Applying the Sun's Azimuth for Orientation on the Paleomagnetic Sample and Determination of the Declination of the Geomagnetic Field.

Rep. Fac. Sci., Kagoshima Univ.
No. 30, 51~61, 1997.

Applying the Sun's Azimuth for Orientation on the Paleomagnetic Sample and Determination of the Declination of the Geomagnetic Field.

Hirotomo UENO*, Takuro MATSUMOTO* and Tetsuichi TAKEDA*

(Received September 10, 1997)

Keywords : Sun's azimuth, Geomagnetic field, Paleomagnetism, Fluxgate magnetometer, Theodolite

Abstract

The orientation devices using the sun's azimuth for paleomagnetic study were developed. These are used for drilled cores and hand samples with error angles of less than one degree. Practical procedures of orientation are described, and a computer program for the calculation of the sun's azimuth is given. Magnetic needle errors detected with the orientation devices are large at every sampling site in volcanic rock regions. The use of the sun compass in the region in which rocks are strongly magnetized is intensively recommended.

The non-magnetic theodolite attached with a sensor of the fluxgate magnetometer was introduced to measure the deflection and inclination of the geomagnetic field. For the declination, the sun's azimuth is used. The passing time of both rims of the sun at the center of a telescope covered by the sun filter and the horizontal angle of theodolite are used to fix the true north direction. The total geomagnetic field (F) is measured at the sampling site with proton magnetometers, and the horizontal (H) and vertical (Z) components, are calculated using the inclination taken by the fluxgate magnetometer. Those fields vary widely at the sampling sites in the volcanic rock region.

Introduction

The orientation procedure on rock samples for paleomagnetic study is important in case of igneous rocks which have usually strong magnetization. There are many methods to collect oriented samples in the field (Tarling and Hrouda, 1993; Collinson, 1983). A magnetic compass is usually used for orientation. Butler (1992) comments that significant deflections of the magnetic compass affect for orientations of sample in lightning-prone regions. There is a possibility of magnetic needle errors in the regions of volcanic rock and others. Magnetic ore samples from underground were oriented by the offset method in order to avoid the magnetic error (Ueno and Tonouchi, 1987). A sun compass is convenient in the field. Orientation devices for the field core-drilling and hand sampling methods and their usage applying the sun's azimuth are described in this paper.

On the other hand, the local anomalies of the geomagnetic field have been detected at many sampling sites. The effect of local anomalies upon the inclination has been recognized (Watanabe, 1959). The inclination of the geomagnetic field is easily measured because the horizontal plane which is the cardinal point of the inclination is caught mechanically. It is not easy to seek the true north which is the cardinal point of the declination. A approach to seek the true north is the use of a gyrocompass, but it has many disadvantages. The most convenient way is to find the position of the sun or stars. The measuring methods of the geomagnetic field with a fluxgate declinometer-inclinometer using

* *Department of Earth and Environmental Sciences, Faculty of Science, Kagoshima University: 21-35, Korimoto 1-chome, Kagoshima 890, Japan*

the sun's azimuth, and their case studies at volcanic rock areas are described in the later part.

Thanks are due to Prof. Minoru Tanaka, Faculty of Science, Kagoshima University for help and discussion and Prof. Toshiki Kakuta, Faculty of Science, Kagoshima University for the use of proton magnetometers. This study is supported by Educational and Research Special Financial Support of Kagoshima University. We want to express our thanks to Former President Dr. Shozo Hayasaka of Kagoshima University.

Applying the Sun's Azimuth for Orientation

The solar compass for geological use is developed by many researchers (Haaf and Wensink, 1962 ; Creer and Sanver, 1967; Verosuo, 1977). The equatorial solar compass (Haaf and Wensink, 1962), one of them, gives the strike angles from the true north directly, but the reading errors grow up to 3° in latitude 40°, and 4° in latitude 30°.

Our orientation device (Fig. 1 a) for the filed core-drilling methods is the same as one used by some paleomagnetists. An invention of the scriber with a diamond crystal to provide a marking line is added. A new orientation device for the hand sampling methods has been recently developed by us (Fig. 1 b). Practical procedures applying the sun's azimuth to both devices are essentially identical. A brunton compass which may rotate around the center axis catches the reflected sun light and indicates the sun's azimuth as angle on the scale. The principle of the sun compass is shown in Figure 2. It is easy to control the fitting of an image of a center line shadow within 1 degree.

It is necessary to note the local time when the sun's azimuth is being read. For this purpose a wrist watch for marathon runners (CASIO, Accelator 1531) is useful. This watch has a function of recording lap times and can store 50 records in the memory. We can easily note the lap time being indicated within 6 seconds when the lap time button is pushed, and reread the time after the field work.

The procedure in the field is as follows.

1. Core-drilling with a drilling machine, or making a flat surface of the hand sample.
2. Drawing an orientation line by a diamond scriber through slit on the tube, or marking a strike line on the surface.

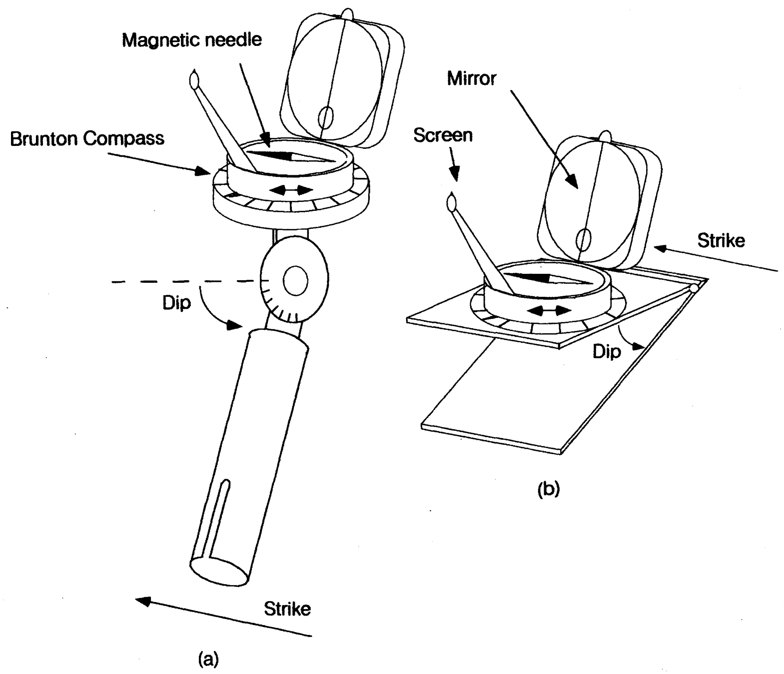

Fig. 1. Schematic view of the sun compasses. (a) Field core drilling use. (b) Hand sampling use.

3. Align fitting of an image of a center line shadow as sun light reflection.
4. Push the lap time button of the watch at the end of step 3, read the lap time which represents the local time, and note it.
5. Collecting the core or hand sample, and remarking the orientation line.

The general analysis for a sun compass is given by Creer and Sanver (1967) and Collinson (1983). Practically, Oota's calculation (Oota, 1993) referring Chronological Scientific Tables (National Astronomical Observatory, 1996) is most convenient for our use. A BASIC program adopting Oota's calculation is given in Appendix Ⅰ.

Applying the Sun's Azimuth for Determination of the Geomagnetic Field

Watanabe (1959) has referred the unpublished data of remanent magnetization by Yoshio Kato and together with Kato's opinion. According to Kato's opinion, the local anomalies of the geomagnetic field of the volcanic region may affect the inclination of remanent magnetization of the lava flow on the top and the side of the volcano, and the value of inclination may represent not the real geomagnetic inclination but the local anomalous geomagnetic inclination because the rock samples were collected on the mountain side of the volcano. The declination and inclination of the geomagnetic field at the sampling site in the volcanic region should be measured by the fluxgate type magnetometer.

As mentioned above, it needs to measure the geomagnetic field at the sampling site for the purpose of not only testing the true reading of sampling direction but also getting local magnetic anomalies.

It is not so difficult to measure the inclination of the geomagnetic field using the combination of a fluxgate magnetometer and a non-magnetic theodolite. It is possible to get the declination of the geomagnetic field only in special case that the topographical unique point such as the top of mountain is caught by a telescope of the theodolite. Then, we adopt the system using the sun's azimuth in order to get the declination from the true north at any place.

Our equipment is the combination of fluxgate magnetometer, Model MAG-01H, Bartington Inst. England, and a non-magnetic theodolite, Model

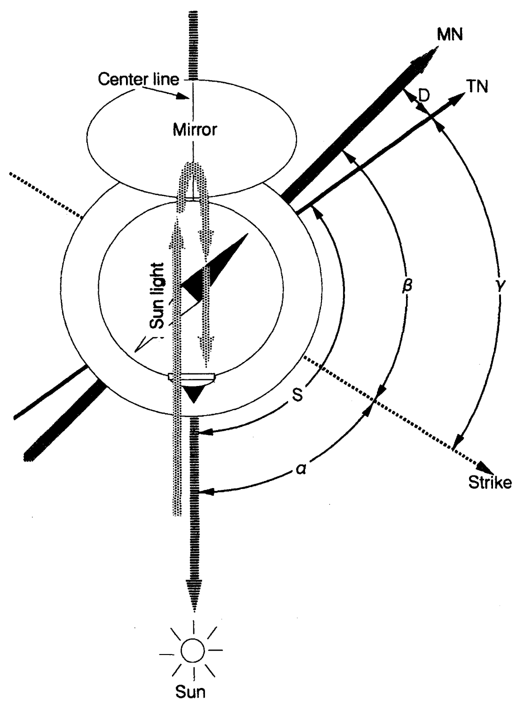

FIg. 2. Principle of the sun compass. MN is the magnetic north. TN is the true north. S is the sun azimuth. α is the angle between the sun and strike line. β is the strike from the magnetic north. γ is the strike from the true north ($S-\alpha$). D is the declination ($\gamma-\beta$) of the geomagnetic filed.

MG2KP of YOM, Hungary. The MAG-01H fluxgate magnetometer has maximum resolution of 0.1nT, rechargeable 12V battery, and 1.5 kg weight. The MG2KP theodolite has 1" micrometer scale, <10" means square error of a horizontal direction, <5" of a vertical direction, and 4.0 kg weight. The alignment of the linear fluxgate sensor is done within 1 nT of offset error by the Bartington Inst. To get the absolute value of the horizontal (H) and vertical (Z) components, a proton magnetometer for portable use, Model G-856 of Geometrics and another proton magnetometer for station use, Model GSM-19 of Gem System are used.

Practical procedure of measuring deflection and inclination of the geomagnetic field at sampling sites is as follows.

1. The head of the linear fluxgate sensor faces east horizontally. Get the zero fields position and read its horizontal angle.
2. Turn the head 90° anticlockwise and read the horizontal component (H_f) by the fluxgate magnetometer for reference.
3. Incline the sensor to get zero field and read the vertical angle. 90° minus the vertical angle is the inclination angle of the geomagnetic field.
4. Keep the head vertical and read the vertical component (Z_f) by the fluxgate magnetometer for reference. Tangent of Z_f / H_f is referred to the inclination. If need accuracy, each step of 1 to 4 is repeated at the opposite position.
5. Catch the sun with the telescope. Note passing times of both rims of the moving sun's image at the center line of the telescope with the sun filter using the wrist watch mentioned before. Read and note the horizontal angle at which the observation was done.
6. Measure the total field (F) of the geomagnetic field with the portable proton magnetometer. H and Z are calculated from this value and the inclination measured by the fluxgate magnetometer.

Results of Field Surveys

Next two volcanic rock areas are studied. There are the historically recorded lava flows in Kirishima volcano, southern Kyushu and Kuchinoerabu island, one of the Osumi Islands. Lava flows of Kirishima volcano consist mainly of two pyroxene andesite. The mean initial intensities ranging 6 to 16 A/m are large comparing with other volcanic region. Q-values of 6 to 17 are also large. Shindake lava flows, Kuchinoerabu composed of two pyroxene andesite have the mean initial intensity of about 2 A/m and Q-value of 2. Results are shown in Figures 3, 4 and 5. The differences between the sun and magnetic compass at the sampling site of Kirishimajingu lavas at Katazoe (Fig. 3 a) and Takaharu (Fig. 3 b) are range from −13° to −1°. Minus means that magnetic needle points westward. This tendency is compatible to −6.4°, Kirishima area standard declination of 1990 (National Astronomical Observatory, 1996). The differences at the sampling sites of Sano lava (Fig. 4 a) and Ohachi scoria flow (Fig. 4 b) are similar to those of Kirishimajingu lavas, but slightly scatter. Those of Takachihogawara lava (Fig. 4 c) are different. Magnetic compass errors at the sampling site of 6028-6039 are ranging 0° to 6° and are not concordant with other sites. It may be explained from the topographical feature of the tip of strongly magnetized lava flow. Those of Shindake lava, Kuchinoerabu (Fig. 5) are relatively small, and magnetic compass errors coincide with the value of −5.4°, Kuchinoerabu area standard declination of 1990 (National Astronomical Observatory, 1996).

Within one sampling site, the difference between the sun and magnetic compass has a wide range. Each measurement of the sun and magnetic compass has been done at each core-drilling site which distributes usually within 1 to 2 m in nearly horizontal width on the rock outcrop. The declination of the geomagnetic field measured with the fluxgate magnetometer around the sampling sites are shown in Figures 3, 4 and 5. It is sure from these figures that the magnetic anomaly is larger at the sampling site (measured by sun compass) than at the vicinity of sampling site (measured by the theodolite-fluxgate). We have to use the sun compass in case of sampling at the volcanic area, otherwise the strike lines of oriented samples have large errors up to over ten degrees.

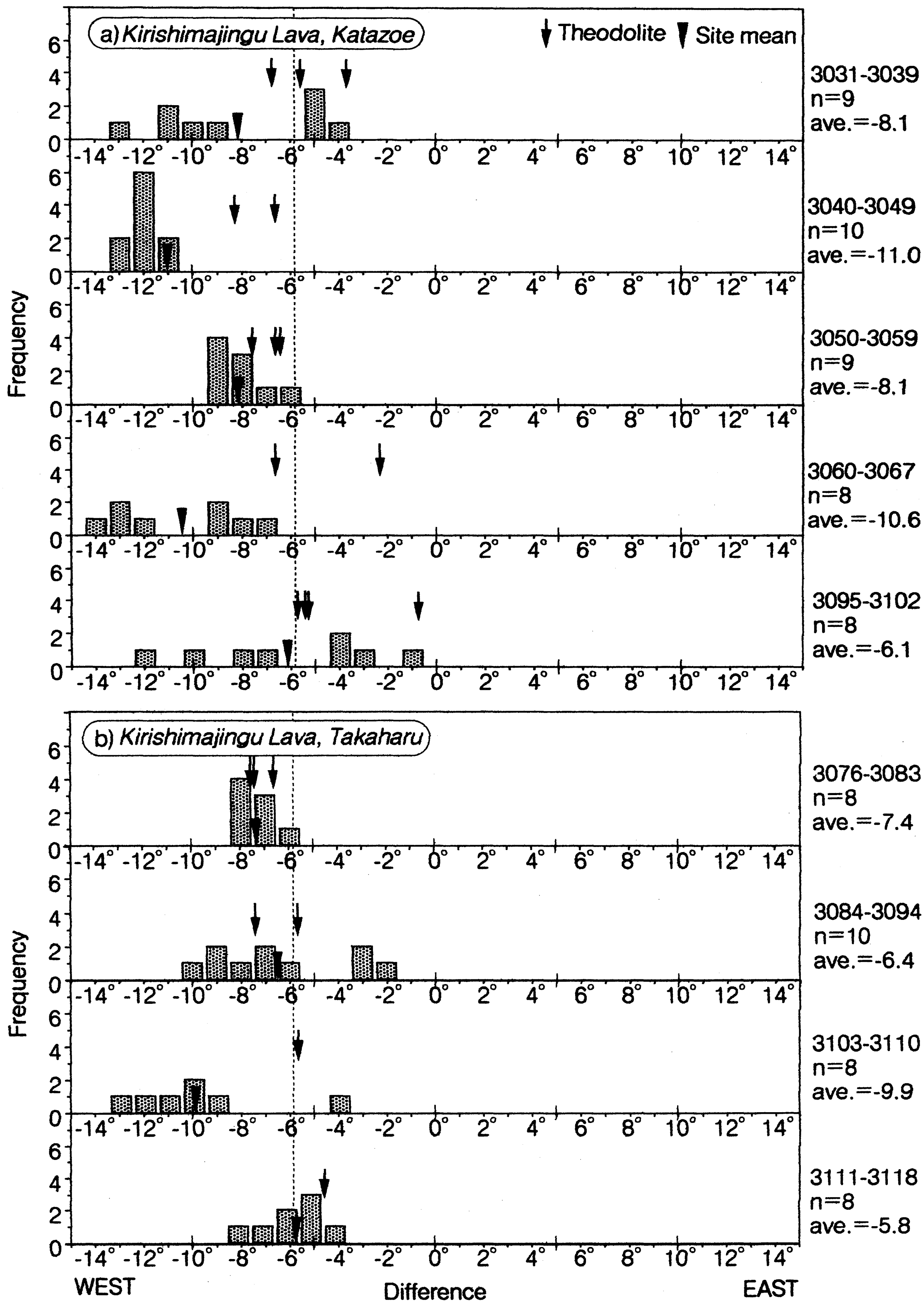

Fig. 3. The deflection between angles measured by the sun and magnetic compasses at Kirishimajingu lava sites, Kirishima area (Appendix II).

The declination measured by the theodolite-fluxgate magnetometer is indicated by arrows.

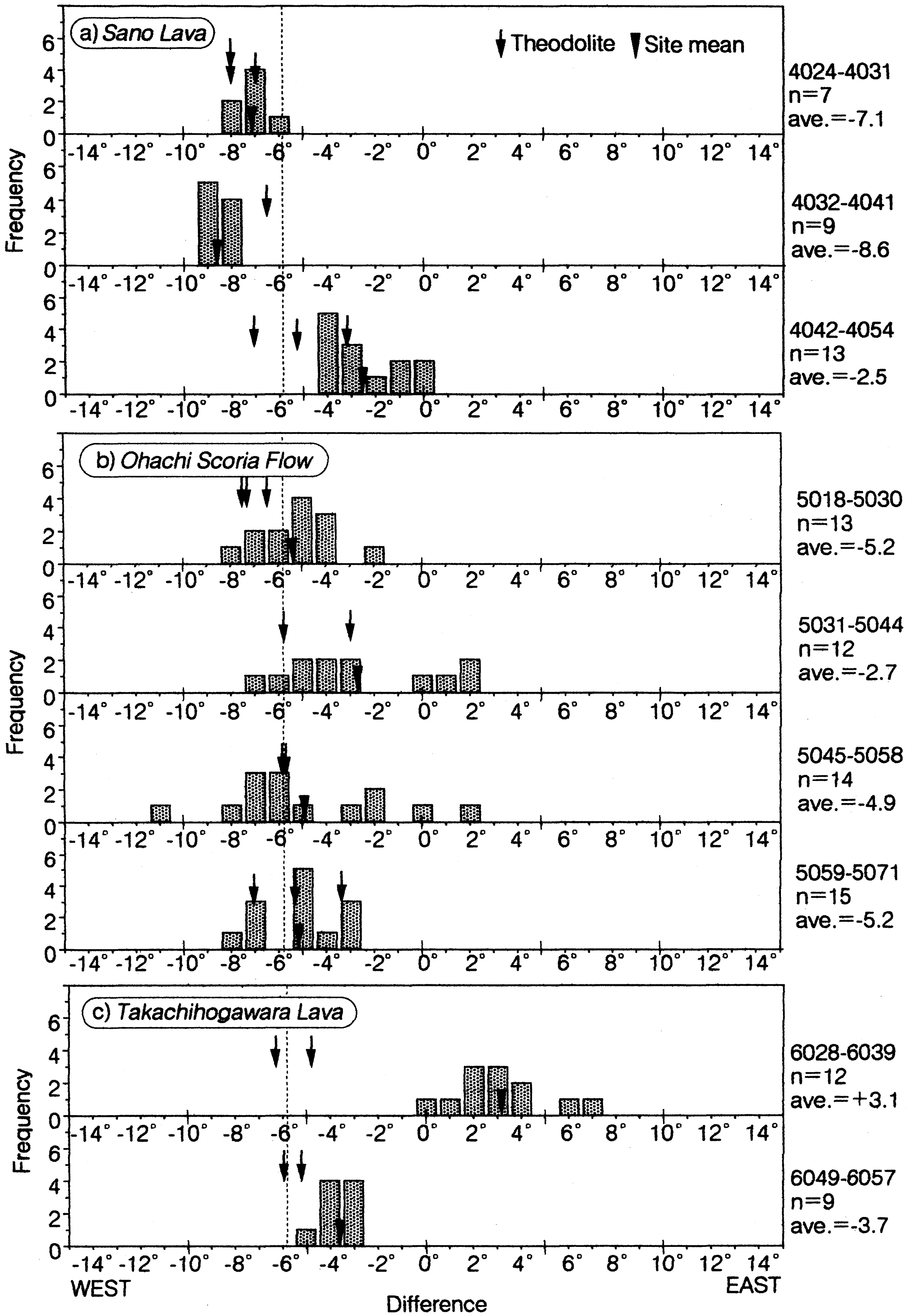

Fig. 4. The deflection between angles measured by the sun compass and magnetic compasses at Sano lava, Ohachi scoria flow and Takachihogawara lava sites, Kirishima area (Appendix II).
Symbols the same as in Figure 3.

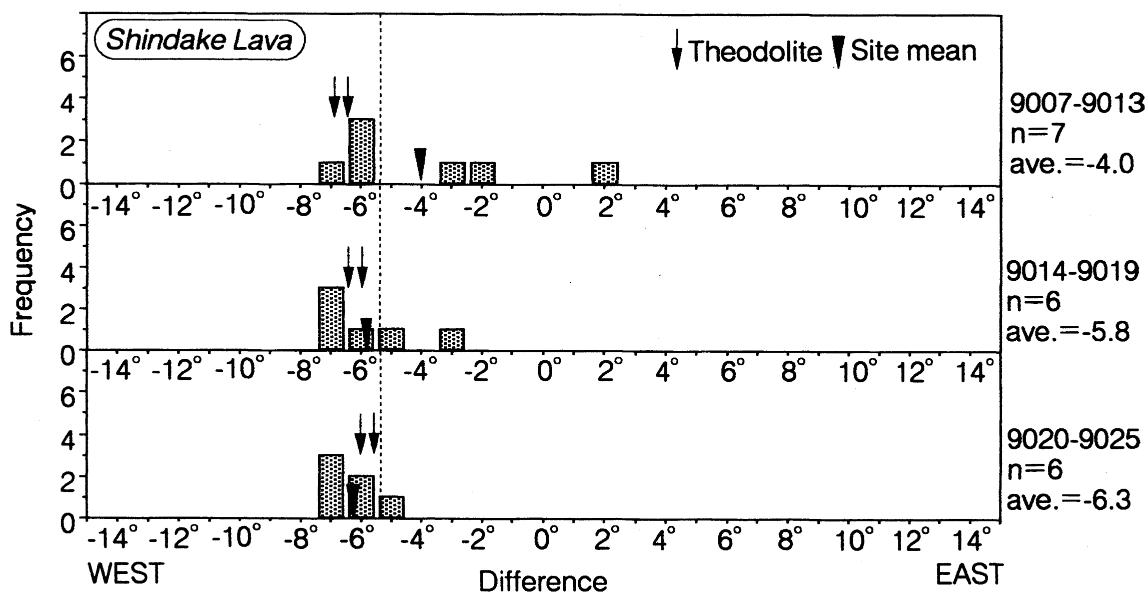

Fig. 5. The deflection between angles measured by the sun and magnetic compasses at Shindake lava sites, Kuchinoerabu island (Appendix II).
Symbols the same as in Figure 3.

Table 3 shows the results of remanent magnetization measurements of typical sites. The declination of remanent magnetization of oriented samples collected by the magnetic compass have errors which correspond to the average difference of sampling sites within one degree. It is clear from this fact paleomagnetists should use the sun compass in the volcanic region.

Measured and calculated results of the geomagnetic field with the proton magnetometers are listed in Tables 1. The total field (F) of the geomagnetic field is corrected by diurnal variation curve obtained continuously at the base station. Total field changes place by place, and ranges from 44100 to 48350 nT. Calculated horizontal component (H) and vertical component (Z) also have wide range.

Considering Kato's opinion mentioned before, the local anomaly correction has been examined on the remanent inclination of the historic lavas of Sakurajima volcano and the coincidence of those of two lava flow units after local anomaly correction are proved (Ueno et al., 1997). Fortunately, Sakurajima volcano has two lava flow units of exactly same age on the both sides of the mountain, and the adequacy of anomaly correction is judged. Kirishima and Kuchinoerabu volcanos have complicated topography, and the correction of the local anomaly has to be considered on declination not only inclination. The methods to examine the adequacy applying the local anomaly correction is not found in this case. Many more attempts for the local anomaly correction on volcano area are needed.

Table 1. Geomagnetic field in the Kirishima area

Site	Measuring Point	Geomagnetic Field D°	Geomagnetic Field I°	F (nT)	H (nT)	Z (nT)
Kirishimajingu Lava, Katazoe						
3031-3039	sampling point	---	39.9N	---	---	---
	18m west	-6.8E	42.7N	46568	33532	32313
	15m southeast	-3.5E	43.9N	44978	33060	30496
	35m northeast	-5.4E	45.0N	47029	33255	33255
3040-3049	sampling point	---	39.6N	---	---	---
	5m southeast	-8.2E	42.8N	46906	34439	31846
	20m souyhwest	-6.5E	44.6N	47186	33610	33120
3050-3059	sampling point	---	42.0N	---	---	---
	7m southwest	-6.6E	42.6N	44962	33096	30434
	25m northwest	-7.5E	41.8N	46140	34402	30748
	100m east	-6.4E	45.5N	46766	32808	33327
3060-3067	sampling point	---	38.0N	---	---	---
	5m east	-2.4E	48.2N	45888	30562	34230
	25m east	-6.8E	44.0N	46827	33685	32529
3095-3102	sampling point	---	42.3N	---	---	---
	8m northwest	-5.7E	41.2N	45623	34348	30027
	15m south	-5.5E	47.8N	45440	30511	33673
	30m south	-5.3E	46.2N	47023	32546	33939
	30m southwest	-0.7E	46.5N	47145	32476	34175
Kirishimajingu Lava, Takaharu						
3076-3083	sampling point	---	44.0N	---	---	---
	6m south	-7.3E	44.3N	45577	32630	31820
	18m southwest	-7.5E	44.1N	46048	33068	32045
	35m southeast	-6.3E	43.6N	46003	33336	31701
3084-3094	sampling point	---	41.4N	---	---	---
	5m northwest	-7.4E	43.6N	45070	32660	31058
	20m east	-5.7E	45.7N	46575	32540	33322
3103-3110	sampling point	---	42.5N	---	---	---
	5m west	-5.8E	43.8N	44439	32101	30730
	15m south	-5.8E	46.1N	46530	32293	33499
3111-3118	sampling point	---	41.9N	---	---	---
	5m west	-5.5E	43.3N	44585	32453	30571
Sano Lava						
4024-4031	sampling point	---	43.6N	---	---	---
	10m north	-8.0E	48.9N	44109	29025	33214
	15m northeast	-8.0E	49.2N	45297	29616	34274
	15m south	-6.9E	44.8N	46351	32918	32632
4032-4041	sampling point	---	39.1N	---	---	---
	200m east	-6.4E	45.9N	46673	32469	33529
4042-4054	sampling point	---	33.7N	---	---	---
	40m east	-5.3E	40.9N	47775	36100	31293
	45m northeast	-7.2E	46.7N	48348	33140	35204
	60m north	-3.4E	47.9N	47201	31639	35027
Ohachi Scoria Flow						
5018-5030	sampling point	---	44.0N	---	---	---
	6m south	-7.3E	44.3N	45577	32630	31820
	18m southwest	-7.5E	44.1N	46048	33068	32045
	35m southeast	-6.3E	43.6N	46003	33336	31701
5031-5044	sampling point		43.0N	---	---	---
	3m west	-5.9E	45.4N	46396	32600	33012
	10m east	-3.0E	50.3N	48239	30839	37094
5045-5058	sampling point	---	43.3N	---	---	---
	10m south	-5.8E	46.0N	45591	31699	32768
	20m south	-5.9E	43.7N	45834	33120	31683
5059-5071	sampling point	---	41.0N	---	---	---
	5m north	-6.0E	46.9N	48281	33008	35236
	15m east	-7.9E	45.4N	47205	33169	33588
Takachihogawara Lava						
6028-6039	sampling point	---	40.1N	---	---	---
	10m southeast	-4.8E	45.6N	47945	33575	34226
	20m southwest	-6.2E	44.8N	47038	33354	33168
6049-6057	sampling point	---	40.0N	---	---	---
	4m south	-5.3E	46.9N	45124	30821	32959
	24m south	-6.0E	45.4N	46036	32313	32790
Kirishima area standard		-5.9E	45.1N			

F: Total field . H: Horizontal componet. Z: Vertical component.
Direction of standard geomagnetic field of 1990 in Kirishima area(National Astronomical Observatory, 1996).

Table 2. Geomagnetic field in Kuchinoerabu island

Site	Measuring Point	Geomagnetic Field D°	Geomagnetic Field I°
Shindake Lava			
9007-9013	Sampling point	-6.9E	43.2N
	5m south	-6.4E	42.6N
9014-9019	Sampling point	-6.4E	41.6N
	5m north	-5.9E	42.9N
9020-9025	Sampling point	-6.0E	41.3N
	5m northwest	-5.6E	42.5N
Kuchinoerabuj area standard		-5.4E	43.1N

Direction of standard geomagnetic field of 1990 in Kuchinoerabu island(National Astronomical Observatory, 1996).

Table 3. Results of remanent magnetization measurements

Site	N	M(A/m)	Dr° Sun	Dr° Mag	I r °	Δ Dr° (Sun−Mag)	Δ L° (S° −D°)
Ohachi Scoria Flow							
5018-5030	13	9.4	003.4	002.4	+52.7	001.0	0.7(5.9−5.2)
5031-5044	12	6.9	001.2	357.7	+51.7	003.3	3.2(5.9−2.7)
Takachihogawara Lava							
6028-6039	12	13.8	000.7	352.0	+51.3	8.7	9.0(5.9+3.1)
6049-6057	9	11.6	001.7	359.3	+51.2	2.4	2.2(5.9−3.7)

N is the number of specimens. M is the mean initial intensity. Dr(Sun) is the declination of remanent magnetization of specimens orientated by the sun compass, and Dr(Mag) is that by the magnetic compass. Ir is the inclination of remanent magetization. Δ Dr is the diffrence of declination, i. e. Dr(Sun)−Dr(Mag). Δ L is the local anomaly. S is the Kirishima area standard declination of the geomagnetic field. D is the average difference between the sun and magnetic compasses indicated in Figure 3.

References

Bartington Inst., 1997, Operation Manual for MAG-01H Declinometer / Inclinometer and MG2KP Steel-free Theodolite: 18pp., London.

Butler, R. F., 1992, Paleomagnetism: 319pp., Blackwell, London.

Creer, K. M. And Sanver, M., 1967, The use of the sun compass: in Methods in Paleomagnetism, 11-15, eds. Collinson, D. W., Creer, D. W. And Runcorn, Elsevir, New York.

Collinson, D. W., 1983, Methods in Rock Magnetism and Paleomagnetism : 530pp., Chapman and Hall, London.

Haff, E and Wensink, H., 1962, Geological solar compass: *Sonderdruck aus der Geologischen Rundschaus*, **52**, 541-548.

National Astronomical Observatory (ed.,), 1996, Chronological Scientific Table: Maruzen, Tokyo (in Japanese).

Oota, A., 1993, Practical Measurement of the Direction (Hoikaku Sokutei no Jissai) : 134pp., Japan Association of Surveyors, Tokyo (in Japanese).

Tarling, D. H. and Hrouda, F., 1993, The Magnetic Anisotropy of Rocks: 217pp., Chapman and Hall, London.

Ueno., H. and Tonouchi, S., 1987, Paleomagnetic evidence for the timing of formation of the Chichibu pyrometasomatic deposits, Japan: *Econ. Geol.*, **82**, 1723-1731.

Ueno, H, Muraoka, M. and Kobayashi, T., 1997, Archeomagnetism in southern Kyushu by historic lavas of Sakurajima volcano: *Chikyu Monthly*, **19**, 223-226 (in Japanese).

Verosuo, K. L., 1977, A poor precision sun compass: *Geology*, **5**, 319.

Watanabe, N., 1959, The direction of remanent magnetism of backed earth and its application to chronology for anthropology and archaeology: *Jour. Fac. Sci. Univ. Tokyo, sect.*V, **2**, 1-186.

Appendix I A computer program for the sun's azimuth

```
10 '
20 ' SUN COMPASS PROGRAM
30 '
40 CLS
50 PRINT"                              ----- SUN COMPASS -----"
60 INPUT"SAMPLING DATE?    Year,Month,Day";ZY,ZM,ZD
70 IF ZY=0 OR ZY<0 GOTO 1030
80 INPUT"EQUATION OF TIME (THE DAY)?   Sign,Minute,Second";SA$,A#,B#
90 CC#=A#/60#+B#/3600#
100 IF SA$="-" THEN C#=-1#*CC# ELSE C#=CC#
110 INPUT"EQUATION OF TIME (NEXT DAY)?  Sign,Minute,Second";SB$,D#,E#
120 FF#=D#/60#+E#/3600#
130 IF SB$="-" THEN F#=-1#*FF# ELSE F#=FF#
140 INPUT"APPARENT DECLINATION (THE DAY)? Sign,Degree,Minute,Second";SC$,G#,H#,I#
150 JJ#=G#+H#/60#+I#/3600#
160 IF SC$="-" THEN J#=-1#*JJ# ELSE J#=JJ#
170 INPUT"APPARENT DECLINATION (NEXT DAY)? Sign,Degree,Minute,Second";SD$,K#,L#,M#
180 NN#=K#+L#/60#+M#/3600#
190 IF SD$="-" THEN N#=-1#*NN# ELSE N#=NN#
200 CLS
210 PRINT"                             ----- SUN COMPASS -----"
220 PRINT"SAMPLING DATE    ";ZY;"/";ZM;"/";ZD
230 INPUT"LATITUDE?  Degree,Minute,Second";IDOD#,IDOM#,IDOS#
240 IF IDOD#<0 GOTO 260
250 GOTO 280
260 CLS
270 GOTO 50
280 IDO#=IDOD#+IDOM#/60#+IDOS#/3600#
290 INPUT"LONGITUDE?  Degree,Minute,Second";KEID#,KEIM#,KEIS#
300 KEI#=KEID#+KEIM#/60#+KEIS#/3600#
310 CLS
320 PRINT"                             ----- SUN COMPASS -----"
330 PRINT"SAMPLING DATE       ";ZY;"/";ZM;"/";ZD
340 PRINT"LATITUDE            ";IDOD#;"/";IDOM#;"/"IDOS#
350 PRINT"LONGITUDE           ";KEID#;"/";KEIM#;"/";KEIS#
360 INPUT"SAMPLE No           ";NO
370 IF NO<0 OR NO=0 GOTO 200
380 INPUT"TIME?  Hour,Minute,Second";HOU#,MIN#,SEC#
390 TIME#=HOU#+MIN#/60#+SEC#/3600#
400 INPUT"ANGLE (SUN)?  Degree";U#
410 INPUT"ANGLE (MAG.)? Degree";Z#
420 UT#=TIME#-9#
430 DE#=UT#/24#
440 KIN#=C#+(F#-C#)*DE#
450 SEK#=J#+(N#-J#)*DE#
460 AUT#=UT#+KIN#
470 ALT#=AUT#+KEI#/15#
480 T#=ALT#-12#
490 TH#=T#*15#
500 O#=TH#*3.141592654#/180#
510 P#=IDO#*3.141592654#/180#
520 Q#=SEK#*3.141592654#/180#
530 RR#=ATN(SIN(O#)/(TAN(Q#)*COS(P#)-COS(O#)*SIN(P#)))
540 R#=RR#*180#/3.141592654#
550 IF T#=0# OR T#>0# GOTO 580
560 IF R#>0# THEN S#=180#-R# ELSE S#=ABS(R#)
570 GOTO 590
580 IF R#>0# THEN S#=360#-R# ELSE S#=180#-R#
590 V#=S#-U#
600 IF V#<0# THEN W#=V#+360# ELSE W#=V#
```

```
610 IF W#<327.68# GOTO 670
620 WW#=W#-300#
630 WA=CINT(WW#*10^2)/10^2
640 WB=WA+300
650 WWW=WB
660 GOTO 680
670 WWW=CINT(W#*10^2)/10^2
680 ZZ#=W#-Z#
690 IF ZZ#>-327.68 GOTO 750
700 ZA#=ZZ#+300#
710 ZB=CINT(ZA#*10^2)/10^2
720 ZC=ZB-300
730 ZZZ=ZC
740 GOTO 820
750 IF ZZ#<327.68 GOTO 810
760 ZA#=ZZ#-300
770 ZB=CINT(ZA#*10^2)/10^2
780 ZC=ZB+300
790 ZZZ=ZC
800 GOTO 820
810 ZZZ=CINT(ZZ#*10^2)/10^2
820 CLS
830 PRINT"                              ----- SUN COMPASS -----"
840 PRINT"SAMPLE No             ";NO
850 PRINT"SAMPLING DATE         ";ZY;"/";ZM;"/";ZD
860 PRINT"LATITUDE              ";IDOD#;"/";IDOM#;"/";IDOS#
870 PRINT"LONGITUDE             ";KEID#;"/";KEIM#;"/";KEIS#
880 PRINT"TIME                  ";HOU#;"/";MIN#;"/";SEC#
890 PRINT"ANGLE (SUN)           ";U#;"Deg."
900 PRINT"ANGLE (MAG.)          ";Z#;"Deg."
910 PRINT"                        "
920 PRINT"--- TRUE STRIKE ---     ";WWW;"Deg."
930 PRINT"--- Declination ---     ";ZZZ;"Deg."
940 PRINT"                                    "
950 PRINT"                                    "
960 PRINT"                                    "
970 PRINT"                                    "
980 PRINT"TOUCH KEY"
990 X$=INKEY$
1000 IF X$="" THEN GOTO 990
1010 CLS
1020 GOTO 310
1030 CLS
1040 PRINT"                        --------  SUN COMPASS     END  --------"
1050 END
```

THE DAY is the sampling day. NEXT DAY is the next day of the sampling day. Sign is "+" or "−". LATITUDE and LONGITUDE are the location of sampling sites. ANGLE (SUN) is the angle between the sun and strike line (α in Fig. 2). ANGLE (MAG.) is the strike from the magnetic north (β) in Fig. 2. TRUE STRIKE is the strike from the true north (γ) in Fig. 2.

Appendix II Locations of sampling sites

Kirishimajingu Lava, Katazoe (31° 51.7′ N, 130° 53.0′ E); Kirishimajingu Lava, Takaharu (31° 51.7′ N, 130° 53.0′ E); Sano Lava (31° 54.0′ N, 130° 57.3′ E); Ohachi Scoria Flow (31° 52.9′ N, 130° 53.9′ E); Takachihogawara Lava (31° 52.5′ N, 130° 53.9′ E); Shindake Lava (30° 27.1′ N, 130° 11.8′ E).