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Links between arc volcanoes and porphyry-epithermal ore deposits

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ABSTRACT

Porphyry and epithermal ore deposits, which are the products of magmatic hydrothermal fluids, are intimately associated with volcanoes in continental and island arcs above subduction zones, but the exact nature of this relationship has remained enigmatic. Although metal deposition is usually thought to occur during the waning stages of volcanism, numerous ore deposits have been demonstrated to be syn-volcanic. Here we show how the formation of these deposits is tied to volcanic cycles. We relate the chemical variations in vapors from Merapi volcano, Indonesia, to different stages of its eruptive cycle. The chemical compositions of volcanic vapors from subduction zone volcanoes are then compared globally to those of fluid inclusions from porphyry-epithermal deposits. These data show that adiabatic decompression is the principal control on mineralization. They also suggest that volcanic and sub-volcanic magmatic-hydrothermal systems are under lithostatic pressure during quiescence but decompress rapidly during injections of mafic magma and explosive eruptions. During quiescence, the magma evolves through fractional crystallization and devolatilization, gradually

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becoming oxidized and enriched in gold and other incompatible metals. Upon the injection of sulfur-rich mafic magmas, subvolcanic intrusions brecciate the overlying rocks, the systems are depressurized, the volcanoes erupt explosively, supercritical fluids unmix into vapor and brine, and base metal sulfides precipitate.

INTRODUCTION

Magmatic-hydrothermal ore deposits form over periods ranging from thousands to millions of years (Sillitoe, 2010), a generally shorter lifespan than that of arc volcanoes which are thought to usually remain active for millions of years (Newhall et al., 2000). Although the economic mineralization is usually considered to postdate volcanism (Williams-Jones and Heinrich, 2005), numerous ore deposits have been shown to be genetically associated with volcanism (Hattori and Keith, 2001) or even interrupted by episodes of renewed magmatic activity (Maughan et al., 2002). Interestingly, the injection of sulfur-rich mafic magmas into shallow porphyry stocks appears to trigger explosive eruptions (Eichelberger, 1980) and generate ore deposits (Hattori and Keith, 2001). This paper reports data on the distribution of metals, sulfur and chlorine in volcanic vapors collected at Merapi volcano during a phase of quiescent degassing in 2004 and after a large explosive eruption in 2006, and compares them to data reported for volcanic vapors globally and for fluid inclusions from porphyry deposits. These data and comparisons provide the first convincing evidence that injections of mafic magma (which commonly coincide with explosive volcanic eruptions) are followed by decompression of the magmatic hydrothermal system, inducing fluid phase separation, rapid cooling and the deposition of porphyry and epithermal ores. In so doing they demonstrate the important links between arc volcanism and porphyry-epithermal ore formation.

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METHODS

Volcanic vapors were sampled by inserting silica tubes into fumaroles and connecting the tubes to ice-trap condensers. The liquid that collected in the ice trap was analyzed by ICP-MS, ICP-OES, INAA and IC. Sublimates from the vapors were collected by inserting silica tubes into fumaroles immediately after the condensates were sampled and waiting several days until sufficient solid had accumulated on the inner walls of the tubes. Temperatures were measured along the tube centerlines using a thermocouple. Aliquots of sublimates were mounted on polished sections for mineral identification via EMPA and the remainder was analyzed using XRD.

RESULTS

Vapor Compositions

The concentrations of ligands (S-Cl) and metals (Au-Cu-Zn-Pb-Mo-Y-U) in condensed vapor were normalized to Na to compensate for variations in density and thus fH_2O of the vapor (Fig. 1a). The vapors were enriched in S-Cl-Pb-Cu-Zn in 2006 (explosive) and enriched in Mo-Y-Au-U in 2004 (quiescent). In 2006, S and Cl concentrations in the vapor ranged from 0.7 to 1.0 wt.% and 0.5–0.7 wt.%, respectively, whereas they varied from 260 to 520 ppm and 890 to 3030 ppm, respectively, in 2004 (Table 1). Copper and Zn concentrations ranged from 0.16 to 0.28 ppm and 0.15 to 0.42 ppm, respectively, in 2006 and only 0.003 ppm and 0.06 to 0.15 ppm, respectively, in 2004. By contrast, concentrations of Mo only reached 0.6 ppb in 2006 compared to 4–20 ppb in 2004. The concentrations of Y were 0.7–4 ppb in 2004 and 0.4–0.5 ppb in 2006, those of Au were 0.2–0.6 ppb in 2004 and 0.02 ppb in 2006, and those of U were 0.09–0.34 ppb in 2004 and 0.06–0.08 ppb in 2006.

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The concentrations of the REE were first normalized to Na and subsequently to chondrite (McDonough and Sun, 1995) to allow comparison with subduction zone fluids (Fig. 1b). The 'doubly-normalized' REE profiles all show LREE enrichment typical of subduction zone fluids. The vapors from 2004 had higher total REE contents compared to those from 2006. The concentrations of LILE and HFSE were first normalized to Na and subsequently to MORB (McDonough and Sun, 1995) to evaluate fluid behavior (Fig. 1c). All samples display gradual enrichment of progressively more incompatible elements, except Ti, because it was compatible in titanomagnetite (Camus, 2000; Nadeau et al., 2013). All incompatible elements are enriched in 2004 samples relative to those for 2006, except for Zr and Hf in one sample.

Sublimate Mineralogy and Redox State

A variety of minerals precipitated from the vapors during cooling along the silica tubes. In 2004, the mineral assemblage consisted of chlorides, sulfates and hydrated sulfates, oxides and native elements, whereas the minerals comprised chlorides, sulfides, arsenosulfides and native elements in 2006 (Fig. 2; Table DR1).

Iron precipitated in ilmenite and hematite in 2004 and in pyrite and smythite in 2006, Pb precipitated as anglesite in 2004 and as galena and tsugaruite ($Pb_4As_2S_7$) in 2006, and Bi, Zn-Cd precipitated as bismuthinite and wurtzite-greenockite in 2006. The magmatic-hydrothermal system was thus relatively oxidized in 2004 and reduced in 2006.

Magmatic Arc Fluids

In order to expand our database beyond that of Merapi and to compare volcanic vapors to ore fluids, we compiled published compositional data for 282 samples of vapor

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condensates from 19 subduction zone stratovolcanoes (Table DR2) and 292 fluid inclusion assemblages from seven major porphyry Cu ± Mo ± Au deposits (Table DR3) (Fig. 3). These data are illustrated in violin plots showing median (black dot) and interquartile range (black line) values as well as the total data distribution (gray envelope) (see supplementary information). The volcanic vapors ranged in temperature from 85 °C to 1020 °C, averaging 445 ±216 °C (1σ), whereas the fluid inclusions were trapped at temperatures from 220 °C to 771 °C or an average of 434 ±130 °C (1σ). On average, base metal concentrations in fluid inclusions from porphyry deposits are more than three orders of magnitude higher than in volcanic vapors. Given their similar temperatures, and experimental studies of metal solubility in aqueous fluids, the higher metal content of the fluid inclusions is attributed to their higher fluid density and resulting higher capacity to hydrate metal complexes. At constant density, metal solubility increases with increasing temperature due to a corresponding increase in the partial pressure of H_2O, which promotes the formation of metal complexes with high hydration numbers (e.g., Migdisov et al., 2014). Increasing temperature, however, destabilizes metal complexes with high hydration numbers, and a maximum solubility is reached when this effect outweighs that of the increasing partial pressure of H_2O. In volcanic emissions, the Pb/Na ratio reaches a maximum in fluids with temperatures of 400–600 °C, Zn/Na is greatest in fluids with temperatures of 400–800 °C and Cu/Na and Au/Na have maxima in fluids with temperatures of 200–400 °C. The use of Y as a proxy for the REE suggests that REE/Na ratios are greatest in vapors with temperatures of 400–600 °C (Fig. 3a).

The Pb/Na, Zn/Na and Mo/Na ratios are much lower in fluid inclusions than in volcanic vapors (Fig. 3b). This probably results from the preferential incorporation of Na

in alteration minerals precipitating from the fluid between the porphyry and the fumaroles. By contrast, Cu/Na is higher in supercritical and vapor fluid inclusions and lower in brines and volcanic vapors. However, the higher content of Cu in vapor inclusions has been interpreted to result from post-entrapment diffusion of Cu toward the vapor inclusions (Lerchbaumer and Audétat, 2012). The Cu/Na ratio is thus higher in supercritical fluids than in brines, vapors and volcanic vapors, implying that Cu-bearing minerals undergo largescale precipitation during the unmixing of supercritical fluids into brine and vapor.

DISCUSSION

Physical State of the Volatile Phase

An important difference between porphyry fluids and volcanic vapors is their physical state. Magmatic volatiles exsolved at pressures and temperatures greater than those of the critical point, i.e., porphyry fluids at depth, are in a supercritical state. When supercritical fluids ascend, they may reach the critical point and unmix into liquid and vapor. Upon unmixing, Cl preferentially partitions into the liquid forming brine (Bodnar et al., 1985) whereas S partitions preferentially into the vapor that is ultimately emitted as a volcanic gas (Simon and Ripley, 2011; Nadeau et al., 2013).

Pressure has a major impact on the physical state of magmatic hydrothermal fluids because decreasing pressure may lead to phase separation. It is possible to relate the pressure at which supercritical fluids unmix into brine and vapor to a critical depth, by assuming lithostatic and hydrostatic pressure gradients. According to experimental studies in the H_2O-NaCl system, for a magmatic fluid at 1000 °C and 5–10 wt. % $NaCl_{eq}$ (Zajacz et al., 2008), the critical depth is 5 km under a lithostatic pressure gradient and 15

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km under a hydrostatic pressure gradient (Driesner and Heinrich, 2007). The addition of CO_2 and sulfur species to the system will increase this critical depth, but phase relationships in the COHS-NaCl system are not sufficiently known to quantify this effect (Webster and Mandeville, 2007).

Variations in Sulfur and Chlorine

Porphyry-type deposits have greater contents of sulfur than of the base and precious metals for which they are exploited. At Merapi, volcanic vapors were highly enriched in S following the explosive eruption of 2006 compared to volcanic vapors that were quiescently degassed in 2004 (Table 1). The total concentration of S in vapor condensates was 6730 and 10,580 ppm in 2006, and 260 and 520 ppm in 2004; the higher concentration of 2006 was attributed to the injection of sulfide melt-saturated mafic magma in that year (Nadeau et al., 2010). Chlorine was present in significant concentrations in volcanic vapors released from Merapi in both 2004 and 2006, but its concentration varied much less than that of sulfur between periods of quiescence and eruption.

Redox Conditions

During periods of quiescent degassing, magma becomes oxidized due to the preferential incorporation of Fe^{2+} in minerals (Kelley and Cottrell, 2012) and fluids (Bell and Simon, 2011) and preferential degassing of H_2 relative to O_2 during H_2O disproportionation (Mathez, 1984). Although primitive arc magmas are usually considered to be oxidized ($fO_2 \geq$ FMQ+2; Mungall, 2002), the deep mafic magmas feeding Merapi were sufficiently reduced, with fO_2 at or near FMQ (Jugo, 2009), to exsolve an immiscible sulfide melt (Nadeau et al., 2010) and an aqueous fluid that

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ultimately precipitated sulfides (Fig. 2b). Such immiscible sulfide melt inclusions also have been observed at other arc volcanoes and in porphyry Cu deposits (Larocque et al., 2000), suggesting that deep mafic feeders commonly may be less oxidized than shallower porphyry stocks.

Variations in the degree of oxidation of magmas and fluids have an important impact on metal transport characteristics. Highly oxidized magmas lack sulfides that could scavenge chalcophile and siderophile metals from magmatic-hydrothermal systems. In contrast, S-rich, reduced magmas may exsolve chalcophile element-rich immiscible sulfide melts that, in turn, can be subsequently dissolved in magmatic hydrothermal fluids (Nadeau et al., 2010; Mungall et al., 2015). High oxidation states of hydrothermal fluids lead to low H_2S/SO_2 ratios, inhibiting the solubility of metals that are dissolved dominantly as bisulfide complexes (Zezin et al., 2011) but enhancing the capacity of the melt to transport sulfur as SO_4^{2-} (Jugo, 2009).

Metallogenesis of Porphyry-Type Deposits

We propose that porphyry-epithermal systems evolve by cycling through periods of volcanic quiescent degassing dominated by fractional crystallization and volatile exsolution, and periods of explosive activity triggered by injection of mafic magmas (Fig. 4). According to this hypothesis, quiescently devolatilizing magmas evolve under lithostatic pressure gradients to relatively shallow depths (the critical depth is 5 km in the H_2O-NaCl system; Driesner and Heinrich, 2007). Incompatible metals such as Au, Mo, REE, HFSE and LILE are gradually enriched in the magmas and fluids and deposited in these relatively oxidizing environments. Injections of less oxidized mafic magmas open up the systems and abruptly decrease the confining pressures to values closer to the

hydrostatic gradient, thereby displacing the critical depth to deeper levels (15 km in the H_2O-NaCl system; Driesner and Heinrich, 2007). Regional tectonic earthquakes, such as that which occurred near Merapi during the eruption of 2006, also may enhance the pressure regime transition by opening the systems. Although experimental studies in the H_2O-NaCl system suggest a critical depth of 15 km under a hydrostatic pressure gradient, a study of rock rheology suggests that a hydrostatic regime would be difficult to maintain at depths greater than ~5–10 km (Sibson, 1992). Hence the pressure regime at this stage may lie between lithostatic and hydrostatic. Upon depressurization, sulfur partitions preferentially into the vapor which rises and expands, whereas chlorine remains in the brine that ponds beneath the volcano.

After the injection of mafic magma, Cu bonds with S to precipitate as a sulfide mineral under the combined effects of decompression and expansion of the hydrated metal complexes. The precipitation of Zn and Pb, which are also enriched in the hydrothermal system after rock failure and decompression, is not as abrupt as that of Cu (Fig. 3b) as these metals form stronger bonds with Cl. Their precipitation in sulfide minerals is thus delayed relative to Cu. After explosive eruptions which typically last several months and contribute to fracturing and brecciating rocks at progressively greater depths, the magmas evolve by fractional crystallization, gradually becoming more oxidized and enriched in incompatible elements. The hydrothermal system seals itself by precipitation of minerals along fractures and in breccias under the weight of the rock column, with pressure returning to lithostatic levels. The ability of the fluid to dissolve metals gradually increases until the next explosive eruption (or rock failure at depth), typically a few years later.

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CONCLUSIONS AND IMPLICATIONS

Although economic mineralization is usually thought to postdate volcanism (Williams-Jones and Heinrich, 2005), numerous ore deposits have been shown to be genetically associated with volcanism (Hattori and Keith, 2001). In this paper, we have related variations in the composition of volcanic vapors from Merapi volcano to different stages of its eruptive cycle and compared these compositions to those of volcanic vapors from other subduction zone volcanoes and porphyry-hosted fluid inclusions. These data provide the first convincing evidence that injections of mafic magma (which commonly coincide with explosive volcanic eruptions) are followed by decompression of the magmatic hydrothermal system, inducing fluid phase separation, rapid cooling and the deposition of porphyry and epithermal ores. In so doing they demonstrate that decompression is the principal control on mineralization, and that pressure in the systems transforms abruptly from lithostatic during quiescence to hydrostatic during and immediately after an explosive eruption (rock failure at depth). During quiescence, magmatic-hydrothermal systems evolve through crystallization and devolatilization, gradually becoming oxidized and enriched in gold and other incompatible metals. Upon injection of mafic magmas, they are depressurized, supercritical fluids unmix into vapor and brine, temperature drops, base metal sulfides precipitate at depth and volcanoes erupt explosively.

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FIGURE CAPTIONS

Figure 1. Compositions of condensed vapors from Merapi in 2004–2006. Elements are normalized to Na (a) and to chondrite (b) or MORB (c) (McDonough and Sun, 1995). The gray envelopes represent all data from Merapi.

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Figure 2. Mineralogy of volcanic vapor sublimates from Merapi in 2004–2006.

Figure 3. Compositions of volcanic vapor condensates (a) and comparison of fluid inclusion and vapor condensate compositions (b) from selected arc volcanoes and porphyry deposits. See supplementary information for references.

Figure 4. Schematic model showing the evolution of porphyry systems based on Merapi volcano, Indonesia.

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TABLE 1. COMPOSITIONS OF CONDENSED VOLCANIC VAPORS FROM MERAPI IN 2004–2006.

Year	Sample	Na	S	Cl	Ti	Cu	Zn	Sr	Y	Zr	Mo	Ba	La	Ce	Pr	Nd
2004	M4W1	3.43	263	3030	0.40		0.150	0.075	0.0039	0.0121	0.0200	0.281	0.0032	0.00718	0.00084	0.00365
2004	M4W3	0.60	520	893	0.21	0.003	0.060	0.015	0.0007	0.0048	0.0040	0.11	0.00078	0.0014	0.00015	0.00065
2006	M6W1	2.31	6733	4849	0.05	0.161	0.420	0.020	0.0004	0.0222		0.0342	0.00023	0.001862	0.000177	0.00072
2006	M6W2	1.21	10579	7193	0.05	0.279	0.150	0.019	0.0005	0.0114	0.0006	0.0555	0.000928	0.001798	0.000221	0.000813

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Year	Sample	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	U
2004	M4W1	0.00089	0.00024	0.00095	0.00014	0.00073	0.00015	0.00041	0.00006	0.00041	0.00006	0.00031	0.00035	0.00060	1.41000	0.00034
2004	M4W3	0.00015	0.00006	0.00013	0.00003	0.00011	0.00003	0.00007		0.00008	0.00001	0.00012	0.00011	0.00020	0.07000	0.00009
2006	M6W1	0.00019	0.00003	0.00009	0.00001	0.00009	0.00002	0.00008	0.00000	0.00005		0.00049	0.00003		8.53000	0.00006
2006	M6W2	0.00020	0.00005	0.00014	0.00007	0.00013	0.00002	0.00009	0.00002	0.00005	0.00001	0.00028	0.00003	0.00002	8.01000	0.00008

350

Figure 1

Click here to download Figure Fig-1-condensates.jpg

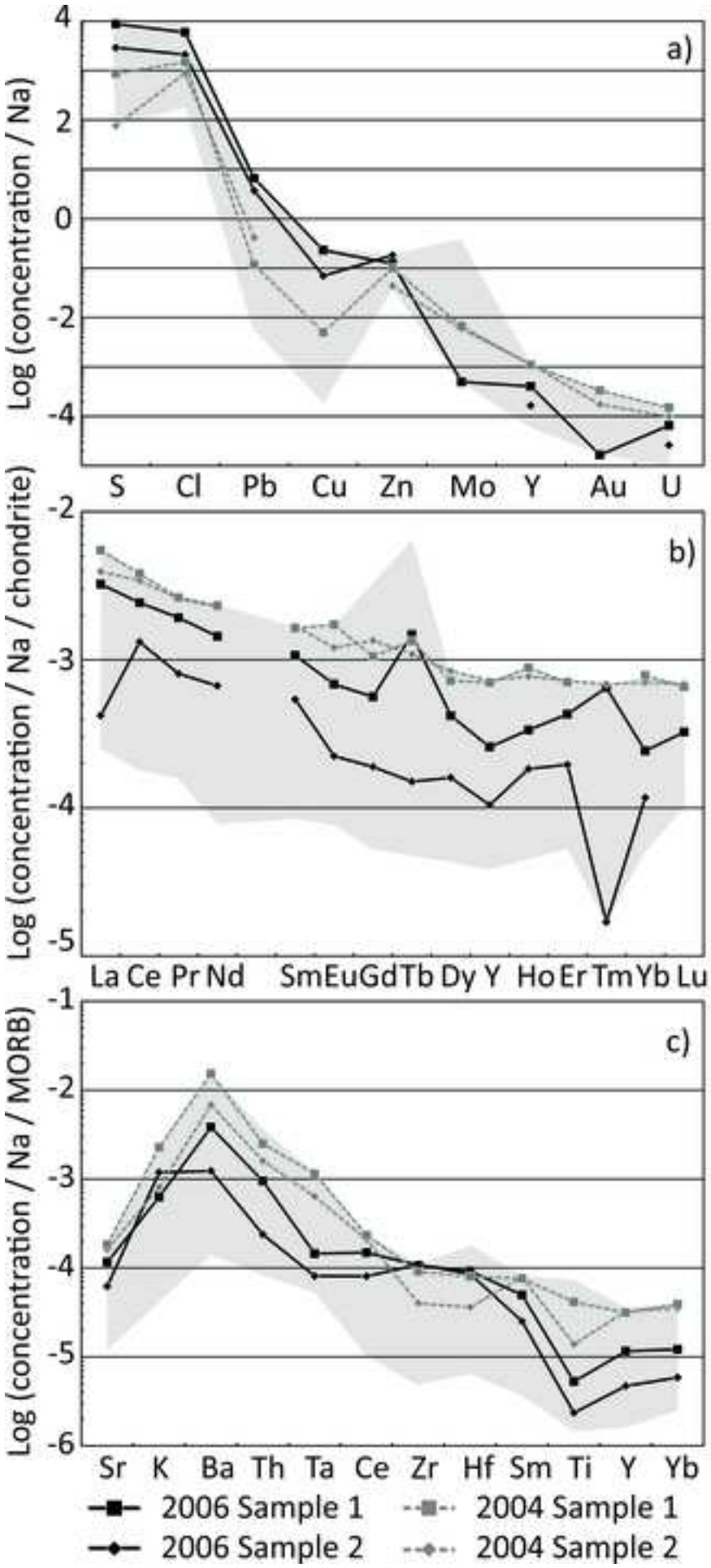

Figure 2

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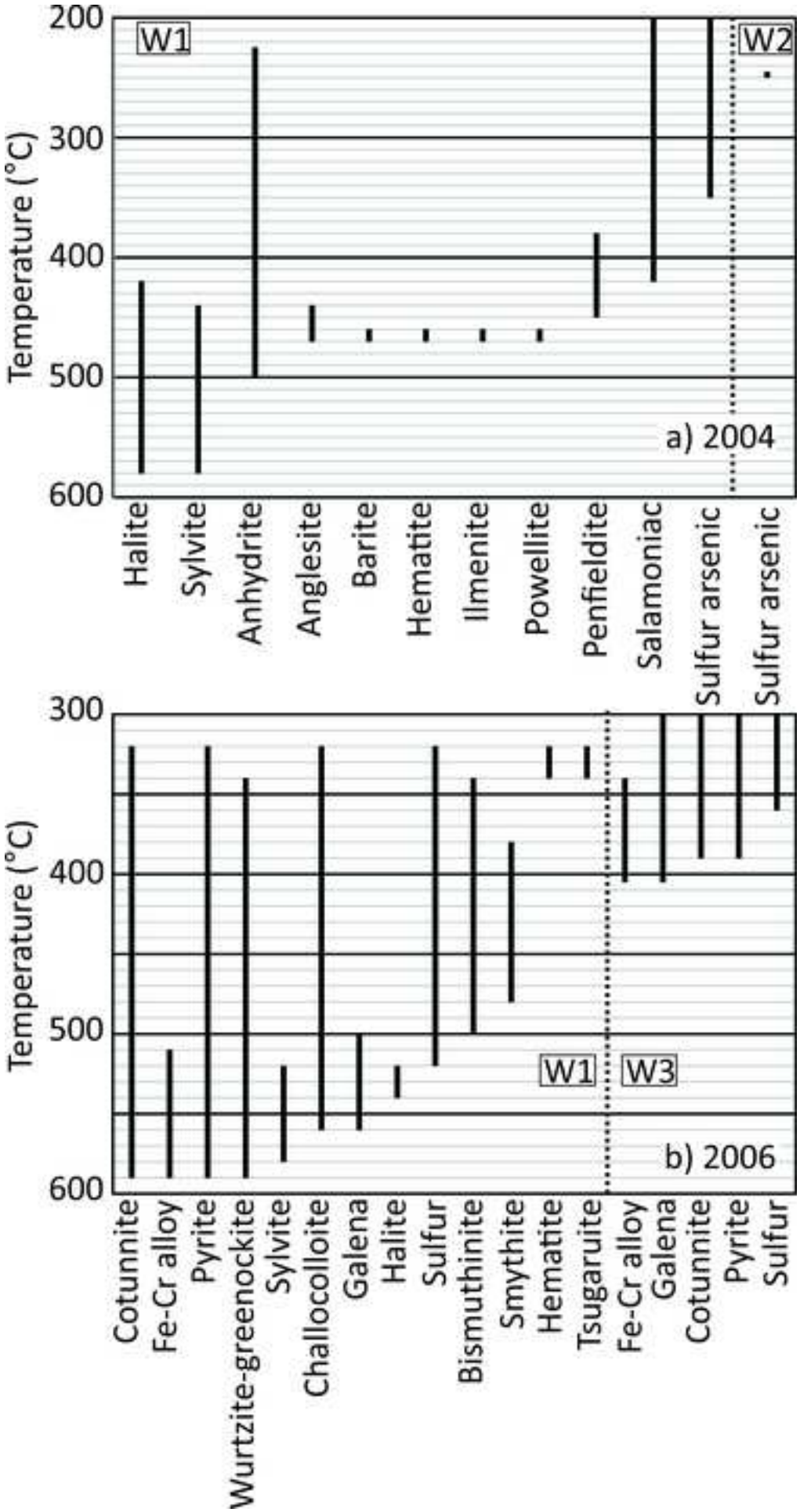

Figure 3

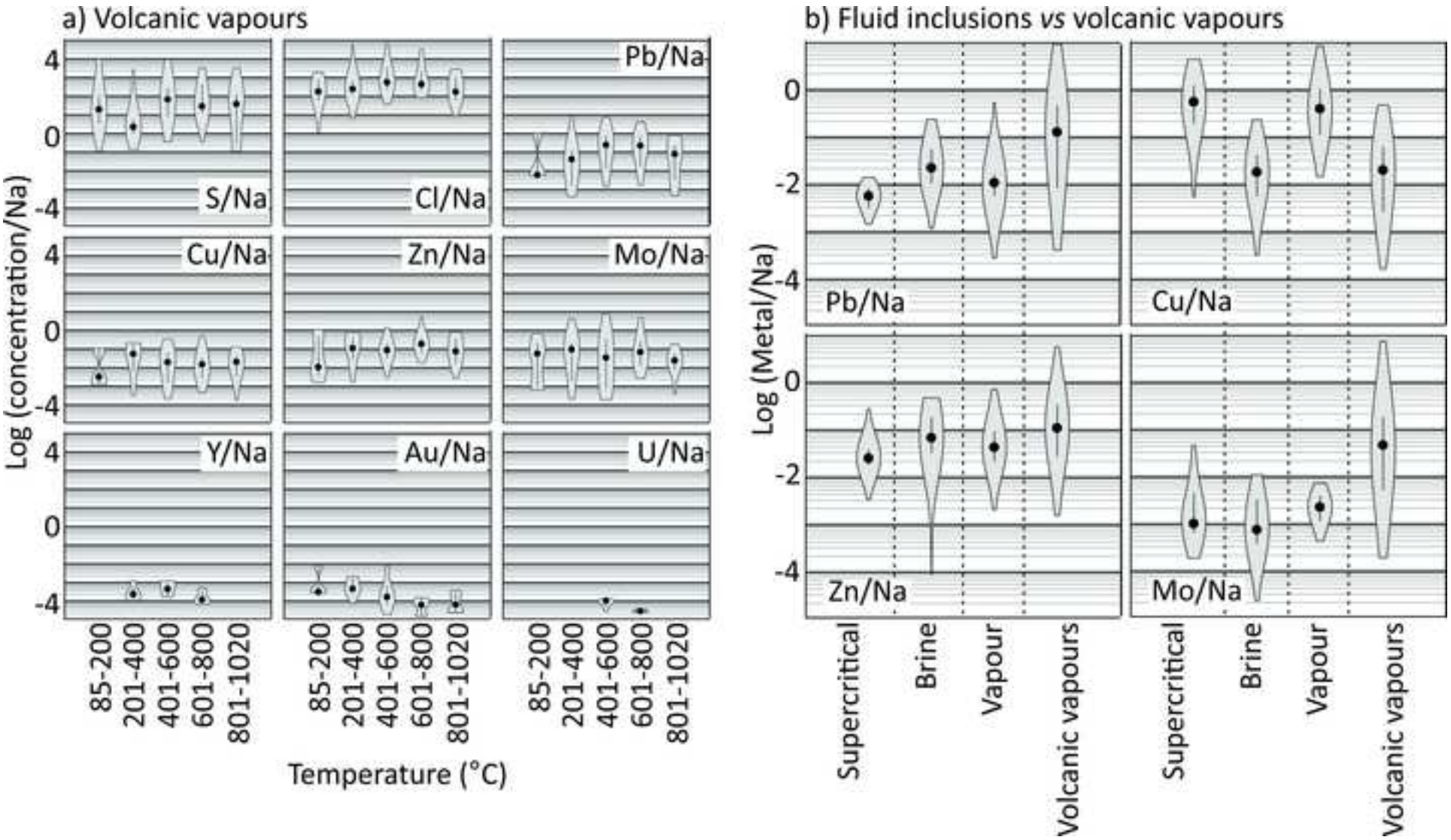

Figure 4

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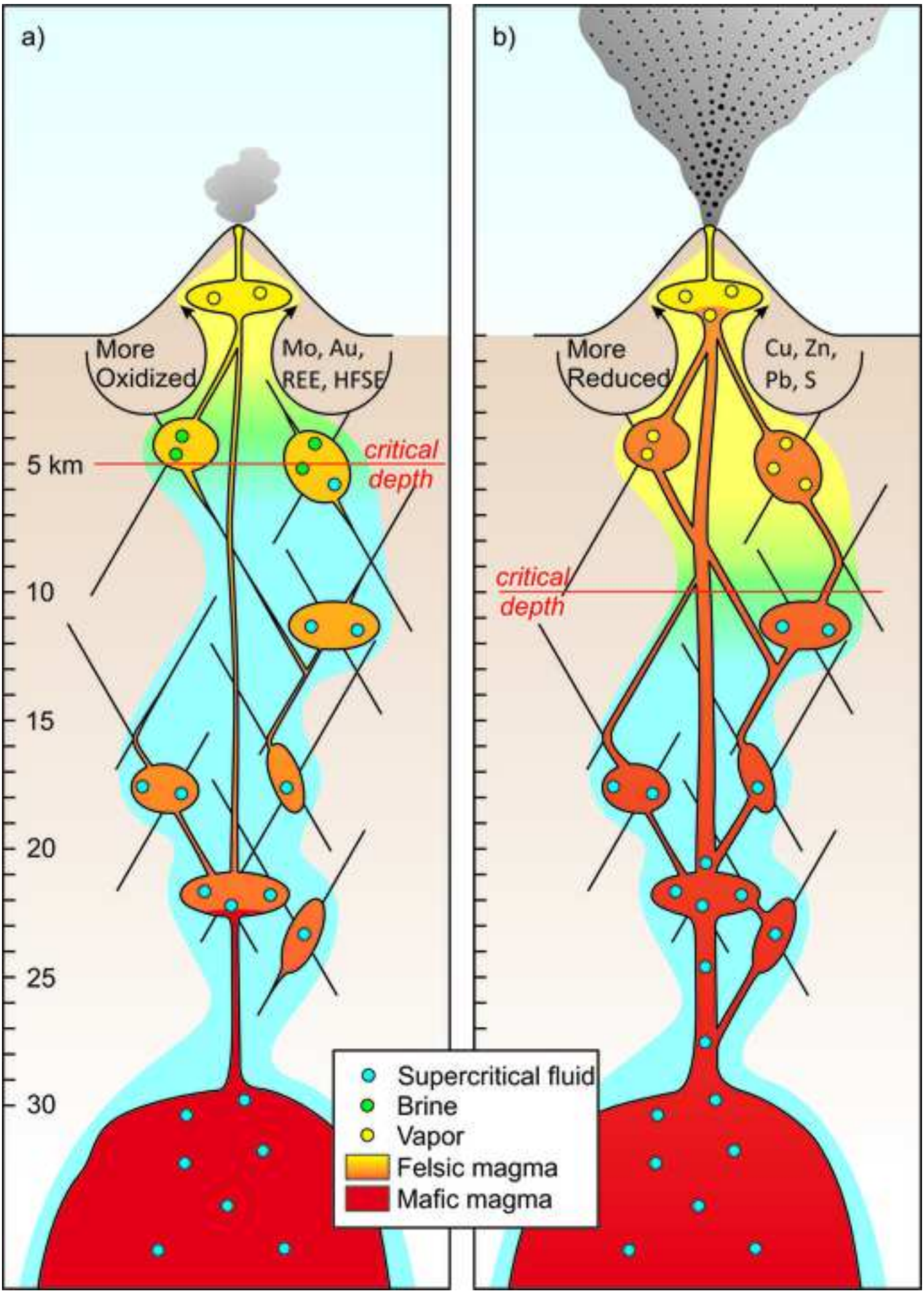

Table 1

Year	Sample	Na	S	Cl	Ti	Cu	Zn	Sr	Y	Zr	Mo	Ba	La	Ce	Pr	Nd
2004	M4W1	3.43	263	3030	0.40		0.150	0.075	0.0039	0.0121	0.0200	0.281	0.0032	0.00718	0.00084	0.00365
2004	M4W3	0.60	520	893	0.21	0.003	0.060	0.015	0.0007	0.0048	0.0040	0.11	0.00078	0.0014	0.00015	0.00065
2006	M6W1	2.31	6733	4849	0.05	0.161	0.420	0.020	0.0004	0.0222		0.0342	0.00023	0.001862	0.000177	0.00072
2006	M6W2	1.21	10579	7193	0.05	0.279	0.150	0.019	0.0005	0.0114	0.0006	0.0555	0.000928	0.001798	0.000221	0.000813
Year	**Sample**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Hf**	**Ta**	**Au**	**Pb**	**U**
2004	M4W1	0.00089	0.00024	0.00095	0.00014	0.00073	0.00015	0.00041	0.00006	0.00041	0.00006	0.00031	0.00035	0.00060	1.41000	0.00034
2004	M4W3	0.00015	0.00006	0.00013	0.00003	0.00011	0.00003	0.00007		0.00008	0.00001	0.00012	0.00011	0.00020	0.07000	0.00009
2006	M6W1	0.00019	0.00003	0.00009	0.00001	0.00009	0.00002	0.00008	0.00000	0.00005		0.00049	0.00003		8.53000	0.00006
2006	M6W2	0.00020	0.00005	0.00014	0.00007	0.00013	0.00002	0.00009	0.00002	0.00005	0.00001	0.00028	0.00003	0.00002	8.01000	0.00008

Volcanic Processes and the Genesis of Porphyry and Epithermal Ore Deposits

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Supplementary Information

Geological Context

Merapi volcano was most active within the last 40,000 years (Camus et al., 2000). Since the beginning of the 20th century, Merapi has alternated between periods of quiescent degassing and lava dome growth and occasional collapse, typically lasting a few years, and periods of explosive activity, with St-Vincent - type explosions, pyroclastic flows and surges, typically lasting several months. From September 2002 to March 2006, the volcano was in a phase of quiescent degassing. From March to July 2006, it went through a phase of explosive activity, with its plume reaching an altitude of 3.7 km and erupting about 1.07×10^{10} kg of rock (Ratdomopurbo et al., 2013). On May 27th 2006, a magnitude 6.3 earthquake occurred about 50 km SW of Merapi at a depth of about 10 km, resulting in a three-fold increase of volcanic activity (Global Volcanism Program of the National Museum of Natural History – Smithsonian Institution (GVP); United States Geological Survey, consulted online in June 2015). From July 2006 and until October 2010, it went back to a phase of quiescence. In 2010, the volcano had its greatest eruption since 1872. From October to November 2010, Merapi erupted about 3.1×10^{11} kg of rock and degassed about 0.44×10^{9} kg of SO_2 (GVP; Surono et al., 2012). Although the initial explosion occurred 19 hours after a magnitude 7.7 earthquake 1200 km NW of Merapi, any links between this seismic event and the major eruption of 2010 are difficult to prove. Volcanic vapours at Merapi emanate from distinct fumarole fields. Gendol was the highest temperature fumarole field, with temperature reaching up to 900°C (Le Guern, 1979), until it was destroyed by the eruption in 2006. Woro was a lower temperature fumarole field, reaching up to 710°C (Le Guern et al., 1982), until it was destroyed by the 2010 eruption. In this paper we used only the volcanic vapour data from Woro as they were the only dataset that could be compared between 2004 and 2006 and because vapours from distinct fumarole fields cannot be compared directly.

Supplementary Methods

Condensates of volcanic vapor

Volcanic vapours were sampled by inserting meter-long fused silica tubes into fumaroles and connecting the quartz tubes to condensers filled with ice and pumping the vapour slowly through the condenser using a hand-held pump. The liquid that collected in the condensor was stored in Teflon bottles and analyzed at Actlabs Inc., Canada, by a combination of inductively coupled plasma mass spectrometry (ICP-MS), ICP optical emission spectrometry (OES), neutron activation (INAA) and ion chromatography.

Sublimates of volcanic vapor

The sampling of vapor condensates was complemented by inserting meter-long, fused silica tubes into the fumaroles immediately after the condensates had been collected and waiting until sufficient solid had precipitated on the inner walls of the tubes (Le Guern et al., 1982). In 2004, tubes were inserted for periods varying between four and six days. In 2006, tubes were in place for a period of 22 days. The sampling was done during the dry season to avoid dissolution and redistribution of sublimates by rain. Temperatures were measured along the tube centerlines at 10 cm intervals using a meter-long thermocouple and the tubes were subsequently cut into sections representing increments of 10 to 20°C. The sublimates were scraped off and a fraction of each sublimate was mounted on a glass slide and polished. As several of the sublimate phases are water soluble (e.g., halite and sylvite), the polishing agent (aluminium oxide or diamond powder) was suspended in alcohol rather than water. The phases in the polished sections were analysed chemically using a JEOL JXA-8900L electron microprobe (EMPA) at McGill University. A second fraction of sublimate was scanned using a Siemens D500 X-ray diffractometer equipped with a Co tube and a Si detector at the Université du Québec à Montréal. The diffraction patterns were analyzed using Jade software at McGill University for identification of major phases.

Supplementary Tables

Table S1. Mineralogy and temperature distribution of of volcanic vapour sublimates collected from Merapi volcano in 2004-2006.

Table S2. Compilation of volcanic vapour condensates

A total of 282 samples of vapour condensates from subduction zone stratovolcanoes with trace element concentrations were compiled from the literature (Fig. 2). Data were taken from Arenal, Costa Rica (Stoiber and Rose, 1970), Augustine, Alaska (Symonds et al., 1990), Cerro Negro, Nicaragua (Gemmel, 1987; Stoiber and Rose, 1970), Colima, Mexico (Taran et al., 2001), Fuego, Guatemala (Stoiber and Rose, 1970), Izalco, El Salvador (Stoiber and Rose, 1970), Kawa Ijen, Indonesia (Berlo et al., 2014), Kudryavy, Russia (Wahrenberger et al., 2002; Taran et al., 1995), Masaya, Nicaragua (Gemmel, 1987), Merapi, Indonesia (this research; Symonds et al., 1987), Momotombo, Nicaragua (Gemmel, 1987), Mutnovsky, Kamchatka (Zelensky et al., 2005), New Tolbachik, Kamchatka (Menyailov and Nikitina, 1980), Pacaya, Guatemala (Stoiber and Rose, 1970), Poas, Costa Rica (Gemmel, 1987), Santiagito, Guatemala (Stoiber and Rose, 1970), Satsuma Iwojima, Japan (Hedenquist et al., 1994), Showa Shinzan, Japan (Oana, 1962; Mizutani, 1970; Symonds et al., 1996) and St-Helens, USA (Bernard et al., 1990). The concentrations of S, Cl, Pb, Cu, Zn, Mo, Y, Au and U were normalized to Na to neutralise the effect of dilution by H_2O. The concentration of these elements did not show any correlation with the silica content nor with the alkalinity of the associated volcanic rocks. Conversely, a correlation was observed between their composition and temperature. The samples were thus separated into five temperature groups, i.e., 85-200°C (n=23), 201-400°C (n=109), 401-600°C (n=55), 601-800°C (n=44) and 801-1020°C (n=19). These results are reported in “violin plots”, using NCSS statistical software, showing the median (black dot), the interquartile range (central vertical line extending from the 25th to 75th percentile) and the total distribution (gray envelopes; width representing the amount of data).

Most of the violin plots show normal distributions, with medians near the centres of the interquartile bars and the latter approximately in the middle of the total distribution, except for some plots of the low temperature group with abnormal distributions, due to limited data. Uranium, Y, and Au to a lesser extent, also have limited data and show a limited temperature distribution and inconsistent statistical values. Sulphur and Cl have the highest concentrations of the elements in the volcanic vapour

condensates other than H and O. Concentrations of S range from 2 ppm to 2.7 wt.% and Cl from 10 ppm to 6.6 wt.%, values which are significantly higher than those of the base metals (Pb-Cu-Zn-Mo), which vary between 0.01 ppb and 21.9 ppm, and trace metals (REE, Au, U) which vary between 0.001 ppb and 0.22 ppm (Gemmel, 1987).

The temperature distribution of the volatile and metallic elements results in convex-upward patterns with maxima at intermediate values (usually around 400-800°C) and lower values at lower (85-400°C) and higher (800-1020°C) temperatures. Copper has a maximum concentration in vapours at 200-400°C, whereas Mo is most concentrated in vapours at 200-400°C and 600-800°C. Although very little data is available for Y, Au and U, Y appears more concentrated in vapours of medium temperature (400-600°C), whereas Au appears to be preferentially concentrated in vapours of lower temperature, 200-400°C.

Table S3. Compilation of fluid inclusion data

A total of 292 analyses of fluid inclusions from seven porphyry Cu ±Mo ±Au deposits with trace element concentrations and physical phase descriptions (supercritical fluid, brine or vapour inclusions) were compiled from the literature (Fig. 4). The data are from Bajo de la Alumbrera Cu-Au porphyry, Chile (Seo et al., 2009; Ulrich et al, 2001), Bingham Cu-Au-Mo porphyry, USA (Landtwing et al., 2005; Seo et al., 2009), Butte Cu-Mo porphyry, USA (Rusk et al., 2004), El Teniente Cu-Mo porphyry, Chile (Klemm et al., 2007), Famatina Cu-Au porphyry-epithermal, Argentina (Pudack et al., 2009), Rosia-Poieni Cu-Au porphyry, Romania (Kouzmanov et al., 2010) and Santa Rita Cu (Mo) porphyry, New Mexico (Audétat et al., 2008). Only Pb, Cu, Zn and Mo are reported here because S, Cl, Au, REE, Au, U and other elements were almost never reported. The concentrations of Pb, Cu, Zn and Mo were normalized to Na to neutralise the effect of dilution by H_2O and to enable comparison between volcanic vapours and fluid inclusions. The Pb/Na, Cu/Na, Zn/Na and Mo/Na ratios are displayed as violin plots for supercritical fluid-, brine- and vapour inclusions and the ratios for volcanic vapours are displayed beside them.

The Pb/Na ratio is smallest for supercritical fluid inclusions, averaging about 0.006 (note that the calculated averages and the medians shown on violin plots are not necessarily identical), and is progressively higher for vapour and brine inclusions. Volcanic vapours have a large range of Pb/Na values that encompass all the fluid inclusion data and reach values much higher than the latter, averaging around 0.6. The Cu/Na ratios are similar for supercritical fluid and vapour inclusions, with values averaging around 0.8. Brine and volcanic vapours also have similar ratios averaging of 0.03 and 0.05, respectively. The distribution of Zn/Na is very similar to that of Pb/Na; values are smallest for supercritical fluid inclusions, averaging around 0.035, and are gradually higher in vapour and brine inclusions. The Zn/Na ratio reaches a maximum average value of about 0.26 in volcanic vapours, where it also has the greatest range, again encompassing that of most fluid inclusions. Finally, Mo/Na ratios show the highest values (average 0.4) and the greatest variations in volcanic vapors like for Pb/Na and Zn/Na. Vapour, supercritical fluid and brine inclusions have gradually lower Mo/Na ratios ranging between 0.005 and 0.002.

Mass balance calculations

An actively forming porphyry system of intermediate size associated with an overlying volcano that erupts every 5 years would cycle 20,000 times during 100 ka. Assuming an intermediate-sized porphyry deposit containing 1 Gt of Cu, 50 t of Cu should be deposited during each cycle. If 50 wt. % of the Cu present in the basalt is deposited in each cycle, 1.67 Gt of basalt containing 60 ppm Cu (a normal value; see georoc database at georoc.mpch-mainz.gwdg.de/georoc) needs to be injected during each cycle.

Given a density of 2800 kg/m^3, this represents a volume of ~ 600 million m^3, which is a reasonable size for a mafic injection in the shallow part of subduction zone magma system (Pallister et al., 1992).

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Supplemental file Table S1 Click here to download Supplemental file Table-S1-Merapi-sublimates.xlsx

Mineral	Formula	Year	Max	Min
Anglesite	$PbSO_4$	2004	470	440
Anhydrite	$CaSO_4$	2004	500	225
Arsenic	As	2004	350	190
Barite	$BaSO_4$	2004	470	460
Bismuthinite	Bi_2S_3	2006	500	340
Challacolloite	KPb_2Cl_5	2006	560	320
Cotunnite	$PbCl_2$	2006	590	300
Fe-Cr alloy	Fe,Cr	2006	590	340
Galena	PbS	2006	560	300
Halite	NaCl	2004, 2006	580	420
Hematite	Fe_2O_3	2004, 2006	600	320
Ilmenite	$FeTiO_3$	2004	470	460
Penfieldite	$Pb_2Cl_3(OH)$	2004	450	380
Powellite	$CaMoO_4$	2004	470	460
Pyrite	FeS_2	2006	590	300
Salamoniac	NH_4Cl	2004	420	190
Smythite	Fe_9S_{11}	2006	480	380
Sulfur	S	2004, 2006	560	190
Sylvite	KCl	2004, 2006	580	440
Tsugaruite	$Pb_4As_2S_7$	2006	340	320
Wurtzite	(Zn,Cd,Fe)S	2006	590	340
Greenockite	CdS	2006	590	340

Supplemental file Table S2 Click here to download Supplemental file Table-S2-flincs.xlsx

magmatic system	type	Na	Cu	Zn	Mo	Pb	Reference
Bajo de la Alumbrera Cu-Au porphyry	b	78000	6500			1420	Seo et al., 2009
Bajo de la Alumbrera Cu-Au porphyry	v	24000	1800			210	Seo et al., 2009
Bajo de la alumbrera Cu-Au porphyry	b	160000	7600	14000	70	4500	Ulrich et al., 1999
Bajo de la alumbrera Cu-Au porphyry	v	17000	33000	1200		200	Ulrich et al., 1999
Bajo de la alumbrera Cu-Au porphyry	b	106000	100	6000	140	1700	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	50000	300	6000		1800	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	92000	200				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	105000	100	6000	30	2000	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	219000	1700				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	105000	10000	18300	220	4400	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	243000	3700				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	252000	2300	20			Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	124000	4800	7400	70	3300	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	100000	500	8900		2800	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	107000	1200	12000	120	3600	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	123000	2200	4600		1600	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	81000	3200	9500	40	2600	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	65000	3200	6000	80	1500	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	198000	1000				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	80000	5500	9900	90	2400	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	110000	2600	5400	130	1700	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	104000	2000	9000	60	2000	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	100000	5200	5700	50	1800	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	97000	700	5000		1200	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	100000	500	1200		1500	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	33000		1000		200	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	20000	300	1300		1600	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	9500	100	200		90	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	b	4700		300		110	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	11000	500				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	3000	1100	200		70	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	7000	900	700		200	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	11000	1200	400		140	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	3000	300	100		30	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	6000	3000	300		100	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	14000	6000	800		170	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	9800	2500	1000		250	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	30000	30000	6800		620	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	13000	29000	1000		40	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	21000	26000	1300		180	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	17000	33000	1200		230	Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	7900	5200				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	3900	1800				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	3900	500				Ulrich et al., 2002
Bajo de la alumbrera Cu-Au porphyry	v	3900	1700				Ulrich et al., 2002
Bingham Cu-Au-Mo porphyry	b	123000	26000	2900	45	2400	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	102000	22000	4100	270	3800	Landtwing et al., 2005

Bingham Cu-Au-Mo porphyry	b	108000	15000	2800	94	3800	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	132000	15000	2700	60	3100	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	112000	6200	4400		3600	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	113000	3500	3500	1060	2900	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	125000	3200	3300	400	3300	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	110000	2500	4500	70	3700	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	113000	2100	3800	140	3300	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	107000	1300	4000	620	4100	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	123000	700	2100		2100	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	116000	600	2100		1800	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	102000	400	3700	44	2900	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	116000	8100	2500	150	3800	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	106000	7100	3100	49	3200	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	980000	6520	3100		3600	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	105000	4500	3300		2500	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	115000	3000	2200		2000	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	960000	2000	3500	21	3200	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	112000	1450	2100		2600	Landtwing et al., 2005
Bingham Cu-Au-Mo porphyry	b	97000	7600		450	2800	Seo et al., 2009
Bingham Cu-Au-Mo porphyry	b	129000	18900		33	3000	Seo et al., 2009
Bingham Cu-Au-Mo porphyry	b	117000	1190		88	3800	Seo et al., 2009
Bingham Cu-Au-Mo porphyry	v	16800	4200		51	390	Seo et al., 2009
Bingham Cu-Au-Mo porphyry	v	23000	10800		18.3	440	Seo et al., 2009
Bingham Cu-Au-Mo porphyry	v	22000	300		21	540	Seo et al., 2009
Butte Cu-Mo porphyry	b	68000	5900	12000		1200	Rusk et al., 2004
Butte Cu-Mo porphyry	b	110000	170	3300		1000	Rusk et al., 2004
Butte Cu-Mo porphyry	b	100000		5600		1000	Rusk et al., 2004
Butte Cu-Mo porphyry	b	55000		9500			Rusk et al., 2004
Butte Cu-Mo porphyry	b	100000	380	4700		1000	Rusk et al., 2004
Butte Cu-Mo porphyry	b	110000	81	4000		860	Rusk et al., 2004
Butte Cu-Mo porphyry	b	110000	1000	4300		1100	Rusk et al., 2004
Butte Cu-Mo porphyry	b	91000	800	5800		810	Rusk et al., 2004
Butte Cu-Mo porphyry	b	100000	1100	4500		800	Rusk et al., 2004
Butte Cu-Mo porphyry	b	80000	88	6900		1300	Rusk et al., 2004
Butte Cu-Mo porphyry	b	100000	140	8300		1600	Rusk et al., 2004
Butte Cu-Mo porphyry	b	97000	440	12000		2000	Rusk et al., 2004
Butte Cu-Mo porphyry	b	83000	150	9800		1400	Rusk et al., 2004
Butte Cu-Mo porphyry	b	96000	760	15000		1700	Rusk et al., 2004
Butte Cu-Mo porphyry	b	97000		7900		1300	Rusk et al., 2004
Butte Cu-Mo porphyry	b	74000		6400		840	Rusk et al., 2004
Butte Cu-Mo porphyry	b	91000	850	7100	16	1500	Rusk et al., 2004
Butte Cu-Mo porphyry	b	100000	2400	2800		790	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6300	4400	130		32	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7800	2100				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6100	3800	64			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7800	3400	170	5	20	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	5900	5600	100		8	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6500	5600	150		24	Rusk et al., 2004

Butte Cu-Mo porphyry	sc	5200	3800	140		10	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6300	10100	140		35	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	4000	13400	81			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	5100	6600	120		19	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8900	1100	28			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6500	6000	100		9	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8200	1800	160		19	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6700	2200				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8100	1500	170			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8600	1200	150	8	14	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6900	5000	160		22	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6600	3600	160		17	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7800	2300	110		22	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7900	2200	170		23	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	10000	51	43		30	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	4300	2000	140		11	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8800	320	100		48	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	5200	2300	100		9	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6400	160	90		15	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8200	130	140		58	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8000	1000				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7600	1200	100			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	13000		230		76	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7200	940	190		93	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9400	600	340		62	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	5700	12000	200		50	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7000	9900	140			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	5800	10000	460	37	63	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9100	3100	560	38	83	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8700	2200	390		48	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7900	5000	300	343	66	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6100	7300	240		42	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	10000	360			61	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6000	12000			77	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9800		60		26	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8100	4300	290		46	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8600	1800	690		63	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8600	4400	110		52	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8100	5200			59	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7100	11000	70		35	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8300	7900				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8500	3400	1500		35	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9700	330	470		100	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	10000				54	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6500	11000	210		52	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9600	890	300		88	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6900	10000	210		44	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	8600	1300	640		81	Rusk et al., 2004

Butte Cu-Mo porphyry	sc	8900	4600			40	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6200	18000	1600		75	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7200	12000	300		23	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7700	13000		42	61	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	10000	5500				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7100	15000	210			Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9900	7200	200		100	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	12000	2100				Rusk et al., 2004
Butte Cu-Mo porphyry	sc	9500	8100	330		68	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	4500	18000	350		59	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	6400	14000	270		56	Rusk et al., 2004
Butte Cu-Mo porphyry	sc	7900	8000	1100			Rusk et al., 2004
El Teniente porphyry Cu-Mo	b	96900	820	2600	4	650	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	112400	450	2600	11	520	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	104600	260	6600	8	2100	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	139500	9600	4800	17	760	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	92400	4900	4400	12	1000	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	86600	2800	4100	55	750	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	114200	5000	4300	760	620	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	152000	4600	1300	660	460	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	159800	7900	1700	1200	610	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	200700	3900	1100	830	220	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	166200	29100	1400	1300	550	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	176400	7400	1300	1000	520	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	177600	4200		1800	400	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	189700	730		610	610	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	97800	400	1700	17	640	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	81000	420	2300		460	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	75300	400	23700	8	800	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	98400	620	910	120	270	Klemm et al., 2007
El Teniente porphyry Cu-Mo	b	96100	2100	4500	60	1000	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	37800	370	1600	80	220	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	34700	1500	980	6	240	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	5400	1400	220		50	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	8600	3300	240	15	40	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	10200	14400	300	17	50	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	13200	4300	220	8	50	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	5100	21100	110		13	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	15400	4500	150	11	75	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	15500	2500			50	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	14400	2800	250		65	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	11800	6200	270	6	55	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	17300	4600	460	8	75	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	8100	8700	120	7	19	Klemm et al., 2007
El Teniente porphyry Cu-Mo	sc	20800	1700	190		59	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	8800	5800	260	60	35	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	900	260	12	6	9	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	2900	350	55	3	11	Klemm et al., 2007

El Teniente porphyry Cu-Mo	v	2200	3200			20	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	7500	9700	140	3	35	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	1200	3700				Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	1900	1500	100	4	16	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	2800	10900	80	8	15	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	3000	23200	90	5	14	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	6800	18800	270	19	50	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	14200	7200	290	55	70	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	6400	16200	220	25	35	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	8600	7900		12	60	Klemm et al., 2007
El Teniente porphyry Cu-Mo	v	14400	3200		7		Klemm et al., 2007
Famatina Cu-Au porphyry / HS epitherm	b	196000	1500		190	1700	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	128000	880		50	1100	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	169000	50		40	930	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	110000	240		360	1200	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	85000	820		30	940	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	96000	4600			610	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	97000	3000			550	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	b	114000	3800			540	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	8000	670		40	90	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	5000	270		6	60	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	4000	1100			60	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	9000	580			70	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	34000	3300		70	200	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	8000	2100		20	110	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	9000	5500			70	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	7000	390		10	90	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	7000	1500			90	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	5000	5400			150	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	10000	1300			110	Pudack et al., 2009
Famatina Cu-Au porphyry / HS epitherm	v	1000	440			8	Pudack et al., 2009
Rosia-Poieni porphyry Cu-Au	b	111628	3009	29240		13251	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	112692	2761	28718		13300	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	109324	3161	31545		14192	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	115614	3370	23792		11069	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	117970	2571	20567		12104	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	117141	1392	20818		9503	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	118096	2366	20364		11002	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	126933	16441	4370		2000	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	119053	13997	3845		1453	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	126294	10272	4176		1079	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	116054	2102	22745		11145	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	108437	8874	30565		14115	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	110684	3970	31198		15865	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	129053	1516	9976		4890	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	113825	2621	24544		12579	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	115400	1487	19633		16947	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	113836	3170	25023		12461	Kouzmanov et al., 2010

Rosia-Poieni porphyry Cu-Au	b	117696	2019	22070		7277	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	120260	2314	16677		10056	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	118632	1860	18853		10462	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	119786		13816		26325	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	122163	1885	17538		10794	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	119590	1317	21814		11815	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	115808	1057	25452		14115	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	105602	1748	39610		17722	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	97573	2581	43213		20343	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	107373	2986	35954		19660	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	108885	3725	34765		19574	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	109691	5232	34364		18912	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	105348	5147	33324		17606	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	94639	139	26504		10189	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	101573	113	23176		10715	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	101142	194	19817		11812	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	107724	244	30213		17146	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	105114	337	5946		3760	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	101035	319	6591		4178	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	102399	235	7808		4189	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	b	96803	167	16573		4911	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1675					Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1642	30	31		1.7	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1957		24			Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1821		3.5			Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1961	47			0.5	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1935	1332	33		13	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1963	67				Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1567		531		153	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1941		40		0.7	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	785		211			Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1664		172		33	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1386		134		9.3	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1617		809		23	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1952		28			Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1014					Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1870				1.4	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1936		4.1		1.5	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1967					Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1226		27		15	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1816					Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1581	113	76		3.8	Kouzmanov et al., 2010
Rosia-Poieni porphyry Cu-Au	v	1252	303	832		625	Kouzmanov et al., 2010
Santa Rita Cu (Mo-u) porphyry	b	67900	2300	3400		800	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	b	68100	2700	2800	13	590	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	b	75000	2200			780	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	b	74300	2800	2300	42	830	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	b	61800	1700	2800		840	Audétat et al., 2008

Santa Rita Cu (Mo-u) porphyry	b	64900	620		380		Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	v	50000	7800	2500	5	410	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	v	50800	8800	1300		390	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	v	28400	4100			200	Audétat et al., 2008
Santa Rita Cu (Mo-u) porphyry	v	50000	3800	1400	15	420	Audétat et al., 2008

Supplemental file Table S3

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Reference	Volcano	Temperature	Sampling date	Li	Be	B	F	Na	Mg	Al	Si	P	S	Cl	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Rb	Sr	Y	Zr
Bernard et al, 1990	St-Helens	657						5.6							3.9																8.0				
	St-Helens	657						5.6							3.9																8.1				
Gemmel, 1987	Cerro Negro	170	november to december 1981				7.5	3.5	2.4	4.6	5		77	330	3.4	5.9	0.009	5.7				3.5	0.003	0.17	0.3	0.7			0.079		0.4				
	Cerro Negro	250					3.5	1.9	2.2	25	20		93	4000	1.7	0.4	0.007	82			0.1	14	0.005	0.72	0.3	0.5			0.085		3				
	Cerro Negro	260					2	1.5	2	5.9	18		83	11000	1.3	1.5	0.004	103			0.1	104	0.008	0.28	0.2	0.8			0.095		3.2				
	Cerro Negro	272					5.4	1	1.3	7.2	7		80	1050	1.5	0.9	0.002	45				46	0.005	0.21	0.2	0.4			0.045		0.5				
	Cerro Negro	274					4.3	3.5	4.8	17	14		280	3100	3.2	2.5	0.006	66		0.06	0.2	14	0.007	0.25	0.4	0.3			0.075		2.4				
	Cerro Negro	300					5.3	4.4	3.4	9.9	10		22	520	1.5	3.6	0.001	4			0.1	3.6	0.007	0.22	0.8	1.6			0.031		0.1				
	Cerro Negro	315					7.5	1.1	1.5	3.9	5		287	2100	1.4	2.9	0.002	25				10	0.002	0.18	0.2	0.4			0.045		0.7				
	Masaya	150					1	3.9						42			0.0003					1.5	0.002	0.3					0.047		0.051				
	Momotombo	456		0.02			6.7	11		11	17		1135	2920	3.6			276		0.23		50			0.4	1.5									
	Momotombo	471		0.05			7	11		53	16		135	1800	5.7	0.1	0.017	334		0.2	0.5	30	0.015	0.38	0.3	0.7			0.23		16				
	Momotombo	485					2	7.7		13	11		163	1550	5.1	0.2	0.009	239		0.15	0.4	21	0.013	0.29	0.3	0.4			0.25		14				
	Momotombo	500					3	3.5		1.9	12		648	2400	1.8	1.5	0.004					21	0.004	0.43	0.2	1.3			0.49		25				
	Momotombo	536					8	3.6		25	18		654	2350	4.8	0.2	0.01	218		0.14	0.3	18	0.008	0.31	0.2	0.9			0.25		12				
	Momotombo	666					5	7.1		14	17		140	2850	11		0.007	252		0.25	0.1	15	0.007	0.3	0.2	0.7			0.28		14				
	Momotombo	765		0.03			5.2	2.7		42	48		1028	5600	25	4.6		156		0.26	0.4	8.1			0.2	1.9									
	Momotombo	770					42	19		133	121		1359	2200	41	0.6		598		0.59	0.5	15			8.4	7.6									
	Poas	344					27	13	1.9	23	19		591	1090	4.8		0.003	57		0.24	0.1	13	0.009	0.81	0.2	8.6									
	Poas	561					5.6	3.4	1.7	23	19		567	1250	4.1	0.2	0.005	170		0.19	0.1	27	0.022	0.69	0.2	4.4									
	Poas	711					2.4	1.6	0.5	2.6	73		668	1200	4.4	0.3	0.004	181		0.19		3.4	0.002	0.5	0.2	0.5									
	Poas	724		0.05			1.4	5.4	0.9	12	23		494	1250	13		0.006	237		0.3	0.1	10	0.068	1.7	0.1	1									
	Poas	819		0.05			1.3	9.2	1.5	23	42		641	1120	17	0.2	0.005	2600		0.34	0.1	24	0.053	0.83	0.6	3.3									
	Poas	830					0.6	6	3.6	38	41		781	910	11	0.2	0.007	416		0.6	0.3	49	0.062	0.69	0.2	4.6									
	Poas	851					0.7	29	11	134	81		875	880	79	4.5	0.005	739		0.69		17	0.071	0.73		6.9									
	Poas	852		0.04			0.8	7.1	0.8	9.9	17		855	1120	14		0.006	112		0.29		7.2	0.067	1.6	0.3	1.3									
	Telica	150		0.04			0.5	0.4	0.4	0.8			5	125	2.4	0.2	0.0001	0.4		0.04	0.1	0.4	0.001	0.18	0.04	0.4			0.077		0.058				
Hedenquist, 1994	Satsuma Iwojima	102	26/10/1990			0.09	0.38	2.8	0.05	0.024			27549	38	0.2	0.07					0.003	0.034			0.003	0.027							0.0007		
	Satsuma Iwojima	105	26/10/1990			0.84	410	6.9	0.04	0.41			24090	12140	1	0.34					0.002	0.06			0.02	0.06			1.71				0.002		
	Satsuma Iwojima	165	27/10/1990			7.43	456	8.3	0.061	0.397			19501	5670	1.5	0.099					0.0003	0.238			0.013	0.012			1.52				0.0004		
	Satsuma Iwojima	330	26/10/1990			28.1	154	8.7	0.05	1.51			21163	20720	1.1	0.2					0.003	0.12			0.006	0.027			3.96				0.002		
	Satsuma Iwojima	505	24/10/1990			13.7	255	6.1	0.064	0.065			25773	34220	1.2	0.284					0.001	0.062			0.064	0.064			4.55				0.002		
	Satsuma Iwojima	705	24/10/1990			29	488	15	0.15	3.74			20449	11800	4.8	16.2						1.18			0.036	0.24			3.27				0.008		
	Satsuma Iwojima	877	24/10/1990			10.7	355	12	0.08	1.33			17965	13670	2.1	0.19						0.62			0.03	0.15			1.74				0.001		
	Satsuma Iwojima	877	27/10/1990			18.07	368	6.3	0.15	1.13			18910	10480	1.3	0.41						0.81			0.009	0.17			1.81				0.002		
Menyailov & Nikitina, 198	New Tolbachik N	950	01/10/1975				540	29.2	7.5	24.5			3	2615	10.2	7.8						7			3.5	0.384									
	New Tolbachik S	980	01/10/1975				2800	420	6.1	290.3			63	14609	182	3						33.5			2.17	15.6									
	New Tolbachik S	1010	14/08/1976			32.3	2100	200	5	45.7			439	18233	165	23.1	0.0019	1.8		0.025	0.38	37	0.012	1.08	5.9	9.61			24		36	0.78			
	New Tolbachik S	1020	01/10/1975				2700	700	9.3	202.5			77	21347	240.5	3.4						9			14	9.26									
Menyailov et al, 1986	Momotombo	790	1982									58	21			3.5				3.8	2.9	0.2								0.1	0.52				
Mizutani, 1970	Showa Shinzan	194	01/07/1959											234												0.14									
	Showa Shinzan	222	08/08/1958											330												0.12									
	Showa Shinzan	300	04/07/1959											290												0.28									
	Showa Shinzan	328	06/07/1959											285												0.27									
	Showa Shinzan	430	04/07/1959											1310											0.009	1.2									
	Showa Shinzan	460	09/07/1959											1130											0.011	1.6									
	Showa Shinzan	464	04/07/1959											250												0.12									
	Showa Shinzan	470	14/08/1958											1130											0.012	1.5									
	Showa Shinzan	645	01/07/1959											970												1									
	Showa Shinzan	661	10/08/1958											885											0.019	1.3									
	Showa Shinzan	700	09/07/1959											1000											0.007	0.55									
	Showa Shinzan	750	07/07/1959											763											0.005	0.6									
	Showa Shinzan	759	12/08/1958											868											0.018	2									
This paper	Merapi	266	01/07/2004			13.000	59.7	0.6	0.37	1.48	17		520	893	1.13			0.209	6.00E-03	1.80E-02	7.30E-02	1.48	9.40E-04	8.00E-03	3.00E-03	0.06	1.00E-03	2.60E-03	0.67		2.37		1.49E-02	6.60E-04	0.005
	Merapi	417	01/08/2006	6.52E-03			245	1.21	0.47	1.35	24		10579	7193	0.63	1.03	1.96E-03	0.054		8.13E-03	2.09E-02	2.02	0.0461	5.56E-02	2.79E-01	0.15	5.87E-04	4.97E-04	2.99	4.60E-02	11.46		1.91E-02	4.90E-04	0.011
	Merapi	515	01/08/2006	3.34E-02		0.330	320	2.31	0.25	1.46	32		6733	4849	2.27	0.4	8.69E-03	0.046	6.89E-04		4.39E-02	1.43	0.00778	9.96E-03	1.61E-01	0.42	3.77E-04	3.98E-04	2.21	4.38E-02	8.22		1.95E-02	3.80E-04	0.022
	Merapi	515				7.550	296	1.2	0.14	1.52	64		3672	5630	0.65	0.6		0.120	1.15E-01		3.10E-02	0.65	1.00E-03	7.00E-03	8.00E-03	0.1	2.00E-03	3.00E-03	0.11	1.37E-01	2.85		3.40E-03	4.00E-04	0.007
	Merapi	526				40.200	185	2.11	1.24	3.39	34		7644	6710	2.83	4.6		1.280	1.88E-01	1.01E-01	3.91E-01	8	4.60E-03	4.70E-02	5.00E-03	0.17	4.00E-03	9.00E-03	0.44	2.10E-02	11.8		2.60E-02	1.70E-03	0.011
	Merapi	572	01/07/2004			36.000	124	3.43	0.89	3.44	24		263	3030	2.3	3.46		0.400	1.10E-02	6.40E-02	1.02E-01	2.58	1.44E-03	2.90E-02		0.15	1.60E-03	4.00E-03	0.98	3.40E-02	5.43		7.53E-02	3.90E-03	0.012
	Merapi	588				19.600	303	2	0.46	2.61	71		5207	6500	1.21	3.7	1.10E-02	0.535	9.00E-02	1.06E-01	1.18E-01	3.06	1.90E-03	5.00E-02	5.00E-03	0.15	3.00E-03	1.30E-02	0.12	1.10E-01	8.32		3.00E-02	1.40E-03	0.011
	Merapi	593				17.500	193	11.5	0.6	5.52	43		5307	3830	2.99	4.3		0.219	2.42E-01	6.60E-02	1.13E-01	4.69	2.00E-03	3.90E-02	2.20E-03	0.52	3.00E-03	2.30E-02	3.45	3.10E-02	3.46		4.80E-02	1.70E-03	0.005
	Merapi	602				8.190	228	2.71	0.32	1.71	4		2597	5330	1.05	2.1		0.034	1.83E-01	8.10E-02	5.10E-02	0.91	1.60E-03	4.60E-02	9.00E-03	0.14	2.00E-03	3.00E-03	0.49	6.60E-02	3.39		1.10E-02	2.90E-04	0.005
	Merapi	604				27.500	223	9	0.81	9.13	28		3638	5420	4.99	5.95		0.179	4.00E-02	1.23E-01	1.54E-01	4.3	2.30E-03	1.40E-02	2.70E-02	0.18	2.00E-03	3.00E-03	0.3	6.80E-02	13.9		8.20E-02	4.20E-03	0.016
	Merapi	622	23-08-2005				110	4.57	0.38	2.49	1000		3438	957	1.5			0.101	0.264		5.10E-02	1.7	6.10E-04	1.00E-02	1.10E-02	0.168	5.00E-04	2.10E-03	0.149	2.40E-02	1.55	1.03E-02	8.10E-03	2.80E-04	0.003
	Merapi	705				38.700	343	1.14	0.12	2.65	6		3438	7250	0.44	0.6		0.077	1.26E-01	1.09E-01	3.40E-02	1.06	7.00E-04	4.90E-02		0.13	2.00E-03	3.40E-02	3.72	1.20E-02	12		7.00E-03	2.50E-04	0.007
	Merapi	754				30.500	194	0.74	0.07	0.25	24		1803	6620	0.31	0.4		0.012	1.99E-01	9.60E-02	2.60E-02	0.12	1.80E-04	3.10E-02	1.00E-02	0.14	1.00E-03	3.00E-03	1.73	4.30E-02	9.2		6.00E-03	7.00E-05	0.003
Oana, 1962	Showa Shinzan	220	01/08/1955					13.3	7.5	13	29				1.7	9.4								0.00075	0.004	0.02		0.00075	0.0075						
	Showa Shinzan	525	01/08/1955					22.9	3.8	13	50				11.2	1.6								0.00075	0.035	0.4		0.003	0.3						
	Showa Shinzan	760	01/08/1955					23	39.6	15	65				15.9	9.86									0.035	0.55			0.75						
Stoiber & Rose, 1970	Arenal	188	29/03/1969				2	2	1				20	240	1	2																			
	Cerro Negro	216	10/07/1968					53	26				19	7300	5	40																			
	Cerro Negro	275	19/01/1969				0.8	48	25				5341	2900	50	58																			
	Cerro Negro	343	10/07/1969				0.7	18	18					4200	8	65																			
	Cerro Negro	427	23/03/1969				0.4	3	1				3	180	3	2																			
	Cerro Negro	570	19/01/1969				1.1	6	3				50	1400	8	9																			
	Cerro Negro	610	09/11/1968					16	6				5	1500	7	15																			
	Cerro Negro	740	24/03/1969				1.5	34	1				170	2800	43	1																			
	Fuego	163	09/02/1969				0.5	7	2				220	5300	1	4																			
	Fuego	257	20/08/1967				2	13	2				10	2100	2	6																			
	Fuego	442	09/02/1969					8	8				935	3200	1	5																			
	Izalco-L	258	05/12/1968					6	2				3	150	2	4																			
	Izalco-L	293	13/07/1969				4	1						750	1																				
	Izalco-L	300	04/07/1968				0.2	2	4				4	1300	8	5																			
	Izalco-L	303	20/06/1967					9	8				5	800	3	9																			
	Izalco-L	307	12/11/1968				3	2						850	2	5																			
	Izalco-L	308	16/03/1969				12	1					4	1300		3																			
	Izalco-L	312	13/08/1968				0.2	2	7				4	900	2	7																			
	Izalco-L	312	21/02/1969				0.4	13	1				2	80	3	5																			
	Izalco-L	327	09/10/1968					1	2				3	850	8	3																			
	Izalco-L	340	18/11/1967				6	2	1				6	1500	1	3																			
	Izalco-L	346	25/07/1967					4	11				4	850	1	5																			
	Izalco-L	346	22/05/1969				0.2	3	1				4	1500	1	4																			
	Izalco-L	347	03/08/1967					3	11				2	1400	1	2																			
	Izalco-L	359	22/11/1966				4	4	2				4	1200	2	3																			
	Izalco-L	361	11/02/1968					2	15				8	1500	1	21																			
	Izalco-L	370	17/11/1967				9	2	2				4	1100	2	7																			
	Izalco-L	374	11/01/1967				6	3	7				9	2500	2	41																			
	Izalco-L	374	15/08/1967				11	1					11	900		2																			
	Izalco-L	375	22/08/1966				7	6	3				4	1800	2	5																			
	Izalco-L	378	25/05/1967				0.2	2	14				6	2700	1	2																			
	Izalco-L	385	26/07/1966					7	8				7	1800	5	20																			
	Izalco-L	388	14/02/1967				0.2	1	4				2	1900	1	5																			
	Izalco-U	238	12/11/1968				4	3	1				4	1700	3	13																			
	Izalco-U	281	03/08/1967				1	1	1				3	150	1																				
	Izalco-U	281	15/08/1967				5	1	1				2	550	1																				
	Izalco-U	306	17/11/1967				5	1	1				4	400	1	2																			
	Izalco-U	306	17/11/1967				4	2	2				4	350	1	8																			
	Izalco-U	338	13/07/1969					3	1					570	1	1																			
	Izalco-U	339	25/07/1967				3	5	1				3	1200	2	6																			
	Izalco-U	374	16/03/1967				4	12	11				13	780	6	59																			
	Izalco-U	480	11/08/1964				92	24	5				17	2700	7	9																			
	Izalco-W	220	04/07/1968				1	3						390	8	1																			
	Izalco-W	220	12/11/1968				0.3	1	1					470	3	3																			
	Izalco-W	223	05/12/1968					1	1					50		1																			
	Izalco-W	225	09/10/1968				0.6	1	1				2	60	2	4																			
	Izalco-W	236	21/02/1969					1					2	35	3	1																			
	Izalco-W	240	13/09/1968				0.2	1	1					60	2	9																			
	Izalco-W	249	13/07/1969					1	1					180	1	1																			
	Izalco-W	263	22/05/1969				0.2							130	1	1																			
	Izalco-W	274	16/03/1969					2	3				2	300	2	1																			
	Izalco-W	297	03/08/1967				1	1					3	350		2																			
	Izalco-W	302	18/11/1967				2	2	1				8	430	1	2																			
	Izalco-W	310	17/11/1967				10	2	1				5	250	1	4																			
	Izalco-W	315	20/06/1967				1	3	2				3	220	1	2																			
	Izalco-W	317	15/08/1967				1	1					5	220		1																			
	Izalco-W	317	16/08/1967				1	4	1				4	190	1	2																			
	Izalco-W	322	25/07/1967				1	4	1				4	230	1	7																			

Nb	Mo	Pd	Ag	Cd	In	Sn	Sb	Te	I	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Pt	Au	Hg	Tl	Pb	Bi	Th	U
	0.095																											0.003									
	0.095																											0.003									
	0.18		0.02	0.19		0.75	0.004				0.15																				0.001	0.004					
	0.28		0.006	0.35		1	0.003				0.09																				0.001	0.005					
	0.29		0.006	0.36		0.95	0.003				0.14																				0.003	0.005					
	0.2		0.005	0.2		0.84	0.003				0.08																				0.002	0.004					
	0.26		0.008	0.33		0.99	0.003				0.12																				0.001	0.005		0.4			
	0.19		0.003	0.16		0.8	0.003				0.26																				0.001	0.004					
	0.2		0.004	0.21		0.82	0.002				0.04																				0.001	0.004					
	0.22		0.006	0.17		0.77	0.002																								0.001	0.004					
											0.24																							2.5			
	0.49		0.011	0.73		1.5	0.003				0.58																				0.001	0.007		?			
	0.48		0.009	0.69		1.4	0.003				0.59																				0.001	0.01		2			
	0.15		0.014	0.02		2.4	0.096				0.83																				0.024	0.096		?			
	0.45		0.006	0.65		1.1	0.003				0.31																				0.001	0.006		5.2			
	0.5		0.005	0.71		1.2	0.004				0.07																				0.001	0.021		1.9			
											0.76																							2.5			
											1.6																							5.1			
			0.009			1.4	0.008				0.14																					0.016		0.8			
			0.11			1.6	0.008				0.14																					0.013		1.1			
			0.006			1.4	0.008				0.13																					0.015		1.1			
			0.02			3.3	0.004				0.31																					0.03		3.7			
			0.18			2.6	0.003				0.58																					0.024		3.7			
			0.25			3.9	0.004				0.37																					0.036		4.2			
			0.13			3.8	0.004				0.23																					0.14		3.4			
			0.10			3.1	0.004				0.22																					0.1		5.4			
	0.25		0.003	0.29		0.66	0.002				0.04																				0.003	0.003		0.4			
											0.002																							0.054			
	0.01					0.08					0.009																							0.008			
	0.005					0.2					0.008																										
						0.33					0.008																							0.24			
	0.03					0.66					0.038																							1.27			
	0.16					0.78	0.03				0.011																							1.77			
	0.43					0.46	0.02				0.003																							1.08			
	1.07					0.57	0.025				0.003																							1.49			
			0.006			0.013																									0.03		0.04			
			0.002			0.09																									0.05		1.58			
			0.006	0.5		0.09	13.8			0.38		0.036	0.016			0.0045	0.00044								0.00009	0.000077	0.13			0.76	0.0044		0.57			
			0.002			0.01																									0.03		0.1			
				1.2			0.016																														

	0.004			5.00E-04	1.24E-03	1.10E-02	3.10E-03	4.00E-03			0.110	7.80E-04	1.40E-03	1.50E-04	6.50E-04	1.50E-04	6.00E-05	1.30E-04	3.00E-05	1.30E-04	3.00E-05	7.00E-05		8.00E-05	1.00E-05	1.20E-04	1.10E-04	6.00E-04	5.40E-04		2.00E-04		1.11E-03	0.07		3.00E-04	9.00E-05
	0.000601	3.00E-05	2.40E-04	4.14E-02	4.18E-03	1.88E-02	2.13E-02	2.80E-02			0.056	9.28E-04	1.80E-03	2.21E-04	8.13E-04	1.98E-04	4.80E-05	1.40E-04	6.70E-05	1.25E-04	2.30E-05	8.60E-05	2.00E-05	5.00E-05	1.00E-05	2.78E-04	2.81E-05	1.21E-03	4.00E-05	1.21E-03	2.00E-05	6.95E-03	2.60E-01	8.93	2.56E-01	2.30E-04	7.90E-05
		1.10E-05		8.40E-02	2.10E-02	2.19E-01	1.95E-02	1.30E-05			0.034	2.30E-04	1.86E-03	1.27E-04	7.20E-04	1.81E-04	1.00E-05	6.00E-05	1.30E-05	5.40E-05	2.40E-05	7.50E-05	1.00E-06	4.60E-05		4.94E-04	3.00E-05	2.20E-03	3.10E-05	1.38E-03			1.70E-01	8.53	2.57E-01	1.10E-04	6.00E-05
	0.477			6.00E-03	3.00E-04	4.00E-03	9.00E-04	9.20E-02			0.009	4.00E-04	7.00E-04	7.00E-05	1.00E-04	8.00E-05		6.00E-05		5.00E-05	1.00E-05	3.00E-05		4.60E-05		2.00E-04	2.00E-04	8.00E-03	7.40E-03				2.00E-03	1.83E-01	0.36	5.67E-01	2.00E-04	8.00E-05
	0.783			3.00E-03	4.90E-03	6.00E-02	5.00E-03	2.31E-01			0.042	1.60E-03	3.20E-03	4.00E-04	1.40E-03	4.00E-04	1.00E-04	4.00E-04	5.00E-04	3.00E-04	6.00E-05	2.00E-04	3.00E-05	2.00E-04		3.00E-04	2.00E-04	3.90E-02	1.30E-02				1.70E-02	2.14E-01	0.03	6.40E-02	4.00E-04	2.00E-04
	0.02	1.00E-04		1.61E-02	4.50E-03	5.60E-02	9.80E-03	3.00E-03			0.281	1.20E-03	7.18E-03	8.40E-04	3.65E-03	8.90E-04	1.40E-04	9.50E-04	1.40E-04	7.30E-04	1.50E-04	4.10E-04	6.00E-05	4.10E-04	5.00E-05	3.10E-04	3.50E-04	4.70E-03	2.60E-04		6.00E-04	2.00E-03	1.54E-01	1.41	2.30E-02	1.10E-03	3.40E-04
	0.346			4.00E-03	1.80E-03	4.10E-02	1.00E-03	1.24E-01			0.048	1.70E-03	3.10E-03	4.00E-04	1.10E-03	4.00E-04	1.00E-04	3.00E-04	4.00E-05	3.00E-04	5.00E-05	2.00E-04	2.00E-05	1.00E-04	3.00E-05	2.00E-04	2.00E-04	5.10E-02	1.30E-02				5.00E-03	2.48E-01	0.44	2.82E-01	5.00E-04	2.00E-04
	0.256	1.00E-03		4.00E-03	2.00E-03	4.60E-02	5.00E-03	2.12E-01			0.020	1.20E-03	3.00E-03	3.00E-04	1.20E-03	5.00E-04	1.00E-04	4.00E-04	5.00E-05	9.00E-04	6.00E-05	2.00E-04	2.00E-05	1.00E-04	3.00E-05	3.30E-04	1.00E-04	7.70E-02	7.10E-03				8.00E-03	1.31E-01	0.07	1.38E-01	2.00E-04	1.40E-03
	0.148			2.00E-03	4.00E-04	3.00E-03	7.00E-04	4.00E-02			0.012	4.00E-04	6.00E-04	7.00E-05	1.00E-04	7.00E-05	2.00E-05	1.50E-04		6.00E-05		3.00E-05		3.00E-05		1.00E-04	2.00E-04	1.60E-02	2.70E-03				4.00E-03	2.27E-01	0.42	4.95E-01	1.00E-04	9.00E-05
	0.161			1.50E-02	1.70E-03		2.00E-03	4.10E-02			0.066	2.70E-03	5.70E-03	8.00E-04	4.10E-03	8.00E-04	1.00E-04	8.00E-04	2.00E-04	5.00E-04	2.00E-04	5.00E-04		4.00E-04		5.00E-04		7.00E-03	1.10E-03		5.00E-04		1.00E-02	2.87E-01	1.31	9.30E-02	7.00E-04	2.00E-04
0.000	0.284			4.00E-03	9.10E-04	1.40E-02	9.00E-04	7.90E-02	1.24E+00		0.009	2.80E-04	5.50E-04	7.00E-05	2.70E-04	6.00E-05	2.00E-05	5.00E-05		5.00E-05		4.00E-05		4.00E-05		8.00E-05		4.02E-02	4.55E-05				3.00E-03	1.34E-01	8.51E-02	3.40E-02	1.10E-04	4.00E-05
	0.357			3.00E-03	1.40E-04	1.30E-02	7.00E-03	2.19E-01			0.015	3.00E-04	6.00E-04	5.00E-05		9.00E-05	1.00E-05	1.00E-04		5.00E-05		2.00E-05		5.00E-05		2.00E-04	2.00E-04	3.50E-02	1.10E-02				8.00E-03	1.99E-01	0.08	1.78E-01	2.00E-04	3.00E-05
	0.182	5.30E-03		3.00E-03	2.00E-05		1.20E-03	3.00E-03			0.005	5.00E-04	1.40E-03	2.00E-05		2.00E-05		1.00E-05								1.30E-04	1.00E-04	3.00E-02	7.50E-03				2.00E-03	1.01E-01	0.26	4.78E-01	5.40E-04	
						0.0015																												0.005			
			0.0075			0.0065																												0.03			
			0.003			0.03																												0.005			

	Izalco-W	331	11/02/1968				1	2	1				5	160	1	3																			
	Izalco-W	342	09/11/1965				43	9	5				5	1700	5	29																			
	Izalco-W	346	22/08/1966				6	2	2					850	2	2																			
	Izalco-W	354	11/08/1966				20	7	6				23	1800	4	35																			
	Izalco-W	368	25/05/1967				1	2	1					160		2																			
	Izalco-W	369	22/11/1966				1	6	3				5	1600	4	4																			
	Izalco-W	382	29/03/1967					12	9					550	4	25																			
	Izalco-W	386	14/02/1967				20	4	3				4	1900	2	27																			
	Izalco-W	391	16/03/1967				4	6	4				4	800	3	27																			
	Izalco-W	399	14/03/1966				37	10	10				33	3300	10	110																			
	Izalco-W	415	21/09/1965				38	4	3				2	850	3	7																			
	Izalco-W	420	15/01/1965				200	9	6				10	4400	7	7																			
	Izalco-Y	378	18/11/1967				7	6	2				7	800	3	5																			
	Izalco-Y	381	16/03/1969					3	1					60	2	2																			
	Izalco-Y	384	01/11/1968				2	16	2				5	4300	3	23																			
	Izalco-Y	385	02/07/1966				2	9	15				9	1800	5	23																			
	Izalco-Y	447	18/11/1967				20	8	6				10	4600	3	18																			
	Izalco-Y	480	09/11/1965				250	25	14				334	9500	11	250																			
	Izalco-Y	488	04/07/1966					4	3						1	9																			
	Izalco-Y	505	12/02/1965				240	22	14					4200	10	17																			
	Izalco-Y	513	11/08/1964				370	6	3					6200	5	6																			
	Pacaya	420	21/01/1966				0.7	53	63				768	50000	35	90																			
	Pacaya	467	08/01/1966				4	17	33				1669	3200	7	55																			
	Pacaya	470	20/03/1966				88	9	22				40	3100	9	45																			
	Pacaya	480	01/02/1966				170	90	69				3104	38000	42	94																			
	Pacaya	796	16/07/1969				240	23	3					10000	15	5																			
	Santiaguito	85	15/11/1966				22	1					67	1200	2																				
	Santiaguito	91	08/08/1967				25	30	6				3	1000	5	75																			
	Santiaguito	126	23/08/1967					9	19				33	12000	1	2																			
	Santiaguito	132	28/01/1966				3	60	120				1669	13000	75	110																			
	Santiaguito	132	21/07/1967				1	10	1				3	800	1	7																			
	Santiaguito	135	02/11/1968					11	2				167	1200	2	7																			
	Santiaguito	135	02/08/1964				160	7	1				3	2100	4	2																			
	Santiaguito	165	28/12/1968				0.1	2	1				367	1600	1	1																			
	Santiaguito	173	20/03/1967					4	7				330	1700		160																			
	Santiaguito	174	19/03/1967				4	3	3				25	370	2	7																			
	Santiaguito	180	08/09/1968					1	1				2	50	2	9																			
	Santiaguito	182	12/07/1968				0.2	10						10	3	5																			
	Santiaguito	197	02/04/1966											14000																					
	Santiaguito	204	30/01/1966				41						501	11000	1	4																			
	Santiaguito	210	22/07/1967				11	23	5				19	4700	4	28																			
	Santiaguito	210	13/11/1967				5	10	1				5	1000	1	8																			
	Santiaguito	212	24/08/1967				3	23	2				4	7500	5	7																			
	Santiaguito	217	12/10/1968					1	1				2	130	2	7																			
	Santiaguito	218	05/01/1967				6	13	9				184	1600	7	41																			
	Santiaguito	224	01/11/1968					2	1				4	230	2																				
	Santiaguito	230	28/12/1968				0.2	1	3				3	230	1	2																			
	Santiaguito	235	23/04/1969				0.2	1	1				3	2100	1	4																			
	Santiaguito	241	19/07/1969				4	1						850	1	1																			
	Santiaguito	248	13/11/1967				16	11	2				4	750	2	12																			
	Santiaguito	260	04/03/1969				1	10	3				4	12000	3	4																			
	Santiaguito	260	19/07/1969				13	2	1				4	5600	1	1																			
	Santiaguito	262	17/02/1965				230	13	5				27	1500	4	17																			
	Santiaguito	265	18/02/1965				60	31	9				33	10000	13	5																			
	Santiaguito	266	24/08/1967				24	18	2				13	2400	3	9																			
	Santiaguito	268	06/07/1967				12	11	2				701	1800	1	4																			
	Santiaguito	281	28/12/1968				1	1	1				22	770	1	2																			
	Santiaguito	295	08/09/1968				2	4	2				9	200	3	9																			
	Santiaguito	305	23/04/1969				3	4	1				12	1100	2	14																			
	Santiaguito	307	12/10/1968				1	4	4				134	1000	3	9																			
	Santiaguito	313	22/07/1967				1	22	2				260	640	1	8																			
	Santiaguito	315	28/12/1968					2	1				501	4600	1	3																			
	Santiaguito	318	06/06/1967				4	9	1				33	550	1	2																			
	Santiaguito	331	13/11/1967				15	49	10				314	1900	7	82																			
	Santiaguito	525	02/08/1964				2600	29	1				13	2600	3	1																			
	Santiaguito	560	29/08/1965				130	8	8						10	48																			
	Santiaguito	574	23/10/1965				170	10	4				3	350	3	15																			
	Santiaguito	650	25/10/1965				37	58	28				150	7200	23	90																			
	Santiaguito	650	25/10/1965				49	46	30				801	7400	14	88																			
	Santiaguito	789	13/02/1966				0.4	41	17				334	8500	27	92																			
Symonds et al, 1990	Augustine. AK	390	10/07/1986			2.2	5400	0.84	0.53	0.95	543		684	47000		0.95		0.97	2	0.02	0.049	15.55		0.008					0.35		200		0.005		0.61
	Augustine. AK	431	10/07/1986			9.2	1600	0.63	0.19	0.71	88		40	15000		0.72		0.26	0.36	0.002	0.038	1.02		0.018					0.12		50		0.002		0.23
	Augustine. AK	433	14/07/1986			7.6	1100	0.5	0.12	0.74	65		17	9000		0.37		0.2	0.13	0.001	0.008	0.34							0.046		25		0.003		0.1
	Augustine. AK	500	10/07/1986			1.2	1000	0.16	0.08	0.14	43		134	9600		0.2		0.2	0.46			0.69							0.14		25				0.004
	Augustine. AK	625	14/07/1986			2.5	2100	0.59	0.16	0.93	92		87	18000		0.74		0.38	0.21	0.003	0.008	1.06		0.006					2.6		50		0.005		0.57
	Augustine. AK	631	10/07/1986	0.007			4250	6.62	0.44	1.07			164	32000	8	0.99			0.031	0.01	0.13	2.07		0.017					6.1		100		0.003		8.1
	Augustine. AK	635	14/07/1986			1.6	480	1.56	0.12	0.71	55		42	6600	1	0.56		0.088	0.27		0.026	0.7							0.22		25		0.003		1
	Augustine. AK	642	10/07/1986			1.8	1200	0.43	0.14	0.38	39		33	9100		0.42		0.086	0.1		0.009	1.03							0.89		25		0.001		0.37
	Augustine. AK	870	29/08/1987	0.028		31	1000	21	0.07	0.49	160		768	20000	22	1.2		0.02	0.007	0.004	0.061	5.7		0.008					4.7		30		0.003		0.004
	Augustine. AK	870	29/08/1987	0.032		32	1100	22	0.08	0.45	140		734	21000	22	1.2		0.02		0.004	0.062	5.7		0.009					4.9		40		0.003		0.016
Symonds et al., 1987	Merapi	576	01- to 02-1984	0.007			120		6.7				164	3500	6.2				0.029	0.12	0.16	8	0.003	0.07			0.02		0.72		22		0.2		
	Merapi	576	01- to 02-1984	0.002			140		3.9				334	3700	2.6				0.98								0.49		0.35		b/l		0.095		
	Merapi	576	01- to 02-1984	0.006			220		3.9	23			197	3300	2.9				0.083								0.01		0.34		40		0.089		
	Merapi	796		0.024			310		2.3	25	n/d		174	3600	20				0.022	0.05	0.22	11	0.002	0.05			0.01		0.96		8		0.19		
	Merapi	796		0.011			110		5	n/d	n/d		274	3200	6.8				0.1	0.08	0.16	7.1		0.26			0.09		0.28		240		0.046		
	Merapi	796		0.01			230		17	n/d	n/d		835	3800	9.6				0.8								0.58		0.84		8		0.098		
	Merapi	796		0.088			130		24	120	n/d		180	3100	14				1.1								0.43		0.63				0.21		
Symonds et al., 1996	Showa Shinzan: Usu	336	6/24/1985			18	64	6	3	18	14			485	2	22		0.008	0.008	0.004	0.2	3.3		0.021	0.034	0.58			1.1			0.01	0.074		
	Showa Shinzan: Usu	560	5/8/1961			12.9	186	3	5	2.5	29		47	1360		2		0.006	0.006	0.027	0.03	1.5		0.023	0.11	0.63			0.96			0.003	0.008		
	Showa Shinzan: Usu	588	9/1/1974			19.6	153			0.88	5			735		3		0.002	0.002		0.009	0.57			0.006	0.25			1.1			0.002	0.003		
	Showa Shinzan: Usu	600	10/5/1973			19.2	170			0.19	7		40	780		0.9		0.002	0.002		0.001	0.04			0.002	0.11			1.1				0.001		
	Showa Shinzan: Usu	635	8/7/1963			24.6	310	9		2.7	54		53	1880		9		0.002	0.002		0.009	0.23			0.004	2.9			1.7			0.002	0.011		
	Showa Shinzan: Usu	637	9/23/1964			20.9	290	3		0.97	32		43	1390		6		0.005	0.005	1.1	0.088	4.2		0.42	0.081	1.8			1.5			0.004	0.01		
	Showa Shinzan: Usu	661	8/10/1958			19.3	209	3	3	1.2	21		33	919		5		0.007	0.007		0.006	0.28			0.015	0.52			1.4		1.1	0.002	0.003		
	Showa Shinzan: Usu	662	8/6/1962			21.7	298	7		2.3	54		53	1990	3	0.9		0.004	0.004		0.004	0.22			0.003	0.41			1.7			0.004	0.005		
	Showa Shinzan: Usu	722	8/11/1960			11.2	213	3	3	0.62	25		57	1010		0.9		0.002	0.002		0.004	0.14		0.028	0.007	0.49			1		0.8	0.003	0.002		
	Showa Shinzan: Usu	830	8/14/1955			27.6	309	130		7.1	130		43	1080	9	53		0.002	0.002		0.14	0.99			0.02	0.32			3.1			0.025	0.032		0.031
Taran et al., 1995	Kudryavy	535	01/01/1992	0.002		35.3		2.44	0.12	4.8	98	22.7		13580	15.5	2300	0.056	0.16		0.015	0.017	2.28		0.05	0.76	0.25		0.09	0.63		0.36	0.01	0.01		1.2
	Kudryavy	585	01/01/1991	0.024		38.5	562	22.5	1.7	9.65	184			12210	12.8	5	n/a	0.7		0.024	0.12	3.7	0.001	0.05	0.032	0.58		0.037	0.73		9.4	0.038	0.023		0.38
	Kudryavy	605	01/01/1992	0.007		17.54	460	2.56	4.3	8.9	11	4		2070	20.5	14.3	0.05	0.64		0.07	0.18	17.65	0.005	0.05	0.91	13.5		0.03	0.54	0.1	0.24	0.01	0.055		0.65
	Kudryavy	825	01/01/1992	0.015		42	105	5	0.88	7.1	99	2		12850	9.53	1.73	0.06	0.13		0.115	0.055	3.62	0.003	0.32	0.09	1		0.01	1.25	0.2	0.75	0.05	0.015		1.28
	Kudryavy	870	01/01/1991	0.029		36.6	503	41.2	1.76	13	197			15380	28.66	5.5	n/a	0.62		0.045	0.21	6.8	0.16	0.055	0.13	1		0.038	1.55		10.4	0.75	0.13		0.46
	Kudryavy	940	01/01/1992	0.03		33	164	6.1	0.5	3.9	79	30.8		8580	5.62	2	0.06	0.14		0.13	0.09	7.3	0.006	0.41	0.27	3.1		0.027	1.2	0.17	0.75	0.045	0.01		0.98
Taran et al., 2001	Colima	738	8/1/1997			26	243	29	1.42		56		768	7320	17	1.35		0.633	160	0.079	0.05	2.6		0.042	0.87	4.97			0.368	0.37			0.032		
Taran et al., 2001	Colima	742	3/1/1997			28	310	36	1.2		98		517	10500	22	1.2		0.623	0.263	0.169	0.056	3.27	2.00E-03	0.023	0.931	5.3			0.433	0.45			0.056		
Taran et al., 2001	Colima	828	6/1/1997			18	250	24	1.025		74		1333	6550	26	1.7		0.7	1.04	0.121	0.008	4.24		0.015	0.44	8.14			0.525	0.298			0.016		
Berlo et al., 2014	Kawa Ijen	350	2007	0.05	0.07	103		320	29	96	209	30	434	25383	45	121	2.8	4.4	1.1	16.5	2.5	131		7.5	13.6	5.2			16.1	6.5		0.13	0.46	0.03	0.03
	Kawa Ijen	350	2007	0.18	0.14	316		464	40	231	1559	62	3636	66821	60	491	6.2	29	2.3	6.6	0.3	133		10.3	21.9	11.8			42.4	23.9		0.3	2.56	0.1	0.2
	Kawa Ijen	350	2007	0.08	0.08	176		199	16	59	605	28	2168	37895	10	113	3.1	14	1.2	3.2	0.1	45		5.2	11.3	5.3			20.4	12.5		0.11	0.27	0.03	0.06
Wahrenberger et al., 2002	Kudryavy	160				16.1			0.0912	0.178										0.0283	0.00347	0.318		0.0735	0.034	0.333			0.264	0.0338	0.578				
	Kudryavy	300				8.73			0.404	8.41								21.9	0.0199	0.142	26.8	1.77		0.0478	0.0311	0.126	0.00479		0.168		2.92	0.00152	0.0507		0.00271
	Kudryavy	470				11.9				0.661	5							0.115	0.00328	0.127	0.00195			0.0455	0.0116	0.115	0.00556		2.32		4.82	0.00266	0.00463		0.0103
	Kudryavy	680				17.7		3.03	0.334	0.665	4					1.66			0.00369	0.103	0.0046	0.0365		0.419	0.0205	0.501	0.00946		2.4	0.7	4.54	0.023			0.0159
	Kudryavy	710				20.1		1.08	0.413	1.01	5							0.123	0.00418	0.239	0.00731	0.601		0.0844	0.0333	0.64	0.0188		2.55		10.4	0.0533			0.0271
	Kudryavy	920	from 27-08-95 to 1-9-95			10.5		13.2	1.19	0.897	3				13.2	1.13		0.345	0.014	0.182	0.035	4.78		0.107	0.0544	1.28	0.0281		1.86		6.85	0.0621			0.0433
Zelenski et al., 2005	Mutnovsky	410	summers of 2000-2002	0.005		18		4.6	0.55	1.6	69				1.6	1.9		0.093	0.017	0.009	0.007	0.61		0.004	0.003	0.06	0.001		6.9	0.32	4	0.003	0.006		0.056
	Mutnovsky	450	summers of 2000-2002	0.003		25		8	0.28	2.1	112				1.6	3.1		0.11	0.015		0.009	0.61		0.01	0.008	0.07	0.001		8.6	0.5	6	0.003	0.011		0.092
	Mutnovsky	480	summers of 2000-2002	0.002		27		18	0.28	4.8	33				2.2	2.8		0.087	0.019	0.02	0.017	2.1		0.019	0.008	0.048	0.002		3.8	0.29	3.8	0.001	0.014		0.025
	Mutnovsky	507	summers of 2000-2002	0.002		26		2.3	0.45	2.2	29				1.5	1.8		0.078	0.017	0.015	0.013	1.1		0.016	0.026	0.16	0.002		4.7	0.11	3.7	0.003	0.026		0.055

	3.1			0.64			0.028				0.012																							7.2			
	1.5			0.16			0.008				0.008																							1.2			
	0.64			0.07			0.005				0.008																							0.36			
	1.1			0.004			0.009				0.003																							0.12			
	2.6			0.1			0.041				0.007																							2.1			
	0.5			0.43			0.21				0.011																							9.1			
	1.6			0.069			0.006				0.004																							0.72			
	0.86			0.051			0.018				0.005																							0.15			
	1.1			0.15			0.3				0.003																							3.1	0.037		
	1.1			0.16			0.3				0.002																							3.3	0.028		
	0.08			0.05																								0.38						0.83	0.03		0.0005
	0.16			0.01																														0.32	0.17		0.0008
	0.18																											0.13						0.35			0.0005
	0.12			0.04																								0.07						1.6	0.13		0.001
	0.11			0.08																								0.07						1.5			
	0.15			0.02																														1	0.23		0.0007
	2.8			0.01			0.16																					1.1						1	0.17		0.0085
	0.61		0.004	0.1						0.009	0.098																							0.23	0.078		
			0.039	0.01							0.1																							0.023	0.049		
			0.035							0.003	0.004																										
			0.014								0.002																								0.028		
			0.037	0.01					0.12	0.002	0.062																							0.065	0.17		
	0.035		0.026	0.013						0.004	0.082																							0.05	0.11		
			0.042						0.12		0.035																								0.12		
			0.031						0.2	0.002	0.088																							0.029	0.062		
			0.076	0.008					0.064	0.002	0.009																								0.13		
	0.046		0.076	0.008			0.13			0.003	0.15																							0.065			
	0.002			0.09		0.1	0.12	0.08	0.8		0.05		0.004													0.015		0.003				0.035	0.2	6.4	0.045	0.015	
	0.004			0.23		0.38	0.24		6.7		0.38																	0.002				0.075	0.06	1.84	0.135		
	0.16			0.7		0.21	0.51	0.015	1.4		0.14		0.005													0.007		0.06	0.002			0.34	3.7	9.7	0.22	0.004	
	0.11			0.88		0.14	0.1	0.005	6.1		0.42		0.003													0.016		0.02	0.01			0.025	0.14	0.11	0.07		
	0.27			0.58		0.13	0.02		11.6	0.01	0.074																	0.04				0.015	0.065	0.58	0.11		
	0.2			0.23		0.14	0.79	0.01	5.4		0.15		0.002													0.01		0.03	0.008			0.028	0.16	1.25	0.04		
	0.097			0.045			0.049				0.45																				1.20E-04		0.034	0.48			
	0.091			0.055			0.042				0.463																				5.00E-04		0.024	0.451			
	0.182			0.74			0.13				0.32																				1.00E-04		0.053	0.078			
	0.06					0.05	0.2	2.1			0.26	0.03	0.03		0.03																	0.22	0.05	0.23			
0.05	0.47			0.01		0.33	0.46	5.5			4.61	0.12	0.22	0.02	0.08	0.01		0.01	0.01		0.05											0.59	0.48	0.8		0.01	
0.03	0.23					0.14	0.21	3			1.65	0.03	0.03								0.03											0.84	0.15	0.31			
	0.00113					0.00997	0.00258	0.00104	0.469		0.0329																	0.011						0.0138	0.00269		
	0.000561					0.0326	0.00258	0.00494	1.89		0.0809																	0.00669					0.0143	0.109	0.00338		
	0.00304			0.0012	0.00108	0.0753		0.0223	1.63	0.00274	0.184																	0.0125					0.0273	0.561	0.0672		
	0.0107			0.0395	0.00469	0.42	0.0406	0.016	1.72	0.0414	0.441																	0.0098					0.0374	0.47	0.0318		
	0.127				0.00389	0.197	0.0221	0.0196	3.07	0.0139	0.892																	0.0121					0.0546	0.668	0.0729		
	0.204			0.0554	0.00437	0.287	0.0145	27.7	2	0.00936	0.85																	0.0182					0.0772	0.791	0.0645		
0.001	0.001		0.001	0.007		0.005	0.013	0.253	1.1		0.008															0.0007		0.003				0.23	0.031	0.025	0.033	0.0001	
0.015	0.005		0.001	0.011		0.008	0.03	0.349	1.7		0.02															0.0015						0.19	0.036	0.04	0.065	0.0002	
0.002	0.005		0.001	0.032		0.014	0.012	0.12	0.35		0.085															0.0007		0.001				0.047	0.11	0.14	0.067	0.0002	
0.002	0.005		0.006	0.025		0.017	0.019	0.145	1.1		0.017															0.0009		0.006				0.16	0.098	0.13	0.063	0.0006	