Flow and emplacement mechanisms of low-aspect ratio ignimbrites inferred from grain fabrics

藤原, 誠

(Degree)
博士（理学）
(Date of Degree)
2015-03-06
(Date of Publication)
2017-03-06
(Resource Type)
doctoral thesis
(Report Number)
乙第3270号
(URL)
https://hdl.handle.net/20.500.14094/D2003270

博士論文

Flow and emplacement mechanisms of low-aspect ratio ignimbrites inferred from grain fabrics

粒子配列からみた拡散型大規模火砕流の流動・堆積機構

平成 27 年 1 月

神戸大学大学院理学研究科

藤原　誠

Flow and emplacement mechanisms of low-aspect ratio ignimbrites inferred from grain fabrics

Abstract

Low-aspect ratio ignimbrite (LARI) is unique pyroclastic flow sediment in which Average layer thickness is several meters and run out distance amounts to several 10 km also in a large-scale pyroclastic flow deposit. Unlike the general pyroclastic flow which flows, gets down from a slope, fills a topographic depression, and it deposits thickly, aspect ratio (equivalent round radius of average layer thickness / distribution area) is up to about 2x10-4 (Dade, 2003), and the example is few also in the world. About these LARI, detailed research is made and the feature is clarified. On the other hand, there is still room for an argument about LARI, how it flows and deposits.

We researched particle array about two examples, Koya pyroclastic flow deposit (Kyushu south direction, Kikai caldera origin) and Tosu pyroclastic flow deposit (one of the subunits of the Aso-4 pyroclastic flow deposit), which are a representative case of the spread type large-scale pyroclastic flow in Japan.There are two kinds of measuring methods of a particle array, particle individual measurement and bulk measurement, and it performed research from both of measuring methods. Particle individual measurement used using the extension axis excellence direction. Bulk measurement using rate of magnetization anisotropy: AMS (Anisotropy of Magnetic Susceptibility) .

Particle individual measurement shows that particles have turned to the random direction by both Koya and Tos pyroclastic flow deposits. The result of Particle individual measurement not having the same significant directivity about the extension axis excellence direction of both Koya and Tosu pyroclastic flow deposits, and it may be the common character in LARI. By Koya pyroclastic flow sediment 13 outcrop, only one outcrop shows the random direction, and a minor axis and a major axis gather well in other 12 outcrops. A minor axis concentrates on a vertical direction in all 12 outcrops, and a major axis concentrates the current direction from the source in 9 outcrops. In Tosu pyroclastic flow sediment 11 outcrop, although a minor axis shows a vertical direction in all the outcrops, a major axis does not gather well. It can be interpreted as having deposited in the state of rest, but there is a possibility of the effect of the compaction by gravity. LARI was deposited in the strong turbulent flow as a result of two kinds of measurement.

Contents

Chapter 1

Introduction

Low-aspect ratio ignimbrite is the products of eruption that is one of the most intense volcanic phenomena as spread over 100 km from the source and possible to destruct a civilization. Low-aspect ratio ignimbrite not so many example but there is two famous deposit, Koya pyroclastic flow deposit and Tosu Pyroclastic flow deposit. In this study, focus on particle orientation and compare both pyroclastic flow deposits and and elucidate a Low-aspect ratio ignimbrite flow and deposit conditions.

Chapter 2

Geology of Koya pyroclastic flow deposit

2-1 Introduction

In this chapter, in order to know about features of Koya pyroclastic flow, investigation by geological exploration was performed for Koya pyroclastic-flow deposit in southern Kyusyu, Japan. Koya pyroclastic flow picked because this is one of the most famous and youngest deposit of low-aspect ratio ignimbrites in Japan. There are fresh outcrops and easy to collect samples. More over, there are many previous works about the eruption and there is much information that becomes reference of research.

2-2 Geology of Kikai caldera

The source of Koya pyroclastic flow is the Kikai caldera of about 15 km in diameter located in the East China Sea southern Kyusyu. It is about 100-500m at the bottom of the sea now. Two islands, Take-shima and Satsuma Iwo-jima, is subaerial parts of the northern caldera rim (Fig.2-1). Kikai caldera was formed by two large eruptions. One is Kikai Tozurahara eruption, the other is Kikai akahoya eruption. Kikai Akahoya eruption, 7300 y.b.p. (Fukuzawa,1995), generates four major units. The lowermost unit is Funakura pumice fallout (Ono et al., 1989). The second unit is Funakura pyroclastic-flow deposit, which is intraplinian flow. The third unit is large volume ignimbrite, which called Koya pyroclastic flow deposit (Ui, 1973) for the distal area, and Take –shima pyroclastic flow deposit (Ono et al., 1982, Walker et al., 1984) for the proximal islands, Take-shima and Satsuma Iwo-jima. The last, co-ignimbrite ash-fall deposit 'Akahoya ash fall' (Machida and Arai, 1978) overlay these ignimbrites (Fig.2-2).

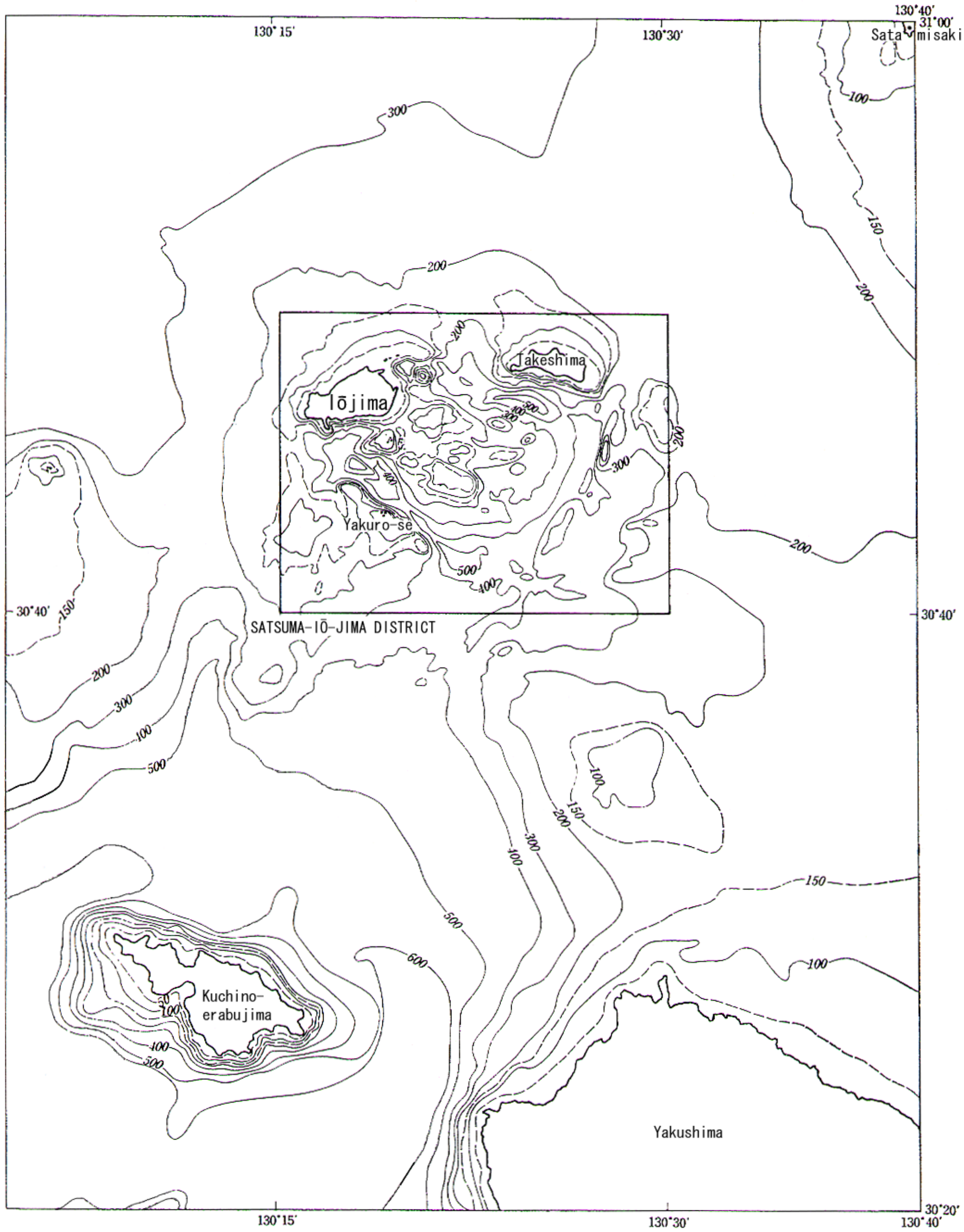


Fig.2-1

Submarine topography in and around the Satsuma Io-jima district (modified from Basic Maps of the Sea, Nos. 6351,6353 and6353[4]). After Ono et al.,1982.

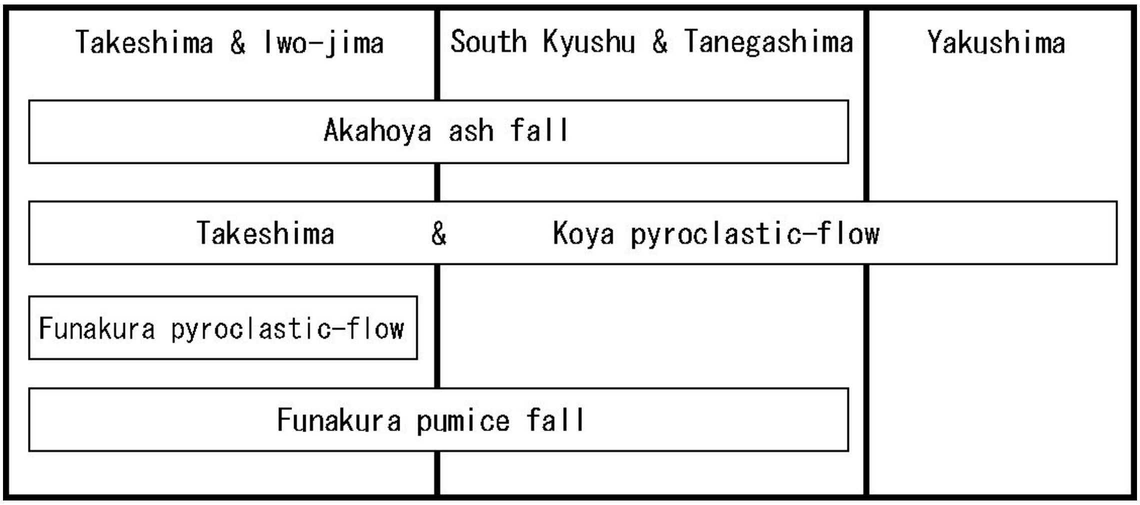


Fig.2-2
Stratigraphic relationship of Koya eruption deposit on caldera rim islands. Funakura pyroclastic-flow exist only Takeshima and Iwo-jima Island. (Adapted from Ono et al 1982)

2-3 Features of the Kikai akahoya eruption ejecta

2-3-1 Funakura pumice fall deposit

The Funakura pumice fall deposit is distributed in the southern part of Kyusyu Island and around islands of Kikai caldera (Fig.2-3). In caldera rim islands, this unit consists about 10 cm diameter pumice lapilli mainly, and shows some normal and reverse graded layers about 1 m thick. In mainland Kyusyu, pumice fall deposit consists several mm - 1 cm diameter pumice, and thickness is 20 - 40 cm or more. The volumes of Funakura pumice fall deposit is estimated about 20 km^3 (Machida and Arai, 1992).

There are intraplinian pyroclastic flow deposits 'Funakura pyroclastic flow deposits' between these layers.

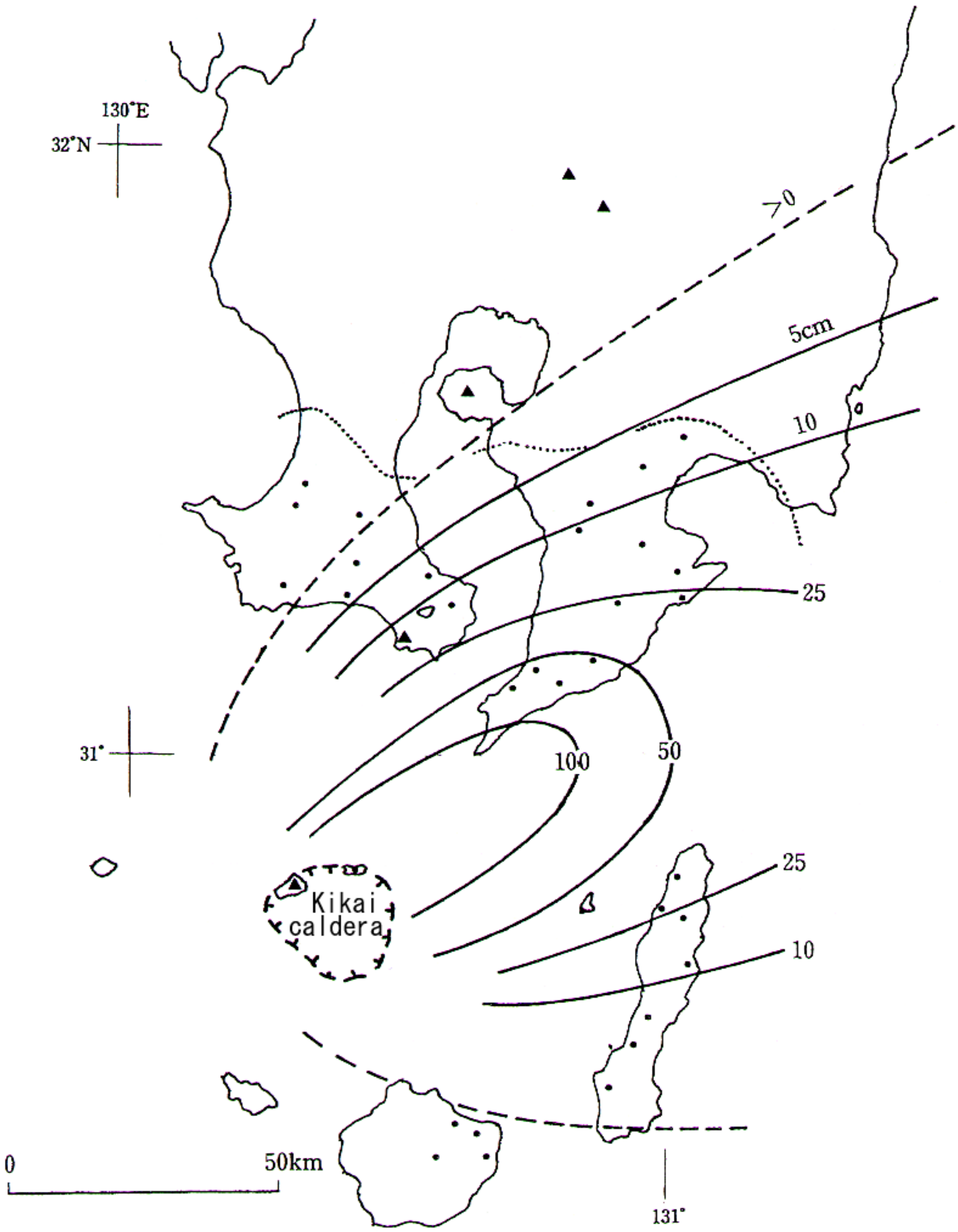


Fig.2-3 Dispersal map of the plinian pumice-fall. Dotted line is distribution limit of the koya pyroclastic flow. From Machida & Arai (1992).

2-3-2 Funakura pyroclastic flow deposit

The Funakura pyroclastic flow deposit is distributes in topographic lows of Take-shima. Maeno et al.,(2007) also discovers it in Satsuma Io-jima, but we could not find. Thickness is few tens of centimeters to 2 meters. The Funakura pyroclastic flow deposit is non-welded or weakly welded.

2-3-3 Take-shima and Koya pyroclastic flow deposit

The Take-shima pyroclastic-flow deposit (Ono et al., 1982) for the proximal areas, expose on the two islands of caldera rim. The Take-shima pyroclastic-flow deposit is non-welded, massive, and fills topographic depressions. It consist white colored pumices, ash, small amount of banded pumices and obsidians. The thickness of it varies few meters to 20 meters or more. The bottom of this ignimbrite, lithic-rich and fines-poor unit that interpreted “Lag breccia” (walker, 1985) is recognized in some locations. Fines-depleted layer or lithic-rich layer divides the Take-shima pyroclastic-flow deposit into some subunits.

The Koya pyroclastic-flow deposit (Ui, 1973) for the distal areas, distributes southern side of mainland Kyusyu, Tanega-shima, Yaku-shima and Kuchinoerabu-jima islands (Fig.2-4). Thickness of this is up to one meter and not depends on topography. Lithic and free crystal-rich, fines-depleted “Ground layer” (Walker et.al., 1981) is often recognized. The Koya pyroclastic-flow deposit sometimes has pumice concentration zone, but it is lack continuity and no unit boundary. It is yellowish color, but in Satsuma peninsula and south west of Osumi peninsula, it shows white to bluish color, because they are covered by pumice-fall deposit from ikeda caldera before altered. The volumes of Take-shima and Koya ignimbrites were estimated to be about 15-25 km^3 in total DRE (Maeno and Taniguchi, 2007).

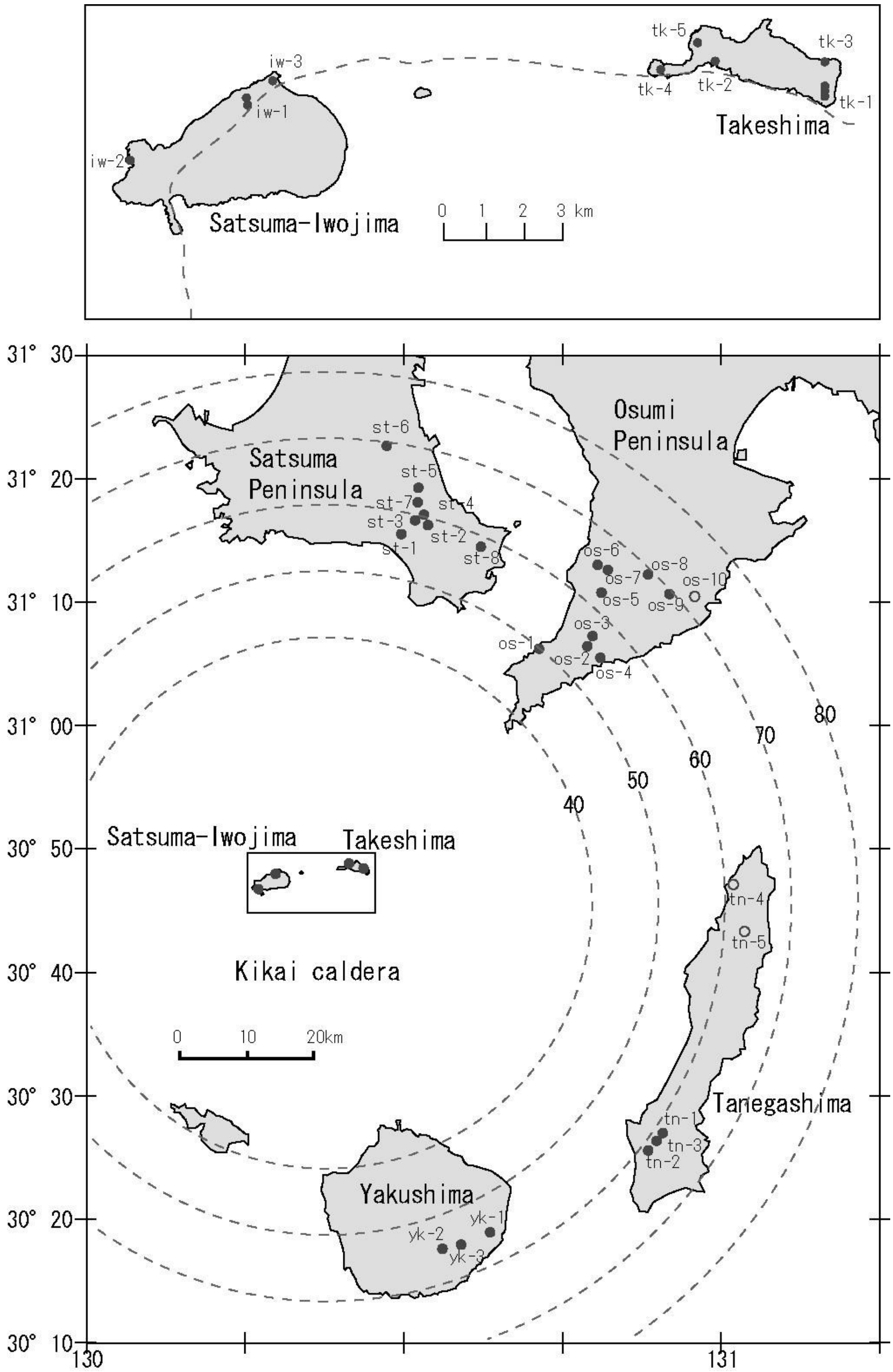


Fig.2-4 Site location map of measured stratigraphic sections in south Kyusyu. Open circles show point that Koya pyroclastic-flow deposit is absent. Dashed circle and number is distance from caldera center. Location number correspond to columner section number of Fig.2-6.

2-3-4 Akahoya co-ignimbrite ash-fall deposit

The Akahoya ash-fall deposit shows nomal grading and orange or yellowish color. Thickness is few tens of centimeters to one meter, which is same thickness of Koya pyroclastic-flow deposit or more in some locations. This unit distributes over 1000km from caldera to central Japan (Fig.2-5). The volume of this tephra estimated to be about 100 km^3 (Machida and Arai, 1978).

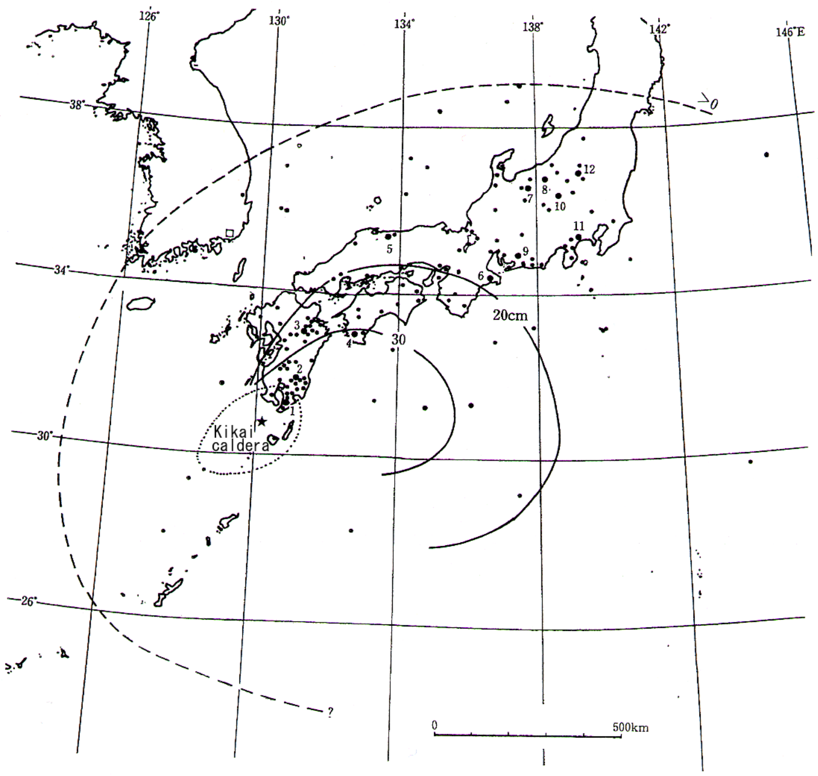


Fig.2-5 Isopach map (thickness values in cm) of the Akahoya co-ignimbrite ash. Dashed line is limit of distribution. From Machida & Arai (1992).

Ah	Akahoya ash fall deposit
Ky	Koya pyro-clastic flow deposit
GL	Ground Layer
F	Funakura pyro-clasitc flow deposit
P	Pulinian fall deposit

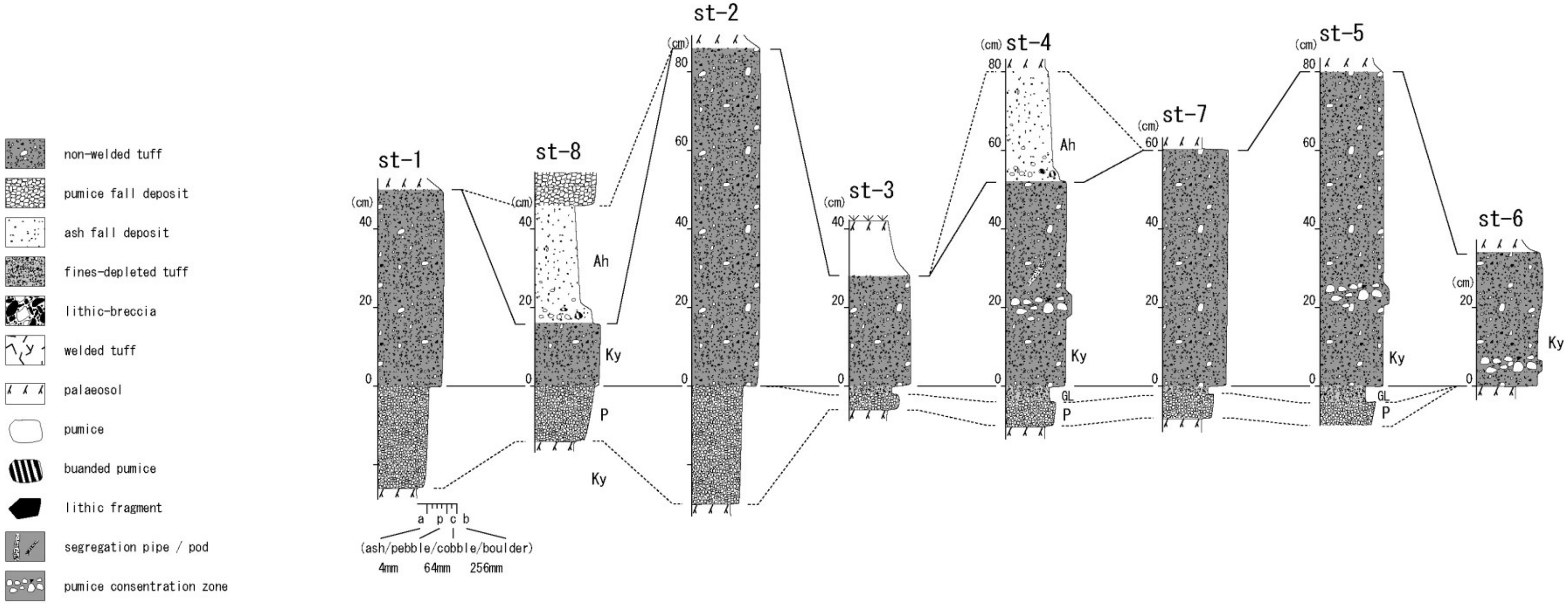
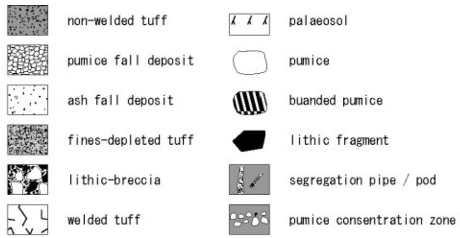
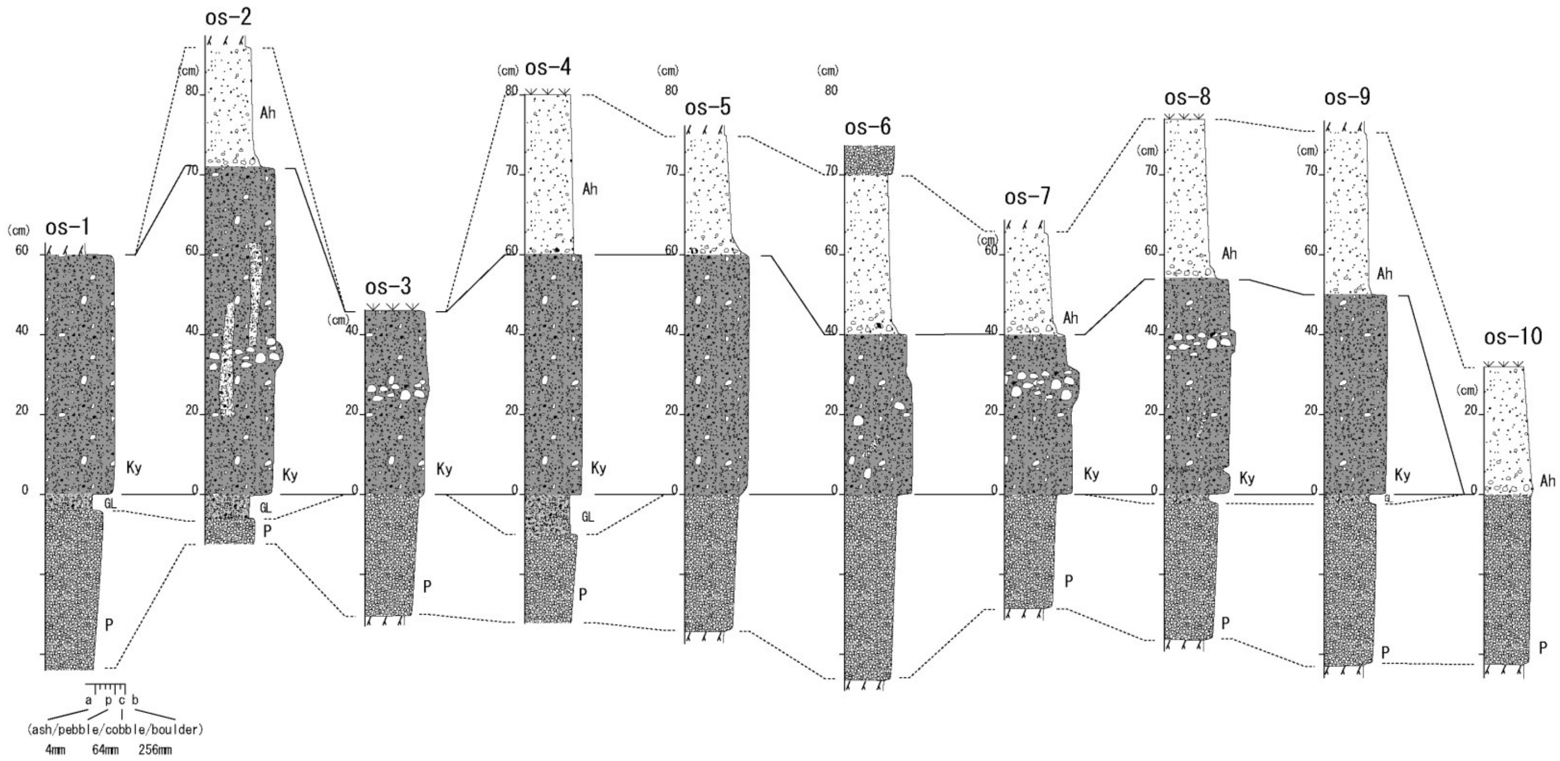


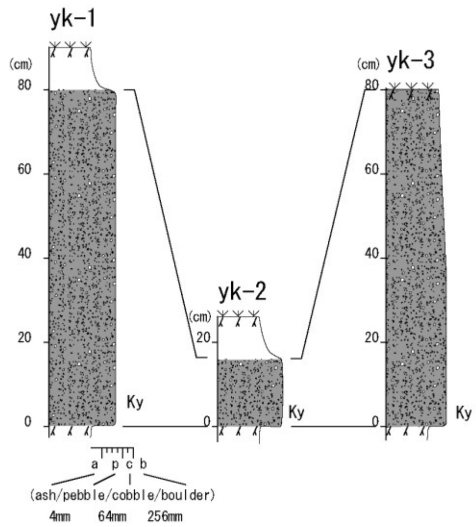
Fig. 2-6 Columner section of Kikai akahoya eruption deposit.

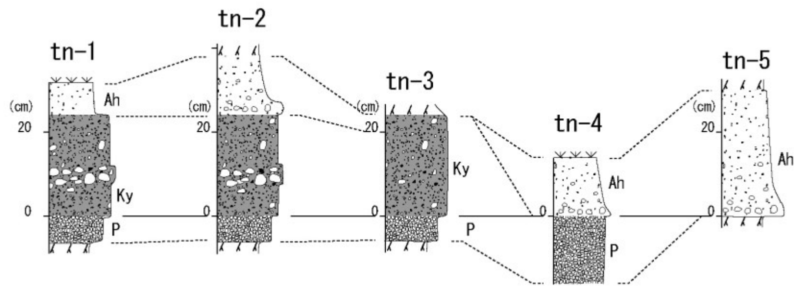
Ah	Akahoya ash fall deposit
Ky	Koya pyro-clastic flow deposit
GL	Ground Layer
F	Funakura pyro-clasitc flow deposit
P	Pulinian fall deposit



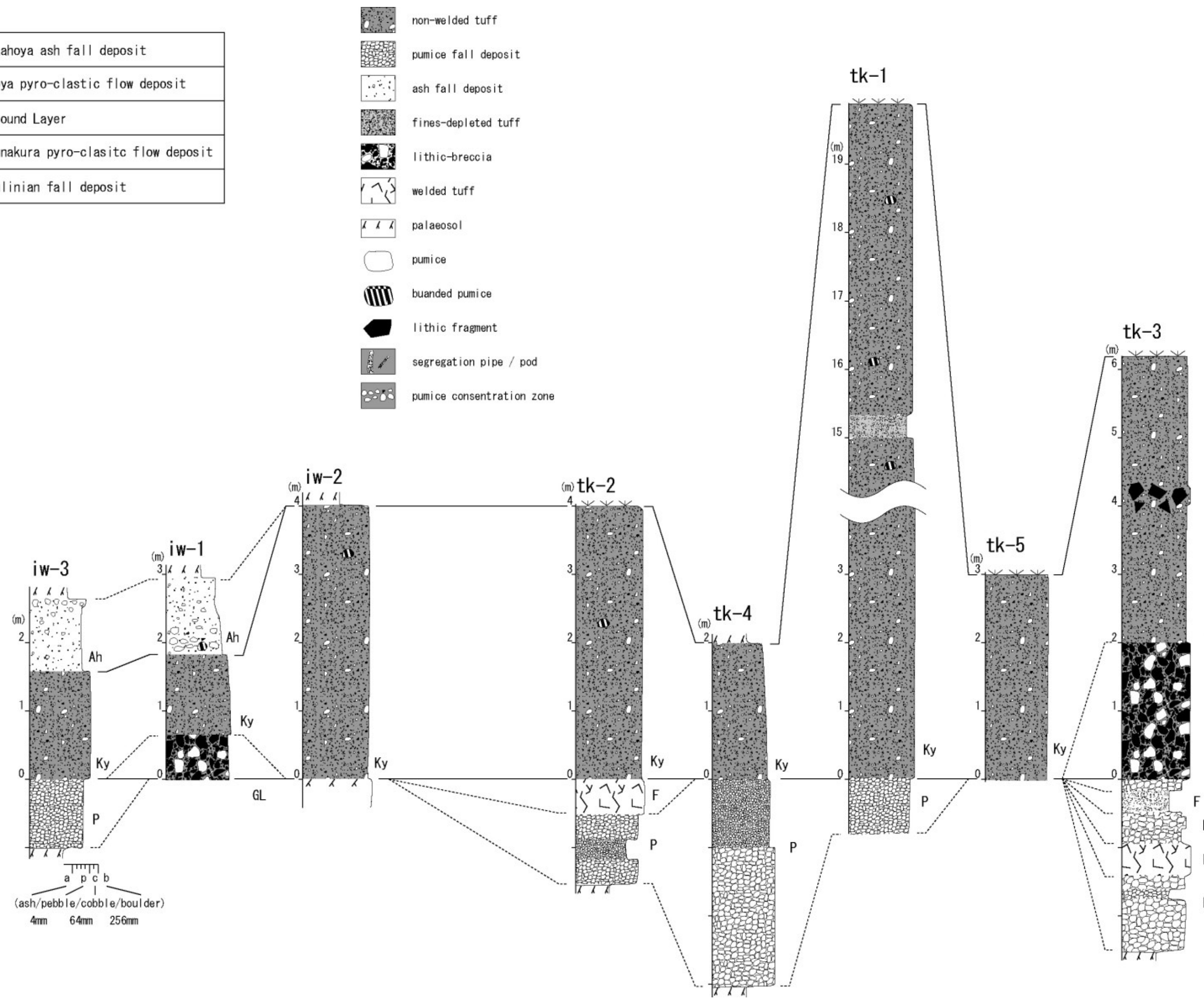


Ah	Akahoya ash fall deposit
Ky	Koya pyro-clastic flow deposit
GL	Ground Layer
F	Funakura pyro-clasitc flow deposit
P	Pulinian fall deposit





Ah	Akahoya ash fall deposit
Ky	Koya pyro-clastic flow deposit
GL	Ground Layer
F	Funakura pyro-clasitc flow deposit
P	Pulinian fall deposit



Chapter 3

Geology of Tosu pyroclastic flow deposit

3-1 Introduction

Tosu pyroclastic-flow deposit is one of low-aspect ratio ignimbrites. It has quit low aspect ratio, wide distribution and very thin deposit. Tosu pyroclastic-flow deposit had erupted from Aso caldera about 100,000 years ago. Tosu pyroclastic-flow deposit is older than Koya pyroclastic-flow deposit, so, it is difficult to earn data from outcrops and samples. Tosu pyroclastic-flow deposit is investigated by Watanabe (1978, 1979), Suzuki – Kamata and Kamata (1990) and another in detail. In this study, the survey take placed, but outcrops of new and exceed previous works areas are not discovered, due to presently decreasing outcrops.

3-2 Geology of Aso caldera

Mount Aso is the largest active volcano in Japan, and is among the largest in the world. Aso volcano is located in Kyushu central part and is polygenic volcano which consists of a central volcanic cone group and caldera of about 20 km of diameter. The eruption which formed the present caldera occurred approximately 300,000 years ago. Four large-scale eruptions (Aso-1 – 4) occurred during a period extending from 300,000 to 90,000 years ago. As large amounts of pyroclastic flow and volcanic ash were emitted from the volcanic chamber, a huge caldera was formed as the chamber collapsed. The fourth eruption (Aso-4) is the largest, with volcanic ash covering the entire Kyusyu region and even extending to Yamaguchi Prefecture.

3-3 Feature of Tosu pyroclastic flow deposit

Tosu pyroclastic-flow deposit is a member of Aso-4 group. Aso-4 pyroclastic flow deposit is reaching More than 180 km from the eruptive center (Watanabe, 1978; Ono Watanabe ,1983; Watanabe ,1986). Aso -4 pyroclastic flow deposit is divided into the sub-unit of some from rock facies and lithological character. Then (Ono et al. 1977) and Oita-prefecture eastern region (Watanabe, 1986; Hoshizumi et al., 1988; Teraoka et al., 1990,1992; Hoshizumi Morishita, 1993; Sakai et al.,, 1993; Yoshioka et al. 1997) are divided by the sub-unit of 2, 4A and 4T into 2 sub-units of the 4A,4B in the Takeda area of (Watanabe,1978) and the Aso caldera east side in 8 sub-units on the west side of the Aso caldera (Fig. 3-2). Aso-4 pyroclastic flow deposit is divided into 8 sub-units on the west side of the Aso caldera (Watanabe,1978), 2 sub-units of the 4A,4B in the Aso caldera east side Takeda area (Ono et al., 1977), and 2 sub-units of the 4A,4B in the eastern region of Oita prefecture (Watanabe, 1986; Hoshizumi etal, 1988; Teraoka etal 1990,1992; Hoshizumi Morishita, 1993; Sakaiet al., 1993; Yoshioka et al., 1997). 4A, 4T, 4B is distributed in the Miyaharu area on the north side of the Aso caldera (Kamata. 1997). 4A is equivalent to the Yame pumice flow deposit (Watanabe 1978) and 4T is equivalent to the Tosu orange pumice flow deposit (Hoshizumi et al., 1988; Teraoka et al., 1990, 1992; Hoshizumi and Morishita ,1993; Sakai et al.,1993). 4A is also distributed on north part of Miyazaki prefecture (Imai et al., 1982). Kunomine scoria flow deposit is distributed on the 4T in the north of caldera (Kamata 1997).

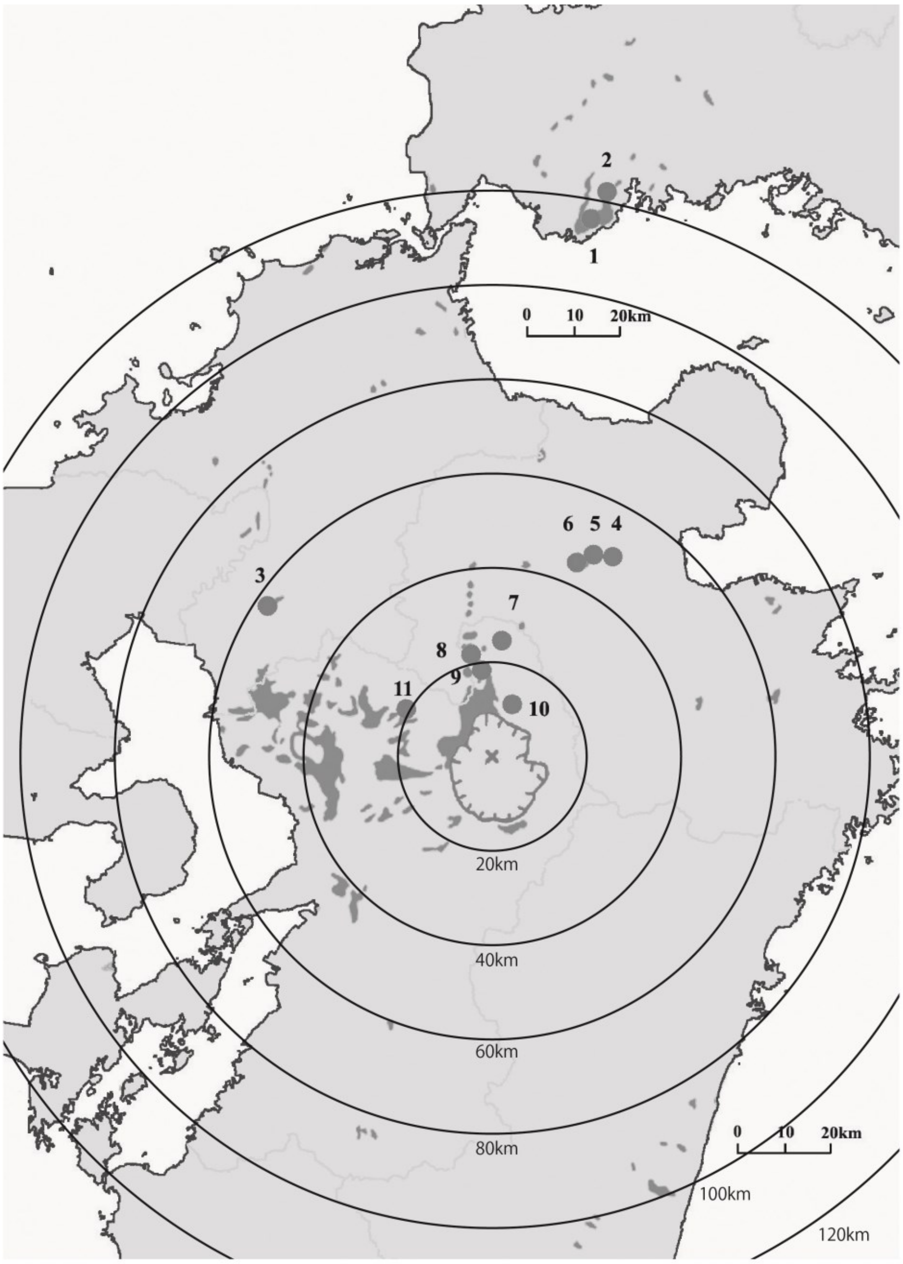


Fig 3-1. Distribution of the Tosu pyroclastic flow deposits and location of sampling points modified from Suzuki – Kamata and Kamata (1990).

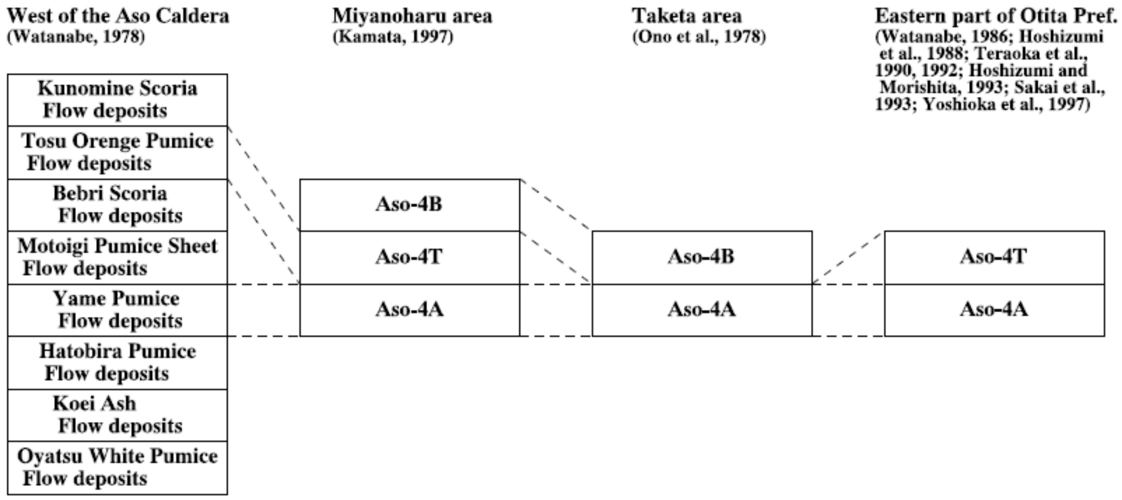


Fig 3-2. Eruptive units of Aso-4 pyroclastic flow deposits.

Chapter 4

Features of low-aspect ratio ignimbrite

4-1 Introduction

Low aspect-ratio ignimbrites (LARI) have extremely wide distribution and thin layer, propound by Walker et al., (1980). Low aspect-ratio ignimbrites (LARI) An ignimbrite sheet displaying a aspect-ratio value for the ratio of its average thickness (V) to its horizontal extent (H) of 10^{-4} to 10^{-5} (Fig4-1), where H is taken as the diameter of a circle whose area is equal to that of the flow.

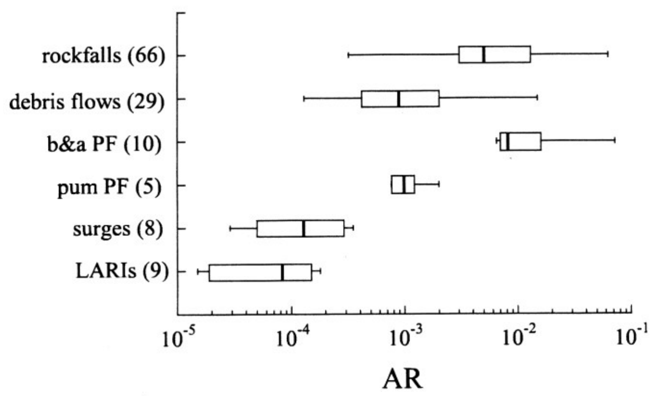


Fig. 4-1. Box and whisker plots from Dade 2003. The aspect ratio AR is ratio of its average thickness to the radius of a circle of equal area in plan. Pum PF is small-volume pyroclastic flows of pumice and ash. B&A PF is small-volume pyroclastic flows of block and ash. The box plot means the median value, the central two quartiles, and the range of the extreme values. It is the order of 10−4 or less.

4-2 Distribution area and thickness

Koya pyroclastic flow deposits distribute 80 km from the source. The depots is absent in 10-50 km from the source because there is sea area (Fig. 4-2). Thickness of the Koya pyroclastic flow deposit of caldera rim (proximal area) is 20m and of distal area is less than 1 m. If the average thickness is 10 m, aspectratio is 1.25×10^{-4} value. Tosu pyroclastic flow deposit distribute 120km from the source and average thickness is 2 m, aspectratio is 1.67×10^{-4} value (Fig. 4-3).

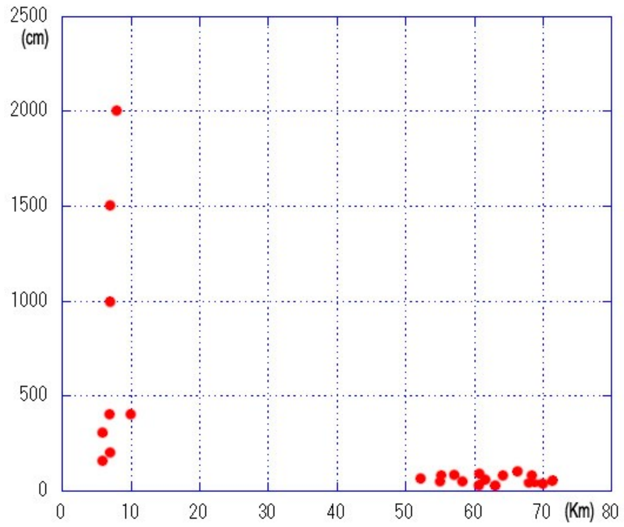


Fig.4-2 Thickness versus distance from the source of Koya pyroclastic flow depsit. There is no data in halfway there, because it's a sea area.

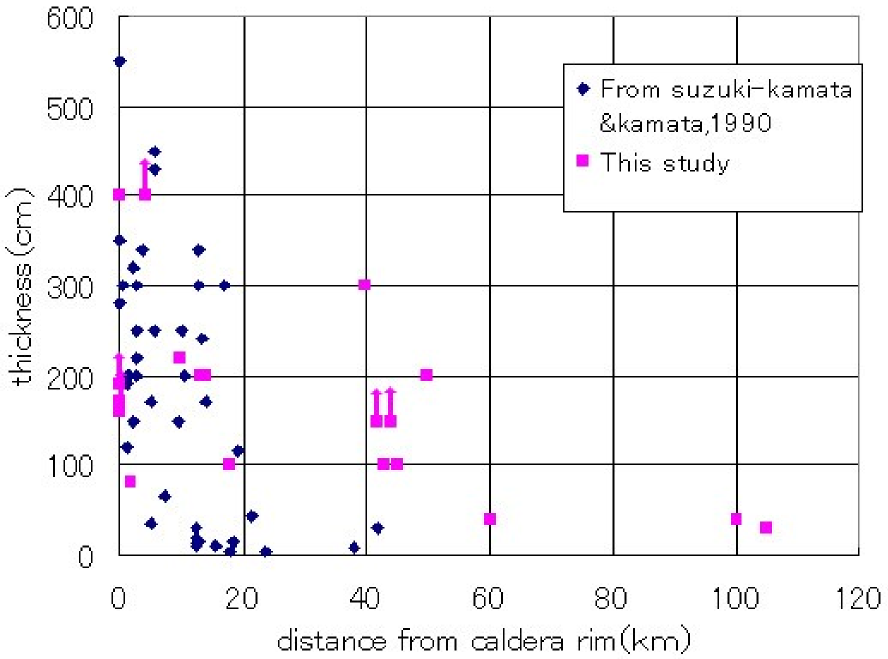


Fig.4-3 Thickness versus distance from the source of Tosu pyroclastic flow deposit. Blue plots data from Suzuki-kamata and kamata 1990.

Chapter 5

Grain fabric

5-1 Introduction

The sequence pattern of the long axis of the deposit particle is called grain fabric or grain shape fabric. Because the formation of the particle arrangement is strongly influenced by the flow and depositional mechanisms of the deposit, various information comes to be included in the particle array. For instance, flow direction and nature, character and anisotropy of deposit can be read from grain fabric.

There are two kinds of particle analysis. One is the Particulate method, which is way to recognize each particle. There is an image method as a typical technique with Particulate method. It can clarify a detailed characteristic of the particle arrangement, but it takes long time and trouble for the measurement. The other is Bulk method, which is a technique for the measurement of some physical properties strongly influenced by the particle arrangement, and presuming the particle arrangement. The example of this is Anisotropy of Magnetic Susceptibility (AMS). Bulk method can measure a large amount of samples in short time, but a detailed characteristic of the particle arrangement cannot be detected. We used both methods and discussed from each side.

5-2 Grain size distribution

The grain size distribution of pyroclasts is determined by the fragmentation process which generates the pyroclastic materials and the transport and depositional processes. There are previous works that examined transport process is estimated from the grain size distribution of pyroclasts for Take-shima and Koya ignimbrite (Walker et al., 1984, Maeno and Taniguchi 2007) and for Tosu pyroclastic flow deposit (Watanabe 1978, Suzuki-Kamata and Kamata 1990). We collect about 1 kg bulk samples par place. Koya samples are collected from upper part and Lower part respectively at sites where are enough thick. Tosu samples are collected from each facis, FD, LI and NI. After making it dry at 110 ℃ for 24 hours or more and classifying the samples into 1 ϕ interval to 1 / 16 mm (4 ϕ) using sieves , the weight of each class was measured. From the grain size analytical result, median diameter (Mdϕ), and sorting($\sigma\phi$)were calculated followed inman (1952) (Fig. 5-1, 5-2, 5-3).

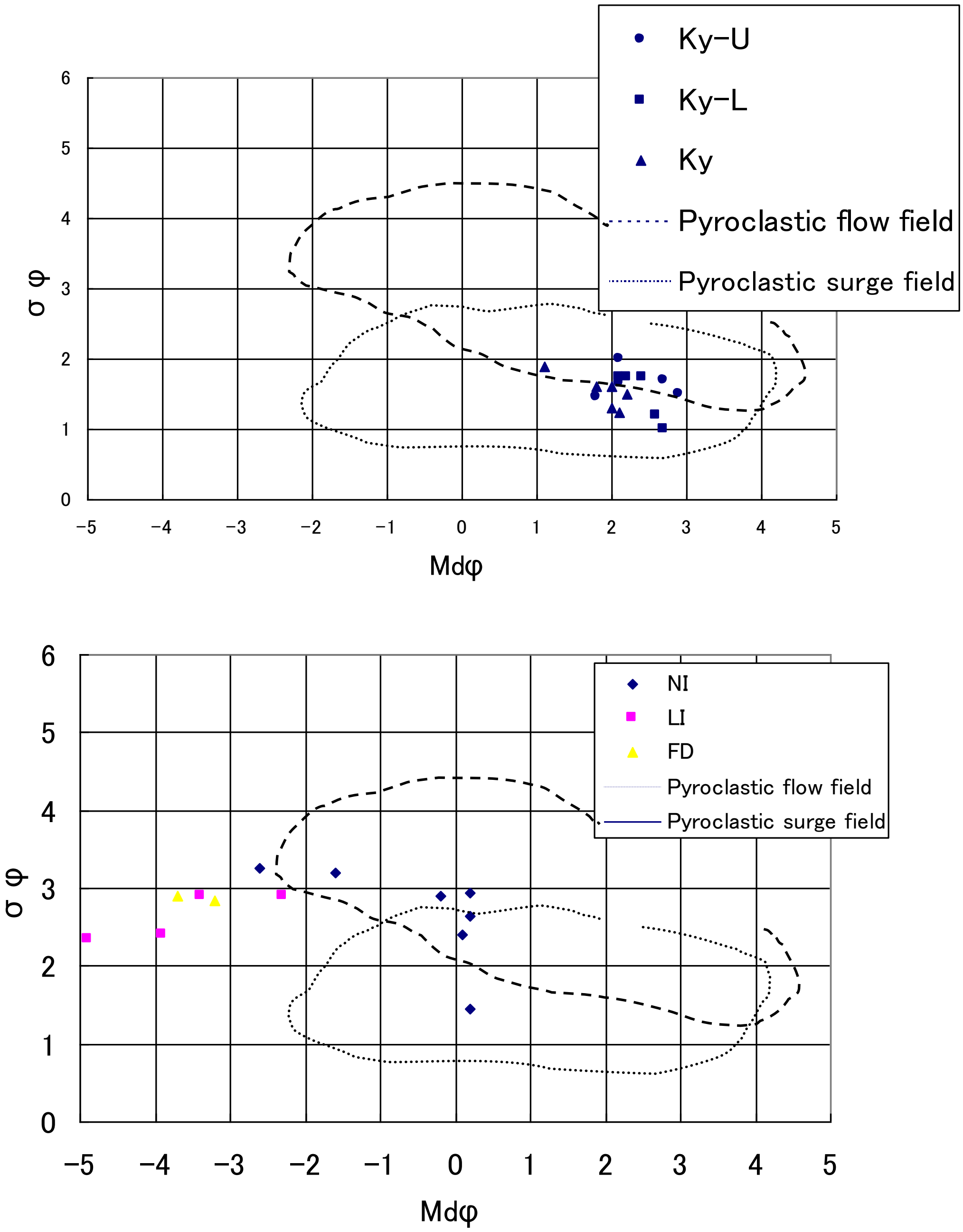
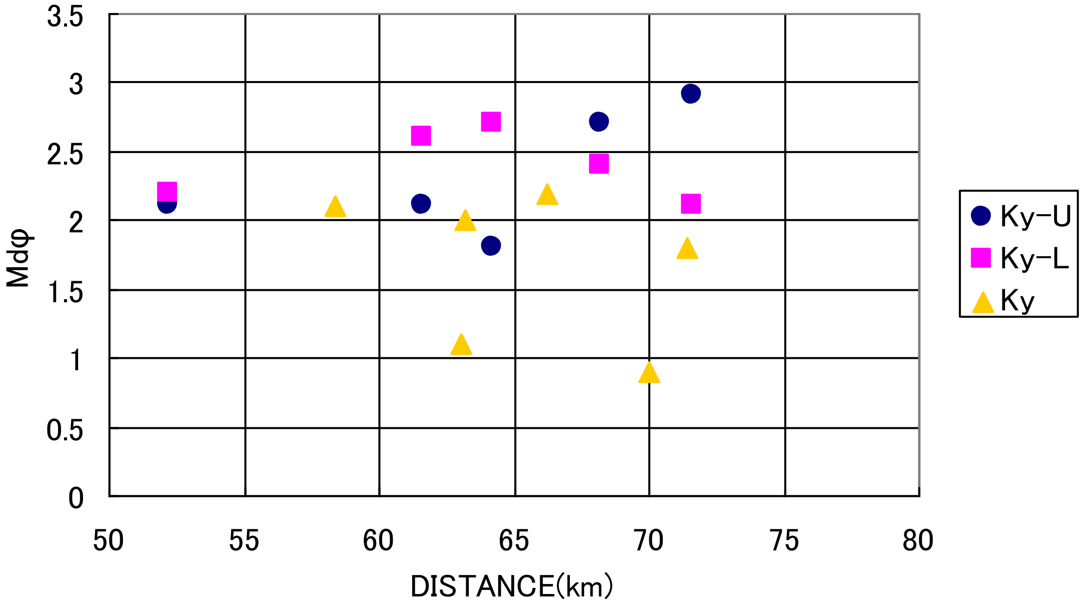


Fig.5-1 Grain-size plots of the Koya pyroclastic-flow deposit and Tosu pyroclastic-flow deposit. Dashed lines – the 2% contour for the pyroclastic flow field. Dotted lines – the 2% contour for the field of pyroclastic surge (Walker1983).



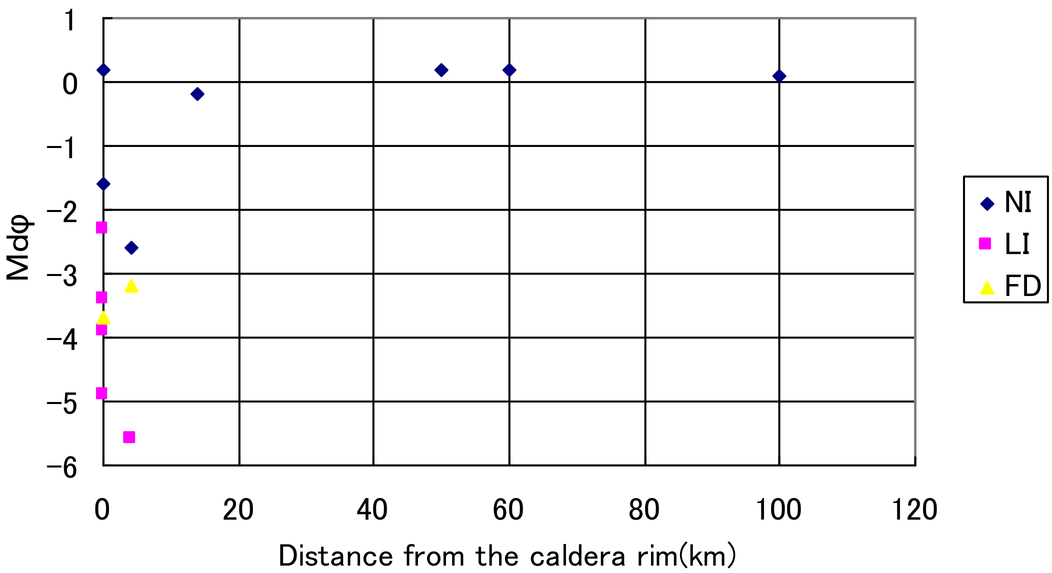
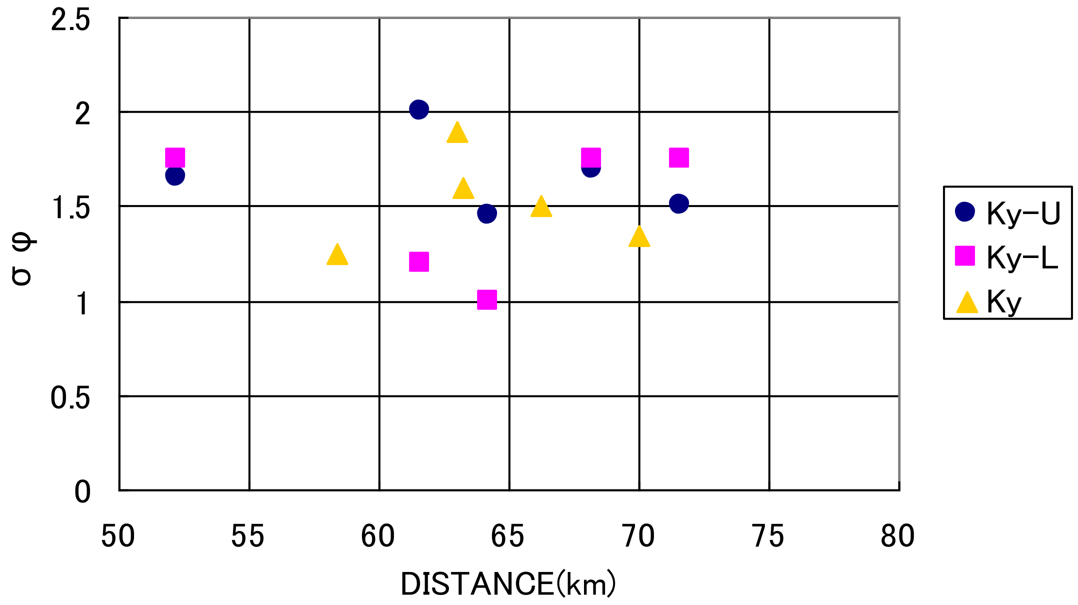


Fig . 5-2 Prot of Md ϕ vs Distance from the source.



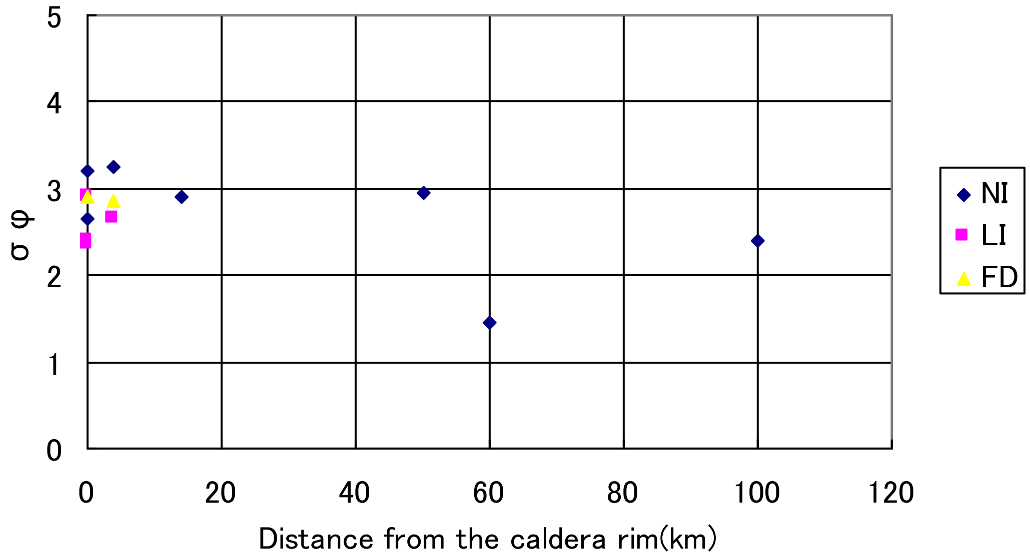


Fig. 5-3 Prot of σ ϕ vs Distance from the source.

5-3 Grain fabrics analysis

5-3-1 Grain fabric analysis

Grain fabric analysis used to determine flow directions in ignimbrites. In some cases flow directions have been successfully determined from textural indicators. These include use of imbricated logs (Froggatt et al., 1981), as well as orientation of glass shards, crystals, pumice, and lithic fragments (Elston and Smith, 1970; Suzuki and Ui, 1982, 1983, 1988; Ui et al., 1989).

5-3-2 Method

The method of measurements is basically identical with that of Elston and Smith (1979) and Suzuki and Ui (1983). Box collected samples were Oriented by using of magnetic compass in the field. Samples cemented by resin in the laboratory. Measurements of preferred lineation were made using cutting thin sections cut parallel to the depositional surface and direction to the source. The long axes of pumices, lithic fragments and free crystals with aspect ratios exceeding 1.5 were measured. Orientations of grains in a slab and thin section were counted in 15° intervals. The significance of the flow lineation data was analyzed using the Tukey Chi-square test (Tukey, 1954). A 90% probability level (Chi-square value for 2 degrees of freedom equals 4.61) is considered to be statistically significant for the flow lineation. Preferred orientation was calculated using the equation of arithmetic mean:

$$\text{Preferred } orientation = 15^\circ X \frac{\sum Xjdj}{\sum Xj} + Middle \text{ value}$$

X: Number of measured fabrics;

dj: The order of the interval j counted from Middle value;

Middle value: The mid-degree value of the interval.

5-3-3 Results

Preferred orientations were showed Table5-1, 5-2 and Fig.5-4, 5-5. Koya and Tosu vertical cut samples show 6 in 13 and 3 in 11 that Chi-square value is more than 4.61. Koya and Tosu Horizontal cut samples show 5 in 13 and 2 in 11.

Table 5-1 Results of grain fabric analysis of Koya pyroclastic flow deposit. The direction means preferred orientations degree clockwise from geographic north or vertical. A number-side is vertical cut thin sections and –up is horizontal cut thin sections.

No.	direction	Chi value	grain number	No.	direction	Chi-squar	grain number
1−side	130.1	1.32	87	1−up	4.8	0.42	99
2−side	86.1	6.23	98	2−up	11.7	4.79	98
3−side	144.5	2.38	161	3−up	128.5	1.03	130
4−side	93.8	3.91	127	4−up	11.5	4.2	123
5−side	151.3	1.25	162	5−up	24.7	1.45	135
6−side	128.5	1.1	111	6−up	39.7	1.95	105
7−side	88.5	5.98	115	7−up	7.9	4.97	87
8−side	84.1	2.53	128	8−up	168.8	1.3	140
9−side	132.7	1.71	125	9−up	2.7	1.85	112
10−side	98.6	10.5	124	10−up	10.8	6.31	112
11−side	83.8	5.03	160	11−up	171.1	3.01	107
12−side	79.7	5.32	123	12−up	166.2	6.73	97
13−side	109.9	6.21	162	13−up	172.8	5.79	131

Table 5-2 Results of grain fabric analysis of Tosu pyroclastic flow deposit.

No.	direction	Chi value	grain number	No.	direction	Chi value	grain number
1−side	87.5	2.79	72	1−up	174.7	0.6	87
2−side	129.8	2.58	135	2−up	14.7	1.56	116
3−side	135.9	0.91	68	3−up	132.18	0.83	93
4−side	78.5	5.2	93	4−up	31.7	4.96	87
5−side	98.7	2.5	103	5−up	2.4	1.82	123
6−side	83.1	4.96	88	6−up	64.1	2.67	109
7−side	118.1	2.07	93	7−up	151.3	1.25	65
8−side	119.5	0.47	128	8−up	11.9	1.33	27
9−side	126.5	2.39	80	9−up	179.2	2.65	87
10−side	101.7	6.02	89	10−up	59.5	5.31	89
11−side	123.1	3.51	188	11−up	136.5	2.68	121

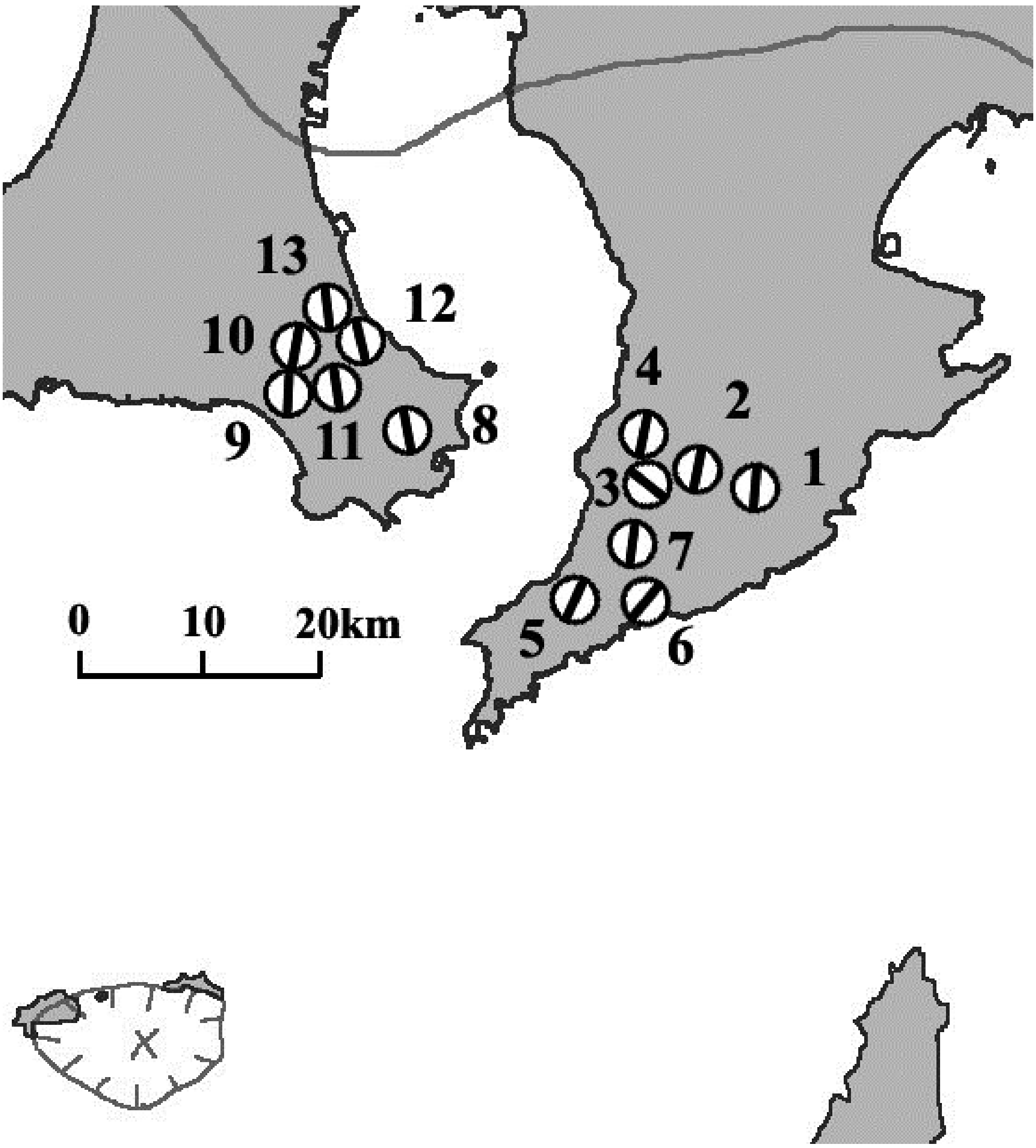


Fig.5-4 Map shows declination of the preferred orientations from horizontal cut samples grain fabric analysis of Koya pyroclastic flow deposit.

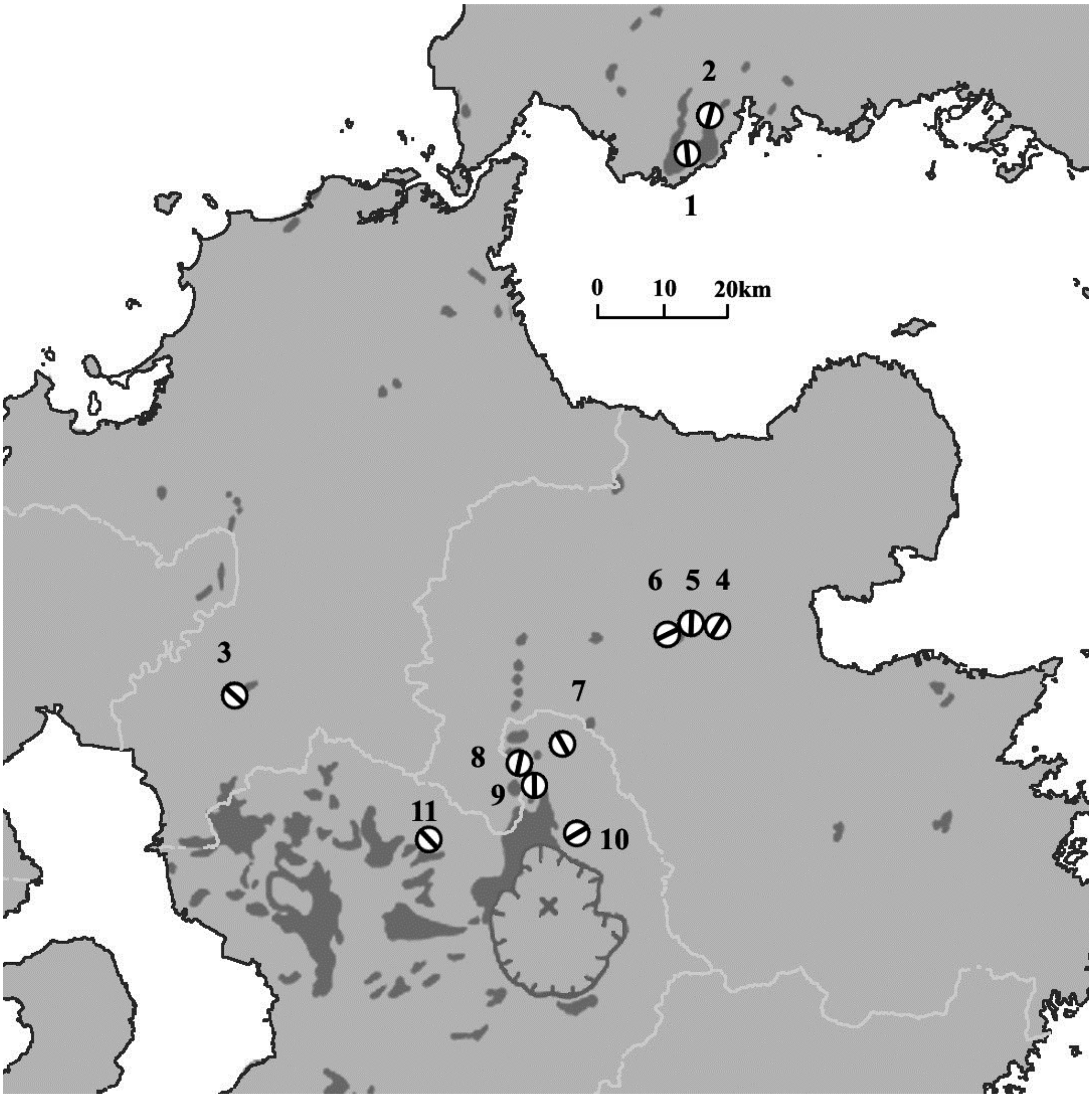


Fig.5-5 Map shows declination of the preferred orientations from horizontal cut samples grain fabric analysis of Koya pyroclastic flow deposit.

5-4 Anisotropy of magnetic susceptibility

5-4-1 Analytical methods

Several studies have successfully determined pyroclastic flow direction from anisotropy of magnetic susceptibility (AMS). AMS method detects the alignment of magnetic minerals in the ignimbrite. An AMS measurement of one specimen results in an ellipsoid of magnetic susceptibility (K) defined by the length and orientation of its three principal axes, $K_1>K_2>K_3$, which are the three eigenvectors of the susceptibility tensor (Tarling and Hrouda 1993) (Fig. 5-6). The long axis of the magnetic susceptibility ellipsoid K_1 defines the magnetic lineation, while the short axis, K_3, is the normal to the plane of the magnetic foliation The mean magnetic susceptibility (Km) is the arithmetic mean of the principal axes K_1, K_2, and K_3. In addition, the AMS technique facilitates the definition of the degree of magnitude of the linear ($L=K_1/K_2$) and planar ($F=K_2/K_3$) fabric components. The technique also quantifies the corrected degree of anisotropy, $Pj = \exp(2[(\eta 1-\eta)^2+(\eta 2-\eta)^2+(\eta 3-\eta)^2]^{1/2})$, where $\eta 1 = \ln K_1$, $\eta 2 = \ln K_2$, $\eta 3 = \ln K_3$, and $\eta = \ln(K_1+ K_2+ K_3)^{1/3}$ where a value of Pj = 1 describes a perfectly isotropic fabric, a Pj value of 1.15 describes a sample with 15 % anisotropy and so on. The shape of the susceptibility ellipsoid (Tj) [$= (2\ln K_2 - \ln K_1 - \ln K_3)/(\ln K_1 - \ln K_3)$; Jelinek 1981] ranges from +1 where purely foliated (oblate) to –1 where purely lineated (prolate) and is triaxial between both end-members.

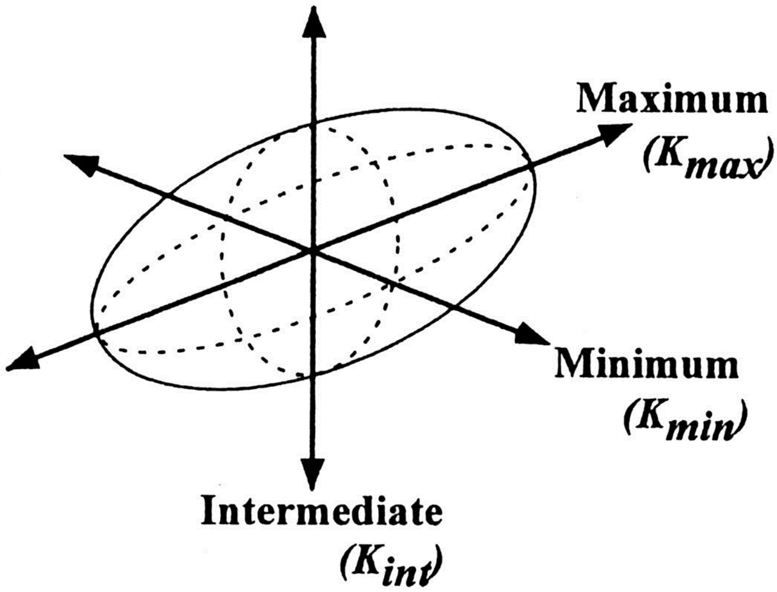


Fig. 5-6 The susceptibility ellipsoid. The tensor defining the susceptibility anisotropy of a sample is more comprehensibly illustrated by means of an ellipsoid with three orthogonal axes that correspond to the maximum, intermediate and minimum principal axes.

5-4-2 Sampling methods

Oriented samples from all sites were collected jam a 7 cc plastic cube into horizontal outcrop surface directly. 10 Samples were collected at each sites, 13 sites from Koya pyroclastic flow deposit and 11 sites from Tosu pyroclastic flow deposit (Fig. 5-7, 5-8). Samples were oriented using a magnetic compass. AMS measurements were ran on a Kappabridge KLY-3S made in AGICO, at the Kobe University faculty of Human Development.

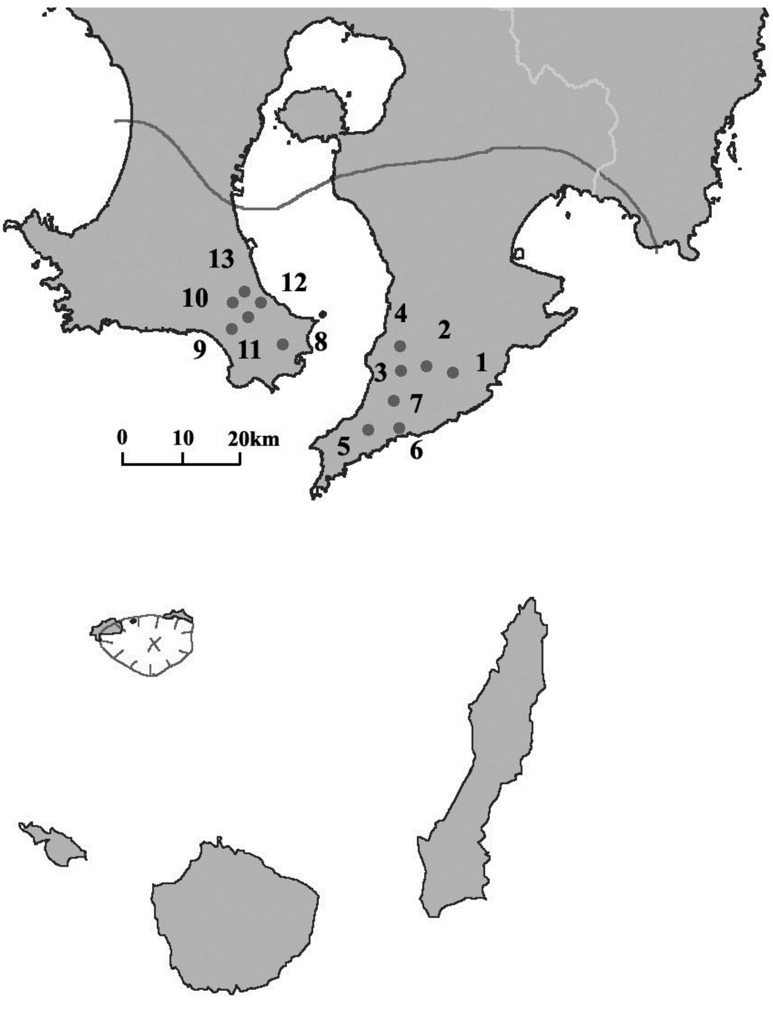


Fig.5-7 Sampling sites of Koya pyroclastic flow deposit.

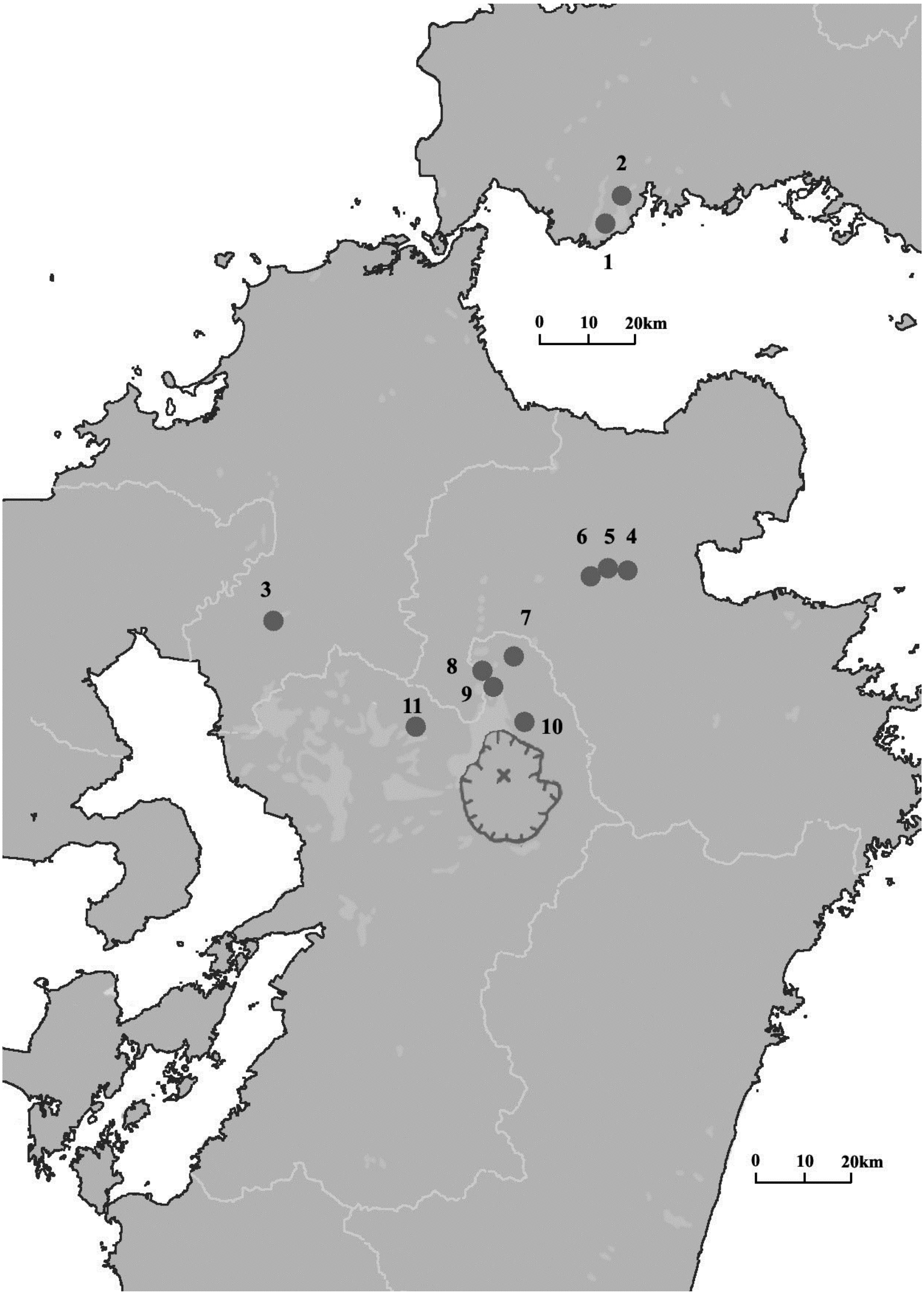
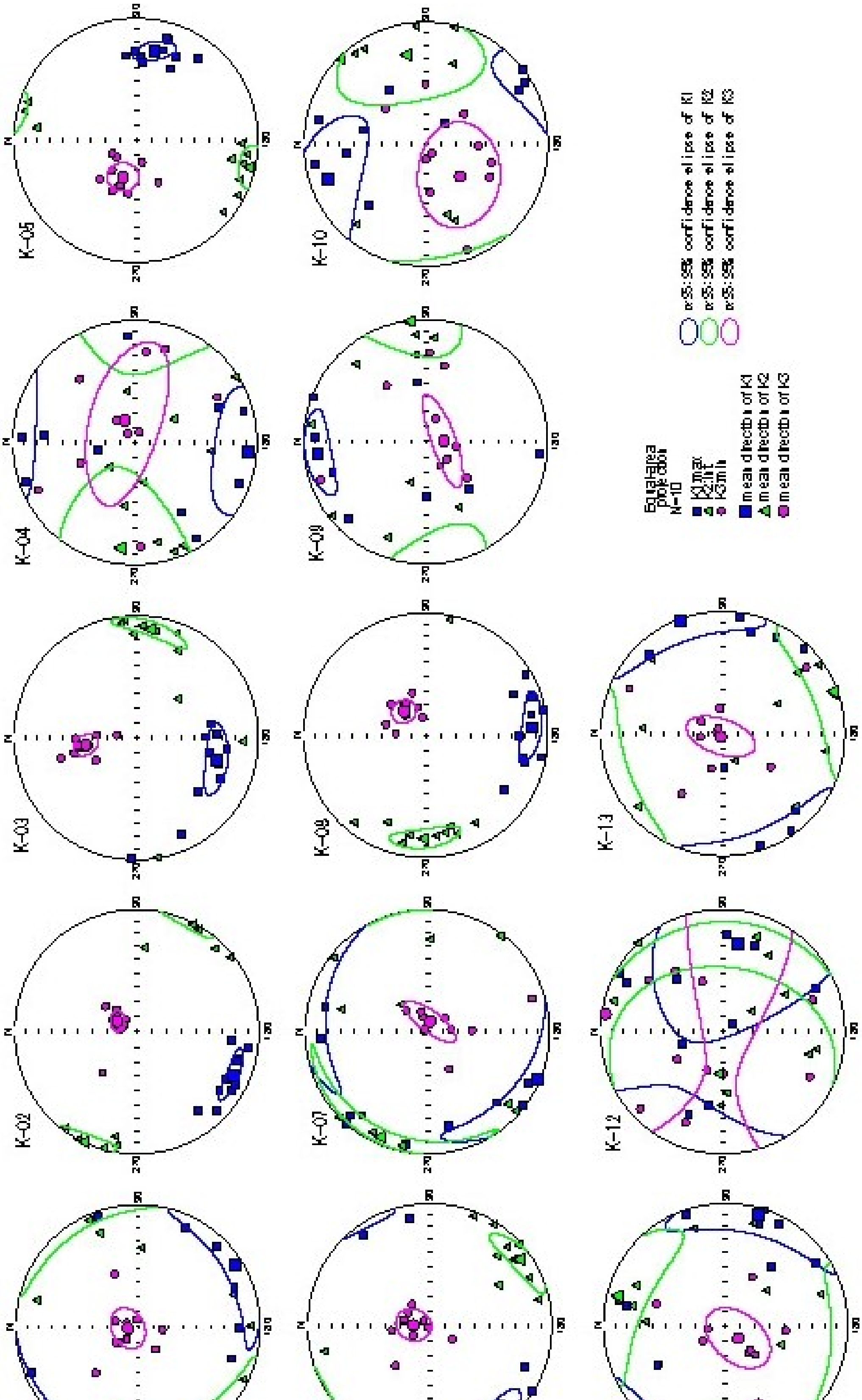


Fig.5-8 Sampling sites of Tosu pyroclastic flow deposit.

5-4-3 AMS results

AMS results are shown in Fig.5-9, 5-10, 5-11. Stereographic projections of AMS show almost minimum axes K_3 have vertical trend either Koya and Tosu pyroclastic-flow deposits. Maximum axes K_1 of Koya results show good concentrations and correspond to the radial flow direction, but K_1 of Tosu pyroclastic-flow deposit poor concentrations and random directions.


K-01
K-02
K-03
K-04
K-05
K-06
K-07
K-08
K-09
K-10
K-11
K-12
K-13

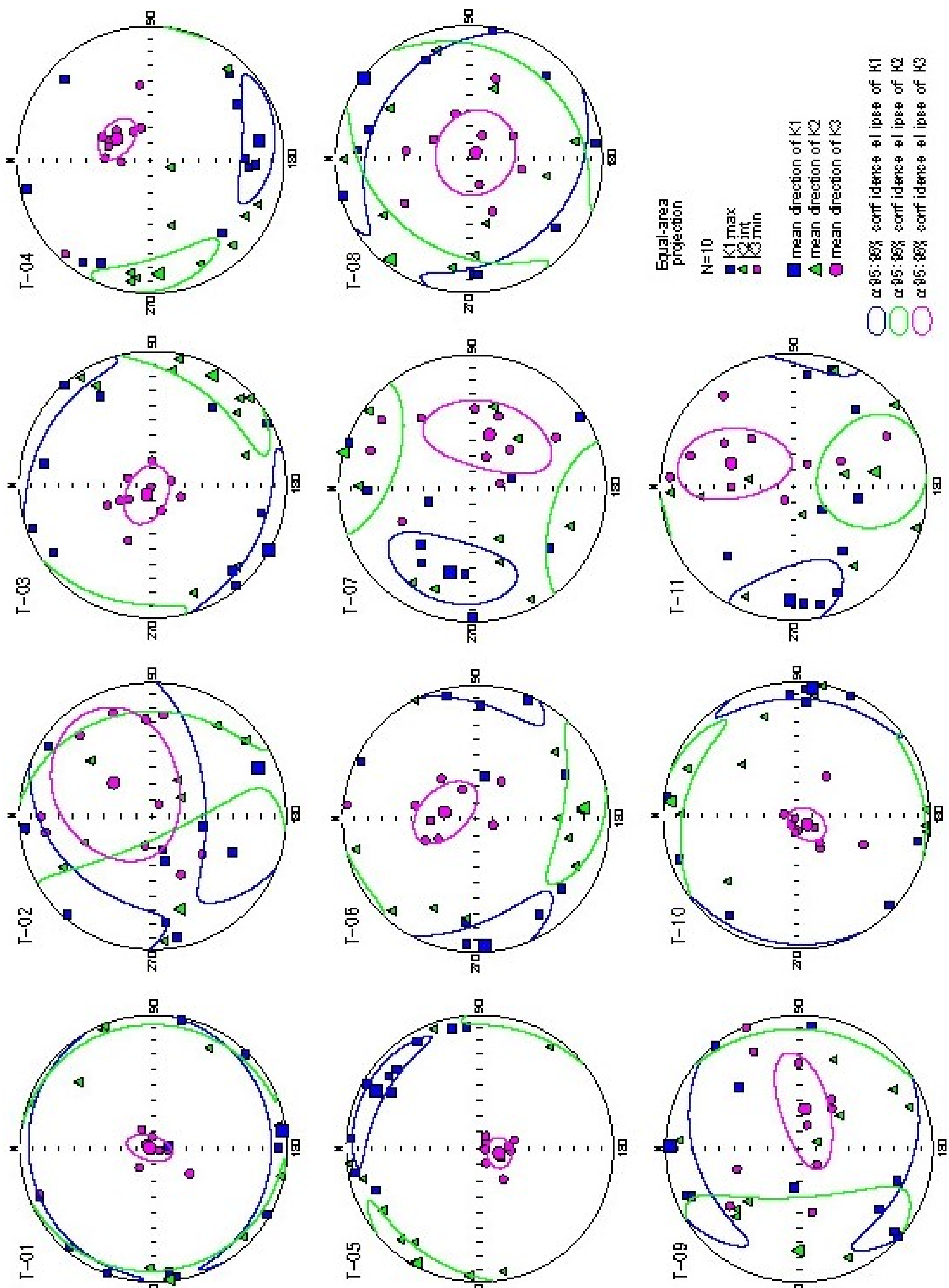
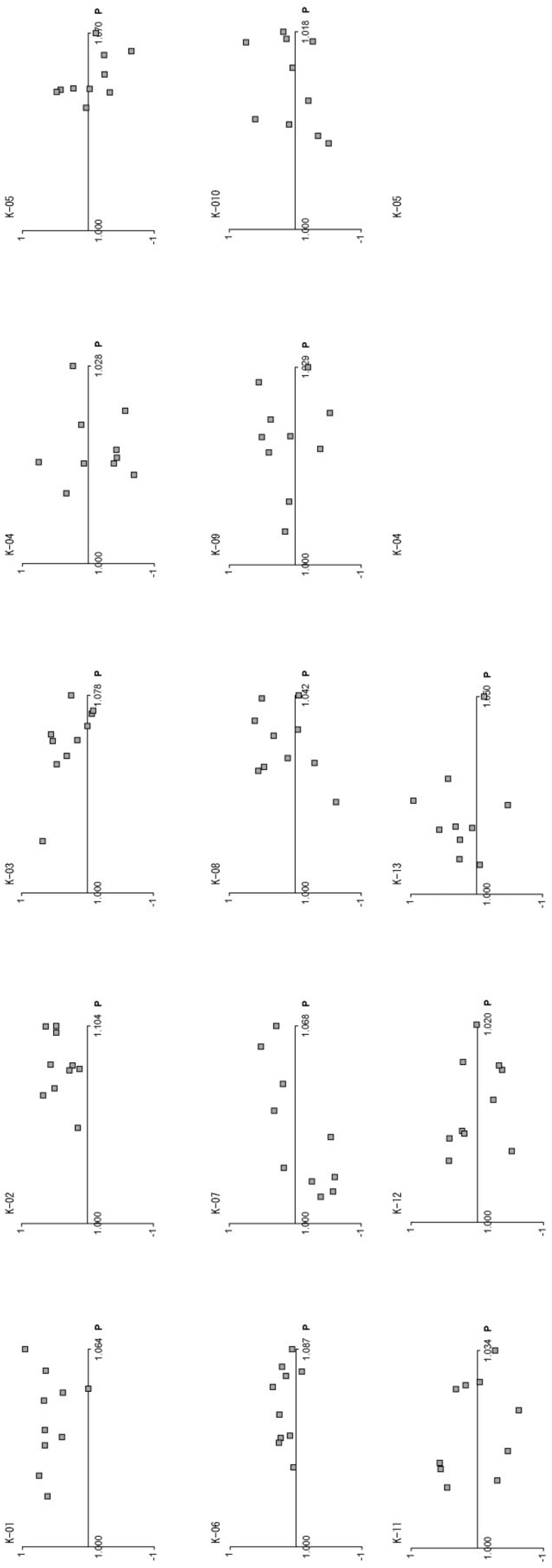


Fig 5-9 Stereographic projections of AMS results (lower hemisphere). Square, Triangle and circle are maximum, intermediate and minimum axes, respectively. Larger markers represent mean directions in one site for each axis. Ellipsoidal lines represent 95% confidence ellipses.


K-01
K-02
K-03
K-04
K-05
K-06
K-07
K-08
K-09
K-010
K-11
K-12
K-13
K-04
K-05

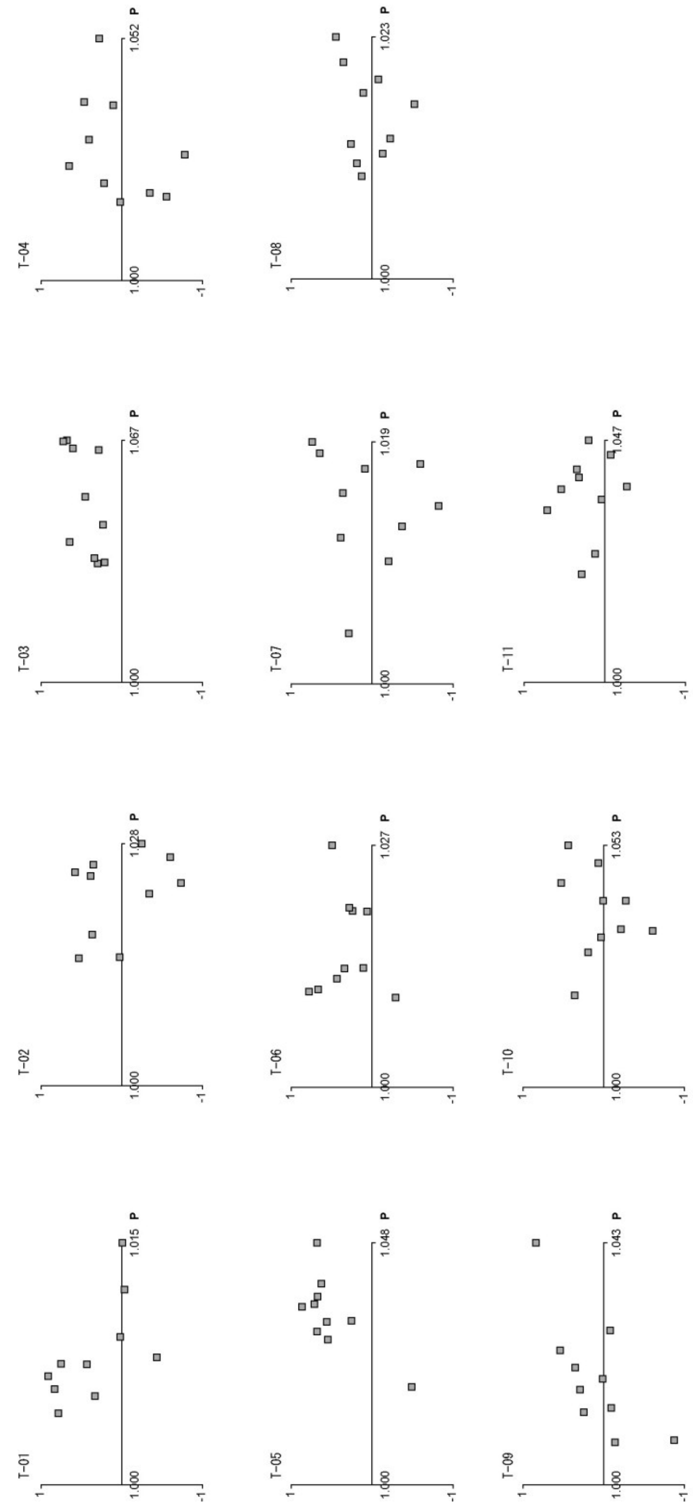
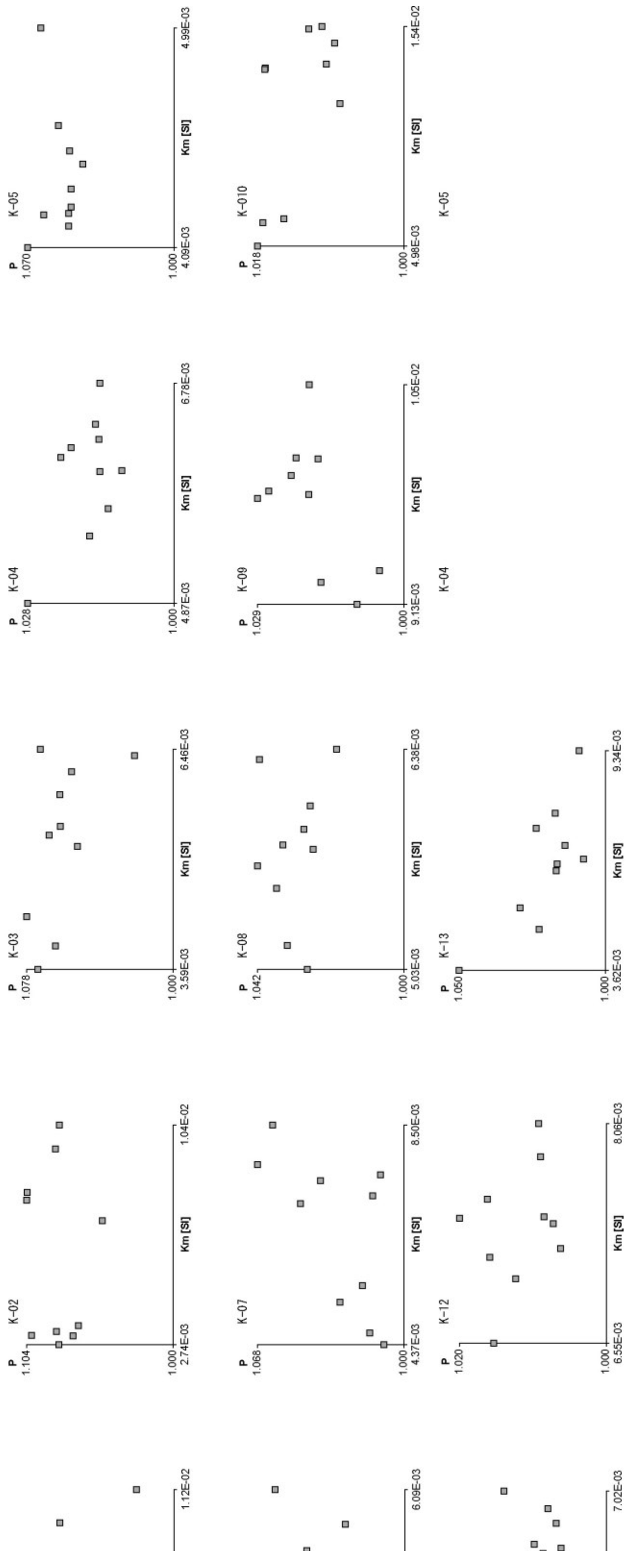


Fig. 5-10 P-T diagram. P and T: anisotropy degree and shape parameter of Jelinek (1981).


K-01
K-02
K-03
K-04
K-05
K-06
K-07
K-08
K-09
K-010
K-11
K-12
K-13
Km [SI]
P

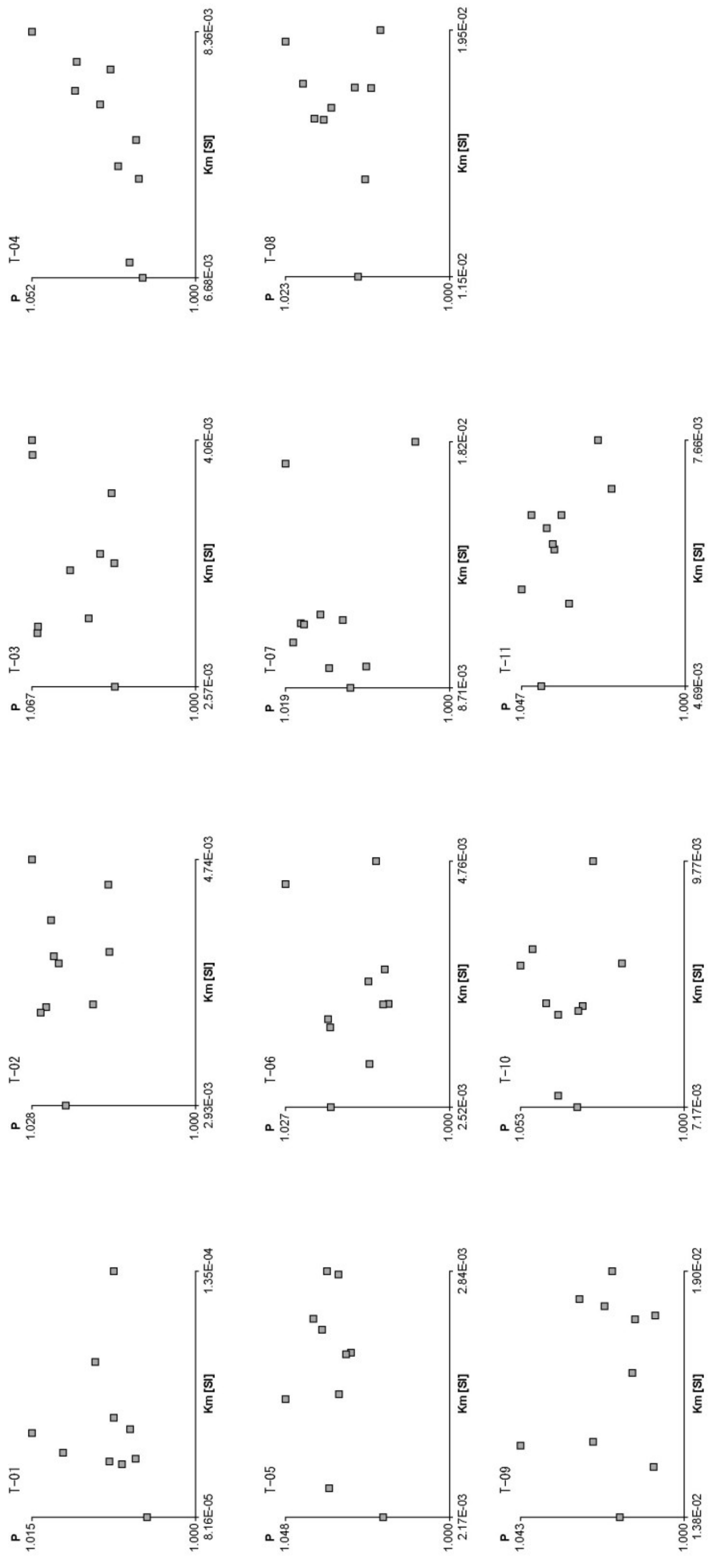


Fig. 5-11 Prot of P vs Km: anisotropy degree and bulk susceptibility.

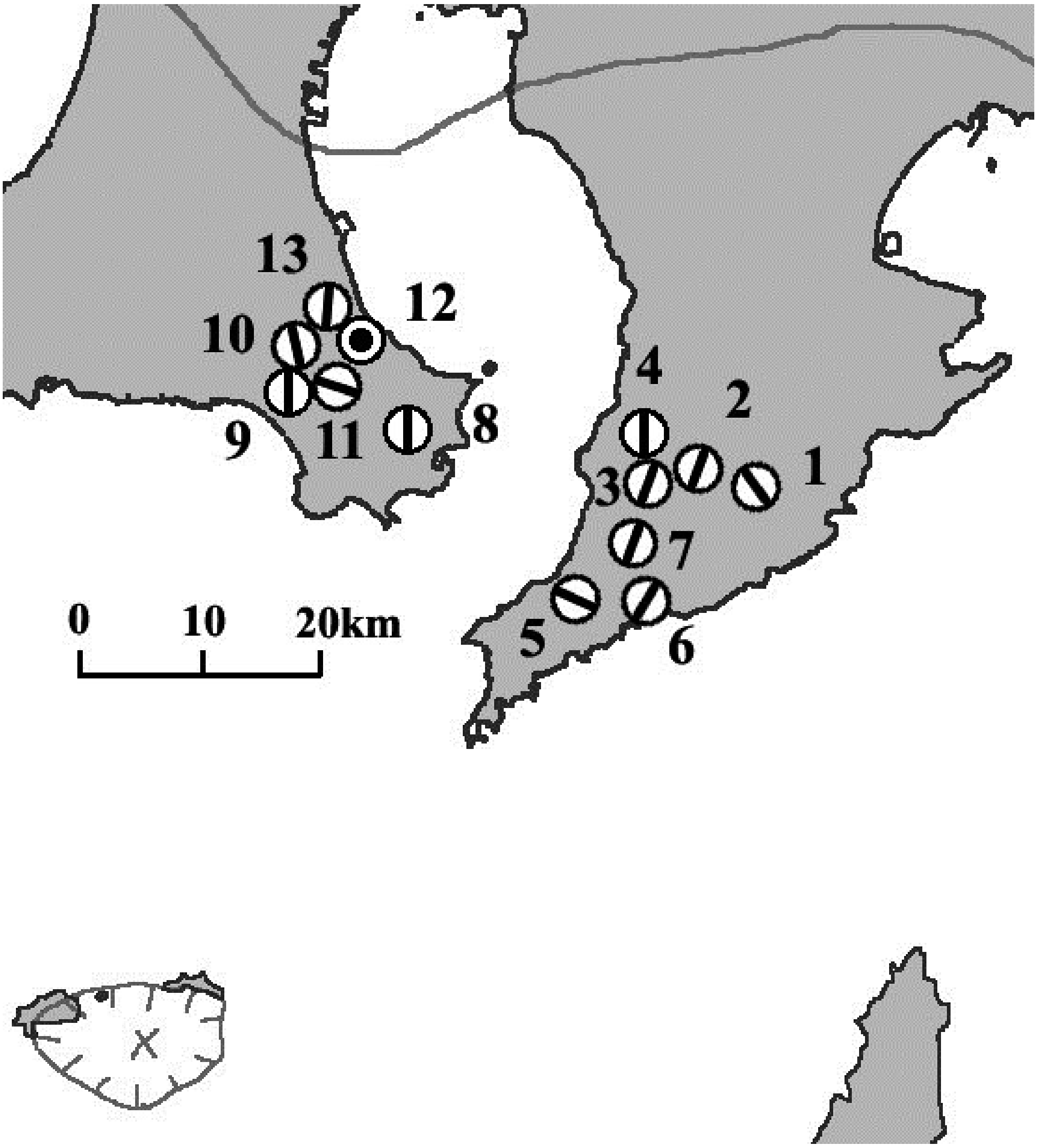


Fig.5-12 Map shows declination of the magnetic lineation (mean direction of K_1); (black marks). Crcles mean no significant direction. Local slope and valley directions estimated from 1/25000 topographic map.

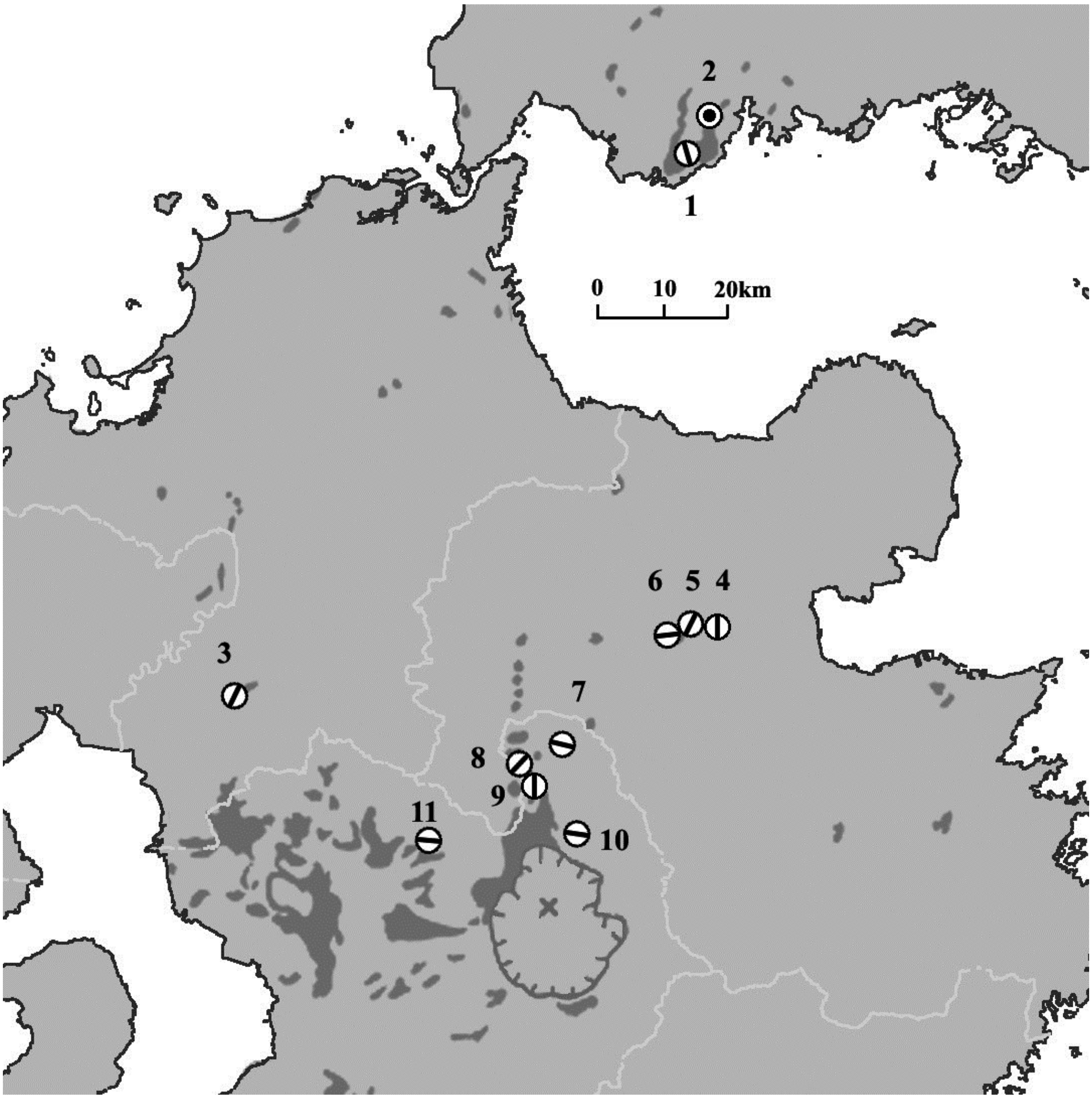


Fig.5-12 continued

5-5 Discussions

Result of grain fabric analysis shows low probability level (χ square value is low) that means particles have random direction. That is considered to be the common nature in LARI. The data of Vertical cut samples value is higher a little than horizontal cut samples value. That interpreted as compaction. Koya value is higher than Tosu value. Preferred orientations are parallel to direction for source caldera. Two pyroclastic flow deposits, data of vertical surface has slightly higher χ square value than horizontal data. And the preferred orientation of vertical surface shows often near horizontal. There is a possibility of the influence with compaction. Preferred orientation of horizontal cut samples means mainly source caldera direction.

AMS analysis, only one outcrop indicates the random way by 13 outcrops of Koya pyroclastic flow deposit, and other 12 outcrops have uniform K_1 and K_3 axis data. K_3 axis concentrates 12 outcrops in vertical direction, and a K_1 axis in 9 outcrops indicate the current direction from the source. Koya pyroclastic flow was laminar flow when it deposited. A K_3 axis indicates vertical direction in all outcrops by 11 outcrops of Tosu pyroclastic flow deposit, but a K_1 axis doesn't concentrate so much and direction is random. That data shows horizontal fabric, so Tosu pyroclastic flow was strong turbulent or completely resting state when accumulating. But there is also a possibility the effect of compaction. The low χ square value of Tosu pyroclastic flow deposit from grain fabric analysis indicates the degree of turbulent flow when accumulating, was high.

To consider what means of preferred orientations grain fabric analysis AMS directions, local topography is important information. AMS directions interpreted not only flow direction from the source but also minor creep on steep slopes and valley. AMS directions, K_1 of Koya ignimbrite correspond to the radial flow direction, but topographic directions too (Fig.5-13).

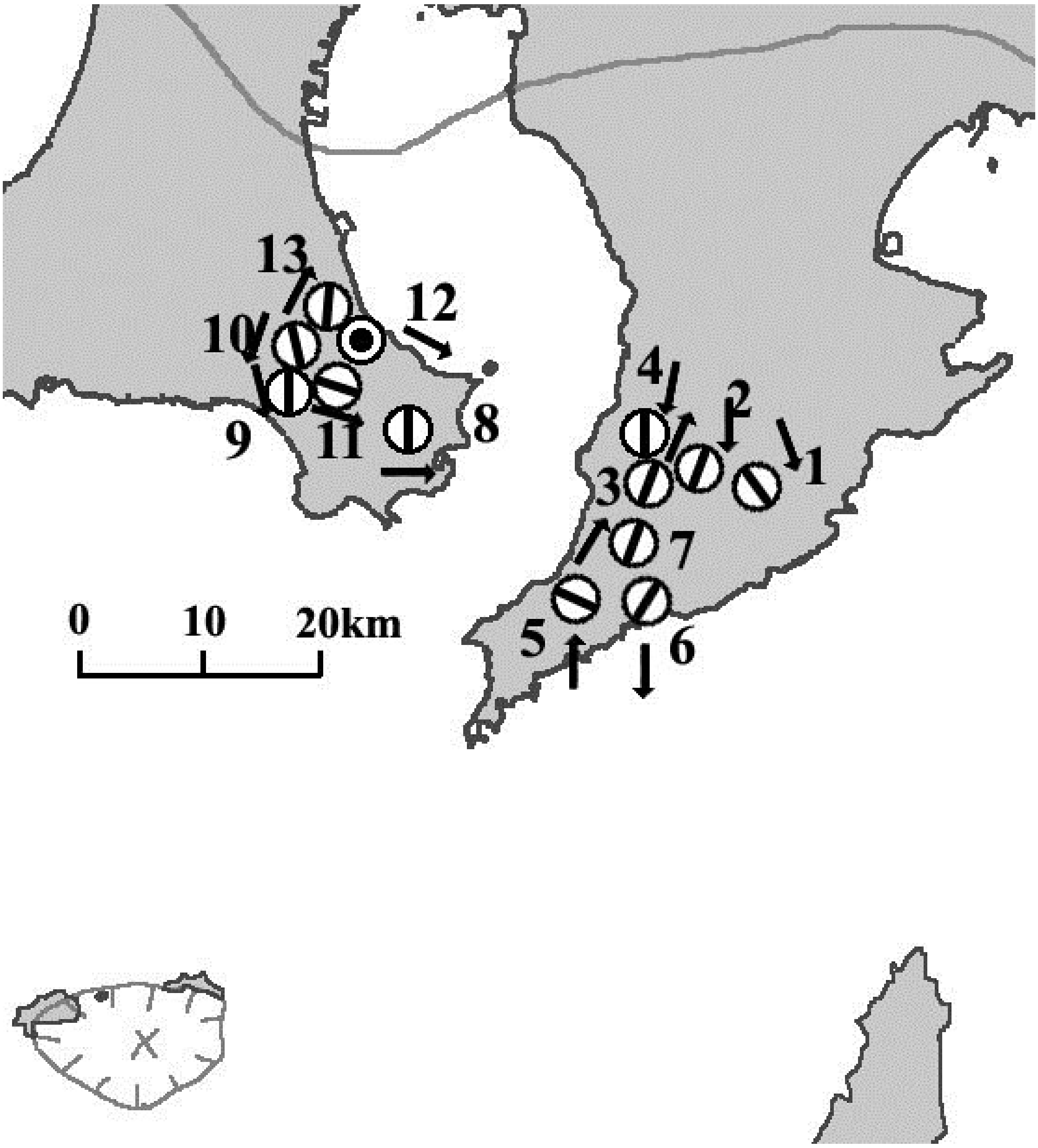


Fig.5-13 Map shows Magnetic lineation (black marks) and topographic slope or valley drainage directions (arrows). Circles mean no significant direction. Local slope and valley directions estimated from 1/25000 topographic map.

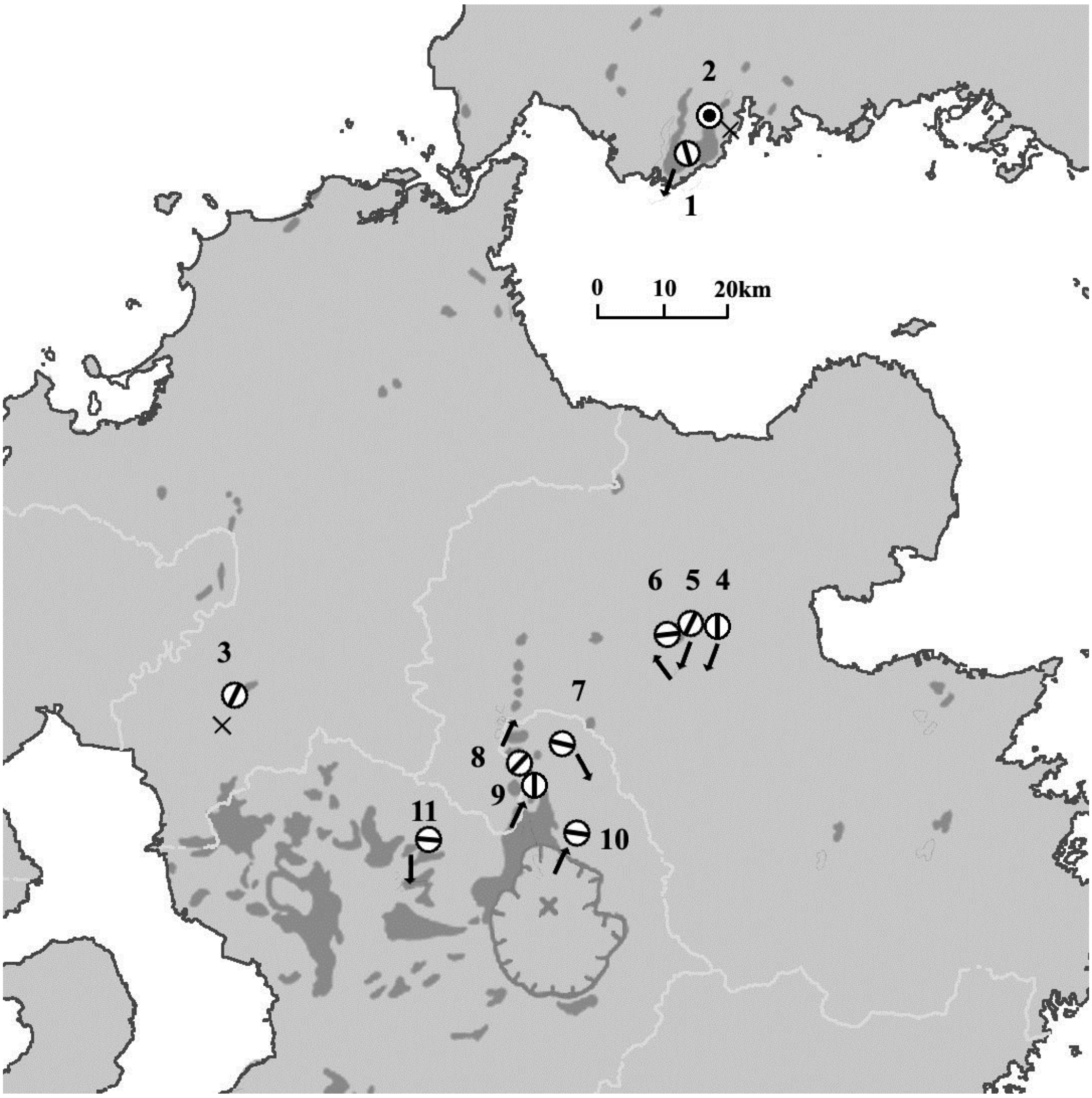


Fig.5-13 ontinued

5-6 Conclusion

Koya pyroclastic flow deposit, grain fabric analysis result doesn't indicate the significant value, but a higher χ square value than that of Tosu pyroclastic flow. AMS result of Koya pyroclastic flow deposit indicates the planar structure and parallel with the direction from the source. AMS result of Tosu pyroclastic flow deposit shows only planar structure. Tosu pyroclastic flow had higher turbulence then Koya pyroclastic flow. The high turbulence occur long flow distance and low aspect ratio.

Chapter 6
Summary

We researched particle array about two examples, Koya pyroclastic flow deposit (Kyushu south direction, Kikai caldera origin) and Tosu pyroclastic flow deposit (one of the subunits of the Aso-4 pyroclastic flow deposit), which are a representative case of the spread type large-scale pyroclastic flow in Japan. There are two kinds of measuring methods of a particle array, particle individual measurement and bulk measurement, and it performed research from both of measuring methods. Particle individual measurement used using the extension axis excellence direction. Bulk measurement using rate of magnetization anisotropy: AMS (Anisotropy of Magnetic Susceptibility) .

Particle individual measurement shows that particles have turned to the random direction by both Koya and Toss pyroclastic flow deposits. The result of Particle individual measurement not having the same significant directivity about the extension axis excellence direction of both Koya and Tosu pyroclastic flow deposits, and it may be the common character in LARI. By Koya pyroclastic flow sediment 13 outcrop, only one outcrop shows the randam direction, and a minor axis and a major axis gather well in other 12 outcrops. A minor axis concentrates on a vertical direction in all 12 outcrops, and a major axis concentrates the current direction from the source in 9 outcropes. In Tosu pyroclastic flow sediment 11 outcrop, although a minor axis shows a vertical direction in all the outcrops, a major axis does not gather well.It can be interpreted as having deopsited in the state of rest, but there is a possibility of the effect of the compaction by gravity. LARI was deposited in the strong turbulent flow as a result of two kinds of measurement.

Acknowledgments

The Author is grateful to Professor K. Suzuki and Professor Y. Otofuji for the constructive suggestions and useful comments. And thanks colleague of Hiruzen Institute for Geology & Chronology.

References

Dade, W.B., 2003. The emplacement of low-aspect ratio ignimbrites by turbulent parent flows. J. Geophys. Res. 108: 2211

Elston, W. E. and Smith, E. I., 1970 Determination of flow direction of rhyolite ash-flow tuffs from fluidal textures. Geot. Soc. Amer. Bull.,81, 3393-3406.

Froggatt, P. C., Wilson, C. J. N. Walker, G. .P. L., 1981. Orientation of logs in the Taupo Ignimbrite as an indicator of flow direction and vent position. Geology 9(3): 109-111.

Fukuzawa F 1995: Non-glacial varved lake sediment as a natural timekeeper and detector of environmental changes. The Quat. Res. (Daiyonki-Kenkyu), 34, 135-149 (in Japanese with English summary)

星住英夫・森下祐一，1993，豊岡地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，75p.

星住英夫・小野晃司・三村弘二・野田徹郎，1988，別府地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，131p.

今井　功・寺岡易司・奥村公男・神戸信和・小野晃司，1982，諸塚山地域の地質，地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，71p.

Jelinek, V., 1981. Characterisation of the magnetic fabrics of rocks. Tectonophysics, 79: 63-67.

鎌田浩毅，1997，宮原地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，127p.

町田洋・新井房夫（1978）南九州鬼界カルデラから噴出した広域テフラ-アカホヤ火山灰．第四紀研究, 17, p. 143-163.

町田　洋・新井房夫（1992）火山灰アトラス．東京大学出版会，276p

Maeno, F. and H. Taniguchi, Spatiotemporal evolution of a marine caldera-forming eruption, generating a low-aspect ratio pyroclastic flow, 7.3 ka, Kikai caldera, Japan: implication from near-vent eruptive deposits., J. Volcanol. Geotherm. Res., 167, 212--238, 2007.

小野晃司・松本征夫・宮久三千年・寺岡易司・神戸信和(1977）竹田地域の地質. 145p. 地域地質研究報告（5 万分ノ 1 地質図幅), 地質調査所.

小野晃司・曽屋龍典・細野武男，1982 薩摩硫黄島地域の地質．地域地質研究報告-5 万分の 1 図幅-, 80p.，地質調査所.

小野晃司・渡辺一徳，1983，阿蘇カルデラ．月刊地球，5（2），73-82.

酒井　彰・寺岡易司・宮崎一博・星住英夫・坂巻幸雄，1993，三重町地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，115p.

Suzuki-Kamata, K. and Kamata, H. 1990 The proximal facies of the Tosu pyroclastic-flow deposit erupted from Aso caldera, Japan. Bull. Volcanol. vol. 52, 325-333.

Suzuki, K. and Ui, T. (1982) Grain orientation and depositional ramp as flow direction indicators of a large-scale pyroclastic flow deposit in Japan. Geology, vol.10, p.429-432.

Suzuki-Kamata, K. and Ui, T. (1988) Depositional ramps: Asymmetrical distribution structure in the Ata pyroclastic flow deposit, Japan. Bull. Volcanol. vol.50, 26-34.

D. H. Tarling & F. Hrouda, 1993. The Magnetic Anisotropy of Rocks. xi + 217 pp. London, Glasgow, New York, Tokyo, Melbourne, Madras: Chapman & Hall.

寺岡易司・宮崎一博・星住英夫・吉岡敏和・酒井　彰・小野晃司，1992，犬飼地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，129p.

寺岡易司・奥村公男・村田明広・星住英夫，1990，佐伯地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，78p.

Tukey, J. W. 1954 Comments and suggestions on note1 by Chyes, Comment no. 1A, Earth Sciences Panel Review Group, mimeo. rept., 5p.

Ui, T., Suzuki-Kamata, K., Matsusue, R., Fujita, K., Metsugi, H. & Araki, M. (1989) Flow behavior of large-scale pyroclastic flows --- Evidence obtained from petrofabric analysis. Bull.Volcanol., 51, 115-122.

宇井忠英（1973）幸屋火砕流――極めて薄く拡がり堆積した火砕流の発見．火山，18, 153-168.

Walker, G. P. L.; Heming, R. F.; Wilson, C. J. N. 1980: Low-aspect ratio ignimbrites. Nature 283: 286-287.

Walker, G. P. L.; Self, S.; Froggatt, P. C. 1981: The ground layer of the Taupo Ignimbrite: a striking example of sedimentation from a pyroclastic flow. Journal of Volcanology and Geothermal Research 10: 1-11.

Walker, G. P. L. 1985: Origin of coarse lithic breccias near ignimbrite source vents. Journal of Volcanology and Geothermal Research 25: 157-171.

Walker, G. P. L. 1983: Ignimbrite types and ignimbrite problems. Journal of

Volcanology and Geothermal Research 17: 65-88.
Watanabe, K., 1979, Studies on the Aso pyroclastic flow deposits in the region to the west of Aso caldera, Southwest Japan, II: petrology of the Aso-4 pyroclastic flow deposits. Mem. Fac. Educ. Kumamoto Univ., no. 28, 75-112.
渡辺一徳，1986，阿蘇カルデラ起源，鳥栖オレンジ軽石流の流動・堆積機構．文部省科学研究費自然災害特別研究，研究計画「火山噴火に伴う乾燥粉体流（火砕流等）の特性と災害」報告書，115-128.
Watanabe, K., 1978. Studies on the Aso pyroclastic flow deposits in the region to the west of Aso caldera, Southwest Japan, I: geology. Mem. Fac. Educ. Kumamoto Univ., no. 27, 97-120.
吉岡敏和・星住英夫・宮崎一博，1997，大分地域の地質．地域地質研究報告（5 万分の 1 地質図幅）．地質調査所，65p.