

# Temporal chemical variation of the Arce tephra from Coatepeque Caldera, El Salvador, Central America

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## 1. Introduction

The Arce tephra is one of the most important time-marker in northern Central America. It was deposited by a plinian eruption which occurred at Coatepeque Caldera in 72 ka (Rose et al, 1999). It covers not only the western part of El Salvador but also the southeastern part of Guatemala, and the Pacific offshore of the both country (Kutterolf, S., et al., 2008). In proximal area, it can be identified by distinctive depositional structure as two coarse pumice units and a fine ash unit intercalated by them. It is easy to be identified also in distal area because it shows the characteristic feature as white or yellowish vitric ash that contains biotite.

In spite of such the clarity of identification in the field, the detail of chemical property of the tephra, which is quite important for correlation in broad area, remains unclear. In Kitamura (2006), the A1 tephra, biotite-bearing white vitric ash in the late Pleistocene in Guatemala Basin, was correlated to the Arce tephra, because of coincidence of the chemical composition of volcanic glass analyzed by wave length dispersive X ray microprobe. However, samples of the A1 tephra collected in Guatemala City and Antigua Guatemala City, which are analyzed prior to this study, show slightly different chemistry from that reported in Kitamura (2006). The difference of analysis suggests that the chemical composition of volcanic glass from the Arce tephra is not homogenous, probably varies during the eruption.

This study aims at revealing the chemical composition of volcanic glass in each stratigraphic unit of the Arce tephra for precise correlation in broad area. The data on vertical variation of chemistry in the sequence of stratigraphic units are also valuable to understand temporal chemical variation during the Arce eruption. Additionally, two pumices at an exposure near San Salvador, the capital city of the Republic of El Salvador, are also analyzed for demonstrating the areal distribution of the Arce tephra to the east in terrestrial region by comparing with data obtained above.

## 2. Previous studies

### (1) Arce tephra

The Arce tephra is a pumice-fall deposit emplaced by a large plinian eruption at Coatepeque Caldera (11.5 × 6.5 km; Lat. 13.87N, Long. 89.55W; Newhall & Dzurisin, 1958), and its eruptive date was determined to be 72 ± 2 ka by highly precise <sup>40</sup>Ar/<sup>39</sup>Ar dating method (Rose, et al., 1999). In CEL (1992), the pumice flow was assumed to occur in the Arce tephra eruption but the pumice-flow deposit has never been found. Around the Chalchuapa, located ca. 20 km northwest of Coatepeque

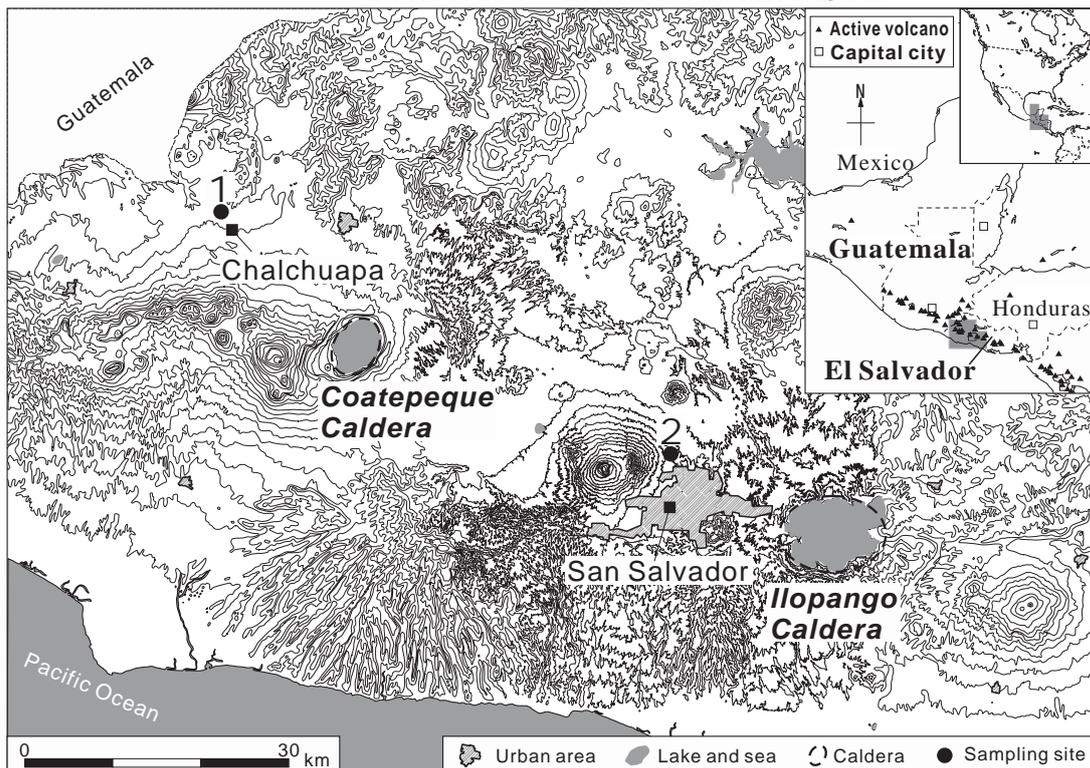


Fig. 1 General map in study area

Number with solid circle shows exposure code corresponding to the text and column number in figure 2.

Caldera (Fig. 1), the Arce tephra is observed to be separated two coarse pumice-fall units by an ash-fall unit, and all units include biotite and hornblende.

In Guatemala Basin located ca. 130 km northwest of Coatepeque Caldera, two vitric ash are known as the A1 tephra and the A2 tephra observed between two pumice-fall deposits, named the E tephra and the C tephra (Koch and McLean, 1975). The A1 tephra is correlated to the Arce tephra because chemical composition of volcanic glass from the A1 tephra is coincident with that from the Arce tephra (Kitamura, 2006).

## (2) Stratigraphic position of the Arce tephra in the tephra stratigraphy

The Arce tephra is observed to be overlain by other two tephra, called the Congo and the Conacaste tephra (Kutterolf, et al., 2006). The underlying Congo tephra was reported in CEL (1992) including pumice-fall deposit and pumice-flow deposit. The overlying Conacaste tephra also includes pumice fall and pumice flow, the former was called Atiquizaya in Kitamura (2006) while the latter was named Conacaste by Hernández, W., and totally called the Conacaste tephra in Kutterolf et al. (2008). Both tephra show similar mineral assemblage, containing hornblende and orthopyroxene and slight clinopyroxene. The depositional age of the Congo tephra was determined to be  $56.9 \pm 2.8 / -2.1$  ka by highly sensitive  $^{14}\text{C}$  dating method (Rose, et al., 1999). In the area near Chalchuapa, a vitric ash underlain by the Conacaste tephra is correlated to the TB4 tephra originating from Ilopango Caldera, another large Caldera in the center of El Salvador (Fig. 1; Kitamura, 2016).

In Guatemala Basin, a vitric ash overlying the A1 tephra is called the A2 tephra, which was

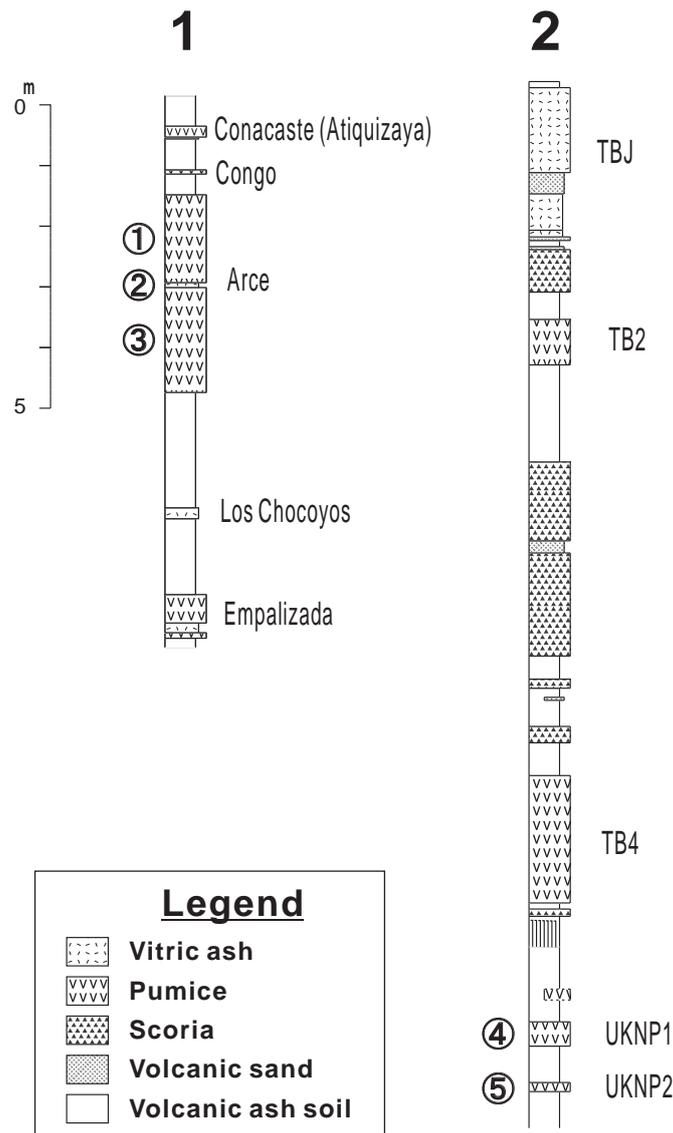


Fig. 2 Tephra stratigraphy and sampling level

Number above the column shows exposure code corresponding to the text and figure 1.  
 Number with circle indicates sample code and sampling level.

correlated to the Congo or the Conacaste tephra on the basis of chemical composition of volcanic glass (Kitamura, 2006).

### 3. Sampling sites

In this study, tephra samples were collected at following two locations.

Exposure 1 is located in Chalchuapa, where the Arce tephra is observed to be separated three units, which is lower coarse pumice, middle fine ash, and upper coarse pumice (Fig. 2). In this study, pumice and ash samples were collected from each unit for chemical analysis. The Arce tephra is identifiable in a stratigraphic sequence, from the underlying Los Chocoyos ash originating from Atitlan Caldera, Guatemala, to the overlying Congo and Conacaste tephra derived from Coatepeque

Caldera (Fig. 2).

Exposure 2, additional exposure to confirm the eastern distribution of the Arce tephra in terrestrial region, is located in the eastern flank of San Salvador Volcano, ca. 40 km eastern southeast of Coatepeque Caldera (Fig. 1). In this exposure, the TB4 tephra from Ilopango Caldera and underlying other two unknown pumice layers were previously reported to be observed (Kitamura, 2016). These are called UNKP1 and UNKP2 from the upper to the lower in this study (Fig. 2).

Two samples of the A1 tephra analyzed prior to this study were collected in the territory of the Republic of Guatemala. The one was collected at the exposure in the northern part of Guatemala City (14° 38' 27"N, 90° 21' 55"W, obtained by measuring the location on the topographical map of 1:50,000 and transforming to the coordinate of WGS84) and the other in Antigua Guatemala (14° 31' 35.05"N, 90°46' 16.90"W). In the former location, ca. 130 km northwest of Coatepeque Caldera, the A1 tephra is found as a thinly bedded vitric ash overlain by the A2 tephra and both tephras are observed between the E tephra and the C tephra. In the latter location, ca. 150 km northwest of the caldera, the A1 tephra is laid in the sequence of scoria and pumice layers, probably originating from Agua Volcano.

#### 4. Analytical methods

Volcanic glass and minerals were isolated from crushed pumice by supersonic washing and sieving. Mineral assemblage was investigated by microscopic observation with polarized microscope. Chemical composition of volcanic glass was analyzed quantitatively with a wave length dispersive electron microprobe (JEOL JXA-8800RL) in the Department of Earth and Environmental Science, Hirosaki University. For analyses, 30 or more glass shards of each sample were randomly selected. Beam currents of  $3 \times 10^{-9}$  A and beam diameters of 10  $\mu\text{m}$  were used at an accelerating voltage of 15 kV. Oxide percentage were renormalized to 100% and averaged with calculating standard deviation from the analysis in each sample, after removal of obvious anomalous results.

#### 5. Result of chemical analysis for volcanic glass

##### (1) Prior analyses of the A1 tephra in Guatemala

In chemical analyses prior to this study, the chemical composition of the A1 tephra collected in Guatemala City is mostly consistent with that of the Arce tephra proposed in Kitamura (2006). However, they were slightly different from each other. The diagram of FeO versus SiO<sub>2</sub> in the analysis of the A1 tephra in Guatemala City shows a trend of higher FeO content in the side of lower SiO<sub>2</sub> (Fig. 3), while a trend of slightly lower FeO in the side of lower SiO<sub>2</sub> was found in the analysis proposed by Kitamura (2006).

The chemical composition of the A1 tephra in Antigua Guatemala City is mostly coincident with that of the Arce tephra in Kitamura (2006). However, several plots are laid on the area of the higher FeO in the side of the lower SiO<sub>2</sub> (Fig. 3).

These data suggest that the Arce tephra is not homogeneous, and chemical composition of volcanic glass varied temporally during the eruption.

##### (2) Chemical composition of volcanic glass from each unit of the Arce tephra

The chemical compositions of volcanic glass from each of the three units of the Arce tephra

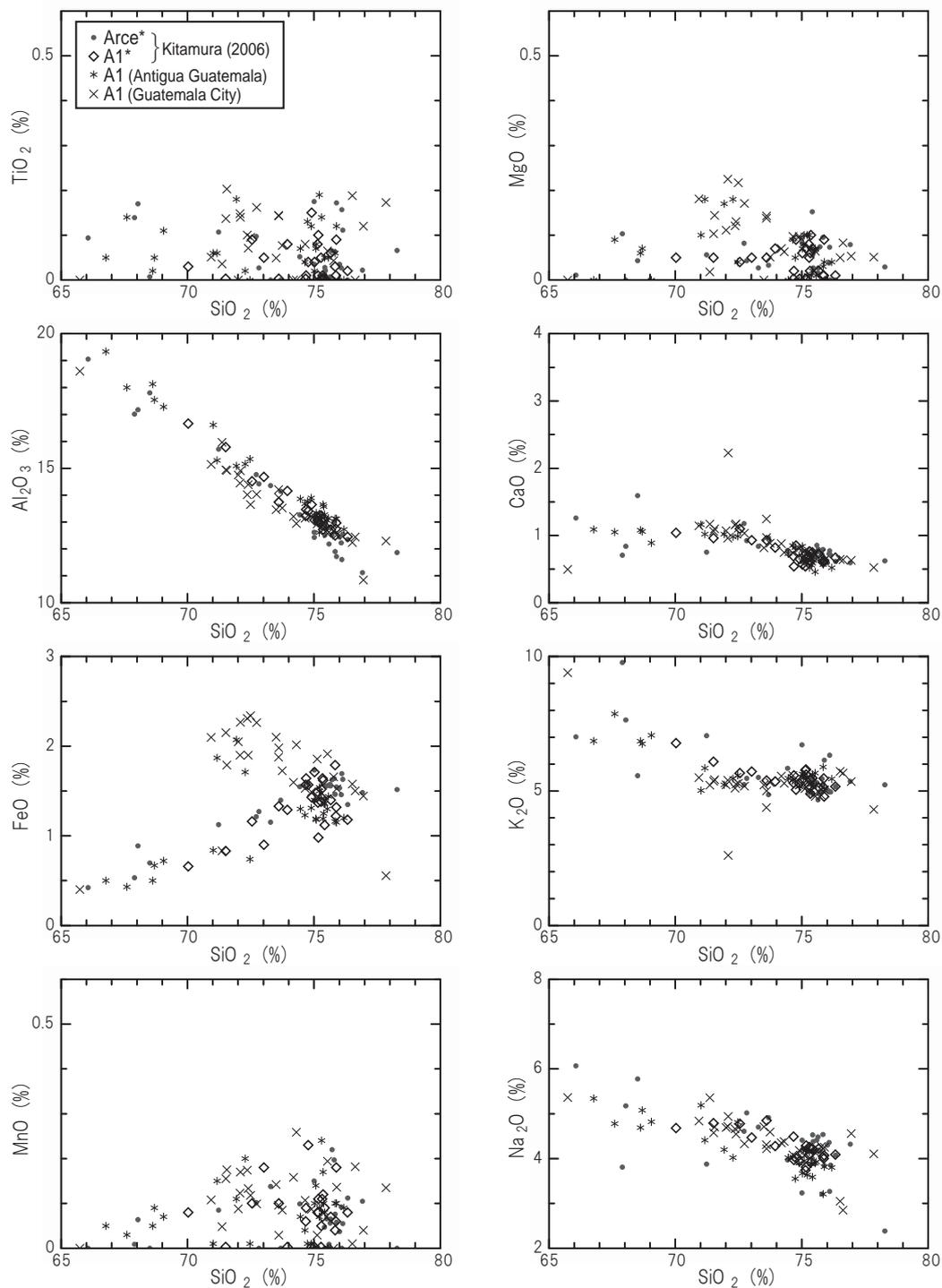


Fig. 3 Harker diagram of previous analysis for the Arce tephra and the A1 tephra. Upper two in legend indicate the chemical composition of volcanic glass from the Arce tephra and the A1 tephra proposed in Kitamura (2006), and lower two exhibit that of the A1 tephra, in Antigua Guatemala City and Guatemala City, analyzed prior to this study. Analytical conditions for all are the same as table 1.

are shown in table 1, and also plotted in Harker diagram as figure 4. The Harker diagram clearly indicates that their compositions are slightly different in  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{FeO}$  contents. In the diagram of  $\text{FeO}$  versus  $\text{SiO}_2$ , the plots of the upper unit are concentrated to the area of relatively

Table 1 Chemical composition of analyzed samples collected in exposure 1

Tephra	Sample No.		SiO <sub>2</sub> (%)	TiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)	Total (%)
Arce (upper unit)	1	Average	74.6	0.1	13.8	1.2	0.1	0.0	0.9	5.0	4.3	100.0
		St. Dev.	3.0	0.0	2.2	0.3	0.0	0.0	0.9	0.8	0.8	(39)
Arce (middle unit)	2	Average	74.9	0.1	13.6	1.5	0.1	0.1	0.8	4.7	4.3	100.0
		St. Dev.	1.5	0.1	0.8	0.3	0.1	0.1	0.2	0.2	0.3	(40)
Arce (lower unit)	3	Average	76.6	0.1	12.6	1.2	0.1	0.0	0.6	4.7	4.1	100.0
		St. Dev.	1.0	0.1	0.5	0.2	0.0	0.0	0.2	0.2	0.3	(39)

The number with parentheses indicates quantity of volcanic glass shards for analysis. Oxide percentage was renormalized to 100%. Chemical quantitative analysis was realized with a wave length dispersive electron microprobe (JEOL JXA-8800RL) in the Department of Earth and Environmental Science, Hirosaki University under the following conditions: beam current,  $3 \times 10^{-9}$  A; beam diameter, 10  $\mu$ m; accelerating voltage, 15 kV.

higher SiO<sub>2</sub> and moderate FeO contents. They are also almost concentrated in the diagram of SiO<sub>2</sub> versus Al<sub>2</sub>O<sub>3</sub>, at least less varied than the others, although they vary slightly to the prolonged area of relatively higher SiO<sub>2</sub> and lower Al<sub>2</sub>O<sub>3</sub>.

On the other hand, the plots of the middle unit vary clearly in the diagram of SiO<sub>2</sub> versus FeO, from relatively moderate SiO<sub>2</sub> and high FeO to high SiO<sub>2</sub> and moderate FeO. The plots in the diagram of Al<sub>2</sub>O<sub>3</sub> versus SiO<sub>2</sub> also vary, from relatively higher SiO<sub>2</sub> and lower Al<sub>2</sub>O<sub>3</sub> to moderate SiO<sub>2</sub> and moderate Al<sub>2</sub>O<sub>3</sub>.

Moreover, the plots of the upper unit vary in other way. While they are concentrated to the area slightly moved to lower SiO<sub>2</sub> and higher FeO from the area where the plots of the lower unit are concentrated. And they are scattered in the prolonged area from relatively higher SiO<sub>2</sub> and moderate FeO to lower SiO<sub>2</sub> and lower FeO. They also vary from relatively higher SiO<sub>2</sub> and lower Al<sub>2</sub>O<sub>3</sub> to lower SiO<sub>2</sub> and higher Al<sub>2</sub>O<sub>3</sub>, in the diagram of SiO<sub>2</sub> versus Al<sub>2</sub>O<sub>3</sub>, although most of the plots are concentrated to the area slightly lower SiO<sub>2</sub> and higher Al<sub>2</sub>O<sub>3</sub> than the plots of the lower unit. Their feature coincides with the previous analysis of a sample collected from the upper unit of the Arce tephra proposed in Kitamura (2006), so that, the previous analysis is confirmed to be correct in this study.

The result of these analyses suggests that the A1 tephra in Guatemala City contains volcanic glass from all three units, because the plots of the tephra are distributed on all areas of the three units in the diagram of FeO versus SiO<sub>2</sub>. Consequently, all three units of the Arce tephra are assumed to be incorporated into thinly bedded vitric ash layer. The analyses from three units in this study are quite valuable to identify the Arce tephra in broad area.

### (3) The distribution of the Arce tephra to the east

The chemical compositions of volcanic glass from the UNKP1 and the UNKP2 are shown in table 2. And the chemical composition of the UNKP1 is plotted in Harker diagram shown in figure 5 while the chemical analysis of the UNKP2 is shown in figure 4.

Most of plots from the UNKP2 are distributed on the area of the middle unit of the Arce tephra, a few plots on the area of the lower unit overlapping the area of the middle unit. Any plot never appeared on the area where FeO content is slightly lower and Al<sub>2</sub>O<sub>3</sub> is higher in the lower side of SiO<sub>2</sub> as the upper unit of the Arce tephra.

The chemical composition of the UNKP1 overlying the UNKP2 is plotted on almost the same

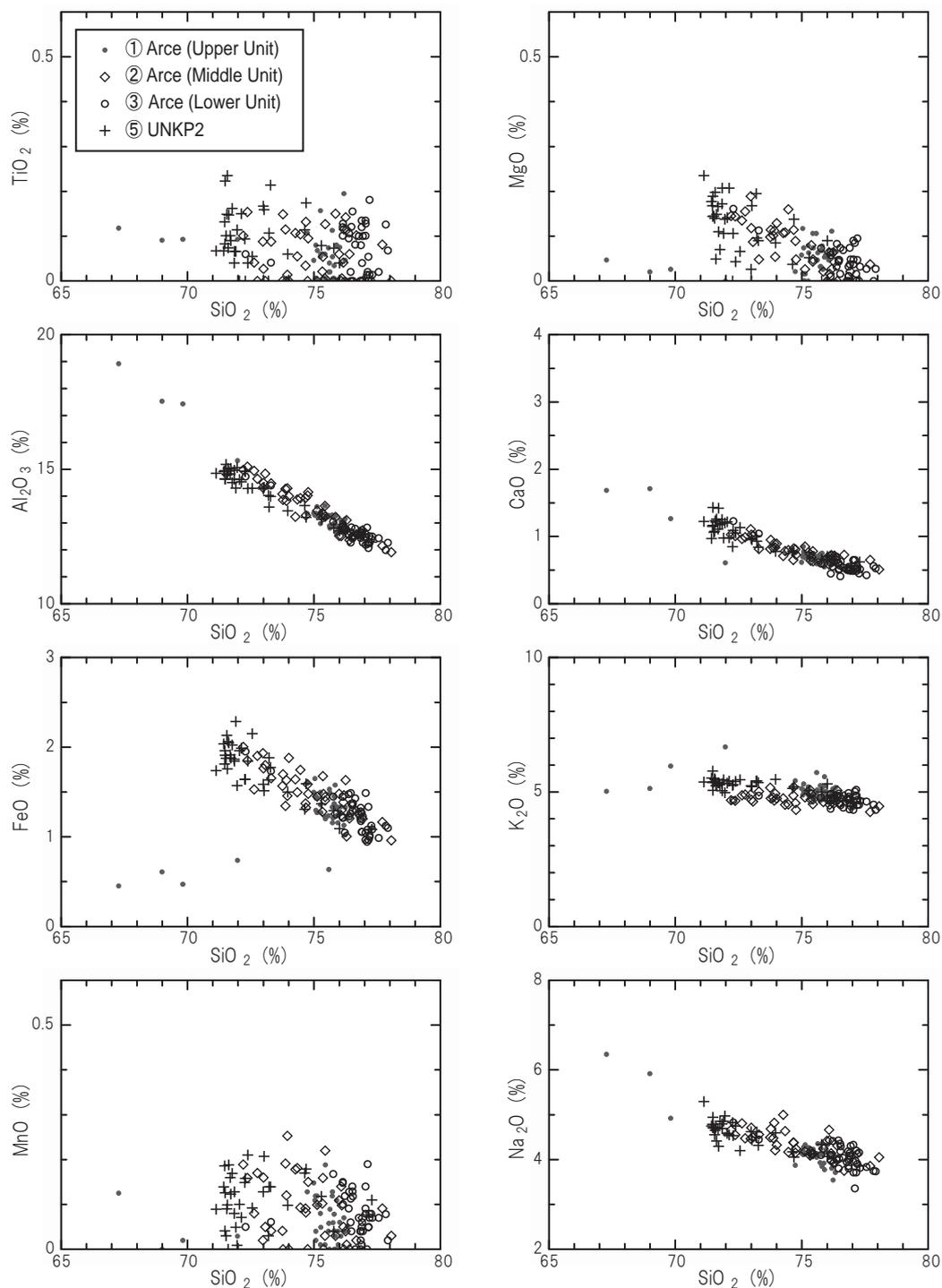


Fig. 4 Harker diagram of analyzed sample in this study  
Analytical conditions for all are the same as table 1.

Table 2 Chemical composition of analyzed samples collected in exposure 2

Tephra	Sample No.		SiO <sub>2</sub> (%)	TiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)	Total (%)
UNKP1	4	Average	74.1	0.1	13.7	1.6	0.1	0.2	1.1	4.7	4.4	100.0
		St. Dev.	0.5	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.3	(20)
UNKP2	5	Average	72.7	0.1	14.3	1.8	0.1	0.1	1.0	5.3	4.6	100.0
		St. Dev.	1.5	0.1	0.8	0.3	0.1	0.1	0.2	0.2	0.3	(35)

Table structure and analytical conditions are the same as table 1.

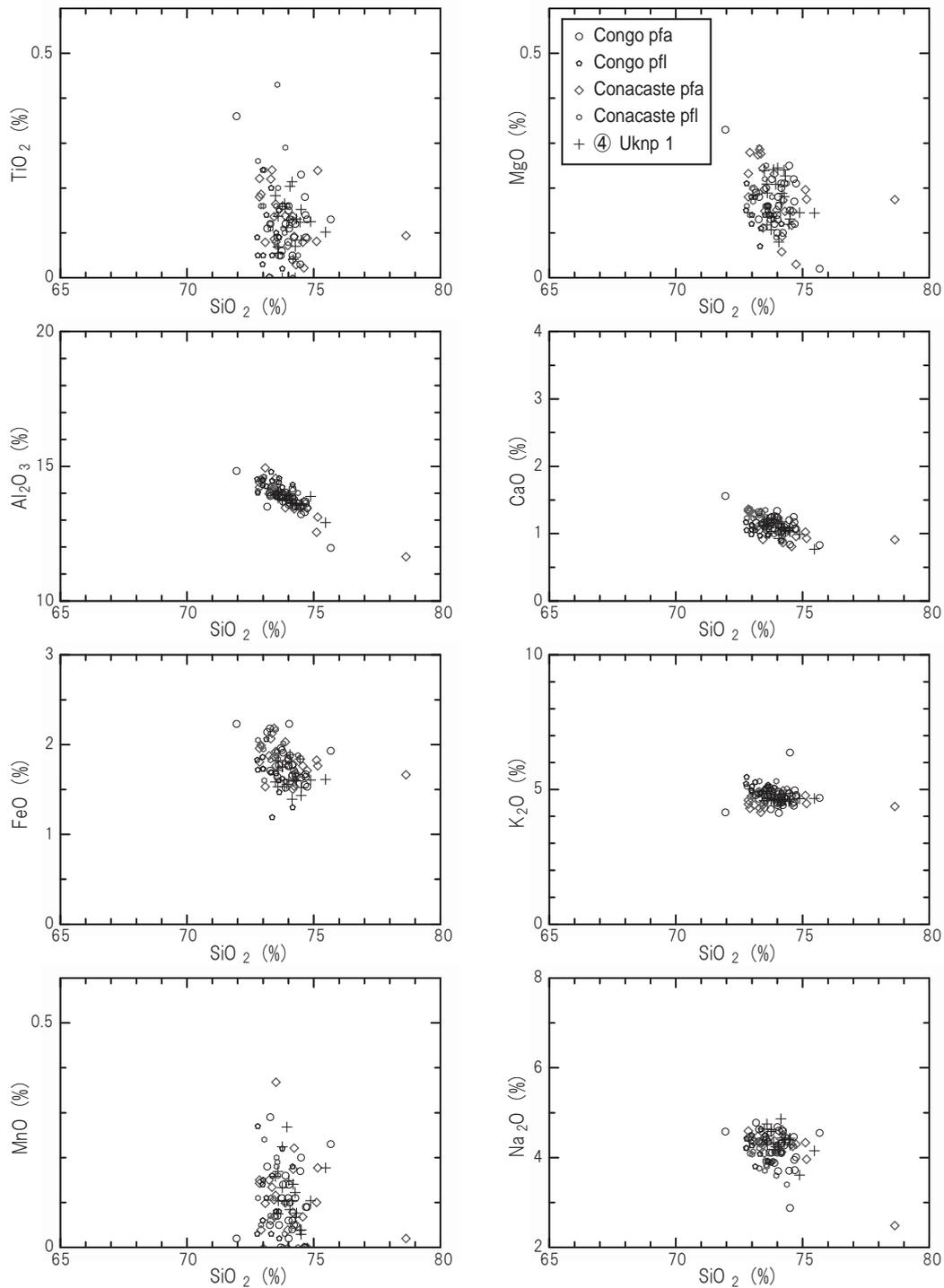


Fig. 5 Harker diagram of analyzed sample in this study and reference analyses. The chemical composition of the Congo and the Conacaste tephra proposed in Kitamura (2016) is also plotted for comparison. Analytical conditions for all are the same as table 1.

area with those of the Congo tephra and the Conacaste tephra (Table 2 and 3; fig. 5), indicating that the UNKP1 would be the Congo or the Conacaste tephra. Kutterolf, et al. (2008) proposed the distribution area of the Congo tephra broader than that of the Conacaste tephra on the basis of the data from bowling core in marine area, so that, the UNKP1 is more probable to be the Congo tephra.

These facts suggest that the UNKP1 and UNKP2 are correlated to be the Congo tephra and

Table 3 Reference chemical data of tephros from Coatepeque Caldera proposed in Kitamura (2006)

Location	Tephra		SiO <sub>2</sub> (%)	TiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)	Total (%)
Chaluchuapa (Western El Salvador)	Arce	Average	74.8	0.1	13.1	1.4	0.1	0.0	0.7	5.7	4.1	100.0
		St. Dev.	2.4	0.1	1.5	0.3	0.1	0.0	0.1	1.1	0.6	(27)
	Congo	Average	74.0	0.1	13.7	1.8	0.1	0.2	1.1	4.7	4.2	100.0
		St. Dev.	0.7	0.1	0.5	0.2	0.1	0.1	0.2	0.4	0.4	(26)
	Conacaste (Atiquizaya)	Average	74.0	0.1	13.8	1.8	0.1	0.2	1.1	4.6	4.3	100.0
		St. Dev.	1.2	0.1	0.7	0.2	0.1	0.1	0.2	0.2	0.4	(23)
Amatitlán (Southern Guatemala)	A1	Average	74.3	0.0	13.7	1.3	0.1	0.0	0.7	5.6	4.3	100.0
		St. Dev.	2.4	0.0	1.5	0.3	0.1	0.0	0.2	0.9	0.4	(26)
	A2	Average	73.5	0.1	14.1	1.8	0.1	0.2	1.2	4.7	4.2	100.0
		St. Dev.	0.7	0.1	0.5	0.2	0.1	0.0	0.1	0.2	0.4	(25)

A tephra name is modified from Kitamura (2006)

the Arce tephra, respectively, and that they are also distributed to the east. Because of similarity of the trends of FeO-SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> in Harker diagram, the middle unit of the Arce tephra was probably dispersed to the east although it appears as fine ash in the area to the west of Coatepeque Caldera.

## 6. Further investigation

The result of this study also indicates that the chemical composition of the Arce tephra varied temporally in the eruption. Temporal variation of chemical composition is also possible to occur during each eruptive phase to emplace the respective unit of the Arce tephra. Therefore, for more precise correlation, it is necessary to clarify the vertical variation of chemistry in each unit.

In order to illustrate the areal distribution of the Arce tephra and the Congo tephra to the east, further field survey is necessary in the volcanic area of central and eastern El Salvador and Nicaragua.

## Acknowledgement

The author wishes to acknowledge the provision of the field information, support for the investigation, suggestions, encouragement throughout the author's study in El Salvador of Walter Hernández, Ministerio de Medio Ambiente y Recursos Naturales de El Salvador. The author is much indebted to Professor Masatoshi Shiba for allowing the use of equipment for analysis in his school.

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