Geomagnetic Secular Variation in Southwest Japan for the Past 2,000 Years by Means of Archaeomagnetism

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CONTENTS

Abstract

In order to clarify the secular variation of the geomagnetic field in Southwest Japan, samples amounting to 665 were collected from 39 sites and the natural remanent magnetizations were measured. Compilation of archaeomagnetic data in Southwest Japan, including the present work, was undertaken from all previously reported measurements on kilns and hearths with known ages. The ages of the data covered a time range from 0 A.D. up to the present. As the result of chronological average of the data, the secular variation of the geomagnetic field in Southwest Japan in the aforementioned time range was brought into light in detail. Comparison of the obtained results with earlier studies on the secular variations at numerous localities in the world suggested that the westward drift has continued throughout the historical age. However, the dipole seemed to have moved in a rather complicated way.

Introduction

A study of secular variation of the geomagnetic field gives not only the basis of palaeomagnetic dating of archaeological remains etc., but also the basic information necessary to construct and verify the theory of the origin of the geomagnetic field and its variation.

Since Folgheraiter (1899) worked on the remanent magnetization of Greek and Etruscan vases, the study to determine the geomagnetic secular variation had been continued mainly in France (Mercanton, 1918a, b; Chevallier, 1925; Thellier, 1937).

After 1950's, it has been studied systematically at various district of the world, for instance Aitken (Aitken and Weaver, 1962; Aitken et al., 1963; Aitken and Hawly, 1966, 67), Burlatskaya (Burlatskaya, 1961, 62; Burlatskaya et al., 1965) and Dubois (1975).

In Japan, after Nagata's and Kato's studies (Nagata, 1943; Kato and Nagata, 1953) of the magnetization of the lava flows belonging to Mt. Fuji and to the volcano in Ooshima Island etc., Yukutake (1964) elucidated the secular-variation in the period from 500 A.D. to 1700 A.D. in Ooshima volcanic area.

The first trial to infer the secular variation of the geomagnetic field by means of archaeomagnetism was carried out by Watanabe (1958, 59). He measured the magnetization of many baked clays of known age to correlate the secular geomagnetic variation to archaeological chronology.

Shortly after Watanabe's investigation, Kawai, Hirooka, Sasajima, Yaskawa, Ito and Kume (archaeomagnetic research group in Kansai, 1963; Kawai et al., 1965) began to make their own investigations. A number of samples from kilns and hearths excavated in the Kansai District, the Southwest Japan, were measured (Kawai et al., 1968; Hirooka, 1971, 79).

Recently Nakajima and Kawai (1973) succeeded in tracing the secular geomagnetic variation by sediment deposited on the bottom of Lake Biwa.

Meanwhile, theoretical studies to explain the secular variations in a global scale have been carried out since 1960's. Under the proposition of the westward drift of the geomagnetic secular variation with the use of instrumental measurements, Yukutake (1967) investigated ages of the maxima and minima of declination and inclination of each location of the world obtained from not only instrumental but also archaeomagnetic measurements, and suggested that westward drift with a velocity of 0.36°/year has continued since 950 A.D.

Kawai et al. (1967) proposed a hypothetic motion of geomagnetic dipole, which is constructed by two counter-acting rotations.

Braginsky (1972, 74) approximated the secular variation by the rotation of dipole and quadrupole calculated from 1st and 2nd order function of spherical harmonics.

Lin et al. (1979), who estimated the trajectory of the geomagnetic pole with the use of inclinations at various locations, concluded that the geomagnetic pole drew counter-clockwise loops before 1300 A.D. and a clockwise loop after

1300 A.D.

As a dating tool, archaeomagnetism in Japan obtained fruitful results (for instance Watanabe, 1971; Hirooka, 1979). But 9 years have passed since the geomagnetic secular variation in the Southwest Japan was inferred by Hirooka (1971). Increase of data and also discoveries of new samples make it necessary to review the secular variation.

In this paper some archaeomagnetic results in the Southwest Japan are reported and all previously reported archaeomagnetic results with known age are compiled and reviewed to give more reliable data for the analysis of the geomagnetic field in historical age and for archaeomagnetic dating.

There are three approaches to determine the secular variation of historical age. (1) One is by thermo-remanent magnetization (TRM) of baked clay in archaeological remains (archaeomagnetism). (2) Second is by TRM of lava flow or detrital remanent magnetization (DRM) of ash-fall tuff of historical eruption. (3) Third is by DRM of sediment whose depositional rate is high, such as that on the bottom of a lake or a bay. Their advantages and disadvantages are tabulated in Table 1.

In this paper the approach (1) is adopted due to the reason that abundance of samples is high.

Approach	Advantages	Disadvantages
1. Baked clay	The magnetization is strong and stable. Samples can be obtained abundantly. Age of each sample is determined precisely by archaeology.	Applicable age of the means is limited.
2. Lava flow or ash-fall tuff of historical eruption	The magnetization is very strong and generally stable. Age of the eruptions which are described in literatures are very precisely known.	As magnetization of the whole volcano makes distortion of geomagnetic field, some corrections are needed.
3. Sediment	As sediment deposits continuously, it has continuous record of geomagnetic field.	It is difficult to determine the absolute age of each sample. The magnetization is weak and sometimes unstable. Absolute declination can rarely be known, but relative one, as orientaion of sample is generally difficult.

Table 1

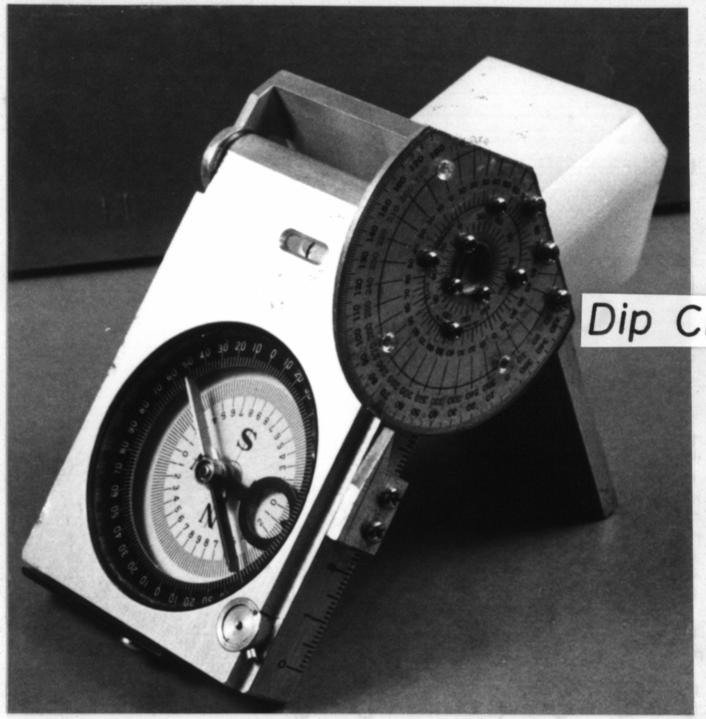
Experimental

1. Sampling of archaeological objects

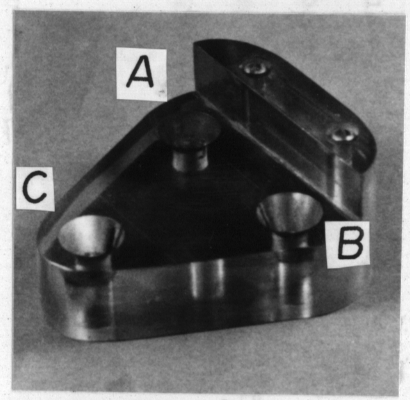
Since it is specially important in an archaeomagnetic study to determine the direction of magnetization as precisely as possible, the method for orientation of sample *in situ* is required to be accurate.

In this work, a small trench of 4 cm deep was dug around a selected part of a baked earth and a stump of the sample, 4 to 5 cm across, was left in centre of the trench. After weakly dissolved plaster was poured into the trench and on the stump, heavily dissolved plaster was set on the top of the stump, and pressed by an aluminium plate so that a flat plane was formed.

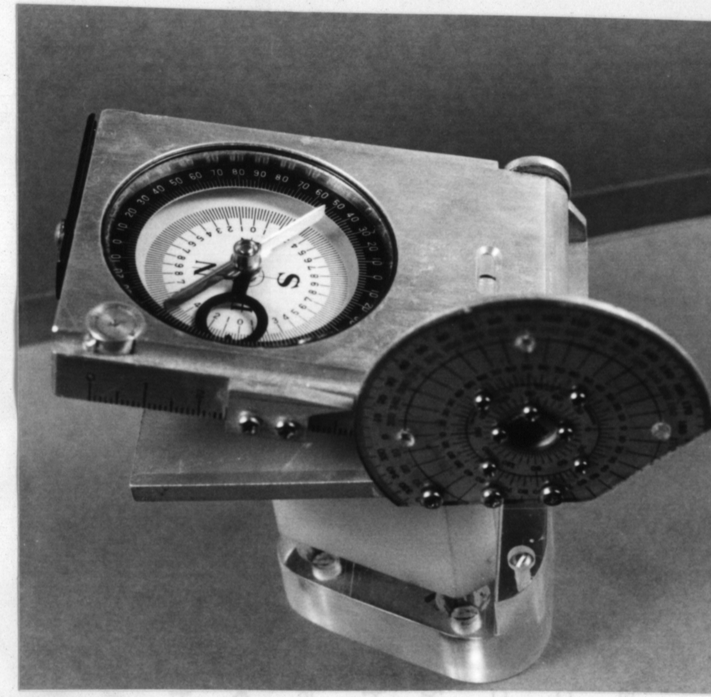
When the plaster was hardened, the aluminium plate was removed. Strike and dip of the plane were measured by a small apparatus (Fig. 1 a) which consisted of a compass plate with a magnetic compass and two levels right-angled to each other, and a dip plate with a dip circle to read the angle between the two plates as follows: First the apparatus was attached on the marker (Fig. 1 b) like Fig. 1 c and the marker was brought into contact with the plane. The compass plate was set horizontally by rotating the marker and adjusting the angle between the two plates of the apparatus. These operations made it



a. Orientation apparatus



b. Marker



c.

Fig. 1 Orientation apparatus and marker

possible to place the two holes A and B of the marker (see Fig. 1 b) on the line along which the plane intersected a horizontal plane. Followingly both of strike and dip of the plane were shown by the compass and the dip circle, respectively. When the strike and the dip were written down, the apparatus was removed except the marker. Through the three holes of the marker, their locations were painted on the plane with oily ink.

Finally the stump was carefully removed from the fireplace. After being brought back to the laboratory, a specimen with the size of 35 mm cube was prepared from each sample using a diamond cutting tool.

2. Measurements of NRM

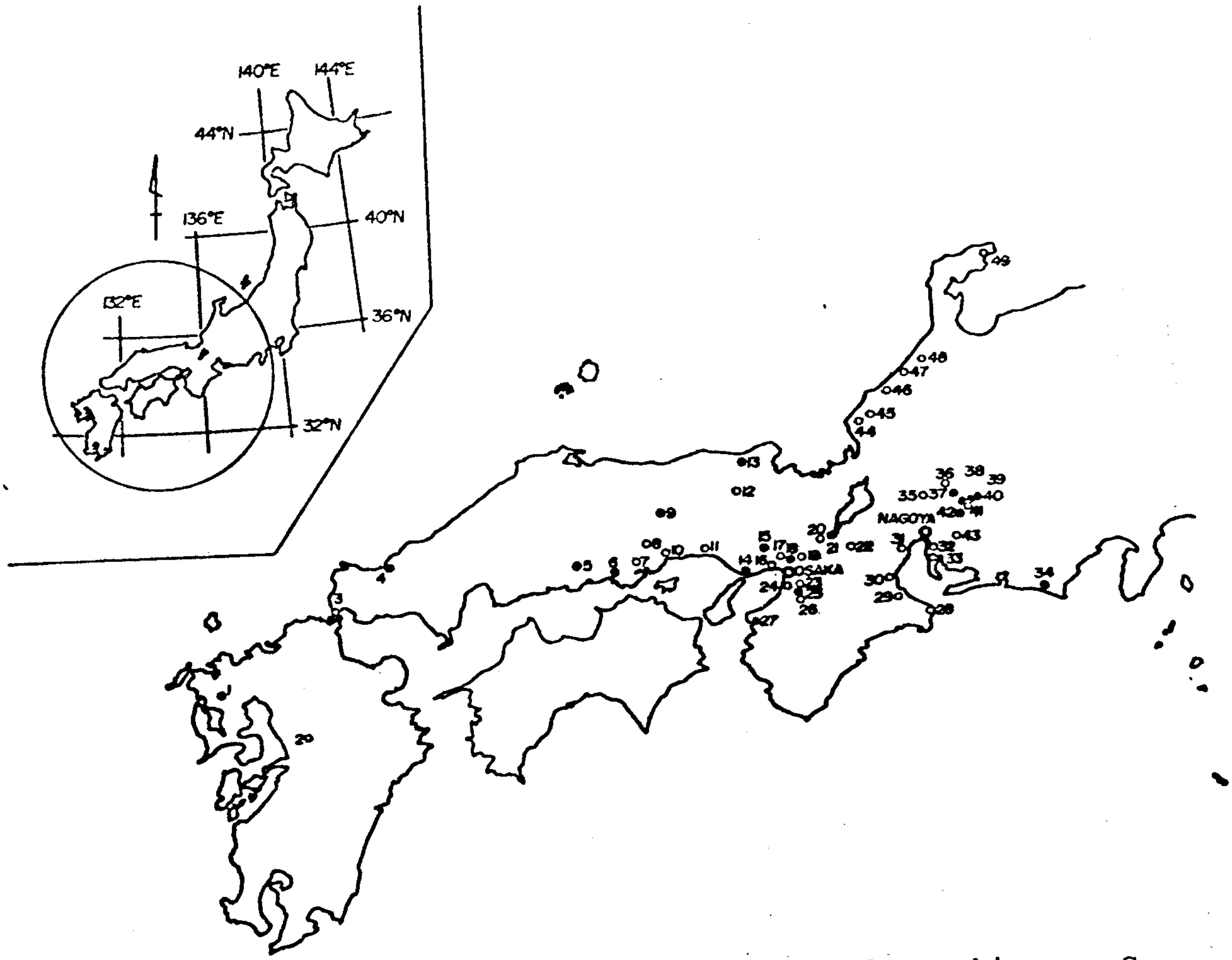
Remanent magnetizations of specimens were measured by an astatic magnetometer which had maximum sensitivity 3.5×10^{-7} e.m.u./deg. The magnetometer consited of two-magnet system suspended with a very thin quartz fibre. The magnets had the size of 1 mm × 2 mm × 4 mm and were connected with a slender quartz tube of 56 mm long. Samples were rotated around the vertical axis right beneath the magnet system.

Results

Samples were collected from 39 sites of various location of the Southwest Japan (see solid circles in Fig. 2). Numbers of the samples amounted to 655. The results are represented in Table 2, and by solid circles in Figs. 3a and b. The virtical line drawn across each solid circle on the diagram represents the experimental errors of the magnetic measurement, and the length of each line shows the actual error angle, hence corresponding to the radius of Fisher's 95% circle of confidence (α_{95}) in Fig. 3a, and α_{95}/cos Im in Fig. 3b. A horizontal line is also drawn on the same diagram across each solid circle. The length of this horizontal line is in inverse portion to the chronological accuracy or proportional to the degree of uncertainty. Data after 1600 A.D. are reduced to Osada by the means described in next chapter.

Published archaeomagnetic data with known ages (Hirooka, 1971, 73, 77, 79; Hirooka et al., 1970; Hirooka and Fujisawa, 1978; Hirooka and Yamamoto, 1975, 76a, 76b; Kawai et al., 1965; Nakajima et al., 1977; Shibuya and Nakajima, 1979; Shibuya et al., 1979; Torii et al., 1976; Watanabe, 1959, 60) are compiled and represented in Table 3 and Fig. 3a and b by open circles. Ages,on which recent archaeological results were obtained, are revised. Reducing to Osaka is also undertaken for data after 1600 A.D.

The results are widely distributed as shown in Fig. 3a and b. Their errors will be discussed in the next chapter.



1. Arita-T. and Ureshino-T.
2. Kikusui-T.
3. Shimonoseki-C.
4. Hagi-C.
5. Kamo-T.
6. Kurashiki-C.
7. Tsudaka-T.
8. Sanyo-T.
9. Shoou-T.
10. Bizen-T.
11. Tatsuno-C.
12. Wadayama-T.
13. Toyooka-C.
14. Akashi-C.
15. Sanda-C.
16. Amagasaki-C.
17. Ikeda-C. and Toyonaka-C.
18. Suita-C.
19. Hirakata-C. and Takatsuki-C.
20. Kyoto-C.
21. Otsu-C.
22. Shigaraki-T.
23. Habikino-C.
24. Izumi-C. and Sakai-C.
25. Tondabayashi-C.
26. Kanan-T. and Kawachinagano-C.
27. Wakayama-C.
28. Isobe-T.
29. Taki-T. and Tamaki-T.
30. Hisai-C.
31. Suzuka-C. and Yokkaichi-C.
32. Chita-T. and Agui-T.
33. Tokoname-C. and Handa-C.
34. Oosuka-T.
35. Kagamihara-C.
36. Seki-C.
37. Kani-T.
38. Tajimi-C.
39. Toki-C.
40. Mizunami-C.
41. Kasahara-T.
42. Seto-C.
43. Miyoshi-T., Nisshin-T. and Togo-T.
44. Miyazaki-V. and Ota-T.
45. Fukui-C.
46. Kaga-C.
47. Komatsu-C.
48. Kanazawa-C.
49. Suzu-C.

Fig. 2 Map of Southwest Japan. Sampling and quoted sites are shown by solid and open circles respectively.

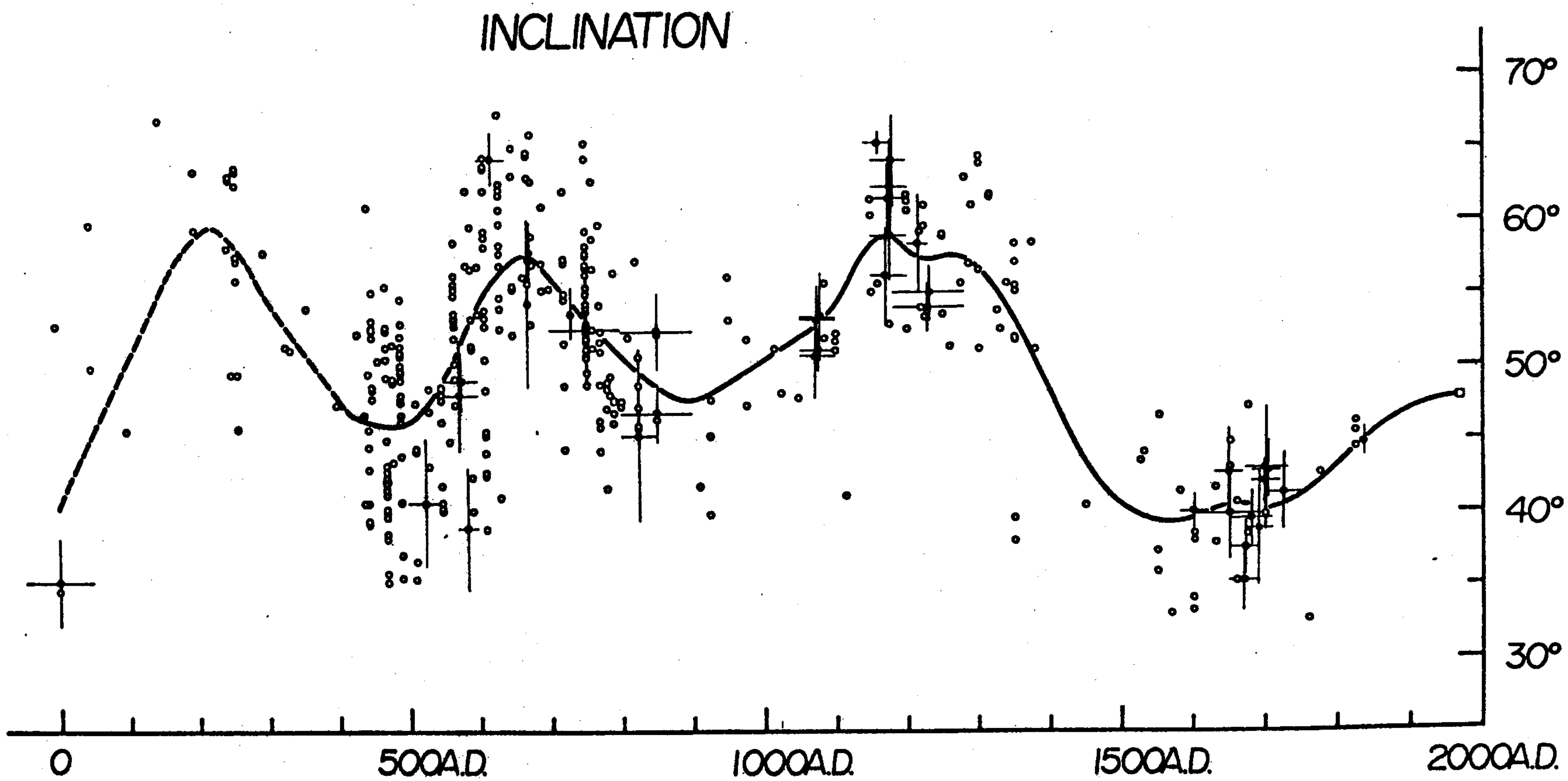


Fig. 3a Secular variation of the geomagnetic inclination in Southwest Japan. Solid and open circles represent the data obtained by this work and the quoted data, respectively.

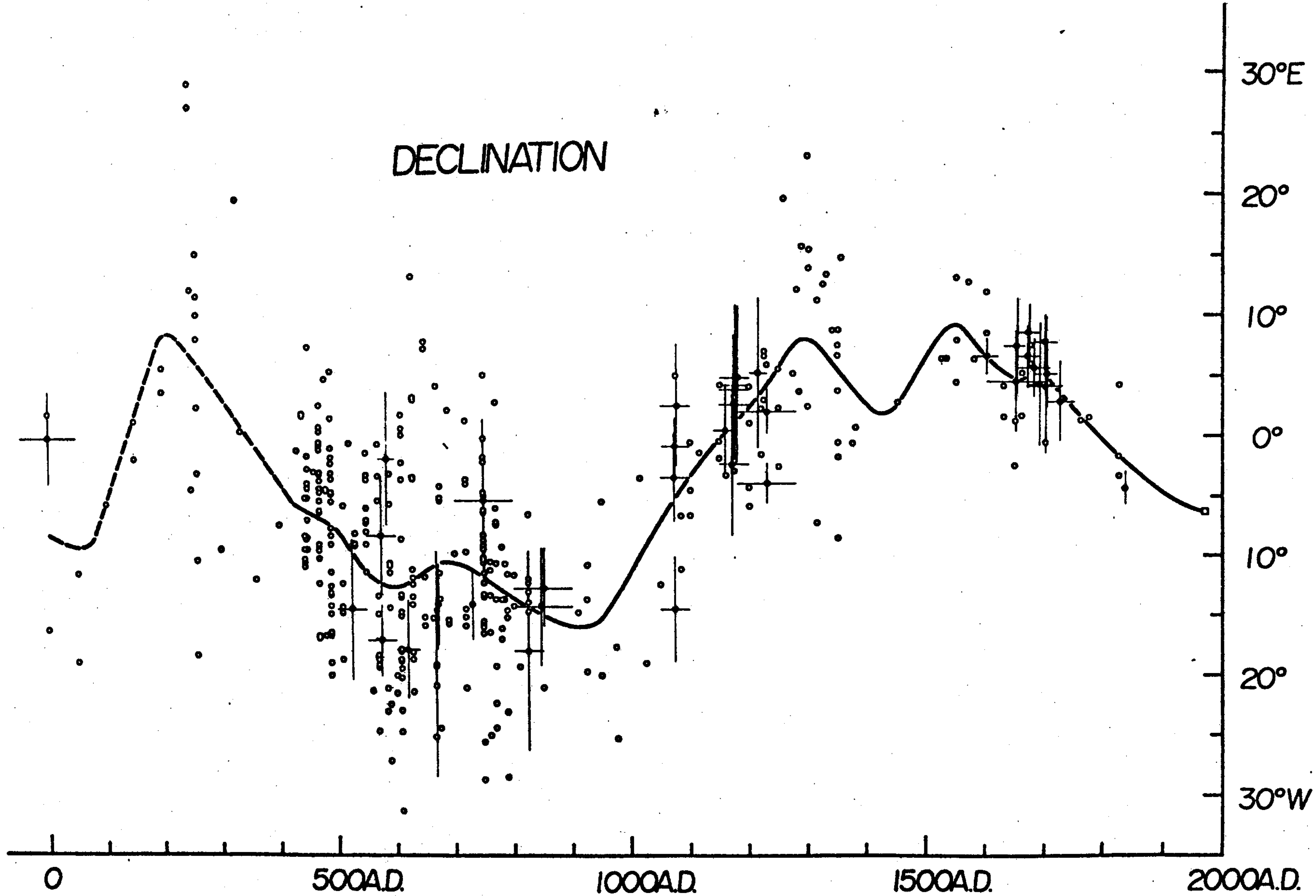


Fig. 3b Secular variation of the geomagnetic declination in Southwest Japan. Solid and open circles represent the data obtained by this work and the quoted data, respectively.

To clarify the secular variation, chronological average of these data was calculated as foolows: Median years were set at intervals of 25 years. The data whose archaeological age fell in the period between 50 years before and after each median year, were averaged by the method given by Fisher (1953). Table 4 and Figs. 4a and b show the results of this average. The virtical line drawn across each point on the diagrams is simular to that in Figs. 3a and b.

Site	Locality	Lat.	Long.	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age
Kishi	Tondabayashi-C.	34°31'	137°37'	18	0.3	35.5	3.1	128.8	0 ± 25
Saradani 4-II	Wakayama-C.	34°13'	135°14'	12	-14.2	40.9	4.5	92.0	525 ± 25
Saradani 2	Wakayama-C.	34°13'	135°14'	23	-16.8	49.3	2.0	249.9	575 ± 25
Saradani 4-I	Wakayama-C.	34°13'	135°14'	12	-8.0	47.3	3.4	165.4	575 ± 25
Saradani 3	Wakayama-C.	34°13'	135°14'	13	-1.5	39.1	4.3	92.6	585 ± 15
Sabuta 5	Kurashiki-C.	34°15'	133°40'	14	-17.6	64.6	1.8	504.1	620 ± 20
Hannokibara KB3	Otsu-C.	35°02'	135°51'	4	-19.0	54.6	5.4	288.3	670 ± 5
Hannokibara KB4	Otsu-C.	35°02'	135°51'	22	-14.3	57.7	1.8	287.2	670 ± 5
Hannokibara KC2	Otsu-C.	35°02'	135°51'	15	-13.8	58.1	1.9	426.1	670 ± 5
Nanao 7	Suita-C.	34°47'	135°32'	14	-13.8	53.9	1.8	512.0	730 ± 5
Suenishi 67	Sanda-C.	34°57'	135°12'	9	-5.0	52.8	4.1	156.0	750 ± 50
Saradani 1	Wakayama-C.	34°13'	135°14'	8	-17.7	45.5	5.9	89.4	825 ± 25
Kitaoka 4	Tajimi-C.	35°22'	137°05'	12	-12.4	51.0	2.1	426.0	850 ± 50
Kitaoka 5	Tajimi-C.	35°22'	137°05'	12	-14.0	56.6	2.7	250.8	850 ± 50
Kitaoka 8	Tajimi-C.	35°22'	137°05'	13	-14.3	50.9	2.8	221.2	1075 ± 25
Hakusan 1A	Oosuka-T.	34°42'	137°58'	12	-3.2	53.5	2.2	399.5	1075 ± 25
Hakusan 2	Oosuka-T.	34°42'	137°58'	11	-0.6	51.3	1.5	908.3	1075 ± 25
Hakusan 3	Oosuka-T.	34°42'	137°58'	12	2.8	53.5	3.0	207.1	1075 ± 25
Yabasama 2	Kani-T.	35°24'	137°03'	14	0.8	65.5	1.5	658.8	1150 ± 20
Uozumi 22	Akashi-C.	34°41'	135°55'	11	4.5	61.7	2.2	415.5	1175 ± 25
Uozumi 29	Akashi-C.	34°41'	135°55'	12	-2.1	56.4	3.3	170.2	1175 ± 25
Uozumi 30L	Akashi-C.	34°41'	135°55'	12	4.1	62.5	3.3	177.1	1175 ± 25
Uozumi 32	Akashi-C.	34°41'	135°55'	12	5.1	64.1	3.1	203.4	1175 ± 25
Uozumi 33	Akashi-C.	34°41'	135°55'	20	2.9	59.1	3.1	115.2	1175 ± 25
Hirako 2	Seto-C.	35°12'	137°05'	12	5.5	58.6	3.3	175.8	1215 ± 20
Shinjodani 1	Shoou-T.	35°01'	134°07'	24	2.3	55.2	1.9	262.4	1230 ± 50
Shinjodani 3	Shoou-T.	35°01'	134°07'	29	-3.7	54.2	1.7	262.6	1230 ± 50

Table 2

Site	Locality	Lat.	Long.	N	D(°)	I(°)	Reduced D(°)	Reduced I(°)	α_{95}(°)	k	Archaeological Age
Inkyoyama W	Toki-C.	35°22'	137°11'	18	7.4	41.2	7.0	40.8	1.2	899.5	1600 ± 20
Saka 1	Hagi-C.	34°23'	131°26'	34	6.2	41.7	7.6	42.8	3.0	69.2	1650 ± 20
Okawa E-3G	Mizunami-T.	35°18'	137°18'	25	5.3	40.8	4.7	39.9	3.2	85.2	1650 ± 50
Saka 3	Hagi-C.	34°23'	131°26'	26	7.5	36.8	8.7	37.8	1.9	225.1	1670 ± 20
Himedani 1	Kamo-T.	34°38'	133°19'	23	6.1	34.8	6.7	35.4	2.1	201.1	1670 ± 20
Sarayadani 3	Ureshino-T.	33°06'	129°56'	30	4.2	36.7	5.7	39.9	1.9	187.1	1680 ± 30
Saka 2	Hagi-C.	34°23'	131°26'	14	3.3	38.0	4.4	38.9	4.0	99.7	1690 ± 20
Tanoso A	Mizunami-C.	35°19'	137°18'	22	8.4	43.0	7.9	42.1	1.6	399.2	1700 ± 20
Tanoso B	Mizunami-C.	35°19'	137°18'	9	5.8	43.8	5.3	42.9	2.0	662.8	1700 ± 20
Sarayadani 1	Ureshino-T.	33°06'	129°56'	14	2.9	40.1	4.3	43.0	4.3	85.4	1700 ± 30
Kakiemon B	Arita-T.	33°11'	129°52'	25	1.7	39.1	2.9	41.5	2.6	125.5	1725 ± 25
Takaya	Toyooka-C.	35°32'	134°48'	33	-4.4	45.8	-4.3	44.8	1.0	681.8	1835 ± 5

Table 2 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Tano TN5L60-18	Amagasaki-C.	10	2.3	34.9	7.6	41.5	0 ± 50	1
Ayaragi	Shimonoseki-C.	17	-16.0	53.3	7.6	22.9	0 ± 50	1
Tano TN4-3-6	Amagasaki-C.	10	-18.7	50.4	10.8	20.9	50 ± 80	1
Miyanomae GI51	Ikeda-C.	10	-11.2	60.4	8.0	37.2	50 ± 80	1
Miyanomae GP49-II	Ikeda-C.	10	-5.3	46.0	4.7	105.8	100 ± 50	1
Miyanomae GP49-I	Ikeda-C.	15	-1.5	26.1	3.8	105.3	150 ± 50	1
Miyanomae GE49	Ikeda-C.	22	1.7	67.6	6.0	27.7	150 ± 50	1
Takatsukayama A	Hirakata-C.	12	6.2	59.9	4.0	118.1	200 ± 15	1
Tsukasaki	Kanazawa-C.	61	4.2	64.0	3.8	23.6	200 ± 50	1
Hata	Suzuka-C.	26	-4.1	49.8	5.0	40.7	250 ± 30	1
Ichisuka B7-A	Kanan-T.	22	28.0	63.4	6.6	23.0	250 ± 50	1
Daishiyama B	Kawachinagano-C.	9	29.9	58.8	10.9	23.0	250 ± 50	1
Benitakeyama 7	Takatsuki-C.	22	12.7	63.6	4.2	54.5	250 ± 50	1
Suwanoharu A 3	Kikusui-T.	9	8.7	46.1	4.8	115.1	260 ± 50	1
Suwanoharu B14	Kikusui-T.	11	10.7	56.4	5.7	65.5	260 ± 50	1
Suwanoharu B15	Kikusui-T.	4	-10.1	63.0	9.6	92.9	260 ± 50	1
Suwanoharu B16	Kikusui-T.	8	15.8	64.2	6.0	86.4	260 ± 50	1
Suwanoharu B22	Kikusui-T.	8	-2.7	49.8	10.9	26.6	260 ± 50	1
Suwanoharu B20	Kikusui-T.	4	12.2	57.7	10.2	82.4	260 ± 50	1
Suwanoharu B35	Kikusui-T.	6	-18.1	64.0	11.0	37.9	260 ± 50	1
Suwanoharu B40	Kikusui-T.	7	2.8	58.0	8.5	50.9	260 ± 50	1
Benitakeyama 18-6	Takatsuki-C.	10	-9.1	58.3	6.6	53.7	300 ± 50	1
Ama B9-P7A	Takatsuki-C.	22	23.0	53.7	5.1	38.1	330 ± 35	1
Ama B9-P7B	Takatsuki-C.	9	0.8	33.5	8.5	37.7	335 ± 35	1
Ootayama B	Fukui-C.	10	-11.7	56.4	4.4	123.6	360 ± 70	9
Ootayama E-N	Fukui-C.	14	-7.1	47.7	6.1	44.0	400 ± 95	9
Suemura ON22-I	Sakai-C.	13	-0.8	52.6	3.6	135.7	430 ± 10	14
Ichisuka 2	Kanan-T.	31	2.2	47.0	2.2	135.9	440 ± 15	1
Ama B9-P7C	Takatsuki-C.	10	2.2	40.8	12.5	15.9	440 ± 35	1
Habikino 1-1	Habikino-C.	18	-4.9	61.4	4.5	68.8	445 ± 10	1

Table 3

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Habikino 1-2	Habikino-C.	27	-9.1	40.9	3.9	51.0	445 ± 10	1
Habikino 3-1	Habikino-C.	9	-10.5	44.8	4.9	110.1	445 ± 10	1
Habikino 3-2	Habikino-C.	9	-8.0	39.4	4.4	139.5	445 ± 10	1
Habikino 3-3	Habikino-C.	9	-10.0	43.3	3.5	217.4	445 ± 10	1
Habikino 4	Habikino-C.	11	-8.3	39.5	6.4	52.6	445 ± 10	1
Habikino 5	Habikino-C.	21	-10.2	46.0	2.8	128.5	445 ± 10	1
Habikino 8	Habikino-C.	20	-9.1	49.9	2.7	146.0	445 ± 10	1
Suemura ON22-II-A1	Sakai-C.	6	-4.8	48.9	5.8	135.4	450 ± 10	14
Suemura ON22-II-A3	Sakai-C.	11	-8.2	53.3	4.9	88.6	450 ± 10	14
Suemura TG22-A	Sakai-C.	9	7.9	55.5	4.1	158.4	450 ± 10	13
Suemura TG22-B	Sakai-C.	8	-3.8	48.7	3.4	274.5	450 ± 10	13
Suemura TG22-C	Sakai-C.	14	-1.3	52.4	2.5	253.5	450 ± 10	13
Suemura TG22-D	Sakai-C.	11	-3.7	53.0	3.6	162.6	450 ± 10	13
Suemura TG22-ML	Sakai-C.	15	-3.4	53.0	2.6	219.9	450 ± 10	13
Naniwanomiya 1	Osaka-C.	9	-6.6	48.2	5.5	87.7	450 ± 50	1
Habikino W-1	Habikino-C.	11	-2.6	50.8	5.0	85.4	460 ± 10	1
Suemura ON53	Izumi-C.	10	-7.8	40.4	4.4	119.5	470 ± 10	14
Suemura ON57	Izumi-C.	11	-5.0	38.6	3.7	150.3	470 ± 10	14
Suemura ON58	Izumi-C.	10	-4.0	38.7	3.3	215.8	470 ± 10	14
Suemura ON151	Sakai-C.	12	-0.2	39.9	3.0	207.9	470 ± 10	14
Suemura ON155	Sakai-C.	10	-9.9	41.5	2.9	280.2	470 ± 10	14
Suemura MT70	Sakai-C.	25	-6.1	42.4	2.9	101.0	470 ± 10	1
Suemura MT206-I-A	Sakai-C.	15	-16.6	41.9	5.1	58.4	470 ± 10	5
Suemura MT206-I-B	Sakai-C.	21	-16.6	43.5	1.4	536.2	470 ± 10	5
Suemura TG19	Sakai-C.	21	-4.0	53.0	2.3	197.8	470 ± 10	13
Suemura TG43-III	Sakai-C.	26	-4.4	43.1	1.6	302.7	470 ± 10	1
Suemura TG201	Sakai-C.	13	-6.0	55.9	4.0	108.0	470 ± 10	11
Suemura TK33-N	Sakai-C.	19	-2.7	45.3	3.4	96.4	470 ± 10	1
Suemura TK50	Sakai-C.	27	-3.4	50.9	3.0	87.5	470 ± 10	1
Suemura TK67-I	Sakai-C.	16	1.2	49.6	4.5	67.6	470 ± 10	1

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TK67-II	Sakai-C.	23	0.8	42.4	6.4	23.6	470 ± 10	1
Suemura TK103-L	Sakai-C.	12	3.0	51.6	2.4	322.6	470 ± 10	11
Suemura TK103-ML	Sakai-C.	20	-0.8	52.8	3.0	118.7	470 ± 10	11
Suemura TK305-I-1	Sakai-C.	14	-9.0	36.0	2.6	231.5	470 ± 10	11
Suemura TK305-I-2	Sakai-C.	15	-8.9	38.4	2.4	262.7	470 ± 10	1
Suemura TK305-I-2P	Sakai-C.	15	-12.0	42.5	4.1	85.4	470 ± 10	11
Suemura TK305-I-L	Sakai-C.	14	-9.1	40.2	2.0	369.3	470 ± 10	1
Suemura TK306	Sakai-C.	24	-0.5	35.4	5.1	35.4	470 ± 10	11
Suemura TK208	Sakai-C.	10	-2.9	42.3	5.8	70.3	470 ± 30	10
Hisai 3	Hisai-C.	14	-16.4	49.2	2.9	188.8	480 ± 10	10
Suemura TK27-U	Sakai-C.	14	-4.3	51.9	2.8	207.0	480 ± 10	1
Suemura TK27-ML	Sakai-C.	12	-4.2	49.5	3.4	160.4	480 ± 10	1
Shimomura 3	Toyonaka-C.	15	5.2	43.7	8.1	32.1	480 ± 35	1
Suemura ON152	Sakai-C.	9	-7.4	49.9	4.2	150.6	490 ± 10	14
Suemura ON222	Izumi-C.	11	-4.6	37.3	3.7	152.6	490 ± 10	14
Suemura KM2	Izumi-C.	31	-18.7	47.0	4.3	36.8	490 ± 10	1
Suemura MT5-II-B1	Sakai-C.	9	1.9	47.9	4.7	120.5	490 ± 10	5
Suemura MT5-II-B2	Sakai-C.	10	-1.9	50.4	2.5	379.7	490 ± 10	5
Suemura MT5-II-B3	Sakai-C.	8	-2.7	46.6	4.2	171.6	490 ± 10	5
Suemura MT5-II-B5	Sakai-C.	7	-1.5	51.2	4.8	158.7	490 ± 10	5
Suemura MT5-II-C	Sakai-C.	8	-5.1	49.9	3.8	210.2	490 ± 10	5
Suemura MT5-II-L	Sakai-C.	16	-3.2	51.2	3.9	91.7	490 ± 10	5
Suemura MT5-II-MD	Sakai-C.	14	-4.5	48.2	3.5	133.7	490 ± 10	5
Suemura MT84	Sakai-C.	22	-7.9	55.0	2.6	145.0	490 ± 10	1
Suemura TG37	Sakai-C.	31	-11.1	41.0	2.3	129.1	490 ± 10	1
Suemura TG39-IV	Sakai-C.	12	5.8	44.2	4.0	120.6	490 ± 10	13
Suemura TG43-I	Sakai-C.	30	-0.6	48.4	2.0	181.0	490 ± 10	1
Suemura TK4-1	Sakai-C.	20	-13.9	35.7	3.2	102.7	490 ± 10	11
Suemura TK4-2	Sakai-C.	14	-14.6	39.5	2.4	274.3	490 ± 10	11
Suemura TK232-1	Sakai-C.	15	-12.3	53.3	2.1	325.4	490 ± 10	1

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TK232-2	Sakai-C.	12	-16.4	52.4	1.7	650.5	490 ± 10	1
Suemura TK232-3	Sakai-C.	14	-14.2	50.6	1.0	1616.9	490 ± 10	1
Suemura TK232-4	Sakai-C.	14	-10.8	51.7	2.2	322.1	490 ± 10	1
Suemura TK232-5	Sakai-C.	10	-8.7	50.0	2.6	323.4	490 ± 10	1
Suemura TK232-6	Sakai-C.	10	-12.9	48.3	2.7	332.1	490 ± 10	1
Suemura TK232-V	Sakai-C.	16	-19.8	51.1	2.4	234.9	490 ± 10	11
Suemura KM126	Sakai-C.	14	-12.0	36.8	3.3	143.2	510 ± 10	11
Suemura MT200-II	Sakai-C.	15	-14.5	44.5	5.3	52.6	510 ± 10	1
Suemura TG43-II	Sakai-C.	29	-5.4	44.6	2.6	106.7	510 ± 10	1
Suemura TK15-II	Sakai-C.	8	-18.4	35.5	5.5	102.2	510 ± 10	11
Suemura TK33-SO	Sakai-C.	10	-14.1	47.8	3.8	166.1	510 ± 10	1
Suemura TK47	Sakai-C.	9	0.2	47.3	4.6	126.2	520 ± 20	10
Suemura TK2	Sakai-C.	14	-8.9	48.8	3.7	113.9	530 ± 10	5
Suemura TK71	Sakai-C.	27	-7.8	47.2	2.6	116.0	530 ± 10	1
Suemura TK85	Sakai-C.	7	-8.7	43.4	5.6	119.3	530 ± 10	1
Suemura ON3-A1	Sakai-C.	7	-11.0	48.8	3.8	259.9	550 ± 10	14
Suemura ON3-B1	Sakai-C.	9	-6.9	48.0	6.4	66.5	550 ± 10	14
Suemura ON3-C	Sakai-C.	16	-7.7	48.8	1.8	415.1	550 ± 10	14
Suemura ON52-A	Izumi-C.	13	-2.9	42.1	1.1	1401.9	550 ± 10	14
Suemura ON52-B	Izumi-C.	5	-1.0	40.9	4.0	370.1	550 ± 10	14
Suemura ON52-C	Izumi-C.	12	-3.3	48.4	8.0	30.4	550 ± 10	14
Suemura TG33-I	Sakai-C.	8	-8.7	46.5	6.1	84.3	550 ± 10	13
Suemura TG211	Sakai-C.	7	-5.7	40.6	5.6	118.6	550 ± 10	13
Shimomura 2	Toyonaka-C.	22	-6.7	40.6	2.4	175.2	550 ± 25	1
Suemura TK10	Sakai-C.	5	-21.1	45.2	7.6	102.3	560 ± 20	10
Suemura TG38-I	Sakai-C.	9	-5.1	49.5	6.6	61.6	570 ± 10	13
Suemura TG38-II	Sakai-C.	10	-0.3	47.7	9.2	28.5	570 ± 10	13
Suemura TG40-I	Sakai-C.	22	-3.0	53.3	6.7	22.1	570 ± 10	1
Suemura TG65	Sakai-C.	10	-13.2	52.3	3.8	160.9	570 ± 10	13
Suemura TK41	Sakai-C.	15	-18.2	50.5	2.7	201.5	570 ± 10	1

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TK43-AU	Sakai-C.	19	-19.1	55.6	2.1	245.9	570 ± 10	1
Suemura TK43-AM	Sakai-C.	15	-1818	56.6	1.6	549.0	570 ± 10	1
Suemura TK43-AL	Sakai-C.	13	-18.3	53.1	2.3	327.9	570 ± 10	1
Suemura TK43-B1	Sakai-C.	8	-18.6	53.6	4.7	141.7	570 ± 10	1
Suemura TK43-B2	Sakai-C.	7	-24.5	58.9	2.0	909.1	570 ± 10	1
Suemura TK43-B3	Sakai-C.	13	-14.7	55.2	1.8	504.2	570 ± 10	1
Suemura TK43-C	Sakai-C.	13	-18.2	56.0	2.4	302.3	570 ± 10	1
Suemura TK43-D	Sakai-C.	8	-18.6	53.9	4.7	141.7	570 ± 10	1
Bungyo 1	Kaga-C.	9	-20.9	57.3	1.5	1150.3	585 ± 15	4
Bungyo 5	Kaga-C.	9	-22.8	62.4	1.6	1005.4	585 ± 15	4
Suemura KM28-II	Sakai-C.	21	-10.4	59.8	3.0	116.3	590 ± 10	1
Suemura TG30-I-ML	Sakai-C.	19	-27.0	51.5	3.7	84.9	590 ± 10	13
Suemura TG39-I	Sakai-C.	15	-2.8	53.6	2.4	261.2	590 ± 10	13
Suemura TG51-A	Sakai-C.	5	-11.1	40.3	17.3	20.5	590 ± 10	11
Suemura TG51-B	Sakai-C.	6	-14.1	42.7	2.6	653.5	590 ± 10	13
Suemura TK305-II	Sakai-C.	20	-10.4	53.6	4.5	53.0	590 ± 10	1
Suemura TK312	Sakai-C.	19	-6.3	57.0	3.2	109.8	590 ± 10	1
Takaoka 14	Akashi-C.	35	-22.2	51.7	1.3	364.0	590 ± 10	1
Hataeda	Kyoto-C.	13	-21.3	57.2	3.1	179.0	600 ± 20	10
Okada 1	Wadayama-T.	26	-19.8	53.9	2.8	107.0	600 ± 25	1
Suemura KM3	Izumi-C.	30	-14.8	53.7	1.4	363.4	610 ± 10	1
Suemura KM115	Sakai-C.	11	-19.3	62.4	4.9	88.3	610 ± 10	11
Suemura TK117	Sakai-C.	8	-11.0	45.6	2.9	362.5	610 ± 10	1
Suemura MT5-III-A	Sakai-C.	5	-24.6	50.8	9.9	61.4	610 ± 10	5
Suemura MT5-III-B	Sakai-C.	14	-18.7	58.5	2.7	216.3	610 ± 10	5
Suemura MT5-III-C	Sakai-C.	9	-8.3	44.4	5.7	83.9	610 ± 10	5
Suemura MT5-III-D	Sakai-C.	7	-20.0	54.2	4.7	169.0	610 ± 10	5
Suemura MT22-I	Sakai-C.	11	-18.5	59.0	3.2	199.6	610 ± 10	5
Suemura MT22-II	Sakai-C.	12	-22.8	64.7	3.3	171.6	610 ± 10	11
Suemura TG10-II-A	Sakai-C.	9	1.0	59.2	3.8	185.6	610 ± 10	13

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TG10-II-B	Sakai-C.	12	-1.9	63.9	5.4	65.8	610 ± 10	13
Suemura TG10-II-C	Sakai-C.	7	-3.3	45.7	8.0	58.6	610 ± 10	13
Suemura TG41-II	Sakai-C.	36	0.5	64.0	3.2	53.8	610 ± 10	13
Suemura TG63-I-B	Sakai-C.	5	-17.6	42.9	6.0	166.8	610 ± 10	13
Suemura TG63-II	Sakai-C.	15	-17.8	42.7	4.3	79.5	610 ± 10	13
Suemura TG200-A	Sakai-C.	3	2.2	39.1	10.8	130.7	610 ± 10	11
Suemura TG200-B	Sakai-C.	7	-31.2	53.1	6.7	83.8	610 ± 10	13
Suemura TK44-I	Sakai-C.	16	-13.7	48.7	2.2	287.4	610 ± 10	5
Suemura TK317	Sakai-C.	19	-14.5	59.6	2.2	233.8	610 ± 10	5
Suemura KM11-U	Izumi-C.	25	-17.9	59.7	1.9	244.2	630 ± 10	1
Suemura KM11-L	Izumi-C.	7	-18.4	60.1	4.0	229.0	630 ± 10	1
Suemura KM28-I-L	Sakai-C.	25	-13.2	58.1	6.2	23.0	630 ± 10	1
Suemura TG10-I-A	Sakai-C.	15	3.5	61.1	4.3	83.0	630 ± 10	13
Suemura TG10-I-B	Sakai-C.	9	3.5	62.9	4.9	109.5	630 ± 10	13
Suemura TG10-I-C	Sakai-C.	12	-3.2	54.3	5.6	62.2	630 ± 10	13
Suemura TG10-I-D	Sakai-C.	10	-3.2	62.5	4.0	150.8	630 ± 10	13
Suemura TG30-II	Sakai-C.	16	13.7	62.1	4.8	59.6	630 ± 10	13
Suemura TG32	Sakai-C.	9	-21.2	67.7	4.6	128.2	630 ± 10	13
Suemura TG41-I	Sakai-C.	20	-10.9	57.2	1.9	311.1	630 ± 10	13
Suemura TG205	Sakai-C.	9	-12.1	52.9	12.2	18.8	630 ± 10	11
Suemura TG206	Sakai-C.	5	-11.6	55.1	4.1	357.3	630 ± 10	13
Suemura TK44-II	Sakai-C.	15	-13.8	41.2	2.8	182.8	630 ± 10	5
Suemura TG11-II	Sakai-C.	8	7.7	65.4	5.0	123.5	650 ± 10	13
Suemura TG17	Sakai-C.	8	8.3	55.6	7.5	55.6	650 ± 10	13
Suemura TG41-III	Sakai-C.	18	-11.5	52.5	2.3	223.4	650 ± 10	11
Suemura TG41-IV	Sakai-C.	43	-14.9	55.7	2.1	104.3	650 ± 10	1
Suemura TK46	Sakai-C.	35	-15.6	63.5	2.1	129.7	650 ± 10	1
Shimomura 1	Toyonaka-C.	30	-15.0	56.4	1.4	341.2	665 ± 5	1
Suemura TG11-I	Sakai-C.	9	-18.9	65.3	4.0	164.5	670 ± 10	13
Suemura TG68	Sakai-C.	10	4.6	66.8	8.5	33.1	670 ± 10	11

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Nishiokane	Yokkaichi-C.	10	-25.0	56.0	6.2	61.6	670 ± 10	1
Hannokibara A1	Otsu-C.	16	-20.7	64.9	3.3	124.7	670 ± 20	7
Takaoka 3	Akashi-C.	19	-3.8	53.2	2.0	283.0	675 ± 5	1
Takaoka 4A	Akashi-C.	16	-13.4	57.2	2.8	171.9	675 ± 5	1
Takaoka 4BN	Akashi-C.	15	-5.0	57.3	2.8	184.5	675 ± 5	1
Takaoka 4BO	Akashi-C.	5	-4.9	63.0	3.7	664.5	675 ± 5	1
Suemura TK68	Sakai-C.	8	-11.2	59.3	3.0	353.3	675 ± 10	1
Suemura TK48	Sakai-C.	14	-24.3	66.3	2.8	196.1	675 ± 15	1
Iwasaki 17	Nisshin-T.	9	-15.2	55.5	6.3	67.7	690 ± 10	10
Suemura TG40-II	Sakai-C.	18	2.6	61.3	2.7	162.2	690 ± 10	13
Suemura TG202	Sakai-C.	8	-15.1	57.4	6.4	77.2	690 ± 10	11
Ikenotani 2	Taki-T.	16	-9.5	55.6	4.5	68.2	700 ± 20	10
Suemura TG40-III	Sakai-C.	16	-3.3	44.6	3.7	102.0	720 ± 10	13
Suemura TG57-I	Sakai-C.	14	-14.8	57.4	6.6	37.0	720 ± 10	13
Suemura TG57-II	Sakai-C.	7	1.7	57.7	7.4	66.8	720 ± 10	13
Suemura TG62	Sakai-C.	9	-3.6	48.9	7.0	55.1	720 ± 10	13
Suemura TG216	Sakai-C.	14	-9.3	51.9	4.8	68.6	720 ± 10	13
Suemura TK316	Sakai-C.	12	-20.8	62.4	3.3	172.1	720 ± 10	5
Suemura TK321	Sakai-C.	9	-14.2	54.9	3.1	264.0	720 ± 10	5
Suemura MT21	Sakai-C.	14	-15.6	55.3	4.2	90.5	720 ± 20	10
Suemura KM60	Izumi-C.	29	-11.0	53.0	1.4	378.4	750 ± 10	1
Suemura KM101	Izumi-C.	26	-8.7	51.5	3.1	83.8	750 ± 10	1
Suemura KM102	Izumi-C.	25	-9.1	57.3	2.2	171.3	750 ± 10	1
Suemura KM125	Sakai-C.	14	-28.5	54.3	3.3	149.8	750 ± 10	11
Suemura TG55	Sakai-C.	23	5.5	55.3	3.0	103.4	750 ± 10	13
Suemura TG70	Sakai-C.	12	0.2	59.6	2.5	288.7	750 ± 10	13
Suemura TG64	Sakai-C.	13	-9.9	64.5	5.6	56.1	750 ± 10	13
Suemura TK20	Sakai-C.	16	-5.8	65.6	3.7	98.5	750 ± 10	5
Suemura TK45	Sakai-C.	19	-9.9	54.1	2.3	223.6	750 ± 10	1
Suemura TK237	Sakai-C.	16	-15.6	57.3	3.9	93.3	750 ± 10	5

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TK238	Sakai-C.	14	-15.5	52.0	4.7	72.0	750 ± 10	11
Shindohaiji V1	Tondabayashi-C.	28	-12.0	50.9	1.9	202.6	750 ± 10	1
Shindohaiji V2	Tondabayashi-C.	23	-13.2	51.2	1.9	269.0	750 ± 10	1
Shindohaiji V3	Tondabayashi-C.	28	-8.5	52.3	2.0	180.2	750 ± 10	1
Inadayama 1	Kagamihara-C.	8	-16.3	49.9	4.7	140.5	750 ± 50	12
Inadayama 2	Kagamihara-C.	11	-13.1	52.4	3.7	151.5	750 ± 50	12
Inadayama 3	Kagamihara-C.	6	-8.0	49.0	4.2	261.6	750 ± 50	12
Inadayama 4	Kagamihara-C.	11	-6.0	57.1	2.1	464.4	750 ± 50	12
Inadayama 6	Kagamihara-C.	12	-15.4	56.6	4.4	99.4	750 ± 50	12
Inadayama 7	Kagamihara-C.	9	-25.4	55.7	4.1	160.8	750 ± 50	12
Inadayama 8	Kagamihara-C.	11	-4.3	52.6	1.7	694.4	750 ± 50	12
Inadayama 10	Kagamihara-C.	9	-10.4	58.1	4.7	120.0	750 ± 50	12
Inadayama 11	Kagamihara-C.	12	-5.9	57.1	2.4	317.6	750 ± 50	12
Inadayama 12	Kagamihara-C.	13	-1.8	57.9	3.0	193.3	750 ± 50	12
Inadayama 13	Kagamihara-C.	10	-8.6	54.5	5.4	81.7	750 ± 50	12
Inadayama 14	Kagamihara-C.	6	-1.5	53.1	6.3	113.5	750 ± 50	12
Inadayama 15	Kagamihara-C.	12	-16.7	58.6	9.1	23.5	750 ± 50	12
Suemura TK53-N	Sakai-C.	19	-10.2	52.8	2.0	275.0	760 ± 10	1
Suemura TK53-O	Sakai-C.	22	-13.0	51.5	1.5	415.0	760 ± 10	1
Suemura Tk57-N	Sakai-C.	10	-10.9	57.0	5.6	75.8	760 ± 10	1
Suemura TK57-O	Sakai-C.	20	-16.2	59.1	2.7	150.2	760 ± 10	1
Hara 5	Tamaki-T.	14	-24.8	63.0	4.6	75.6	760 ± 20	10
Suemura KM22	Izumi-C.	32	-10.3	49.0	3.8	46.0	770 ± 10	1
Suemura KM31	Izumi-C.	30	-22.1	46.5	2.5	113.1	770 ± 10	1
Suemura KM38-II	Izumi-C.	40	-13.4	51.2	1.9	149.9	770 ± 10	1
Suemura KM51	Izumi-C.	29	-6.9	44.4	2.5	116.2	770 ± 10	1
Suemura MT71	Sakai-C.	16	-19.0	60.0	2.9	165.2	770 ± 10	11
Suemura TG15	Sakai-C.	23	-24.2	52.0	2.3	172.6	770 ± 10	1
Suemura TG77	Sakai-C.	13	-7.0	46.1	8.4	25.1	770 ± 10	13
Suemura TG212	Sakai-C.	9	3.2	52.6	3.5	217.1	770 ± 10	11

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Suemura TK36-II	Sakai-C.	8	-5.7	54.5	6.6	72.2	770 ± 10	11
Okayama 1	Yokkaichi-C.	14	-16.7	49.2	5.0	65.2	780 ± 10	1
Suemura TK33-SN	Sakai-C.	5	-8.9	41.9	5.2	156.3	780 ± 10	1
Suemura KM33	Sakai-C.	31	-13.4	48.7	2.2	144.4	780 ± 10	1
Suemura KM13	Sakai-C.	14	-15.8	47.4	3.8	110.4	780 ± 20	10
Chinjuan 3	Kyoto-C.	9	-10.4	48.3	2.2	554.9	785 ± 15	4
Chinjuan 4	Kyoto-C.	23	-13.4	49.5	1.4	496.1	785 ± 15	4
Suemura KM28	Sakai-C.	7	-11.3	47.9	2.7	485.3	790 ± 10	11
Suemura KM38-I	Izumi-C.	35	-28.4	56.7	3.9	39.6	790 ± 10	1
Suemura MT209-I	Sakai-C.	12	-22.9	46.3	4.9	79.8	790 ± 10	5
Kishibe H-1	Suita-C.	16	-14.3	47.9	2.7	182.0	790 ± 10	1
Kishibe N-1	Suita-C.	15	-14.9	47.0	3.0	163.0	790 ± 10	1
Kurozasa 84	Miyoshi-T.	6	-11.3	47.8	9.3	52.9	800 ± 10	10
Totsu 5	Komatsu-C.	14	-13.9	47.5	2.9	194.1	800 ± 15	4
Suemura MT83	Sakai-C.	11	-19.1	52.2	7.6	37.1	810 ± 20	10
Suemura MT5-I-A	Sakai-C.	14	-6.2	46.1	4.0	98.7	825 ± 25	1
Suemura MT5-I-B	Sakai-C.	13	-11.7	47.4	3.7	126.8	825 ± 25	1
Suemura MT5-I-C	Sakai-C.	19	-13.7	48.9	2.8	142.3	825 ± 25	1
Suemura MT200-I	Sakai-C.	15	-12.1	46.0	2.6	223.2	825 ± 25	1
Suemura MT201	Sakai-C.	8	-12.7	57.5	9.7	33.5	825 ± 25	1
Kurozasa 7	Togo-T.	17	-14.4	50.8	2.1	300.0	825 ± 25	4
Kaneiba	Tsudaka-T.	21	-14.0	46.6	2.1	230.7	850 ± 50	1
Kurozasa 40	Miyoshi-T.	9	-20.8	52.4	1.2	1950.0	850 ± 50	15
Orito 9	Nisshin-T.	11	-14.5	42.0	5.1	80.5	910 ± 30	15
Suemura MT93-A	Sakai-C.	14	-19.0	41.9	4.0	101.2	925 ± 10	1
Suemura MT93-B	Sakai-C.	7	-10.5	45.4	2.8	449.2	925 ± 10	1
Suemura TK314	Sakai-C.	20	-13.4	47.9	2.8	137.4	925 ± 25	1
Nakai	Tatsuno-C.	31	-19.8	53.4	2.0	169.5	950 ± 25	1
Ryusenji 4	Tondabayashi-C.	9	-5.2	56.3	3.7	199.3	950 ± 50	12
Kurozasa 5	Miyoshi-T.	6	-25.1	52.1	3.1	463.7	975 ± 25	15

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Kurozasa 14	Miyoshi-T.	9	-17.4	47.5	7.3	50.7	975 ± 25	10
Kuroyatanodo	Seki-C.	11	-3.2	51.4	3.4	176.9	1015 ± 15	12
Kurozasa 90	Miyoshi-T.	12	-18.9	48.3	1.2	1385.1	1025 ± 25	15
Totsu 9	Komatsu-C.	22	-12.2	48.0	2.2	205.0	1050 ± 50	4
Maruishi 1	Toki-C.	8	5.3	51.2	4.1	186.6	1075 ± 25	1
Okayama 4	Yokkaichi-C.	11	-10.9	52.1	4.9	88.3	1085 ± 15	1
Kokeizan 3	Tajimi-C.	16	-6.4	55.9	1.8	440.3	1085 ± 15	4
Orito 53	Nisshin-T.	10	-4.3	51.2	5.2	87.3	1100 ± 20	10
Maruishi 2	Toki-C.	14	-0.2	52.4	2.9	178.6	1100 ± 30	1
Yabasama 1	Kani-T.	15	-6.3	51.9	1.8	456.4	1100 ± 30	12
Maruishi 4	Toki-C.	7	-1.1	41.3	2.3	674.2	1115 ± 15	1
Kakishita	Kani-T.	15	4.5	55.2	1.3	938.0	1150 ± 30	12
Shibayama	Tokoname-C.	15	-0.2	60.5	2.2	304.9	1150 ± 50	3
Shibayama 2	Tokoname-C.	47	-1.6	61.7	2.4	220.1	1150 ± 50	3
Higashiyama 101	Nagoya-C.	12	-3.0	55.9	3.9	123.6	1160 ± 20	4
Kamichosa 4	Miyazaki-V.	20	-2.6	58.7	1.6	403.4	1175 ± 25	4
Fukuzumi 61	Agui-T.	17	-1.9	53.1	2.2	260.3	1175 ± 25	6
Kamichosa 3	Miyazaki-V.	28	3.5	59.2	1.5	354.3	1175 ± 25	4
Mozuhachiman W	Sakai-C.	19	-5.7	61.9	2.9	134.3	1200 ± 50	1
Inadayama 5	Kagamihara-C.	5	4.4	52.7	3.4	501.8	1200 ± 50	12
Inadayama 9	Kagamihara-C.	10	-4.0	61.5	2.4	394.9	1200 ± 50	12
Inadayama 16	Kagamihara-C.	10	1.3	60.8	4.0	150.1	1200 ± 50	12
Aigafuchi N	Bizen-T.	17	2.5	54.2	4.1	74.1	1220 ± 50	1
Sanzobata	Sanyo-T.	18	-1.3	59.4	3.0	137.8	1220 ± 50	8
Kamichosa 5	Miyazaki-V.	14	3.4	61.2	1.9	421.2	1225 ± 25	4
Kamichosa 6	Miyazaki-V.	19	6.9	59.8	1.6	468.8	1225 ± 25	4
Fukuzumi 54	Agui-T.	14	7.3	53.6	2.1	350.8	1225 ± 25	6
Kagoike 3	Tokoname-C.	16	6.2	54.0	2.0	337.8	1230 ± 30	4
Kagoike 9	Tokoname-C.	15	5.9	59.1	2.0	377.2	1250 ± 20	4
Odó E-1	Toki-C.	5	-2.3	53.7	13.5	33.3	1250 ± 50	12

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Tatsumigaoka 2	Toki-C.	8	2.6	59.0	2.7	454.6	1250 ± 50	16
Kamioshidani E	Ota-T.	9	20.0	51.6	9.5	30.5	1260 ± 20	1
Okudonodan 1	Miyazaki-V.	15	5.4	55.8	1.8	449.9	1275 ± 25	4
Fuso 3	Seto-C.	7	12.4	63.1	8.1	56.5	1280 ± 50	10
Ryusenji 2	Tondabayashi-C.	7	3.9	57.2	2.9	423.5	1285 ± 15	12
Maruishi 3-L	Toki-C.	11	16.0	61.2	4.3	112.0	1290 ± 30	1
Aigafuchi S1	Bizen-T.	16	2.7	51.3	2.4	226.6	1300 ± 30	1
Maruishi 3-U	Toki-C.	11	23.4	45.8	5.2	79.6	1300 ± 30	1
Daitennodani 1	Komatsu-C.	14	14.1	64.1	1.6	593.2	1300 ± 30	4
Daitennodani 2	Komatsu-C.	19	15.8	64.6	1.4	587.7	1300 ± 30	4
Ootakayama	Handa-C.	16	11.5	61.8	2.7	193.5	1315 ± 15	4
Kayakari	Seto-C.	18	-7.0	61.9	1.9	347.5	1315 ± 15	4
Fuso 1	Seto-C.	7	12.8	54.0	4.1	217.0	1325 ± 25	10
Furoyama W1	Bizen-T.	27	13.0	52.7	1.6	301.6	1330 ± 30	1
Meiwa 1	Tafimi-C.	16	9.0	55.9	2.0	351.0	1340 ± 15	4
Magoemon 1	Yokkaichi-C.	9	-8.3	52.0	10.4	24.9	1350 ± 10	1
Anayama	Yokkaichi-C.	10	15.0	52.0	3.9	153.1	1350 ± 10	1
Magoemon 2	Yokkaichi-C.	14	-1.5	55.3	7.2	31.3	1350 ± 15	1
Takasaka 1	Tokoname-C.	9	-0.3	55.7	0.8	3198.4	1350 ± 15	15
Matsuo 1	Shigaraki-T.	6	9.0	38.1	4.2	260.6	1350 ± 50	1
Matsuo 2	Shigaraki-T.	14	4.0	39.7	5.2	58.0	1350 ± 50	1
Mozuhachiman E	Sakai-C.	8	7.7	57.4	4.2	175.9	1350 ± 50	1
Hojuji 3	Suzu-C.	40	6.9	58.5	2.0	132.3	1350 ± 50	2
Fukuzumi 23	Agui-T.	17	-0.4	58.6	1.7	457.9	1375 ± 25	6
Ogai	Isobe-T.	20	1.0	41.3	4.8	47.1	1380 ± 50	1
Furoyama E	Bizen-T.	27	2.9	40.6	2.7	104.9	1450 ± 50	1
Myodo	Kasahara-T.	19	6.6	43.6	1.4	605.9	1525 ± 25	4
Toshiro	Toki-C.	17	6.6	44.2	1.9	340.1	1530 ± 20	4
Jorinji 3	Toki-C.	12	13.3	35.3	6.6	45.2	1550 ± 15	1
Furoyama W2	Bizen-T.	32	8.1	36.0	1.6	239.4	1550 ± 30	1

Table 3 (continued)

Site	Locality	N	D(°)	I(°)	Reduced D(°)	Reduced I(°)	α_{95}(°)	k	Archaeological Age	Ref.
Mukashida	Kasahara-T.	19	4.6	46.7			1.5	520.5	1550 ± 50	4
Nakaide 1	Shigaraki-T.	9	12.9	33.1			6.5	63.8	1570 ± 30	1
Inkyoyama E	Toki-C.	16	6.5	42.5			1.6	513.8	1580 ± 20	4
Nakaide 2	Shigaraki-T.	21	12.3	35.4	1.2	35.1	3.5	81.4	1600 ± 30	1
Motoyashiki	Toki-C.	7	9.1	39.5	8.7	38.5	3.7	269.1	1600 ± 30	1
Jorinji 1	Toki-C.	21	4.9	42.7	4.3	41.7	2.8	123.4	1630 ± 30	1
Jorinji 4	Toki-C.	7	2.3	38.9	1.7	37.9	2.8	471.0	1630 ± 30	1
Tenjinmori 2	Arita-T.	17	-0.6	40.2	1.3	43.1	2.1	285.3	1650 ± 50	4
Tenjinmori 8	Arita-T.	16	-4.3	41.9	-2.4	44.8	2.3	260.2	1650 ± 50	4
Kamagane 2	Toki-C.	6	2.4	41.6	1.8	40.7	2.4	781.3	1660 ± 40	1
Jorinji 2	Toki-C.	16	5.0	36.3	5.4	35.3	2.6	210.7	1660 ± 40	1
Jurokusen	Seki-C.	7	6.5	39.5	6.1	38.5	3.6	288.7	1675 ± 25	12
Kokutani 1	Yamanaka-T.	19	8.0	49.3	7.7	47.3	3.0	122.7	1675 ± 25	2
Kokutani 2	Yamanaka-T.	10	5.6	42.9	5.2	41.0	4.0	149.3	1700 ± 15	2
Himedani 2	Kamo-T.	13	-0.9	39.4	-0.4	39.9	3.1	178.6	1700 ± 20	4
Kamagane 1	Toki-C.	7	1.9	33.3	1.4	32.6	4.7	163.0	1760 ± 50	1
Kakiemon A	Arita-T.	11	0.6	40.9	1.6	42.7	4.0	131.4	1775 ± 25	12
Kokutani Y	Yamanaka-T.	11	-1.6	47.3	-1.6	45.6	2.3	384.9	1825 ± 2	2
Wakasugi 1	Komatsu-C.	20	4.3	48.1	4.3	46.2	2.7	143.2	1825 ± 10	2
Sandaseiji 3	Sanda-C.	19	-3.3	44.5	-3.3	44.4	2.8	142.8	1825 ± 25	12

Table 3 (continued)

Figures of the column Ref. are as follows:

1. Hirooka, 1971
2. Hirooka, 1973
3. Hirooka, 1977
4. Hirooka, 1979
5. Hirooka et al., 1970
6. Hirooka and Fujisawa, 1978
7. Hirooka and Yamamoto, 1975
8. Hirooka and Yamamoto, 1976a
9. Hirooka and Yamamoto, 1976b
10. Kawai et al. 1965
11. Nakajima et al. 1979
12. Shibuya and Nakajima, 1979
13. Shibuya et al., 1979
14. Torii et al., 1976
15. Watanabe, 1959
16. Watanabe, 1960

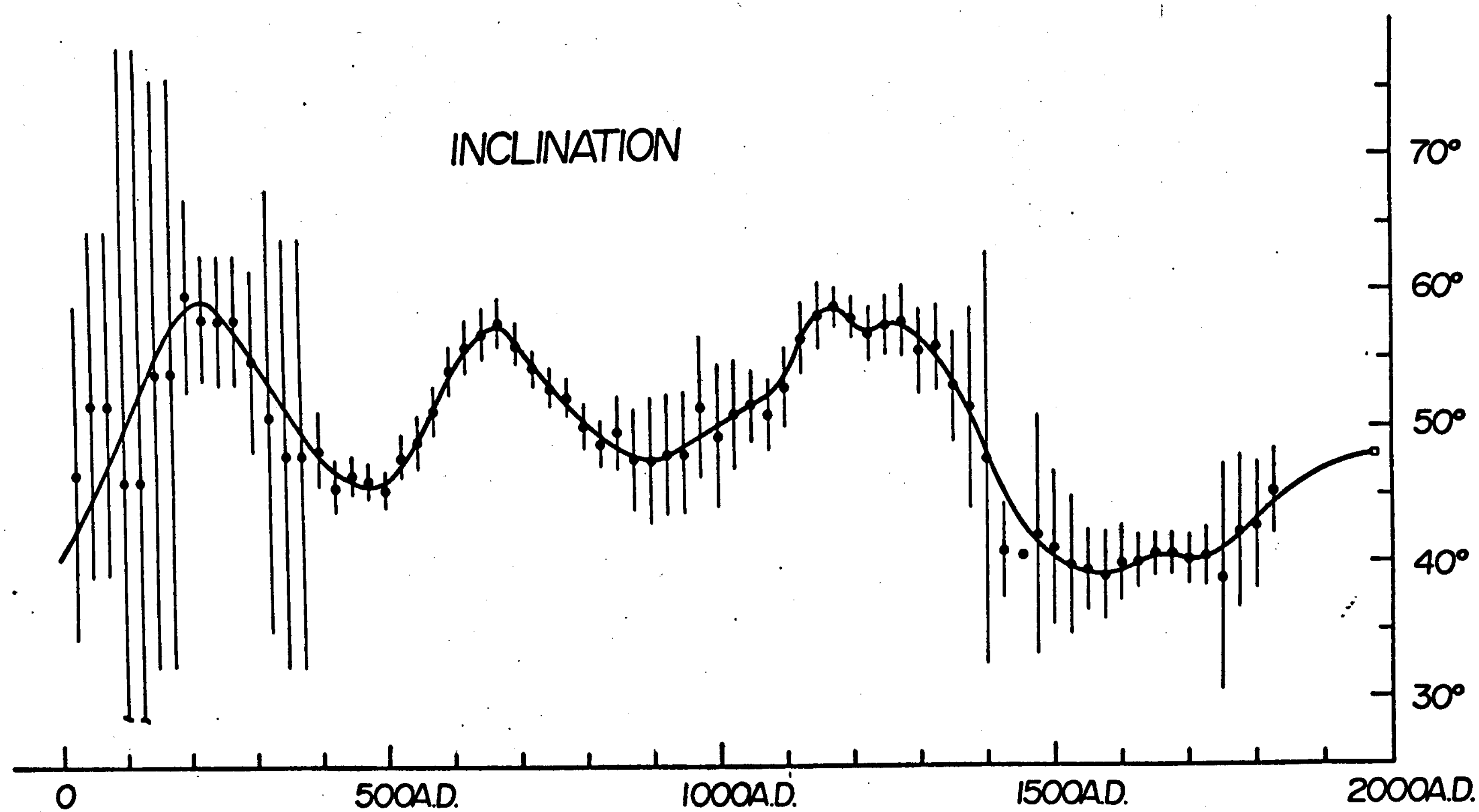


Fig. 4a Result of chronological average (inclination).

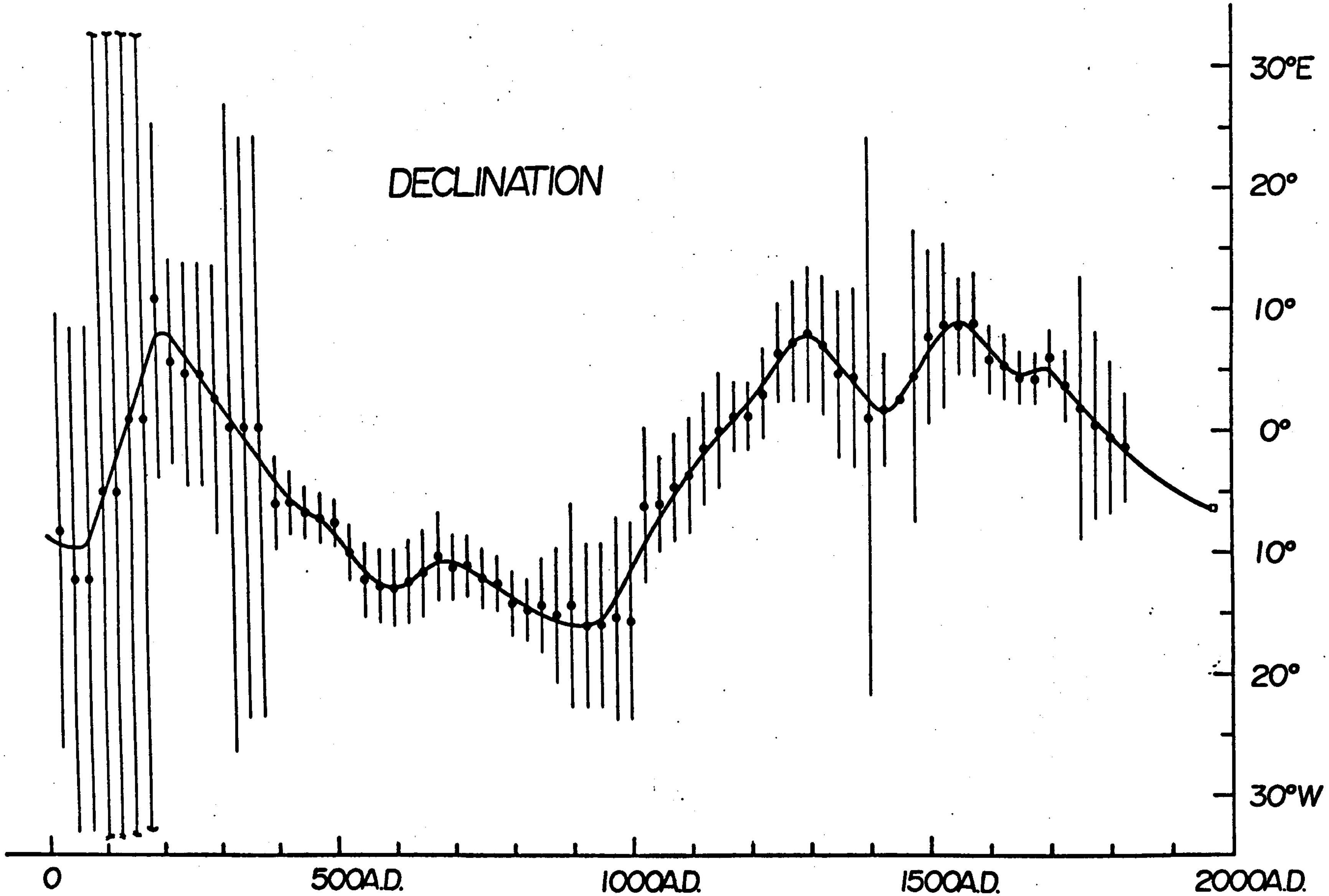


Fig. 4b Result of chronological average (declination).

Median Age	Number of Sites	Dec.(°)	Inc.(°)	α_{95}(°)	k
25	5	-7.4	47.2	12.5	38.5
50	3	-11.6	52.4	13.0	90.4
75	3	-11.6	52.4	13.0	90.4
100	3	-2.2	46.6	32.7	15.2
125	3	-2.2	46.6	32.7	15.2
150	4	1.9	54.7	22.2	18.0
175	4	1.9	54.7	22.2	18.0
200	6	12.0	60.5	7.3	84.6
225	14	6.7	59.1	4.4	82.7
250	13	5.6	58.6	4.9	73.3
275	13	5.6	58.6	4.9	73.3
300	11	3.5	55.5	6.4	51.9
325	4	1.1	51.3	17.1	29.8
350	4	1.1	48.5	16.1	33.4
375	4	1.1	48.5	16.1	33.4
400	21	-5.3	48.8	2.7	143.3
425	44	-5.3	46.1	1.9	132.5
450	70	-6.1	46.9	1.5	132.3
475	77	-6.6	46.5	1.4	128.0
500	70	-7.0	45.8	1.4	145.2
525	62	-9.5	48.2	1.6	132.8
550	48	-11.8	49.4	2.0	105.2
575	61	-12.3	51.7	1.9	90.1
600	67	-12.5	54.7	1.9	86.5
625	65	-12.0	56.4	2.0	82.1
650	56	-11.3	57.3	2.0	90.4
675	44	-9.9	58.2	1.9	125.4
700	55	-10.8	56.5	1.5	170.8
725	55	-10.7	54.8	1.5	170.2
750	64	-11.7	53.3	1.4	153.2
775	64	-12.2	52.7	1.4	159.4
800	39	-13.8	50.6	1.7	184.0
825	25	-14.4	49.2	1.7	295.4
850	12	-14.0	50.1	2.6	289.0
875	8	-14.8	48.0	3.8	208.8
900	6	-14.0	47.9	5.7	137.7
925	8	-15.7	48.4	4.5	153.4
950	8	-15.7	48.4	4.5	153.4
975	6	-15.1	51.8	5.2	167.5
1000	5	-15.4	49.7	5.3	206.9

Table 4

Median Age	Number of Sites	Dec. (°)	Inc. (°)	α_{95} (°)	k
1025	8	-5.8	51.3	4.0	193.4
1050	13	-5.7	51.9	2.5	281.4
1075	12	-4.3	51.2	2.8	240.1
1100	14	-2.7	53.2	2.9	192.3
1125	19	-1.1	56.8	2.6	170.6
1150	18	0.4	58.5	2.5	193.0
1175	23	1.5	59.1	1.5	403.3
1200	26	1.6	58.3	1.5	379.8
1225	18	3.4	57.1	2.0	295.4
1250	21	6.8	57.7	2.2	212.0
1275	18	7.7	58.0	2.6	171.6
1300	22	8.3	55.8	3.1	98.8
1325	21	7.4	56.1	3.2	97.2
1350	15	5.0	53.2	4.1	87.2
1375	12	4.7	51.6	4.6	90.2
1400	3	1.4	46.8	15.7	62.6
1425	2	2.0	41.0	3.5	5146.4
1450	1	2.9	40.6	---	-----
1475	2	4.7	42.1	8.9	794.4
1500	5	8.0	41.2	5.4	198.8
1525	6	8.9	39.9	5.2	164.8
1550	10	8.8	39.5	3.1	244.2
1575	9	9.0	39.1	3.3	237.9
1600	11	6.0	40.0	2.8	260.1
1625	16	5.5	40.1	2.0	334.6
1650	19	4.5	40.7	1.6	459.0
1675	20	4.4	40.7	1.5	481.3
1700	14	5.1	40.3	1.8	483.3
1725	10	3.8	40.5	2.2	497.0
1750	3	2.0	38.9	8.4	214.4
1775	5	0.5	42.3	5.7	183.7
1800	6	-0.3	42.8	4.7	207.6
1825	4	-1.3	45.3	3.2	829.0

Table 4 (continued)

Causes of errors

1. Measurements

As one of ways to estimate the error caused by measurement, the reproducibility of the measurements can be useful and this is represented by statistical parameters using Fisher's cone angle of confidence of 95 %, α_{95}, or his precision constant, k, which is given by the repeated measurements of the same sample. Five repeated measurements of a sample were carried out for this purpose. The value α_{95} and k are given 0.9° and 7286.5, respectively, by this experiment.

2. Sampling

As the values of α_{95} are given about 1.5° on good data, the contribution of this error is less than 1.5°.

3. Displacement of sample relative to others after acquiring thermo-remanent magnetization (TRM)

The contribution of this error is within the value of α_{95} of each site. The histogram of the angles is represented in Fig. 5.

4. Stability of natural remanent magnetization (NRM)

The stability of NRM of samples was tested by the progressive alternating field demagnetization in the

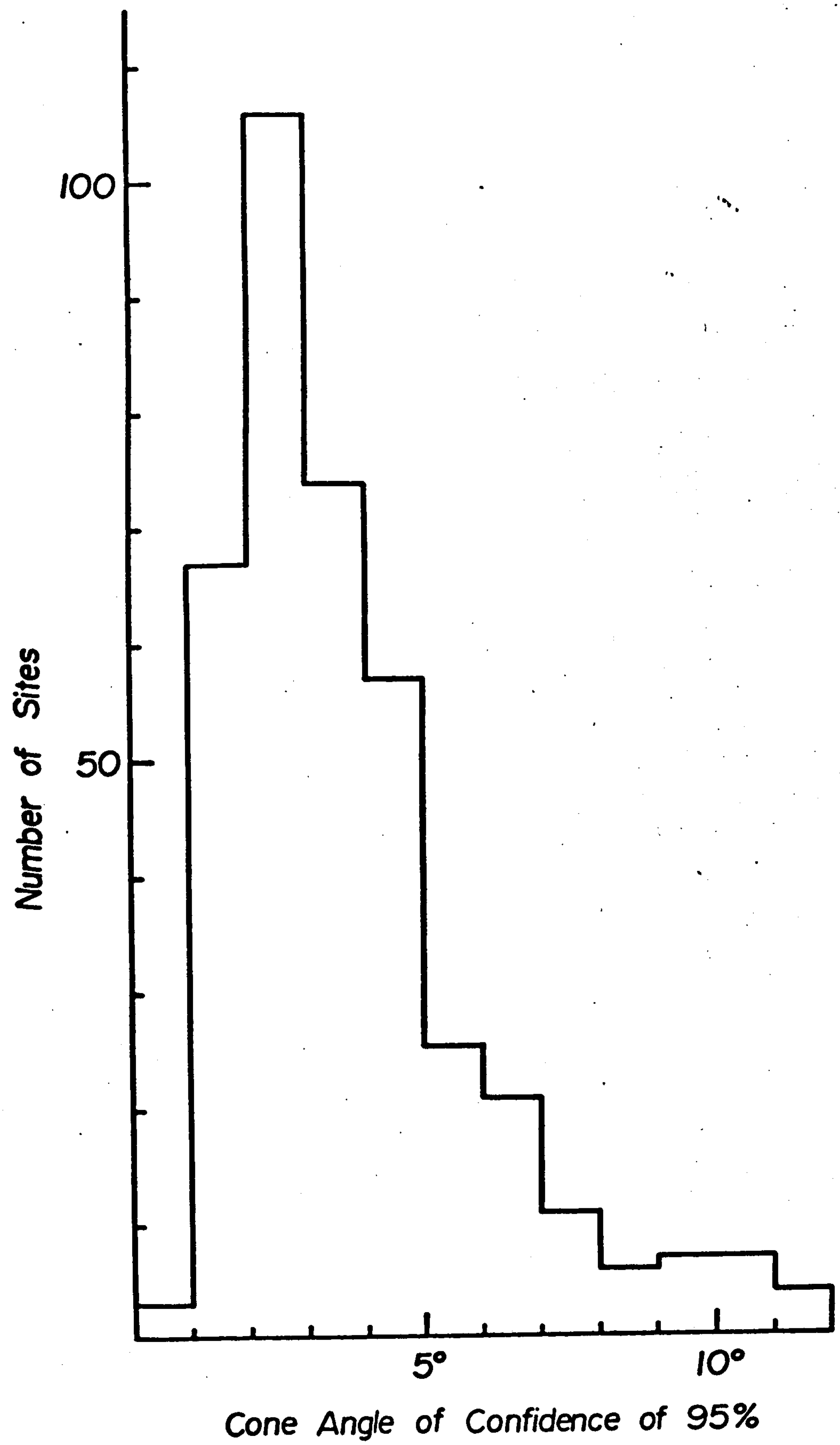


Fig. 5 Histogram of Fisher's cone angle of confidence (α_{95}).

field of 100, 200, 300, 400, 600, 800 and 1,000 Oe. Figure 6 shows an example of intensity decay of samples by demagnetization. From the results, the direction of remanent magnetization shows no obvious change in the field up to 1,000 Oe as shown in Fig. 7. The present author, therefore, assumed that the NRM of samples was stable enough for the study and the mean values of NRM direction were reliable for the archaeomagnetic data in this paper.

5. Distortion of the magnetic line of force inside kilns on cooling

Distortion of the magnetic line of force is caused by two reasons. One is due to magnetization of a portion which is already cooled. The other is due to demagnetization field. To estimate the contribution of the former, a kiln was approximated to a magnetized plate with the size of 10 cm × 100 cm × 500 cm. Even if the magnetization is 10^{-2} times as strong as the magnetic field, the distortion is less than 0.5° at the centre of the plate. On the other hand, the contribution of the demagnetization field is larger than this. Supposing that cooling takes place on a thin layer, the demagnetization field amounts to $-4\pi M_p$, where M_p is the component of the magnetization perpendicular to the kiln floor. Dependence of direction of the magnetization on direction of centreline and dip angle of a kiln is calculated (Fig. 8), when the kiln

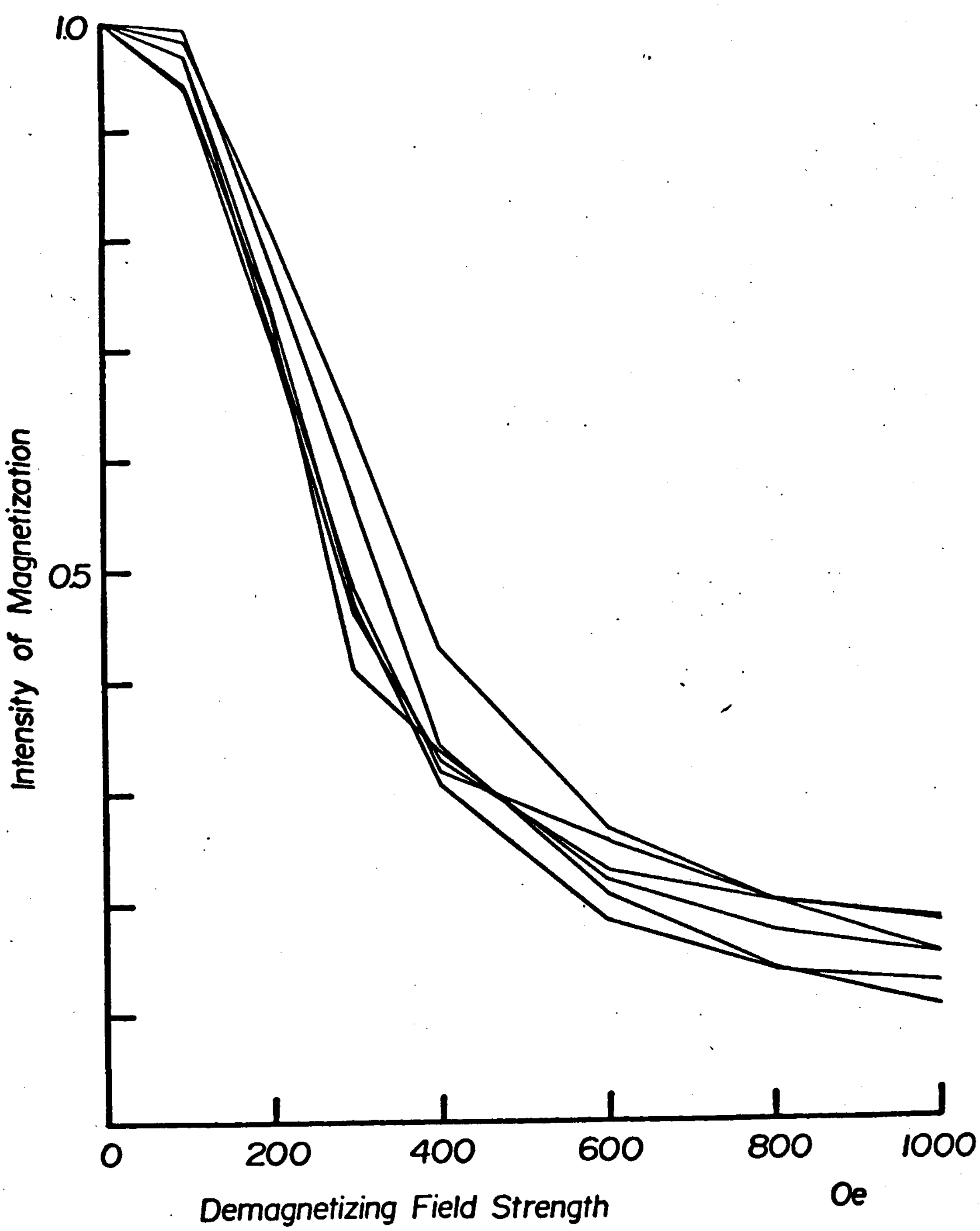


Fig. 6 An example of alternating field demagnetization curves of samples (Kiln Hakusan 3).

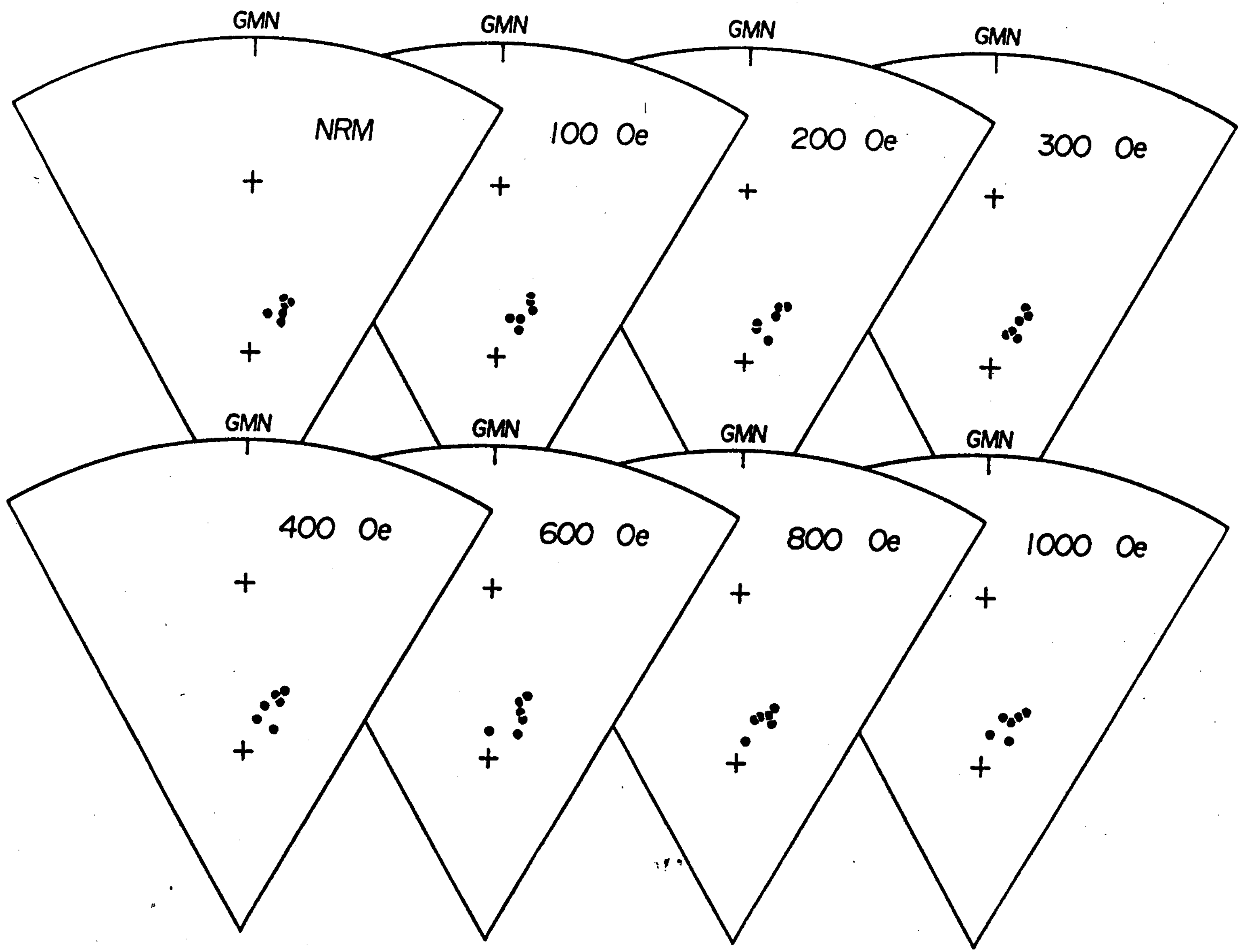


Fig. 7 An example of direction changes of samples of a kiln by alternating field demagnetization (Kiln Hakusan 3).

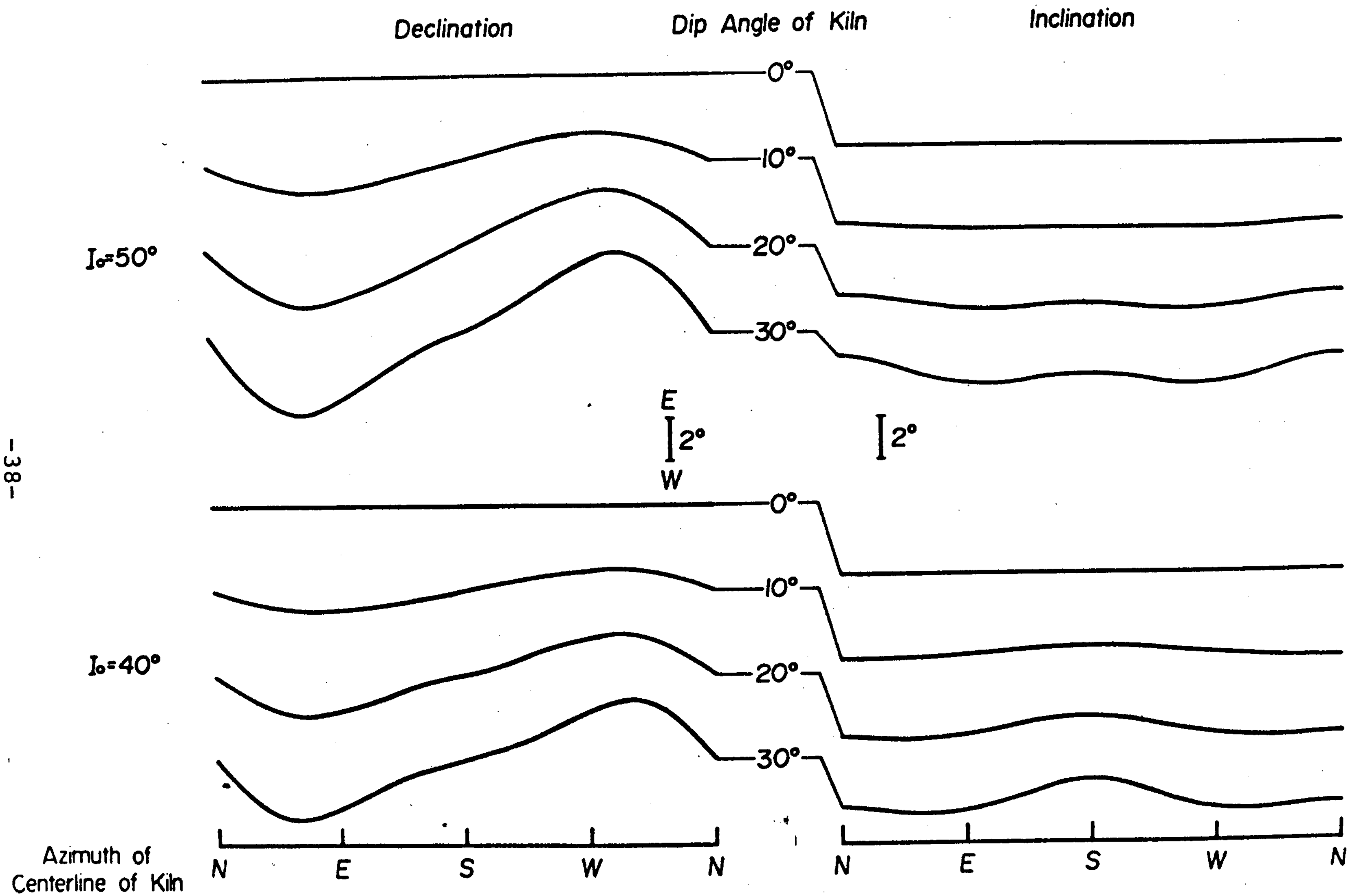


Fig. 8 Distortion of magnetic field of a kiln by demagnetization field, when the kiln is approximated to a magnetized plate and the magnetization is 1/100 times as strong as magnetic field. I_0 is the inclination of the ambient geomagnetic field.

floor is smooth and the magnetization is 10^{-2} times as strong as the magnetic field.

The characteristic of this result is that inclination of the magnetization is less than that of ambient magnetic field without reference to direction of the centreline of kiln. This result is consistent with the report of Nakajima et al. (1974), who mentioned that inclination of the magnetization of the reconstructed ancient kiln was 3°22' smaller than that of ambient geomagnetic field.

6. Displacement of kiln after acquiring TRM

A kiln might be moved by local crustal deformation or a landslide. But a movement as small as several degrees could not be detected by other means and the error caused by this movement was not verified.

7. Local anomaly of magnetic line of force

The direction of the magnetic line of force has been affected by local anomaly and its change. The variation of the direction at the collecting sites in this work, however, has been known as within a few degrees, as the samples were obtained mainly from Kinki District and the areas around it. The kilns whose ages are after 1600 A.D. are dispersed from Kyusyu District to Tokai District. Spherical harmonic analyses of the geomagnetic field after 1600 A.D. were fortunately carried out by Barraclough

(1974) with the use of instrumental measurements. Using the result of the analyses, the present data on the inclination and declination at each site were reduced to those of Osaka.

8. Archaeological dating

There exists some uncertainties in the archaeological dating from chronology. In Japanese remains, however, archaeological chronology is more reliable dating tool than other methods.

The errors except the items 3 and 6 are too small to explain the dispersion of magnetizations. As there are data which are dispersed from the average direction in spite of its small α_{95} , the item 6 forms large portion of the error. But the items 3 and 6 produce random errors. If enough data are collected, the average can be considered to represent the direction of the magnetic line of force.

The error 5 makes all inclination of magnetizaion small. However, the distortion depends on fine structure of the kiln and on the temperature distribution of the kiln. No correction is made in this paper. The actual secular variation of inclination would be in a range of a few degrees steeper than this result, even if a proper correction is made.

Discussion

In Figs. 9a and b, the result of this archaeomagnetic approach is compared with those of other approaches and instrumental measurements. It shows good coincidences except for the declination of approach (3) mentioned in Introduction. It would be attributed to a difficulty of orientation or tilting of the core sample. Generally, this result can be said to represent the secular variation in Japan.

Secular variations of the Southwest Japan (this work), China (Smith and Needham, 1967; Phang and Lee, 1965), Caucasus, Ukraine (Burlatskaya and Braginsky, 1978), Sicily (Tanguy, 1970), Britain (Aitken et al., 1963), Iceland (Brinjolfsson, 1957) and Southwest of United States (DuBois, 1975) are shown from east to west approximately in portion to longitude of the localities (Figs. 10a and b). It can be noted in Fig. 10a that the minima and maxima of inclination have drifted westwards. This trend is traced back to about 200 A.D. But it is difficult to find a similar trend in declination (Fig. 10b). It would be caused by the fact that the maxima or minima of declination do not occur at the centre of a geomagnetic anomaly but the situation is different in inclination.

When the secular variation obtained by this work is compared with that calculated by Braginsky (Braginsky, 1974, see Figs. 9a and b), they show a good coinsidence in inclination after 900 A.D. In declination, they have a same trend after 1400 A.D. As a whole, they are consistent with each other after 1400 A.D.

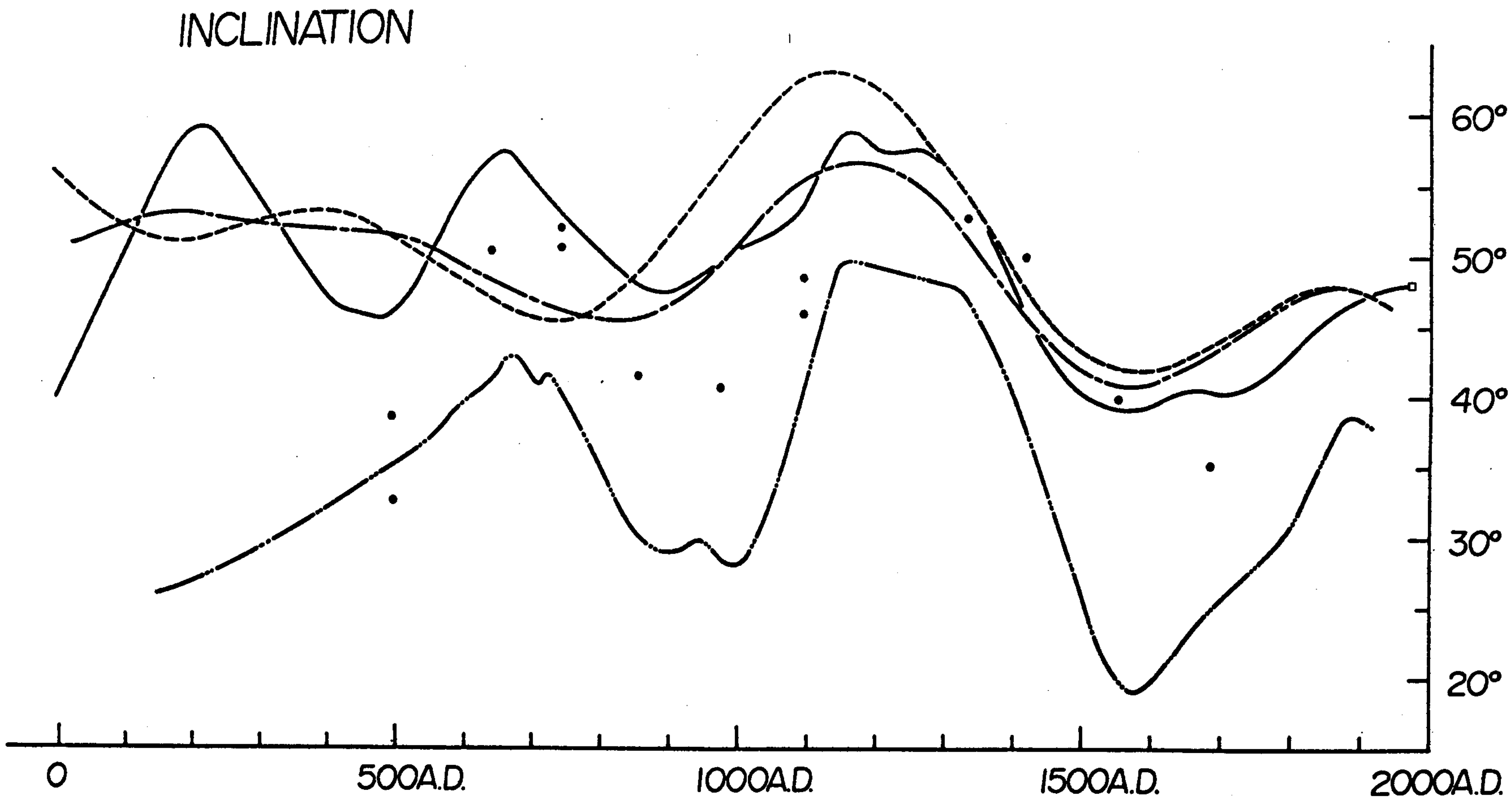


Fig. 9a Comparison of the present result of inclination with other approaches and analytical descriptions.

- This work.
- The results obtained from lava flows and ash-fall tuffs of historical eruptions of Ooshima volcanic area (Yukutake et al., 1964)
- The results obtained from sediments on the bottom of the Lake Biwa (Nakajima and Kawai 1973).
- Calculated value obtained by model 1 of the Braginsky's analyses (Braginsky 1974).
- Calculated value obtained by model 2 of the Braginsky's analyses (Braginsky 1974).

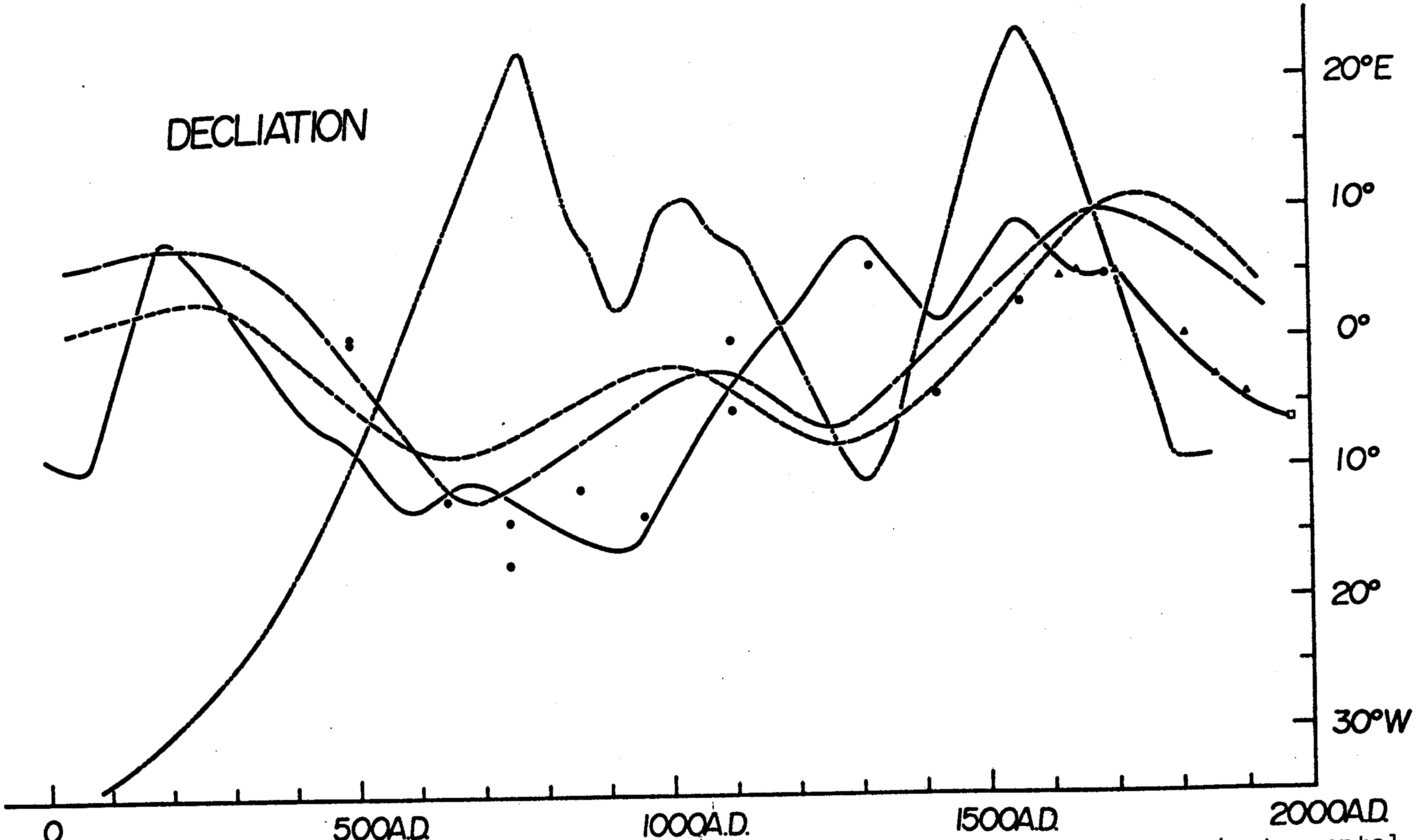


Fig. 9b Comparison of the present result of declination with other approaches, instrumental measurements and analytical descriptions.

—— This work

● The results obtained from lava flows and ash-fall tuffs of historical eruptions of Ooshima volcanic area (Yukutake et al., 1964)

▲ The results of instrumental measurements (Imamiti, 1956) reduced to Osaka by the means described in the text

—·—·— The results obtained from sediments on the bottom of the Lake Biwa (Nakajima and Kawai, 1973)

- - - - - Calculated value obtained by model 1 of the Braginsky's analyses (Braginsky, 1974)

—·— Calculated value obtained by model 2 of the Braginsky's analyses (Braginsky, 1974)

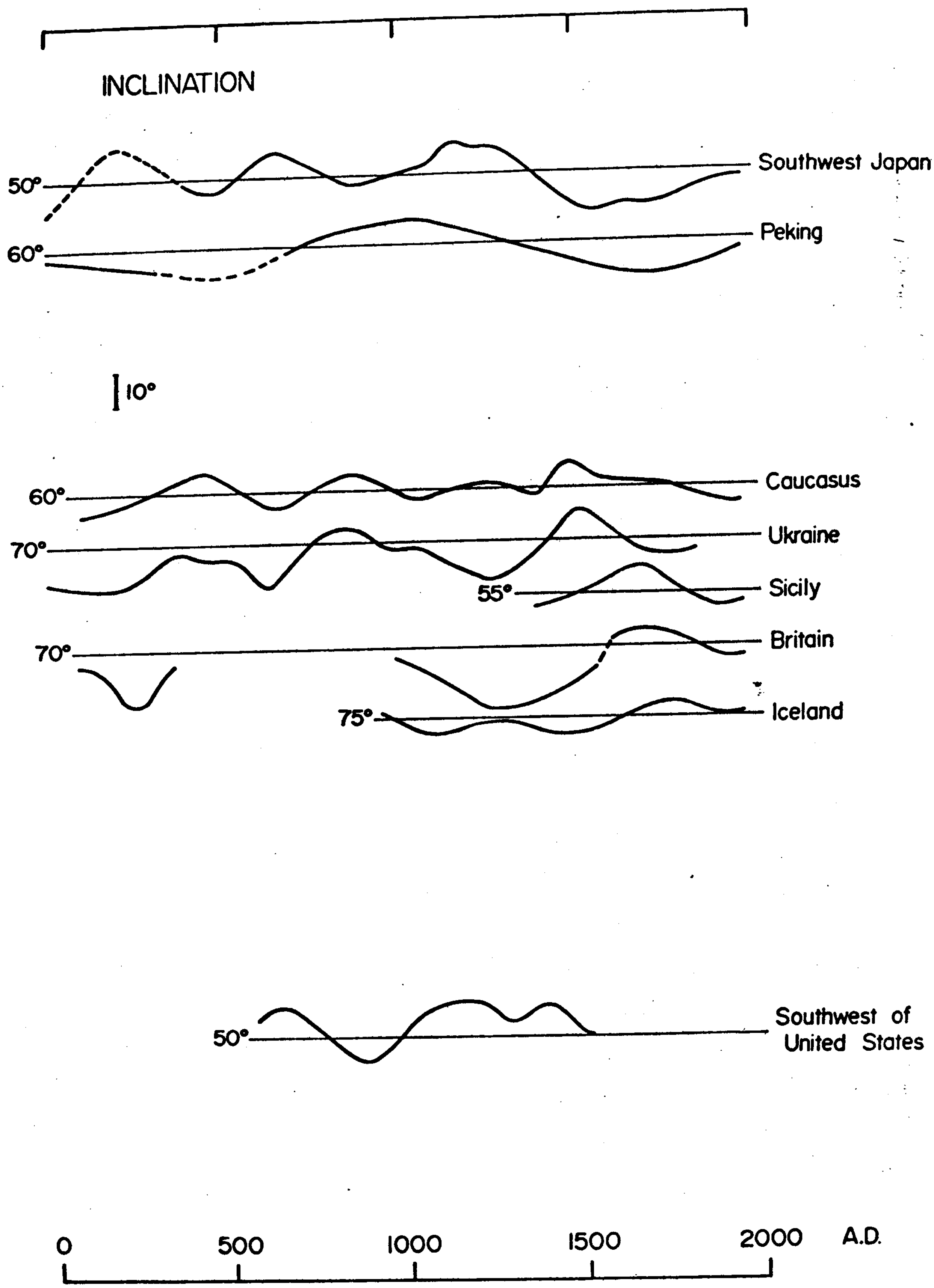


Fig. 10a Secular variation of the geomagnetic inclination at various localities. Mean values of inclination are shown on the left of the base lines, which are drawn so as to give logitudinal distance from east to west.

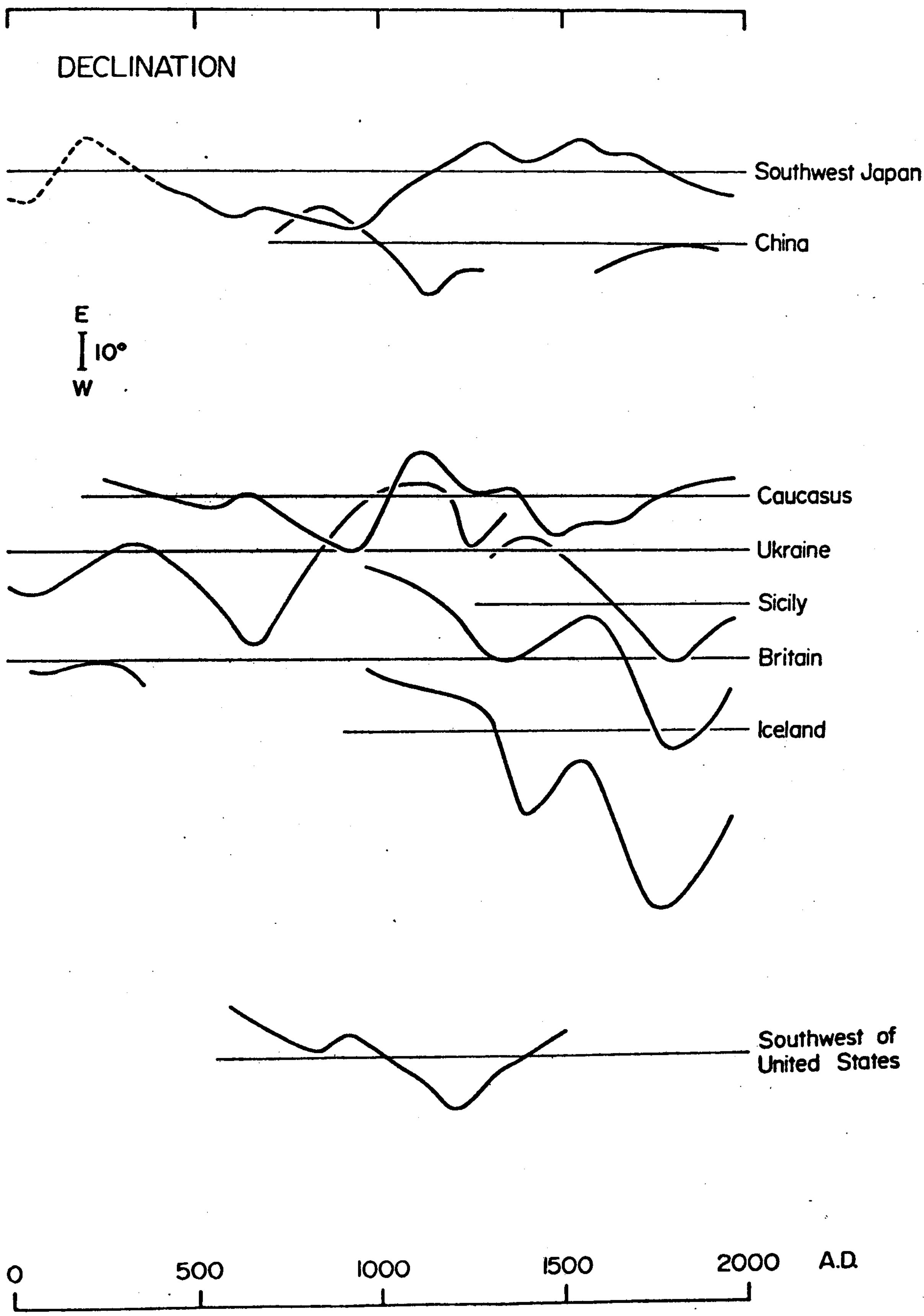


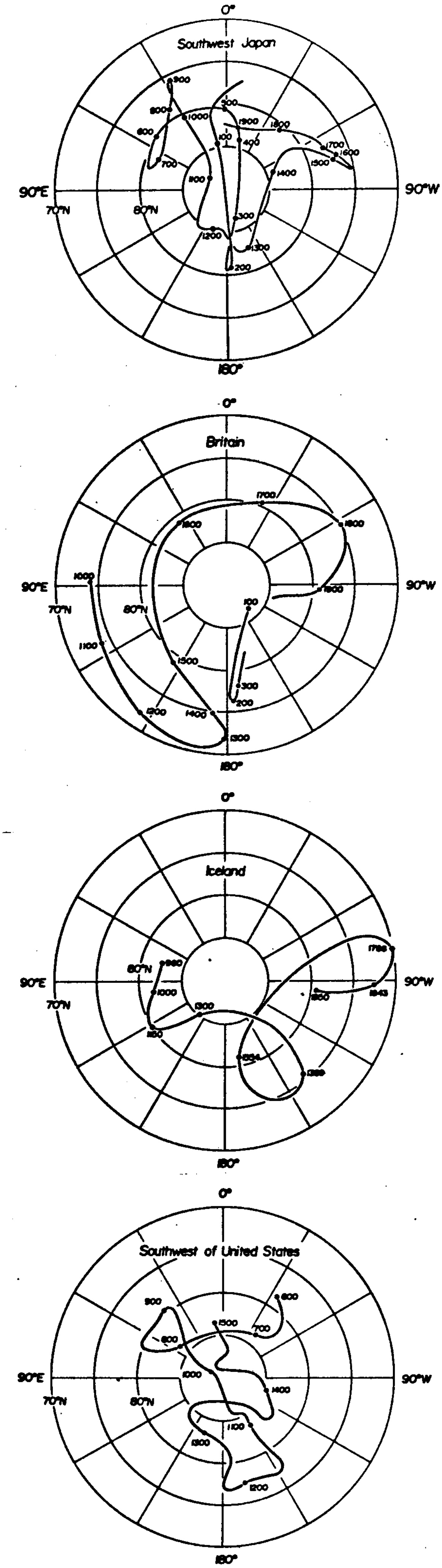
Fig. 10b Secular variation of the geomagnetic declination at various localities. The zero lines of declination are drawn so as to give relative longitudial distance from east to west.

Braginsky attempts to explain the secular variation by models 1 and 2. The model 1 assumes that the geomagnetic field consists of a system of dipole and quadrupole and rotate with a constant angular velocity. The model 2 assumes that the geomagnetic field consists of rotating and steady system of dipole and quadrupole. The angular velocity is common and unchanged throughout the historical age. The weight of the instrumental measurements is 50 times large as much as that of the archaeomagnetic measurements. Then he could show only a clockwise movement of the geomagnetic dipole after 1300 A.D. within the clockwise and anticlockwise movements shown by Lin et al. (1979). And before the age calculated and observed secular variations were apart from each other.

Trajectories of virtual geomagnetic pole (see Fig. 11) bends at around 1300 A.D. on most of the locations of the world. This seems to support the report of Lin et al.. (1979)

As the dipole is considered to have moved in a complicated way, it would not be appropriate to describe the dipole by constant angular velocities throughout the historical age. But the nondipole seems to have a different nature, as the westward drift can be traced back to about 200 A.D. This difference would be caused by the difference between the origin of generating the dipole and that of the nondipole. More accumulation of data is desired to develop this kind of investigation.

From the viewpoint of archaeomagnetic dating, there are large α_{95}'s in the 14th and 10th centuries and also years before 4th century. This is mainly caused by small number of sites. In future, samples from the sites in that ages have to be intensively measured.



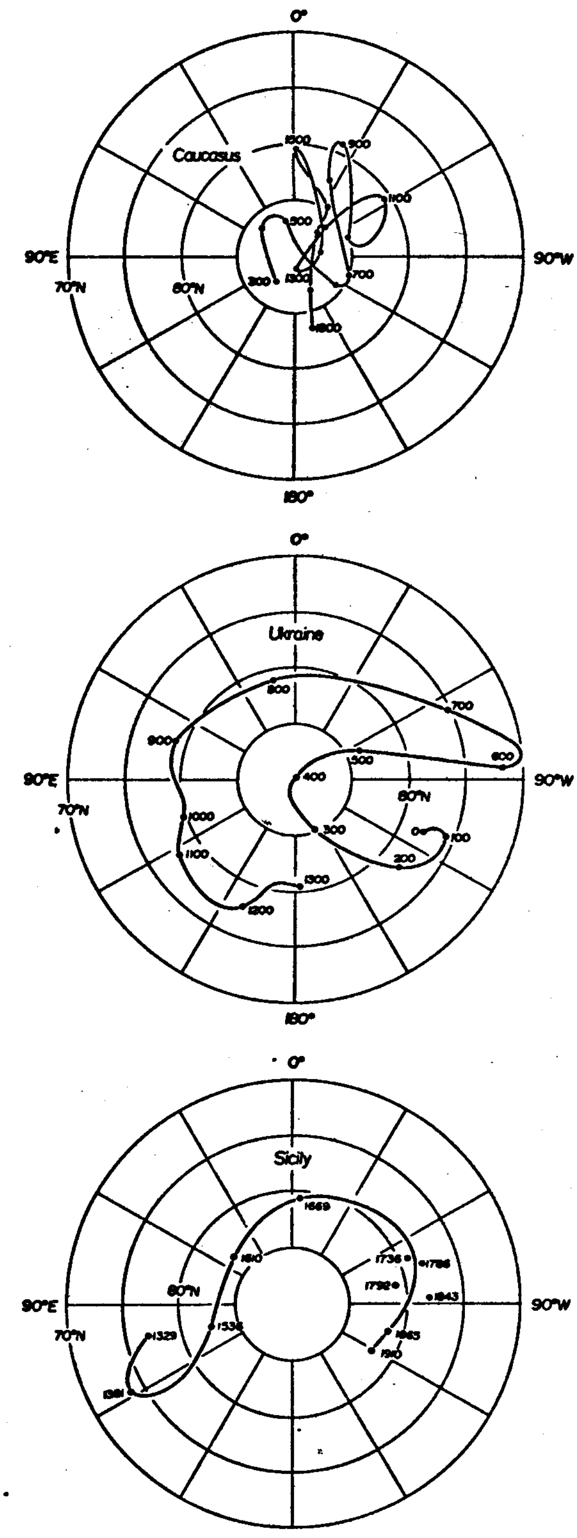


Fig. 11 The trajectory of the virtual pole position of various localities.

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