1	9.6	9.8	8.5	9.4	9.6	10.1	9.5
Rb	7.5	6.8	8.6	8.4	9.8	9.1	9.1	7.9
Sr	261	265	265	267	262	262	261	262
Y	18.4	19.1	19.3	18.3	16.7	18.2	18.8	18.1
Zr	44.4	44.0	44.4	43.4	43.0	42.9	45.8	41.4
Ba	122	125	124	119	115	113	123	125
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	35	36	39	40	44	45	43	48
Latitude (°N)	39°45'2"	39°45'3"	39°45'1"	39°45'3"	39°45'3"	39°45'3"	39°45'3"	39°45'0"
Longitude (°E)	140°48'8"	140°48'5"	140°48'4"	140°48'0"	140°48'4"	140°48'4"	140°48'4"	140°48'22"
Stage	III	III	III	III	III	III	III	III
Unit	Nko	Nko	Nko	Nko	Nko	Nko	Nko	Nko
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	53.22	53.75	53.34	53.27	53.56	53.70	52.98	53.48
TiO ₂	1.02	1.03	1.03	1.02	1.03	1.03	1.02	1.02
Al ₂ O ₃	16.52	16.43	16.47	16.57	16.55	16.48	16.29	16.46
Fe ₂ O ₃	11.98	12.14	12.14	11.94	12.19	12.12	12.11	12.02
MnO	0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.20
MgO	4.96	4.95	4.92	5.08	4.92	5.01	5.04	5.00
CaO	10.10	9.93	10.01	9.86	9.74	9.87	9.77	10.01
Na ₂ O	2.32	2.48	2.45	2.45	2.47	2.44	2.50	2.50
K ₂ O	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.33
P ₂ O ₅	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10
Total	100.74	101.35	100.99	100.82	101.09	101.26	100.33	101.13
LOI	-0.16	-0.43	-0.23	0.65	-0.01	-0.32	-0.01	-0.53
<i>Trace elements, ppm (XRF)</i>								
Sc	42.8	44.0	42.1	47.4	45.9	44.2	45.3	43.5
V	318	324	322	323	321	322	317	323
Cr	53.6	55.6	57.1	61.3	54.8	57.6	57.2	60.1
Co	32.8	33.2	32.8	33.2	34.3	35.8	32.3	32.7
Ni	9.0	8.5	8.0	8.9	8.6	8.9	9.7	8.4
Rb	7.5	7.4	7.6	7.2	6.2	7.7	8.1	8.1
Sr	267	263	264	258	264	260	262	264
Y	18.2	17.8	18.3	18.2	17.5	18.3	17.6	17.8
Zr	41.7	41.6	42.1	43.1	42.7	43.2	41.8	41.9
Ba	120	123	123	117	117	119	111	118
<i>Trace elements, ppm (ICP-MS)</i>								
Nb							1.66	
Cs							0.41	
La							3.88	
Ce							10.2	
Pr							1.50	
Nd							7.59	
Sm							2.34	
Eu							0.84	
Gd							3.04	
Tb							0.51	
Dy							3.40	
Ho							0.72	
Er							2.17	
Tm							0.31	
Yb							2.09	
Lu							0.32	
Hf							1.37	
Ta							0.09	
Pb							3.15	
Th							0.66	
U							0.21	
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr							0.704161	
2SE							0.000026	
¹⁴³ Nd/ ¹⁴⁴ Nd							0.512867	
2SE							0.000010	
²⁰⁶ Pb/ ²⁰⁴ Pb							18.5298	
2SE							0.0018	
²⁰⁷ Pb/ ²⁰⁴ Pb							15.5863	
2SE							0.0014	
²⁰⁸ Pb/ ²⁰⁴ Pb							38.5563	
2SE							0.0044	

Appendix (whole-rock chemical compositions)

Sample	AK10	OY3	oy5	oy6	oy7	oy8	oy4	22AK100-3
Latitude (°N)	39°44'56"	39°44'56"	39°44'53"	39°44'50"	39°44'50"	39°44'53"	39°44'54"	39°44'9"
Longitude (°E)	140°48'16"	140°48'17"	140°48'15"	140°48'16"	140°48'19"	140°48'21"	140°48'17"	140°50'7"
Stage	III	III	III	III	III	III	III	III
Unit	Nko	Nko	Nko	Nko	Nko	Nko	Nko	AK1
Subunit								AK1-1
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	53.30	53.89	53.27	54.28	54.04	53.52	54.78	52.43
TiO ₂	1.03	1.03	1.01	1.03	1.02	1.02	1.03	1.06
Al ₂ O ₃	16.43	15.94	16.35	16.13	16.42	16.10	16.26	15.39
Fe ₂ O ₃	12.17	11.92	12.18	12.10	12.06	11.98	11.92	12.33
MnO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21
MgO	4.86	4.54	4.91	4.73	4.95	4.58	4.57	5.44
CaO	9.94	9.40	9.94	9.48	9.82	9.52	9.39	9.56
Na ₂ O	2.50	2.69	2.54	2.65	2.55	2.66	2.70	2.31
K ₂ O	0.35	0.45	0.34	0.42	0.36	0.43	0.44	0.36
P ₂ O ₅	0.10	0.11	0.10	0.11	0.10	0.11	0.11	0.11
Total	100.86	100.16	100.85	101.13	101.50	100.12	101.39	99.19
LOI	-0.46	-0.51	-0.53	-0.57	-0.54	-0.60	-0.59	0.50
<i>Trace elements, ppm (XRF)</i>								
Sc	42.9	43.3	45.0	41.7	41.8	41.7	41.8	46.1
V	318	297	320	306	314	299	300	332
Cr	54.3	46.4	55.6	49.4	54.8	50.8	45.7	65.4
Co	33.6	30.8	32.2	32.3	31.9	30.8	32.0	32.8
Ni	7.8	7.9	9.2	9.2	9.5	8.1	8.3	9.6
Rb	7.8	10.3	7.8	9.2	7.7	9.9	11.7	7.6
Sr	263	260	264	261	261	260	258	255
Y	18.9	19.6	17.5	19.6	18.9	19.2	19.4	20.2
Zr	43.8	51.1	42.9	49.5	44.1	49.2	50.6	45.8
Ba	125	145	125	136	127	146	144	125
<i>Trace elements, ppm (ICP-MS)</i>								
Nb							2.16	
Cs							0.52	
La							4.94	
Ce							12.5	
Pr							1.80	
Nd							8.95	
Sm							2.69	
Eu							0.91	
Gd							3.40	
Tb							0.58	
Dy							3.82	
Ho							0.81	
Er							2.42	
Tm							0.35	
Yb							2.34	
Lu							0.35	
Hf							1.62	
Ta							0.12	
Pb							4.23	
Th							0.95	
U							0.29	
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr							0.704178	
2SE							0.000026	
¹⁴³ Nd/ ¹⁴⁴ Nd							0.512853	
2SE							0.000010	
²⁰⁶ Pb/ ²⁰⁴ Pb							18.5383	
2SE							0.0018	
²⁰⁷ Pb/ ²⁰⁴ Pb							15.5900	
2SE							0.0014	
²⁰⁸ Pb/ ²⁰⁴ Pb							38.5749	
2SE							0.0044	

Appendix (whole-rock chemical compositions)

Sample	22AK101-12	ak102-102kuro	AK102-29	AK102-34	AK102-37	22AK101-11	ak102-19	AK102-11
Latitude (°N)	39°44'33"	39°45'19"	39°45'19"	39°45'19"	39°45'19"	39°44'33"	39°45'19"	39°45'19"
Longitude (°E)	140°49'55"	140°48'34"	140°48'34"	140°48'34"	140°48'34"	140°49'55"	140°48'34"	140°48'34"
Stage	III	III	III	III	III	III	III	III
Unit	AK1	AK1	AK1	AK1	AK1	AK1	AK1	AK1
Subunit	AK1-1	AK1-1	AK1-1	AK1-1	AK1-1	AK1-2	AK1-2	AK1-2
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	48.10	52.60	53.25	52.89	52.48	54.14	50.50	52.74
TiO ₂	0.97	1.02	1.03	1.02	1.03	1.06	1.00	1.04
Al ₂ O ₃	14.99	16.31	16.40	16.51	16.14	16.09	15.81	16.18
Fe ₂ O ₃	11.51	12.08	11.79	11.76	12.01	11.63	11.74	12.02
MnO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21
MgO	5.07	4.93	4.86	4.93	5.10	4.58	4.85	4.97
CaO	10.15	9.95	9.89	9.91	9.77	9.17	9.78	9.78
Na ₂ O	2.34	2.53	2.37	2.32	2.33	2.54	2.32	2.29
K ₂ O	0.35	0.38	0.34	0.33	0.34	0.45	0.34	0.35
P ₂ O ₅	0.10	0.11	0.10	0.10	0.10	0.12	0.10	0.10
Total	93.78	100.10	100.24	99.96	99.50	99.98	96.64	99.67
LOI	0.15	-0.15	-0.11	0.33	0.27	0.50	-0.38	0.15
<i>Trace elements, ppm (XRF)</i>								
Sc	45.2	43.4	46.8	42.0	47.1	41.7	42.6	45.7
V	309	312	320	317	320	304	315	324
Cr	63.2	55.1	53.8	59.6	60.4	43.9	56.7	54.7
Co	29.3	34.1	34.2	33.8	33.9	30.9	35.0	32.7
Ni	10.7	10.7	8.1	9.2	9.8	7.7	9.7	9.2
Rb	7.7	9.1	8.7	8.8	9.1	10.0	7.6	8.4
Sr	264	265	268	267	266	257	260	264
Y	18.9	19.2	18.4	18.6	17.7	21.6	16.6	18.9
Zr	44.8	45.1	43.9	43.3	45.4	53.6	42.8	45.3
Ba	121	124	119	109	116	144	123	117
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	AK102-12	AK102-13	AK102-16	AK102-25	ak102-100kuro	19ak46-1	20AK37-8-1	20AK37-8-2
Latitude (°N)	39°45'19"	39°45'19"	39°45'19"	39°45'19"	39°45'19"	39°45'26"	39°44'14"	39°44'14"
Longitude (°E)	140°48'34"	140°48'34"	140°48'34"	140°48'34"	140°48'34"	140°48'11"	140°50'5"	140°50'5"
Stage	III	III	III	III	III	III	III	III
Unit	AK1	AK1	AK1	AK1	AK1	AK1	AK1	AK1
Subunit	AK1-2	AK1-2	AK1-2	AK1-2	AK1-2	AK1-2	AK1-2	AK1-2
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	52.41	51.82	52.25	52.99	52.94	51.67	52.47	52.51
TiO ₂	1.01	1.02	1.03	1.01	1.03	1.04	1.05	1.03
Al ₂ O ₃	16.55	16.36	16.10	16.69	16.26	16.29	15.70	16.22
Fe ₂ O ₃	11.75	11.88	11.86	11.55	12.26	12.12	11.84	11.75
MnO	0.20	0.20	0.20	0.20	0.21	0.20	0.20	0.20
MgO	4.99	4.95	4.92	4.77	4.99	4.77	4.49	4.37
CaO	9.98	10.04	9.90	10.05	9.75	9.80	9.21	9.43
Na ₂ O	2.25	2.31	2.33	2.34	2.40	2.26	2.51	2.49
K ₂ O	0.32	0.33	0.34	0.33	0.35	0.32	0.45	0.44
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.12
Total	99.57	98.99	99.04	100.03	100.29	98.57	98.04	98.57
LOI	0.77	0.24	0.03	-0.01	-0.41	0.16	0.50	0.44
<i>Trace elements, ppm (XRF)</i>								
Sc	44.4	44.9	46.8	43.8	45.3	41.6	41.1	39.3
V	313	313	318	314	320	320	303	296
Cr	56.8	60.2	55.9	53.8	58.3	55.8	45.3	43.8
Co	34.5	32.7	33.3	31.7	31.7	31.0	30.5	28.1
Ni	9.9	8.9	8.5	7.9	9.4	8.6	8.3	7.4
Rb	8.4	8.5	8.4	8.6	10.1	7.6	10.7	10.1
Sr	268	271	267	270	260	269	260	266
Y	17.4	17.7	17.6	16.8	18.8	18.9	22.0	21.1
Zr	43.3	44.3	44.0	42.7	42.8	44.2	53.6	52.0
Ba	112	112	119	114	120	116	142	142
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			1.71					
Cs			0.48					
La			4.18					
Ce			10.8					
Pr			1.57					
Nd			7.98					
Sm			2.48					
Eu			0.87					
Gd			3.16					
Tb			0.53					
Dy			3.56					
Ho			0.75					
Er			2.27					
Tm			0.33					
Yb			2.18					
Lu			0.33					
Hf			1.40					
Ta			0.09					
Pb			3.69					
Th			0.74					
U			0.22					
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.704154					
2SE			0.000026					
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512865					
2SE			0.000010					
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5304					
2SE			0.0018					
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5866					
2SE			0.0014					
²⁰⁸ Pb/ ²⁰⁴ Pb			38.5591					
2SE			0.0044					

Appendix (whole-rock chemical compositions)

Sample	20ak37-8timitu	ak116-1	ak116-2	AK102-54	22AK101-10	ak102-2	AK102-7	AK102-7
Latitude (°N)	39°44'14"	39°45'37"	39°45'37"	39°45'19"	39°44'33"	39°45'19"	39°45'19"	39°45'19"
Longitude (°E)	140°50'5"	140°48'37"	140°48'37"	140°48'34"	140°49'55"	140°48'34"	140°48'34"	140°48'34"
Stage	III	III	III	III	III	III	III	III
Unit	AK1	AK1	AK1	AK1	AK1	AK1	AK1	AK1
Subunit	AK1-2	AK1-2	AK1-2	AK1-2	AK1-3	AK1-3	AK1-3	AK1-3
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	53.23	51.96	53.26	52.50	51.52	55.39	54.72	55.07
TiO ₂	1.02	1.00	1.02	1.02	1.00	1.00	1.01	1.05
Al ₂ O ₃	15.68	16.72	17.08	16.16	15.31	15.61	15.91	16.09
Fe ₂ O ₃	11.59	11.53	11.89	11.60	11.25	11.41	11.25	10.52
MnO	0.20	0.20	0.20	0.20	0.20	0.19	0.20	0.20
MgO	5.07	4.95	4.89	4.75	4.71	4.73	4.47	4.48
CaO	9.14	10.30	10.11	9.78	9.23	8.84	9.16	9.30
Na ₂ O	2.50	2.41	2.36	2.36	2.49	2.66	2.62	2.67
K ₂ O	0.44	0.34	0.34	0.38	0.49	0.49	0.47	0.49
P ₂ O ₅	0.11	0.10	0.10	0.10	0.11	0.12	0.12	0.12
Total	98.97	99.50	101.23	98.85	96.29	100.44	99.93	2.35
LOI	0.61	-0.28	-0.29	0.25	0.48	-0.53	-0.53	3.16
<i>Trace elements, ppm (XRF)</i>								
Sc	41.3	41.1	43.9	43.9	40.6	39.1	43.4	43.0
V	297	305	311	303	291	282	290	297
Cr	52.2	57.4	55.9	49.3	61.8	46.5	45.6	43.1
Co	33.1	31.9	32.1	31.5	29.1	31.4	30.7	28.8
Ni	13.9	9.3	8.3	8.7	9.8	12.3	7.8	7.6
Rb	10.8	7.4	8.1	9.5	11.3	12.0	10.9	11.9
Sr	260	267	268	269	251	247	259	262
Y	20.2	18.0	18.2	18.9	21.5	19.5	19.7	20.2
Zr	51.0	41.6	41.9	48.0	56.1	53.8	53.6	55.8
Ba	136	121	120	124	141	151	145	149
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	AK102-45	19ak102-2	ak106-9	20ak37-7	ak90-1	ak90-2	731-2	731-6
Latitude (°N)	39°45'19"	39°45'19"	39°44'9"	39°44'14"	39°44'17"	39°44'17"	39°44'22"	39°44'23"
Longitude (°E)	140°48'34"	140°48'34"	140°50'7"	140°50'5"	140°45'52"	140°45'52"	140°46'14"	140°46'44"
Stage	III	III	III	III	III	III	III	III
Unit	AK1	AK1	AK1	AK1	Me	Me	Me	Me
Subunit	AK1-3	AK1-3	AK1-3	AK1-3				
Type	Scoria	Scoria	Scoria	Scoria	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	54.09	54.18	55.25	53.77	50.78	50.53	50.30	49.62
TiO ₂	1.02	1.03	1.02	1.03	0.81	0.80	0.80	0.80
Al ₂ O ₃	15.93	15.56	16.42	15.85	20.14	20.16	19.85	19.64
Fe ₂ O ₃	11.30	11.65	11.64	11.72	9.91	9.72	10.13	9.61
MnO	0.19	0.20	0.19	0.19	0.16	0.16	0.16	0.16
MgO	4.37	4.30	4.43	4.31	4.52	4.44	4.43	4.30
CaO	9.20	8.87	9.09	8.96	12.01	11.96	11.86	12.04
Na ₂ O	2.61	2.66	2.64	2.55	2.27	2.24	2.10	2.11
K ₂ O	0.48	0.50	0.49	0.51	0.22	0.22	0.22	0.21
P ₂ O ₅	0.12	0.12	0.12	0.12	0.08	0.08	0.08	0.08
Total	99.32	99.07	101.29	99.02	100.90	100.31	99.93	98.57
LOI	0.46	0.49	-0.18	0.49	-0.26	-0.34	-0.52	-0.22
<i>Trace elements, ppm (XRF)</i>								
Sc	42.1	38.7	39.4	41.8	36.0	34.1	33.7	35.2
V	293	294	289	297	241	238	246	250
Cr	41.6	42.5	45.3	44.7	71.7	71.1	74.3	72.9
Co	29.7	29.2	29.8	27.5	27.2	26.0	27.6	24.4
Ni	7.9	6.7	8.1	7.6	12.2	12.5	13.5	11.2
Rb	12.8	11.5	12.4	13.3	4.6	4.5	4.4	4.4
Sr	261	262	254	260	295	298	298	297
Y	21.0	22.3	20.0	22.2	14.1	14.1	15.2	14.5
Zr	55.8	58.1	54.4	57.8	30.6	30.0	30.1	30.2
Ba	146	156	147	152	84.8	84.8	87.3	91.2
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		2.43						
Cs		0.61						
La		5.55						
Ce		14.0						
Pr		1.97						
Nd		9.80						
Sm		2.89						
Eu		0.97						
Gd		3.62						
Tb		0.61						
Dy		4.08						
Ho		0.86						
Er		2.58						
Tm		0.38						
Yb		2.50						
Lu		0.38						
Hf		1.79						
Ta		0.14						
Pb		4.98						
Th		1.10						
U		0.34						
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.704202						
2SE		0.000026						
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512837						
2SE		0.000010						
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5402						
2SE		0.0018						
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5905						
2SE		0.0014						
²⁰⁸ Pb/ ²⁰⁴ Pb		38.5776						
2SE		0.0044						

Appendix (whole-rock chemical compositions)

Sample	20AK13	22AK12	ak115	ak119-8	20AK11-10	20AK11-11	AK1-1	AK1-2
Latitude (°N)	39°44'26"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'25"	39°44'25"
Longitude (°E)	140°46'55"	140°47'8"	140°47'11"	140°47'8"	140°47'11"	140°47'11"	140°47'20"	140°47'20"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	49.33	49.36	50.91	50.85	49.34	49.56	51.17	50.85
TiO ₂	0.81	0.80	0.80	0.81	0.80	0.79	0.82	0.80
Al ₂ O ₃	19.42	19.74	20.44	20.39	19.56	19.64	20.14	20.21
Fe ₂ O ₃	10.09	9.83	10.11	9.91	9.94	9.81	10.07	9.86
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
MgO	4.24	4.38	4.27	4.34	4.18	4.25	4.62	4.37
CaO	11.89	12.00	11.94	11.95	11.91	11.87	11.70	11.80
Na ₂ O	2.07	2.03	2.19	2.19	2.07	2.06	2.22	2.26
K ₂ O	0.21	0.22	0.22	0.23	0.22	0.21	0.24	0.23
P ₂ O ₅	0.08	0.08	0.08	0.09	0.08	0.08	0.09	0.08
Total	98.30	98.59	101.11	100.93	98.25	98.42	101.24	100.62
LOI	-0.38	-0.12	-0.30	-0.32	-0.38	-0.26	-0.03	-0.26
<i>Trace elements, ppm (XRF)</i>								
Sc	32.6	36.1	33.6	35.3	32.2	32.2	33.1	34.1
V	244	241	240	244	240	240	244	241
Cr	73.6	75.0	72.7	72.4	71.9	73.9	65.2	60.1
Co	25.4	25.0	24.4	24.6	23.5	24.5	29.5	29.5
Ni	11.8	11.7	11.3	11.5	11.9	11.6	15.6	13.4
Rb	5.0	4.6	4.6	4.7	4.4	4.7	4.9	5.1
Sr	298	297	299	296	298	296	289	293
Y	15.0	14.6	14.0	14.1	14.0	14.4	14.3	13.7
Zr	31.9	30.3	30.1	31.6	29.9	29.9	30.5	30.7
Ba	84.6	81.2	89.3	92.8	83.8	77.9	88.1	94.9
<i>Trace elements, ppm (ICP-MS)</i>								
Nb				1.21				
Cs				0.32				
La				2.78				
Ce				7.36				
Pr				1.11				
Nd				5.75				
Sm				1.81				
Eu				0.70				
Gd				2.34				
Tb				0.40				
Dy				2.68				
Ho				0.56				
Er				1.69				
Tm				0.24				
Yb				1.63				
Lu				0.25				
Hf				0.99				
Ta				0.07				
Pb				2.53				
Th				0.37				
U				0.12				
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr				0.704163				
2SE				0.000026				
¹⁴³ Nd/ ¹⁴⁴ Nd				0.512866				
2SE				0.000010				
²⁰⁶ Pb/ ²⁰⁴ Pb				18.5283				
2SE				0.0018				
²⁰⁷ Pb/ ²⁰⁴ Pb				15.5850				
2SE				0.0014				
²⁰⁸ Pb/ ²⁰⁴ Pb				38.5533				
2SE				0.0044				

Appendix (whole-rock chemical compositions)

Sample	AK2-1	AK2-2-2	AK3-1	AK3-2	AK5-1	AK5-2	22AK13	22AK5
Latitude (°N)	39°44'25"	39°44'25"	39°44'24"	39°44'24"	39°44'25"	39°44'25"	39°44'27"	39°44'42"
Longitude (°E)	140°47'22"	140°47'22"	140°46'39"	140°46'39"	140°46'42"	140°46'42"	140°47'34"	140°47'2"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.00	51.60	50.66	51.17	50.44	51.07	50.72	50.35
TiO ₂	0.81	0.82	0.80	0.80	0.80	0.81	0.80	0.80
Al ₂ O ₃	20.32	20.39	20.18	20.55	20.06	20.16	20.22	19.84
Fe ₂ O ₃	9.90	9.97	9.85	9.68	9.97	10.01	9.81	9.84
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
MgO	4.37	4.40	4.40	4.26	4.43	4.51	4.43	4.54
CaO	11.90	11.81	11.99	11.96	11.94	11.90	11.88	11.79
Na ₂ O	2.23	2.25	2.20	2.18	2.19	2.19	2.05	2.16
K ₂ O	0.23	0.24	0.22	0.22	0.22	0.21	0.21	0.23
P ₂ O ₅	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08
Total	101.00	101.72	100.52	101.06	100.29	101.09	100.36	99.79
LOI	-0.23	-0.35	-0.28	0.19	-0.29	-0.23	-0.31	-0.24
<i>Trace elements, ppm (XRF)</i>								
Sc	34.3	34.3	34.3	34.7	33.5	33.5	37.4	34.2
V	241	243	244	244	243	249	247	235
Cr	62.6	60.9	73.6	73.7	75.0	74.2	75.2	62.9
Co	26.8	29.7	28.1	27.6	28.0	28.6	27.9	25.8
Ni	14.2	12.8	12.0	11.9	12.3	12.6	12.0	16.7
Rb	4.9	5.0	5.2	4.7	5.2	4.7	4.6	4.5
Sr	293	297	292	290	290	291	290	296
Y	14.1	14.8	14.2	14.4	14.1	15.2	14.3	14.3
Zr	30.3	32.0	30.4	29.6	30.2	30.4	29.3	30.4
Ba	96.8	95.5	84.6	90.6	88.7	87.7	93.1	94.7
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	22AK18	22AK19-6	22AK18	22AK23	22AK20	22AK3	22AK2-3	22AK2-2
Latitude (°N)	39°44'46"	39°44'46"	39°44'46"	39°44'38"	39°44'48"	39°44'46"	39°44'40"	39°44'40"
Longitude (°E)	140°47'25"	140°47'25"	140°47'25"	140°47'19"	140°47'17"	140°47'13"	140°47'11"	140°47'11"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.60	50.53	50.37	49.54	50.97	51.24	50.74	50.95
TiO ₂	0.81	0.81	0.81	0.81	0.82	0.81	0.81	0.82
Al ₂ O ₃	20.19	19.88	20.05	19.89	19.78	19.94	20.09	19.96
Fe ₂ O ₃	9.97	9.97	9.81	9.66	10.02	10.03	9.79	9.93
MnO	0.16	0.16	0.16	0.16	0.17	0.16	0.16	0.16
MgO	4.09	4.53	4.28	4.20	4.47	4.72	4.28	4.12
CaO	11.72	11.70	11.80	11.90	11.65	11.62	11.74	11.48
Na ₂ O	2.13	2.11	2.10	2.16	2.17	2.12	2.14	2.25
K ₂ O	0.22	0.23	0.22	0.24	0.23	0.23	0.22	0.26
P ₂ O ₅	0.09	0.08	0.08	0.09	0.08	0.08	0.08	0.09
Total	99.96	100.02	99.68	98.65	100.36	100.96	100.06	100.00
LOI	-0.16	-0.33	-0.20	1.73	-0.28	-0.36	-0.34	-0.14
<i>Trace elements, ppm (XRF)</i>								
Sc	33.0	34.1	34.8	35.3	36.2	35.7	35.5	33.0
V	242	239	242	232	247	244	239	235
Cr	55.9	59.5	56.6	51.0	62.1	61.8	59.6	49.6
Co	26.3	28.2	29.5	26.9	30.1	29.2	25.9	27.3
Ni	12.3	14.5	12.6	13.8	13.7	15.1	13.0	17.1
Rb	5.0	3.6	3.7	4.6	4.1	5.4	4.0	6.1
Sr	298	294	299	303	292	292	293	299
Y	14.3	15.3	14.5	15.7	15.6	14.9	14.0	15.2
Zr	32.0	31.7	30.9	32.9	31.0	31.8	30.0	35.0
Ba	75.0	92.8	87.3	86.7	99.7	93.0	90.7	88.1
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	1.38							
Cs	0.24							
La	2.91							
Ce	7.71							
Pr	1.15							
Nd	5.93							
Sm	1.89							
Eu	0.72							
Gd	2.41							
Tb	0.41							
Dy	2.75							
Ho	0.58							
Er	1.73							
Tm	0.25							
Yb	1.65							
Lu	0.25							
Hf	1.03							
Ta	0.06							
Pb	2.83							
Th	0.43							
U	0.13							
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704202							
2SE	0.000026							
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512861							
2SE	0.000010							
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5281							
2SE	0.0018							
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5841							
2SE	0.0014							
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5521							
2SE	0.0044							

Appendix (whole-rock chemical compositions)

Sample	22AK2-1	22AK16	AK8-2	AK8-1	22AK8	22AK21	22AK7	17
Latitude (°N)	39°44'40"	39°44'39"	39°44'39"	39°44'39"	39°44'43"	39°44'48"	39°44'48"	39°45'2"
Longitude (°E)	140°47'11"	140°47'22"	140°46'40"	140°46'40"	140°46'55"	140°47'13"	140°47'2"	140°47'14"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Agglutinate
<i>Major elements, wt. %</i>								
SiO ₂	50.61	48.92	51.15	50.81	50.46	50.92	50.39	51.40
TiO ₂	0.80	0.81	0.81	0.81	0.81	0.82	0.79	0.80
Al ₂ O ₃	20.04	19.52	20.20	20.07	19.91	20.06	20.02	20.32
Fe ₂ O ₃	9.85	9.65	10.04	10.08	9.96	9.91	9.77	9.93
MnO	0.16	0.16	0.16	0.16	0.17	0.16	0.16	0.16
MgO	4.40	4.16	4.44	4.40	4.47	4.27	4.64	4.52
CaO	11.78	11.90	11.71	11.67	11.75	11.75	11.96	11.79
Na ₂ O	2.12	2.18	2.27	2.23	2.11	2.18	2.08	2.16
K ₂ O	0.22	0.24	0.24	0.24	0.23	0.24	0.21	0.22
P ₂ O ₅	0.08	0.08	0.09	0.09	0.09	0.09	0.08	0.08
Total	100.05	97.60	101.11	100.55	99.93	100.39	100.09	101.36
LOI	-0.38	-0.16	-0.04	-0.04	-0.23	-0.31	-0.11	-0.19
<i>Trace elements, ppm (XRF)</i>								
Sc	35.3	32.8	33.8	34.6	36.0	34.6	35.6	33.8
V	238	241	236	242	244	245	244	244
Cr	60.9	53.7	53.6	60.5	63.9	58.6	77.3	75.3
Co	27.4	28.7	28.0	30.3	28.9	27.2	30.1	28.1
Ni	12.8	12.2	15.3	13.8	13.7	12.3	14.0	13.0
Rb	4.0	5.2	4.6	3.3	4.7	4.9	4.2	5.3
Sr	294	298	301	290	295	296	294	290
Y	14.8	14.6	14.8	14.3	14.3	14.7	14.0	14.4
Zr	30.2	32.1	33.4	31.0	31.4	31.5	29.4	30.3
Ba	86.3	89.5	89.1	91.8	92.7	89.8	84.0	89.1
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	22AK4	22AK6	24	22	23	ak65-3	20AK16	ak65-2
Latitude (°N)	39°44'44"	39°44'45"	39°45'2"	39°45'2"	39°45'2"	39°45'12"	39°45'14"	39°45'12"
Longitude (°E)	140°47'7"	140°47'1"	140°47'15"	140°47'15"	140°47'15"	140°47'40"	140°47'43"	140°47'40"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Lava	Lava	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate
<i>Major elements, wt. %</i>								
SiO ₂	50.42	50.60	50.69	51.07	51.08	51.42	49.52	50.88
TiO ₂	0.79	0.79	0.80	0.80	0.81	0.82	0.81	0.82
Al ₂ O ₃	19.31	19.60	19.84	19.97	19.67	20.53	19.31	20.26
Fe ₂ O ₃	10.06	9.88	10.36	10.42	10.36	10.02	10.09	10.11
MnO	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16
MgO	4.71	4.74	4.63	4.67	4.87	4.49	4.46	4.60
CaO	11.68	11.76	11.74	11.59	11.49	11.67	11.74	11.44
Na ₂ O	2.04	2.05	2.19	2.18	2.09	2.15	2.02	1.98
K ₂ O	0.22	0.22	0.23	0.22	0.21	0.19	0.20	0.16
P ₂ O ₅	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.08
Total	99.46	99.87	100.72	101.16	100.81	101.54	98.38	100.50
LOI	-0.39	-0.19	-0.42	0.37	0.17	0.11	0.11	0.11
<i>Trace elements, ppm (XRF)</i>								
Sc	35.7	37.3	34.4	34.8	35.8	33.5	32.6	35.6
V	250	251	247	252	252	243	246	244
Cr	76.3	74.9	75.6	75.8	76.7	75.2	76.0	76.1
Co	29.1	29.7	30.3	27.8	28.4	26.6	31.8	27.3
Ni	14.8	15.6	14.5	14.9	16.1	13.4	14.0	14.6
Rb	4.6	4.5	4.4	5.2	5.1	4.4	4.0	5.5
Sr	288	289	285	287	288	297	295	290
Y	14.2	13.8	13.9	12.9	14.3	14.2	15.0	15.3
Zr	29.8	28.9	30.1	30.5	29.3	30.8	31.0	32.9
Ba	96.4	87.6	82.1	93.3	94.5	89.4	84.0	92.7
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								1.26
Cs								0.32
La								2.92
Ce								7.70
Pr								1.15
Nd								5.90
Sm								1.88
Eu								0.71
Gd								2.40
Tb								0.41
Dy								2.74
Ho								0.59
Er								1.74
Tm								0.25
Yb								1.67
Lu								0.25
Hf								1.00
Ta								0.07
Pb								3.74
Th								0.43
U								0.12
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								0.704157
2SE								0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd								0.512872
2SE								0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb								18.5278
2SE								0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb								15.5853
2SE								0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb								38.5549
2SE								0.0044

Appendix (whole-rock chemical compositions)

Sample	20AK15	ak66	20ak17	20AK23	ak67-4	ak67-3	6	20AK19
Latitude (°N)	39°45'12"	39°45'10"	39°45'12"	39°45'0"	39°45'6"	39°45'6"	39°45'4"	39°45'3"
Longitude (°E)	140°47'42"	140°47'42"	140°47'48"	140°47'43"	140°47'44"	140°47'43"	140°47'45"	140°47'41"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate
<i>Major elements, wt. %</i>								
SiO ₂	49.26	51.11	49.88	50.05	51.11	50.41	50.30	49.68
TiO ₂	0.81	0.81	0.80	0.82	0.79	0.78	0.78	0.78
Al ₂ O ₃	19.46	20.72	19.58	19.17	20.80	20.07	19.74	19.68
Fe ₂ O ₃	10.13	9.38	9.93	10.18	9.58	9.83	10.19	10.01
MnO	0.16	0.16	0.16	0.14	0.15	0.16	0.16	0.15
MgO	4.51	4.38	4.42	4.19	4.36	4.84	4.71	4.64
CaO	11.45	11.57	11.72	11.69	11.45	11.91	11.49	11.52
Na ₂ O	1.99	2.18	2.07	2.04	2.02	2.12	2.12	1.93
K ₂ O	0.21	0.22	0.22	0.20	0.20	0.19	0.21	0.18
P ₂ O ₅	0.08	0.08	0.08	0.08	0.08	0.07	0.08	0.06
Total	98.06	100.61	98.85	98.56	100.53	100.39	99.78	98.64
LOI	0.49	0.80	-0.24	-0.19	1.07	-0.41	0.40	0.67
<i>Trace elements, ppm (XRF)</i>								
Sc	33.6	36.1	31.1	30.8	35.5	36.0	34.1	33.7
V	247	235	242	252	243	245	248	242
Cr	76.2	74.1	75.1	78.6	85.1	86.2	87.0	88.0
Co	27.4	25.4	26.2	25.5	25.5	28.4	26.5	28.5
Ni	15.2	12.3	13.1	16.0	16.0	17.9	18.7	18.3
Rb	5.7	4.1	3.6	4.4	5.8	4.9	5.0	3.4
Sr	290	301	293	294	311	291	291	297
Y	13.5	11.9	14.5	14.9	12.7	13.5	11.4	12.9
Zr	30.0	31.8	30.7	31.3	30.2	27.4	28.6	28.5
Ba	84.2	97.3	84.6	89.7	87.4	84.7	91.5	82.8
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	29	ak67-1	ak67-2	20AK24	20AK26	20AK28	28	20AK20
Latitude (°N)	39°45'6"	39°45'7"	39°45'6"	39°44'59"	39°44'57"	39°44'57"	39°45'0"	39°45'1"
Longitude (°E)	140°47'45"	140°47'43"	140°47'43"	140°47'48"	140°47'37"	140°47'38"	140°47'37"	140°47'38"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate
<i>Major elements, wt. %</i>								
SiO ₂	50.85	51.46	50.84	49.65	49.70	49.76	51.41	49.38
TiO ₂	0.79	0.79	0.80	0.79	0.80	0.84	0.80	0.80
Al ₂ O ₃	20.03	20.19	19.76	19.18	19.56	19.14	20.56	19.95
Fe ₂ O ₃	9.96	9.29	9.99	10.16	10.11	10.36	9.67	9.63
MnO	0.16	0.16	0.16	0.16	0.16	0.17	0.16	0.15
MgO	4.68	4.79	4.88	5.01	4.53	4.43	4.44	4.27
CaO	11.49	10.87	11.69	11.64	11.67	11.57	11.86	11.81
Na ₂ O	1.96	2.07	2.12	1.95	2.07	2.11	2.22	2.11
K ₂ O	0.18	0.21	0.22	0.19	0.22	0.23	0.20	0.21
P ₂ O ₅	0.07	0.08	0.08	0.07	0.08	0.08	0.08	0.08
Total	100.17	99.90	100.54	98.80	98.89	98.69	101.40	98.39
LOI	0.82	1.74	-0.17	-0.23	-0.44	-0.41	-0.11	0.32
<i>Trace elements, ppm (XRF)</i>								
Sc	34.4	38.2	35.0	33.5	33.7	34.6	34.3	32.4
V	249	244	251	246	243	251	249	239
Cr	88.2	88.6	89.3	91.0	65.5	65.7	66.1	67.8
Co	28.7	26.4	28.0	28.4	29.6	26.9	28.8	25.2
Ni	17.7	18.5	17.9	20.5	15.2	13.7	14.2	13.5
Rb	5.2	4.8	5.5	4.0	4.9	5.3	4.9	3.5
Sr	288	293	289	291	296	297	294	306
Y	12.2	14.6	14.1	14.6	14.7	15.1	14.4	14.4
Zr	28.7	30.6	29.8	30.6	31.6	32.3	29.8	30.1
Ba	85.9	92.0	85.9	82.3	85.5	91.7	89.9	87.0
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	20AK27	20AK25	20AK30	27	20AK29	20AK31	25r	25b
Latitude (°N)	39°44'57"	39°45'1"	39°45'0"	39°45'0"	39°45'0"	39°45'6"	39°45'6"	39°45'6"
Longitude (°E)	140°47'37"	140°47'36"	140°47'31"	140°47'34"	140°47'32"	140°47'24"	140°47'23"	140°47'23"
Stage	III	III	III	III	III	III	III	III
Unit	Me	Me	Me	Me	Me	Me	Me	Me
Subunit								
Type	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate	Agglutinate
<i>Major elements, wt. %</i>								
SiO ₂	49.54	49.39	49.49	51.33	49.83	50.17	51.37	51.09
TiO ₂	0.82	0.82	0.81	0.82	0.82	0.80	0.81	0.80
Al ₂ O ₃	19.49	19.85	19.63	20.27	19.51	19.13	20.02	20.15
Fe ₂ O ₃	10.08	10.27	9.97	10.09	10.14	10.36	10.06	9.98
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.16
MgO	4.47	4.19	4.23	4.40	4.29	4.54	4.74	4.62
CaO	11.71	11.37	11.73	11.67	11.63	11.61	11.54	11.74
Na ₂ O	2.08	2.02	2.06	2.13	2.12	2.04	2.16	2.16
K ₂ O	0.21	0.17	0.21	0.21	0.23	0.21	0.22	0.22
P ₂ O ₅	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.08
Total	98.63	98.33	98.36	101.16	98.81	99.12	101.16	100.99
LOI	-0.26	-0.31	1.27	0.16	-0.42	-0.36	0.41	0.10
<i>Trace elements, ppm (XRF)</i>								
Sc	31.9	32.8	32.6	35.0	33.5	36.4	36.2	32.8
V	237	231	241	210	243	256	251	247
Cr	67.5	59.6	59.9	60.9	61.8	77.7	78.1	75.3
Co	25.1	26.3	25.9	30.8	26.2	28.2	31.4	27.6
Ni	14.1	13.4	12.4	13.1	14.8	14.1	15.0	14.2
Rb	4.1	3.9	4.2	3.8	5.5	5.4	4.9	4.8
Sr	298	310	299	290	299	292	281	285
Y	14.8	13.3	13.8	15.3	14.8	14.8	13.9	13.0
Zr	30.9	32.1	32.5	31.3	32.2	31.2	30.2	29.5
Ba	81.8	88.8	89.1	86.4	88.3	83.8	87.4	87.5
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	ak106-6-1	ak106-6-2	ak50-1	ak46-1	ak63-2	20AK37-6-1	20AK37-6-2	ak106-3-1
Latitude (°N)	39°44'9"	39°44'9"	39°45'29"	39°45'26"	39°45'32"	39°44'14"	39°44'14"	39°44'9"
Longitude (°E)	140°50'7"	140°50'7"	140°47'53"	140°48'11"	140°48'6"	140°50'5"	140°50'5"	140°50'7"
Stage	III	III	III	III	III	III	III	III
Unit	AK2	AK2	AK2	AK2	AK2	AK2	AK2	AK3
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	50.13	50.37	50.49	50.54	50.27	49.24	49.21	54.57
TiO ₂	0.75	0.74	0.82	0.83	0.84	0.79	0.78	0.94
Al ₂ O ₃	20.89	21.63	20.35	21.20	19.97	19.93	20.16	16.33
Fe ₂ O ₃	9.07	8.71	9.84	9.76	10.25	9.64	9.62	10.49
MnO	0.15	0.15	0.16	0.16	0.17	0.16	0.16	0.20
MgO	4.64	4.21	4.62	4.24	4.70	4.32	4.31	4.41
CaO	12.32	12.53	11.80	11.76	11.66	11.98	11.98	8.79
Na ₂ O	2.12	2.10	2.15	2.13	2.15	2.03	2.00	2.73
K ₂ O	0.21	0.20	0.23	0.22	0.22	0.21	0.20	0.47
P ₂ O ₅	0.08	0.08	0.09	0.09	0.09	0.08	0.08	0.11
Total	100.35	100.72	100.54	100.93	100.30	98.38	98.49	99.03
LOI	0.39	0.26	0.33	0.40	0.19	0.76	0.53	0.54
<i>Trace elements, ppm (XRF)</i>								
Sc	33.4	31.9	33.8	34.6	35.3	34.9	34.0	38.6
V	226	221	248	245	254	243	237	237
Cr	68.1	64.2	73.2	73.7	76.5	74.3	71.6	41.5
Co	25.7	23.9	26.7	26.0	28.3	26.2	24.6	28.4
Ni	15.0	12.1	12.9	11.6	14.1	12.4	13.0	9.1
Rb	5.2	4.9	4.9	5.3	6.2	5.0	4.5	10.7
Sr	307	312	288	292	289	298	298	251
Y	13.7	13.6	13.7	14.1	14.6	14.0	14.1	20.4
Zr	28.7	29.8	31.3	33.8	32.7	29.4	28.8	54.9
Ba	85.6	84.3	83.0	83.7	92.9	80.4	82.9	158
<i>Trace elements, ppm (ICP-MS)</i>								
Nb				1.32	1.25			2.44
Cs				0.33	0.34			0.64
La				2.97	2.86			5.14
Ce				7.83	7.63			12.6
Pr				1.19	1.13			1.81
Nd				6.11	5.81			8.81
Sm				1.92	1.85			2.63
Eu				0.73	0.70			0.94
Gd				2.43	2.40			3.34
Tb				0.41	0.41			0.56
Dy				2.79	2.73			3.76
Ho				0.59	0.57			0.80
Er				1.76	1.72			2.41
Tm				0.26	0.25			0.35
Yb				1.68	1.65			2.39
Lu				0.25	0.25			0.36
Hf				1.08	1.02			1.77
Ta				0.07	0.07			0.14
Pb				2.82	4.60			5.51
Th				0.46	0.43			1.01
U				0.13	0.13			0.29
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr				0.704186	0.704182			0.704198
2SE				0.000026	0.000026			0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd				0.512867	0.512874			0.512831
2SE				0.000010	0.000010			0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb				18.5273	18.5234			18.5340
2SE				0.0018	0.0018			0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb				15.5839	15.5840			15.5883
2SE				0.0014	0.0014			0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb				38.5496	38.5474			38.5620
2SE				0.0044	0.0044			0.0044

Appendix (whole-rock chemical compositions)

Sample	ak106-3-2	20ak37-2	20AK37-1	ak106-1	19ak117-4	nak61-2	61	22ak47-2
Latitude (°N)	39°44'9"	39°44'14"	39°44'14"	39°44'9"	39°44'30"	39°45'50"	39°45'50"	39°45'49"
Longitude (°E)	140°50'7"	140°50'5"	140°50'5"	140°50'7"	140°47'52"	140°48'20"	140°48'20"	140°48'21"
Stage	III	III	III	III	III	II	II	II
Unit	AK3	AK3	AK3	AK3	AK3	On-2	On-2	On-2
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	54.18	55.56	54.69	55.13	55.33	56.33	56.81	56.98
TiO ₂	0.96	0.92	0.93	0.93	0.89	0.78	0.79	0.88
Al ₂ O ₃	16.71	16.73	16.85	17.32	17.63	16.62	16.71	14.71
Fe ₂ O ₃	10.12	10.09	9.97	9.90	9.78	9.37	9.32	10.19
MnO	0.19	0.19	0.19	0.19	0.19	0.16	0.15	0.17
MgO	3.61	3.65	3.28	3.26	3.27	4.41	4.28	4.77
CaO	8.70	8.55	9.01	9.11	9.10	8.83	8.95	7.63
Na ₂ O	2.87	2.72	2.80	2.89	2.79	2.58	2.60	2.54
K ₂ O	0.50	0.47	0.46	0.47	0.43	0.82	0.78	0.89
P ₂ O ₅	0.12	0.12	0.13	0.13	0.12	0.10	0.08	0.10
Total	97.97	98.99	98.30	99.32	99.55	99.98	100.47	98.84
LOI	0.89	0.70	0.46	0.06	0.13	-0.21	-0.16	0.87
<i>Trace elements, ppm (XRF)</i>								
Sc	35.1	35.7	36.9	34.9	35.3	32.1	32.9	37.9
V	228	218	215	206	210	219	228	259
Cr	29.2	32.9	26.4	23.3	26.8	77.7	71.1	73.7
Co	26.9	23.4	20.8	24.8	21.5	24.9	26.3	28.2
Ni	7.1	6.1	4.4	4.5	4.4	18.2	16.6	19.3
Rb	12.4	10.6	10.8	11.3	11.4	22.5	20.7	26.4
Sr	264	261	271	275	268	230	228	209
Y	20.5	21.0	22.0	21.7	20.0	21.3	20.6	23.7
Zr	58.9	56.0	55.5	54.9	51.6	84.0	81.4	94.0
Ba	164	156	146	149	146	209	205	230
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		2.56					2.97	3.47
Cs		0.82					1.20	1.52
La		5.75					7.02	7.81
Ce		14.5					17.3	19.3
Pr		2.04					2.33	2.58
Nd		9.96					10.9	11.8
Sm		2.95					3.02	3.24
Eu		1.00					0.81	0.82
Gd		3.71					3.64	3.91
Tb		0.63					0.61	0.66
Dy		4.15					4.00	4.32
Ho		0.88					0.84	0.91
Er		2.66					2.52	2.73
Tm		0.39					0.37	0.40
Yb		2.59					2.47	2.70
Lu		0.39					0.37	0.40
Hf		1.79					2.63	2.96
Ta		0.14					0.19	0.22
Pb		5.91					5.49	6.75
Th		1.06					2.22	2.61
U		0.33					0.59	0.68
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.704232					0.704206	0.704235
2SE		0.000026					0.000026	0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512836					0.512834	0.512821
2SE		0.000010					0.000010	0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5333					18.5520	18.5510
2SE		0.0018					0.0018	0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5897					15.5960	15.5944
2SE		0.0014					0.0014	0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb		38.5702					38.6076	38.6043
2SE		0.0044					0.0044	0.0044

Appendix (whole-rock chemical compositions)

Sample	22ak47-5	22ak47-6	ak35	ak35-2	ak56-2	ak56-3	22ak84-1	22ak44-1
Latitude (°N)	39°45'49"	39°45'49"	39°45'49"	39°45'49"	39°45'53"	39°45'53"	39°45'53"	39°45'54"
Longitude (°E)	140°48'21"	140°48'21"	140°48'27"	140°48'27"	140°48'27"	140°48'27"	140°48'27"	140°48'9"
Stage	II	II	II	II	II	II	II	II
Unit	On-2	On-2	AK4	AK4	AK4	AK4	AK4	AK4
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	56.00	54.93	56.33	55.79	56.49	56.68	55.21	54.69
TiO ₂	0.81	0.80	0.80	0.84	0.82	0.80	0.79	0.86
Al ₂ O ₃	15.59	16.03	16.68	17.37	15.97	16.76	16.34	15.24
Fe ₂ O ₃	9.55	9.45	9.59	9.78	9.60	9.50	8.83	11.26
MnO	0.17	0.16	0.15	0.16	0.16	0.16	0.15	0.18
MgO	4.64	4.55	4.38	4.19	4.47	4.47	4.06	5.23
CaO	8.35	8.95	8.66	8.56	8.63	8.91	8.92	8.73
Na ₂ O	2.53	2.48	2.58	2.54	2.60	2.54	2.55	2.38
K ₂ O	0.82	0.75	0.81	0.78	0.83	0.75	0.79	0.62
P ₂ O ₅	0.10	0.10	0.09	0.10	0.10	0.10	0.10	0.09
Total	98.55	98.20	100.07	100.12	99.66	100.67	97.75	99.29
LOI	0.33	0.09	0.15	1.26	-0.31	-0.24	0.55	0.63
<i>Trace elements, ppm (XRF)</i>								
Sc	34.0	35.8	33.8	36.0	35.1	36.5	34.1	41.3
V	235	245	232	232	235	240	229	279
Cr	83.9	71.4	72.7	66.3	74.8	74.4	62.2	77.3
Co	27.7	25.1	25.5	25.6	26.5	25.8	22.7	30.0
Ni	20.3	18.1	18.4	15.2	17.7	16.4	15.0	19.9
Rb	24.6	21.4	22.8	22.6	25.3	24.4	23.0	18.6
Sr	221	231	228	221	219	222	236	225
Y	22.3	20.9	20.8	22.1	22.3	20.8	20.8	19.9
Zr	86.1	79.0	83.0	84.9	85.9	80.2	82.4	70.0
Ba	215	198	205	202	208	193	212	178
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		2.90			3.09			
Cs		1.20			1.26			
La		6.90			7.29			
Ce		17.0			18.0			
Pr		2.30			2.43			
Nd		10.8			11.4			
Sm		3.03			3.16			
Eu		0.81			0.81			
Gd		3.68			3.73			
Tb		0.61			0.63			
Dy		4.05			4.15			
Ho		0.85			0.88			
Er		2.55			2.60			
Tm		0.37			0.38			
Yb		2.49			2.54			
Lu		0.37			0.38			
Hf		2.50			2.71			
Ta		0.18			0.19			
Pb		5.70			6.23			
Th		2.14			2.33			
U		0.56			0.61			
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.704237			0.704227			
2SE		0.000026			0.000026			
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512823			0.512826			
2SE		0.000010			0.000010			
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5506			18.5507			
2SE		0.0018			0.0018			
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5942			15.5939			
2SE		0.0014			0.0014			
²⁰⁸ Pb/ ²⁰⁴ Pb		38.6031			38.6027			
2SE		0.0044			0.0044			

Appendix (whole-rock chemical compositions)

Sample	22ak64-4	22ak69-11	22ak69-9	22ak82-3	22ak82-4	ak29-1	ak29-2	22ak60
Latitude (°N)	39°45'40"	39°45'43"	39°45'43"	39°46'26"	39°46'26"	39°45'38"	39°45'38"	39°46'0"
Longitude (°E)	140°48'47"	140°48'25"	140°48'25"	140°48'7"	140°48'7"	140°48'21"	140°48'19"	140°48'34"
Stage	II	II	II	II	II	II	II	II
Unit	AK4	AK4	AK4	AK4	AK4	On-1	On-1	On-1
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	53.64	53.87	54.21	56.09	55.91	51.71	51.40	50.71
TiO ₂	0.89	0.83	0.88	0.88	0.89	0.80	0.81	0.80
Al ₂ O ₃	16.82	15.68	15.50	15.78	15.89	17.91	18.21	17.98
Fe ₂ O ₃	11.70	10.56	11.09	10.50	11.18	10.59	10.71	10.60
MnO	0.17	0.17	0.18	0.17	0.16	0.18	0.17	0.18
MgO	4.62	4.79	5.31	4.58	4.59	6.52	5.87	6.03
CaO	8.68	9.22	8.96	8.24	7.99	10.87	10.56	10.65
Na ₂ O	2.22	2.40	2.29	2.47	2.35	2.18	2.10	2.14
K ₂ O	0.59	0.61	0.59	0.72	0.70	0.18	0.25	0.21
P ₂ O ₅	0.10	0.09	0.10	0.09	0.09	0.10	0.10	0.09
Total	99.43	98.21	99.08	99.51	98.63	101.05	100.18	99.39
LOI	1.71	0.13	0.67	0.77	1.91	0.23	0.81	0.30
<i>Trace elements, ppm (XRF)</i>								
Sc	40.6	37.9	43.7	40.2		37.1	37.8	37.7
V	283	269	283	271		246	246	259
Cr	67.9	81.0	97.3	71.9		138	114	110
Co	27.3	27.8	32.2	30.7		32.9	31.7	32.7
Ni	16.1	16.6	19.3	16.1		35.9	32.9	33.0
Rb	17.2	17.9	17.1	21.1		4.8	5.9	3.7
Sr	223	230	220	219		254	248	259
Y	18.8	19.6	19.5	20.7		15.5	16.5	14.7
Zr	72.7	68.7	71.8	81.2		39.6	38.8	40.6
Ba	168	170	173	198		102	97.7	100
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.66	2.53						
Cs	1.05	0.95						
La	5.78	5.86						
Ce	14.6	14.6						
Pr	2.00	2.00						
Nd	9.59	9.49						
Sm	2.75	2.70						
Eu	0.80	0.79						
Gd	3.33	3.35						
Tb	0.56	0.56						
Dy	3.68	3.72						
Ho	0.77	0.79						
Er	2.29	2.37						
Tm	0.34	0.34						
Yb	2.24	2.29						
Lu	0.34	0.34						
Hf	2.27	2.14						
Ta	0.16	0.15						
Pb	5.65	5.06						
Th	1.80	1.69						
U	0.46	0.45						
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704201	0.704180						
2SE	0.000026	0.000026						
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512836	0.512845						
2SE	0.000010	0.000010						
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5452	18.5444						
2SE	0.0018	0.0018						
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5914	15.5905						
2SE	0.0014	0.0014						
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5903	38.5860						
2SE	0.0044	0.0044						

Appendix (whole-rock chemical compositions)

Sample	22ak61	22ak63	ak34	ak24k1	ak14k(HO3)	ak47(HO3)	730-10	1006-11
Latitude (°N)	39°45'54"	39°45'45"	39°45'54"	39°45'29"	39°45'29"	39°45'29"	39°46'6"	39°46'24"
Longitude (°E)	140°48'36"	140°48'28"	140°48'27"	140°48'9"	140°48'9"	140°48'10"	140°48'30"	140°48'11"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.48	50.90	51.80	51.17	51.61	51.48	50.78	51.15
TiO ₂	0.81	0.82	0.83	0.81	0.83	0.81	0.81	0.82
Al ₂ O ₃	17.66	18.00	18.00	18.29	18.30	17.72	17.59	17.84
Fe ₂ O ₃	10.70	10.67	10.97	10.82	10.80	11.06	10.74	10.45
MnO	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
MgO	6.07	6.04	6.19	6.13	5.96	6.79	6.22	5.95
CaO	10.68	10.54	10.64	10.82	10.60	10.47	10.91	10.89
Na ₂ O	2.16	2.14	2.14	2.20	2.27	2.15	2.14	2.17
K ₂ O	0.24	0.23	0.22	0.25	0.26	0.25	0.23	0.24
P ₂ O ₅	0.10	0.10	0.10	0.10	0.11	0.11	0.10	0.10
Total	99.06	99.60	101.07	100.77	100.91	101.03	99.69	99.78
LOI	-0.05	0.39	-0.04	-0.22	0.17	-0.11	-0.48	-0.23
<i>Trace elements, ppm (XRF)</i>								
Sc	39.4	38.5	38.3	37.8	36.2	38.9	38.3	36.5
V	262	264	260	252	260	258	259	260
Cr	114	115	116	108	109	126	116	111
Co	34.2	34.4	32.8	33.5	32.2	34.1	32.6	35.9
Ni	35.3	34.0	33.5	33.1	30.9	40.3	36.4	32.2
Rb	6.6	6.0	4.6	6.2	4.6	5.6	4.8	4.8
Sr	255	254	256	256	255	249	263	265
Y	14.7	13.7	16.3	14.6	15.7	16.3	15.6	16.2
Zr	39.8	40.6	41.2	40.5	41.6	40.2	40.5	42.0
Ba	102	101	103	98.9	102	100	104	103
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	1006-12	1006-13	805-2	728-2	19ak71-14	19ak71-15	830-1	830-5-1
Latitude (°N)	39°46'26"	39°46'28"	39°46'29"	39°46'29"	39°46'28"	39°46'7"	39°47'8"	39°47'2"
Longitude (°E)	140°48'3"	140°47'51"	140°48'15"	140°48'15"	140°47'51"	140°48'24"	140°46'33"	140°46'44"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.00	51.19	50.45	50.10	50.18	49.92	50.04	50.48
TiO ₂	0.79	0.82	0.81	0.81	0.81	0.79	0.80	0.84
Al ₂ O ₃	17.23	17.76	17.59	17.92	17.50	17.62	17.51	17.18
Fe ₂ O ₃	11.15	10.79	10.95	10.30	10.81	10.82	10.45	10.78
MnO	0.18	0.18	0.18	0.17	0.18	0.17	0.18	0.18
MgO	6.07	6.00	5.94	5.45	5.86	5.93	5.97	6.01
CaO	10.75	10.74	10.76	11.30	10.68	10.70	10.78	10.75
Na ₂ O	2.13	2.13	2.13	2.18	2.09	2.09	2.14	2.19
K ₂ O	0.24	0.25	0.24	0.23	0.24	0.23	0.25	0.25
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
Total	98.64	99.95	99.15	98.57	98.45	98.37	98.21	98.76
LOI	-0.56	-0.31	-0.19	-0.30	-0.07	-0.29	-0.03	-0.40
<i>Trace elements, ppm (XRF)</i>								
Sc	37.4	35.1	37.1	38.3	36.6	36.4	36.4	39.1
V	258	253	255	255	255	247	257	261
Cr	110	109	106	102	98.2	109	209	110
Co	35.1	31.3	34.0	29.5	33.4	30.8	32.7	34.4
Ni	31.9	34.8	32.7	27.3	18.0	33.9	90.3	34.3
Rb	5.0	5.2	4.1	4.4	5.7	4.7	5.1	4.8
Sr	262	263	261	274	255	260	262	260
Y	16.7	16.0	15.3	16.3	16.0	16.4	15.1	15.5
Zr	41.6	40.8	41.5	41.6	43.0	40.1	40.2	41.7
Ba	108	99.5	99.2	101	104	102	102	104
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	830-6	904-15	906-4	JMA-V13 14.0m	22ak50	22ak56	22ak88-1	22ak59
Latitude (°N)	39°46'55"	39°46'2"	39°46'30"	39°46'5"	39°45'55"	39°45'58"	39°46'6"	39°46'0"
Longitude (°E)	140°46'50"	140°47'5"	140°47'31"	140°48'25"	140°48'25"	140°48'26"	140°48'22"	140°48'35"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.51	50.38	51.20	51.43	50.80	50.54	51.11	50.69
TiO ₂	0.80	0.80	0.81	0.79	0.80	0.80	0.81	0.80
Al ₂ O ₃	17.52	17.19	17.78	18.06	17.77	17.92	18.16	17.84
Fe ₂ O ₃	10.81	10.68	10.86	10.33	10.73	10.72	10.85	10.43
MnO	0.18	0.18	0.18	0.17	0.18	0.18	0.18	0.18
MgO	6.15	5.87	6.07	5.93	6.00	6.03	5.94	5.92
CaO	10.77	10.78	10.77	10.85	10.60	10.57	10.39	10.79
Na ₂ O	2.10	2.18	2.15	2.21	2.14	2.14	2.00	2.15
K ₂ O	0.23	0.26	0.24	0.24	0.23	0.22	0.21	0.24
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09
Total	99.16	98.41	100.16	100.11	99.33	99.20	99.74	99.11
LOI	-0.42	-0.46	-0.38	-0.43	0.18	0.26	0.61	0.33
<i>Trace elements, ppm (XRF)</i>								
Sc	33.2	36.4	34.6	37.7	37.8	38.0	37.7	39.5
V	215	254	259	255	256	261	260	206
Cr	168	93.5	114	112	113	111	114	110
Co	32.1	31.3	35.6	33.8	33.8	33.9	33.0	32.8
Ni	55.7	18.9	33.5	32.7	35.0	34.2	33.4	34.1
Rb	4.7	5.9	4.5	5.1	6.6	6.2	6.1	7.0
Sr	252	264	260	263	255	256	252	258
Y	16.6	15.9	15.3	15.7	13.9	12.5	14.3	14.6
Zr	40.5	41.9	40.9	40.2	39.1	40.3	41.2	39.2
Ba	98.9	105	105	108	102	101	94.4	102
<i>Trace elements, ppm (ICP-MS)</i>								
Nb						1.86		
Cs						0.24		
La						2.68		
Ce						7.13		
Pr						1.04		
Nd						5.28		
Sm						1.66		
Eu						0.71		
Gd						2.16		
Tb						0.37		
Dy						2.55		
Ho						0.55		
Er						1.67		
Tm						0.25		
Yb						1.70		
Lu						0.26		
Hf						1.26		
Ta						0.09		
Pb						2.99		
Th						0.42		
U						0.13		
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr						0.704125		
2SE						0.000026		
¹⁴³ Nd/ ¹⁴⁴ Nd						0.512876		
2SE						0.000018		
²⁰⁶ Pb/ ²⁰⁴ Pb						18.5206		
2SE						0.0018		
²⁰⁷ Pb/ ²⁰⁴ Pb						15.5797		
2SE						0.0014		
²⁰⁸ Pb/ ²⁰⁴ Pb						38.5254		
2SE						0.0044		

Appendix (whole-rock chemical compositions)

Sample	20AK4	20ak3-7-2	20AK3-7-3	20AK3-7-4	20AK3-7-5	20AK33	AK11-1	AK11-2
Latitude (°N)	39°46'1"	39°46'19"	39°46'19"	39°46'19"	39°46'19"	39°46'11"	39°45'29"	39°45'29"
Longitude (°E)	140°48'24"	140°48'23"	140°48'23"	140°48'23"	140°48'23"	140°48'36"	140°48'25"	140°48'25"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	AK6	AK6
Subunit								
Type	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	50.73	50.58	50.67	50.07	50.54	50.12	51.45	52.06
TiO ₂	0.84	0.81	0.81	0.80	0.82	0.82	0.83	0.81
Al ₂ O ₃	17.07	17.74	17.52	17.39	17.54	17.18	17.86	18.03
Fe ₂ O ₃	11.05	10.67	10.81	10.84	10.74	10.94	10.89	10.80
MnO	0.18	0.17	0.18	0.18	0.18	0.18	0.18	0.18
MgO	6.23	5.86	6.00	6.04	5.75	5.97	6.15	6.24
CaO	10.32	10.83	10.67	10.80	10.72	10.72	10.68	10.75
Na ₂ O	2.12	2.12	2.08	2.13	2.14	2.11	2.17	2.20
K ₂ O	0.25	0.24	0.24	0.24	0.25	0.24	0.25	0.25
P ₂ O ₅	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	98.89	99.11	99.09	98.57	98.78	98.37	100.56	101.43
LOI	0.25	-0.32	-0.09	-0.34	-0.24	-0.31	0.04	-0.43
<i>Trace elements, ppm (XRF)</i>								
Sc	37.1	37.1	35.5	37.4	36.2	36.8	40.5	38.6
V	270	252	254	254	257	257	257	257
Cr	113	111	112	112	107	110	112	110
Co	35.1	32.0	33.5	31.9	32.4	31.6	36.3	36.5
Ni	35.0	32.5	33.2	34.2	30.0	33.7	35.2	36.1
Rb	4.8	5.2	4.4	4.1	4.6	4.2	5.5	5.6
Sr	256	261	260	264	263	262	253	254
Y	17.6	15.4	15.2	16.3	16.2	15.6	15.4	15.8
Zr	43.4	40.4	40.8	40.1	41.7	41.6	40.2	39.9
Ba	105	100	99.1	96.7	98.0	98.4	103	104
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	ak11-103?	20AK36-5-1	20a136-5-2	20ak2-3	20AK2-5	22ak64-7	22ak69-15	22ak82-1
Latitude (°N)	39°45'29"	39°45'18"	39°45'18"	39°46'6"	39°46'6"	39°45'40"	39°45'43"	39°46'26"
Longitude (°E)	140°48'25"	140°50'6"	140°50'6"	140°48'30"	140°48'30"	140°48'47"	140°48'25"	140°48'7"
Stage	II	II	II	II	II	II	II	II
Unit	AK6	AK6	AK6	AK6	AK6	AK6	AK6	AK6
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	51.46	49.96	50.60	51.45	49.32	50.52	50.86	50.59
TiO ₂	0.82	0.82	0.81	0.89	0.74	0.81	0.78	0.82
Al ₂ O ₃	18.09	18.05	18.52	16.49	18.88	18.12	17.44	18.42
Fe ₂ O ₃	10.80	10.62	10.36	11.45	9.68	10.66	10.37	10.77
MnO	0.18	0.19	0.18	0.19	0.16	0.18	0.18	0.19
MgO	6.04	5.61	5.49	6.61	5.88	6.44	6.67	6.24
CaO	10.86	10.59	10.90	9.45	11.23	10.25	10.80	10.38
Na ₂ O	2.21	2.01	1.95	2.01	1.90	2.01	1.97	1.93
K ₂ O	0.26	0.24	0.23	0.26	0.21	0.24	0.23	0.22
P ₂ O ₅	0.10	0.10	0.10	0.11	0.09	0.10	0.10	0.11
Total	100.83	98.19	99.14	98.90	98.08	99.34	99.39	99.65
LOI	-0.27	0.98	1.01	1.32	0.96	1.20	0.77	1.62
<i>Trace elements, ppm (XRF)</i>								
Sc	41.7	39.2	38.6	41.6	32.4	38.6	41.5	39.6
V	241	262	258	286	228	264	260	266
Cr	125	97.8	109	125	115	110	167	116
Co	38.5	33.0	33.6	38.1	33.4	37.3	35.3	40.0
Ni	38.5	17.1	15.6	38.1	39.6	37.5	38.3	42.9
Rb	5.9	4.3	4.7	4.9	3.8	7.0	6.5	6.7
Sr	245	256	256	232	273	245	243	247
Y	16.9	17.2	15.6	17.7	14.7	15.5	15.0	17.2
Zr	43.4	41.8	41.1	46.6	36.3	40.2	38.6	39.9
Ba	101	96.4	95.9	109	91.9	99.4	98.4	94.9
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	22ak83-2	22ak83-2ss	22ak85-1	22ak85-2	22ak85-3	22ak85-4	22ak85-9	22ak85-13
Latitude (°N)	39°45'55"	39°45'55"	39°45'42"	39°45'42"	39°45'42"	39°45'42"	39°45'42"	39°45'42"
Longitude (°E)	140°48'27"	140°48'27"	140°48'42"	140°48'42"	140°48'42"	140°48'42"	140°48'42"	140°48'42"
Stage	II	II	II	II	II	II	II	II
Unit	AK6	AK6	AK6	AK6	AK6	AK6	AK6	AK6
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	47.28	50.35	50.54	50.61	50.94	50.87	50.56	50.76
TiO ₂	0.77	0.79	0.80	0.80	0.82	0.88	0.86	0.83
Al ₂ O ₃	16.42	18.25	17.87	17.86	17.83	18.60	18.72	18.52
Fe ₂ O ₃	11.80	10.63	10.61	10.55	10.56	10.88	10.79	10.37
MnO	0.16	0.18	0.18	0.18	0.18	0.18	0.18	0.17
MgO	5.74	6.20	6.58	5.97	6.24	5.91	5.93	5.70
CaO	9.62	10.60	10.42	10.88	10.52	10.06	10.14	10.55
Na ₂ O	1.87	2.03	2.00	2.10	2.04	2.02	1.95	2.04
K ₂ O	0.22	0.23	0.23	0.23	0.23	0.24	0.23	0.24
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10
Total	93.97	99.36	99.32	99.28	99.44	99.74	99.46	99.30
LOI	1.40	1.08	0.57	-0.05	0.53	1.62	1.83	1.31
<i>Trace elements, ppm (XRF)</i>								
Sc	37.2	38.3	41.0	37.1	38.1	41.7	43.1	38.5
V	263	256	255	256	262	279	271	266
Cr	134	111	113	110	113	114	109	109
Co	35.1	35.0	36.2	34.8	35.1	33.4	33.8	34.4
Ni	38.2	38.0	37.5	33.2	36.3	34.1	31.4	30.7
Rb	6.2	6.3	6.5	6.2	6.5	8.0	6.0	7.4
Sr	240	253	250	261	254	244	249	254
Y	15.6	15.3	15.4	15.4	15.8	16.6	16.1	15.5
Zr	39.5	38.8	40.6	40.2	40.5	44.3	42.6	40.7
Ba	108	104	93.2	98.5	101	105	102	98.7
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			1.65					
Cs			0.33					
La			3.75					
Ce			9.68					
Pr			1.43					
Nd			7.17					
Sm			2.12					
Eu			0.76					
Gd			2.68					
Tb			0.45					
Dy			3.00					
Ho			0.63					
Er			1.90					
Tm			0.28					
Yb			1.83					
Lu			0.28					
Hf			1.25					
Ta			0.09					
Pb			2.63					
Th			0.41					
U			0.13					
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.704144					
2SE			0.000026					
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512870					
2SE			0.000010					
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5203					
2SE			0.0018					
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5800					
2SE			0.0014					
²⁰⁸ Pb/ ²⁰⁴ Pb			38.5275					
2SE			0.0044					

Appendix (whole-rock chemical compositions)

Sample	ak86c-11	ak86c-11-1	ak116-6	ak116-8kuro	20ak35-2	19AK100-29	20AK3-7-1	20AK32-3
Latitude (°N)	39°45'42"	39°45'18"	39°45'37"	39°45'37"	39°45'37"	39°45'25"	39°46'19"	39°46'11"
Longitude (°E)	140°48'42"	140°50'6"	140°48'37"	140°48'37"	140°48'37"	140°48'36"	140°48'23"	140°48'33"
Stage	II	II	II	II	II	II	II	II
Unit	AK6	AK6	AK6	AK6	AK6	AK6	AK6	AK6
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	51.18	50.93	50.48	51.07	50.19	49.09	50.86	50.81
TiO ₂	0.77	0.75	0.74	0.79	0.75	0.77	0.76	0.78
Al ₂ O ₃	19.72	20.02	19.59	19.25	19.34	19.10	18.31	18.33
Fe ₂ O ₃	9.68	9.48	9.82	10.24	9.77	10.07	10.25	10.35
MnO	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.17
MgO	5.32	5.24	5.38	5.19	5.24	5.31	5.18	5.01
CaO	11.28	11.41	11.53	11.12	11.21	11.31	11.01	11.01
Na ₂ O	2.07	2.08	2.05	2.13	1.93	1.90	2.05	2.10
K ₂ O	0.24	0.23	0.23	0.24	0.22	0.21	0.24	0.24
P ₂ O ₅	0.10	0.10	0.09	0.10	0.09	0.09	0.09	0.10
Total	100.53	100.41	100.07	100.29	98.91	98.02	98.91	98.89
LOI	0.61	0.58	0.27	0.19	0.86	0.83	0.19	-0.31
<i>Trace elements, ppm (XRF)</i>								
Sc	38.8	37.2	40.4	37.7	37.6	38.8	33.8	34.0
V	243	237	236	245	234	240	240	243
Cr	104	88.8	111	88.5	95.6	95.6	109	92.1
Co	27.6	28.5	27.7	28.8	31.1	31.2	28.2	28.8
Ni	14.3	14.8	17.6	14.3	17.1	17.9	15.2	14.5
Rb	4.7	4.6	4.5	5.6	4.6	4.2	4.6	4.4
Sr	260	264	267	263	265	268	263	269
Y	15.1	14.4	15.4	15.3	15.4	16.3	15.7	15.6
Zr	39.7	38.2	37.7	40.4	38.8	39.9	39.5	41.0
Ba	97.3	91.7	102	98.8	97.5	94.7	89.7	102
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	22ak85-8	22ak64-11	4	5	32	51	52	53
Latitude (°N)	39°45'42"	39°45'40"	39°45'55"	39°45'49"	39°45'48"	39°46'11"	39°46'0"	39°45'52"
Longitude (°E)	140°48'42"	140°48'47"	140°47'48"	140°47'45"	140°47'44"	140°47'59"	140°47'58"	140°47'46"
Stage	II	II	II	II	II	II	II	II
Unit	AK6	AK6	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Scoria	Scoria	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.16	49.80	51.98	52.08	51.00	52.28	51.16	51.36
TiO ₂	0.78	0.71	0.88	0.89	0.90	0.88	0.88	0.91
Al ₂ O ₃	18.79	20.31	20.09	19.98	20.65	20.35	19.36	20.16
Fe ₂ O ₃	9.95	9.04	10.14	10.23	10.11	10.09	10.37	10.26
MnO	0.17	0.16	0.16	0.16	0.16	0.16	0.17	0.17
MgO	5.24	5.19	3.78	3.78	3.71	3.84	4.04	4.00
CaO	10.92	11.78	11.05	11.07	11.52	11.08	11.09	11.00
Na ₂ O	2.07	1.93	2.43	2.47	2.41	2.41	2.44	2.32
K ₂ O	0.25	0.21	0.30	0.29	0.23	0.29	0.30	0.21
P ₂ O ₅	0.10	0.09	0.11	0.11	0.11	0.12	0.12	0.12
Total	99.42	99.21	100.91	101.06	100.81	101.49	99.91	100.51
LOI	0.65	0.65	0.17	0.17	0.82	0.24	0.58	0.82
<i>Trace elements, ppm (XRF)</i>								
Sc	36.6	33.0	34.2	34.1	32.5	34.2	35.8	36.9
V	251	224	259	261	264	260	260	266
Cr	92.5	97.8	35.6	32.9	32.5	34.9	44.2	38.6
Co	29.8	27.1	27.4	26.6	24.7	25.7	25.6	28.6
Ni	15.4	28.7	13.4	12.6	12.4	12.5	14.9	13.9
Rb	6.3	6.5	6.6	4.8	5.1	5.8	6.7	2.6
Sr	265	271	290	290	294	287	279	282
Y	15.7	13.7	18.2	18.5	17.7	17.6	17.4	18.7
Zr	41.9	34.6	49.0	48.9	47.8	47.4	46.7	47.6
Ba	99.7	88.1	113	114	118	111	118	112
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	1.76							
Cs	0.34							
La	3.81							
Ce	9.80							
Pr	1.41							
Nd	7.07							
Sm	2.09							
Eu	0.76							
Gd	2.59							
Tb	0.44							
Dy	2.90							
Ho	0.62							
Er	1.80							
Tm	0.26							
Yb	1.77							
Lu	0.27							
Hf	1.23							
Ta	0.09							
Pb	2.66							
Th	0.44							
U	0.14							
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704201							
2SE	0.000026							
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512862							
2SE	0.000010							
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5250							
2SE	0.0018							
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5833							
2SE	0.0014							
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5408							
2SE	0.0044							

Appendix (whole-rock chemical compositions)

Sample	54	55	56	59	57_2	57_3	ak30	605-1
Latitude (°N)	39°45'46"	39°45'37"	39°45'39"	39°45'37"	39°45'39"	39°45'39"	39°45'33"	39°45'41"
Longitude (°E)	140°47'44"	140°47'45"	140°47'57"	140°48'0"	140°47'57"	140°47'57"	140°48'17"	140°47'56"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.45	51.45	51.65	51.16	51.88	51.74	51.71	51.08
TiO ₂	0.90	0.88	0.89	0.87	0.88	0.88	0.87	0.86
Al ₂ O ₃	19.95	20.01	19.61	19.89	20.11	19.71	20.14	19.79
Fe ₂ O ₃	10.35	10.31	10.32	9.93	10.04	10.18	10.13	9.80
MnO	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
MgO	3.88	4.02	4.08	4.06	3.86	4.07	3.99	3.76
CaO	10.97	10.97	11.03	11.51	11.22	11.07	11.17	11.42
Na ₂ O	2.47	2.34	2.41	2.42	2.40	2.40	2.39	2.32
K ₂ O	0.30	0.25	0.30	0.27	0.27	0.27	0.29	0.26
P ₂ O ₅	0.12	0.10	0.12	0.11	0.12	0.11	0.11	0.11
Total	101.54	100.49	100.56	100.38	100.93	100.59	100.96	99.55
LOI	0.16	0.46	0.45	0.13	0.16	0.30	0.04	-0.08
<i>Trace elements, ppm (XRF)</i>								
Sc	36.7	32.3	35.3	32.6	34.8	34.6	33.8	34.7
V	266	257	263	260	261	265	257	262
Cr	34.5	42.4	45.7	42.6	37.0	45.1	41.1	38.3
Co	30.0	27.7	28.7	27.2	28.6	29.2	27.5	25.3
Ni	13.4	14.9	15.3	14.9	13.5	14.9	13.7	13.3
Rb	5.4	5.2	6.2	6.1	5.2	6.4	6.7	5.0
Sr	279	277	276	288	295	278	289	294
Y	17.2	16.7	17.0	16.8	16.4	16.6	17.6	18.5
Zr	47.9	46.2	47.2	44.7	47.4	45.7	46.7	45.2
Ba	117	118	114	109	116	115	113	107
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	605-3	915-15	915-16	919-1	917-14	917-5	917-6	904-18
Latitude (°N)	39°45'33"	39°47'46"	39°47'46"	39°45'55"	39°45'49"	39°45'56"	39°45'56"	39°45'57"
Longitude (°E)	140°48'17"	140°47'46"	140°47'46"	140°48'9"	140°47'45"	140°47'22"	140°47'22"	140°47'15"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.13	50.79	51.07	51.15	50.45	51.00	51.47	50.49
TiO ₂	0.87	0.88	0.88	0.86	0.89	0.88	0.89	0.88
Al ₂ O ₃	19.04	19.18	19.51	19.42	19.09	19.28	19.56	19.51
Fe ₂ O ₃	9.91	10.16	10.15	10.20	10.07	10.36	10.18	9.87
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
MgO	4.04	3.93	3.78	4.14	3.73	3.92	3.76	3.58
CaO	11.43	11.23	11.19	11.26	11.26	11.15	11.03	11.47
Na ₂ O	2.35	2.42	2.37	2.34	2.43	2.32	2.38	2.42
K ₂ O	0.27	0.28	0.29	0.27	0.29	0.28	0.29	0.29
P ₂ O ₅	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.12
Total	98.30	99.13	99.51	99.92	98.50	99.46	99.83	98.76
LOI	-0.32	-0.49	-0.17	-0.45	-0.47	-0.23	-0.21	-0.35
<i>Trace elements, ppm (XRF)</i>								
Sc	32.6	32.9	33.1	34.8	34.4	34.2	31.4	32.0
V	260	265	262	261	265	259	262	258
Cr	41.7	38.6	37.5	43.3	34.0	42.8	31.9	29.4
Co	28.7	27.9	26.4	28.7	24.9	26.4	26.2	24.9
Ni	14.5	14.3	12.8	14.8	12.5	13.9	12.5	11.5
Rb	5.7	4.4	6.0	5.5	5.8	5.7	6.3	5.5
Sr	293	290	287	289	294	287	289	298
Y	17.2	17.6	17.8	18.0	18.0	18.4	18.0	18.2
Zr	46.0	47.0	46.5	45.3	47.8	48.6	48.3	47.8
Ba	115	113	113	111	113	111	115	118
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	1006-16	19ak71-10	19AK71-12	19AK71-2	915-2	915-4	909-5	909-6
Latitude (°N)	39°46'22"	39°46'22"	39°46'25"	39°46'22"	39°46'5"	39°46'5"	39°46'14"	39°46'14"
Longitude (°E)	140°47'20"	140°47'8"	140°47'30"	140°47'20"	140°47'3"	140°47'15"	140°46'3"	140°46'3"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.29	50.48	50.47	50.28	51.19	50.01	50.46	51.47
TiO ₂	0.88	0.88	0.88	0.88	0.89	0.88	0.77	0.79
Al ₂ O ₃	19.45	19.19	19.21	18.94	19.49	19.29	18.65	18.64
Fe ₂ O ₃	10.01	10.03	10.23	10.33	10.19	10.16	10.20	10.23
MnO	0.16	0.16	0.16	0.17	0.16	0.16	0.17	0.17
MgO	3.82	3.66	3.71	3.85	3.72	3.73	5.10	5.14
CaO	11.25	11.18	11.01	10.89	11.10	11.29	11.33	11.15
Na ₂ O	2.41	2.35	2.36	2.33	2.39	2.39	2.11	2.10
K ₂ O	0.29	0.28	0.30	0.27	0.29	0.28	0.23	0.23
P ₂ O ₅	0.12	0.12	0.11	0.11	0.12	0.12	0.09	0.10
Total	99.68	98.30	98.44	98.04	99.54	98.31	99.11	100.01
LOI	-0.48	-0.35	-0.15	0.11	-0.16	0.06	-0.21	-0.11
<i>Trace elements, ppm (XRF)</i>								
Sc	33.9	30.9	32.8	34.0	35.1	33.5	35.9	37.7
V	264	258	261	261	263	259	238	243
Cr	36.7	35.0	34.4	39.5	34.4	36.0	92.3	94.1
Co	27.5	26.4	24.6	24.2	27.4	24.3	28.1	28.8
Ni	12.6	12.3	12.8	13.8	12.8	12.4	14.6	13.7
Rb	5.0	5.7	6.1	5.6	6.8	4.8	4.4	5.3
Sr	289	291	287	282	288	292	273	270
Y	17.5	18.4	18.1	18.1	18.0	17.1	15.0	15.3
Zr	47.3	47.9	47.7	46.7	48.5	46.4	39.8	40.2
Ba	126	111	114	113	118	115	94.2	104
<i>Trace elements, ppm (ICP-MS)</i>								
Nb					2.14			
Cs					0.31			
La					4.54			
Ce					11.7			
Pr					1.67			
Nd					8.25			
Sm					2.44			
Eu					0.86			
Gd					3.02			
Tb					0.50			
Dy					3.32			
Ho					0.70			
Er					2.08			
Tm					0.30			
Yb					2.01			
Lu					0.30			
Hf					1.47			
Ta					0.11			
Pb					3.19			
Th					0.55			
U					0.17			
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr					0.704153			
2SE					0.000026			
¹⁴³ Nd/ ¹⁴⁴ Nd					0.512859			
2SE					0.000010			
²⁰⁶ Pb/ ²⁰⁴ Pb					18.5221			
2SE					0.0018			
²⁰⁷ Pb/ ²⁰⁴ Pb					15.5817			
2SE					0.0014			
²⁰⁸ Pb/ ²⁰⁴ Pb					38.5302			
2SE					0.0044			

Appendix (whole-rock chemical compositions)

Sample	909-7	1006-18	1006-20	1006-21	1006-23	15	AK21-13-(2)	H26-B1_7.8m
Latitude (°N)	39°46'20"	39°46'26"	39°46'20"	39°46'34"	39°46'37"	39°46'19"	39°46'37"	39°46'26"
Longitude (°E)	140°46'12"	140°46'52"	140°46'29"	140°46'14"	140°46'12"	140°46'11"	140°46'12"	140°46'52"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.18	51.30	51.46	50.79	50.92	52.23	51.96	51.80
TiO ₂	0.79	0.77	0.78	0.78	0.79	0.79	0.79	0.79
Al ₂ O ₃	18.50	18.69	18.67	18.56	18.27	19.15	18.91	18.77
Fe ₂ O ₃	10.31	10.24	10.26	10.24	10.27	10.17	10.03	10.08
MnO	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
MgO	5.15	5.15	5.20	5.06	5.18	5.25	5.11	5.22
CaO	11.15	11.19	11.07	11.22	11.16	11.01	10.91	11.12
Na ₂ O	2.13	2.11	2.10	2.13	2.17	2.20	2.14	2.13
K ₂ O	0.23	0.24	0.24	0.24	0.24	0.24	0.25	0.24
P ₂ O ₅	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	99.70	99.95	100.05	99.30	99.27	101.30	100.35	100.41
LOI	-0.35	-0.34	-0.26	-0.33	-0.52	0.32	0.12	-0.14
<i>Trace elements, ppm (XRF)</i>								
Sc	37.0	36.2	35.4	35.9	36.8	36.7	36.0	36.8
V	248	247	245	248	251	249	249	243
Cr	91.6	90.5	93.6	86.5	89.7	101	85.8	92.0
Co	27.4	30.6	30.1	30.8	30.2	33.9	30.5	29.2
Ni	15.2	15.0	15.2	14.5	15.8	19.3	14.0	15.0
Rb	5.0	4.6	3.9	3.5	4.1	4.7	4.4	5.5
Sr	269	271	269	273	271	259	268	269
Y	15.4	15.3	15.9	15.3	15.5	14.8	15.3	15.4
Zr	40.2	39.7	41.1	39.5	41.0	39.6	41.2	39.7
Ba	100	106	97.3	103	107	91.0	104	106
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	19AK71-3	19AK71-4	19ak71-8	19AK71-9	19AK71-11	915-1	915-14	915-3
Latitude (°N)	39°46'26"	39°46'16"	39°46'28"	39°46'29"	39°46'24"	39°46'5"	39°45'57"	39°46'5"
Longitude (°E)	140°46'52"	140°46'30"	140°46'40"	140°46'41"	140°47'25"	140°47'2"	140°47'46"	140°47'6"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.25	50.67	50.37	50.24	50.70	51.53	52.04	51.72
TiO ₂	0.77	0.78	0.78	0.77	0.81	0.82	0.83	0.81
Al ₂ O ₃	18.46	18.36	18.22	18.27	17.83	18.46	18.68	18.13
Fe ₂ O ₃	10.22	10.36	10.38	10.35	10.69	10.20	10.05	10.50
MnO	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.17
MgO	5.09	5.24	5.16	5.23	5.39	4.51	4.51	5.25
CaO	10.98	10.90	11.02	10.97	10.44	10.87	10.98	10.91
Na ₂ O	2.04	2.07	2.07	2.07	2.08	2.28	2.33	2.16
K ₂ O	0.23	0.23	0.23	0.24	0.26	0.28	0.28	0.26
P ₂ O ₅	0.09	0.09	0.09	0.09	0.09	0.11	0.11	0.10
Total	98.31	98.88	98.48	98.40	98.47	99.22	99.96	100.03
LOI	0.01	0.01	-0.40	-0.25	0.34	-0.28	-0.39	-0.37
<i>Trace elements, ppm (XRF)</i>								
Sc	36.3	37.2	32.8	35.1	36.4	36.2	34.4	37.9
V	244	245	243	232	259	256	253	254
Cr	92.7	90.7	92.6	91.0	111	66.3	61.8	85.8
Co	31.6	31.7	28.4	26.3	33.1	28.5	28.7	33.5
Ni	15.5	16.1	15.2	16.8	33.2	11.8	11.3	15.4
Rb	5.2	4.4	3.7	5.3	5.1	7.0	5.8	5.4
Sr	266	265	268	260	259	276	281	267
Y	15.0	14.7	15.4	15.0	15.5	15.4	17.3	15.7
Zr	39.2	39.5	40.3	37.6	40.8	43.7	45.6	42.2
Ba	95.9	96.9	92.1	96.3	100	109	111	106
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	904-13	904-16	917-11	917-3	917-7	917-8	917-4	904-8
Latitude (°N)	39°46'3"	39°46'1"	39°45'52"	39°45'56"	39°45'52"	39°45'54"	39°45'56"	39°46'6"
Longitude (°E)	140°46'59"	140°47'9"	140°47'34"	140°47'22"	140°47'26"	140°47'27"	140°47'22"	140°46'46"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	On-1	On-1	On-1	On-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	50.39	51.09	50.70	51.61	51.67	50.85	51.33	51.98
TiO ₂	0.82	0.81	0.81	0.80	0.81	0.80	0.83	0.84
Al ₂ O ₃	17.75	18.38	17.89	18.20	18.22	18.08	17.79	17.94
Fe ₂ O ₃	10.34	9.86	10.33	10.44	10.46	10.53	10.64	10.57
MnO	0.18	0.17	0.18	0.18	0.17	0.18	0.18	0.18
MgO	5.15	4.51	5.34	5.39	5.31	5.22	5.28	5.09
CaO	11.01	11.14	10.97	10.95	10.96	11.05	10.92	10.68
Na ₂ O	2.19	2.29	2.19	2.18	2.19	2.18	2.22	2.30
K ₂ O	0.26	0.28	0.25	0.25	0.25	0.24	0.26	0.28
P ₂ O ₅	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10
Total	98.17	98.64	98.75	100.08	100.14	99.23	99.53	99.96
LOI	-0.30	-0.28	-0.07	-0.59	-0.45	-0.32	-0.53	-0.49
<i>Trace elements, ppm (XRF)</i>								
Sc	35.0	36.2	37.8	36.6	35.0	36.5	38.0	36.7
V	253	230	255	254	253	253	259	268
Cr	139	92.8	141	84.7	86.9	87.1	87.8	79.8
Co	28.6	20.2	32.2	31.5	31.2	29.6	31.1	32.4
Ni	50.6	30.1	45.6	16.8	16.4	15.7	15.0	12.9
Rb	4.9	4.5	5.6	4.0	4.8	4.5	4.2	5.5
Sr	270	268	270	268	271	271	270	265
Y	16.4	15.2	15.5	15.8	17.1	16.5	16.7	16.8
Zr	42.9	39.4	42.4	42.1	42.5	41.6	44.1	44.8
Ba	108	102	109	107	107	105	111	107
<i>Trace elements, ppm (ICP-MS)</i>								
Nb							1.83	
Cs							0.30	
La							3.95	
Ce							10.1	
Pr							1.46	
Nd							7.32	
Sm							2.18	
Eu							0.78	
Gd							2.69	
Tb							0.45	
Dy							2.99	
Ho							0.63	
Er							1.90	
Tm							0.27	
Yb							1.84	
Lu							0.28	
Hf							1.30	
Ta							0.10	
Pb							2.71	
Th							0.48	
U							0.15	
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr							0.704160	
2SE							0.000026	
¹⁴³ Nd/ ¹⁴⁴ Nd							0.512859	
2SE							0.000015	
²⁰⁶ Pb/ ²⁰⁴ Pb							18.5231	
2SE							0.0018	
²⁰⁷ Pb/ ²⁰⁴ Pb							15.5819	
2SE							0.0014	
²⁰⁸ Pb/ ²⁰⁴ Pb							38.5339	
2SE							0.0044	

Appendix (whole-rock chemical compositions)

Sample	906-8	ak104-1	ak104-2	ak104-2-2	ak86c-2	ak86c-2-2	ak26-14	20AK36-4
Latitude (°N)	39°46'35"	39°45'42"	39°45'42"	39°45'42"	39°45'18"	39°45'18"	39°45'18"	39°45'18"
Longitude (°E)	140°47'24"	140°48'4"	140°48'4"	140°48'4"	140°50'6"	140°50'6"	140°50'6"	140°50'6"
Stage	II	II	II	II	II	II	II	II
Unit	On-1	On-1	On-1	On-1	AK7	AK7	AK7	AK7
Subunit								
Type	Lava	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	51.50	51.68	51.99	51.41	51.60	51.87	53.43	52.83
TiO ₂	0.81	0.82	0.90	0.90	0.77	0.73	0.84	0.85
Al ₂ O ₃	17.93	17.84	19.96	19.72	20.27	20.33	18.00	17.64
Fe ₂ O ₃	10.51	10.74	9.87	9.74	9.99	9.88	10.80	10.77
MnO	0.18	0.18	0.14	0.15	0.20	0.20	0.20	0.19
MgO	5.31	5.99	3.54	3.53	4.30	4.54	4.51	4.16
CaO	10.86	10.96	10.37	10.48	10.78	10.86	10.02	9.86
Na ₂ O	2.15	2.20	2.29	2.31	2.04	2.00	2.30	2.21
K ₂ O	0.27	0.24	0.28	0.29	0.28	0.27	0.34	0.34
P ₂ O ₅	0.10	0.10	0.12	0.12	0.09	0.09	0.10	0.10
Total	99.61	100.76	99.46	98.63	100.31	100.77	100.52	98.96
LOI	-0.38	0.20	1.57	1.47	1.26	1.11	1.11	0.91
<i>Trace elements, ppm (XRF)</i>								
Sc	38.5	39.0	34.5	34.4	41.1	41.3	42.6	41.3
V	255	260	269	277	260	251	290	293
Cr	85.7	118	36.4	35.1	32.8	36.7	29.1	27.1
Co	30.1	35.1	27.3	27.5	27.7	28.5	29.1	28.5
Ni	16.6	36.0	11.6	11.5	4.9	5.1	4.8	4.3
Rb	5.0	5.9	6.2	6.0	6.5	6.2	8.1	7.0
Sr	267	260	282	283	251	253	248	252
Y	16.2	17.4	16.2	16.6	16.0	14.7	17.3	18.0
Zr	42.6	40.8	49.0	48.8	42.7	42.3	48.5	50.0
Ba	106	95.2	112	115	106	106	126	123
<i>Trace elements, ppm (ICP-MS)</i>								
Nb					1.72		1.87	
Cs					0.66		0.70	
La					3.90		4.37	
Ce					10.7		11.3	
Pr					1.45		1.58	
Nd					7.03		7.72	
Sm					2.11		2.30	
Eu					0.73		0.78	
Gd					2.63		2.86	
Tb					0.44		0.49	
Dy					2.98		3.26	
Ho					0.63		0.69	
Er					1.87		2.06	
Tm					0.27		0.30	
Yb					1.85		2.02	
Lu					0.28		0.31	
Hf					1.37		1.48	
Ta					0.10		0.10	
Pb					2.99		3.12	
Th					0.68		0.69	
U					0.20		0.22	
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr					0.704119		0.704158	
2SE					0.000026		0.000026	
¹⁴³ Nd/ ¹⁴⁴ Nd					0.512881		0.512873	
2SE					0.000010		0.000010	
²⁰⁶ Pb/ ²⁰⁴ Pb					18.5204		18.5209	
2SE					0.0018		0.0018	
²⁰⁷ Pb/ ²⁰⁴ Pb					15.5781		15.5787	
2SE					0.0014		0.0014	
²⁰⁸ Pb/ ²⁰⁴ Pb					38.5170		38.5203	
2SE					0.0044		0.0044	

Appendix (whole-rock chemical compositions)

Sample	1	JMA-V13 36.2m 906-1	20AK3-2-1	20AK3-2-2	20AK3-2-3	20AK3-2-4	20AK3-2-5
Latitude (°N)	39°46'2"	39°46'5"	39°46'28"	39°46'19"	39°46'19"	39°46'19"	39°46'19"
Longitude (°E)	140°48'13"	140°48'25"	140°47'44"	140°48'23"	140°48'23"	140°48'23"	140°48'23"
Stage	II	II	II	II	II	II	II
Unit	Kt-2	Kt-2	Kt-2	Kt-2	Kt-2	Kt-2	Kt-2
Subunit							
Type	Scoria	Scoria	Scoria	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)
<i>Major elements, wt. %</i>							
SiO ₂	57.46	57.55	57.25	56.28	56.48	56.44	55.86
TiO ₂	0.99	0.98	0.97	0.96	0.99	0.98	0.98
Al ₂ O ₃	17.00	16.69	16.36	16.56	16.20	16.18	16.31
Fe ₂ O ₃	10.50	10.14	10.60	10.26	10.56	10.39	10.47
MnO	0.20	0.19	0.19	0.19	0.20	0.19	0.20
MgO	2.66	2.63	2.59	2.52	2.58	2.51	2.61
CaO	7.60	7.75	7.84	8.03	7.85	7.81	7.89
Na ₂ O	3.17	3.07	3.15	3.04	3.09	3.07	3.07
K ₂ O	0.57	0.66	0.64	0.60	0.61	0.63	0.60
P ₂ O ₅	0.15	0.17	0.17	0.16	0.17	0.17	0.16
Total	100.30	99.82	99.76	98.61	98.72	98.36	98.15
LOI	0.74	0.23	-0.04	0.09	0.13	0.13	-0.03
<i>Trace elements, ppm (XRF)</i>							
Sc	39.6	38.6	35.5	33.9	36.8	36.4	34.0
V	255	255	254	248	257	251	250
Cr	4.7	6.5	7.3	6.9	8.0	4.5	10.7
Co	24.0	21.5	21.4	20.5	19.9	19.7	18.5
Ni	2.0	1.4	1.9	2.4	2.4	1.8	3.0
Rb	13.9	13.8	13.2	11.2	11.8	12.5	12.1
Sr	261	262	264	267	266	267	266
Y	26.1	26.7	26.3	25.5	26.1	26.0	25.8
Zr	81.8	80.1	81.0	78.7	81.3	81.2	80.3
Ba	226	217	221	211	216	216	214
<i>Trace elements, ppm (ICP-MS)</i>							
Nb		2.96		2.78			
Cs		0.65		0.57			
La		8.03		7.82			
Ce		19.6		19.1			
Pr		2.67		2.63			
Nd		12.9		12.6			
Sm		3.62		3.52			
Eu		1.17		1.16			
Gd		4.43		4.31			
Tb		0.73		0.72			
Dy		4.89		4.79			
Ho		1.03		1.02			
Er		3.09		3.07			
Tm		0.45		0.44			
Yb		3.01		2.98			
Lu		0.46		0.45			
Hf		2.33		2.35			
Ta		0.16		0.16			
Pb		5.14		4.35			
Th		1.29		1.27			
U		0.46		0.46			
<i>Isotope ratios</i>							
⁸⁷ Sr/ ⁸⁶ Sr		0.704042		0.703994			
2SE		0.000026		0.000026			
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512862		0.512874			
2SE		0.000010		0.000010			
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5138		18.5150			
2SE		0.0018		0.0018			
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5786		15.5810			
2SE		0.0014		0.0014			
²⁰⁸ Pb/ ²⁰⁴ Pb		38.5172		38.5245			
2SE		0.0044		0.0044			

Appendix (whole-rock chemical compositions)

Sample	20AK3-3-1	20AK3-3-2	20AK32-1	805-1	20AK32-2	AK86b-12	20AK36-3.5-1	20AK36-3.5-2
Latitude (°N)	39°46'19"	39°46'19"	39°46'11"	39°46'19"	39°46'11"	39°45'18"	39°45'18"	39°45'18"
Longitude (°E)	140°48'23"	140°48'23"	140°48'33"	140°48'23"	140°48'33"	140°50'6"	140°50'6"	140°50'6"
Stage	II	II	II	II	II	II	II	II
Unit	Kt-2	Kt-2	Kt-2	Kt-2	Kt-2	AK8	AK8	AK8
Subunit								
Type	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria (pfl)	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	56.23	55.79	55.97	58.66	56.26	55.57	52.29	51.97
TiO ₂	0.97	0.95	0.99	0.94	1.05	1.14	0.92	0.93
Al ₂ O ₃	16.59	16.42	16.19	16.42	17.64	15.46	17.84	17.54
Fe ₂ O ₃	10.40	10.20	10.60	10.04	10.20	12.36	11.00	11.50
MnO	0.19	0.19	0.20	0.19	0.21	0.22	0.19	0.20
MgO	2.72	2.72	2.54	2.57	3.01	4.06	3.49	3.85
CaO	8.19	8.04	7.84	7.52	7.99	7.41	9.47	9.45
Na ₂ O	2.89	2.95	3.12	3.03	2.92	2.73	2.58	2.51
K ₂ O	0.61	0.60	0.62	0.64	0.54	0.49	0.41	0.39
P ₂ O ₅	0.16	0.16	0.17	0.16	0.18	0.16	0.14	0.14
Total	98.95	98.01	98.23	100.17	100.00	99.59	98.31	98.47
LOI	0.46	0.29	0.40	0.06	1.56	2.17	1.85	1.68
<i>Trace elements, ppm (XRF)</i>								
Sc	36.3	36.5	35.0	37.0	37.6	48.9	37.6	43.4
V	269	255	254	247	292	350	285	306
Cr	7.9	6.4	6.7	8.9	7.7	26.2	21.8	22.9
Co	22.3	16.7	19.5	20.8	23.7	27.6	20.8	26.8
Ni	3.0	1.8	1.7	3.0	2.0	3.9	4.7	3.7
Rb	12.7	12.3	12.5	13.2	10.8	11.3	7.9	7.0
Sr	264	262	268	250	255	228	265	261
Y	25.8	25.2	26.2	25.8	25.8	24.6	22.1	21.6
Zr	78.6	78.1	82.4	80.9	79.2	78.9	63.7	62.0
Ba	209	204	221	219	199	184	151	159
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								2.11
Cs								0.55
La								5.69
Ce								13.9
Pr								1.98
Nd								9.55
Sm								2.80
Eu								0.97
Gd								3.51
Tb								0.59
Dy								3.94
Ho								0.84
Er								2.53
Tm								0.37
Yb								2.47
Lu								0.38
Hf								1.81
Ta								0.11
Pb								4.00
Th								0.88
U								0.28
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								0.703968
2SE								0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd								0.512877
2SE								0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb								18.5089
2SE								0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb								15.5738
2SE								0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb								38.4984
2SE								0.0044

Appendix (whole-rock chemical compositions)

Sample	20AK3-6-1	20AK3-6-2	20AK3-6-3	20ak36-3-1	ak86b-8	20ak36-3-2	20AK36-3-3	20ak36-2-2
Latitude (°N)	39°46'19"	39°46'19"	39°46'19"	39°45'18"	39°45'18"	39°45'18"	39°45'18"	39°45'18"
Longitude (°E)	140°48'23"	140°48'23"	140°48'23"	140°50'6"	140°50'6"	140°50'6"	140°50'6"	140°50'6"
Stage	II	II	II	II	II	II	II	II
Unit	AK8	AK8	AK8	AK8	AK8	AK8	AK8	AK8
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	55.58	55.16	55.60	53.78	55.08	53.81	52.97	54.85
TiO ₂	0.99	1.00	1.01	0.95	0.98	0.95	0.94	1.02
Al ₂ O ₃	17.20	16.91	16.87	17.16	17.47	16.94	17.08	18.11
Fe ₂ O ₃	10.85	10.66	10.82	11.26	10.99	11.14	11.29	10.96
MnO	0.20	0.19	0.19	0.20	0.20	0.20	0.20	0.19
MgO	2.93	2.70	2.87	3.67	3.09	3.66	3.76	2.74
CaO	7.67	7.86	7.65	8.65	8.70	8.72	8.95	7.43
Na ₂ O	2.83	2.87	2.89	2.75	2.94	2.76	2.67	2.82
K ₂ O	0.54	0.54	0.53	0.45	0.55	0.45	0.44	0.55
P ₂ O ₅	0.16	0.16	0.16	0.15	0.16	0.14	0.15	0.17
Total	98.94	98.05	98.58	99.01	100.15	98.77	98.44	98.83
LOI	1.86	1.44	1.41	0.48	0.37	0.56	0.50	2.90
<i>Trace elements, ppm (XRF)</i>								
Sc	40.6	36.0	33.4	37.7	39.5	40.0	39.0	39.2
V	284	269	274	280	291	279	285	271
Cr	8.5	7.3	7.7	15.6	12.5	15.4	19.3	8.7
Co	22.3	20.4	22.6	25.0	25.6	23.4	23.7	21.4
Ni	3.2	2.5	3.3	5.4	2.5	6.1	5.2	1.7
Rb	10.4	11.3	10.4	8.8	11.2	9.7	9.6	13.2
Sr	253	272	266	260	265	262	261	244
Y	25.2	25.8	24.8	23.6	24.1	23.0	22.9	27.3
Zr	79.4	83.5	82.7	68.4	70.9	68.7	67.3	92.0
Ba	198	208	202	171	191	174	166	189
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			3.02	2.39				3.59
Cs			0.71	0.51				0.53
La			7.59	6.28				8.60
Ce			19.2	15.6				21.1
Pr			2.56	2.21				2.88
Nd			12.2	10.7				13.7
Sm			3.42	3.11				3.82
Eu			1.12	1.05				1.17
Gd			4.17	3.85				4.52
Tb			0.69	0.65				0.75
Dy			4.64	4.29				5.06
Ho			0.98	0.91				1.06
Er			2.94	2.74				3.20
Tm			0.44	0.40				0.47
Yb			2.93	2.67				3.18
Lu			0.44	0.41				0.48
Hf			2.37	2.01				2.60
Ta			0.17	0.13				0.21
Pb			5.05	5.30				6.37
Th			1.43	0.98				1.82
U			0.51	0.32				0.58
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.704023	0.703974				0.704063
2SE			0.000026	0.000026				0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512874	0.512880				0.512847
2SE			0.000010	0.000010				0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5156	18.4751				18.5215
2SE			0.0018	0.0018				0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5817	15.5788				15.5801
2SE			0.0014	0.0014				0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb			38.5280	38.4667				38.5254
2SE			0.0044	0.0044				0.0044

Appendix (whole-rock chemical compositions)

Sample	20ak36-2-3	ak86b-3iwa	ak86b-3	20AK3-4-1	20AK3-4-2	906-6	906-3	1006-15
Latitude (°N)	39°45'18"	39°45'18"	39°45'18"	39°46'19"	39°46'19"	39°46'33"	39°46'29"	39°46'26"
Longitude (°E)	140°50'6"	140°50'6"	140°50'6"	140°48'23"	140°48'23"	140°47'26"	140°47'36"	140°47'40"
Stage	II	II	II	II	II	II	II	II
Unit	AK8	AK8	AK8	AK8	AK8	Kt-1	Kt-1	Kt-1
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	55.58	55.31	54.47	53.95	56.34	54.54	55.09	55.12
TiO ₂	0.98	1.06	1.07	1.04	0.99	0.96	0.98	0.97
Al ₂ O ₃	17.03	17.70	18.13	17.72	16.38	16.22	16.33	16.30
Fe ₂ O ₃	10.63	11.42	11.26	11.37	10.69	10.85	10.78	10.63
MnO	0.19	0.19	0.21	0.19	0.19	0.21	0.22	0.21
MgO	2.81	2.89	2.67	3.08	2.86	3.22	3.31	3.15
CaO	8.21	7.49	7.59	7.65	7.79	8.33	8.13	8.28
Na ₂ O	2.83	2.85	2.63	2.49	2.77	3.11	3.04	3.12
K ₂ O	0.52	0.55	0.53	0.41	0.53	0.44	0.44	0.44
P ₂ O ₅	0.17	0.19	0.18	0.16	0.16	0.14	0.14	0.14
Total	98.93	99.65	98.75	98.05	98.68	98.02	98.44	98.36
LOI	1.05	1.76	2.24	3.29	1.18	-0.16	0.36	-0.23
<i>Trace elements, ppm (XRF)</i>								
Sc	37.7	42.4	45.0	41.8	36.9	39.0		38.8
V	279	269	277	295	288	228		234
Cr	8.8	9.2	6.2	11.7	11.2	8.2		8.3
Co	21.6	27.4	25.9	21.1	19.3	19.6		20.0
Ni	1.2	2.7	2.0	3.2	2.4	1.4		1.4
Rb	11.2	13.6	13.2	8.7	11.1	8.3		8.1
Sr	262	241	248	266	257	245		249
Y	24.9	26.6	25.2	22.7	24.4	25.2		26.1
Zr	77.6	86.5	84.4	81.3	76.7	69.0		69.6
Ba	190	191	187	203	192	158		161
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		3.09						
Cs		0.57						
La		7.61						
Ce		19.5						
Pr		2.67						
Nd		12.9						
Sm		3.71						
Eu		1.16						
Gd		4.43						
Tb		0.74						
Dy		4.88						
Ho		1.03						
Er		3.08						
Tm		0.45						
Yb		3.07						
Lu		0.47						
Hf		2.50						
Ta		0.17						
Pb		6.58						
Th		1.49						
U		0.45						
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.704007						
2SE		0.000026						
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512876						
2SE		0.000010						
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5091						
2SE		0.0018						
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5784						
2SE		0.0014						
²⁰⁸ Pb/ ²⁰⁴ Pb		38.5156						
2SE		0.0044						

Appendix (whole-rock chemical compositions)

Sample	19AK71-1	915-9	915-11	906-2	22ak46	JMA-V13 40.4m	JMA-V13 52.9m	JMA-V13 59.6m
Latitude (°N)	39°46'24"	39°46'1"	39°46'0"	39°46'29"	39°45'58"	39°46'5"	39°46'5"	39°46'5"
Longitude (°E)	140°47'29"	140°47'33"	140°47'38"	140°47'37"	140°48'11"	140°48'25"	140°48'25"	140°48'25"
Stage	II	II	II	II	II	II	II	II
Unit	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1
Subunit								
Type	Lava	Lava	Lava	Lava	Agglutinate	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	55.73	56.32	55.89	53.88	53.81	54.49	55.03	55.17
TiO ₂	0.97	1.00	0.99	1.10	1.06	1.07	1.09	1.09
Al ₂ O ₃	16.35	16.30	16.12	16.06	16.45	16.69	16.36	16.45
Fe ₂ O ₃	10.92	10.75	10.72	12.67	12.34	12.48	12.52	12.42
MnO	0.21	0.22	0.22	0.23	0.22	0.22	0.22	0.22
MgO	3.15	3.14	3.14	3.17	3.46	3.59	3.27	3.19
CaO	7.95	8.00	7.88	8.60	8.80	8.66	8.37	8.26
Na ₂ O	2.95	3.20	3.06	2.95	2.67	2.69	2.80	2.90
K ₂ O	0.41	0.43	0.52	0.35	0.36	0.32	0.28	0.35
P ₂ O ₅	0.13	0.14	0.14	0.12	0.11	0.11	0.11	0.11
Total	98.77	99.49	98.68	99.12	99.27	100.32	100.05	100.16
LOI	-0.02	-0.25	0.80	-0.40	0.54	0.01	0.01	-0.01
<i>Trace elements, ppm (XRF)</i>								
Sc	39.6	43.2	39.9	45.6	49.7	44.6	45.2	45.8
V	239	233	223	321	342	342	322	363
Cr	8.9	5.6	5.5	3.8	10.4	9.7	5.1	5.0
Co	23.5	21.1	19.9	25.7	21.9	29.6	25.9	26.4
Ni	2.0	2.0	1.5	0.8	1.2	2.1	1.3	0.3
Rb	9.5	7.2	11.3	7.3	9.8	7.2	4.9	6.6
Sr	241	251	249	241	233	234	238	234
Y	26.0	27.9	28.1	24.4	26.2	21.2	25.3	25.2
Zr	70.6	72.9	72.8	63.3	57.8	58.6	61.8	61.8
Ba	150	162	163	128	115	127	129	136
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.43							2.03
Cs	0.39							0.24
La	5.66							4.64
Ce	14.9							12.0
Pr	2.13							1.87
Nd	10.6							9.48
Sm	3.23							2.99
Eu	1.07							1.06
Gd	4.11							3.93
Tb	0.71							0.68
Dy	4.74							4.57
Ho	1.01							0.99
Er	3.04							2.99
Tm	0.45							0.43
Yb	2.98							2.91
Lu	0.45							0.44
Hf	2.05							1.89
Ta	0.13							0.11
Pb	3.87							2.54
Th	0.97							0.82
U	0.29							0.23
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704009							0.703969
2SE	0.000026							0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512870							0.512887
2SE	0.000016							0.000013
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5175							18.5036
2SE	0.0018							0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5803							15.5695
2SE	0.0014							0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5190							38.4780
2SE	0.0044							0.0044

Appendix (whole-rock chemical compositions)

Sample	JMA-V13 62.8m 917-9	917-1	917-10	915-8	915-7	915-6	19AK71-13
Latitude (°N)	39°46'5"	39°45'53"	39°45'56"	39°45'53"	39°46'3"	39°46'5"	39°46'26"
Longitude (°E)	140°48'25"	140°47'30"	140°47'22"	140°47'30"	140°47'28"	140°47'22"	140°47'49"
Stage	II	II	II	II	II	II	II
Unit	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1
Subunit							
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>							
SiO ₂	55.02	56.83	57.70	57.41	59.09	59.52	57.27
TiO ₂	1.09	0.90	0.89	0.88	0.96	0.96	1.00
Al ₂ O ₃	16.40	17.35	17.67	17.61	15.53	15.39	15.26
Fe ₂ O ₃	12.18	9.03	9.12	9.15	9.83	9.59	10.59
MnO	0.22	0.18	0.18	0.18	0.22	0.22	0.23
MgO	3.15	2.23	2.23	2.18	2.40	2.39	2.76
CaO	8.58	8.13	8.15	8.10	6.59	6.58	6.95
Na ₂ O	2.97	3.40	3.39	3.32	3.65	3.70	3.39
K ₂ O	0.35	0.51	0.51	0.47	0.61	0.63	0.55
P ₂ O ₅	0.12	0.15	0.15	0.15	0.16	0.16	0.15
Total	100.06	98.70	99.99	99.46	99.02	99.13	98.14
LOI	-0.57	-0.08	-0.36	-0.14	-0.08	-0.48	-0.06
<i>Trace elements, ppm (XRF)</i>							
Sc	43.5	35.1	34.2	35.8	37.5	35.7	37.4
V	320	170	170	166	135	135	175
Cr	4.1	5.8	6.3	5.3	2.1	4.1	4.0
Co	26.5	17.4	19.0	17.0	17.2	16.4	14.6
Ni	0.5	1.6	1.2	1.8	1.1	1.1	1.4
Rb	6.6	10.0	9.6	8.8	13.6	12.9	12.2
Sr	240	259	261	264	247	245	243
Y	24.6	27.9	27.5	28.0	29.7	29.7	28.4
Zr	61.7	77.7	78.2	78.2	87.3	85.9	78.9
Ba	135	171	180	181	209	201	180
<i>Trace elements, ppm (ICP-MS)</i>							
Nb			2.79			3.23	
Cs			0.14			0.34	
La			6.09			8.13	
Ce			16.0			19.8	
Pr			2.31			2.90	
Nd			11.4			14.3	
Sm			3.48			4.16	
Eu			1.18			1.32	
Gd			4.43			5.36	
Tb			0.76			0.91	
Dy			5.06			6.09	
Ho			1.09			1.32	
Er			3.28			3.99	
Tm			0.48			0.58	
Yb			3.22			3.91	
Lu			0.49			0.59	
Hf			2.38			2.68	
Ta			0.16			0.18	
Pb			3.83			5.66	
Th			1.16			1.46	
U			0.33			0.42	
<i>Isotope ratios</i>							
⁸⁷ Sr/ ⁸⁶ Sr			0.703995			0.704026	
2SE			0.000026			0.000026	
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512858			0.512891	
2SE			0.000013			0.000021	
²⁰⁶ Pb/ ²⁰⁴ Pb			18.4937			18.5157	
2SE			0.0018			0.0018	
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5733			15.5757	
2SE			0.0014			0.0014	
²⁰⁸ Pb/ ²⁰⁴ Pb			38.4746			38.5083	
2SE			0.0044			0.0044	

Appendix (whole-rock chemical compositions)

Sample	906-5	804-1	804-2	904-14	1006-14	H26-B1_23.6m	H26-B1_27.9m	909-1
Latitude (°N)	39°46'30"	39°46'26"	39°46'27"	39°46'2"	39°46'26"	39°46'26"	39°46'26"	39°47'12"
Longitude (°E)	140°47'31"	140°47'49"	140°47'48"	140°47'3"	140°47'52"	140°46'52"	140°46'52"	140°46'16"
Stage	II	II	II	II	II	II	II	II
Unit	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	57.59	58.17	58.24	58.81	58.46	55.76	56.21	55.05
TiO ₂	1.00	1.00	1.00	1.00	1.00	0.89	0.87	0.90
Al ₂ O ₃	15.41	15.52	15.53	15.82	15.60	18.29	18.54	17.57
Fe ₂ O ₃	10.39	10.35	10.54	10.37	10.25	9.89	9.32	10.20
MnO	0.23	0.23	0.23	0.23	0.23	0.18	0.17	0.20
MgO	2.76	2.78	2.79	2.80	2.73	2.66	2.24	2.95
CaO	7.01	7.12	7.01	6.98	7.07	8.93	8.96	8.52
Na ₂ O	3.49	3.50	3.41	3.49	3.50	3.05	3.18	3.10
K ₂ O	0.55	0.54	0.55	0.54	0.55	0.43	0.46	0.50
P ₂ O ₅	0.16	0.15	0.15	0.15	0.15	0.12	0.13	0.13
Total	98.59	99.35	99.44	100.19	99.53	100.20	100.07	99.12
LOI	-0.28	-0.38	-0.20	-0.36	-0.53	-0.19	-0.25	0.16
<i>Trace elements, ppm (XRF)</i>								
Sc	39.5	39.2	38.6	39.5	29.0	35.8	32.8	
V	173	174	171	177	213	220	195	
Cr	3.9	3.9	3.1	3.6	7.5	11.2	8.6	
Co	17.4	18.2	18.7	19.6	24.6	21.4	21.4	
Ni	1.0	0.8	0.9	0.8	3.8	1.2	1.0	
Rb	11.8	10.8	11.8	11.1	11.8	8.9	9.1	
Sr	243	246	244	243	280	253	259	
Y	27.2	28.4	28.6	26.9	26.7	24.6	25.3	
Zr	77.5	77.7	78.9	77.7	96.2	68.1	70.0	
Ba	176	177	177	182	225	152	162	
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	AK21-8-(1)	AK21-8-(2)	AK21-9-(1)	830-11	830-13	906-10	JMA-V13 78.2m	JMA-V13 96.9m
Latitude (°N)	39°47'9"	39°47'9"	39°47'15"	39°46'48"	39°46'46"	39°46'37"	39°46'5"	39°46'5"
Longitude (°E)	140°46'28"	140°46'28"	140°46'23"	140°46'57"	140°46'57"	140°47'7"	140°48'25"	140°48'25"
Stage	II	II	II	II	II	II	II	II
Unit	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1	Kt-1
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	56.05	56.34	56.30	52.85	52.28	53.51	54.32	54.18
TiO ₂	0.90	0.90	0.89	0.85	0.84	0.87	0.85	0.86
Al ₂ O ₃	17.80	17.92	17.88	17.34	17.47	17.31	18.27	17.60
Fe ₂ O ₃	9.84	10.05	9.84	10.46	10.70	10.78	9.85	10.43
MnO	0.19	0.20	0.19	0.19	0.19	0.19	0.18	0.20
MgO	2.94	3.03	2.90	3.95	4.47	4.04	3.52	4.11
CaO	8.54	8.51	8.57	9.51	10.00	9.07	9.51	9.43
Na ₂ O	3.09	3.07	3.12	2.80	2.59	2.73	2.87	2.78
K ₂ O	0.51	0.50	0.50	0.44	0.35	0.44	0.42	0.40
P ₂ O ₅	0.14	0.14	0.14	0.12	0.11	0.12	0.12	0.12
Total	99.99	100.65	100.33	98.49	99.02	99.05	99.91	100.09
LOI	0.10	0.18	-0.26	-0.39	-0.35	0.17	-0.40	-0.44
<i>Trace elements, ppm (XRF)</i>								
Sc	36.9	37.6	34.2	42.1	38.2	38.2	35.1	37.6
V	218	222	217	255	245	248	237	249
Cr	10.7	11.6	10.6	54.5	33.1	36.7	29.7	40.1
Co	22.9	23.9	21.9	28.7	22.7	26.7	24.5	28.6
Ni	1.6	2.2	1.7	9.8	6.6	6.6	4.6	6.3
Rb	11.2	11.1	9.6	7.6	7.4	10.7	7.0	8.4
Sr	256	254	259	243	247	238	254	242
Y	25.4	24.9	24.2	20.9	23.0	22.2	22.5	22.6
Zr	63.9	63.5	63.3	52.6	60.2	61.0	60.4	57.2
Ba	163	168	174	127	146	141	142	140
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.40			2.13				
Cs	0.49			0.20				
La	5.82			4.84				
Ce	14.8			12.9				
Pr	2.15			1.85				
Nd	10.6			9.24				
Sm	3.24			2.82				
Eu	1.08			0.95				
Gd	4.08			3.59				
Tb	0.70			0.62				
Dy	4.69			4.16				
Ho	1.01			0.89				
Er	3.06			2.67				
Tm	0.45			0.40				
Yb	2.95			2.63				
Lu	0.45			0.40				
Hf	2.02			1.85				
Ta	0.13			0.12				
Pb	4.15			2.41				
Th	1.09			0.96				
U	0.32			0.28				
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704011			0.704002				
2SE	0.000026			0.000026				
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512881			0.512869				
2SE	0.000010			0.000014				
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5227			18.5143				
2SE	0.0018			0.0018				
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5808			15.5749				
2SE	0.0014			0.0014				
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5266			38.5052				
2SE	0.0044			0.0044				

Appendix (whole-rock chemical compositions)

Sample	JMA-V13 74.8m	20AK34-5	19AK86A-5-1	19AK86A-5-2	ak86a-2	ak86aiwa	20AK34-3	20AK36-1-1
Latitude (°N)	39°46'5"	39°46'43"	39°45'18"	39°45'18"	39°45'18"	39°45'18"	39°46'43"	39°45'18"
Longitude (°E)	140°48'25"	140°49'58"	140°50'6"	140°50'6"	140°50'6"	140°50'6"	140°49'58"	140°50'6"
Stage	II	II	II	II	II	II	II	II
Unit	Kt-1	AK9	AK9	AK9	AK9	AK9	AK9	AK9
Subunit								
Type	Lava	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	54.66	52.66	51.22	51.74	53.57	51.45	53.50	51.98
TiO ₂	0.86	1.16	1.14	1.13	1.10	1.08	1.18	1.08
Al ₂ O ₃	18.06	16.26	17.11	16.70	16.57	15.88	16.05	17.32
Fe ₂ O ₃	10.43	13.06	13.01	12.84	12.80	12.54	13.01	12.36
MnO	0.18	0.25	0.23	0.23	0.23	0.23	0.25	0.22
MgO	3.74	3.44	3.73	3.63	3.67	3.60	3.34	3.39
CaO	9.04	8.14	8.68	8.79	8.73	9.04	8.07	9.19
Na ₂ O	2.80	2.65	2.51	2.55	2.62	2.81	2.77	2.53
K ₂ O	0.36	0.35	0.28	0.30	0.34	0.35	0.36	0.30
P ₂ O ₅	0.12	0.12	0.11	0.11	0.11	0.11	0.12	0.11
Total	100.25	98.10	98.02	98.02	99.74	97.09	98.65	98.48
LOI	0.13	1.51	2.09	1.34	0.18	-0.09	1.11	0.92
<i>Trace elements, ppm (XRF)</i>								
Sc	35.4	49.1	48.7	49.3	48.1	47.8	49.3	45.0
V	241	352	346	352	341	337	343	329
Cr	33.7	5.3	7.7	8.4	9.1	7.5	4.0	8.5
Co	29.1	27.2	30.5	27.5	31.5	31.6	25.6	26.4
Ni	5.7	1.2	1.5	1.4	1.8	1.8	1.2	1.0
Rb	4.7	7.1	6.8	6.3	8.7	7.5	8.7	6.6
Sr	243	224	229	234	243	236	229	247
Y	25.0	25.1	23.9	24.5	22.5	22.3	26.2	22.6
Zr	61.4	65.6	64.4	61.8	58.7	55.9	66.8	60.1
Ba	146	140	107	111	133	136	142	124
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			1.95					
Cs			0.56					
La			4.54					
Ce			11.8					
Pr			1.80					
Nd			9.15					
Sm			2.91					
Eu			1.04					
Gd			3.78					
Tb			0.66					
Dy			4.49					
Ho			0.97					
Er			2.91					
Tm			0.43					
Yb			2.86					
Lu			0.44					
Hf			1.91					
Ta			0.11					
Pb			3.61					
Th			0.76					
U			0.21					
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.703966					
2SE			0.000026					
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512901					
2SE			0.000010					
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5070					
2SE			0.0018					
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5739					
2SE			0.0014					
²⁰⁸ Pb/ ²⁰⁴ Pb			38.4941					
2SE			0.0044					

Appendix (whole-rock chemical compositions)

Sample	20ak36-1-2	20ak36-1-3	22ak85b-1	22ak85b-2	22ak85b-3	22ak85b-4	22ak85b-5	ak86e-7
Latitude (°N)	39°45'18"	39°45'18"	39°45'42"	39°45'42"	39°45'42"	39°45'42"	39°45'42"	39°45'18"
Longitude (°E)	140°50'6"	140°50'6"	140°48'43"	140°48'43"	140°48'43"	140°48'43"	140°48'43"	140°50'6"
Stage	II	II	II	II	II	II	II	II
Unit	AK9	AK9	AK9	AK9	AK9	AK9	AK9	AK10
Subunit								
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	52.03	52.54	53.18	53.67	53.52	54.01	53.60	58.23
TiO ₂	1.13	1.11	1.09	1.07	1.07	1.07	1.11	1.16
Al ₂ O ₃	16.66	16.72	16.62	16.48	16.21	16.66	16.30	14.68
Fe ₂ O ₃	12.90	12.83	12.58	12.27	12.26	12.22	12.37	11.94
MnO	0.23	0.23	0.24	0.22	0.22	0.23	0.24	0.25
MgO	3.57	3.75	3.71	3.56	3.55	3.54	3.24	3.63
CaO	8.64	8.72	8.58	8.95	8.96	8.87	8.53	6.90
Na ₂ O	2.45	2.55	2.60	2.61	2.70	2.55	2.74	3.27
K ₂ O	0.30	0.31	0.32	0.34	0.35	0.34	0.35	0.48
P ₂ O ₅	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.13
Total	98.02	98.87	99.02	99.27	98.96	99.58	98.59	100.66
LOI	0.79	0.79	0.90	-0.06	-0.06	0.27	0.53	0.37
<i>Trace elements, ppm (XRF)</i>								
Sc	49.0	46.8	49.6	50.0	49.1	50.6	50.8	47.4
V	352	344	354	338	350	338	329	253
Cr	7.7	9.8	10.7	8.2	8.0	8.7	5.5	8.2
Co	25.8	27.6	30.5	26.9	25.8	27.2	25.9	29.2
Ni	1.9	2.1	1.0	1.6	1.5	1.7	0.7	1.5
Rb	7.4	7.2	8.9	8.7	9.2	9.1	9.8	10.4
Sr	251	246	224	237	237	235	235	212
Y	23.8	23.3	22.1	23.2	22.6	22.6	23.8	26.3
Zr	63.1	60.1	59.8	58.4	57.2	57.4	62.6	78.8
Ba	139	139	133	122	117	127	135	172
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		1.88					2.04	2.84
Cs		0.39					0.60	0.55
La		4.25					4.74	6.49
Ce		11.4					12.9	16.7
Pr		1.68					1.89	2.41
Nd		8.59					9.60	11.9
Sm		2.72					2.98	3.60
Eu		0.96					1.07	1.20
Gd		3.53					3.94	4.62
Tb		0.62					0.69	0.79
Dy		4.24					4.64	5.33
Ho		0.91					0.99	1.14
Er		2.75					2.98	3.44
Tm		0.40					0.44	0.51
Yb		2.70					2.91	3.38
Lu		0.41					0.44	0.52
Hf		1.81					1.95	2.45
Ta		0.10					0.11	0.15
Pb		3.38					3.62	4.64
Th		0.68					0.74	1.24
U		0.20					0.22	0.36
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.703953					0.703983	0.704032
2SE		0.000026					0.000026	0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512901					0.512897	0.512871
2SE		0.000010					0.000010	0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5017					18.5084	18.5159
2SE		0.0018					0.0018	0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5754					15.5755	15.5783
2SE		0.0014					0.0014	0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb		38.4902					38.4981	38.5130
2SE		0.0044					0.0044	0.0044

Appendix (whole-rock chemical compositions)

Sample	ak86e-5	AK111-32HK	AK111-32AH	AK111-27hs-1	AK111-27sm-2	AK111-23sm	AK111-23sm3	AK111-23sm4
Latitude (°N)	39°45'18"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"
Longitude (°E)	140°50'6"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"
Stage	II	I	I	I	I	I	I	I
Unit	AK11	AK12	AK12	AK12	AK12	AK12	AK12	AK12
Subunit		Y1P	Y1P	Y2P-U	Y2P-U	Y2P-U	Y2P-U	Y2P-U
Type	Scoria	Pumice	Banded pumice	Banded pumice	Banded pumice	Banded pumice	Banded pumice	Banded pumice
<i>Major elements, wt. %</i>								
SiO ₂	52.96	59.12	57.33	57.58	57.45	55.84	55.93	58.20
TiO ₂	0.92	0.75	0.81	0.78	0.83	0.84	0.82	0.77
Al ₂ O ₃	17.61	15.75	16.38	16.40	16.15	17.03	16.45	16.64
Fe ₂ O ₃	10.87	8.16	9.58	9.07	9.39	10.13	9.82	8.54
MnO	0.20	0.19	0.20	0.19	0.20	0.20	0.19	0.18
MgO	4.35	2.87	3.60	3.27	3.40	3.96	3.89	2.96
CaO	9.08	6.10	7.55	7.69	7.32	8.43	7.94	7.26
Na ₂ O	2.75	3.64	3.27	3.11	3.14	2.86	2.84	3.16
K ₂ O	0.40	0.92	0.71	0.72	0.73	0.63	0.66	0.79
P ₂ O ₅	0.12	0.15	0.13	0.13	0.14	0.11	0.12	0.13
Total	99.27	97.65	99.56	98.94	98.73	100.02	98.66	98.63
LOI	1.00	1.24	0.98	0.71	0.96	0.49	1.14	1.47
<i>Trace elements, ppm (XRF)</i>								
Sc	40.1	29.9	35.5	36.9	35.2	35.0	39.7	33.9
V	266	121	177	169	184	230	223	167
Cr	35.8	14.9	22.6	26.6	25.7	31.9	31.6	22.4
Co	30.3	14.5	22.2	17.5	19.2	25.6	24.4	18.9
Ni	7.5	5.6	5.4	3.2	4.8	3.2	3.6	3.3
Rb	9.1	21.7	16.8	17.8	17.7	15.5	16.4	18.8
Sr	233	241	258	243	238	241	234	239
Y	22.5	27.8	25.4	25.6	25.9	22.6	25.0	26.6
Zr	57.8	95.1	72.7	72.1	76.2	64.4	71.5	82.5
Ba	139	276	208	205	207	187	196	225
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.25			3.07				
Cs	0.82			0.59				
La	5.05			7.18				
Ce	13.3			17.2				
Pr	1.97			2.39				
Nd	9.84			11.5				
Sm	3.03			3.36				
Eu	1.03			1.03				
Gd	3.90			4.13				
Tb	0.68			0.71				
Dy	4.55			4.73				
Ho	0.97			1.01				
Er	2.91			3.07				
Tm	0.43			0.44				
Yb	2.84			2.98				
Lu	0.43			0.46				
Hf	1.96			2.23				
Ta	0.12			0.19				
Pb	5.20			5.64				
Th	0.96			1.75				
U	0.28			0.49				
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704000			0.704242				
2SE	0.000026			0.000026				
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512867			0.512798				
2SE	0.000010			0.000010				
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5146			18.5573				
2SE	0.0018			0.0018				
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5777			15.5964				
2SE	0.0014			0.0014				
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5103			38.6051				
2SE	0.0044			0.0044				

Appendix (whole-rock chemical compositions)

Sample	AK111-27khs-1	AK111-27khs-2	AK111sima	AK111smon	AK111-23HKS	AK111-23AKS	AK111-23khs-1	AK111-23khs-2
Latitude (°N)	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"
Longitude (°E)	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"
Stage	I	I	I	I	I	I	I	I
Unit	AK12	AK12	AK12	AK12	AK12	AK12	AK12	AK12
Subunit	Y2P-U	Y2P-U	Y2P-U	Y2P-U	Y2P-U	Y2P-U	Y2P-U	Y2P-U
Type	Banded pumice	Banded pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	58.08	58.08	54.34	53.57	53.99	54.57	52.19	54.42
TiO ₂	0.78	0.83	0.85	0.84	0.86	0.87	0.71	0.84
Al ₂ O ₃	16.05	15.88	16.59	16.35	16.80	16.60	16.23	16.38
Fe ₂ O ₃	9.18	9.37	11.01	10.93	11.00	10.09	10.61	10.45
MnO	0.19	0.20	0.20	0.20	0.20	0.21	0.18	0.20
MgO	3.13	3.18	5.00	4.98	4.79	5.26	6.84	4.31
CaO	7.27	7.17	9.07	9.09	9.12	9.14	8.42	8.95
Na ₂ O	3.21	3.22	2.65	2.65	2.59	2.62	2.39	2.62
K ₂ O	0.78	0.77	0.54	0.54	0.54	0.55	0.52	0.57
P ₂ O ₅	0.12	0.12	0.10	0.10	0.10	0.10	0.08	0.10
Total	98.79	98.81	100.34	99.26	99.98	100.00	98.18	98.85
LOI	1.03	0.83	-0.18	-0.14	0.18	0.18	0.35	0.71
<i>Trace elements, ppm (XRF)</i>								
Sc	33.0	35.3	43.5	41.0	42.0	42.2	32.1	41.3
V	169	175	260	258	270	276	208	256
Cr	20.6	19.1	46.0	45.0	42.4	39.5	54.8	37.8
Co	18.1	18.2	30.1	28.3	26.7	30.0	38.1	26.8
Ni	3.7	3.7	5.3	5.4	4.4	7.0	17.0	3.7
Rb	18.3	17.9	13.5	14.4	12.6	13.7	11.9	14.3
Sr	240	237	235	236	238	234	236	237
Y	26.5	26.6	20.7	21.1	21.3	20.7	20.1	22.7
Zr	75.9	76.7	54.4	55.5	55.8	55.1	54.1	60.5
Ba	222	212	164	157	164	160	161	168
<i>Trace elements, ppm (ICP-MS)</i>								
Nb				2.64			2.25	2.49
Cs				0.44			0.42	0.52
La				6.06			5.27	5.82
Ce				14.5			12.6	14.2
Pr				1.97			1.77	1.99
Nd				9.32			8.52	9.58
Sm				2.67			2.50	2.85
Eu				0.75			0.83	0.92
Gd				3.21			3.11	3.61
Tb				0.55			0.53	0.62
Dy				3.68			3.57	4.13
Ho				0.79			0.76	0.87
Er				2.34			2.26	2.64
Tm				0.35			0.33	0.38
Yb				2.33			2.21	2.57
Lu				0.35			0.34	0.39
Hf				1.83			1.64	1.84
Ta				0.16			0.12	0.15
Pb				4.88			4.18	5.22
Th				1.56			1.22	1.47
U				0.42			0.35	0.40
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr				0.704288			0.704228	0.704209
2SE				0.000026			0.000026	0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd				0.512789			0.512801	0.512822
2SE				0.000010			0.000010	0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb				18.5601			18.5529	18.5516
2SE				0.0018			0.0018	0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb				15.5988			15.5954	15.5934
2SE				0.0014			0.0014	0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb				38.6154			38.5995	38.5926
2SE				0.0044			0.0044	0.0044

Appendix (whole-rock chemical compositions)

Sample	AK111-23sm1	AK111-23sm2	AK111-20kk	AK111-101	AK111-18P-2	AK21-21-pm2	AK21-21-pm3	AK114hg-1
Latitude (°N)	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'23"	39°44'23"	39°44'27"
Longitude (°E)	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°46'42"	140°46'42"	140°47'13"
Stage	I	I	I	I	I	I	I	I
Unit	AK12	AK12	AK12	AK12	AK12	Ku	Ku	Mi
Subunit	Y2P-U	Y2P-U	Y2P-L	Y2P-L	Y2P-L			
Type	Scoria	Scoria	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	52.72	52.50	61.33	63.66	63.44	66.05	63.41	52.35
TiO ₂	0.86	0.88	0.75	0.70	0.67	0.64	0.77	0.91
Al ₂ O ₃	16.29	17.02	16.79	16.80	16.38	15.83	16.55	17.80
Fe ₂ O ₃	11.34	11.20	7.49	6.75	6.52	6.10	7.47	11.45
MnO	0.20	0.20	0.19	0.18	0.17	0.17	0.19	0.20
MgO	4.92	4.66	1.90	1.43	1.27	1.24	1.72	5.57
CaO	9.19	9.10	5.78	4.98	4.71	4.64	5.10	7.96
Na ₂ O	2.39	2.33	3.68	3.92	3.91	4.01	3.68	2.50
K ₂ O	0.50	0.48	0.99	1.07	1.09	1.18	1.01	0.48
P ₂ O ₅	0.10	0.10	0.15	0.16	0.15	0.15	0.16	0.11
Total	98.50	98.46	99.06	99.63	98.31	99.98	100.04	99.32
LOI	0.23	0.95	1.99	2.78	2.81	2.05	2.61	2.62
<i>Trace elements, ppm (XRF)</i>								
Sc	44.3	42.0	28.1	25.7	24.6	25.1		40.6
V	291	288	93.8	62.8	53.4	53.4		256
Cr	42.0	40.1	9.9	5.1	3.9	4.3		63.8
Co	29.4	29.2	10.1	8.5	6.2	9.4		35.8
Ni	5.7	5.5	1.7	2.0	1.6	2.3		20.4
Rb	12.9	11.4	25.2	26.9	26.3	28.1		10.9
Sr	234	237	240	232	239	229		215
Y	21.5	20.9	32.0	33.6	34.5	33.1		20.5
Zr	54.9	57.2	105	114	117	110		58.3
Ba	152	165	270	299	321	317		157
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			4.69		5.34	5.07		2.46
Cs			0.73		0.95	1.50		0.56
La			10.1		11.1	11.1		5.01
Ce			24.6		27.4	26.6		12.8
Pr			3.32		3.63	3.59		1.80
Nd			15.5		16.8	16.6		8.82
Sm			4.33		4.69	4.66		2.69
Eu			1.15		1.34	1.29		0.89
Gd			5.17		5.68	5.61		3.28
Tb			0.88		0.95	0.95		0.57
Dy			5.91		6.37	6.29		3.82
Ho			1.26		1.36	1.35		0.81
Er			3.79		4.08	4.12		2.43
Tm			0.56		0.60	0.61		0.36
Yb			3.75		4.07	4.07		2.40
Lu			0.57		0.63	0.62		0.36
Hf			3.16		3.52	3.48		1.85
Ta			0.29		0.32	0.32		0.14
Pb			8.39		9.51	9.41		5.11
Th			2.85		3.21	3.36		1.26
U			0.73		0.80	0.83		0.35
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.704325		0.704339	0.704318		0.704183
2SE			0.000026		0.000026	0.000026		0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512778		0.512773	0.512778		0.512822
2SE			0.000010		0.000010	0.000010		0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5643		18.5637	18.5639		18.5539
2SE			0.0018		0.0018	0.0018		0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb			15.5998		15.5998	15.5999		15.5930
2SE			0.0014		0.0014	0.0014		0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb			38.6216		38.6226	38.6220		38.5896
2SE			0.0044		0.0044	0.0044		0.0044

Appendix (whole-rock chemical compositions)

Sample	19AK114hg-2	20AK12-1	AK111-13	AK111-13hg	AK111-13hk	AK111-13khs-1	AK111-13hk	AK111-11hg
Latitude (°N)	39°44'27"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"
Longitude (°E)	140°47'13"	140°47'9"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"
Stage	I	I	I	I	I	I	I	I
Unit	Mi	Mi	AK13	AK13	AK13	AK13	AK13	AK13
Subunit			K1P	K1P	K1P	K1P	K1P	K2P
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	55.72	52.97	55.55	57.58	54.44	55.11	54.86	56.67
TiO ₂	0.92	0.91	0.86	0.83	0.85	0.85	0.89	0.83
Al ₂ O ₃	16.77	18.09	16.84	16.81	18.19	16.32	17.46	16.65
Fe ₂ O ₃	11.06	10.54	10.19	9.98	10.17	10.47	10.92	9.95
MnO	0.21	0.19	0.20	0.20	0.20	0.20	0.21	0.20
MgO	4.65	3.91	3.23	3.14	3.29	3.56	4.08	3.32
CaO	7.12	8.40	8.07	8.01	8.46	8.09	8.24	8.17
Na ₂ O	2.81	2.48	2.96	3.04	2.61	2.85	2.56	2.96
K ₂ O	0.64	0.50	0.69	0.75	0.58	0.65	0.57	0.70
P ₂ O ₅	0.11	0.10	0.12	0.11	0.11	0.11	0.12	0.11
Total	100.02	98.08	98.70	100.45	98.90	98.22	99.89	99.57
LOI	1.95	2.30	0.58	-0.28	1.39	0.78	1.63	-0.08
<i>Trace elements, ppm (XRF)</i>								
Sc	40.5	35.4	35.7	34.4	38.4	36.5	34.9	35.5
V	258	252	224	221	243	234	228	236
Cr	44.5	34.4	14.2	13.1	51.9	18.1	20.0	27.5
Co	31.2	26.8	23.4	18.7	26.8	22.5	22.1	26.7
Ni	12.7	12.0	3.3	3.1	6.2	5.8	4.5	9.7
Rb	15.0	11.1	17.5	17.9	15.2	14.5	13.9	9.2
Sr	213	257	270	246	262	250	279	286
Y	22.6	21.7	24.9	23.9	23.1	24.2	23.8	22.2
Zr	68.2	58.9	69.9	66.0	68.3	64.5	67.5	57.5
Ba	196	173	215	194	201	190	190	171
<i>Trace elements, ppm (ICP-MS)</i>								
Nb		2.32		2.99	3.02			2.32
Cs		0.71		0.49	0.43			0.32
La		5.77		7.05	7.05			5.64
Ce		13.5		16.8	16.5			13.2
Pr		2.00		2.31	2.36			1.94
Nd		9.69		11.0	11.2			9.50
Sm		2.84		3.17	3.24			2.84
Eu		0.95		1.01	1.01			1.00
Gd		3.54		3.99	3.95			3.57
Tb		0.60		0.66	0.67			0.61
Dy		3.97		4.48	4.47			4.12
Ho		0.85		0.96	0.95			0.87
Er		2.54		2.86	2.87			2.64
Tm		0.37		0.42	0.42			0.38
Yb		2.44		2.82	2.80			2.56
Lu		0.37		0.43	0.43			0.39
Hf		1.81		2.07	2.14			1.80
Ta		0.14		0.17	0.19			0.13
Pb		5.47		5.77	6.07			3.74
Th		1.27		1.87	2.03			1.02
U		0.34		0.47	0.51			0.30
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr		0.704134		0.704286	0.704254			0.704094
2SE		0.000026		0.000026	0.000026			0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd		0.512816		0.512765	0.512774			0.512844
2SE		0.000010		0.000010	0.000010			0.000012
²⁰⁶ Pb/ ²⁰⁴ Pb		18.5539		18.5708	18.5680			18.5451
2SE		0.0018		0.0018	0.0018			0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb		15.5916		15.6049	15.6031			15.5824
2SE		0.0014		0.0014	0.0014			0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb		38.5871		38.6459	38.6397			38.5448
2SE		0.0044		0.0044	0.0044			0.0044

Appendix (whole-rock chemical compositions)

Sample	AK111-11hk	AK111-100	AK111-9khs	AK111-10khs	AK111-9hk	AK111-4hg	AK111-3khs-1	AK111-3khs-2
Latitude (°N)	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"	39°44'28"
Longitude (°E)	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"	140°49'49"
Stage	I	I	I	I	I	I	I	I
Unit	AK13	AK13	AK13	AK13	AK13	AK13	AK13	AK13
Subunit	K2P	K2P	K2P	K2P	K2P	K3P	K3P	K3P
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
<i>Major elements, wt. %</i>								
SiO ₂	56.67	56.23	55.10	56.30	54.48	56.07	54.45	55.14
TiO ₂	0.83	0.83	0.78	0.81	0.90	0.84	0.81	0.85
Al ₂ O ₃	16.65	17.82	17.11	16.92	19.28	16.85	17.05	16.38
Fe ₂ O ₃	9.95	10.09	9.83	9.79	9.87	10.05	10.30	10.77
MnO	0.20	0.20	0.19	0.19	0.20	0.18	0.19	0.20
MgO	3.32	3.32	3.17	2.96	3.61	4.03	3.54	3.61
CaO	8.17	8.44	8.54	8.09	8.69	8.27	8.83	8.41
Na ₂ O	2.96	2.76	2.74	2.86	2.35	2.94	2.66	2.74
K ₂ O	0.70	0.63	0.64	0.71	0.52	0.70	0.59	0.63
P ₂ O ₅	0.11	0.11	0.10	0.11	0.10	0.11	0.10	0.10
Total	99.57	100.42	98.19	98.74	100.00	100.03	98.51	98.81
LOI	0.35	0.45	0.56	0.41	3.16	-0.24	0.51	0.76
<i>Trace elements, ppm (XRF)</i>								
Sc	37.9	35.4	33.2	31.9	38.4	35.5	38.4	36.3
V	224	227	218	214	219	229	236	250
Cr	24.7	20.1	17.7	13.8	38.9	33.6	20.2	14.4
Co	23.5	24.0	20.2	22.6	22.8	27.2	22.1	23.2
Ni	3.3	3.8	3.7	2.7	5.0	11.8	3.0	3.5
Rb	16.3	16.3	22.2	16.9	13.6	16.1	15.0	15.4
Sr	250	253	250	255	282	253	254	247
Y	23.6	23.3	21.6	24.2	24.9	21.7	21.8	23.3
Zr	66.4	64.8	62.3	67.5	69.8	66.7	58.2	62.2
Ba	196	193	179	201	203	202	173	175
<i>Trace elements, ppm (ICP-MS)</i>								
Nb			2.73		3.01			
Cs			0.56		0.64			
La			6.37		7.11			
Ce			15.4		16.2			
Pr			2.10		2.39			
Nd			10.0		11.3			
Sm			2.91		3.26			
Eu			0.94		1.03			
Gd			3.63		4.03			
Tb			0.62		0.68			
Dy			4.12		4.55			
Ho			0.88		0.97			
Er			2.68		2.90			
Tm			0.39		0.43			
Yb			2.62		2.86			
Lu			0.40		0.43			
Hf			1.91		2.15			
Ta			0.16		0.17			
Pb			5.66		5.78			
Th			1.77		1.89			
U			0.43		0.46			
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr			0.704241		0.704283			
2SE			0.000026		0.000026			
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512780		0.512762			
2SE			0.000010		0.000010			
²⁰⁶ Pb/ ²⁰⁴ Pb			18.5664		18.5673			
2SE			0.0018		0.0018			
²⁰⁷ Pb/ ²⁰⁴ Pb			15.6023		15.6028			
2SE			0.0014		0.0014			
²⁰⁸ Pb/ ²⁰⁴ Pb			38.6349		38.6373			
2SE			0.0044		0.0044			

Appendix (whole-rock chemical compositions)

Sample	AK111-3hk	AK93-3	AK93-3-2	AK92	AK88s	AK91	AK21-7-pfl-1	AK21-7-pfl-2
Latitude (°N)	39°44'28"	39°44'18"	39°44'18"	39°44'18"	39°43'19"	39°44'19"	39°45'34"	39°45'34"
Longitude (°E)	140°49'49"	140°45'41"	140°45'41"	140°45'49"	140°47'46"	140°45'50"	140°45'9"	140°45'9"
Stage	I	I	I	I	I	I	I	I
Unit	AK13	Obo	Obo	Obo	Obo	Obo	Obo	Obo
Subunit	K3P							
Type	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Ob-pfl?	Ob-pfl?
<i>Major elements, wt. %</i>								
SiO ₂	53.88	56.55	53.50	58.27	57.66	57.41	56.03	56.49
TiO ₂	0.87	0.84	0.75	0.88	0.85	0.83	0.85	0.86
Al ₂ O ₃	18.13	17.10	20.02	16.68	16.92	16.91	18.15	17.57
Fe ₂ O ₃	10.65	10.00	9.14	10.23	10.24	10.05	10.02	10.13
MnO	0.19	0.20	0.17	0.20	0.20	0.19	0.19	0.20
MgO	3.41	3.29	3.46	2.92	3.42	3.22	3.32	3.38
CaO	8.58	8.09	9.31	7.49	7.35	7.98	8.01	7.56
Na ₂ O	2.56	2.91	2.52	3.18	2.89	2.92	2.76	2.64
K ₂ O	0.52	0.72	0.49	0.67	0.71	0.71	0.63	0.65
P ₂ O ₅	0.09	0.11	0.11	0.12	0.12	0.11	0.11	0.12
Total	98.88	99.79	99.46	100.63	100.34	100.34	100.08	99.60
LOI	2.48	0.68	1.51	-0.02	1.09	0.09	1.84	1.70
<i>Trace elements, ppm (XRF)</i>								
Sc	37.4	37.5	33.1	37.1	35.5	34.3	35.3	31.9
V	237	229	194	222	229	225	235	229
Cr	16.8	13.8	18.6	5.6	13.9	14.7	20.8	12.6
Co	24.7	23.4	21.0	23.8	22.7	21.5	24.4	23.3
Ni	3.4	3.3	5.9	1.4	3.1	4.0	2.9	3.2
Rb	15.5	17.9	12.7	16.9	17.9	16.9	16.1	17.0
Sr	274	248	276	264	224	242	238	231
Y	23.9	23.3	22.9	26.5	24.0	23.5	23.4	24.9
Zr	66.5	66.3	62.0	74.4	67.0	65.5	68.5	71.5
Ba	194	197	165	221	200	194	183	196
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	AK21-7-pfl-3	22ak89	sabopark	731-12obo?	731-13	19AK89	731-1	731-11
Latitude (°N)	39°45'34"	39°45'34"	39°45'35"	39°44'18"	39°44'18"	39°44'17"	39°44'22"	39°44'19"
Longitude (°E)	140°45'9"	140°45'9"	140°44'28"	140°45'58"	140°45'58"	140°45'57"	140°46'13"	140°46'5"
Stage	I	I	I	I	Odake	Odake	Odake	Odake
Unit	Obo	Obo	Obo	Obo				
Subunit								
Type	Ob-pfl?	Scoria	Scoria	Scoria	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	55.69	56.65	56.17	56.70	54.41	58.15	57.91	58.06
TiO ₂	0.88	0.85	0.83	0.82	0.83	0.84	0.86	0.85
Al ₂ O ₃	17.96	16.82	17.03	16.62	17.16	16.24	15.92	16.03
Fe ₂ O ₃	10.50	9.91	9.99	10.08	10.75	9.85	10.24	9.47
MnO	0.20	0.20	0.19	0.19	0.20	0.20	0.20	0.19
MgO	3.49	3.16	3.50	3.16	3.47	2.83	2.88	2.77
CaO	7.91	8.04	8.14	7.99	9.11	7.49	7.33	7.41
Na ₂ O	2.71	2.94	2.80	2.84	2.68	3.26	3.14	3.17
K ₂ O	0.61	0.70	0.66	0.71	0.54	0.80	0.78	0.79
P ₂ O ₅	0.11	0.11	0.11	0.11	0.09	0.12	0.12	0.12
Total	100.07	99.37	99.42	99.22	99.23	99.77	99.37	98.84
LOI	2.33	0.87	0.91	0.22	-0.38	-0.54	-0.27	-0.26
<i>Trace elements, ppm (XRF)</i>								
Sc	36.7	37.6	36.8	35.9		32.8	35.0	34.0
V	246	238	245	223		210	222	214
Cr	15.7	13.9	19.6	19.3		6.3	6.4	6.2
Co	23.3	20.5	23.3	21.4		22.6	18.8	18.1
Ni	2.4	2.5	3.7	3.9		1.9	2.5	1.6
Rb	16.4	18.5	17.4	17.1		18.9	17.3	17.7
Sr	236	240	232	249		247	238	244
Y	24.3	22.9	23.0	24.7		25.6	25.4	25.3
Zr	68.8	65.2	61.4	66.9		71.6	72.3	71.3
Ba	189	202	180	208		210	212	219
<i>Trace elements, ppm (ICP-MS)</i>								
Nb				3.00				
Cs				0.48				
La				7.04				
Ce				16.8				
Pr				2.30				
Nd				10.9				
Sm				3.11				
Eu				0.99				
Gd				3.85				
Tb				0.65				
Dy				4.41				
Ho				0.93				
Er				2.83				
Tm				0.41				
Yb				2.77				
Lu				0.42				
Hf				2.05				
Ta				0.18				
Pb				5.39				
Th				1.84				
U				0.51				
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr				0.704294				
2SE				0.000026				
¹⁴³ Nd/ ¹⁴⁴ Nd				0.512762				
2SE				0.000010				
²⁰⁶ Pb/ ²⁰⁴ Pb				18.5645				
2SE				0.0018				
²⁰⁷ Pb/ ²⁰⁴ Pb				15.6054				
2SE				0.0014				
²⁰⁸ Pb/ ²⁰⁴ Pb				38.6428				
2SE				0.0044				

Appendix (whole-rock chemical compositions)

Sample	731-3	19AK93-4	19ak94	19AK95	731-15	1014-2	809-2	607-5
Latitude (°N)	39°44'29"	39°44'18"	39°44'13"	39°44'18"	39°44'16"	39°44'16"	39°43'27"	39°43'38"
Longitude (°E)	140°46'24"	140°45'41"	140°45'21"	140°45'20"	140°45'12"	140°46'4"	140°48'4"	140°47'42"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	58.03	58.65	53.57	58.91	57.61	57.43	61.42	52.62
TiO ₂	0.84	0.87	0.82	0.86	0.83	0.87	0.81	0.74
Al ₂ O ₃	16.09	16.26	17.24	16.81	15.95	16.23	17.11	18.47
Fe ₂ O ₃	9.91	10.17	10.64	9.92	9.78	10.44	8.47	9.44
MnO	0.20	0.20	0.19	0.20	0.20	0.20	0.17	0.16
MgO	2.73	2.99	3.41	2.89	2.78	3.00	2.53	3.87
CaO	7.12	7.26	9.19	7.27	7.49	7.62	4.73	9.78
Na ₂ O	3.22	3.19	2.66	3.19	3.19	3.08	3.41	2.62
K ₂ O	0.81	0.77	0.54	0.78	0.79	0.73	1.04	0.49
P ₂ O ₅	0.12	0.12	0.09	0.12	0.12	0.11	0.20	0.10
Total	99.06	100.48	98.35	100.94	98.73	99.71	99.89	98.29
LOI	0.00	-0.02	-0.47	0.05	-0.54	3.06	2.52	0.16
<i>Trace elements, ppm (XRF)</i>								
Sc	31.5	34.2	37.6	36.8	34.2	37.1	24.8	32.1
V	214	229	254	218	211	234	126	218
Cr	7.4	6.7	17.2	6.4	7.5	7.9	5.7	37.6
Co	18.3	23.4	22.5	22.8	17.5	21.9	18.4	27.9
Ni	1.8	1.8	3.2	2.5	2.8	2.0	2.9	9.8
Rb	17.5	17.7	12.6	18.4	16.6	16.8	19.6	9.4
Sr	238	235	250	243	246	240	267	275
Y	25.3	25.7	20.5	25.0	25.3	24.0	28.4	20.4
Zr	72.8	71.0	54.4	72.2	71.2	69.4	117	63.2
Ba	214	212	162	216	213	211	330	164
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	923-11	923-12	923-13	923-15	923-10	923-9	920-5	607-1
Latitude (°N)	39°43'41"	39°43'42"	39°43'43"	39°43'37"	39°43'50"	39°43'50"	39°45'30"	39°44'31"
Longitude (°E)	140°47'26"	140°47'25"	140°47'26"	140°47'40"	140°47'18"	140°47'18"	140°46'1"	140°49'28"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.79	49.67	51.20	52.44	51.53	52.34	53.75	50.13
TiO ₂	0.91	0.88	0.82	0.87	0.92	0.81	0.87	0.77
Al ₂ O ₃	18.60	18.61	18.48	17.98	17.51	19.77	17.51	18.05
Fe ₂ O ₃	11.11	10.87	10.48	10.79	11.11	9.94	10.73	10.76
MnO	0.19	0.18	0.18	0.18	0.19	0.17	0.20	0.18
MgO	4.55	4.83	4.58	4.74	5.12	3.42	4.21	6.60
CaO	9.72	10.76	9.65	9.80	9.09	10.03	8.80	10.52
Na ₂ O	2.64	2.28	2.43	2.45	2.75	2.62	2.96	1.96
K ₂ O	0.34	0.24	0.30	0.45	0.39	0.37	0.42	0.12
P ₂ O ₅	0.11	0.10	0.11	0.10	0.13	0.11	0.12	0.08
Total	99.96	98.42	98.21	99.79	98.73	99.57	99.58	99.16
LOI	-0.36	-0.04	0.65	-0.21	-0.18	0.28	-0.33	0.48
<i>Trace elements, ppm (XRF)</i>								
Sc	34.4	36.7	33.1	36.7	32.8	33.4	35.9	35.7
V	256	269	244	263	254	239	236	247
Cr	32.0	56.2	39.8	56.9	34.5	27.1	27.2	96.5
Co	30.8	30.1	30.1	29.7	33.2	25.8	27.1	37.1
Ni	11.2	16.6	14.7	16.4	16.4	6.7	6.8	36.0
Rb	5.1	4.3	4.7	9.8	6.2	6.1	7.5	1.9
Sr	292	308	281	280	282	291	297	319
Y	20.1	17.1	18.0	18.2	21.4	17.7	21.2	14.5
Zr	47.8	36.7	50.0	46.4	60.9	50.3	56.0	31.1
Ba	151	114	144	144	171	145	152	119
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	607-3	607-4	819-1	819-11	819-7	924-3	924-4	924-1
Latitude (°N)	39°44'38"	39°44'42"	39°44'52"	39°44'44"	39°44'39"	39°43'51"	39°43'52"	39°43'40"
Longitude (°E)	140°49'15"	140°49'10"	140°48'41"	140°48'52"	140°49'0"	140°49'15"	140°49'14"	140°49'22"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	58.76	53.38	50.76	52.68	52.61	50.44	50.48	53.42
TiO ₂	0.80	0.79	0.90	0.81	0.75	0.72	0.84	0.77
Al ₂ O ₃	16.41	17.46	18.13	16.35	16.15	18.33	16.34	17.18
Fe ₂ O ₃	8.40	10.15	11.26	10.42	10.63	11.32	11.93	11.02
MnO	0.17	0.18	0.19	0.18	0.18	0.19	0.19	0.19
MgO	2.79	4.64	5.74	6.14	7.32	5.55	7.86	5.04
CaO	6.54	9.50	9.69	8.87	9.11	10.32	9.04	8.99
Na ₂ O	3.49	2.64	2.42	2.52	2.28	1.93	2.29	2.52
K ₂ O	0.74	0.43	0.20	0.47	0.45	0.24	0.31	0.46
P ₂ O ₅	0.16	0.11	0.10	0.10	0.09	0.08	0.10	0.11
Total	98.27	99.28	99.37	98.54	99.55	99.11	99.37	99.68
LOI	0.64	-0.35	0.62	-0.25	-0.30	0.72	-0.42	-0.07
<i>Trace elements, ppm (XRF)</i>								
Sc	24.2	38.3	34.5	30.7	34.2	42.2	35.9	40.3
V	128	251	240	224	227	274	247	250
Cr	43.3	47.7	80.9	88.2	218	52.4	102	49.0
Co	15.6	29.5	37.5	34.8	41.5	37.1	46.2	33.8
Ni	22.8	7.8	31.2	38.4	91.3	20.1	55.6	10.5
Rb	15.9	8.5	2.2	9.1	9.6	3.8	5.2	8.4
Sr	301	257	313	274	255	234	271	258
Y	24.8	21.3	18.1	19.4	17.1	15.3	17.5	22.0
Zr	93.8	59.5	48.9	60.3	49.8	39.7	42.3	60.7
Ba	252	157	145	184	156	113	130	170
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	924-2	826-1	901-1	901-2	901-3	901-5	901-6	923-17
Latitude (°N)	39°43'42"	39°43'36"	39°43'39"	39°43'42"	39°43'43"	39°43'45"	39°43'50"	39°43'40"
Longitude (°E)	140°49'22"	140°49'9"	140°49'1"	140°48'55"	140°48'43"	140°48'36"	140°48'21"	140°47'44"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.12	51.88	51.14	51.67	51.46	51.39	54.06	51.83
TiO ₂	0.79	0.83	0.83	0.83	0.83	0.82	0.77	0.82
Al ₂ O ₃	16.91	16.83	16.42	16.35	16.35	17.13	15.84	19.40
Fe ₂ O ₃	11.09	11.23	11.07	11.76	11.36	11.16	10.49	10.50
MnO	0.19	0.18	0.19	0.20	0.19	0.18	0.17	0.18
MgO	4.93	6.70	6.82	7.08	6.68	6.87	6.16	4.47
CaO	9.34	9.32	9.30	8.99	9.30	9.83	8.11	9.92
Na ₂ O	2.54	2.36	2.37	2.30	2.42	2.28	2.56	2.50
K ₂ O	0.41	0.33	0.36	0.37	0.38	0.33	0.65	0.23
P ₂ O ₅	0.11	0.10	0.10	0.10	0.10	0.09	0.10	0.11
Total	98.42	99.75	98.60	99.65	99.05	100.08	98.91	99.96
LOI	-0.15	-0.06	-0.03	0.08	-0.23	-0.49	-0.11	0.68
<i>Trace elements, ppm (XRF)</i>								
Sc	38.9	35.7	33.9	35.0	33.6	36.1	31.1	
V	254	246	244	251	247	244	212	
Cr	44.7	129	178	124	122	130	117	
Co	31.5	37.6	38.2	41.3	37.1	39.5	35.0	
Ni	8.2	45.5	79.9	51.4	45.3	47.4	46.0	
Rb	7.4	6.3	5.7	7.2	6.4	6.9	15.7	
Sr	259	273	270	258	267	272	243	
Y	20.8	18.5	17.8	17.6	18.2	16.3	20.1	
Zr	60.9	48.4	47.3	46.2	47.4	41.4	63.6	
Ba	159	145	140	137	149	125	188	
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	829-1	829-6	908-10	908-11	908-12	908-9	806-12	806-13
Latitude (°N)	39°45'29"	39°45'16"	39°45'21"	39°45'22"	39°45'13"	39°45'24"	39°45'27"	39°45'26"
Longitude (°E)	140°47'26"	140°47'21"	140°47'23"	140°47'25"	140°47'14"	140°47'27"	140°46'46"	140°46'43"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	53.22	55.73	52.38	52.23	52.27	54.33	57.16	51.40
TiO ₂	0.87	1.01	0.83	0.83	0.86	0.86	0.77	0.82
Al ₂ O ₃	17.30	15.54	17.96	17.95	17.89	17.56	17.51	17.98
Fe ₂ O ₃	10.83	11.56	10.84	10.59	10.96	10.72	8.28	11.09
MnO	0.19	0.22	0.19	0.19	0.20	0.20	0.15	0.19
MgO	4.15	3.35	4.96	4.76	4.25	3.86	2.94	5.01
CaO	9.01	7.69	9.65	9.62	9.52	9.18	7.80	9.45
Na ₂ O	2.83	3.16	2.59	2.58	2.67	2.73	3.35	2.51
K ₂ O	0.42	0.50	0.29	0.32	0.33	0.41	0.78	0.28
P ₂ O ₅	0.12	0.13	0.11	0.11	0.11	0.11	0.13	0.11
Total	98.95	98.88	99.80	99.18	99.07	99.95	98.87	98.84
LOI	-0.03	0.17	0.00	0.48	0.03	-0.09	0.16	0.26
<i>Trace elements, ppm (XRF)</i>								
Sc	35.3	41.9	36.8	33.1	39.2	37.7	26.8	36.4
V	239	270	237	235	241	243	179	237
Cr	29.7	4.9	60.4	69.9	37.1	24.2	59.6	42.7
Co	27.1	22.9	31.4	30.2	30.6	24.6	21.1	33.4
Ni	6.9	3.1	21.1	28.3	6.2	3.5	27.3	12.2
Rb	7.8	8.4	3.0	5.5	5.0	8.6	13.5	4.6
Sr	304	283	315	320	303	289	290	302
Y	21.7	25.7	19.8	19.2	20.4	21.6	23.7	18.2
Zr	55.8	61.5	47.7	48.4	50.8	52.9	78.0	46.2
Ba	154	167	135	132	140	143	244	135
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	920-5	828-2	828-3	920-4	806-10	806-11	806-5	806-8
Latitude (°N)	39°45'30"	39°45'44"	39°45'44"	39°45'31"	39°45'26"	39°45'26"	39°45'23"	39°45'25"
Longitude (°E)	140°46'1"	140°45'50"	140°45'50"	140°45'58"	140°46'55"	140°46'55"	140°46'43"	140°46'52"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	53.75	51.14	59.93	48.58	54.17	53.69	57.10	51.18
TiO ₂	0.87	0.83	0.91	0.76	0.87	0.87	0.78	0.85
Al ₂ O ₃	17.51	17.84	21.10	17.33	18.14	18.89	17.49	17.47
Fe ₂ O ₃	10.73	11.07	11.48	11.73	9.71	9.87	8.57	10.77
MnO	0.20	0.19	0.20	0.19	0.17	0.18	0.15	0.18
MgO	4.21	4.71	4.67	7.92	2.91	3.04	2.95	5.40
CaO	8.80	9.61	10.19	10.01	9.07	9.24	7.80	9.51
Na ₂ O	2.96	2.59	3.17	1.95	2.95	2.80	3.35	2.61
K ₂ O	0.42	0.29	0.34	0.16	0.55	0.34	0.76	0.35
P ₂ O ₅	0.12	0.11	0.13	0.08	0.13	0.13	0.13	0.12
Total	99.58	98.39	112.11	98.69	98.68	99.03	99.08	98.44
LOI	-0.24	-0.23	-0.24	-0.03	0.24	0.59	-0.09	0.40
<i>Trace elements, ppm (XRF)</i>								
Sc	36.1	35.2		33.6	36.1	35.5	25.4	
V	234	231		271	237	235	183	
Cr	76.9	38.3		170	14.4	17.2	18.3	
Co	29.5	31.5		42.8	21.6	24.6	20.2	
Ni	31.9	11.2		60.3	4.4	4.7	5.8	
Rb	8.0	4.3		1.7	9.6	4.6	14.2	
Sr	297	314		273	289	297	289	
Y	21.2	18.5		13.6	21.4	21.8	24.2	
Zr	56.8	46.7		31.8	63.8	64.9	77.6	
Ba	152	136		80.0	197	200	247	
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	908-3	908-6	801-3	801-7	801-8	801-10	914-1	914-3
Latitude (°N)	39°45'24"	39°45'23"	39°45'5"	39°45'5"	39°45'5"	39°45'4"	39°44'59"	39°44'50"
Longitude (°E)	140°47'3"	140°47'13"	140°46'12"	140°46'35"	140°46'35"	140°46'40"	140°46'7"	140°46'17"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.77	51.64	53.10	53.01	55.80	53.56	53.29	52.53
TiO ₂	0.86	0.88	0.90	0.89	0.84	0.90	0.83	0.83
Al ₂ O ₃	19.67	17.48	18.16	17.25	16.86	18.70	19.07	19.19
Fe ₂ O ₃	9.84	11.82	10.61	10.88	9.88	10.54	9.41	9.74
MnO	0.17	0.19	0.19	0.18	0.17	0.19	0.17	0.17
MgO	3.14	5.85	3.29	4.95	3.92	3.18	3.33	3.93
CaO	10.19	9.34	9.49	9.55	8.13	9.32	9.61	10.18
Na ₂ O	2.71	2.23	2.81	2.61	3.06	2.81	2.75	2.67
K ₂ O	0.33	0.37	0.37	0.44	0.67	0.38	0.43	0.38
P ₂ O ₅	0.11	0.09	0.12	0.12	0.12	0.12	0.12	0.12
Total	98.78	99.88	99.03	99.89	99.44	99.69	99.01	99.73
LOI	0.09	0.63	-0.36	-0.48	-0.34	0.15	0.12	0.01
<i>Trace elements, ppm (XRF)</i>								
Sc	34.1	32.3	38.6	37.0	33.8	34.2	33.4	32.7
V	249	246	255	261	242	246	230	237
Cr	61.2	62.5	15.8	69.2	33.1	16.4	96.2	30.7
Co	25.0	37.6	23.4	31.8	27.9	23.9	25.4	27.5
Ni	35.4	22.2	5.3	20.7	7.6	5.1	44.8	12.3
Rb	4.6	10.4	6.2	9.4	12.9	7.1	7.5	6.9
Sr	325	310	319	274	273	321	295	294
Y	19.1	19.2	20.1	18.4	21.6	20.5	19.3	19.5
Zr	49.1	49.7	52.2	50.2	71.0	53.3	57.1	52.4
Ba	148	142	147	151	219	155	195	147
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	914-3	731-7	807-5	807-8	807-10	807-11	807-12	807-13
Latitude (°N)	39°44'50"	39°44'24"	39°45'17"	39°45'15"	39°45'10"	39°45'9"	39°45'6"	39°44'59"
Longitude (°E)	140°46'17"	140°46'39"	140°48'53"	140°48'58"	140°49'9"	140°49'12"	140°49'14"	140°49'30"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.53	52.28	51.18	59.95	61.28	60.29	60.31	53.88
TiO ₂	0.83	0.82	0.89	0.88	0.84	0.84	0.84	0.75
Al ₂ O ₃	19.19	18.27	18.03	16.25	15.57	15.37	15.43	20.12
Fe ₂ O ₃	9.74	10.11	12.04	9.45	8.89	8.83	8.55	8.33
MnO	0.17	0.18	0.20	0.18	0.17	0.17	0.17	0.14
MgO	3.93	4.05	5.55	2.33	2.14	2.17	2.15	2.72
CaO	10.18	9.58	9.16	6.48	6.34	6.48	6.38	9.84
Na ₂ O	2.67	2.60	2.45	3.39	3.47	3.47	3.45	2.84
K ₂ O	0.38	0.42	0.28	0.82	1.04	1.04	1.04	0.55
P ₂ O ₅	0.12	0.11	0.09	0.14	0.14	0.14	0.13	0.12
Total	99.73	98.41	99.87	99.89	99.90	98.79	98.46	99.28
LOI	0.01	-0.22	0.11	0.77	-0.19	0.01	-0.11	0.13
<i>Trace elements, ppm (XRF)</i>								
Sc	31.8	34.2	33.1	37.9	33.3	33.7	30.6	
V	240	235	258	190	180	176	176	
Cr	126	34.5	29.2	5.2	5.6	5.4	41.4	
Co	30.3	27.0	37.5	20.0	19.3	17.2	16.2	
Ni	65.3	11.6	17.3	1.9	1.9	2.3	20.3	
Rb	8.2	7.4	4.2	17.0	24.9	23.1	24.0	
Sr	295	286	311	244	238	242	242	
Y	18.2	19.1	18.9	30.6	31.7	31.4	28.6	
Zr	51.7	52.9	47.0	108	101	102	104	
Ba	150	154	139	289	294	301	294	
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	730-4	730-7	1001-1	1004-1inc	1004-2	1004-6	829-11	829-10
Latitude (°N)	39°45'25"	39°45'23"	39°45'28"	39°45'16"	39°45'18"	39°45'21"	39°45'25"	39°45'3"
Longitude (°E)	140°48'0"	140°48'9"	140°47'50"	140°48'2"	140°48'8"	140°48'4"	140°47'40"	140°47'35"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	56.23	50.80	55.45	58.06	56.66	56.48	53.44	49.75
TiO ₂	0.91	0.88	0.95	0.84	0.88	0.90	0.89	0.79
Al ₂ O ₃	16.69	17.43	16.93	16.74	16.54	16.44	17.39	19.41
Fe ₂ O ₃	10.01	12.14	10.66	8.95	9.65	9.89	10.93	10.09
MnO	0.17	0.20	0.20	0.16	0.17	0.17	0.20	0.16
MgO	3.46	5.56	3.47	3.22	3.25	3.36	3.98	5.07
CaO	7.60	9.42	8.40	7.27	7.27	7.42	9.02	11.76
Na ₂ O	3.23	2.43	3.09	3.03	3.27	3.30	2.82	1.99
K ₂ O	0.68	0.33	0.48	0.74	0.74	0.70	0.32	0.18
P ₂ O ₅	0.17	0.10	0.14	0.16	0.16	0.17	0.10	0.08
Total	99.15	99.27	99.78	99.19	98.59	98.84	99.09	99.28
LOI	0.31	-0.14	-0.22	0.19	0.76	-0.16	0.04	-0.18
<i>Trace elements, ppm (XRF)</i>								
Sc	30.8	33.4	39.5	28.5	29.7	37.8	36.3	31.7
V	219	245	246	198	218	173	243	242
Cr	9.8	28.0	15.8	10.1	8.3	4.3	26.9	81.1
Co	31.2	37.4	23.2	20.1	24.1	15.5	25.6	30.0
Ni	4.6	16.3	3.6	4.0	4.0	1.0	5.8	19.5
Rb	12.4	5.5	9.5	14.9	15.0	10.2	6.5	2.3
Sr	283	315	308	275	278	247	309	296
Y	27.5	18.3	24.2	31.8	26.5	28.8	27.8	14.5
Zr	95.6	45.3	62.9	106	96.7	78.7	56.4	31.0
Ba	218	134	172	259	238	181	146	82.5
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	905-19	905-20	AK21-17-(1)	920-1	920-2	905-1	905-11	905-12
Latitude (°N)	39°45'36"	39°45'34"	39°45'36"	39°45'33"	39°45'33"	39°45'51"	39°45'45"	39°45'45"
Longitude (°E)	140°47'22"	140°47'26"	140°45'28"	140°45'35"	140°45'37"	140°46'52"	140°47'4"	140°47'6"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	54.26	56.18	54.37	49.51	50.63	51.93	51.33	51.86
TiO ₂	0.98	1.02	0.84	0.76	0.78	0.83	0.80	0.80
Al ₂ O ₃	16.53	15.68	18.19	17.81	17.70	17.74	18.06	18.16
Fe ₂ O ₃	10.95	11.45	10.28	12.17	11.19	10.95	10.76	10.69
MnO	0.21	0.22	0.18	0.19	0.19	0.19	0.19	0.19
MgO	3.46	3.34	4.35	7.84	7.16	4.98	5.09	5.11
CaO	8.34	7.76	8.80	9.87	10.26	9.76	9.62	9.83
Na ₂ O	3.05	3.24	2.81	1.91	2.13	2.65	2.53	2.57
K ₂ O	0.48	0.50	0.42	0.14	0.16	0.31	0.29	0.29
P ₂ O ₅	0.14	0.13	0.12	0.08	0.09	0.12	0.11	0.11
Total	98.39	99.52	100.36	100.26	100.28	99.46	98.77	99.61
LOI	0.17	-0.05	0.55	0.36	-0.47	-0.40	-0.04	-0.34
<i>Trace elements, ppm (XRF)</i>								
Sc	36.8	43.3	32.1	35.4	35.8	36.2	35.1	35.2
V	252	268	228	271	264	232	225	226
Cr	12.3	35.1	29.7	170	190	68.0	68.7	87.3
Co	21.1	25.7	28.9	44.7	40.2	31.5	31.0	30.3
Ni	2.8	17.8	8.1	56.5	65.4	26.4	27.6	34.9
Rb	8.9	8.8	9.3	1.5	1.9	3.9	2.5	4.0
Sr	316	286	296	268	284	324	337	322
Y	23.6	24.9	21.4	12.8	14.7	19.1	18.8	18.1
Zr	62.5	63.2	57.9	31.3	35.1	49.0	46.1	46.3
Ba	177	181	158	74.7	92.2	135	154	132
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	905-15	905-16	905-17	905-2	905-3	905-5	905-6	905-8
Latitude (°N)	39°45'41"	39°45'40"	39°45'39"	39°45'49"	39°45'48"	39°45'47"	39°45'47"	39°45'46"
Longitude (°E)	140°47'14"	140°47'14"	140°47'16"	140°46'53"	140°46'55"	140°46'57"	140°46'57"	140°46'58"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.40	51.75	51.49	52.66	52.36	51.95	52.12	51.57
TiO ₂	0.83	0.82	0.83	0.85	0.83	0.83	0.84	0.82
Al ₂ O ₃	18.64	18.40	18.59	18.04	18.00	17.96	18.15	17.96
Fe ₂ O ₃	10.49	10.50	10.52	11.30	11.02	10.74	10.95	10.92
MnO	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19
MgO	3.93	4.30	3.95	4.83	4.98	4.74	4.65	4.79
CaO	9.52	9.59	9.48	9.30	9.40	9.71	9.55	9.49
Na ₂ O	2.81	2.71	2.73	2.62	2.57	2.63	2.63	2.68
K ₂ O	0.35	0.33	0.33	0.33	0.33	0.33	0.33	0.33
P ₂ O ₅	0.12	0.12	0.12	0.12	0.11	0.12	0.12	0.11
Total	99.27	98.69	98.22	100.24	99.78	99.19	99.52	98.86
LOI	0.04	-0.15	0.44	0.03	-0.21	-0.26	-0.15	0.01
<i>Trace elements, ppm (XRF)</i>								
Sc	34.9	34.4	34.0	34.3	34.5	37.1	33.3	33.6
V	220	222	217	233	233	234	232	231
Cr	26.3	31.6	27.3	38.8	39.3	80.1	35.0	40.0
Co	29.9	27.3	26.4	33.3	34.7	31.1	29.4	30.8
Ni	7.9	8.5	8.4	11.5	11.3	33.1	10.8	10.9
Rb	5.8	5.4	4.6	5.4	6.7	4.8	5.3	5.6
Sr	329	333	351	311	320	328	326	309
Y	19.6	19.7	19.9	19.8	18.5	19.3	18.9	18.9
Zr	52.0	50.2	52.1	50.1	48.4	49.0	48.7	47.8
Ba	153	141	160	140	140	147	149	141
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	905-9	905-4	907-1	907-4	907-5	909-4	1015-1	1015-2
Latitude (°N)	39°45'46"	39°45'48"	39°47'11"	39°46'58"	39°46'51"	39°46'15"	39°46'46"	39°46'23"
Longitude (°E)	140°46'58"	140°46'55"	140°45'48"	140°45'30"	140°45'29"	140°45'51"	140°45'46"	140°45'49"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.89	51.56	58.72	59.88	59.33	60.23	59.58	60.02
TiO ₂	0.82	0.83	0.80	0.79	0.79	0.81	0.82	0.81
Al ₂ O ₃	17.70	17.66	15.22	15.52	15.24	15.65	15.33	15.55
Fe ₂ O ₃	10.99	11.09	8.89	8.76	8.69	8.86	9.18	9.10
MnO	0.19	0.19	0.16	0.16	0.16	0.16	0.16	0.16
MgO	4.95	4.81	3.23	3.10	3.08	3.20	3.29	3.27
CaO	9.71	9.27	7.26	7.11	7.07	6.96	6.68	7.09
Na ₂ O	2.62	2.57	2.94	2.98	3.00	2.95	2.95	2.95
K ₂ O	0.30	0.32	1.07	1.07	1.09	1.07	1.11	1.05
P ₂ O ₅	0.11	0.11	0.11	0.11	0.11	0.10	0.11	0.11
Total	99.28	98.41	98.39	99.47	98.54	99.98	99.20	100.12
LOI	-0.46	-0.08	-0.11	-0.29	-0.40	0.38	0.88	0.14
<i>Trace elements, ppm (XRF)</i>								
Sc	35.2	36.3	29.2	31.1	29.8		32.0	31.1
V	235	238	198	196	192		206	208
Cr	38.4	39.0	22.3	20.2	21.8		20.7	22.9
Co	31.4	30.2	20.9	18.6	18.0		21.8	23.0
Ni	10.8	11.3	6.8	7.4	6.6		7.8	7.0
Rb	4.3	6.2	28.1	28.0	28.1		30.3	26.7
Sr	315	314	228	227	227		212	223
Y	18.7	18.7	27.9	26.5	25.8		26.6	25.7
Zr	48.1	48.4	110	110	111		116	110
Ba	138	167	276	288	279		288	275
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	914-6	914-8	AK21-7-(2)	820-12kai	904-1	904-3	904-5	904-7
Latitude (°N)	39°45'28"	39°45'39"	39°45'34"	39°45'51"	39°46'7"	39°46'6"	39°46'6"	39°46'5"
Longitude (°E)	140°46'5"	140°45'50"	140°45'9"	140°46'48"	140°46'29"	140°46'33"	140°46'40"	140°46'43"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	51.95	52.13	54.33	51.39	53.92	54.28	53.22	54.10
TiO ₂	0.82	0.85	0.89	0.83	0.90	0.93	0.93	0.86
Al ₂ O ₃	17.94	17.84	18.94	17.46	17.58	17.45	17.07	17.77
Fe ₂ O ₃	10.96	11.29	10.33	10.97	10.91	10.79	10.85	10.68
MnO	0.19	0.20	0.19	0.19	0.20	0.20	0.20	0.19
MgO	5.05	5.03	3.25	4.90	4.06	3.72	3.63	4.33
CaO	9.66	9.32	9.23	9.69	8.62	8.65	8.78	8.96
Na ₂ O	2.57	2.59	2.78	2.63	2.93	2.95	3.00	2.85
K ₂ O	0.29	0.28	0.37	0.32	0.42	0.41	0.44	0.43
P ₂ O ₅	0.11	0.12	0.13	0.11	0.13	0.11	0.13	0.12
Total	99.54	99.63	100.44	98.50	99.67	99.49	98.24	100.29
LOI	-0.35	-0.01	0.35	-0.50	0.18	0.01	0.02	-0.24
<i>Trace elements, ppm (XRF)</i>								
Sc	34.8	35.0	36.5	36.7	38.3	37.1	38.0	33.8
V	237	239	248	235	241	246	250	234
Cr	43.3	40.9	14.3	41.1	28.4	20.7	17.7	32.2
Co	33.8	31.0	24.3	31.1	26.3	23.9	23.4	29.3
Ni	11.3	11.8	4.2	11.4	6.7	3.7	3.9	6.9
Rb	4.2	4.7	5.9	5.4	8.1	6.4	7.4	7.2
Sr	327	304	311	315	294	304	305	304
Y	19.4	19.3	19.7	19.3	22.9	22.1	22.8	21.6
Zr	46.3	48.9	51.9	47.7	57.1	58.0	57.0	56.7
Ba	137	133	148	134	158	155	148	154
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	904-12	904-9	820-1	820-10	820-2	820-3	820-4	820-5
Latitude (°N)	39°46'4"	39°46'5"	39°46'7"	39°45'54"	39°46'5"	39°46'3"	39°46'2"	39°46'1"
Longitude (°E)	140°46'52"	140°46'48"	140°46'19"	140°46'43"	140°46'28"	140°46'31"	140°46'35"	140°46'37"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.13	52.33	52.10	52.00	50.87	51.24	51.97	51.85
TiO ₂	0.81	0.83	0.80	0.82	0.79	0.80	0.79	0.83
Al ₂ O ₃	18.27	18.30	18.38	18.34	17.62	18.13	18.11	17.96
Fe ₂ O ₃	10.60	10.66	10.49	10.79	11.22	11.25	10.89	10.92
MnO	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.19
MgO	4.39	4.23	4.89	4.48	5.38	5.05	5.08	4.74
CaO	9.58	9.61	9.67	9.70	9.54	9.44	9.79	9.67
Na ₂ O	2.76	2.76	2.57	2.64	2.53	2.50	2.58	2.63
K ₂ O	0.35	0.34	0.31	0.31	0.28	0.27	0.31	0.30
P ₂ O ₅	0.12	0.12	0.11	0.12	0.11	0.08	0.11	0.11
Total	99.18	99.36	99.51	99.38	98.52	98.95	99.81	99.21
LOI	-0.33	-0.24	-0.03	-0.20	-0.15	0.18	-0.48	-0.40
<i>Trace elements, ppm (XRF)</i>								
Sc	33.8	33.9	33.8	36.4	34.3	35.1	33.9	35.0
V	221	226	222	231	226	223	226	235
Cr	33.1	29.7	96.1	34.3	47.2	43.4	42.5	37.1
Co	30.9	29.3	31.7	31.3	32.4	29.4	32.5	31.9
Ni	9.6	9.0	40.0	9.8	13.3	12.8	12.4	11.0
Rb	6.1	4.2	4.2	5.5	3.9	3.2	4.1	4.5
Sr	318	324	316	315	308	328	313	316
Y	18.9	19.8	19.0	18.9	17.9	18.6	19.2	19.1
Zr	48.7	49.9	46.0	47.4	45.7	46.7	44.2	47.0
Ba	137	153	133	131	128	134	133	136
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	820-8	820-7N	904-20	1006-22	19AK71-5	19AK71-6	AK21-13-(1)	H26-B1_59.8m
Latitude (°N)	39°45'57"	39°45'59"	39°46'6"	39°46'35"	39°46'17"	39°46'14"	39°46'37"	39°46'26"
Longitude (°E)	140°46'40"	140°46'39"	140°46'17"	140°46'13"	140°46'19"	140°46'28"	140°46'12"	140°46'52"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	52.34	51.00	58.45	57.87	58.71	59.79	60.80	60.89
TiO ₂	0.82	0.80	0.81	0.84	0.82	0.79	0.82	0.81
Al ₂ O ₃	18.03	17.80	15.49	15.41	15.46	15.36	15.59	15.66
Fe ₂ O ₃	10.85	10.74	8.98	10.58	9.22	8.73	8.93	8.81
MnO	0.19	0.19	0.16	0.19	0.16	0.15	0.16	0.15
MgO	4.80	4.94	3.33	3.30	3.23	3.05	3.34	3.01
CaO	9.65	9.65	7.17	7.50	6.78	6.63	6.67	6.87
Na ₂ O	2.63	2.56	2.90	2.85	2.86	2.93	2.92	2.85
K ₂ O	0.32	0.32	1.03	0.88	1.04	1.13	1.04	1.03
P ₂ O ₅	0.11	0.11	0.11	0.09	0.11	0.11	0.10	0.13
Total	99.75	98.09	98.42	99.50	98.39	98.67	100.35	100.21
LOI	-0.63	-0.37	0.53	-0.06	0.72	0.64	0.78	1.02
<i>Trace elements, ppm (XRF)</i>								
Sc	35.2	31.7	30.2	38.4	32.4	31.1	31.9	29.2
V	235	220	209	263	211	195	193	206
Cr	39.8	41.7	64.9	15.0	20.9	23.0	24.2	24.3
Co	31.1	31.5	21.7	26.1	22.0	18.8	21.5	23.7
Ni	11.1	11.7	29.3	3.3	6.8	7.4	6.7	6.0
Rb	5.7	4.6	28.6	22.7	27.9	31.6	28.4	29.1
Sr	313	318	221	214	214	214	216	226
Y	18.2	18.8	25.0	25.8	25.8	26.3	25.8	27.0
Zr	47.1	46.2	107	86.9	108	115	113	111
Ba	135	128	268	237	264	285	280	345
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	H26-B1_70.0m	H26-B1_75.9m	H26-B1_78.8m	H26-B1_85.3m	H26-B1_93.8m	H26-B1_96.9m	H26-B1_101.0m	Bor.R3,4.0m
Latitude (°N)	39°46'26"	39°46'26"	39°46'26"	39°46'26"	39°46'26"	39°46'26"	39°46'26"	39°46'46"
Longitude (°E)	140°46'52"	140°46'52"	140°46'52"	140°46'52"	140°46'52"	140°46'52"	140°46'52"	140°45'51"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	60.83	60.47	59.76	61.10	60.51	61.00	60.80	59.85
TiO ₂	0.79	0.82	0.80	0.79	0.79	0.79	0.80	0.79
Al ₂ O ₃	15.84	15.58	15.71	15.77	15.72	15.70	15.64	15.43
Fe ₂ O ₃	8.49	8.87	9.14	8.44	8.65	8.50	8.72	9.00
MnO	0.25	0.16	0.18	0.15	0.15	0.15	0.15	0.16
MgO	2.96	3.18	3.18	3.02	3.08	3.06	3.14	3.13
CaO	7.04	6.79	7.17	6.88	6.89	6.85	6.86	6.82
Na ₂ O	2.98	2.94	2.93	2.99	2.98	2.99	2.99	2.95
K ₂ O	1.08	1.07	1.01	1.08	1.08	1.10	1.07	1.07
P ₂ O ₅	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Total	100.36	99.99	99.98	100.31	99.96	100.26	100.28	99.30
LOI	0.44	0.44	0.07	0.43	0.34	0.30	0.21	0.35
<i>Trace elements, ppm (XRF)</i>								
Sc	29.9	32.9	30.8	30.3	30.1	31.2	30.6	31.3
V	198	207	210	195	196	194	199	196
Cr	23.3	24.6	23.3	22.5	27.1	19.9	22.2	23.4
Co	21.4	22.7	22.1	22.4	22.8	23.4	22.5	22.6
Ni	6.1	7.4	6.7	6.5	7.2	6.4	7.4	7.4
Rb	28.6	29.4	27.8	30.9	27.9	30.6	28.7	30.4
Sr	225	220	225	223	225	222	222	217
Y	26.7	23.7	24.9	24.8	25.7	26.6	25.2	26.3
Zr	111	112	106	113	112	113	112	111
Ba	277	282	271	282	284	288	291	282
<i>Trace elements, ppm (ICP-MS)</i>								
Nb								
Cs								
La								
Ce								
Pr								
Nd								
Sm								
Eu								
Gd								
Tb								
Dy								
Ho								
Er								
Tm								
Yb								
Lu								
Hf								
Ta								
Pb								
Th								
U								
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr								
2SE								
¹⁴³ Nd/ ¹⁴⁴ Nd								
2SE								
²⁰⁶ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁷ Pb/ ²⁰⁴ Pb								
2SE								
²⁰⁸ Pb/ ²⁰⁴ Pb								
2SE								

Appendix (whole-rock chemical compositions)

Sample	Bor.R3,43.9m	Bor.R3,43.9mkoi	Bor.R3,45.8m	Bor.R3,64.0m	Bor.R3,90.2m	22ak74-2	731-10	923-4
Latitude (°N)	39°46'46"	39°46'46"	39°46'46"	39°46'46"	39°46'46"	39°46'49"	39°44'22"	39°44'1"
Longitude (°E)	140°45'51"	140°45'51"	140°45'51"	140°45'51"	140°45'51"	140°46'26"	140°46'31"	140°46'54"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	59.80	60.17	60.05	59.10	59.16	59.40	58.01	55.72
TiO ₂	0.80	0.81	0.80	0.81	0.80	0.80	0.83	0.81
Al ₂ O ₃	15.09	15.30	15.31	15.21	15.69	15.54	16.16	16.65
Fe ₂ O ₃	8.90	8.97	8.86	9.08	8.78	8.76	9.77	10.29
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.20	0.20
MgO	3.07	3.08	3.06	3.14	3.11	3.18	2.76	3.32
CaO	6.74	6.64	6.83	7.11	6.97	6.94	7.30	8.39
Na ₂ O	2.97	2.93	2.92	2.95	2.95	2.96	3.15	2.87
K ₂ O	1.13	1.13	1.12	1.04	1.02	1.06	0.79	0.68
P ₂ O ₅	0.11	0.11	0.11	0.11	0.10	0.11	0.11	0.10
Total	98.76	99.29	99.21	98.70	98.73	98.91	99.08	99.03
LOI	-0.18	-0.20	-0.01	-0.29	0.30	0.55	0.31	-0.17
<i>Trace elements, ppm (XRF)</i>								
Sc	30.9	29.7	28.4	30.4	29.7	32.6	36.9	36.6
V	193	195	198	202	201	205	208	227
Cr	22.0	23.0	24.2	22.9	22.3	23.9	6.9	14.4
Co	21.0	23.0	19.2	19.6	21.5	19.8	20.5	19.3
Ni	8.5	7.8	8.5	7.6	6.6	6.7	2.0	2.9
Rb	31.3	30.0	31.2	28.8	26.7	30.8	19.0	15.7
Sr	221	223	227	225	226	215	242	243
Y	26.3	25.4	25.7	24.8	20.8	25.4	25.3	23.2
Zr	115	114	112	110	108	108	72.3	63.7
Ba	299	304	291	279	287	279	219	191
<i>Trace elements, ppm (ICP-MS)</i>								
Nb							3.38	2.88
Cs							0.50	0.43
La							7.32	6.62
Ce							17.6	15.9
Pr							2.37	2.18
Nd							11.2	10.5
Sm							3.22	3.02
Eu							1.04	0.96
Gd							3.96	3.71
Tb							0.68	0.63
Dy							4.55	4.26
Ho							0.97	0.91
Er							2.94	2.75
Tm							0.43	0.40
Yb							2.89	2.69
Lu							0.44	0.41
Hf							2.27	1.98
Ta							0.20	0.17
Pb							6.17	5.34
Th							2.06	1.73
U							0.51	0.44
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr							0.704301	0.704267
2SE							0.000026	0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd							0.512759	0.512768
2SE							0.000011	0.000010
²⁰⁶ Pb/ ²⁰⁴ Pb							18.5722	18.5686
2SE							0.0018	0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb							15.6074	15.6033
2SE							0.0014	0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb							38.6466	38.6391
2SE							0.0044	0.0044

Appendix (whole-rock chemical compositions)

Sample	819-10	801-2	AK21-16-(1)	AK21-18-(1)	820-11	AK21-12-(1)	22ak74-1	809-1
Latitude (°N)	39°44'26"	39°45'5"	39°45'57"	39°46'5"	39°45'53"	39°46'43"	39°46'49"	39°43'21"
Longitude (°E)	140°49'18"	140°46'11"	140°44'52"	140°45'5"	140°46'45"	140°45'55"	140°46'26"	140°48'4"
Stage	Odake	Odake	Odake	Odake	Odake	Odake	Odake	Odake
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	53.79	52.77	53.28	50.74	51.71	61.36	59.03	50.25
TiO ₂	0.81	0.83	0.85	0.76	0.81	0.81	0.81	0.90
Al ₂ O ₃	16.21	18.78	18.97	17.54	17.75	15.55	15.77	18.27
Fe ₂ O ₃	10.21	9.99	10.02	11.21	10.98	8.62	8.81	11.30
MnO	0.17	0.17	0.18	0.19	0.19	0.16	0.16	0.19
MgO	5.52	3.40	3.59	7.56	4.96	3.13	3.15	4.70
CaO	8.59	9.60	9.46	10.11	9.69	6.74	6.85	9.70
Na ₂ O	2.60	2.79	2.85	2.05	2.56	2.99	2.94	2.58
K ₂ O	0.64	0.44	0.37	0.18	0.30	1.09	1.02	0.32
P ₂ O ₅	0.10	0.12	0.12	0.08	0.11	0.09	0.10	0.11
Total	98.64	98.90	99.69	100.41	99.06	100.53	98.63	98.33
LOI	-0.17	-0.08	0.06	-0.50	-0.43	0.52	1.24	-0.07
<i>Trace elements, ppm (XRF)</i>								
Sc	32.6	32.5	32.1	34.5	38.8	30.2	32.2	34.8
V	222	231	223	266	233	200	202	250
Cr	84.5	23.7	22.7	180	39.3	19.8	22.2	33.3
Co	34.3	24.4	25.9	40.6	32.3	21.3	21.4	30.0
Ni	32.5	7.2	6.9	58.8	11.7	6.1	6.9	11.3
Rb	13.8	7.6	5.9	2.9	4.3	29.8	29.4	4.6
Sr	258	293	324	272	311	219	216	296
Y	19.7	19.6	19.9	13.9	17.2	27.3	25.3	20.8
Zr	61.3	56.3	51.1	31.3	45.2	114	109	47.7
Ba	194	162	149	96.5	130	288	274	135
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	2.50	2.55	2.16	1.30	1.90	4.19	4.10	1.61
Cs	0.59	0.14	0.13	0.12	0.15	1.58	1.38	0.23
La	5.64	5.43	5.11	2.77	4.40	9.71	9.56	4.27
Ce	13.7	13.3	12.8	7.34	11.2	23.5	24.1	10.8
Pr	1.93	1.85	1.86	1.09	1.63	3.10	3.06	1.63
Nd	9.21	8.93	9.22	5.63	8.16	14.2	13.9	8.32
Sm	2.63	2.60	2.71	1.76	2.44	3.81	3.78	2.60
Eu	0.81	0.88	0.96	0.68	0.87	0.92	0.93	0.92
Gd	3.15	3.18	3.37	2.20	3.03	4.48	4.37	3.36
Tb	0.53	0.53	0.57	0.38	0.51	0.74	0.73	0.57
Dy	3.50	3.59	3.77	2.50	3.40	4.96	4.82	3.85
Ho	0.74	0.76	0.80	0.53	0.72	1.04	1.01	0.82
Er	2.22	2.30	2.39	1.57	2.17	3.15	3.07	2.47
Tm	0.32	0.34	0.35	0.23	0.32	0.46	0.45	0.36
Yb	2.12	2.23	2.32	1.53	2.09	3.08	3.00	2.35
Lu	0.32	0.34	0.35	0.23	0.32	0.47	0.45	0.35
Hf	1.93	1.69	1.65	1.01	1.45	3.55	3.39	1.51
Ta	0.15	0.14	0.11	0.06	0.10	0.26	0.26	0.09
Pb	4.97	4.07	4.78	2.56	2.80	8.00	6.36	3.17
Th	0.86	0.85	0.62	0.28	0.51	3.12	3.01	0.63
U	0.39	0.26	0.20	0.09	0.16	0.83	0.79	0.19
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704179	0.704223	0.704112	0.704194	0.704120	0.704249	0.704243	0.703936
2SE	0.000026	0.000026	0.000026	0.000026	0.000026	0.000026	0.000026	0.000026
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512812	0.512818	0.512841	0.512858	0.512863	0.512820	0.512818	0.512874
2SE	0.000012	0.000013	0.000017	0.000015	0.000015	0.000010	0.000010	0.000014
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5588	18.5413	18.5164	18.5215	18.5189	18.5542	18.5559	18.5270
2SE	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5920	15.5781	15.5696	15.5820	15.5715	15.5945	15.5967	15.5679
2SE	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
²⁰⁸ Pb/ ²⁰⁴ Pb	38.5962	38.5255	38.4895	38.5356	38.4948	38.6037	38.6107	38.4817
2SE	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044

Appendix (whole-rock chemical compositions)

Sample	1001-6	808-1	808-2	808-6	818-4	805-3	805-4	805-5
Latitude (°N)	39°45'25"	39°46'43"	39°46'43"	39°46'55"	39°47'15"	39°46'30"	39°46'34"	39°46'34"
Longitude (°E)	140°47'47"	140°48'2"	140°48'1"	140°47'26"	140°47'54"	140°48'14"	140°48'13"	140°48'13"
Stage	Odake	Sasamori	Sasamori	Sasamori	Sasamori	Sasamori	Sasamori	Sasamori
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava	Lava	Lava
<i>Major elements, wt. %</i>								
SiO ₂	49.26	62.77	60.33	63.23	56.00	58.91	58.21	57.92
TiO ₂	0.86	0.71	0.75	0.70	0.85	0.86	0.87	0.86
Al ₂ O ₃	16.96	15.66	15.79	15.88	16.49	16.26	15.42	15.60
Fe ₂ O ₃	11.82	7.52	8.42	7.22	10.58	8.93	10.71	10.51
MnO	0.20	0.16	0.14	0.15	0.21	0.16	0.20	0.20
MgO	6.50	2.71	3.75	2.45	3.41	3.45	3.36	3.28
CaO	10.04	6.00	6.90	5.91	7.77	7.18	7.29	7.38
Na ₂ O	2.31	3.16	2.91	3.44	2.81	2.60	2.96	2.96
K ₂ O	0.27	1.21	1.23	1.06	0.56	0.98	0.81	0.80
P ₂ O ₅	0.10	0.12	0.11	0.13	0.10	0.11	0.10	0.10
Total	98.32	100.01	100.32	100.18	98.77	99.44	99.91	99.60
LOI	-0.28	0.49	0.38	0.31	0.37	1.86	-0.10	-0.13
<i>Trace elements, ppm (XRF)</i>								
Sc	34.2	24.9	24.9	23.6	36.5	35.4	39.1	37.1
V	252	136	185	133	217	232	225	233
Cr	147	18.2	32.4	13.3	4.6	19.4	13.4	6.8
Co	37.3	18.6	23.3	17.2	20.0	23.4	23.6	22.5
Ni	38.9	6.3	15.2	5.3	1.5	6.3	2.7	2.1
Rb	4.6	29.8	32.6	24.2	11.3	23.6	21.0	18.1
Sr	318	237	235	253	285	226	227	240
Y	18.0	31.0	27.4	31.5	22.6	24.2	24.9	24.0
Zr	39.3	115	115	116	67.2	93.4	79.5	69.1
Ba	120	356	308	313	211	230	213	215
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	1.29							
Cs	0.13							
La	3.54							
Ce	8.87							
Pr	1.35							
Nd	6.98							
Sm	2.14							
Eu	0.79							
Gd	2.65							
Tb	0.45							
Dy	2.99							
Ho	0.64							
Er	1.91							
Tm	0.27							
Yb	1.81							
Lu	0.27							
Hf	1.21							
Ta	0.07							
Pb	4.26							
Th	0.29							
U	0.17							
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.703910							
2SE	0.000026							
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512896							
2SE	0.000010							
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5298							
2SE	0.0018							
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5673							
2SE	0.0014							
²⁰⁸ Pb/ ²⁰⁴ Pb	38.4846							
2SE	0.0044							

Appendix (whole-rock chemical compositions)

Sample	805-6	728-1	803-4	803-5	22ak65	729-4	JB-3	JB-3 ^a
Latitude (°N)	39°46'16"	39°46'28"	39°47'2"	39°47'0"	39°46'2"	39°47'29"		
Longitude (°E)	140°48'29"	140°48'43"	140°47'13"	140°47'15"	140°48'47"	140°50'44"		
Stage	Sasamori	Sasamori	Sasamori	Sasamori	Yunomori	Zarumori	This study	Reference
Unit								
Subunit								
Type	Lava	Lava	Lava	Lava	Lava	Lava		
<i>Major elements, wt. %</i>								
SiO ₂	64.96	53.54	54.15	54.61	52.74	53.08	50.75	50.71
TiO ₂	0.67	0.92	1.04	1.05	0.72	0.85	1.43	1.43
Al ₂ O ₃	14.69	16.42	17.50	17.67	17.43	16.87	17.13	17.12
Fe ₂ O ₃	6.72	11.77	10.49	10.82	10.26	10.54	11.90	11.87
MnO	0.13	0.20	0.21	0.23	0.18	0.19	0.18	0.18
MgO	2.02	3.81	3.06	3.13	5.30	4.42	5.13	5.16
CaO	5.34	8.96	8.48	8.35	9.88	9.12	9.67	9.74
Na ₂ O	3.42	2.48	3.19	3.21	2.20	2.51	2.77	2.72
K ₂ O	1.47	0.60	0.48	0.48	0.45	0.52	0.76	0.78
P ₂ O ₅	0.10	0.09	0.18	0.18	0.08	0.11	0.29	0.29
Total	99.51	98.80	98.78	99.71	99.22	98.19	100.00	100.00
LOI	0.08	-0.24	0.15	-0.01	0.42	-0.08		
<i>Trace elements, ppm (XRF)</i>								
Sc	25.2	40.3	32.7	34.0	45.5	35.0	34.8	33.8
V	131	283	199	202	263	242	383	372
Cr	14.7	15.9	4.4	5.5	78.4	45.9	59.3	58.1
Co	15.6	24.8	19.9	20.7	33.3	27.5	38.6	34.3
Ni	4.3	4.3	3.6	3.3	10.0	14.7	38.2	36.2
Rb	38.1	13.0	8.6	10.3	10.0	10.9	16.6	15.1
Sr	194	249	329	326	229	269	407	403
Y	35.4	22.8	23.2	24.3	19.3	20.3	23.7	23.7
Zr	138	61.7	70.1	69.9	54.8	58.2	86.4	86.2
Ba	366	158	174	214	166	162	242	245
<i>Trace elements, ppm (ICP-MS)</i>								
Nb	4.77						1.87	1.87
Cs	0.76						0.92	0.93
La	13.7						8.11	8.14
Ce	33.3						20.7	20.8
Pr	4.55						3.15	3.15
Nd	20.4						15.6	15.6
Sm	5.38						4.25	4.27
Eu	1.08						1.30	1.30
Gd	6.25						4.72	4.72
Tb	1.03						0.74	0.74
Dy	6.78						4.64	4.65
Ho	1.43						0.95	0.94
Er	4.29						2.76	2.77
Tm	0.63						0.39	0.39
Yb	4.17						2.58	2.58
Lu	0.63						0.39	0.39
Hf	4.42						2.65	2.64
Ta	0.32						0.13	0.13
Pb	8.26						5.00	4.92
Th	4.65						1.30	1.31
U	1.13						0.48	0.48
<i>Isotope ratios</i>								
⁸⁷ Sr/ ⁸⁶ Sr	0.704273						0.703412	(n=155) ^b 0.703410
2SE	0.000026						0.000024	
¹⁴³ Nd/ ¹⁴⁴ Nd	0.512798						0.513064	(n=92) ^b 0.513069
2SE	0.000010						0.000010	
²⁰⁶ Pb/ ²⁰⁴ Pb	18.5573						18.2971	(n=92) ^b 18.2987
2SE	0.0018						0.0016	
²⁰⁷ Pb/ ²⁰⁴ Pb	15.5982						15.5397	15.5406
2SE	0.0014						0.0016	
²⁰⁸ Pb/ ²⁰⁴ Pb	38.6194						38.2562	38.2575
2SE	0.0044						0.0044	

^a Major elements and Sc, V, Cr, Co, Ni, Rb, Sr, and Ba contents are from Imai et al. (1995).

Zr, Nb, Hf and Ta contents are from Lu et al. (2007), Y and other trace element content are from Yokoyama et al. (2017).

⁸⁷Sr/⁸⁶Sr ratio is from Miyazaki and Shuto (1998), ¹⁴³Nd/¹⁴⁴Nd ratio is from Makishima et al. (2008), and Pb isotopic ratios are from Kuritani and Nakamura (2003).

The ⁸⁷Sr/⁸⁶Sr ratio of Miyazaki and Shuto (1998) and ¹⁴³Nd/¹⁴⁴Nd ratio of Makishima et al. (2008) were normalized for NITS987 to be 0.710240 and Jndi to be 0.512117, respectively, for direct comparison with the result of this study.

^b The long-term average of the replicate analyses in my laboratory.