Wide-spread tephras as a time-marker and chronological framework of eruptive history in the Berlín-Pacayal volcanic area, eastern El Salvador, Central America.

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I. Introduction

It is valuable to demonstrate eruptive history for evaluating volcanic risk in the area around the volcano. Tephra stratigraphy and properties of tephra are necessary to clarify eruptive sequence and the detail process of each eruption in eruptive history. Not only age measurement but also tephrochronology can provide a chronological framework on the eruptive history. In particular, tephrochronological work to identify wide-spread tephra, which is spread out by large scale eruption in geologically instantaneous and provides an excellent isochronous surface, is quite important for correlation over long distances. In the field, wide-spread tephra shows distinctive features such as thinly bedded, fine-grained white vitric ash, and is identifiable by mineral assemblage and chemical composition of volcanic glass.

In the mountainous inland of the department of Usulután, eastern El Salvador, Central America, one of the largest geothermal power plant in El Salvador and many facilities for tourists are located. On the other hand, various volcanoes including very active stratovolcano are also situated in this area, which is called the Berlín-Pacayal volcanic area. Therefore, it is important to reveal eruptive history and to evaluate volcanic risk to which this area is exposed. However, the detail of eruptive history in the area remains unknown and volcanic risk is underestimated or ignored.

This study aims at revealing the stratigraphic positions of the wide-spread tephras as a time-marker, by microscopic identification of mineral grains and chemical analysis of volcanic glass using X-ray microprobe analyzer, and providing an available chronological framework of eruptive history to evaluate the volcanic risk in the area.

II. Study area

A volcanic chain extends along the Pacific coast of Central America from the Tacaná Volcano, Guatemala, to Irazú Volcano, Costa Rica, through southern Guatemala and El Salvador, on the E-W tensional field between the Motagua-Polochic transform fault and marine trench on the subduction zone of the Cocos Plate. Five large calderas, called Atitán, Amatitlán, Ayarza, Coatepeque and Ilopango, are located in the northern part of Central America (Fig. 1).

In the mountain of the department of Usulután, eastern El Salvador, there is an volcanic area where various volcanoes are concentrated, called the Berlín-Chinameca volcanic area. It comprises several stratovolcanoes, cones and calderas (Fig. 2). Berlín-Tecapa Volcano is a large volcanic complex composed of basal stratovolcano with large caldera, the diameter of which is ca. 7 km, and

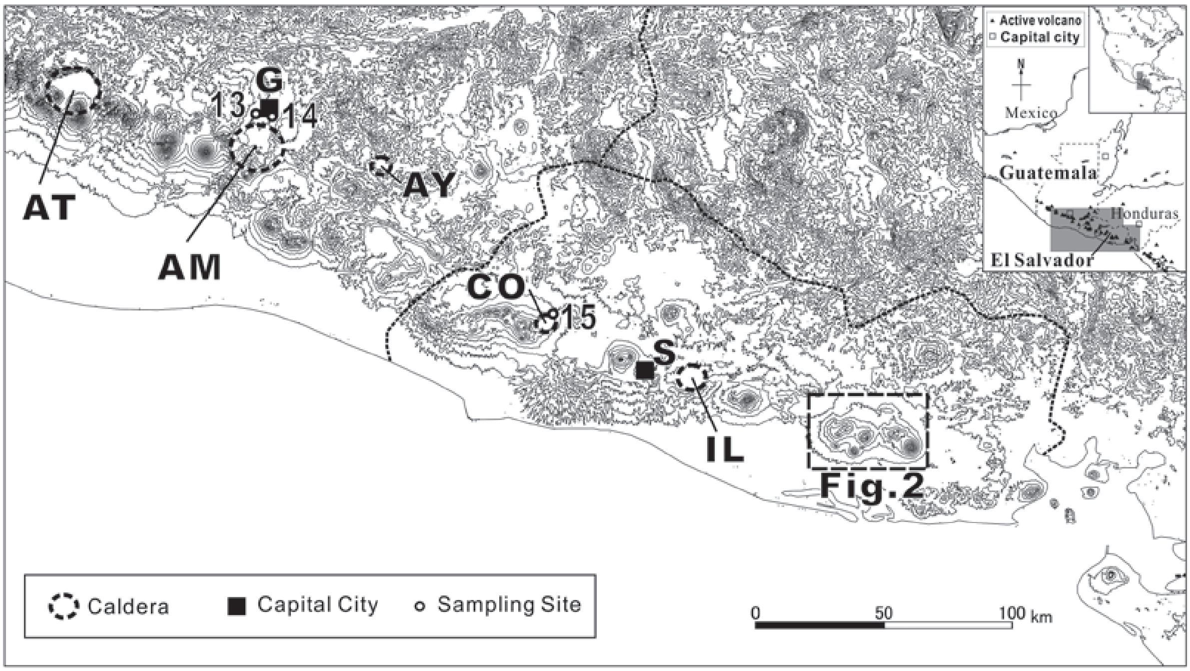

Fig. 1 Index map of southern Guatemala and El Salvador

Contour was created using 7.5-arc-second DEM data from GMTED2000 (Danielson & Gesch, 2011) and GSHHG vector data (Ver.2.3.6; August 19, 2016) distributed by National Oceanic and Atmospheric Administration (NOAA), U. S. Department of Commerce, was used for drawing coastlines. The contour interval is 200 m. Quadrangle delineated by break line exhibits the extent shown in fig. 2. Open circle with number shows location of sampling site and the number corresponds to the column number shown in figs. 6 and 7.
Caldera ; **AT**: Atitlan, **AM**: Amatitan, **AY**: Ayarza, **CO**: Coatepeque, **IL**: Iloapngo. Cities; **G**: Guatemala, **S**: San Salvador.

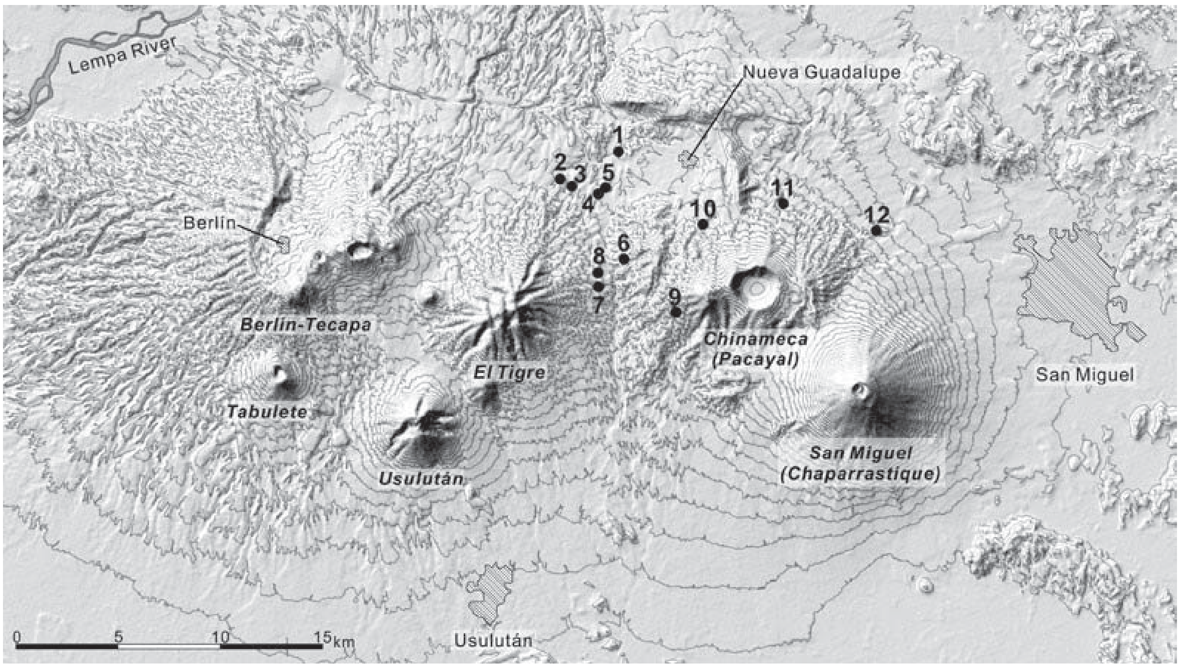

Fig. 2 Volcanoes in the Berlín-Chinameca volcanic area.

Shaded map was created using 30-arc-second DEM data from SRTM provided by National Aeronautics and Space Administration, NASA, U.S., and shown with superimposed contour map (contour interval: 50 m) originating from Arc/Info vectors of topographic map of El Salvador with the scale of 1:25,000, offered by Patrimonio del Cultura de El Salvador. The solid circle with number exhibits location of exposure and the number corresponds to the column number in fig. 5.

several cones formed on the southern rim of the caldera. Tabulete volcano is a small stratovolcano situated on the south flank of the Berlín-Tecapa Volcano, with a crater of ca. 800 m in diameter. Usulután Volcano is a dissected cone-shaped stratovolcano, located to the southeast of Tabulete Volcano, southernmost of the volcanic area. El Tigre Volcano is a dissected large stratovolcano situated at the center of the volcanic area. Two small cones called Cerro Oromontique and Cerro la Manita are observed to be formed on the west and the south flank of El Tigre Volcano. Chinameca-Pacayal Volcano is a stratovolcano with 2-km-wide crater called "Laguna Seca El Pacayal" on the top, which occupies the northeastern part of the Berlín-Chinameca volcanic area. A parasitic cone, Cerro El Limbo, is located on the west of the crater. San Miguel Volcano, another name "Chaparrastique", is the most active volcano in the present in the volcanic area. At the 700-m-wide crater on th top of the volcano, small eruptive plume has been frequently observed since 2013.

III. Previous studies on tephra stratigraphy

1）Tephra stratigraphy in the Berlín-Chinameca volcanic area

CEL (1995) reported many pumice layers and prominent scoria in and around the Berlín-Chinameca volcanic area, and proposed their stratigraphy as follows, from the lower to the upper; Triunfo scoria, Mercedes scoria, Blanca Rosa pumice, Grey Chip scoria, Twin/Las Gemeras pumice, Unit/Unidad-A pumice, Pacayal 1 pumice, Volcan pumice, Pacayal 3 pumice and Pacayal 4 pumice.

The Triunfo scoria was reported as well-sorted stratified dark grey scoria-fall deposit that includes a basal unit of dacite lapilli called "Arturo lapilli". Above the Triunfo scoria, slightly poorly sorted scoria-fall deposit is observed, which called the Mercedes scoria, and it includes dark-colored scoriaceous lapilli and bomb that shows "breadcrust" structure.

The Blanca Rosa pumice is composed of white and pink pumice lapilli, comprising multiple units of well-sorted pumice lapilli intercalating poorly-sorted pumice with volcanic ash. The Ar-Ar date of 75±10 ka was proposed for the Blanca Rosa pumice. The Grey Chip scoria is composed of poorly-vesiculated angular scoria-fall deposit, observed above the Blanca Rosa pumice, which is shown in the column, in distribution map and also in diagram of chemical analysis, in spite of no description in the text of CEL (1995). The Twin/Las Gemelas pumice is thickly accumulated pumice-fall deposit comprising two major units. Another pumice-fall deposit named "Unit-A" is shown in columnar sections of CEL (1995) above the Twin/Las Gemelas pumice, despite of no description in the text. Kutterolf, *et al.* (2008) identified volcanic glass layers from the Blanca Rosa tephra and the Twin/Las Gemelas tephra in boring core at the sea floor of the Pacific Ocean, although the Twin/Las Gemelas tephra was combined with the Unit/Unidad-A tephra as single layer called TT/AT. The depsitional age of the TT/AT was estimated as 61 ka from the depositional rate of marine deposit and the dates of several tephras in M66-222 core (Kutterolf, *et al.,* 2008).

The Pacayal 1 pumice is thickly accumulated pumice-fall deposit composed of well-sorted "pure" white pumice and pink block, and overlying pumice-flow deposit that buries lowland. The Volcan pumice is pumice-fall deposit that contains grey pumice. Although it was called "Volcan" in CEL (1995) because it was suggested to be possible to originate from the San Miguel Volcano, the name of the Volcan/Pacayal 2 pumice is adopted in this study for uncertainty of the origin. The Pacayal 3 pumice contains pale grey and light grey pumice, comprises pyroclastic-flow and pumice-fall deposits. The Pacayal 4 pumice is assumed to comprise pyroclastic-flow deposit and pumice-fall deposit, because the former was reported in the text of CEL (1995) and the latter was described in the column caption. It contains light-grey pumice, pale-grey pumice and pink pumice.

2) Wide-spread tephra in the northern part of Central America

Rose, *et al.* (1999) shows a stratigraphic framework of tephra in the northern part of Central America with wide-spread tephras as a time-marker. The Los Chocoyos (H) tephra, which originates from Atitlan Caldera, Guatemala, has been found at the sea floor around Central America, and known as "Layer-D", the time-marker of 84 ka in marine cores (Fig. 3) ; nevertheless it has not been reported so much to be found out in the terrestrial region. Tephras called Bellavista, Arce, Congo and Conacaste, in stratigraphically ascending order, are derived from Coatepeque Caldera. The upper three tephras are broadly dispersed and found out in the marine core at the sea floor of the Pacific Ocean (Fig. 4; Kutterolf, *et al.,* 2008). The Arce and the either of the Congo or the Conacaste reached until Guatemala City and has been called the A1 and the A2 tephras (Koch & McLean, 1975; Kitamura, 2006; Kutterolf, *et al.* 2008), respectively. Four tephras from Ilopango Caldera are called TB4, TB3, TB2 and TBJ, in ascending order. The TB4 and the TBJ tephras are broadly observed in the terrestrial region as well as in the marine cores at the sea floor of the Pacific Ocean (Fig. 4; Kutterolf, *et al.,* 2008).

The radiocarbon dating demonstrated depositional age of the TBJ tephra the 4th to 6th century (Dull, *et al.,* 2001; Dull, *et al.,* 2010; Kitamura, 2010). The Congo tephra was dated as 56.9 +2.8/−2.1 ka by high-sensitivity radiocarbon measurement, and the Bellavista and the Arce tephras were dated as 77±2 and 72±3 ka, respectively, by K-Ar measurement (Rose, *et al.,* 1999). The depositional ages of the TB4 and the Conacaste tephras were estimated as 36 ka and 51 ka, respectively, on the basis of depsotional rate of marine deposit (Kutterolf, *et al.,* 2008).

In the terrestrial region as well as in marine core, the TB4 tephra is confirmed to be

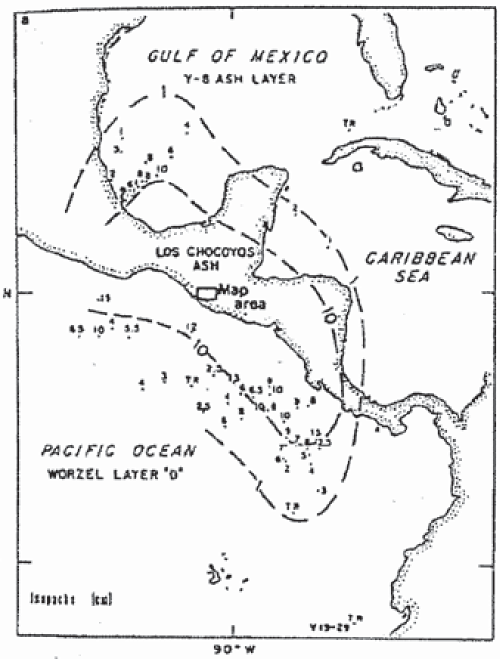

Fig. 3 Distribution of the Los Chocoyos (H) tephra proposed from marine boring cores (Rose, et al., 1980)

stratigraphically above the Conacaste tephra, and the Los Chocoyos (H) tephra, below the Arce tephra (Kutterolf, *et al.,* 2008; Kitamura, 2016). The Twin/Las Gemelas tephra was discovered below the Congo tephra in marine core. The stratigraphic relationship of the Blanca Rosa tephra with other tephras listed here except the TBJ tephra remains undetermined, because it was found out in only one marine core, SO173-18, in which other tephras were absent despite the TBJ tephra was intercalated near the top of the core (Kutterolf, *et. al,* 2008).

The Los Chocoyos (H) tephra bears biotite and the Arce tephra bears biotite and hornblend. Other tephras mentioned above bear orthopyroxene and hornblende. Chemical composition of volcanic glass from the Arce tephra and the TBJ tephra includes concentrated component and dispersal component (Fig. 8 & 11). The chemical analyses from the Congo tephra and the Conacaste tephra show almost concentrated but slightly dispersal plots in Harker diagram (Fig. 10). Chemical plots from other tephras are mostly concentrated in the diagram.

IV. Methods of the study

In this study, tephra stratigraphy was revealed by the observation and the identification of tephras at the exposures in the field. Tephra samples are collected from the exposures for analyses in the laboratory.

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 analyzer (JEOL JXA-8800RL) in the Department of Earth and Environmental

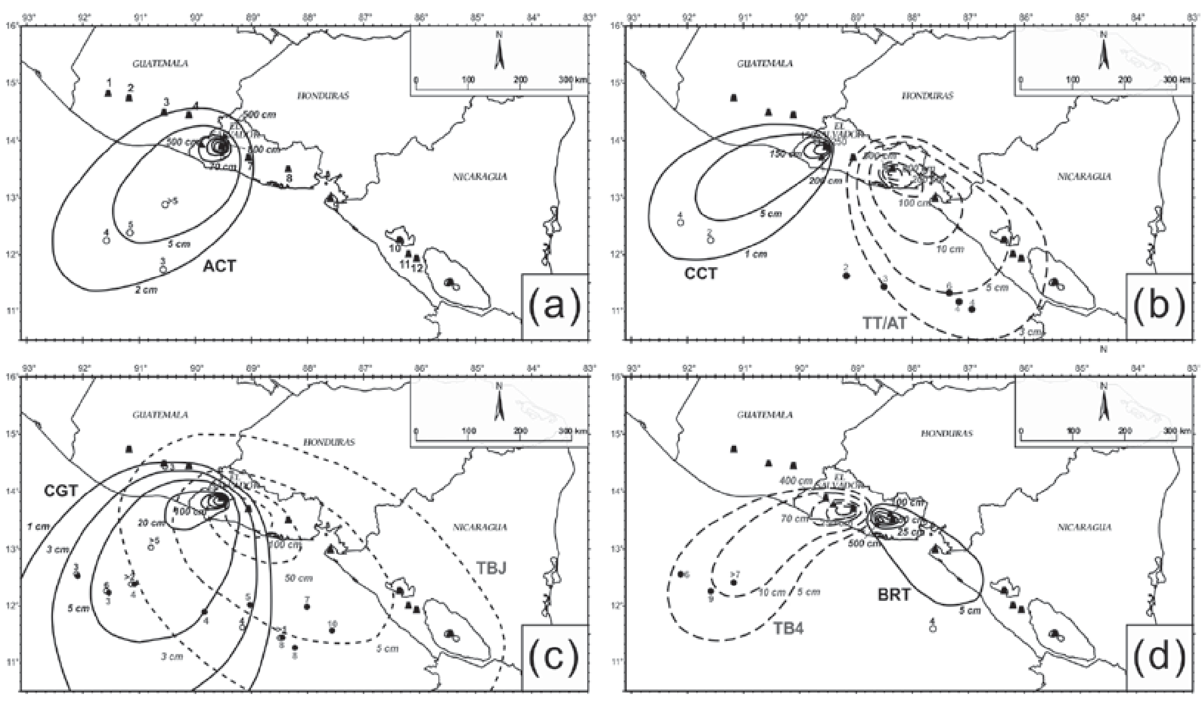

Fig. 4　Distribution of tephras proposed from boring cores at the sea floor of the Pacific Ocean (Kutterolf, et al., 2008)

(a) Arce tephra (ACT); (b) Conacasete tephra (CCT), and Twin/Las Gemelas and Unit/Unidad-A tephras (TT/AT); (c) Congo tephra (CGT) and TBJ tephra; (d) TB4 tephra and Blanca Rosa tephra (BRT)

Science, Hirosaki University. For analyses, 30 or more glass shards of each sample were randomly selected. Beam currents of 3 x 10^{-9} A and beam diameters of 10 μm 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.

V. Result

1) Tephra stratigraphy

Tephras described in previous study were observed in the field survey of this study in spite of remained uncertainty of identification in Volcan/Pacayal 2, Pacayal 3 and Pacayal 4. Additionally, four pumice and four vitric ash were discovered in this study (Fig. 3).

Although the four pumice layers were previously shown in columnar sections in CEL (1995), they were not given names nor detailed description. In this study, they were called the the Jucuapa 1 pumice, the Jucuapa 2 pumice, the Jucuapa 3 pumice and the Jucuapa 4 pumice, in ascending order. The Jucuapa 1 pumice, the Jucuapa 2 pumice and the Jucuapa 3 pumice are observed between the Blanca Rosa pumice and the Twin/Las Gemelas pumice. On the other hand, the Jucuapa 4 pumice is observed between the Unit/Unidad-A pumice and the Pacayal 1 pumice.

Four vitric ash layers discovered in this study are called the Chinameca 1 ash, Chinameca 2 ash, Chinameca 3 ash and Chinameca 4 ash, in ascending order. The Chinameca 1 ash is reddish yellow ash-fall deposit observed bellow the Blanca Rosa pumice intercalating many pumice and scoria layers between them (Fig. 5). It is not described in detail in this study because it is observed only in Loc. 10 (Figs. 2 & 5). The Chinameca 2 ash is white vitric ash observed bellow the Jucuapa 1 pumice. It is observed to be several centimeters thick and covered by a thinly-bedded scoria layer in several exposure (Fig. 5). The Chinameca 3 ash is white vitric ash slightly bearing biotite. It is observed bellow the Jucuapa 2. It can be observed extensively over the study area, regarded as the best stratigraphic maker (Fig. 5). The Chinameca 4 ash is white vitric ash, deposited bellow the Pacayal 1 pumice. Their stratigraphic positions are very close to the Pacayal 1 pumice. In some exposure, the basal purple fine ash unit of the Pacayal 1 pumice seems to cover the Chinameca 4 ash in contact (Fig. 5).

2) Sample collection of standard for correlation

Mineral assemblage and chemical composition of volcanic glass of the Arce, the Congo and the Conacaste pumices from Coatepeque Caldera, and the TBJ, the TB2, the TB3 and the TB4 pumices from Ilopango Caldera were previously clarified (Kitamura, 2005; Kitamura, 2015; Kitamura, 2016). On the other hand, mineralogical and chemical analyses were performed for the Los Chocoyos (H) tephra from Atitlan Caldera and the Bellavista tephra from Coatepeque Caldera in this study, using pumice samples collected previously in the past.

Some samples of the Los Chocoyos (H) tephra were collected in Guatemala City (Fig. 1) in 1992. These samples collected from various horizons or units; basal pumice fall, lower pumice flow, middel pumice flow, upper pumice flow, lower coarser co-ignimbrite ash and upper finer co-ignimbrite ash, in ascending order (Fig. 6).

Samples from the pumice fall and the pumice flow of the Bellavista tephra were collected in 2005 at the north rim of Coatepeque Caldera (Fig. 1 & 7). Although some sample were collected

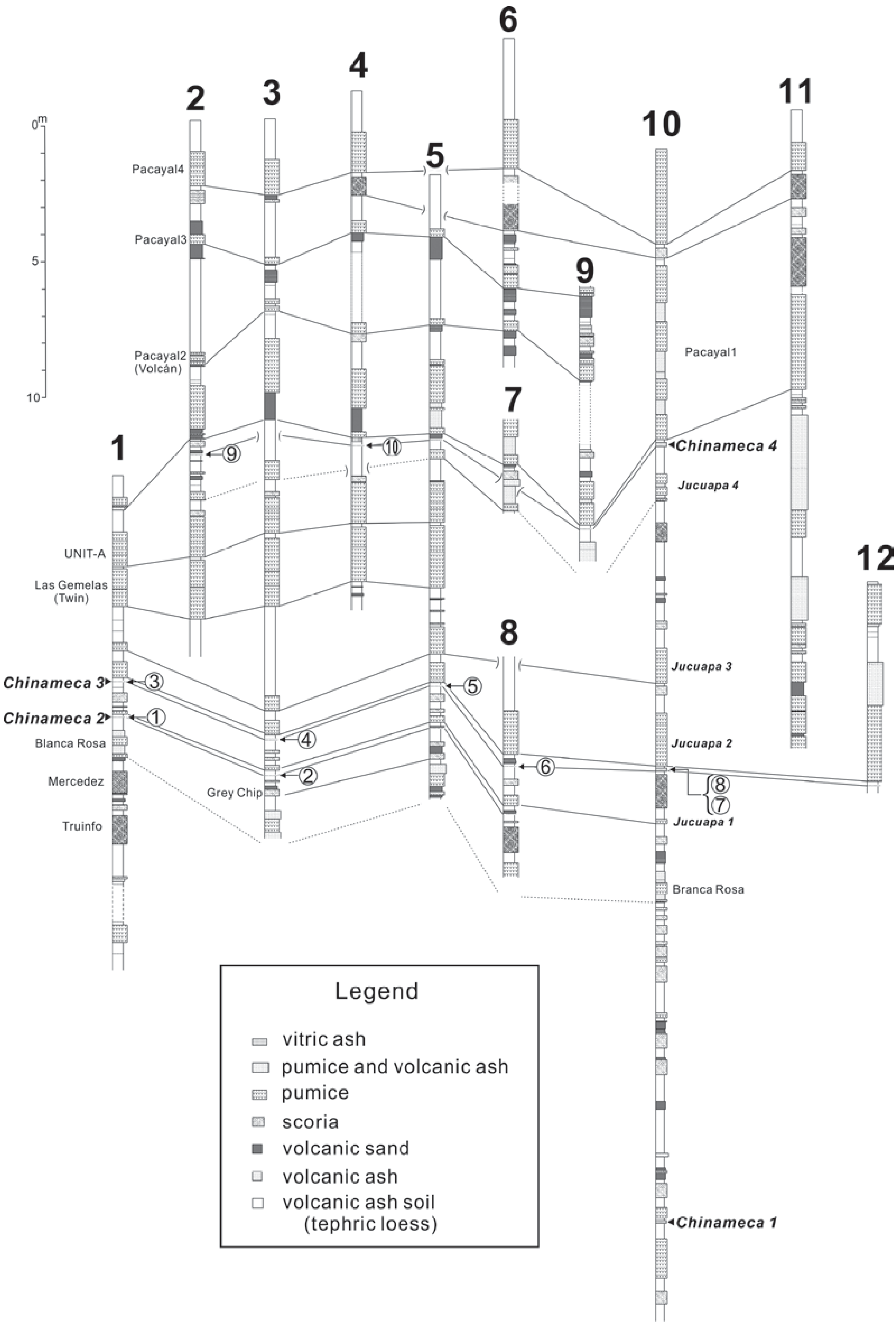

Fig. 5　Tephra stratigraphy at the sampling sites in study area

Number above the column corresponds to exposure number shown in fig. 2. Number with circle at the side of the column shows the number of sample collected at the level, corresponding the number shown in figs. 9 to 11 and table 1.

from various horizons, two sample were analyzed in this study.

3) Mineral assemblage and chemical composition of volcanic glass

Mineral assemblage and chemical composition of volcanic glass of the Chinameca 2, 3 and 4 ash layers are shown in Table 1. The previously known tephras, which are the Bellavista, the Arce, the Congo and the Conacaste tephras from the Coatepeque Caldera, the TBJ, the TB2, the TB3 and the TB4 tephras from Ilopango Caldera, the Los Chocoyos tephra from Atitlán Caldera, are shown

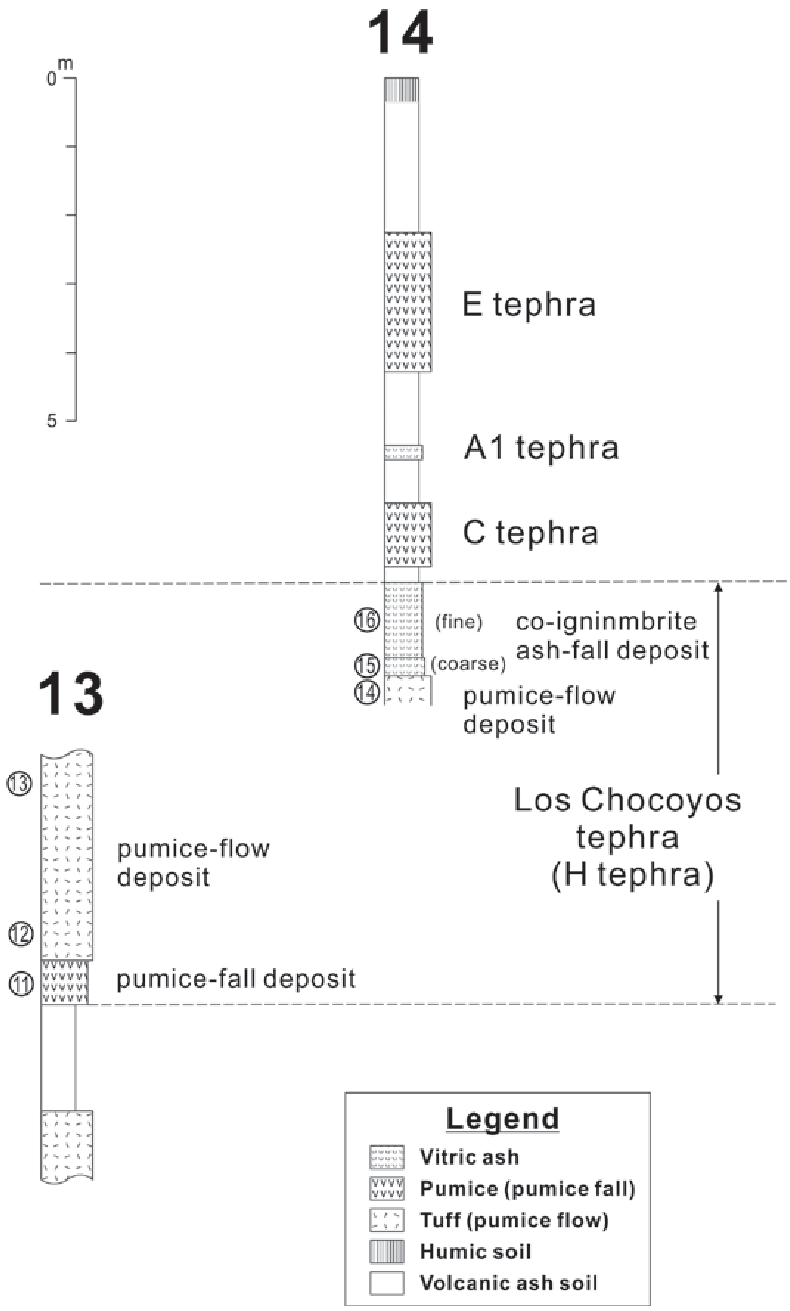

Fig. 6 Tephra stratigraphy and depositional units of the Los Chocoyos (H) tephra at the sampling sites in Guatemala City

Number above the column corresponds to exposure number in fig. 1. Number with circle at the side of the column shows the number of sample collected at the level, corresponding the number shown in fig. 8 and table 2.

in table 2. Harker diagrams of the chemical analyses are shown in figs. 8 to 11 for the comparison between vitric ash layers discovered in this study and the previously known tephras. Because the Chinameca 1 ash is considered to be much older than the Blanca Rosa pumice, it is not discuss in this article.

The Chinameca 2 ash and the Chinameca 4 ash dominantly contain pumice-type volcanic glass and bear orthopyroxene and hornblende. The Chinameca 3 ash is composed of abundant bable-wall-type volcanic glass and slightly bears biotite. In standards for correlation, the Los Chocoyos (H) pumice contains biotite and the Arce pumice bears biotite and hornblende. Other tephras bear orthopyroxene and clinopyroxene.

The chemistry of volcanic glass from tephras bearing biotite, which are the Los Chocoyos (H) and the Arce, is plotted on Harker diagrams shown in fig. 8. The diagrams indicate that the plots from the Los Chocoyos (H) tephra are concentrated showing uni-modal distribution while the plots from the Arce tephra are dispersal on a trend. The plots of chemistry from the Chinameca 3, which

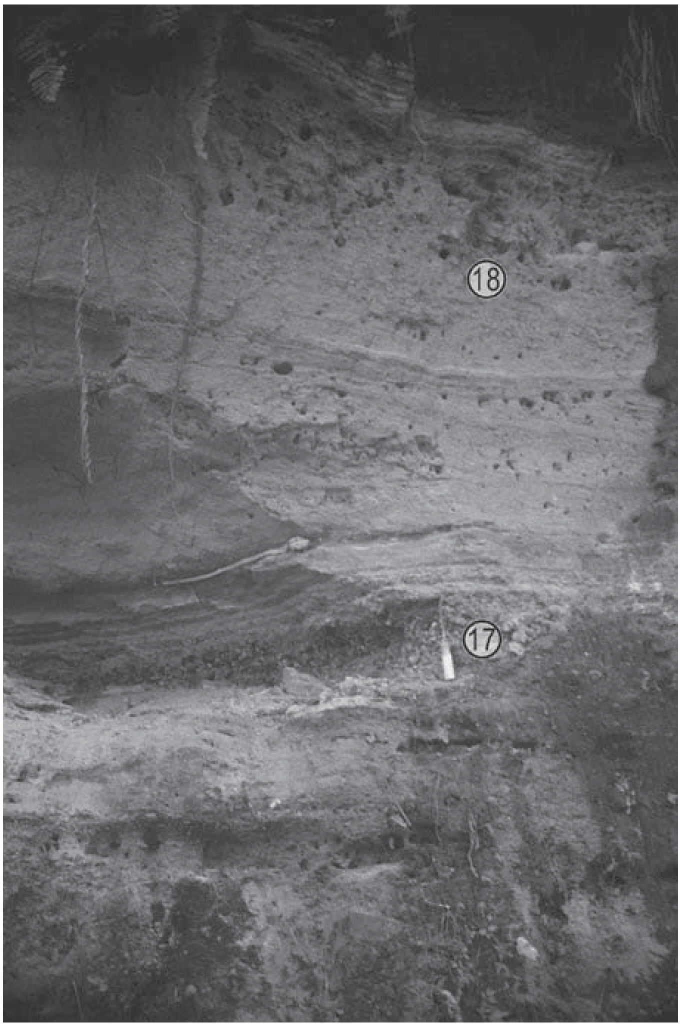

Fig. 7　Photograph of exposure at the north rim of Coatepeque Caldera for sampling the Bellavista tephra

Location is shown in fig. 1 as the number of 15. The length of the sickle in the photograph is 25 cm. Number with circle on the photo indicates the number of sample collected at the level, corresponding the number shown in fig. 10 and table 2.

slightly bears biotite, shows uni-modal distribution and its plotted range is coincident with that of the Los Chocoyos (H) tephra (Fig. 9).

The Chinameca 4 ash does not bear biotite and shows higher potassium in chemistry of volcanic glass, assuming it to be correlated to either of tephras from Coatepeque Caldera. The Harker diagrams exhibit that the chemistry of volcanic glass from the Chinameca 4 ash coincides with either from the Congo tephra or the Conacaste tephra, which are hardly distinguishable in chemistry (Fig. 10). Therefore, the Chinameca 4 ash can be correlated to either of the Congo tephra or the Conacaste tephra from Coatepeque Caldera, located ca. 140 km northwest of the area, erupted in the age of 57 or 51 ka.

As the Chinameca 2 ash is older than 84 ka and does not bear biotite nor shows high potassium in chemistry of volcanic glass, the candidate to be correlated to the ash were not found. On the other hand, the chemistry of the volcanic glass is similar to the chemistries of tephras from Ilopango Caldera and they are plotted on the same trend on the Harker diagram. This fact suggests that the Chinameca 2 ash would be produced by unknown large eruption at Ilopango Caldera.

VI. Conclusion

Mineralogical and chemical data in this study indicate that the Chinameca 3 tephra is correlated to the Los Chocoyos (H) tephra from Atitlan Caldera. They also clarify that the Chinameca 4 tephra is correlated to either of the Congo tephra or the Conacaste tephra from Coatepeque Caldera. Although the Chinameca 2 tephra cannot be correlated to any known tephra, it is supposed to be derived from Ilopango Caldera because chemical composition of volcanic glass

Table 1 Analyses of volcanic glass from vitric ash in the study area

tephra	mineral assemblage	deposit	sample		SiO2 (%)	TiO2 (%)	Al2O3 (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)	K2O (%)	Na2O (%)	Total (%)
Chinameca 2	opx, ho	vitric ash	①	Average	76.0	0.2	13.0	1.6	0.1	0.3	1.5	2.9	4.3	100.0
				St. Dev.	0.4	0.1	0.2	0.2	0.1	0.0	0.1	0.2	0.2	(27)
			②	Average	76.1	0.2	13.1	1.6	0.1	0.3	1.5	2.8	4.4	100.0
				St. Dev.	0.5	0.0	0.3	0.2	0.1	0.1	0.2	0.2	0.3	(20)
Chinameca 3	bi	vitric ash	③	Average	77.8	0.1	12.6	0.5	0.1	0.1	0.6	4.3	3.9	100.0
				St. Dev.	0.4	0.1	0.2	0.1	0.1	0.0	0.1	0.3	0.2	(30)
			④	Average	77.9	0.1	12.4	0.5	0.1	0.1	0.6	4.1	4.1	100.0
				St. Dev.	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.3	(37)
			⑤	Average	77.7	0.1	12.6	0.5	0.1	0.1	0.6	4.3	4.0	100.0
				St. Dev.	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.3	0.3	(30)
			⑥	Average	77.8	0.1	12.5	0.6	0.1	0.1	0.6	4.3	4.0	100.0
				St. Dev.	0.3	0.1	0.3	0.1	0.1	0.0	0.1	0.3	0.3	(30)
			⑦	Average	77.9	0.1	12.1	0.6	0.1	0.1	0.6	4.5	4.0	100.0
				St. Dev.	0.4	0.1	0.3	0.1	0.1	0.0	0.1	0.5	0.3	(32)
			⑧	Average	77.8	0.1	12.5	0.6	0.1	0.1	0.6	4.4	3.8	100.0
				St. Dev.	0.4	0.1	0.2	0.1	0.1	0.0	0.1	0.4	0.3	(30)
Chinameca 4	ho, opx	vitric ash	⑨	Average	74.0	0.1	13.8	1.6	0.1	0.1	1.1	4.7	4.4	100.0
				St. Dev.	0.5	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.2	(34)
			⑩	Average	74.3	0.1	13.9	1.5	0.1	0.1	1.0	4.6	4.4	100.0
				St. Dev.	0.6	0.1	0.3	0.2	0.1	0.1	0.1	0.2	0.3	(28)

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

contained in the Chinameca 2 tephra is similar to those of tephras from Ilopango caldera.

On the basis of stratigraphic position of the Chinameca 4 clarified in this study, the Pacayal 1 tephra was illustrated to be stratigraphically close to either of the Congo tephra or the Conacaste tephra, and slightly younger than the either of 57 or 51 ka.

The stratigraphic position and previous Ar-Ar age of the Blanca Rosa tephra was corrected in this study because it was demonstrated to underlie the Los Chocoyos (H) tephra dated to be 84 ka.

And chemical analysis of the Chinameca 2 ash suggests that other large eruption might occur at Ilopango Caldera before 84 ka.

Table 2 Analyses of volcanic glass from tephras produced by caldera eruptions

	tephra	mineral assemblage	deposit	sample		SiO2 (%)	TiO2 (%)	Al2O3 (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)	K2O (%)	Na2O (%)	Total (%)
Atitlan Caldera	Los Chocoyos (H tephra)	bi (tr. Cum)	pumice fall	⑪	Average	77.8	0.1	12.4	0.5	0.1	0.1	0.6	4.5	3.9	100.0
					St. Dev.	0.4	0.1	0.2	0.1	0.0	0.0	0.1	0.2	0.4	(10)
			pumice flow (lower part)	⑫	Average	77.8	0.1	12.5	0.5	0.1	0.1	0.6	4.5	3.9	100.0
					St. Dev.	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.3	0.2	(30)
			pumice flow (middle part)	⑬	Average	77.6	0.1	12.5	0.5	0.1	0.1	0.6	4.5	3.9	100.0
					St. Dev.	0.4	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.2	(42)
			pumice flow (upper part)	⑭	Average	77.7	0.1	12.4	0.6	0.1	0.1	0.6	4.5	4.0	100.0
					St. Dev.	0.2	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.2	(40)
			co-ignimbrite ash	⑮	Average	77.8	0.1	12.2	0.5	0.1	0.1	0.6	4.6	4.0	100.0
					St. Dev.	0.3	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.2	(29)
				⑯	Average	77.8	0.1	12.2	0.5	0.1	0.1	0.6	4.5	4.0	100.0
					St. Dev.	0.3	0.0	0.2	0.1	0.1	0.0	0.1	0.2	0.2	(30)
Coatepeque Caldera	Bellavista	opx, ho	pumice fall	⑰	Average	77.3	0.1	12.2	1.1	0.1	0.0	0.5	5.3	3.5	100.0
					St. Dev.	0.3	0.1	0.3	0.2	0.1	0.0	0.1	0.2	0.2	(29)
			pyroclastic flow	⑱	Average	77.1	0.0	12.2	1.2	0.1	0.0	0.5	5.4	3.5	100.0
					St. Dev.	0.4	0.0	0.3	0.2	0.1	0.0	0.1	0.2	0.2	(30)
	Arce	bi, ho	pumice fall (lower unit)	Kitamura (2017)	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)
			pumice fall (middle unit)		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)
			pumice fall (upper unit)		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)
	Congo	ho, opx	pumice fall	Kitamura (2006)	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)
			pyroclastic flow		Average	73.3	0.1	14.4	1.7	0.1	0.1	1.1	5.1	4.2	100.0
					St. Dev.	0.4	0.1	0.2	0.2	0.1	0.0	0.1	0.2	0.3	(13)
	Conacaste	ho, opx	pumice fall		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)
			pyroclastic flow		Average	73.5	0.2	14.1	1.9	0.1	0.2	1.2	4.9	3.9	100.0
					St. Dev.	0.4	0.1	0.3	0.2	0.1	0.0	0.1	0.2	0.2	(16)
Ilopango Caldera	TB4	opx, ho	pumice fall	Kitamura (2016)	Average	77.2	0.2	12.8	1.1	0.1	0.2	1.1	2.9	4.5	100.0
					St. Dev.	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	(30)
	TB3	opx, ho	pumice fall		Average	76.9	0.2	12.8	1.2	0.1	0.2	1.4	3.0	4.2	100.0
					St. Dev.	0.5	0.1	0.3	0.2	0.0	0.1	0.2	0.1	0.2	(28)
			pumice fall		Average	77.2	0.2	12.8	1.1	0.1	0.2	1.3	3.0	4.2	100.0
					St. Dev.	0.5	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.3	(27)
	TB2	opx, ho	pumice fall		Average	76.3	0.3	13.0	1.4	0.1	0.3	1.5	2.9	4.1	100.0
					St. Dev.	1.2	0.1	0.6	0.3	0.1	0.1	0.3	0.3	0.6	(26)
			pumice fall		Average	76.4	0.2	13.0	1.3	0.1	0.2	1.4	2.9	4.4	100.0
					St. Dev.	0.7	0.1	0.4	0.2	0.1	0.1	0.2	0.2	0.2	(20)
	TBJ	opx, ho	co-ignimbrite ash		Average	77.2	0.2	12.9	1.2	0.1	0.2	1.2	3.1	3.9	100.0
					St. Dev.	1.5	0.1	1.2	0.2	0.1	0.1	0.4	0.3	0.5	(29)
			pyroclastic flow		Average	77.0	0.2	12.9	1.1	0.1	0.2	1.2	3.0	4.3	100.0
					St. Dev.	1.4	0.1	1.0	0.2	0.1	0.1	0.4	0.3	0.4	(21)
			ash fall		Average	77.4	0.2	12.8	1.2	0.1	0.2	1.2	3.0	4.0	100.0
					St. Dev.	0.3	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.3	(27)

See text and table 1 for analytical conditions. The Chemical composition of tephras from Coatepeque Caldera and Ilopango Caldera is referred from previous studies, in which chemical analysis was realized under the same condition as this study.

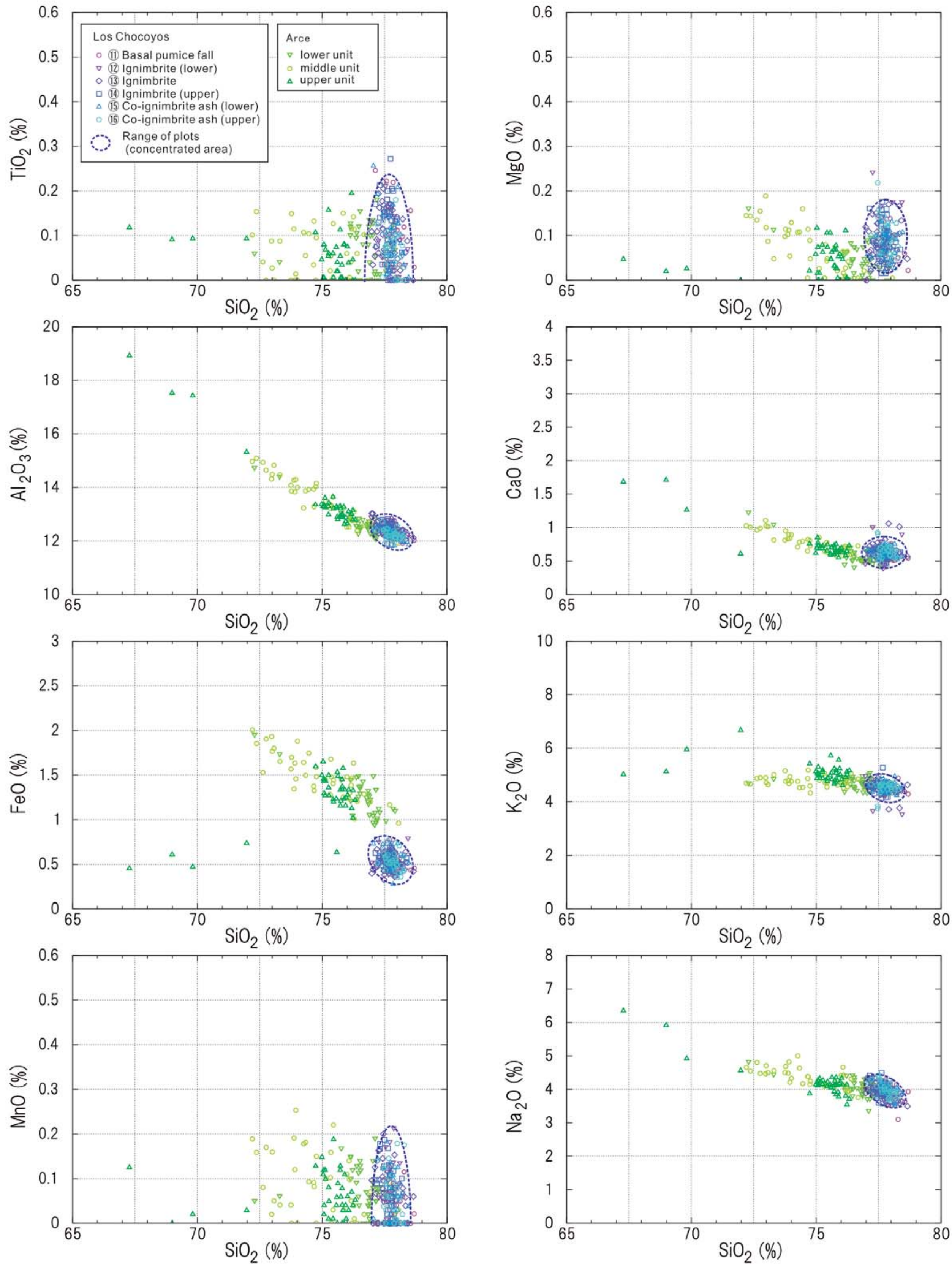

Fig. 8 Chemical composition of volcanic glass from the Los Chocoyos (H) tephra and the Arce tephra

See text and table 1 for analytical conditions. Sampling level is shown in fig. 6 by corresponding number. Ovals delineated with break line exhibit approximate ranges where chemical plots of the Los Chocoyos (H) tephra are concentrated.

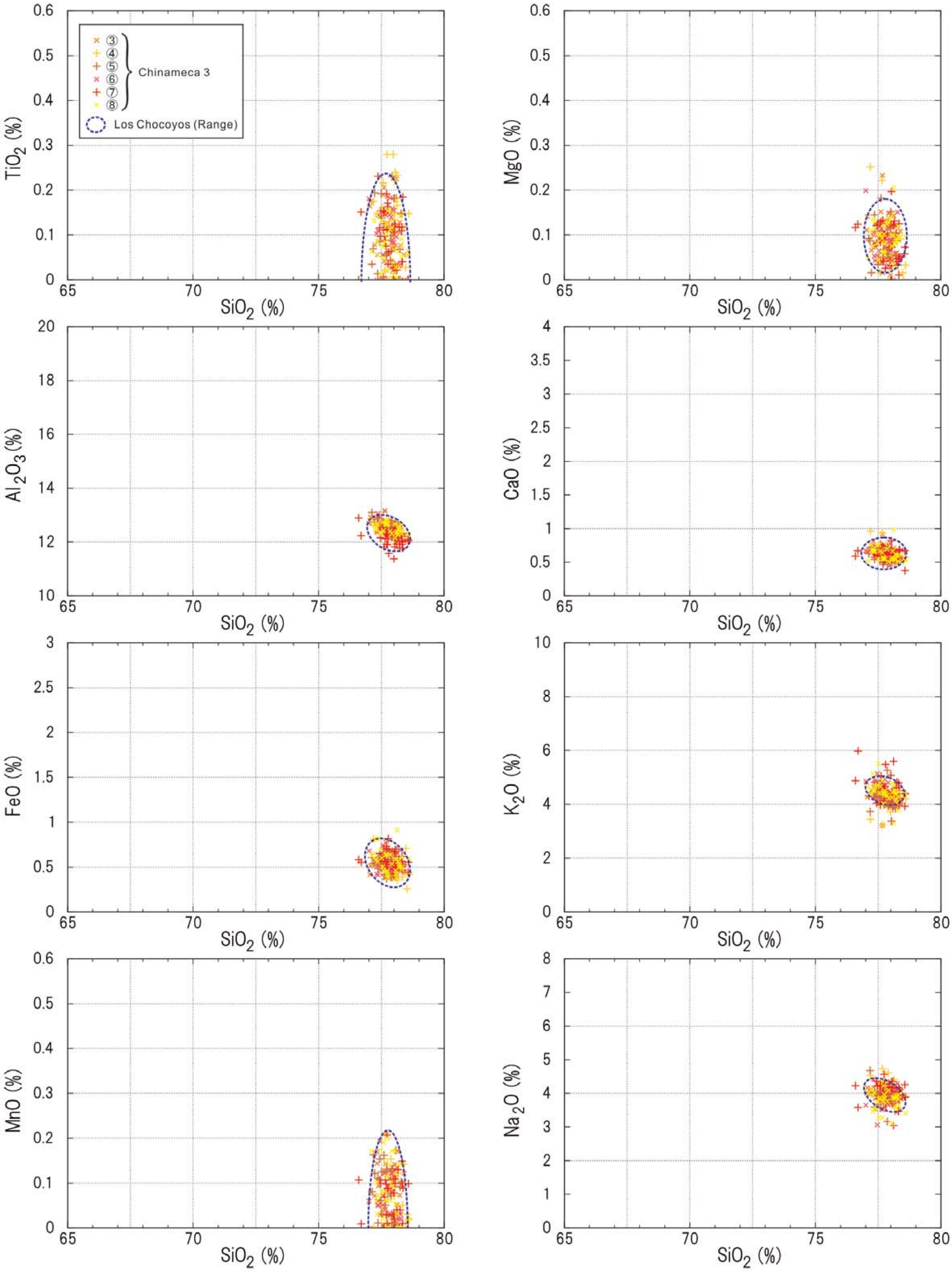

Fig. 9　Chemical composition of volcanic glass from the Chinameca 3 ash

See text and table 1 for analytical conditions. Sampling level is shown in fig. 5 by corresponding number. Ovals delineated with break line is the same with ovals shown in fig. 8 as the chemical variation of the Los Chocoyos (H) tephra.

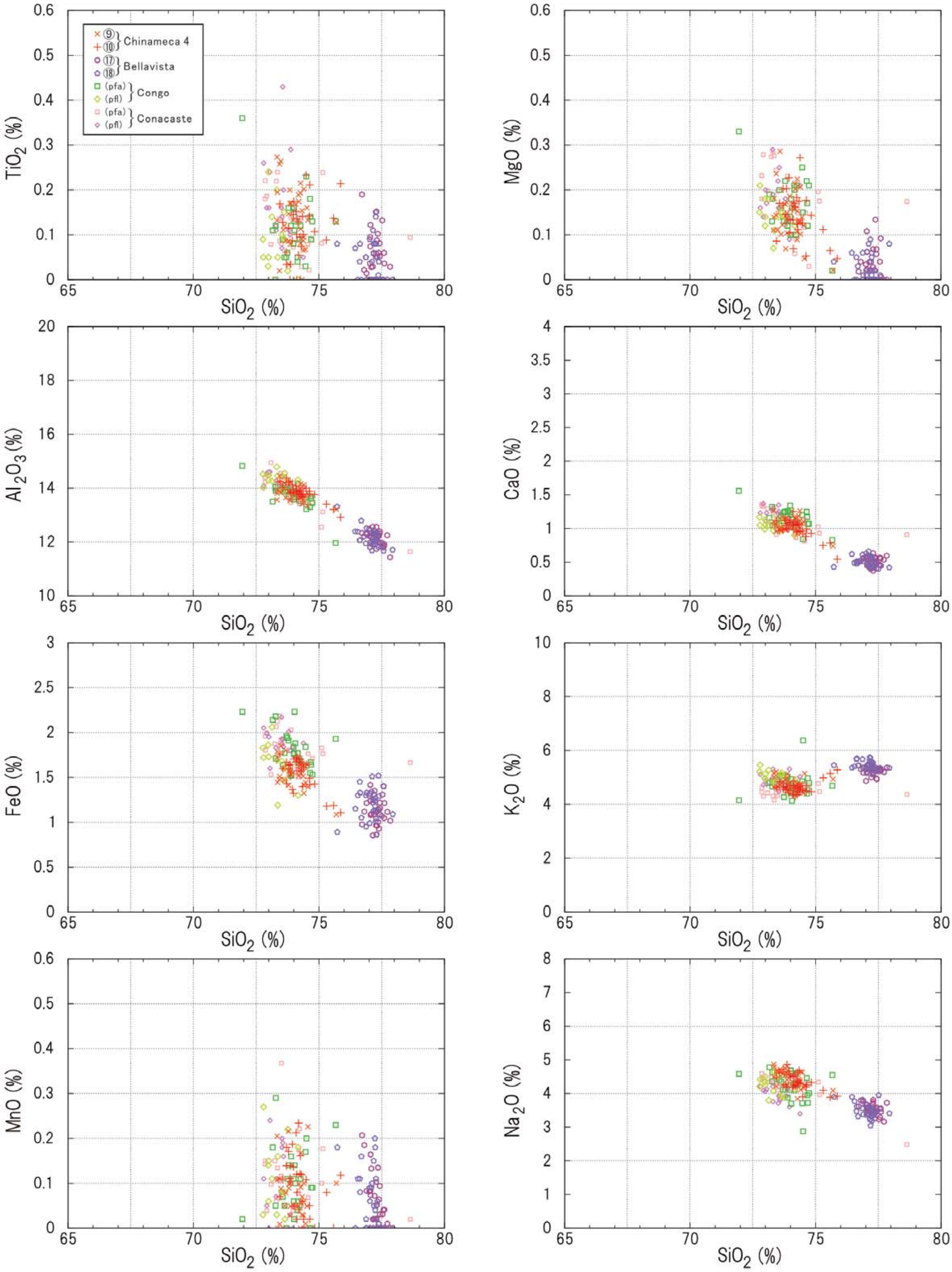

Fig. 10 Chemical composition of volcanic glass from the Chinameca 4 ash and tephras from Coatepeque Caldera

See text and table 1 for analytical conditions. Sampling level is shown in fig. 5 and 7 by corresponding number.

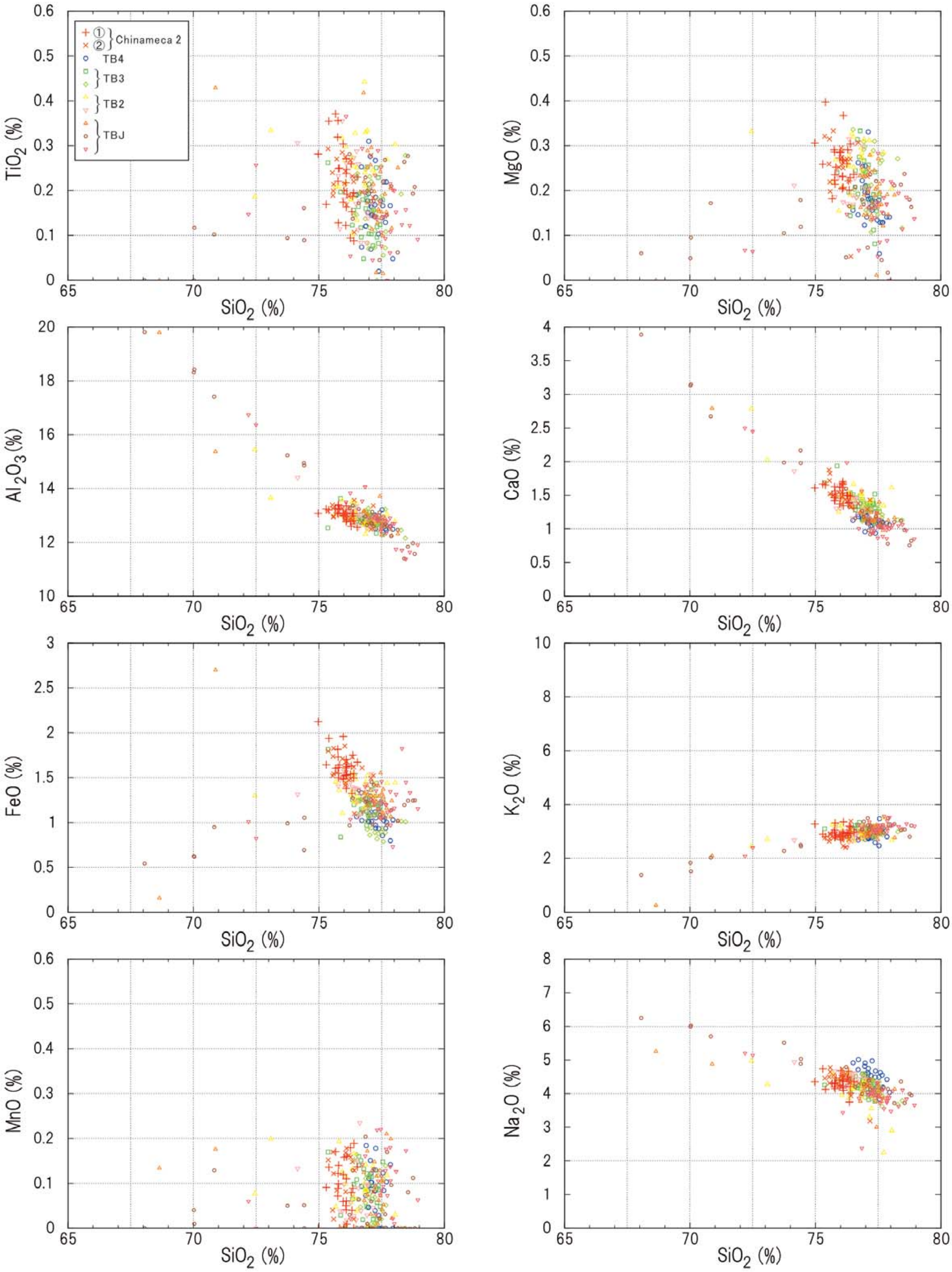

Fig. 11　Chemical composition of volcanic glass from the Chinameca 2 ash and tephras from Ilopango Caldera

See text and table 1 for analytical conditions. Sampling level is shown in fig. 5 by corresponding number.

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