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論文内容の要旨

This study aims to elucidate the evolutional process of the complex interaction between magma and hydrothermal system, focusing on the ash petrology of non-juvenile eruption products in geologic successions from multiple volcanoes. Petrological observation of individual ash grains was carried out for the following cases: (1) Holocene volcanic products from Tokachidake volcano (4.7ka, 3.3ka , and 1926AD) (Chapter 1); (2) volcanic ash from the 2014 hydrothermal eruption of Ontake volcano (Chapter 2); (3) Holocene volcanic tephra layers around 1331AD from Azuma-Jododaira volcano (Chapter 3). As a result, the conclusive remarks below were obtained.

(1) Holocene volcanic products from Tokachidake volcano (4.7ka, 3.3ka, and 1926AD) (Chapter 1): Each sample of ash grains underwent alteration to various degrees from unaltered to intensely altered. Alteration was categorized into silica type (only silcia), alunite type (silica+alunite±kaolin group mineral), and kaolin type (silica+kaolin group mineral). All of the altered ash grains are derived from the acidic alteration zone in subvolcanic hydrothermal system of Tokachidake. The hydrothermal alteration was caused by the acid-sulfate-chloride hydrothermal fluid formed by volcanic vapor that separated from the intruded magma. The rock textures of the weakly altered ash grains were formed by acidic hydrothermal fluid-rock interaction at open-flow through-system. The reaction process is explained by that a large amount of acidic hydrothermal fluid passes through and reacts with the rocks. The brief, incomplete, acidic hydrothermal alteration was caused by the Tokachidake subvolcanic hydrothermal system temporally formed with a magma intrusion.

(2) Volcanic ash from the 2014 hydrothermal eruption of Ontake volcano (Chapter 2): The petrographical and mineralogical study of ash grains from the 2014 Ontake volcano hydrothermal eruption resulted in the discovery of previously undescribed minerals in an active volcano. Aluminum-phosphate-sulfates (APS) minerals (woodhouseite), Zn-sulfide, and monazite were found in this ash grains. The discovery of woodhouseite in the volcanic ash of the Ontake 2014 hydrothermal eruption represents the first reported presence of these minerals within an active volcano. Furthermore, two types of woodhouseite were observed: zoned alunite-woodhouseite-APS and micro-wormy vein woodhouseite-APS. The genetic environment of APS minerals is proposed to be highly acidic hydrothermal fluids existing beneath the volcanic summit, formed by condensation with magmatic volatiles exsolved from the magma chamber underneath Ontake volcano. Under these conditions, an advanced argillic alteration assemblage formed, consisting of silica, pyrophyllite, alunite, and kaolinite/dickite, plus APS, among other minerals. Further detailed studies might prove that the presence of APS at Ontake is not an exception, but likely commonplace among such active volcanoes. These characteristics are an obvious similarity with the epithermal-porphyry environments.

(3) Holocene volcanic tephra layers around 1331AD from Azuma-Jododaira volcano (Chapter 3): This study found eight tephra layers below, L1-1, L1-2, L2, L3, L4, L5, L6 and L7 from bottom to top. L1-1 and L1-2 were corelated with Az-OA unit (1331AD eruption), and L3 and L4 are corresponded layers from 1711AD eruption. For all samples from the eight layers, XRD and microscopic observation (binocular-stereoscopic microscope and SEM-EDS) had clarified the tendency of componentry change. L1-1, L1-2, L5, L7 are characterized by the X-ray peak of both 14Å-smectite and 7Å-kaolin or either of them, and by abundance of ash grains categorized into partly altered volcanic rock (PAVR), massive altered rock (MAR), and dense volcanic rock (DVR). While, L2, L3, L4, L6 are characterized by the X-ray peak of intense igneous minerals (plagioclase and pyroxene) with the disappearance (or decrease) of 14Å-smectite and 7Å-kaolin, and by abundance of unaltered ash grains as dense volcanic rock (DVR) and vesicular volcanic rock (VVR). Alterations in all samples are classified into acidic to neutral hydrothermal alterations, which are silica type (silica+titanium oxide±pyrite), pyrophyllite type (silica+pyrophyllite±alunite), kaolin type (silica+kaolin mineral±alunite), alunite type (silica+alunite), mica-chlorite type (silica+illite+sericite±chlorite±biotite), chlorite type (silica+chlorite±epidote) and mica-K-feldspar type (silica+chlorite+bioite+K-feldspar). Only L1-1 and L1-2 samples contain altered ash grains of all sets of the above alterations. Other samples than L1-1 and L1-2 indicated alterations of silica, alunite, kaolin, and pyrophyllite types with minor mica-chlorite type. Furthermore, some samples richly contain VVR-andesitic scoria or scoriaceous fragment (especially in L2), DVR-blocky highly crystalline andesitic lava and DVR-blocky holocrystalline andesitic rock (L4, L5, and L6). These ash grains (VVR-scoria) are possible to be an essential juvenile material.

From these componentry trends, Jododaira volcano of Azuma volcano group seems to repeat the hydrothermal eruption derived from a well-developed subvolcanic hydrothermal system (L1-1, L3, L5, and L7) or the magmatic hydrothermal eruption with fragmentation of the hydrothermal alteration zone and an intruded magma (L1-2, L2, and L6).

From these observations, this study defines three types of subvolcanic hydrothermal systems within active volcanoes: Tokachidake-type, Ontake-type, and Azuma-Jododaira-Type. Tokachidake type of subvolcanic hydrothermal system are directly driven by a magma intrusion, which accompanies the chemical and physical modification of the hydrothermal system. Ontake type is a well-developed and mature subvolcanic hydrothermal system similar to the epithermal-porphyry system. Finally, Azuma-Jododaira type is a subvolcanic hydrothermal system with repetitions of magmatic and non-juvenile eruptions. The above three types could be considered as the evolutional series of a subvolcanic hydrothermal system, corresponding to the very-early stage of the epithermal-porphyry system. Through initial (Tokachidake-type) and middle (Azuma-Jododaira type) stages, with various degrees of magma intrusion or eruption, the subvolcanic hydrothermal system evolves into the stable stage defined as Ontake-type during the ore-forming process in volcano.

論文審査結果の要旨

本研究は、火山噴出物中の非本質物質に注目し、その岩石・鉱物学的な分析を基に噴火機構、準備過程、噴火発生場等を解明することを目的したものである。十勝岳火山、御嶽火山、吾妻浄土平火山を事例フィールドとし、それらの火山において野外での地質産状記載と試料採取を実施し、採取試料の分析・解析を行った。十勝岳では大正噴火噴出物と完新世の複数の火砕流堆積物を、御嶽山については 2014 年水蒸気噴火噴出物をそれぞれ採取した。吾妻浄土平火山については、14 世紀と考えられる大穴火口噴火以降の複数の堆積物について、新たに層序確立を図るとともに、試料採取を行った。これらの試料にふくまれる火山灰粒子、非本質物質からなる火山灰の岩石、鉱物、地質産状に着目した固体物質科学的研究を行った。いずれの火山の非本質物質も、変質鉱物が特徴的に含まれる。十勝岳噴出物では強変質岩、弱変質、未変質火山灰が含まれシリカ鉱物、ミョウバン石が主要な変質鉱物である。不完全な酸性変質が一般的であることから、酸性流体による短時間の流通系変質作用が主要であると考えた。この現象の解釈として、頻繁にマグマが貫入することにより短期間のみ熱水系が形成され、そのマグマ由来の流体に起因する酸性変質が生じたものとした。一方、御嶽山 2014 年噴出物は斑岩銅－浅熱水鉱床系に類似する熱水系に由来すると考えた。御嶽山の火山噴出物中からは、鉱床産のものに類似する APS 鉱物を発見した。これは火山灰からの記載としては初めてのものである。吾妻－浄土平火山にて大穴噴火以降の層序に従う鉱物組成変化を調査したところ、御嶽山のように珪化、粘土化、カリ

の多様な変質帯に由来するテフラ層があり、累帯変質に由来数する変質火山灰が認められる一方、少量の高度粘土化変質を伴うものの未変質火山灰を主体とするテフラ層も認められた。これは、御嶽山で認められるような累帯変質を形成する熱水系に由来する噴火が発生する一方、貫入マグマの影響を強く受けた噴火が生じる時期もあり、吾妻浄土平火山は十勝岳火山と御嶽火山 2014 年噴火の中間的な状態であるものと考察した。以上の事例から、火山灰の鉱物学的特徴は、マグマの貫入頻度や熱水系の発達と強く関連していることを結論づけた。また、いわゆる水蒸気噴火がどのような機構で発生するかについて、本論文で得られたデータを基に議論した。

本研究の内容は、すでに査読付き学術雑誌の論文として 2 編（地質学雑誌、Minerals）を出版している。予備審査で指摘された英語の不備や、噴火の原因に関する議論も修正・追加されている。本論文は、博士論文として十分なレベルに到達していると判断できる。