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Morphological Transition of the Japanese Cranium: An Analysis of the Cross-sectional Outlines*

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Abstract Despite the fact that the origin or formation of the Japanese people has long been discussed, we still have yet to reach a consensus about it. Due to this situation, we focused our attention on the studies of detailed and precise morphological informations concerning the Japanese crania. Using the midsagittal and horizontal outlines of the cranium, the morphological transition of the mainland Japanese crania from the Paleolithic age to recent times was analyzed, along with an analysis of the relations of the populations in mainland Japan to the adjacent populations, such as the Nansei Islanders (Okinawan), Ainu, Korean, and Northeastern Chinese.

Among the changes in cranial shape, the occipital represented the largest intragroup variation, with marked changes in shape from the late/final Jomon (Neolithic) period to Kamakura (Medieval) period. The lateral profile of the forehead showed a directional change, whereas the facial profile and horizontal outline of the calvaria showed a two-phased change. In the latter case, the phase change occurred at the Kamakura period, and the people in this period showed the extreme. Great morphological changes occurred between the late/final Jomon period and Yayoi (Aeneolithic) period, and between the Edo (Shogunate age) period and recent times. Geographical variations corresponding to the process of the morphological changes were considerably great, especially in the change occurring between the Edo period and recent times. The recent Kyoto group showed a drastic change from the Edo people, whereas the Niigata group underwent almost no change. The regional differences in the recent and late/final Jomon peoples were great when compared with the temporal changes from the late/final Jomon period to recent times. The genetic influence of the adjacent populations on the changes in the Japanese cranium could not be positively supported from the standpoint of craniometry. These results call previous hypotheses on the origin and formation of the Japanese into question.

INTRODUCTION

The origin or formation of the Japanese continues to fascinate many Japanese anthropologists, and a great deal of study on this subject has been carried out. Suzuki (1981), Ikeda (1986), Mizoguchi (1986), and others performed specific reveiws on the previous studies. In 1981, Suzuki classified previously proposed hypotheses on this problem into three categories, i.e. the substitution, hybridization, and transformation theories. The transformation and hybridization or substitution hypotheses have developed in opposition to each other for a long time. This opposition has prompted the

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development of a hypothesis based on geographical variations in the morphological changes of the Japanese. Ikeda (1981, 1986) critically synthesized the hypotheses by taking into consideration geographical and social inequality in the change of the physical characteristics. He then proposed a hypothesis based on population genetics.

The discussuon on the problem of Japanese lineage has been mainly involved morphological data, in particular craniometrical data. However, previous morphometrical data has almost exclusively been comprised of interlandmark distances and/or angles. This tendency has not changed, and in fact, it has become more widespread due to anthropologist's familiarity with multivariate analysis. Not infrequently, published data has been uncritically quoted to the multivariate analyses. Kouchi and Koizumi (1985) analyzed the interobserver errors in cranial measurements and warned of the considerable effects which the errors would have on results, when closely similar populations are analyzed. Moreover, since interlandmark distances and angles selected *a priori* result in the loss of a considerable amount of information (Jacobshagen, 1981; Strauss & Bookstein, 1982), it needs to be clarified as to how to select a set of measurement items. The results obtained by multivariate analyses could be meaningless if this point is not clarified. Concerning morphometrical studies, Bookstein (1982a) stated: "Good morphometrics is incompatible with the notion of a predetermined character set. Rather, the characters should be defined post hoc as a reflection of the comparisons they are intended to capture (p. 464)."

In response to this deficiency of convertional measuring data, there have been many attempts to develop a suitable method (Sneath, 1967; Lestrel, 1974; Ramaekers, 1975; Bookstein, 1977; Chevelud *et al.*, 1983). The infomation treated in thoses methods has been extended from one dimension to two or three dimensions, but still there remain some problems when they are applied to the analysis of detailed morphological changes. Yasui (1986) proposed a method in which subtle morphological differences are analyzed qualitatively as well as quantitatively at populational level. In his method, an averaged outline of form is produced as a representative form of a population.

Recently the discussion on the origin and formation of the Japanese has begun to focus on more specific aspects, however, it is questionable whether satisfactory data has been used in the studies. In this paper, to ascertain the basic information on the formation of the Japanese, the morphological changes of the Japanese cranium from the Neolithic Jomon period, including the upper Pleistocene Minatogawa man, to recent times (ca. 1900s A. D.) are analyzed by the use of Yasui's (1986) and Bookstein's (1982b) methods. Also geographical variations, sexual differences in the groups from the Jomon period to recent times and relationships to the several populations in the adjacent areas are taken into consideration, key hypotheses previously proposed are reexamined.

MATERIALS

The cranial series used in this study were from several collections which were excavated or collected in Japan, Korea, Northeastern China, and Sakhalin and Kurile (Kunashiri) islands. The time span of the specimens ranges from the upper Pleistocene to recent times (ca. 1900s A. D.). Totally, 768 cranial specimens were studied (Table 1). Among the specimens from recent times, crania which showed atrophy at the alveolar process or other deformations were exclued, while those suitable for midsagittal and horizontal outlines from the excavated collections were used because of a limited sample

Table 1. Materials studied.

Sample	Male		Female		Total
	MSO[1]	HZO[2]	MSO	HZO	
Recent	110	107	111	110	233
Kyoto	60	56	70	70	
Niigata	50	51	41	40	
Edo	57	55	29	27	86
Kamakura	27	28	13	10	46
Kofun	40	36	21	19	68
Yayoi	32	31	12	10	44
Doigahama, Mitsu	25	25	11	9	
Jomon	34	29	31	25	67
Initial/early	1	1	2	1	
Middle	2	1	2	2	
Late/final	31	27	27	22	
Northeastern	8	10	8	6	
Tsukumo	7	7	9	9	
Upper Pleistocene	1	1			1
Ainu	62	63	44	40	114
Sakhalin	21	21	11	10	
Southwestern Hokkaido	8	8	10	8	
Okhotsk Culture	2				2
Aleut			1	1	1
Nansei Islands	18	19	21	20	40
Korea	19	19	8	8	27
Northeastern China	27	27	12	12	39
Total	429	415	307	286	768

[1] Midsagittal outline; [2] Horizontal outline.

size. All of the specimens used were determined as being adult; either from the original papers or reports, or from the record of the cadavers kept in the departments of anatomy. Sexual determination was also derived from the original records. The sex and age of the specimens whose data have not been published were determined independently by two researchers including this author.

As all areas around the midsagital outline or horizontal outline at the level of the glabella are needed to remain, the number of specimens was severely restricted in the case of excavated collections. The specimens in the upper Pleistocene (Minatogawa I) and initial/early/middle Jomon could not be treated as a population. The late/final Jomon specimens covered all areas of Japan, although the number of samples was small and geographically uneven. The Aeneolithic Yayoi specimens were mainly from the Mitsu (Saga prefecture) and Doigahama (Yamaguchi prefecture) collections. Specimens from the northwestern part of Kyushu, Kanto, and Chugoku districts were also included, although they were small in number. Most specimens of the protohistoric Kofun period were excavated from the western part of Honshu, but some specimens from the Kanto district were also included. Specimens of the Kofun period were incorporated with those exceveted from kofuns (kofun: specific old tumulus developed in the final Yayoi and

Kofun periods), yokoanas (yokoana: a type of old tunnellike tomb produced in this period), and a natural cave. All of the medieval kamakura specimens were from the Zaimokuza collection excavated from Kanagawa prefecture. Specimens of the Edo period (Shogunate age) were from Tokyo except for two specimens from Osaka prefecture. The recent Japanese specimens were from Niigata and Kyoto prefectures. The localities of samples and the time span of each age are shown in Figure 1 and Table 2, respectively.

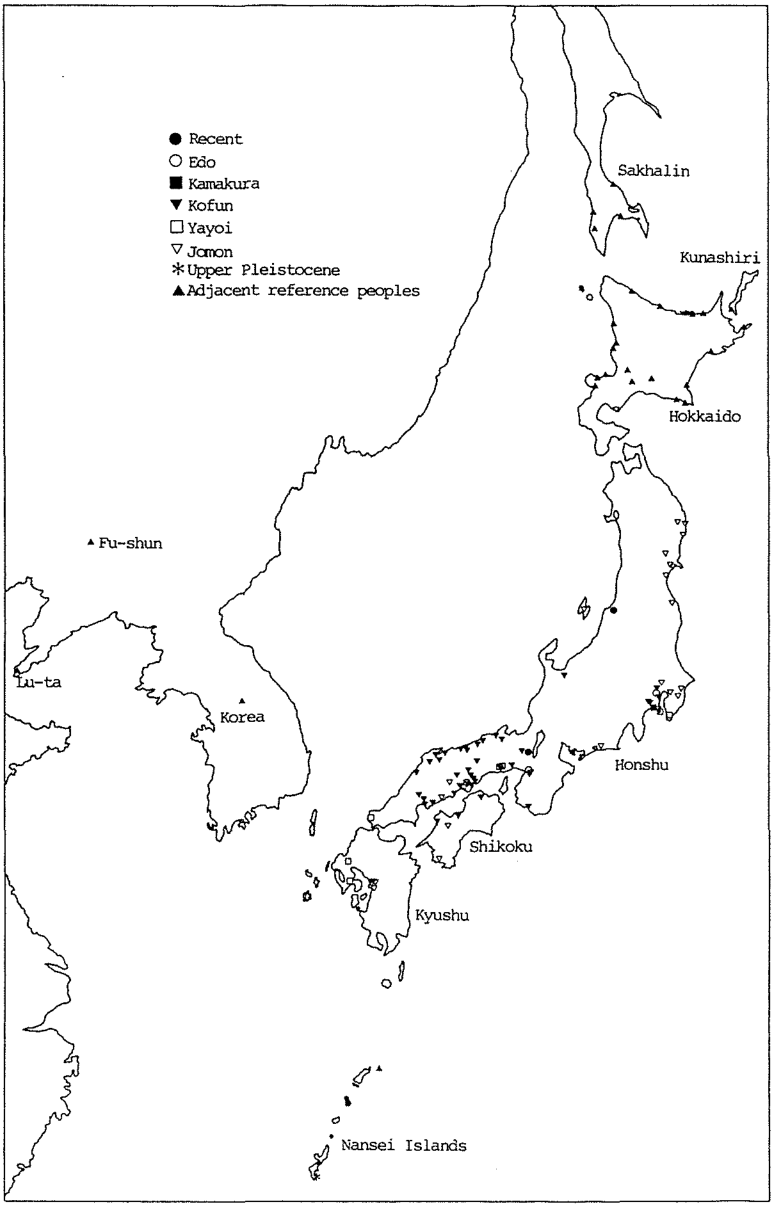


Fig. 1. Localities of specimens.

Table 2. Chronology of cultural periods in Japan.

		(years B. P.)
Recent		110–present
Edo		380– 110
Kamakura		800– 650
Kofun		1,700– 1,400
Yayoi		2,300– 1,700
Jomon		13,000– 2,300
	Final	3,000–2,300
	Late	4,500–3,000
	Middle	5,600–4,500
	Early	7,300–5,600
	Initial	9,500–7,300
Paleolithic		before 13,000

The specimens from the adjacent areas used as reference populations were Ainu, Nansei Islanders, Korean, and Northeastern Chinese. In addition, two specimens from the Okhotsk culture region and one Aleut were included. Ainu specimens contained the Hokkaido, Sakhalin, and Kurile (Kunashiri) groups. Specimens of Nansei Islanders were collections from the Amami, Kikai, Tokunoshima, and Okinawa islands. the Northeastern Chinese specimens were collected from nearby Lu-ta (Lu-shun) and Fu-shun. The locality of the Korean specimens was not clear. The age of the Ainu and Nansei Islanders ranged from the Edo period to recent times (Ikeda, 1974). The Korean and Northeastern Chinese specimens were from recent times.

METHODS

1. Drawing of Outlines

Outlines were drawn by the help of a cubic craniophore and a diagraph. Two outlines par cranium were analyzed: the midsagittal outline (*norma lateralis*) defined by the nasion, subspinale, and inion, and the horizontal outline (*norma verticalis*) which is on a plane parallel to the OAE at the glabellar level. In the *norma lateralis* (N. L.), a left lateral profile was drawn at the piriformic aperture, and the basion and opisthion were joined by a straight line at the foramen magnum. Thus, a closed outline was obtained for each specimen.

Anatomical landmarks were also plotted by projecting them on each plane defined above. The landmarks plotted on the N. L. were the nasion, subspinale, prosthion, staphylion, basion, opisthion, inion, lambda, bregma, glabella, left suprakonchion (point where vertical axis and upper margin of the orbita are intersected), left ektokonchion, left orbitale, left sphenion, left krotaphion, left and right porions, left zygomaxillare, and left asterion, and those plotted on the *norma verticalis* (N. V.) were nasion, prosthion, inion, lambda, bregma, glabella, staphylion, basion, opisthion, and porion, zygion, asterion, ektokonchion, frontotemporale, and maxillofrontale of both sides.

Figures 5–32, 35–38, 42, 43, and their explanations are placed collectively at the end of this paper (pages 52–88).

2. RECONSTRUCTION OF THE OUTLINE AT DAMAGED PARTS

Most damage on the N. L. occurred at the tip of the nasal, margin of the piriformic aperture, posterior ends of the palate and vomer, and basioccipital, whereas damages on the N. V. occurred on a part of the parietal and occipital. The palate or nuchal plane was reconstructed by a straight line which was produced based on the mean values of the palatal length and sagittal length of the foramen magnum calculated from intact specimens. The nasal, piriformic aperture and basioccipital were reconstructed based on the mean outlines which were produced as shown in Figure 2. A specimen of the Okhotsk culture which was broken at the cranial base was reconstructed by the outline of the other intact specimen of the same group. In the N. V., broken areas were reconstructed by visual interpolation from the remaining portions for each specimen.

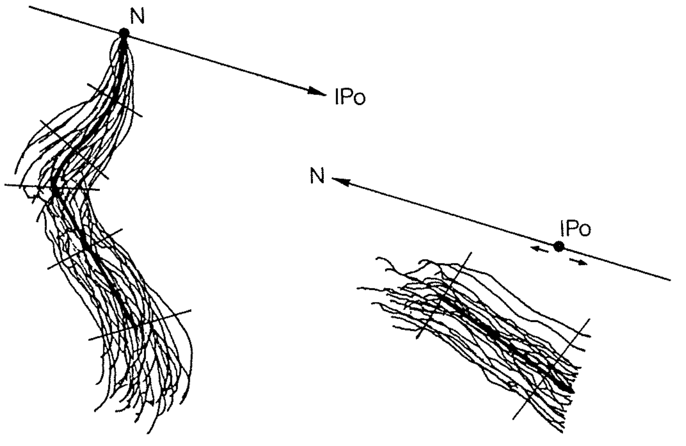


Fig. 2. Method for reconstruction of the outlines at the piriformic aperture and basilar parts.

3. ANALYSIS OF OUTLINES

The outlines and anatomical landmarks were drawn on the high quality paper and digitized by the use of a tablet digitizer (Bit Pad One BOP–11, Mutho Kogyo Co. Ltd.). The digitized data was analyzed by the method of Yasui (1986). The interpolational interval was determined at 2 degree for the N. V. and 1 degree for the N. L.; thus the number of data for each outline was 180 and 360, respectively.

Modifications were made to the posterior margins of the alveolar process and vomer, and the anterior nasal spine on the N. L., and the posterior part of orbital rim of some specimens on the N. V. (Fig. 3), because of the limitation of the interpolational procedure.

4. ANALYSIS OF DEFORMATION BY USING BIORTHOGONAL METHOD

Bookstein (1982b) presented a method called Biorthogonal analysis for analyzing the orientation and magnitude of morphological changes without any registrations. In Biorthogonal analysis, a form is divided into triangular elements based on anatomical landmarks. The principle axes which show the maximum and minimum dilatations in the deformation of each triangular element are computed. The product of the maximum and

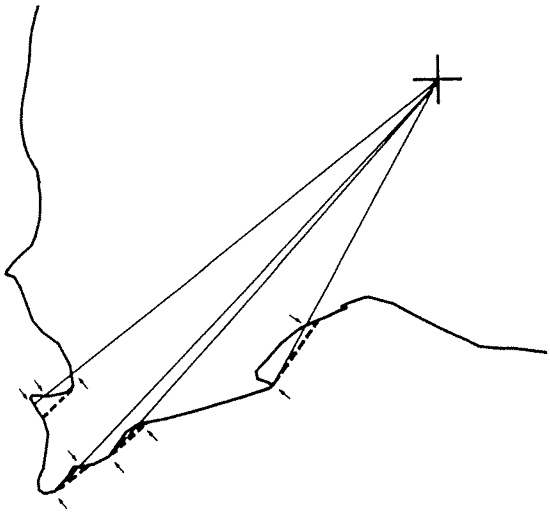


Fig. 3. Modification of the outlines; solid line is original and broken line modified.

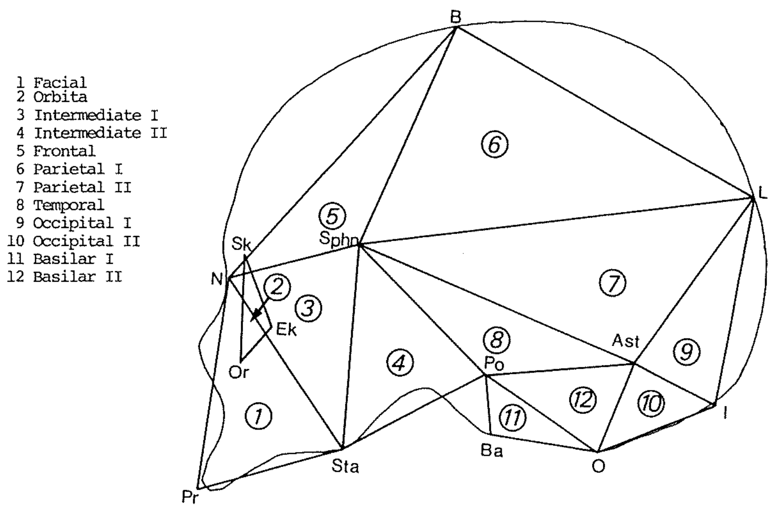


Fig. 4. Triangulation of midsagittal section in Biorthogonal analysis.

minimum dilatatoins is the ratio by which the area of the triangular element has increased. The ratio is a measure of the directionality of the deformation, which is called anisotropy in engineering. There are several ways for making clear the direction and ratio of dilatation in accordance with Bookstein's method. Here, I applied his method to the averaged midsagittal forms of the cranial series from the late/final Jomon period to recent times by using the shape function of the finite element method. Figure 4 shows the triangulation of the N. L., where each element corresponds to the bone element as much as possible.

RESULTS

I. Characteristics of the Outlines

1. INTRAGROUP VARIATIONS

The results of the test for normal distribution and the examination for relative variability in each group are shown in Table 3. Generally, the occipital in both sexes and the forehead in females had greater variabilities than the other parts of the N. L.. On the N. V., the parts showing large variability differed among the groups, but the occipital generally varied greatly among all of the groups. The test for nomal distribution showed that all groups seem to be unimodal, although quite small areas of the outlines in each group did not show normality ($P<0.05$).

2. ANALYSES OF INTRAGROUP ALLOMETRY

Intragroup allometry analyses were conducted on the N. L. (Table 4) and N. V. (Table 5) for each group. The parts showing weak allometric tendencies are included in the tables, however they were not statistically significant. In the N. L., positive or negative allometry ($P<0.05$) could be seen in small portions of the outline in most groups, although the Ainu, Korean, and Northeastern Chinese males exhibited allometries widely extended along the outline. Generally, the glabellar area and external occipital protuberance were positively allometric. These positive allometries were stronger in males than in females. The allometries in facial parts, especially at the upper part of the piriformic aperture, were different between the mainland Japanese groups from the late/final Jomon period to recent times and the groups from the adjacent areas, except for the Nansei Islanders. The former showed a negative allometry whereas the latter showed a positive allometry. The forehead was positively allometric in the mainland Japanese groups from the late/final Jomon period to recent times, while the Ainu showed a negative allometry.

In the N. V., allometries occurred widely expanding along the outline. The male and female Ainu exhibited allometries on almost all parts of the outline. The anterior part of the frontal and occipital were positive, but lateral parts were negatively allometric in all of the mainland Japanese groups and in the Ainu. Korean and Northeastern Chinese groups showed isometry in the anterior and posterior parts, and a positive allometry in the lateral parts. The Nansei Islanders were positively allometric at the bilateral temporal fossae. Among the mainland Japanese groups, those before the Kofun period were allometric in the posterior part of the outlines, while those after this period were allometric in the anterior part of the outlines.

According to the allometric analysis, the effect of size on shape was removed by the use of log-scaled regression lines for each element in each group. Intragroup variations after size standardization were reduced from two thirds to half of the original variation in all groups.

II. Geographical Variations

Geographical variations in the Jomon, Yayoi, Kofun, recent periods, and the Ainu were analyzed using the multidimensional scaling (MDS) method (Yanai & Takai, 1980)

Table 3. Test for normal distribution and intragroup variability.

	L.Jomon M	L.Jomon F	Yayoi M	Yayoi F	Kofun M	Kofun F	Kamakura M	Kamakura F	Edo M	Edo F	Niigata M	Niigata F	Kyoto M	Kyoto F	Ainu M	Ainu F	Nansei M	Nansei F	Korea M	Korea F	NE China M	NE China F
Test for normality																						
(Midsagittal) (N=)	31	27	32	12	40	21	27	13	57	29	50	41	60	70	62	44	18	21	19	8	27	12
Glabellar part																*						
Nasal											*		*									
Tip of nasal	*			*				*														
Upper part of a. piriformis																						*
Subspinale	**	*	*		*				*		**	*	**	**		*						
Alveolar process					*						*	*		**	**	**	**					
Anterior part of palate		**	*																**			**
Posterior margin of vomer		*	**	*	**	**	*		**	*	**	**	**	**	**	**	**	**			**	
Basisphenoid							*										*		*			
Basioccipital										**	*											
Anterior part of f. magnum												**				*						
Posterior part of f. magnum	*	**												**	*							
Nuchal plane	*		*						*							*						
Ext. occipital protuberance	*				**				*		*						*				*	
Lambda part						**									**							
Posterior part of parietal			*		*	*									*							
Anterior part of parietal		*																				
Posterior part of frontal																*						
(Horizontal) (N=)	27	22	31	10	36	19	28	10	55	27	51	40	56	70	63	40	19	20	19	8	27	12
L. superior margin of orbita			*						*													
L. temporal fossa		**	*						*		*	*										
L. squamosal									**			**		*			**					
L. occipital															**	**						
R. occipital				*		**		*					*		**							
R. squamosal									*			*					*					
R. temporal fossa						*							*	**		*						
R. lateral margin of orbita									*		*			**								
Relative variability																						
(Midsagittal)																						
Forehead		+								+								+				
Basilar	++	++	++	++	++	+	++	+	+	+	+	++	+	++	++	++	++				+	++
Occipital	+	+	+	+				+	+	+	+		+	+	+		++	+	++		++	++
Bregmatic part		+																				
(Horizontal)																						
Frontal												+		+	+	+					+	+
L. temporal fossa	+		+															++				
L. squamosal				+	+		+		+								+		++	++	+	++
Occipital	+	+	++	++			+		+	+	++	+		+	+	++	+		+		++	+
R. squamosal				+	++		+										+		++	++	+	++
R. temporal fossa	+										+							++				

* P<0.05; ** p<0.01; + moderate; ++ great.

Table 4. Analysis of intragroup allometry for midsagittal outline.

	L.Jomon		Yayoi		Kofun		Kamakura		Edo		Niigata		Kyoto		Nansei		Ainu		Korea		NE China	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
(N=)	31	27	32	12	37	19	27	13	57	29	50	41	60	70	18	21	62	44	19	8	27	12
Forehead	+	+*	+				+		+	+	+*		+	+*			-*	-			+	
Glabellar part			+				+		+	+*					-		+	+*	+*		+*	
Nasal root		-			-*					+					-	-*						
Upper half of a. piriformis	-	-*	-*		-	-				+	-	-*					+*	-	+*	+*	+*	+*
Lower half of a. piriformis	-*	-*				-*	-	-			-*	-*	-*	-*	-							
Alveolar process						-*						-*	-*	-*	-*		+*			+*	-*	
Hard palate						-*			+*					-*				+*	+*			
Basioccipital					+*		+						+	+	+*	+*						
Anterior margin of f. magnum									-*											+		
Posterior margin of f. magnum	-					+			-*	-*						+	-				-*	
Nuchal plane		+	-	+					+			+			-*	+	-*	-*				
Ext. occipital protuberance	+*	+*		+*					+*	+	+	+	+*		+		-*				+*	+
Occipital plane	+			+	-*			+		-	-		-*				+*		+*		+*	-*
Posterior part of parietal	-*	-*	-				-*			-	+	-	-	-			+*	-*	+*	+*	-*	
Anterior part of parietal		+	-		+*		-*		-*			+				-*			-*	-	-	+*
Posteriot part of frontal		+	-							-*						-*			-*	-		+*

+ positive allometry; - negative allometry; * significant at P<0.05.

Table 5. Analysis of intragroup allometry for horizontal outline.

	L.Jomon		Yayoi		Kofun		Kamakura		Edo		Niigata		Kyoto		Nansei		Ainu		Korea		NE China	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
(N=)	30	25	31	10	36	19	28	10	55	27	51	40	56	70	19	20	63	40	19	8	27	12
Glabellar part					-*		+*					+*		+*	-		+*					
L. upper orbital margin		+*				+*	+*			+*	-*	+*		+*			+*	+*				
L. temporal fossa												-*			+	+*	-*	-*				+*
L. squamosal	-*	-*	-*		+*	-	-*			-*			-*	-		-*	-*	-*		+*		+*
L. parietal notch		+*			+*		+*		-*			-*			-	+						-*
L. half of occipital	+*	+	+	+													+*	+*				
R. half of occipital	+*		+*		-*			+*						+*			+*	+*				
R. parietal notch								+*		+*					-	-	+*		-*	+*		-*
R. squamosal	-*	-*	-*		+*	-*			-	-*				-*			-*	-*				+*
R. temporal fossa				+*							+*	-*			+*	+	-*	-*				+*
R. upper orbital margin		+*			-*	+*					-*						+*	+*				-*

+ positive allometry; - negative allometry; * significant at P<0.05.

based on the interindividual DIR (a shape distance introduced by Yasui (1986)) matrices. Although the cumulative proportions of the variance were not high, the relationships between the shape of individual outlines and their locations on the MDS plane seem to be meaningful in explaining the interrelation of individual outlines. The averaged outlines of the regional groups were compared using the size-standardized method (Yasui, 1986) when the groups could be geographically subdivided.

1. JOMON PERIOD

The Minatogawa specimen from the upper Pleistocene was included in the analysis.

In the males (Fig. 5), the late/final Jomon specimens from Northeastern Honshu (from the Kanto district's northeastern wards) and from the Tsukumo shell mound in Okayama prefecture were separated on the secound axis among all of the male specimens in the N. L. and N. V. outlines. The cranial shape of the Tsukumo people was lower in height and shallower in the temporal fossae than that of the Northeastern group. Generally, in both outlines, the other late/final Jomon specimens from the Yoshigo shell mound in Aichi prefecture, Shikoku, and Kyushu were situated closer to the Northeastern late/final Jomon group than to Tsukumo group.

The Minatogawa man was distingushable from the Jomon specimens by a rather low cranium and markedly concaved temporal fossae. An initial Jomon specimen from Kamikuroiwa cave in Ehime prefecture was different from the Minatogawa man in that it had a relatively rounder cranial form. The Ota specimens from Hiroshima prefecture, which is dated from the end of early to middle of the Jomon period, showed a high cranial vault, but were widely separated from the Kamikuroiwa on the first axis.

The females (Fig. 6) showed a clear division between the Northeastern and Tukumo specimens only in the N. L. outline. The Northeastern group had a higher cranial vault than Tsukumo people. The final Jomon Shijimizuka specimens from Shizuoka prefecture and Domen specimen from Hiroshima prefecture situated near the Tsukumo, but most Yoshigo and other late/final Jomon specimens were situated near the Northeastern group. According to N. V. outlines, every specimens was co-mixed, and no clear geographical or temporal distinction could be found.

The early Jomon female specimens from the Kaigara shell mound in Iwate prefecture and the Kou site in Osaka prefecture had a rather low cranial vault in contrast with the male cranium, They were situated close to the Tsukumo specimens. The Ota and middle Jomon Fujizuka specimen from Niigata prefecture showed a high cranial vault, like that shown in the male specimens.

Because both sexes of the Northeastern group and Tsukumo people were distinguishable from each other, their averaged outlines were compared by the size-standardization method. Figure 7 shows that significant differences found in the nasal root, upper part of the piriformic aperture, forehead, and right temporal fossa of the male specimens (95% confidence bands for each averaged outline showed no overlap). On the N. L. outlines, the Northeastern group had a relatively high cranium compared with the Tsukumo people, and the outline of palate and cranial base was situated inferiorly. The inclination angle of the foramen magnum also differed. On the N. V., it was noticed that the bulge at the temporal fossae in the outline of Tsukumo people and protrusion of glabellar area in the Northeastern group. Three anatomical landmarks on the orbital rim of the Northeastern group were located slightly higher than on the N. L.

of the Tsukumo. The bregma of Tsukumo was situated anteriorly, and its frontal was relatively slanted and short in sagittal direction. Zygions and porions of the Northeastern group were located anteriorly.

In the femles (Fig. 8), almost all parts along the N. L. outline were significantly different between the Northeastern and Tsukumo groups. The frontal and parietal of the Northeastern group were strongly curved in comparison with those of the Tsukumo, and the calvaria of the former showed a rectrangular form. The cranial base and the inclination of the foramen magnum also differed. Three anatomical landmarks on the orbital rim and asterion of the Tsukumo females were situated slightly inferiorly, and their lambda was located superiorly compared with those of the Northeastern females. On the N. V. outlines, no difference could be ascertained because of the insufficient sample size of the females from the Northeastern area.

2. Yayoi Period

The result of MDS anlysis on the Yayoi males is shown in Figure 9. The specimens from the Doigahama site, Yamaguchi prefecture (early period) and from the Mitsu site, Saga prefecture (middle period) were not distinguishable from each other in either outline. The specimens from the Northwestern Kyushu and Kanto district were also within the range of the Doigahama and Mitsu specimens. The specimens from the Myojin-yama and Shirasagi-yama kofuns in Hyogo prefecture exhibited a round and rather high cranial shape, somewhat separated from the Doigahama/Mitsu's groups.

All of the females were from the Doigahama site except for one that was from the Tono-yama kofun in Okayama prefecture. The Tono-yama cranium showed a rather round cranial shape in the N. L. outline and was located at the end of first axis (Fig. 10).

3. Kofun Period

In the N. L. outlines of the males (Fig. 11), the specimens from the yokoanas and a cave were distributed close together in the central part, but no geographical trend could be found. They also exhibited a round cranial shape and were distinguishable from all other specimens in the N. V. outlines. The male specimens from the Kanto district which displayed a relatively long and narrow N. V. outline were also distinguishable from the others.

The N. L. outlines of the females (Fig. 12) showed neither geographical nor tomb type specificities, but the round cranium of the yokoana and cave specimens was noticeable, which corresponded to the findings in the males.

Among the tomb sites from which more than one specimen was unearthed, the specimens from the Torisaka kofun in Hyogo prefecture, Hongo-kamikuchi yokoana in Shimane prefecture, and Isoma cave in Wakayama prefecture showed a close intrasite similarity in cranial shape.

4. Recent Times

In Figure 13, the averaged outlines of the males from Niigata and Kyoto prefectures are compared by eliminating the size effect on the shape difference. All parts along the outline, except for the facial, were significantly ($P<0.05$) different from each other in the N. L. outline. The cranium of the Kyoto group was relatively short in antero-posterior diameter, yet higher than that of the Niigata group. On the other hand, the horizontal outlines showed little difference, except for a somewhat rounded shape and relatively deepened temporal fossae in the Kyoto cranium. Regional differences in the females (Fig. 14) were similar to, but not as pronounced as those in the males.

5. AINU, OKHOTSUK CULTURE MAN, AND ALEUT

The male sample included specimens from the Hokkaido, Sakhalin, and Kurile (Kunashiri) Ainu groups and Okhotsk culture men. The N. L. outline (Fig. 15, B) suggested that all of the specimens were interspersed and did not suggest any distinct geographical trend. The specimen from the Minami shell mound in Sakhalin island was located whithin the range of the Ainu specimens from the Rorei site in the same island, but those from the Honto site in Sakhalin island were located at some distance from the Rorei. Ainu specimens from the Kunashiri island were situated close to the Okhotsk culture men, however, these two groups did not show any special similarity to the Hokkaido or Sakhalin Ainu group. In the N. V. outline (Fig. 15, A), the Ainu specimens from the Rorei site and the Okhotsk coast of Hokkaido were distinguishable from each other, although there were some exceptional specimens. The Hokkaido Ainu from the southwestern area was situated in between them. The Sakhalin Ainu from the Honto site and Hokkaido Ainu from the Pacific coast/Tomamae area were widely scattered.

An Aleut and the specimens from the Susuya shell mound in Sakhalin island were incorporated with the Ainu female groups from the Hokkaido, Sakhalin, Kurile islands (Fig. 16). From the N. L. outlines, the Hokkaido Ainu from the southwestern area and Sakhalin Ainu appeared distinctly separated. Specimens from the Susuya shell mound were located within the range of the Southwestern Hokkaido Ainu. The Hokkaido Ainu groups from Okhotsk and Pacific coasts were widely scattered. The Kurile Ainu and Aleut (only one specimen in each group) were situated close to each other, and were relatively near the Sakhalin Ainu. From the N. V., it appears that the Ainu groups from Southwestern Hokkaido and Sakhalin were separated from each other. The Aleut and Kurile Ainu were located at some distance from the other Ainu specimens.

Although there was no consistent separation of local groups between both sexes, Sakhalin and Southwestern Hokkaido Ainu groups were somewhat separated from each other in the females. These two groups were used for a comparison of averaged outlines. The N. L. outlines of the males (Fig. 17, B) showed significant differences ($P<0.05$) at the piriformic aperture and anterior part of the parietal. The Southwestern Hokkaido Ainu exhibited a less projected margin of the piriformic aperture, more slanted forehead and higher location of the vertex. The location of the anatomical landmarks showed that the Southwestern Hokkaido Ainu had a relatively lower face. In the N. V. of the males (Fig. 17, A), the temporal fossae of the Southwestern Hokkaido Ainu were deepened, and its glabellar area was projected anteriad. In the females (Fig. 18), the pattern of differences was similar to, but more remarkable than that of the males.

III. Morphological Changes from Late/final Jomon Period to Recent Times

In accordance with the analysis of geographical variations, the late/final Jomon people were subdivided into the Tsukumo and Northeastern groups, and the recent mainland Japanese were divided into the Niigata and Kyoto groups. The Yayoi people were represented by the specimens from the Doigahama and Mitsu sites.

1. Comparison of the Averaged Outlines

a) *From Late/final Jomon to Yayoi Periods*

In a comparison of N. L. outlines of the males from the Yayoi period and Tsukumo Jomon site (Fig. 19), significant differences ($p<0.05$) occurred only in the glabellar area and the tip of the nasal. Comparison was hampered due to the small sample size of the Tsukumo specimens. The cranium of the Yayoi males did not show a prominent glabella, a developed external occipital protuberance, a project nasal, nor a deep-set nasion, which have been regarded as special characteristics of the Jomon cranium. Furthermore, the Yayoi males showed a higher face and somewhat rounded calvaria in contrast with the slanted forehead and protruded parietal of the Tsukumo males on the N. L. outlines, and also showed an evenly rounded anterior margin and a relatively shortened antero-posterior diameter on the N. V. outlines. The bregma of the Yayoi people was shifted posteriad, associated with the inferiad shift of the lambda. The zygions and porions were also shifted posteriad. The differences between the Yayoi and Tsukumo Jomon crania in the females (Fig. 20) were similar to those of the males.

The results of the comparison between the Yayoi males and the other late/final Jomon counterpart, Northeastern group, differed from those of the former case. In the males (Fig. 21), since so-called Jomonoid characteristics described above were less developed in the cranium of the Northeastern Jomon group, the facial part and calvaria of the Yayoi people were not clearly different. The major difference between them occurred at the cranial base. The basion was shifted superiad, resulting in a change of the inclination angle of the foramen magnum. On the other hand, in the Yayoi people, an evenly rounded anterior margin with a relatively short antero-posterior diameter and a shallow temporal fossa were more clearly noticeable on the N. V. outline than in the comparison between the Yayoi and Tsukumo males. The comparison between the Yayoi females and Northeastern female group (Fig. 22) showed quite large differences, although the comparison was carried out of the N. L. outline only because of an inadequate sample size. The most distinct difference (significantly at $P<0.05$) occurred at the cranial base, which was also seen in the males, and the curvature of the parietal also significantly ($P<0.05$) reduced in the Yayoi females.

b) *From Yayoi to Kofun Periods*

In the males (Fig. 23), significant differences ($P<0.05$) in the N. L. occurred at the areas around the opisthion and lambda. The posterior part of cranium in the Kofun males was somewhat protruded, and opisthion shifted relatively superiad. The shift of the opisthion resulted in a retrograde change in the inclinaton angle of the foraman mugnum as compared with that occurred between the late/final Northeastern Jomon group and the Yayoi people. On the N. V. outlines, the Kofun males showed a relatively long cranial shape with significant differences ($P<0.05$) in the left side of the occipital and, though not so marked, anteriorly projected glabellar area. The Kofun females showed an almost identical shape to that of the Yayoi females, except for the inclination angle of the foramen magnum which changed in a manner similar to that of the males (Fig. 24).

c) *From Kofun to Kamakura Periods*

The males in the Kamakura period (Fig. 25) differed from the Kofun males. The N.

L. outlines showed differences in the alveolar process, anterior and posterior parts of the bregma, and the occipital plane. The N. V. outline differed in the upper margin of the right orbita and left half of the occipital. The cranium of the Kamakura males was relatively high and round in the N. L. outline, while it was somewhat long in antero-posterior diameter in the N. V. outline. In the Kamakura females (Fig. 26), the N. L. outline revealed a more vertical forehead, but the N. V. showed a dolichocranic shape. A low nasal roof among the Kamakura people was also marked in both sexes.

d) *From Kamakura to Edo Periods*

The cranial differences between the Kamakura and Edo periods were not too great in the males (Fig. 27). The N. L. revealed that significant differences ($P<0.05$) occurred at the margin of the piriformic aperture and external occipital protuberance, while the N. V. outlines revealed differences in the left temporal and right temporal fossa. The development of the external occipital protuberance was marked in the Edo period. In addition, a high nasal roof and a round forehead were noticed in the Edo people; the high nasal roof was a retrograde change compared with the change which occurred from the late/final Jomon to Kamakura periods. The N. V. outline of the Edo males was rounder than that of the Kamakura males, especially the anterior part of the temporal, which was distinctly round on both sides. In the females (Fig. 28), the N. L. of the Edo period showed little change from that of the Kamakura period, except for a more rounded forehead in the former, whereas the N. V. of the former showed a markedly rounded shape. The facial height in the Edo period was relatively higher in both sexes.

e) *From Edo Period to Recent Times*

In a comparison between the Edo and recent Niigata groups, the N. L. outlines of the males (Fig. 29) showed significant differences ($P<0.05$) in the nasal, posterior part of the frontal, and occipital plane. Among the recent Niigata group, the nasal roof continued to become higher, but the frontal and occipital showed a retrograde change. The cranial vault of the Niigata group was relatively lengthened in antero-posterior diameter, and the lateral profile showed a slant frontal. The N. V. outline were almost identical to each other, but somewhat more rounded in the Niigata group. In the females (Fig. 30), the N. L. showed that differeces had occurred at the margin of piriformic aperture and foramen magnum, while the N. V. revealed changes in the glabellar area and bilateral temporals. The foramen magnum shifted relatively inferiad, and the N. V. outline become more rounded, especially, a protrusion of temporal on both sides was noticeable in the Niigata group.

The recent Kyoto group displayed quite different results from those of the Niigata group and showed a great difference from the Edo people in both sexes as well as in both outlines. In the males (Fig. 31), the N. L. outline revealed significant ($P<0.05$) differences in the forehead, nasal, and all areas of the occipital, while the N. V. differed in the anterior margin, right temporal fossa, and the temporal on both sides. The higher nasal roof, downward shift of the cranial base resulted in a higher cranial vault, and an evenly rounded occipital outline were noticeable in the recent Kyoto group. On the N. V. outline of the males, it was revealed that the cranium of the Kyoto group was relatively shortened in antero-posterior diameter with bilaterally protruding temporal. The Kyoto females (Fig. 32) also differed from the Edo females in almost the same manner as the males.

In the cranial changes from the Edo period to recent times, the Niigata and Kyoto groups had a common facial change, but they greatly differed from each other in neurocranial shape, especially in the males.

f) *Summary of Averaged Outline Comparisons*

A well developed glabellar area and deep-set nasion occurred in the late/final Jomon but disappeared after this period, whereas the developed external occipital protuberance in males occurred again in the Edo period. The lateral profile of the forehead showed a consistent change in which the profile become more and more vertical, except for the recent Niigata males. The projection of the nasal roof and shape of the horizontal outline showed a two-phased change. The first phase was from the Jomon to Kamakura periods, where the nasal roof become lower and lower, and the shape of the horizontal outline became relatively longer and longer in antro-posterior diameter and narrower and narrower in width. The other phase occurred during the periods after the Kamakura, where changes reversed from the former phase. The Kamakura people, especially the females, had the lowest nasal roof and the most dolichocranic from.

Shape differences in the averaged outlines between two temporally adjacent groups (Fig. 33) were assessed by the use of the intergroup DIRs. The largest intergroup differences occurred, in both sexes, between the late/final Jomon and Yayoi periods, and between the Edo period and Kyoto recent group. Differences between the Kofun and Kamakura periods and between the Kamakura and Edo periods concerning the N. V. outlines of the females were also quite large.

In the changes of the N. L. outline from the late/final Jomon to Yayoi periods, two regional Jomon groups showed almost equivalent DIR values when compared with the Yayoi people, except for the Northeastern Jomon females. The Northeastern Jomon females showed the largest DIR values among the comparisons of all groups and differed greatly from the contemporary Tsukumo females. As described above, however, changing parts of the outlines between these periods differed according to which group

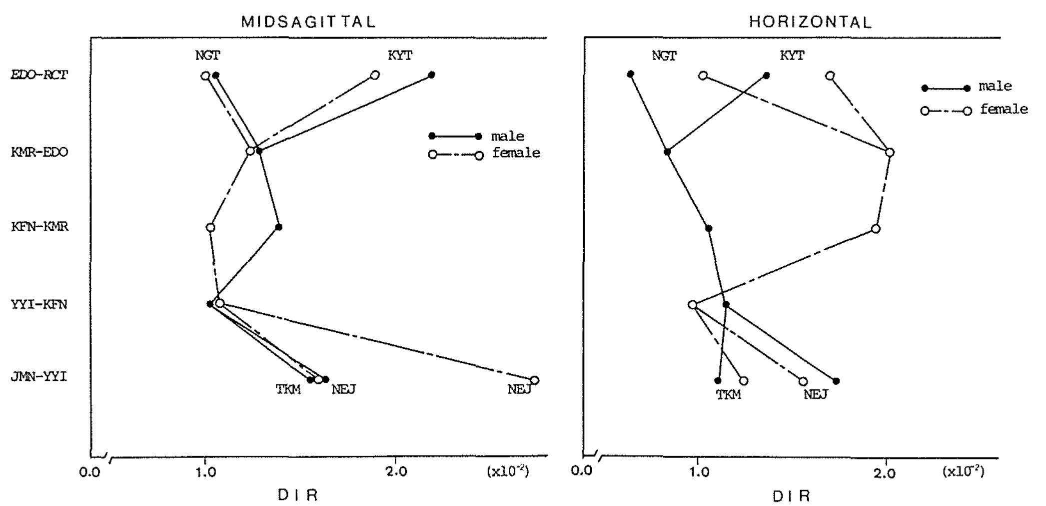


Fig. 33. Changing rate of the cranial shape (DIR). See the legend of Fig. 34 for abbreviations.

was used for the comparison. In the changes of the horizontal outline between the late/final Jomon and Yayoi periods, the Tsukumo people had smaller DIRs than the Northeastern group. The N. V. of the Kamakura females differed from those of two adjacent periods owing to the specific morphology of cranial vault. The changes from the Edo period to recent times showed regional differences. The cranial shape of the recent Kyoto group changed from that of the Edo people showing one of the largest DIR values in both sexes, whereas the Niigata group had the smallest of all DIR values when compared with the Edo people.

2. CHANGE IN CRANIAL SIZE

Figure 34 shows the cranial size (radius length of a circle whose area is approximated to the area enclosed by each averaged outline) of each group. Concerning the N. L. outlines of males, the recent Kyoto group showed the largest N. L. size. The prehistoric group (Jomon and Yayoi peoples) were also large. The smallest N. L. was of the recent Niigata group which displayed a striking contrast to the Kyoto group from the same period. In the N. L. outlines of females, the largest group was the late/final Northeastern Jomon group, followed by the Kofun people. The smallest size was of the recent Niigata. Almost the same results as those for the N. L. outlines were obtained for the N. V., however, in comparison with the N. L. sizes, disproportionate sizes of the N. V. outlines were recognized in the Tsukumo and recent Kyoto groups; i.e. the former was relatively large and latter small. Generally, the more ancient the group is, the larger the size, with some exceptions.

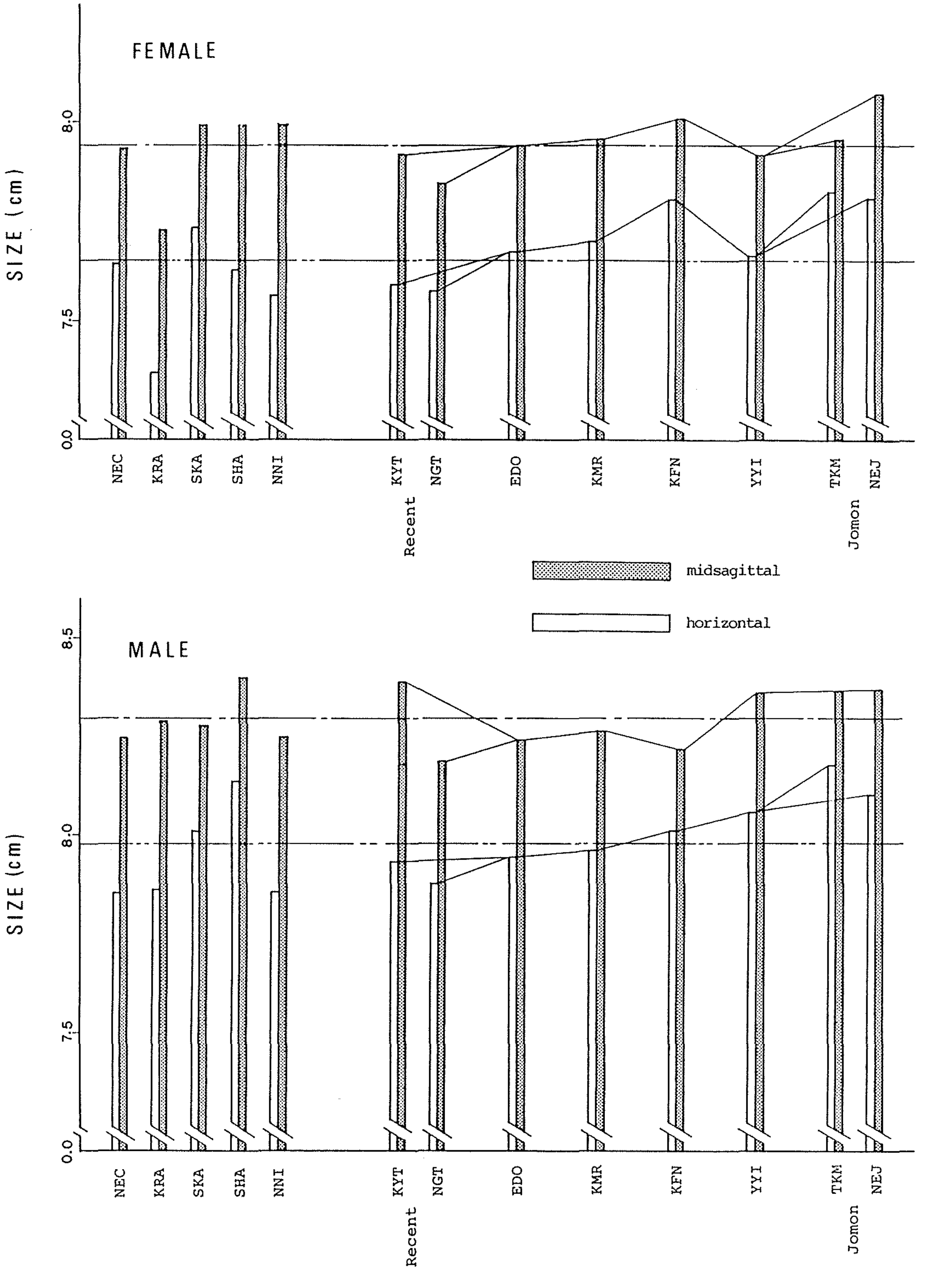
For the N. L. outlines of males among the reference groups from the adjacent areas, the Southwestern Hokkaido Ainu showed the largest size (it was also largest among all of the groups), followed by the Korean and Sakhalin Ainu groups. The Nansei Islanders showed the smallest size. For the N. L. of reference females, the Ainu groups from Sakhalin and Southwestern Hokkaido, and Nansei Islanders were almost the same in size, whereas the N. L. of the Korean was remarkably small. For the N. V. outlines, the two Ainu groups except for the female Ainu from Southwestern Hokkaido were relatively large. The Korean females were relatively small in comparison with its N. L. size, a characteristic also found in the Tsukumo and Kyoto groups.

3. MDS ANALYSIS OF THE GROUPS FROM JOMON PERIOD TO RECENT TIMES

Beside the groups of each period, the Minatogawa, initial/early and middle Jomon specimens were included in this analysis, so that non size-stadardized DIRs were used. The size-standardized DIR matrices are set out in Appendixes 3 and 4.

The results of the males are shown in Figure 35. Cumulative percentages for the first two axes were 73.8% and 73.7% in the N. L. and N. V. respectively. In the N. L. outlines, the Minatogawa, Kamikuroiwa, and Ota specimens could not be situated near the late/final Jomon groups and were separated far from each other, each showing a

Fig. 34. Changes of the cranial size in the mainland Japanese groups, and the cranial size of the reference groups: JMN, late/final Jomon period; YYI, Yayoi period; KFN, Kofun period; KMR, Kamakura period; EDO, Edo period; RCT, recent times; TKM, Tsukumo group; NEJ, Northeastern Jomon group; NGT, Niigata group; KYT, Kyoto group; NEC, Northeastern Chinese group; KRA, Korean group; SKA, Sakhalin Ainu group; SHA Southwestern Hokkaido Ainu group; NNI, Nansei Islanders.


FEMALE
SIZE (cm)
8.0
7.5
0.0
NEC
KRA
SKA
SHA
NNI
KYT
NGT
EDO
KMR
KFN
YYI
TKM
NEJ
Recent
Jomon
midsagittal
horizontal
MALE
SIZE (cm)
8.5
8.0
7.5
0.0
NEC
KRA
SKA
SHA
NNI
KYT
NGT
EDO
KMR
KFN
YYI
TKM
NEJ
Recent
Jomon

specific shape; the Minatogawa man was situated near the Tsukumo and Kofun peoples, the Kamikuroiwa specimen was near such modern groups as the recent Niigata and Edo, and the Ota specimens were near the recent Kyoto and late/final Northeastern Jomon groups. Among the groups from the late/final Jomon period to recent times, the Tsukumo and Kofun peoples made one cluster, while the Yayoi, Kamakura, Edo, and recent Niigata groups made another. The Northeastern group in the late/final Jomon and Kyoto people, especially the latter, were isolated from the others. Each group was temporally aligned along either axis, except for the Northeastern group in the late/final Jomon and recent Niigata group. Concerning the N. V. outlines, the Minatogawa and Kamikuroiwa specimens were separated far from the others. The former had well-developed temporal fossae, and the latter showed, though not so developed, a similar shape to the Minatogawa man. The Ota people were situated close to the cluster which contained all of the groups, but within the cluster it was closer to the Kamakura and Edo peoples than to the late/final Jomon people. There was no temporal alignment in the N. V. outlines.

In the females (Fig. 36), cumulative percentages were 70.4% and 74.6% for the N. L. and N. V., respectively. In the N. L. outlines, the Jomon samples did not align temporally. The Ota people were separated farthest from the early Jomon specimens and were situated close to the Kyoto group. The late/final Jomon people were situated in between them. The groups after the late/final Jomon period aligned temporally except for the Kamakura people which were situated relatively near to the Tsukumo people. In the N. V., the Kamakura people were the only group separated from the others showing a dolichocranic shape. The two recent groups and the Ota and Fujizuka specimens in the end of early or middle Jomon period showed a round cranial shape and separated farthest from the Kamakura people. The late/final Jomon people were situated more closely to the recent groups than the Yayoi, Kofun and Kamakura peoples.

The changes throughout all of the periods can be summarized as: (1) the end of early or middle Jomon people occupied a peculiar position among Jomon samples and were always situated near the recent groups, which resulted in a lack of temporal alignment among them; (2) in the two late/final Jomon groups, the Tsukumo group was closer to the later groups than the Northeastern group; (3) the groups from the late/final Jomon period to recent times almost aligned temoporally in the N. L. outlines, whereas there was no temporal alignment in the N. V., where the late/final Jomon and recent groups situated close to each other; (4) the recent Kyoto group was always situated with considerable distance from the other groups.

4. Biorthogonal Analysis of Shape Change

The partial deformations of the cranium corresponding to the changes of outline morphology were analyzed according to its triangular elements (Fig. 4). The maximum and minimum dilatations, and anisotropy for all of the triangular elements are set out in Tables 6 and 7. The deformation ellipses for males and females are shown in Figures 37 and 38, respectively.

In the change from the late/final Jomon to Yayoi periods, the orientations of the maximum dilatation for each element in the males were almost identical between the two cases, where the Tsukumo group was used for one case and Northeastern group for the

Table 6. Directions of maximum dilatation (first 2 arrays), values of maximum dilatation (3rd array), and anisotropies (4th array) for males.

	Frontal	Orbita	Intermed.I	Intermed.II	Facial	ParietalI	ParietalII	Temporal	OccipitalI	OccipitalII	BasilarI	BasilarII
TKM-YYI	N->(SPH-B)	SK->(OR-EK)	SPH->(N-STA)	STA->(SPH-PO)	N->(PR-STA)	B->(SPH-L)	AST->(SPH-L)	PO->(SPH-AST)	AST->(I-L)	I->(AST-O)	BA->(PO-O)	AST->(PO-O)
	4.40	90.6	55.1	15.7	19.6	21.0	60.2	41.8	18.6	46.2	54.3	64.1
	1.071	1.080	1.140	1.119	1.088	0.994	1.028	1.180	1.077	1.096	1.051	0.953
	1.141	1.153	1.115	1.063	1.122	1.032	1.067	1.261	1.124	1.189	1.244	1.057
NEJ-YYI	SPH->(N-B)	OR->(SK-EK)	SPH->(N-STA)	STA->(SPH-PO)	N->(PR-STA)	B->(SPH-L)	AST->(SPH-L)	PO->(SPH-AST)	AST->(I-L)	I->(AST-O)	BA->(PO-O)	AST->(PO-O)
	3.5	16.6	68.1	16.5	37.6	94.7	55.3	27.9	32.1	70.8	93.5	6.5
	1.033	1.076	1.101	1.094	1.07	0.999	1.115	1.075	1.093	1.195	1.013	1.003
	1.098	1.221	1.093	1.037	1.140	1.031	1.138	1.085	1.180	1.431	1.300	1.135
YYI-KFN	SPH->(N-B)	OR->(SK-EK)	N->(SPH-STA)	PO->(SPH-STA)	STA->(N-PR)	L->(SPH-B)	L->(SPH-AST)	PO->(SPH-AST)	I->(L-AST)	AST->(O-I)	BA->(PO-O)	O->(PO-AST)
	55.3	40.0	55.0	62.1	80.6	35.9	29.0	67.3	63.9	47.9	17.4	70.7
	0.987	0.963	0.970	0.992	1.012	1.004	1.004	0.985	1.022	1.073	1.076	1.024
	1.027	1.030	1.014	1.034	1.069	1.024	1.077	1.008	1.074	1.177	1.086	1.123
KFN-KMR	SPH->(N-B)	EK->(SK-OR)	STA->(N-SPH)	PO->(SPH-STA)	STA->(N-PR)	B->(SPH-L)	AST->(SPH-L)	SPH->(PO-AST)	I->(L-AST)	O->(AST-I)	BA->(PO-O)	O->(PO-AST)
	66.2	70.6	74.7	55.0	25.8	17.6	26.2	39.0	53.1	40.7	11.1	2.0
	1.034	1.015	0.999	1.038	0.993	1.032	1.027	1.025	0.986	1.069	1.063	1.061
	1.082	1.039	1.033	1.040	1.034	1.032	1.060	1.031	1.032	1.105	1.118	1.086
KMR-EDO	SPH->(N-B)	SK->(OR-EK)	STA->(N-SPH)	STA->(SPH-PO)	N->(PR-STA)	SPH->(B-L)	AST->(SPH-L)	AST->(SPH-PO)	I->(L-AST)	AST->(O-I)	O->(PO-BA)	O->(PO-AST)
	59.0	95.4	35.0	26.7	3.5	15.8	54.3	90.0	65.6	48.8	95.6	68.0
	1.010	1.019	1.023	1.016	1.052	1.003	1.004	1.002	1.040	1.043	1.023	1.031
	1.046	1.048	1.057	1.033	1.070	1.018	1.012	1.026	1.071	1.061	1.038	1.029
EDO-RCT	SPH->(N-B)	SK->(OR-EK)	N->(SPH-STA)	PO->(SPH-STA)	PR->(N-STA)	SPH->(B-L)	SPH->(AST-L)	SPH->(PO-AST)	AST->(L-I)	I->(AST-O)	BA->(PO-O)	PO->(AST-O)
(Niigata)	25.5	89.7	25.0	50.0	70.1	56.2	37.8	74.0	62.3	64.5	36.4	25.0
	1.022	1.026	1.022	1.015	1.000	1.006	1.006	1.006	1.026	1.025	1.028	0.993
	1.020	1.101	1.059	1.051	1.008	1.011	1.011	1.063	1.081	1.117	1.054	1.061

In first 2 arrays, for instance, N->(SPH-B) and 4.40 indicate that muximum dilatation orients from N to a point 0.044 of the way from SPH to B.

Table 7. Directions of maximum dilatation (first 2 arrays), values of maximum dilatation (3rd array), and anisotropies (4th array) for males.

	Frontal	Orbita	Intermed.I	Intermed.II	Facial	ParietalI	ParietalII	Temporal	OccipitalI	OccipitalII	BasilarI	BasilarII
TKM-YYI	N->(SPH-B)	OR->(SK-EK)	SPH->(N-STA)	STA->(SPH-PO)	PR->(N-STA)	B->(SPH-L)	SPH->(AST-L)	PO->(SPH-AST)	AST->(L-I)	O->(AST-I)	BA->(PO-O)	O->(PO-AST)
	40.4	76.6	80.9	43.0	24.2	50.0	11.9	54.0	95.5	76.7	17.6	96.9
	1.008	1.020	1.068	1.077	1.099	1.010	1.005	1.054	1.114	1.141	1.183	1.126
	1.079	1.031	1.086	1.072	1.109	1.035	1.143	1.050	1.257	1.032	1.201	1.132
NEJ-YYI	N->(SPH-B)	SK->(OR-EK)	STA->(N-SPH)	SPH->(STA-PO)	PR->(N-STA)	L->(SPH-B)	AST->(SPH-L)	SPH->(PO-AST)	AST->(L-I)	I->(AST-O)	BA->(PO-O)	PO->(AST-O)
	41.1	76.3	82.9	77.2	89.1	6.0	37.5	6.3	82.1	41.5	95.7	67.3
	0.985	0.989	1.022	1.049	1.064	0.988	1.042	1.046	1.059	1.109	1.015	0.977
	1.187	1.090	1.068	1.075	1.064	1.064	1.091	1.104	1.140	1.198	1.233	1.035
YYI-KFN	SPH->(N-B)	EK->(SK-OR)	N->(SPH-STA)	SPH->(STA-PO)	STA->(N-PR)	B->(SPH-L)	AST->(SPH-L)	SPH->(PO-AST)	AST->(L-I)	I->(AST-O)	BA->(PO-O)	O->(PO-AST)
	36.9	71.4	16.2	49.4	50.4	14.8	87.5	10.9	58.1	56.3	28.1	41.3
	1.082	1.040	1.029	1.046	1.013	1.034	1.056	0.995	1.073	1.055	1.181	0.983
	1.063	1.039	1.037	1.065	1.040	1.031	1.071	1.085	1.078	1.098	1.216	1.031
KFN-KMR	SPH->(N-B)	EK->(SK-OR)	SPH->(N-STA)	STA->(SPH-PO)	STA->(N-PR)	B->(SPH-L)	AST->(SPH-L)	PO->(SPH-AST)	I->(L-AST)	AST->(O-I)	BA->(PO-O)	AST->(PO-O)
	22.8	63.6	22.4	89.3	89.4	70.9	17.7	80.1	38.1	19.7	7.0	67.4
	1.022	0.972	1.014	1.004	0.970	1.009	0.992	1.020	1.041	1.036	1.052	1.046
	1.046	1.015	1.051	1.035	1.006	1.038	1.017	1.063	1.186	1.149	1.124	1.081
KMR-EDO	SPH->(N-B)	EK->(SK-OR)	STA->(N-SPH)	SPH->(STA-PO)	PR->(N-STA)	SPH->(B-L)	SPH->(AST-L)	PO->(SPH-AST)	AST->(L-I)	O->(AST-I)	O->(PO-BA)	O->(PO-AST)
	10.0	24.4	56.7	68.6	12.7	30.9	3.2	34.7	81.2	58.3	38.1	26.3
	1.021	1.085	1.030	1.038	1.059	1.029	1.026	1.037	1.013	1.023	1.024	1.022
	1.174	1.116	1.112	1.056	1.076	1.045	1.056	1.021	1.049	1.022	1.073	1.005
EDO-RCT	SPH->(N-B)	OR->(SK-EK)	N->(SPH-STA)	PO->(SPH-STA)	N->(PR-STA)	SPH->(B-L)	AST->(SPH-L)	SPH->(PO-AST)	I->(L-AST)	O->(AST-I)	BA->(PO-O)	PO->(AST-O)
(Niigata)	47.6	84.6	85.0	38.7	64.5	20.4	45.4	18.1	32.3	7.6	20.9	11.9
	1.026	1.031	1.010	1.023	1.011	1.005	1.024	1.017	1.000	0.989	1.048	0.994
	1.077	1.078	1.071	1.047	1.023	1.028	1.043	1.052	1.053	1.027	1.062	1.006

In first 2 arrays, for instance, N->(SPH-B) and 40.4 indicate that muximum dilatation orients from N to a point 0.404 of the way from SPH to B.

other as a late/final Jomon group. On the contrary, the results of the females differed according to which group was used as a late/final Jomon group. In the females, the axis of the maximum dilatation oriented nearly vertical in most elements when the Tsukumo group was involved, whereas the facial and parietal elements showed horizontal direction when the Northeastern group was used. The facial and parietal elements sexually differed in direction; the directions were more vertical in the males than in the females. The direction in the basilar and occipital elements showed no sexual differences.

The change from the Yayoi to Kofun periods differed from the previous change. The maximum dilatation shifted to a more horizontal direction in many elements. However, this shift in direction did not necessarily occur in the same manner in both sexes. Horizontal direction occurred in the facial, intermediate II, and parietal elements in the males, whereas it occurred in the orbita, intermediate, basilar, and occipital elements in the females.

Sexual differences were great in the change from the Kofun to Kamakura periods. Most of the elements were dilated showing vertically oriented maximum dilatation in the males, whereas in the females anterior elements such as the facial, orbita, and frontal showed horizontal direction, while the basilar and occipital elements showed vertical direction.

The change from the Kamakura to Edo periods also showed sexual differences. The direction of the maximum dilatation continued from the preceding change, except for the temporal and basilar I elements in the males. In the females, the facial, intermediate I, and temporal elements dilated with vertically oriented maximum dilatation, while the others dilated in oblique angle to the vertical.

In the change from the Edo period to recent times (Niigata group), for all elements saving the orbita, the maximum dilatation in the males showed horizontal direction. By contrast, the females showed no horizontal direction in the elements except for the intermediate II. The facial, frontal, basilar I, and occipital I dilated in a vertical direction. The orbital element showed vertical direction in both sexes.

Throughout all of the changes, in both sexes, the largest anisotropy occurred in the change from the late/final Jomon to Yayoi periods (Fig. 39). The elements in the occipital part greatly deformed until the Kamakura period. The elements other than basilar and occipital were moderately deformed from the Yayoi to Kamakura periods. In the change from the Kamakura to Edo periods, the anterior part of cranium was subjected to great deformations in the females, whereas all of the elements were evenly deformed in the males. From the Edo period to recent times (Niigata) only small deformations occurred in both sexes, except for the elements of orbita and occipital II which showed somewhat great deformations in the males.

As a whole, the magnitude of the deformations was almost equivalent, as shown in Figure 39, but the principle axes of the deformations differed in their orientation for each sex.

5. Change of Sexual Differences

The sexual differences estimated by the DIRs in each period are shown in Figure 40. The difference in the N. L. outlines was greatest in the late/final Jomon period but suddenly reduced in the Yayoi period. Thereafter the weak reduction continued into the Edo period, but the difference increased again in the recent groups. The N. V. showed

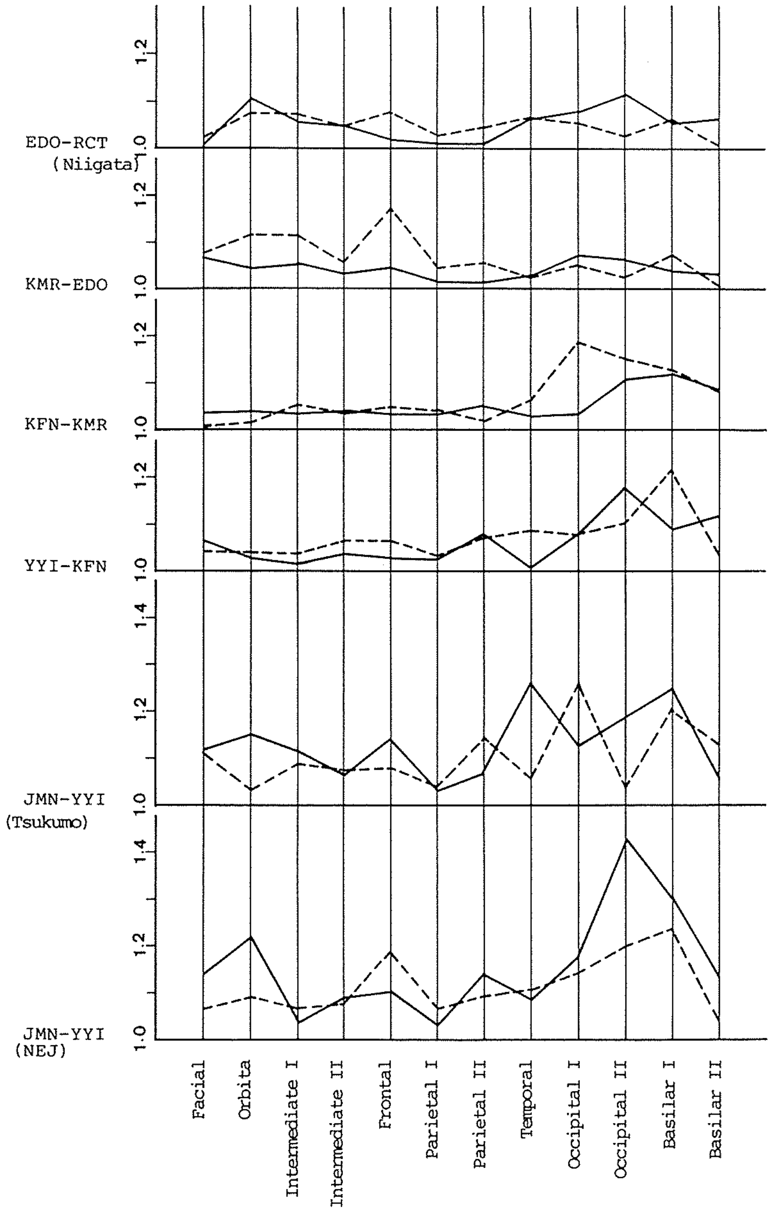


Fig. 39. Anisotropies of deformation in 12 triangular elements. Solid line is for males and broken line for females. See the legend of Fig. 34 for abbreviations.

similar change to that of the N. L. outlines, but there were some differences. On the N. V. outlines, a moderate change of the sexual differences between the late/final Jomon and Yayoi periods occurred with rather great geographical variations, and a leap of the change was shown between the Edo period and recent times. Among the reference groups from the adjacent areas, the groups other than the Nansei Islanders and Sakhalin Ainu showed the same great differences in the N. L. as the late/final Jomon people

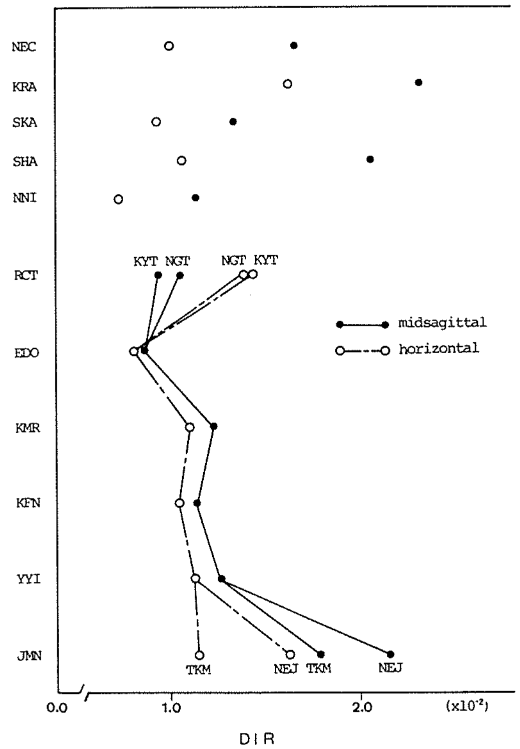


Fig. 40. Changes of sexual differences in the cranial shape (DIR). See the legend of Fig. 34 for abbreviations.

showed. On the other hand, the sexual differences in the N. V. outlines were small, except for the Korean group. These differences in the reference groups were a little greater than or equivalent to the difference of the Edo people which exhibited the smallest difference among the mainland Japanese groups. The difference in the Korean group was largest in both outlines.

Sexual differences in the size (Fig. 41) were assessed using the SZD (a size distance introduced by Yasui (1986)). The difference in size become larger from the late/final Jomon to Yayoi periods, but it suddenly reduced to the smallest in the Kofun period. Thereafter the sexual difference in size continued to increase and became equivalent to the level of the late/final Jomon people in the recent groups. Among the groups from the adjacent areas, the Korean and Southwestern Hokkaido Ainu groups were distinguished from the others by their large SZD values. Their values were also larger than that of the Yayoi people which were the largest among the the mainland Japanese groups.

IV. Relationships Between Mainland Japanese Groups and Peoples in Adjacent Areas

MDS analyses based on the size-standardized DIR matrix were carried out for the groups from the late/final Jomon period to recent times and the Nansei Islanders, Southwestern Hokkaido and Sakhlin Ainu, Korean, and Northeastern Chinese groups.

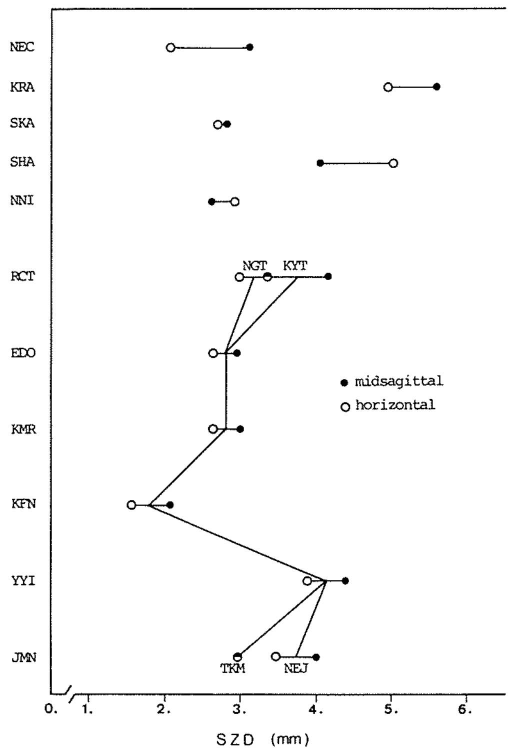


Fig. 41. Change of sexual differences in the cranial size (SZD). See the legend of Fig. 34 for abbreviations.

1. MALES

Cumulative percentages of the first two axes were 71.9% and 73.4% for the N. L. and N. V. outlines, respectively (Fig. 42). Concerning the analysis of the N. L. outlines, the mainland Japanese groups were aligned temporally along the second axis. The recent Kyoto group was off this alignment and was situated close to the Northeastern Chinese group. All of the mainland Japanese groups were situated in between the Korean and Ainu groups on the first axis. Two Ainu groups were situated close to each other yet separated from the groups of the mainland Japanese by some distance. Among the mainland Japanese groups, the Kofun people were relatively near the Ainu groups. The Korean and Northeastern Chinese groups were also separated from the mainland Japanese groups. The Korean group was separated the farthest among the reference groups. Nearby the recent Niigata and Edo groups there was the Nasei Islanders.

Concerning the N. V. outlines, the Korean and Southwestern Hokkaido Ainu groups were separated from each other at each end of the first axis, as was shown in the N. L. outlines. The Sakhalin Ainu group was separated from the Southwestern Hokkaido Ainu and was situated close to the Kofun people. The Northeastern late/final Jomon and Kamakura groups were located close to the Southwestern Hokkaido Ainu. The Northeastern Chinese group was separated from the recent Kyoto group, and the Yayoi people were situated in between them. The Nansei Islanders were near the Kofun and Sakhalin Ainu groups. The Korean group was the most dissimilar group to the mainland Japanese, as was also shown in the N. L. analysis.

2. FEMALES

In the females, 73.1% and 78.1% were the cumulative percentages for the N. L. and N. V. outlines, respectively (Fig. 43). The Korean group was situated at one end, and the Sakhalin Ainu group at the oppsite end in the N. L. outline. The other groups were in between them but nearer to the Sakhalin Ainu. The Southwestern Hokkaido Ainu group was separated from the Sakhalin Ainu group and situated close to the Nansei Islanders; both were near the Kofun and Kamakura groups. Among the groups of the mainland Japanese, the Tsukumo people showed the greatest similarity to the Sakhalin Ainu, while the late/final Jomon people from Northeastern Japan were separated from the others on the second axis. The Northeastern Chinese female group was more similar to the mainland Japanese groups than the males were. The Korean female group was separated the farthest from mainland Japanese groups, as was also shown in the male analysis.

The analysis of the N. V. outlines revealed the Kamakura people at one end and the Korean group at the opposite end. Two Ainu groups were situated between the Kamakura and some mainland Japanese groups which were situated close to the Kamakura people. The Sakhalin Ainu group was closer to the Kofun and Yayoi peoples than to the Southwestern Hokkaido Ainu group. The Nansei Islanders were situated within the range of the mainland Japanese groups and showed a similarity to the Edo and Kofun peoples. The Northeastern Chinese group was close to the recent Kyoto and Niigata groups, whereas the Korean group was separated from all groups from mainland Japan.

As a whole, for both sexes, the Korean group was the most dissimilar group among the reference groups. The recent Kyoto group was situated relatively near the Korean group among the mainland Japanese groups, while the Kyoto group was always separated from the other mainland Japanese groups with considerable distance. On the other hand, the Northeastern Chinese group showed a similarity to the recent groups of the mainland Japanese, especially among the females. Two Ainu groups showed a distinct shape and were separated from the mainland Japanese groups. The Nansei Islanders were closest to the mainland Japanese groups.

DISCUSSION

1. MINATOGAWA MAN AND JOMON PERIOD

The Minatogawa specimens were given an age of 18,250–16,600 years B. P. on the basis of C–14 analysis (Kobayashi *et al.*, 1974), and the primitiveness of their morphological characteristics was stressed by Suzuki (1982). The analysis of the outline morphology also showed a specific shape of the Minatogawa cranium in comparison to the Jomon cranium. Although the specimens of the late/final Jomon period, such as the Harazaki (Okayama prefecture) and Kasori (Chiba prefecture) specimens, had relatively lower cranial vaults than the Minatogawa specimen, the shape of their calvaria on the N. L. was clearly distinguishable from that of the Minatogawa man; projection of the glabellar area was rather weak, and the forehead was oriented vertically in the Jomon specimens, while the glabellar protrusion of the Minatogawa man was not only projected anteriad, but also widely extended around the glabella. On the N. V. outline of the Minatogawa man, as pointed out by Suzuki (1982), deeply concaved temporal fossae were conspicuous, and the parts where the lambdoidal suture passes through were also concaved. These characters did not arise in the Jomon people. Therefore, it could be concluded that the Minatogawa specimen belongs to a group which is morphologically different from the Jomon people.

Suzuki (1982) suggested a genetic closeness between the Minatogawa man and Jomon people. However, the cranial shape of the Minatogawa man is not easily joined to the initial/early and middle Jomon people of the mainland Japan. The difference between the initial/early or middle Jomon people and the Minatogawa man is larger than the differnce between the late/final Jomon people and the Minatogawa man. Consideration of the specific morphology of the initial/early and middle Jomon people is needed when the genetic relationship between the Minatogawa man and Jomon people is discussed.

The morphological changes during the Jomon period were discussed by Ogata (1973, 1977, 1981). According to him, the initial/early Jomon people had a small face, especially small in facial height, in comparison with the later Jomon people, and displayed a somewhat femalelike appearance. Some sexual differences were found in this analysis, although the materials of the initial/early Jomon period studied were only one male and two females. The Kamikuroiwa male specimen had a rather round cranial vault, though not very high, and was distinguishable from the later Jomon people. The female specimens of the early Jomon period, however, had a low neurocranium and were similar to the Tsukumo people in the final Jomon period. By the end of early or middle Jomon period, the height of cranium had become large in both sexes, judging by the specimens from the Ota (Hiroshima prefecture) and Fujizaka (Niigata prefecture) sites. In the late/final Jomon period the specimens from Northeastern Japan displayed a high cranial vault, while those from the Tsukumo shell mound showed a reduced cranial height, which appears to show a specific morphology to this area.

Morhological changes in the Jomon period were, generally, greater in males than in females, which is in agreement with Ogata's findings (1977). But his classification of the Jomon people into the gracile initial/early group and the robust middle/late/final group is oversimplified. The early Jomon females were not only similar to the Tsukumo people, but were also somewhat larger in size than the late/final Jomon people.

The regional differences in the late/final Jomon period occurred most clearly between the Tsukumo site and Northeastern Japan. The latter area includes the Kanto and Tohoku districts (and Hokkaido in the case of the females), where the specimens were decidedly similar to each other, as pointed out by Dodo (1982). Yamaguchi (1981a) compared the craniometrical data obtained from three regional groups (Kanto, Yoshigo, Tsukumo) and found certain geographical morphoclines. According to this analysis, however, the Yoshigo specimens were not situated midpoint between the Northeastern and Tsukumo specimens, but instead showed a close similarity to the Northeastern specimens. Moreover, the specimens recovered from Shikoku and Kyushu islands, which are situated west of the Tsukumo site, were more similar to the Northeastern group than to the Tsukumo group. Therefore, no morphocline was recognizable when the cranial shape was compared by the outline analysis. Rather, among the late/final Jomon people a specific morphology of the Tsukumo people could be pointed out. It is necessary to reveal the geographical pattern of such site specificities as Tsukumo's for accurate analysis.

In the discussion on the affinity of the Jomon people with other ancient or modern peoples, Konganei (1890, 1894) stressed that the Ainu were direct descendants of the Jomon people. Although there were objections to Koganei's conclusion (e.g., Kiyono & Miyatmoto, 1926), the morphological similarity between the Jomon people and Ainu has been recently pointed out (Dodo, 1982; Yamaguchi, 1982). According to this analysis, close similarity between them was shown only in the N. L. outlines of the females. Generally, the Ainu were similar to the Kofun and Kamakura peoples rather than the late/final Jomon people, judging from the other outlines. Because the Ainu showed a specific morphology when compared with the mainland Japanese groups, in particular the long and narrow shape in the horizontal outlin, it is difficult to conclude that the Jomon people show a closer affinity with the Ainu than with the other mainland Japanese groups.

2. Yayoi Period

The Yayoi people have been the most controversial group in the study of the formation of the Japanese. It has been said that the Yayoi people, especially those from the west tip of Honshu and the northern part of Kyushu, greatly differed from the Jomon people. A great difference between the Jomon and Yayoi peoples became evident in this analysis. The cause of this morphological difference has been discussed from two different standpoints. One standpoint is that the morphological difference was ascribed to the change in life style caused by the introduction of agriculture (Suzuki, 1969), and the other is that the difference was due to the immigrants who brought the race cultivation from the continent to Japan (Kanaseki, 1955, 1962, 1972). It is possible to consistently integrate these two explanations taking geographical variation into account. Indeed, Kanaseki (1962) and Naito (1971, 1981) found a geographical variation of the Yayoi people in Kyushu and pointed out that immigrants and their descendants were regionally restricted to the northern part of Kyushu.

Owing to the scarcity of Yayoi specimens other than from the Doigahama and Mitsu sites, analysis of geographical variations in the whole of mainland Japan is limited. Table 8 shows the DIR values between each Yayoi specimen and averaged outlines of the late/final Jomon groups among the males. The Yayoi specimens from Kanto district and Northwestern Kyushu showed somewhat smaller DIR values than the Doigahama/Mitsu specimens when compared with the late/final Jomon people. The Yayoi specimens from Kanto district used here are the same specimens that Suzuki (1969) analyzed when he pointed out the morphological continuity from the Jomon people in the Kanto district. Those obtained from Northwestern Kyushu have been said to retain Jomonlike characteristics (Naito, 1971). These specimens were pooled, and the mean values of DIRs were compared.

As a result, the difference in the N. L. outlines between the Doigahama/Mitsu and the pooled Kanto/Northwestern Kyushu groups was not significant ($t=0.866$, $df=28$) when compared with the averaged outline of the Tsukumo people. However, the difference between them was significant ($P<0.05$) in comparison with the late/final Jomon people from the Northeastern Japan. The difference in N. V. outlines between the Doigahama/Mitsu and pooled Kanto/Northwestern Kyushu groups was not apparent, because of large individual variations in the latter group. The Yayoi specimens from Kanto/Northwestern Kyushu were more similar to the Jomon specimens from Northeastern Japan than those from the Tsukumo site, although the difference was not significant (t=2.22, df=8). This may indicate that the Yayoi people in these areas were directly descended from the native Jomon people, since the late/final Jomon specimens in Kyushu showed a close similarity to those from Kanto district. The Doigahama/Mitsu people, on the other hand, showed almost equivalent DIR values when compared the two late/final Jomon groups, and those values were somewhat larger than the values of the pooled Kanto/Northwestern Kyushu group.

Table 8. DIR values (×100) for the Yayoi specimens against the averaged outlines of two late/final Jomon local groups in males.

	Midsagittal Outline		Horizontal Outline	
	NE Jomon	Tsukumo	NE Jomon	Tsukumo
Sano 1	2.20	2.83	3.32	2.63
Sano 2	2.62	2.54	1.42	2.48
Ourayama 4	2.74	3.28		
Ohama	2.49	3.69	1.26	1.79
Ropponmatsu 657	2.66	2.84	2.31	1.94
Pooled	2.54±0.28*	3.04±0.45	2.08±0.95	2.21±0.41
Mean±SD for				
Doigahama/Mitsu	3.26±0.65	3.29±0.62	2.62±0.83	2.27±0.88
(min.-max.)	(2.26−5.01)	(2.30−5.09)	(1.63−4.71)	(1.12−4.63)

* significantly differed from Doigahama/Mitsu at $p<0.05$.

The morphological peculiarity of the Doigahama/Mitsu specimens, especially in facial height and stature, was pointed out by Kanaseki (1959), and here again their peculiarity could be recognized from the N. L. outlines, but not the degree which Kanaseki stressed. Kanaseki (1959) concluded that the peculiar shape of the Doigahama/Mitsu crania suggested their origin was from the Korean peninsula. Prehistoric data from the continent is indispensable to such a migrant hypothesis as Kanaseki's, but suitable materials were not adequately available at that time, nor are they. In this context, based on craniometrical data, Nagai (1985) recognized a close similarity between the Doigahama and Iean-li old mound specimens near Busan, South Korea (2–7 A. D.), and Ikeda (1981, 1982) pointed out that the Doigahama people were similar to the Neolithic specimens from the northern part of the Korean peninsula and Northern China. Terakado (1985) said that the specimens from the Iean-li old mound were the most similar to the Doigaham people, and that those from the Unggi Neolithic and Nangnang old mound in North Korea showed a distinct shape distance against the Doigahama people. In his analysis, he illustrated that although the Doigahama specimens showed the greatest similarity to the specimens from the Iean-li old mound, the shape distance between them was almost equivalent to those between the Doigahama and Tsukumo people, and between the Doigahama and Ainu. These three conclusions are quite varied, and, moreover, the age of the materials studied is not contemporary with that of the Doigahama/Mitsu. The Jodo shell mound in South Korea, which is said to be almost the same age as that of the Doigahama/Mitsu, showed quite a large shape distance in comparison with the Doigahama people (Ikeda, 1982). Therefore, it cannot be said that there are enough data to support the immigration hypothesis.

When modern specimens from the continent are used in an analysis of the relationships between the Doigahama/Mitsu and certain continental groups, many difficulties arise because of the scarcity of studies. In this study, modern Korean and Northeastern Chinese were used, of which the Northeastern Chinese group more resembled the Doigahama/Mitsu people. The Korean group was the most dissimilar group to the Doigahama/Mitsu people among all the samples studied. The dissimilarities appeared in DIR values, allometric analysis, and sexual differences. Hanihera (1984) pointed out a close similarity of the Doigahama/Mitsu people to those from Northern China (Mongolian) and Siberia, but the Northeastern Chinese (not Mongolian) used here showed a DIR value almost equivalent to those of the recent Niigata and Tsukumo peoples when compared with the Doigahama/Mitsu people. Specific similarity of the Doigahama/Mitsu people to the two continetal samples could not be recognized.

The Doigahama/Mitsu people showed some peculiarities in comparison with the other Yayoi people, but it is uncertain whether or not their peculiarity is a result of the immigration of certain continental people. The Doigahama and Mitsu sites have a different nature from those of the Kanto district and Northwestern Kyushu. In the former areas, the tombs utilizing burial urns were predomainant. Therefore, it is undeniable that the cause for the morphological differences between the Doigahama/Mitsu and the other Yayoi people is not the immigration from the continent but is only the difference of their subsistence.

Some specimens in the late Yayoi period were recovered from the kofuns which were typical of the next Kofun period. Those specimens (three individuals were used here; Shirasagi-yama and Myojin-yama in Hyogo prefecture and Tono-yama in Okayama prefecture) were outside of the variation of the Doigahama/Mitsu specimens and showed a round cranial shape similar to the shape shown in the recent Kyoto people and the modern Korean group. Ikeda (1984) has already pointed out their specific morphology based on craniometrics. However, futher discussion is difficult until enough material can be utilized for the analysis.

3. Kofun Period

The averaged cranial shape of the Kofun people showed the greatest similarity to the Doigahama/Mitsu people and also resembled the Yayoi specimens from the Kanto and Northwestern Kyushu. The similarity between the Kofun and Yayoi peoples has been pointed out by Kanaseki (1955) and Suzuki (1965), and recently, the continuity between the two groups has been studied by taking geographical variations into accout (Nagai, 1985; Naito, 1985; Terakado, 1985; Yamaguchi, 1985). Since all of these authors agreed with the continuity between the Yayoi and Kofun peoples, it is thought that most Kofun people originated from the Yayoi people, without marked morphological changes.

The geographical variations in the Kofun people were first analyzed by Morisawa

(1976). He pointed out that the Kofun people in the eastern part of Japan had a larger neurocranium than those in the western part of Japan. Contrary to his conclusions, this study concluded that the crania from Kanto district were smaller than those from the western part of Japan. According to the DIR analysis, although the Kofun people showed a great individual variations, no geographical trends could be found. The specimens from Kanto district barely showed a somewhat long and narrow shape on the N. V. outline, and were distinguishable from the others. These findings are also inconsistent with the discussion on the Kofun people recently presented by Ikeda *et al.* (1985).

When morphological variations in the Kofun people are analyzed, consideration of the type of tombs as well as geographical division is required. Various tomb types, such as kofun (tumulus), congregated tombs, yokoana, and cave tombs appeared as a result of the complicated socioeconomical system during this period. The distribution of a type of tomb does not necessarily correspond to a geographical division. Among the specimens from various tomb types, the N. L. outlines of the specimens from the yokoana and cave sites were less variable than those from kofuns, especially in males, and the analysis of the N. V. showed a somewhat rounded shape in both sexes. Regarding the large variation in the Kofun people as a whole, this uniformity in the yokoana and cave sites compared with the other types of tombs indicates the emergence of morphological differences in accordance with social status.

4. KAMAKURA PERIOD

All of the specimens in the Kamakura period studied here were from the Zaimokuza site in Kanagawa prefecture, on which Suzuki *et al.* (1956) based their study which emphasized the extremely long and low cranial form and marked alveolar prognathism of the specimens. These characteritics were confirmed in this study, but not to the degree which Suzuki *et al.* stated. These characteristics developed to the highest level in the Kamakura period, especially the dolichocranic condition of the females, which was remarkably different from the crania in the periods before and after this period. On the other hand, the lateral profile of the forehead showed an intermediate stage of development between the Kofun and Edo periods. Naito and Matsushita (1978) recognized the same characteristics as those of the Zaimokuza people in the medieval specimens from Kyushu and concluded that the characteristics found by Suzuki *et al.* (1956) were widespread all over the mainland Japan during this period. Since there seems to be no drastic environmental change, socioeconomical change nor the movement of people during this period, the peculiar characteristics are curious. Ikeda (1982) suggested that the characteristics which appeared in the medieval cranium were caused by an intensified endogamy. His suggestion may be a clue to explain this phenomenon.

5. EDO PERIOD AND RECENT TIMES

Although the Edo people did not differed very much from the Kamakura people, except for the N. V. outlines of the females, the cranial shape of the Edo people did show some mordernized characteristics, such as a higher face with an anteriorly projected nasal roof, a more rounded and vertical forehead, and a reduced dolichocranic condition. All of these morphological changes have continued up to recent times. This result confirms the studies by Suzuki *et al.* (1957, 1962) and Suzuki (1969).

The recent people from Niigata prefecture have undergone quite small changes from the Edo people in Tokyo. By contrast, the recent Kyoto people showed largely different characteristics from the latter. They exhibited the roundest cranial shape among all of the mainland Japanese groups in this study. On the other hand, the Edo specimens from Osaka prefecture had a rounder crania than those from Tokyo. They were situated the margin or outside of the variation of the Edo people from Tokyo in the MDS analysis. Kanda (1959) pointed out the close similarity of the Edo specimens from Osaka city to the modern specimens from Kinki district, excluding the weak difference of facial profile. This indicates a close similarity between the Edo and recent peoples in the Kinki district. Indeed, the comparison between the craniometrical data obtained from Kanto district (Suzuki *et al.*, 1962) and those from Kinki district (Kanda, 1959) suggests that the people in Kinki district underwest smaller changes between these periods than the people in Kanto district.

As a whole, it can be said that the Edo people were on the way to moderization, but the process of modernization was not uniform throughout all areas of the mainland Japan. In this contex, it is probable that the people in Niigata prefecture, especially the males, underwent quite small changes between these periods.

Regional differences of cranial shape have obviously existed between Niigata and Kyoto prefectures in recent times. The cranium from Niigata prefecture was relatively low and somewhat long and narrow in its horizontal outline compared with the cranium from Kyoto prefecture and closely similar to the cranium of the Edo people from Tokyo, as mentioned above. The morphological differences between the Niigata and Kyoto groups recognized in this study are in agreement with the study by Hanihara *et al.* (1982) who examined the craniomentrical data from 12 regional groups.

Concerning the magnitude of the differences, however, Yamaguchi (1981a) and Dodo (1982) concluded that the regional differences between contemporary groups can be ignored when they are compared to the differences between the groups in different periods. Their conclusion is opposite to the present results.

6. Ainu and Nansei Islanders

The local variations in the Ainu have naturally been an analytical subject of interest because they have lived in such a wide area, including the whole of Hokkaido, Sakhalin, and some of the Kurile islands. According to this analysis, although some local differences were found, as have been pointed out by previous studies (Ito, 1967; Yamaguchi 1981b), there are some conflicting conclusions. The local differences in the Ainu were genarally greater in the females than in the males. The Ainu groups from the Sakhalin, and the Southwestern and Okhotsk coast areas of Hokkaido each showed a local specificity. In males, the variations in the N. L. outlines of these three Ainu groups almost overlapped, while the variations in the N. V. the groups from Sakhalin and Okhotsk coast of Hokkaido were distinct from each other. Although Ito (1967) pointed out a similarity between the Sakhalin and Okhotsk coast Ainu groups, present results do not. Yamaguchi (1981b) said that there existed a clear craniomentrical differences between the two Hokkaido Ainu groups from the Southwestern and Pacific coast areas, however, this study does not agree with his conclusions, since the Ainu from Pacific coast area showed great individual variations, and did not clearly differ from the Southwestern Hokkaido Ainu. Among the females, the Sakhalin and Southwestern

Hokkaido Ainu groups were distingunishable from each other, and the differences between them were rather great.

Genetic influences on the Ainu from outer peoples have been sometimes suggested, with the introgressions from the Northern peoples (Yamaguchi, 1982) and from the mainland Japanese (Yamaguchi, 1981b) as the most likely route. The specimens of the Okhotsk culture and Aleut, though quite few in number, were compared with the Ainu groups, but none showed special similarity to any Ainu groups. The Southwestern Hokkaido Ainu showed a somewhat close similarity to the female mainland Japanese groups in the N. L. outline but, as a whole, the Ainu were similar to each other and seem to have their own special characteristics.

Although Yamaguchi (1981b) suggested that the Ainu groups from the Pacific coast and nearby Tomamae (Eastern Hokkaido in his term) are typical, the cranial outlines of this Ainu group showed a great individual variation which comprised the variation of the other Ainu groups.

Hanihara (1985) and Dodo (1986) stated that the Ainu originated from the Jomon people and that they retain many Jomonoid characteristics as a result of a different process of morphological change from that of the mainland Japanese. They classified the Jomon and Ainu peoples as Proto- or Pre-Mongoloid. Present analysis of the outline morphology led us to a different conclusion from them. It was only in the N. L. outline of the Sakhalin Ainu females that a close similarity to the Jomon (Tsukumo) people appeared. The other Ainu groups relatively resembled the Kofun and Kamakura peoples rather than Jomon people among prehistoric and historic groups. As a whole, they showed a specific shape difference to the mainland Japanese groups. If the Ainu originated from the common Jomon people, it might be said that the morphological changes of the Ainu are parallel to the changes of the mainland Japanese which occurred from the Jomon to Kofun periods.

The outlines of the Nansei Islanders in all cases were within the range of the mainland Japanese groups in contrast to Ainu. The studies on the affinity of the Nansei Islanders to other peoples have been inconsistent between craniometric analysis (Tagaya & Ikeda, 1976) and somatometric analysis (Ikeda & Tagaya, 1980) or biochemical analyses (e.g., Nakajima *et al.*, 1976). Present results were in agreement with the craniometric study. But since the Nansei Islanders showed a similarity to the Kofun people and somewhat differed from the contemporary Edo and recent mainland people, except for the N. L. outline of the males, they may have changed through a different process than that of the mainland Japanese.

7. HISTRY OF CRANIAL MORPHOLOGY IN JAPANESE

Until Suzuki's study (1967), it was not revealed with a background of morphological detail that the cranial form in the Japanese had changed through the history of this population. Most anthropological studies in Japan before him focused upon the affinity between populations based on some morphological similarity without regarding the temporal change of morphological characteristics. Suzuki (1969) revealed that Japanese (in Kanto district) underwent drastic changes of cranial form and stature in the Yayoi period, and from the Edo period onward. He attributed the cause of these changes to the changes in the socioeconomical system which was proposed by Hasebe (1949).

According to this study, the part on the outlines which underwent the greatest change throughout all of the periods was the occipital. This bone seems to be easily modified by mechanical stress arisen from the sustentacular muscular system. In the analysis of intragroup allometry, the area showing positive allometries gradually shifted from the posterior margin to the anterior in the horizontal outline. These facts seem to support the transformation hypothesis (Suzuki, 1981), but there remain some problems which cannot be explained by this hypothesis. It is thought that the Jomon people developed their masticatory muscles because they had heavily worn teeth. However, the form of temporal fossa which is susceptive to the stress of the temporal muscle showed a great difference between the two late/final Jomon regional groups. The temporal fossa of the final Jomon people from the Tsukumo site was shallow and had an odd bulge at the midplace in contrast with a deeply concaved temporal fossa in the Northeastern group. This suggests that the form of the temporal fossa does not necessarily correspond to masticatory stress. Rather it is thought that there was some site-specific morphological traits independent of the life mode, because no data indicates a difference in their subsistence economies.

Among the changes in cranial shape, the profile of the forehead showed a directional change in which it became more and more rounded and vertically oriented throughout all of the periods, whereas the projection of the nasal roof, alveolar prognathism, and shape of the horizontal outline altered their mode of change in the medieval Kamakura period. Although most of them were revealed by Suzuki (1969), these facts are not concordant with his transformation hypothesis. Moreover, in the changes from the Edo period onward, there seems to be some geographical variation in morphological changes. Despite the fact that the two recent groups are contemporary, or rather the Kyoto specimens were older, the recent Niigata group underwent quite small changes from the Edo people, whereas the recent Kyoto group showed great changes from the Edo people, and displayed a peculiar round cranial shape when compared with the other mainland Japanese groups (it is probable that the Edo people in the area nearby Kyoto prefecture had a vestige of the cranial shape of the recent Kyoto people). It is improbable that there was a great regional difference in the socioeconomical system which caused this large variation of morphological change between the Edo period and recent times.

Another suggestion for the cause of the morphological changes, especially in the Yayoi period, is migration from the Asian continent (Kanaseki, 1955). In this case, it is impossible to separate the physical effects of migration on the morphological change from those of socioeconomical change, because the immigrants from the Asian continent might have come to Japan bringing a subsistence economy differed from that of the native people. The replacement or absorption of the Japanese by the immigrants is a phylogenetic problem. It is necessary to identify the characteristics which remain stable under environmental stress and which can be used for the estimation of the phylogenetic affinity. This criterion cannot be certified now. In this study, although I used an overall similarity of the outlines, all of the adjacent populations showed a specific morphology of their own compared with the prehistoric and historic mainland Japanese groups (Yayoi people were not an exception), so that it is impossible to infer which is the ancestral population of the present Japanese. Since it is thought that the peoples of the outer areas also underwent some morphological changes a study on morphological changes involving many populations in adjacent areas is required.

The cranial shape in the Japanese changed from the Jomon period to recent times. Each cranial part did not necessarily have a uniform contribution to this change. Nevertheless, according to the analyses of the outlines and of the allometory as a whole, the changes of cranial morphology in the mainland Japanese apparently restricted within a limit when compared with the adjacent populations. The cranial shape of any mainland Japanese groups decidedly differed from the Ainu and modern Korean. In the history of this morphological change, there were some geographical variations, of which the variations in the Jomon period and recent times were considerably great. This fact claims to reconsider the result of Yamaguchi (1981a) and Dodo (1982) who underestimated the geographical variation against the temporal change.

In the geographical variations clarified by the present study, the Tsukumo people which have most frequently been referred to as the representative group of the Jomon people showed site-specific characteristics. The specificity of the Tsukumo people may support the suggestion of Howells (1966) who pointed out that the Jomon people were isolated in relatively small tribal populations. On this point we must await more detailed analyses of site specificity in the Jomon period. To make clear the geographical variation in the Jomon period, it is necessary to analyze the subtle morphological traits of each site. On the other hand, the Kofun people who lived in the first imperialized society showd a morphological variation corresponding to tumb types, which may reflect the differentiation of the socioeconomy during this period. Also they showed a large-scaled geographical variation in which the specimens from Kanto district had a longer and narrower cranium in contrast with the specimens from the western part of Honshu. This geographical variation also occurred in the Edo period and recent times, with emphasized differences. These facts indicate that the pattern of geographical variations in the cranial shape of the mainland Japanese changed with the times. Therefore, accurate analyses on the changing pattern of geographical variation throughout the times could give a clue for revealing the cause of morphological change in the Japanese.

Suzuki (1967) suggested that the drastic change in the modern Japanese is caused by an "Urbanizing injury", but he attributed most of it to changes in life style. On the other hand, Ikeda (1981) stated that morphological changes showing geographical or social differences were produced by the geographical or social inequality of mating distances (exogamy in urbunization and endogamy in ruralization). His hypothesis is reasonably explicable to the process of morphological changes in the Japanese, but it can also explain everything if there is no prudent check. It needs further examination in detail.

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Appendix 1. Non-size-standardized DIRs (×100) for all male groups and individuals.

	KYT	NGT	EDO	KMR	KFN	YYI	TSM	NEJ	OTA	KMW	MTW
R Kyoto		0.93	1.30	1.48	0.96	0.92	0.98	1.48	2.07	2.36	2.68
R Niigata	2.13		0.65	1.04	0.55	1.05	0.69	1.35	1.78	2.51	3.03
Edo	1.69	1.06		0.84	0.69	1.23	0.92	1.30	1.70	2.74	3.15
Kamakura	2.07	1.71	1.28		1.04	1.66	1.41	1.23	1.84	3.13	3.13
Kofun	2.64	1.25	1.53	1.41		1.15	0.77	1.11	1.75	2.44	2.77
Yayoi	1.99	1.10	1.25	1.43	1.03		1.13	1.74	2.28	2.42	2.82
Tsukumo	2.89	2.02	2.25	2.05	1.60	1.54		1.58	1.92	2.35	3.12
NE Jomon	2.17	2.04	1.95	1.55	1.74	1.63	1.96		1.89	2.87	2.43
Ota	2.22	3.11	3.06	2.94	3.17	2.79	3.04	2.30		3.42	3.56
Kamikuroiwa	3.60	3.06	3.07	3.55	3.76	3.55	4.01	4.17	4.91		2.92
Minatogawa	4.34	3.87	4.03	3.33	3.07	3.44	3.00	3.04	5.85	3.71	

Upper right is horizontal outline and lower left midsagittal one.

Appendix 2. Non-size-standardized DIRs (×100) for all female groups and individuals.

	KYT	NGT	EDO	KMR	KFN	YYI	TSM	NEJ	OTA	FJZ
R Kyoto		1.14	1.75	3.44	1.83	1.82	1.55	1.51	1.56	1.30
R Niigata	1.49		1.11	2.95	1.32	1.16	1.08	1.31	1.81	1.60
Edo	1.88	1.01		2.00	0.66	1.05	1.19	1.27	2.03	2.14
Kamakura	2.43	1.72	1.24		1.83	2.21	2.72	2.75	3.55	3.58
Kofun	2.09	1.36	1.27	1.04		0.89	1.08	1.26	1.99	1.94
Yayoi	2.27	1.60	1.43	1.53	1.08		1.20	1.54	2.19	1.88
Tsukumo	3.21	2.40	2.30	1.89	1.62	1.59		1.13	1.75	1.69
NE Jomon	2.10	2.38	2.45	2.47	2.28	2.65	2.92		1.79	1.86
Ota	2.34	2.64	2.90	3.41	2.99	3.01	3.61	3.01		1.50
Fujizuka Early Jomon	4.26	3.62	3.37	3.01	2.92	2.92	2.48	3.22	4.70	

Upper right is horizontal outline and lower left midsagittal one.

Appendix 3. Size-standardized DIRs (×100) for all male groups in the mainland Japan and neighboring populations.

	KYT	NGT	EDO	KMR	KFN	YYI	TSM	NEJ	SKA	SHA	NNI	KRA	NEC
R Kyoto		1.03	1.36	1.52	1.09	0.90	1.09	1.56	1.32	1.89	1.08	1.79	1.15
R Niigata	2.20		0.63	1.02	0.60	1.11	0.73	1.39	0.85	1.61	0.58	1.89	1.25
Edo	1.94	1.06		0.83	0.68	1.29	0.94	1.28	0.76	1.42	0.80	2.11	1.62
Kamakura	2.05	1.70	1.28		1.05	1.72	1.49	1.22	0.93	0.82	0.95	2.68	2.06
Kofun	2.52	1.30	1.44	1.39		1.14	0.81	1.19	0.90	1.65	0.53	2.13	1.52
Yayoi	2.06	1.13	1.23	1.43	1.03		1.10	1.73	1.42	2.11	1.21	1.51	1.04
Tsukumo	2.90	2.01	2.27	2.05	1.61	1.55		1.58	1.26	1.84	0.97	1.76	1.28
NE Jomon	2.16	2.00	2.02	1.57	1.60	1.63	1.94		1.14	1.24	1.05	2.73	2.09
Sakhalin Ainu	3.43	1.96	2.12	2.10	1.29	1.88	2.29	2.42		1.24	0.73	2.17	1.55
S Hokkaido Ainu	3.73	2.28	2.37	2.18	1.54	2.25	2.25	2.41	1.35		1.41	3.17	2.55
Nansei Is.	2.12	1.81	1.55	1.28	1.70	1.61	2.33	1.70	2.31	2.22		2.04	1.45
Korea	1.72	3.10	2.76	3.11	3.72	3.01	3.92	3.26	4.43	4.64	3.13		0.95
NE China	1.23	1.97	1.78	1.90	2.35	1.75	2.65	1.94	3.09	3.42	2.12	1.99	

Upper right is horizontal outline and lower left mdsagittal one.

Appendix 4. Size-standardized DIRs (×100) for all female groups in the mainland Japan and neighboring populations.

	KYT	NGT	EDO	KMR	KFN	YYI	TSM	NEJ	SKA	SHA	NNI	KRA	NEC
R Kyoto		1.18	1.70	3.35	1.67	1.77	1.53	1.44	2.33	2.76	1.98	1.50	1.15
R Niigata	1.48		1.10	2.89	1.23	1.15	1.06	1.24	1.77	2.33	1.45	1.83	0.82
Edo	1.88	1.01		2.01	0.81	1.05	1.25	1.31	1.24	1.47	0.96	2.71	1.32
Kamakura	2.44	1.72	1.24		1.96	2.19	2.77	2.81	1.47	1.30	1.97	4.46	3.26
Kofun	2.10	1.36	1.26	1.03		0.97	1.21	1.37	1.06	1.81	0.99	2.82	1.87
Yayoi	2.27	1.61	1.43	1.53	1.08		1.24	1.56	1.13	1.99	1.06	2.74	1.64
Tsukumo	3.20	2.39	2.29	1.89	1.61	1.59		1.13	1.54	2.51	1.26	2.60	1.63
NE Jomon	2.21	2.52	2.47	2.47	2.28	2.73	2.93		1.88	2.40	1.44	2.34	1.57
Sakhalin Ainu	3.46	2.51	2.17	1.95	1.87	2.02	1.85	3.02		1.64	0.92	3.46	2.33
S Hokkaido Ainu	2.00	1.37	1.46	1.51	1.23	1.74	2.24	2.10	1.93		1.66	3.52	2.44
Nansei Is.	1.63	1.19	1.40	1.56	1.27	1.58	2.24	1.87	2.20	1.52		2.84	1.63
Korea	1.99	3.19	3.41	3.93	3.60	3.82	4.73	3.09	5.02	3.26	3.18		2.16
NE China	1.67	1.41	1.47	1.73	1.42	1.81	2.69	2.52	2.59	1.32	1.74	2.85	

Upper right is horizontal outline and lower left mdsagittal one.

EXPLANATION OF FIGURES 5–32, 35–38, 42, AND 43

Fig. 5. MDS analysis using the DIRs for the Minatogawa man and Jomon males: A, horizontal outline; B, midsagittal outline.

Fig. 6. MDS analysis using the DIRs for the Jomon females: A, horizontal outline; B, midsagittal outline.

Fig. 7. Comparison between two local late/final Jomon male groups from the Tsukumo site (n=7 in both outlines, solid line) and Northeastern Japan (n=8 in midsagittal and n=10 in horizontal, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. Zone within two thin lines is 95% confidence limit for averaged outline. Innermost lines are C. V.×0.5. Arrows indicate the differences between two groups.

Fig. 8. Comparison between two local late/final Jomon female groups the Tsukumo site (n=9 in both outlines, solid line) and Northeastern Japan (n=8 in midsagittal and n=6 in horizontal, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 7.

Fig. 9. MDS analysis using the DIRs for the Yayoi males: A, horizontal outline; B, midsagittal outline.

Fig. 10. MDS analysis using the DIRs for the Yayoi females: A, horizontal outline; B, midsagittal outline.

Fig. 11. MDS analysis using the DIRs for the Kofun males: A, horizontal outline; B, midsagittal outline.

Fig. 12. MDS analysis using the DIRs for the Kofun females: A, horizontal outline; B, midsagittal outline.

Fig. 13. Comparison between two recent local male groups from Niigata (n=50 in midsagittal and n=51 in horizontal, solid line) and Kyoto (n=60 in midsagittal and n=56 in hroizontal, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 7.

Fig. 14. Comparison between two recent local female groups from Niigata (n=41 in midsagittal and n=40 in horizontal, solid line) and Kyoto (n=70 in both outlines, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 7.

Fig. 15. MDS analysis using the DIRs for the Ainu and Okhotsk culture males: A, horizontal outline; B, midsagittal outline.

Fig. 16. MDS analysis using the DIRs for the Ainu and Aleut females: A, horizontal outline; B, midsagittal outline.

Fig. 17. Comparison between two Ainu local male groups from Sakahalin (n=21 in both outlines, solid line) and southwestern Hokkaido (n=8 in both outlines, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 7.

Fig. 18. Comparison between two Ainu local female groups from Sakhalin (n=11 in midsagittal and n=10 in horizontal, solid line) and southwestern Hokkaido (n=10 in midsagittal and n=8 in horizontal, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 7.

Fig. 19. Changes of the male cranial outlines from the late/final Jomon (Tsukumo; n=7 in both outlines, solid line) to Yayoi (n=25 in both outlines, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. Zone within two thin lines is 95% confidence limit for averaged outline. Innermost lines are C. V.×0.5. Arrows indicate the differences between two groups.

Fig. 20. Changes of the female cranial outlines from the late/final Jomon (Tsukumo; n=9 in both outlines, solid line) to Yayoi (n=11 in midsagittal and n=9 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 21. Changes of the male cranial outlines from the late/final Jomon (Northeastern; n=8 in midsagittal and n=10 in horizontal, solid line) to Yayoi (n=25 in both outlines, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 22. Changes of the midsagittal outline of the female crania between the Northeastern late/final Jomon group (n=8, solid line) and Yayoi people (n=11, broken line). Averaged outlines were size-standardized. See the explanation of Fig. 19.

Fig. 23. Changes of the male cranial outlines from the Yayoi (n=25 in both outlines, solid line) to Kofun (n=40 in midsagittal and n=36 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 24. Changes of the female cranial outlines from the Yayoi (n=11 in midsagittal and n=9 in horizontal, solid line) to Kofun (n=21 in midsagittal and n=19 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 25. Changes of the male cranial outlines from the Kofun (n=40 in midsagittal and n=36 in horizontal, solid line) to Kamakura (n=27 in midsagittal and n=28 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 26. Changes of the female cranial outlines from the Kofun (n=21 in midsagittal and n=19 in horizontal, solid line) to Kamakura (n=13 in midsagittal and n=10 in horizontal, broken line) periods. Average outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 27. Changes of the male cranial outlines from the Kamakura (n=27 in midsagittal and n=28 in horizontal, solid line) to Edo (n=57 in midsagittal and n=55 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 28. Changes of the female cranial outlines from the Kamakura (n=13 in midsagittal and n=10 in horizontal, solid line) to Edo (n=29 in midsagittal and n=27 in horizontal, broken line) periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 29. Changes of the male cranial outlines from the Edo period (n=57 in midsagittal and n=55 in horizontal, solid line) to recent times (Niigata; n=50 in midsagittal and n=51 in horizontal, broken line). Averaged outline were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 30. Changes of the female cranial outlines from the Edo period (n=29 in midsagittal andn=27 in horizontal, solid line) to recent times (Niigata; n=41 in midsagittal and n=40 in horizontal, broken line). Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 31. Changes of the male cranial outlines from the Edo period (n=57 in midsagittal and n=55 in horizontal, solid line) to recent times (Kyoto; n=60 in midsagittal and n=56 in horizontal, broken line) periods. Average outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 32. Changes of the female cranial outlines from the Edo period (n=29 in midsagittal and n=27 in horizontal, solid line) to recent times (Kyoto; n=70 in both outlines, broken line)

periods. Averaged outlines were size-standardized: A, horizontal outline; B, midsagittal outline. See the explanation of Fig. 19.

Fig. 35. MDS analysis of the cranial shape changes in males based on the intergroup DIRs: A, horizontal outline; B, midsagittal outline.

Fig. 36. MDS analysis of the cranial shape changes in females based on the intergroup DIRs: A, horizontal outline; B, midsagittal outline.

Fig. 37. Partial deformations occurred in the changes of cranial form in males. Each ellipsis shows the magnitude of deformation, and cross shows the orientation of maximum and minimum dilatations. See the legend of Fig. 34 for abbreviations.

Fig. 38. Partial deformations occurred in the change of cranial form in females. See the legends of Figures 34 and 37.

Fig. 42. Relationship among the male groups of the mainland Japanese and neighboring populations, based on the size-standardized DIRs.

Fig. 43. Relationship among the female groups of the mainland Japanese and neighboring populations, based on the size-standardized DIRs.

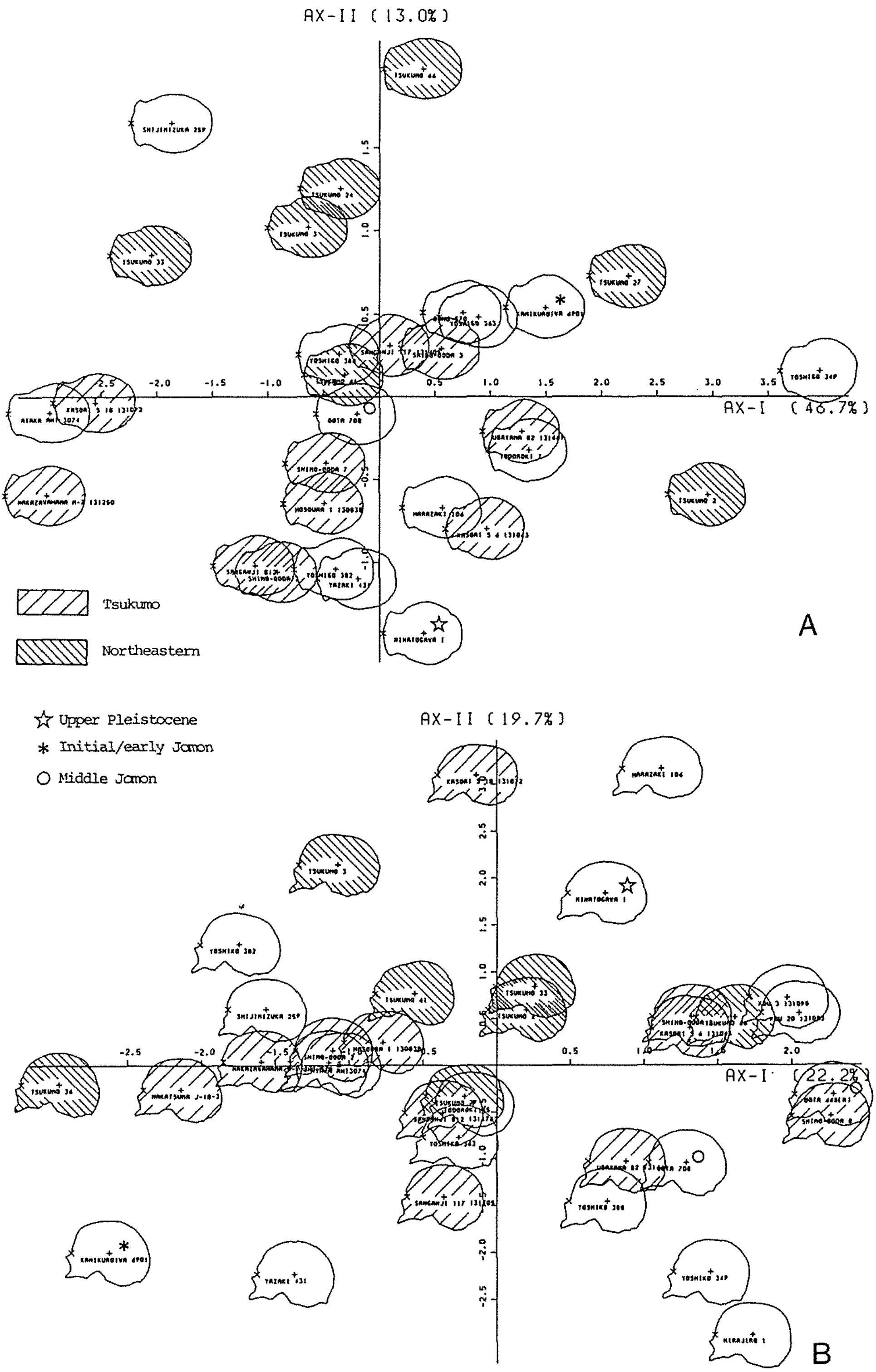

AX-II (13.0%)
AX-I (46.7%)
Tsukumo
Northeastern
A
Upper Pleistocene
Initial/early Jomon
Middle Jomon
AX-II (19.7%)
AX-I (22.2%)
B

Fig. 5

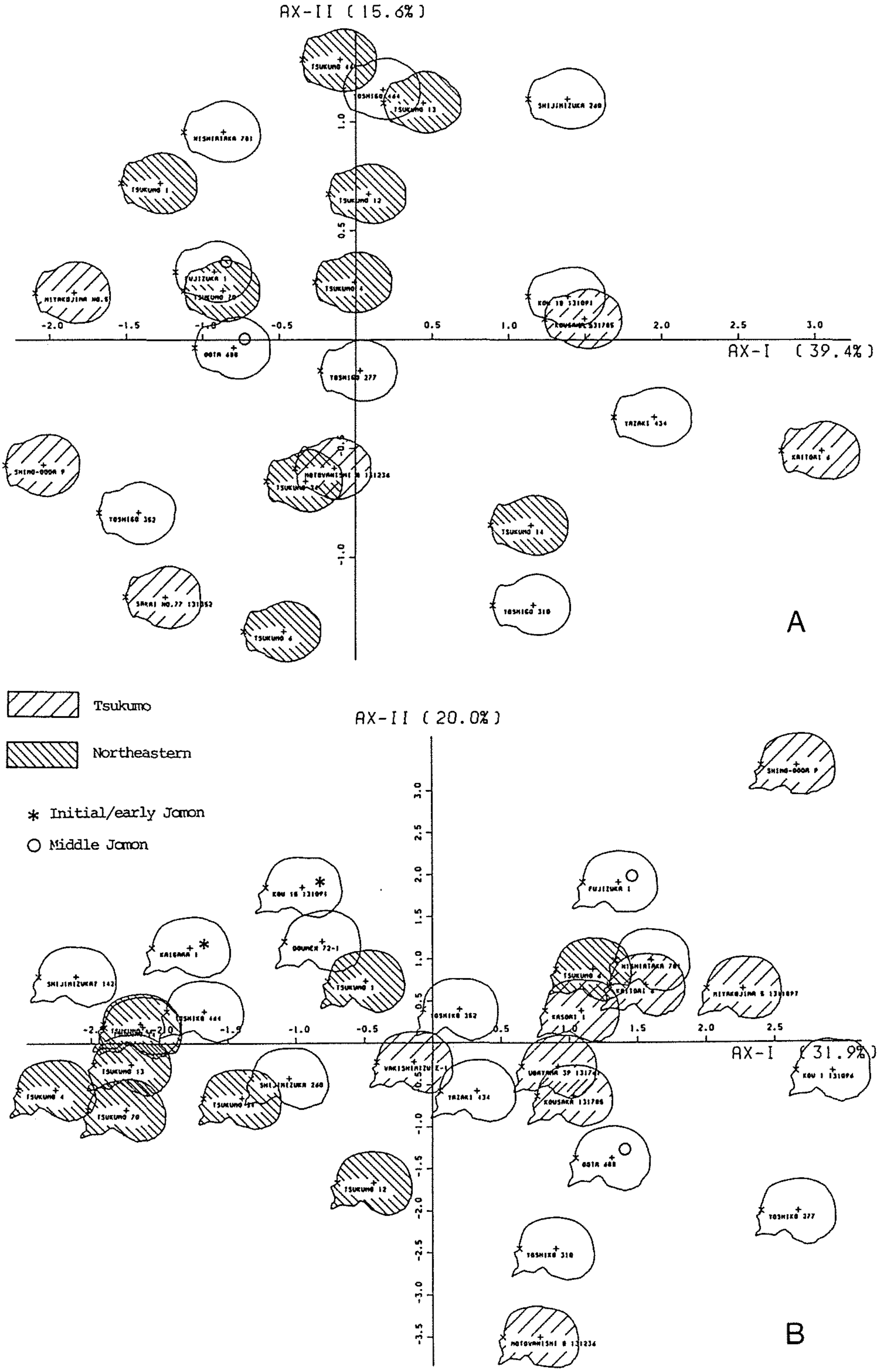

AX-II (15.6%)
AX-I (39.4%)
A
Tsukumo
Northeastern
* Initial/early Jomon
O Middle Jomon
AX-II (20.0%)
AX-I (31.9%)
B

Fig. 6

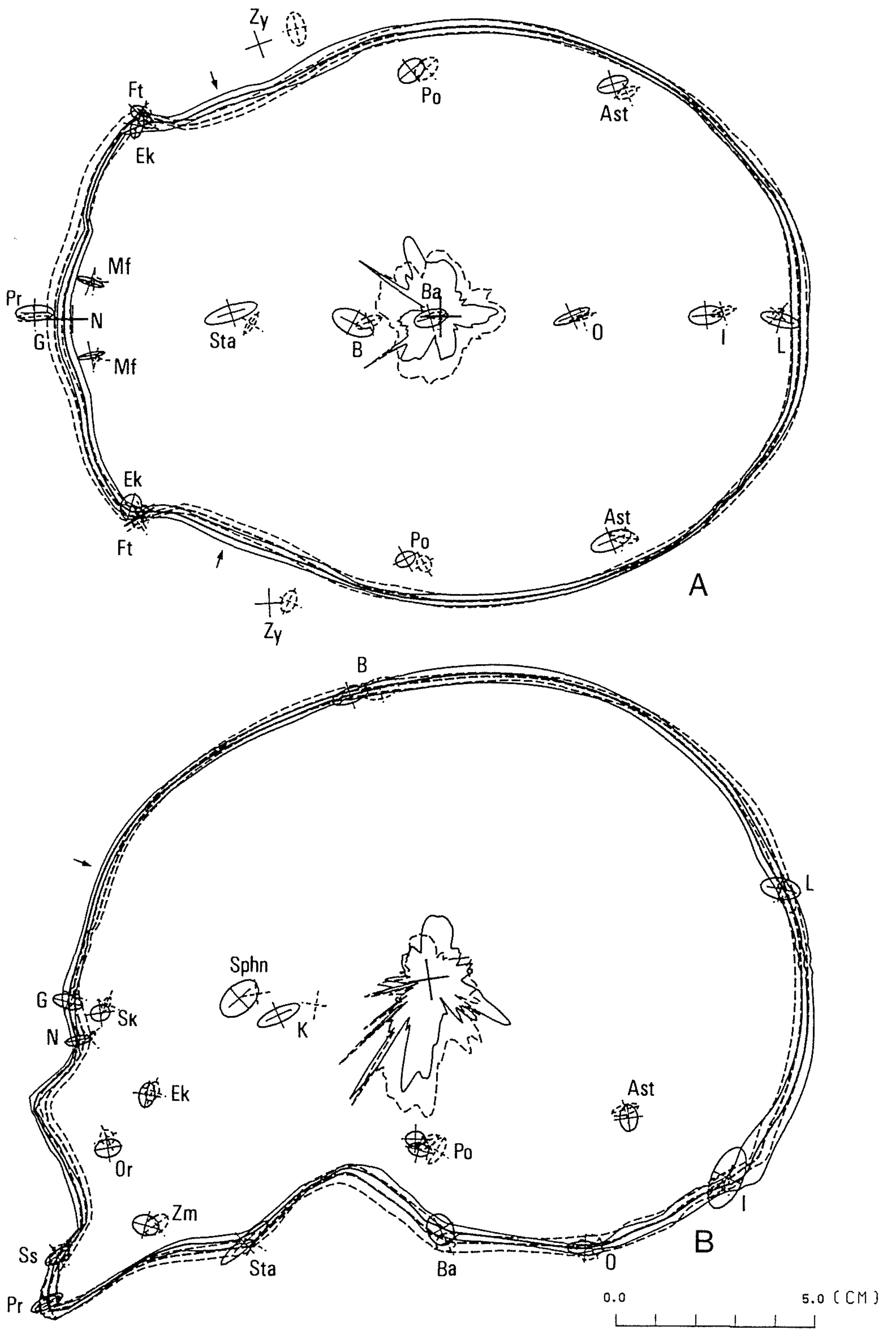

Zy
Ft
Po
Ast
Ek
Mf
Pr
N
G
Sta
Ba
B
O
I
L
Mf
Ek
Ft
Po
Ast
A
Zy
B
L
Sphn
G
Sk
K
N
Ek
Ast
Or
Po
Zm
I
B
Ss
Sta
Ba
O
Pr
0.0
5.0 (CM)

Fig. 7

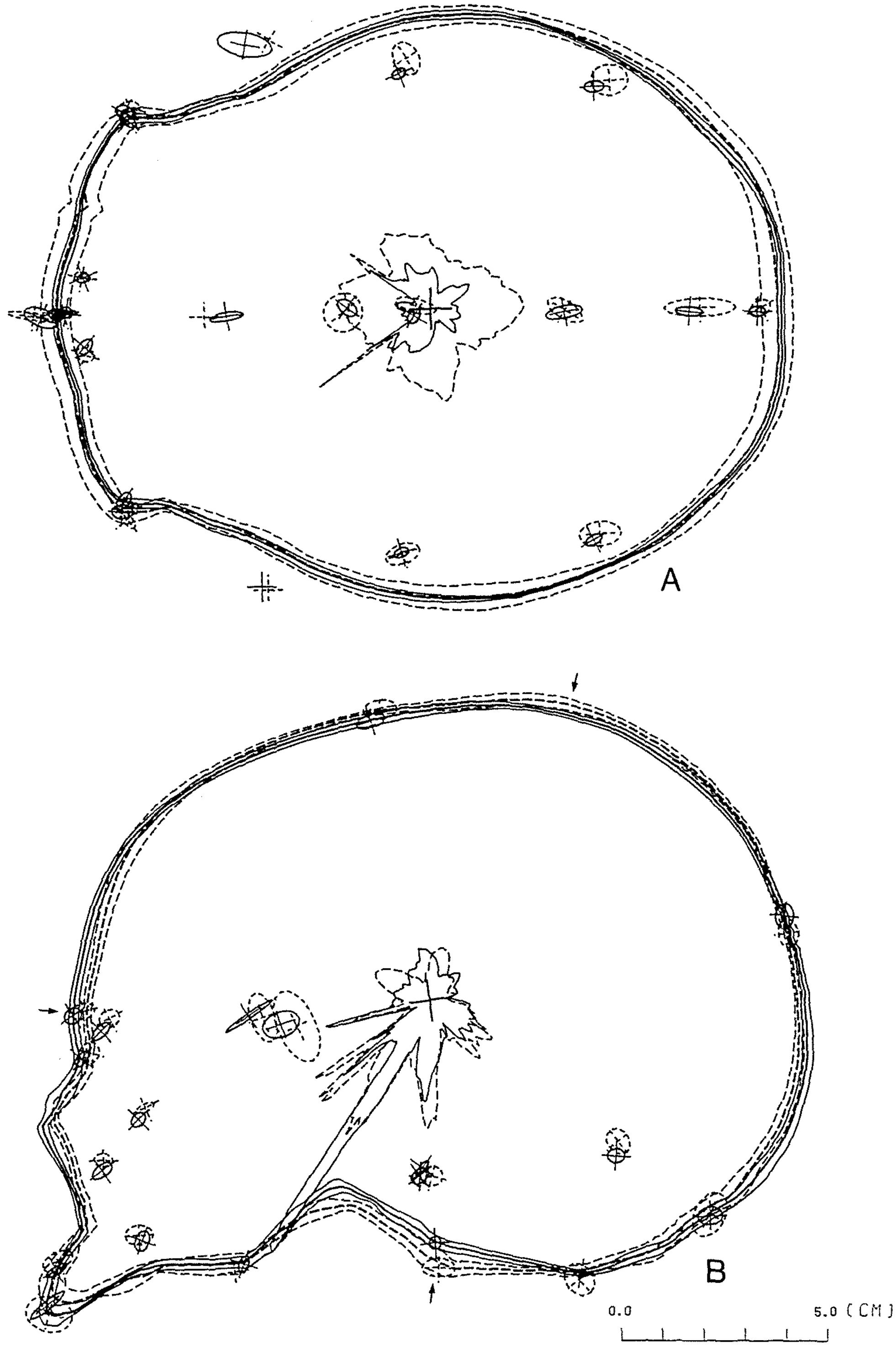


Fig. 8

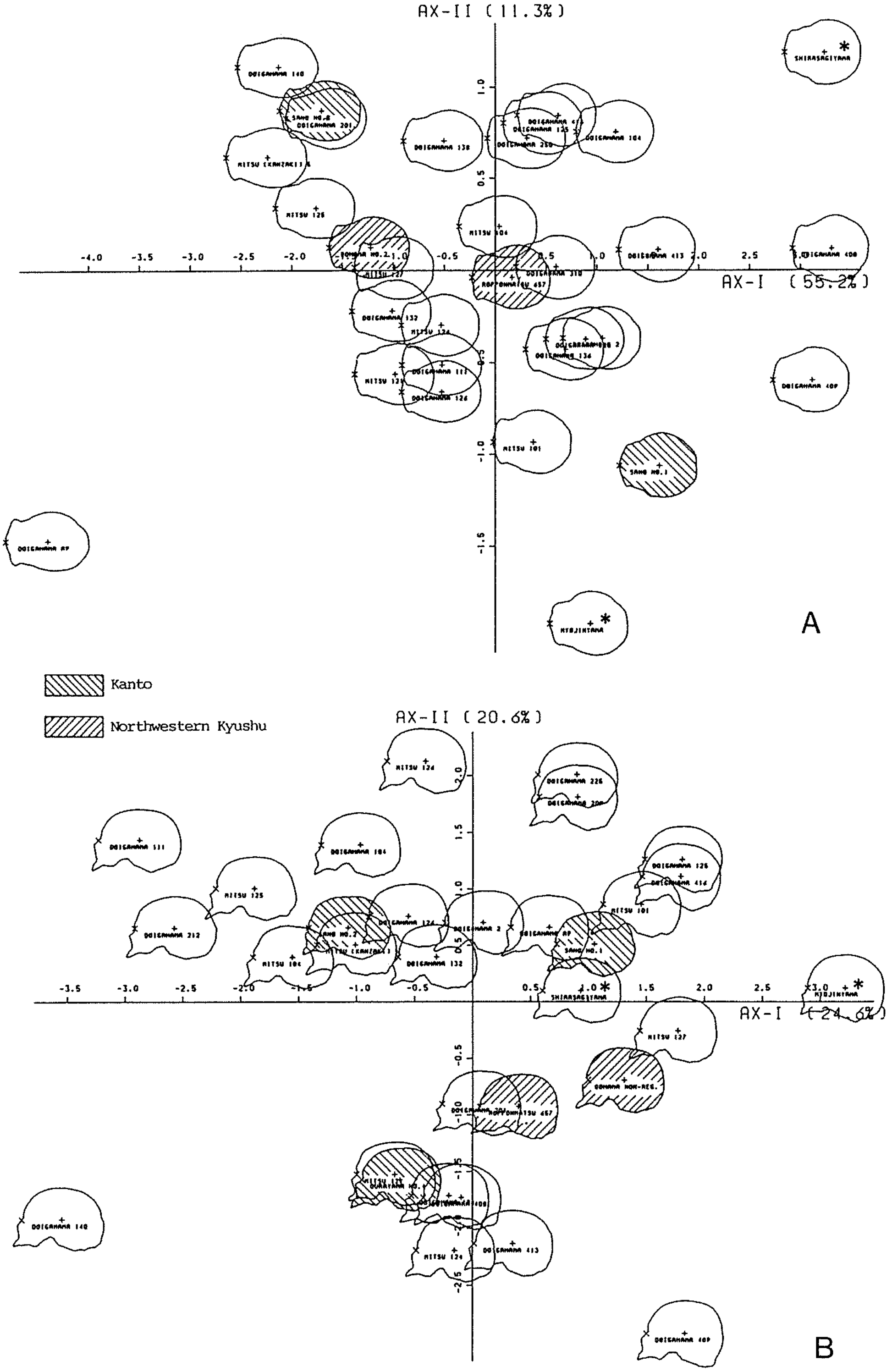

AX-II (11.3%)
AX-I (55.2%)
A
Kanto
Northwestern Kyushu
AX-II (20.6%)
AX-I (24.6%)
B

Fig. 9

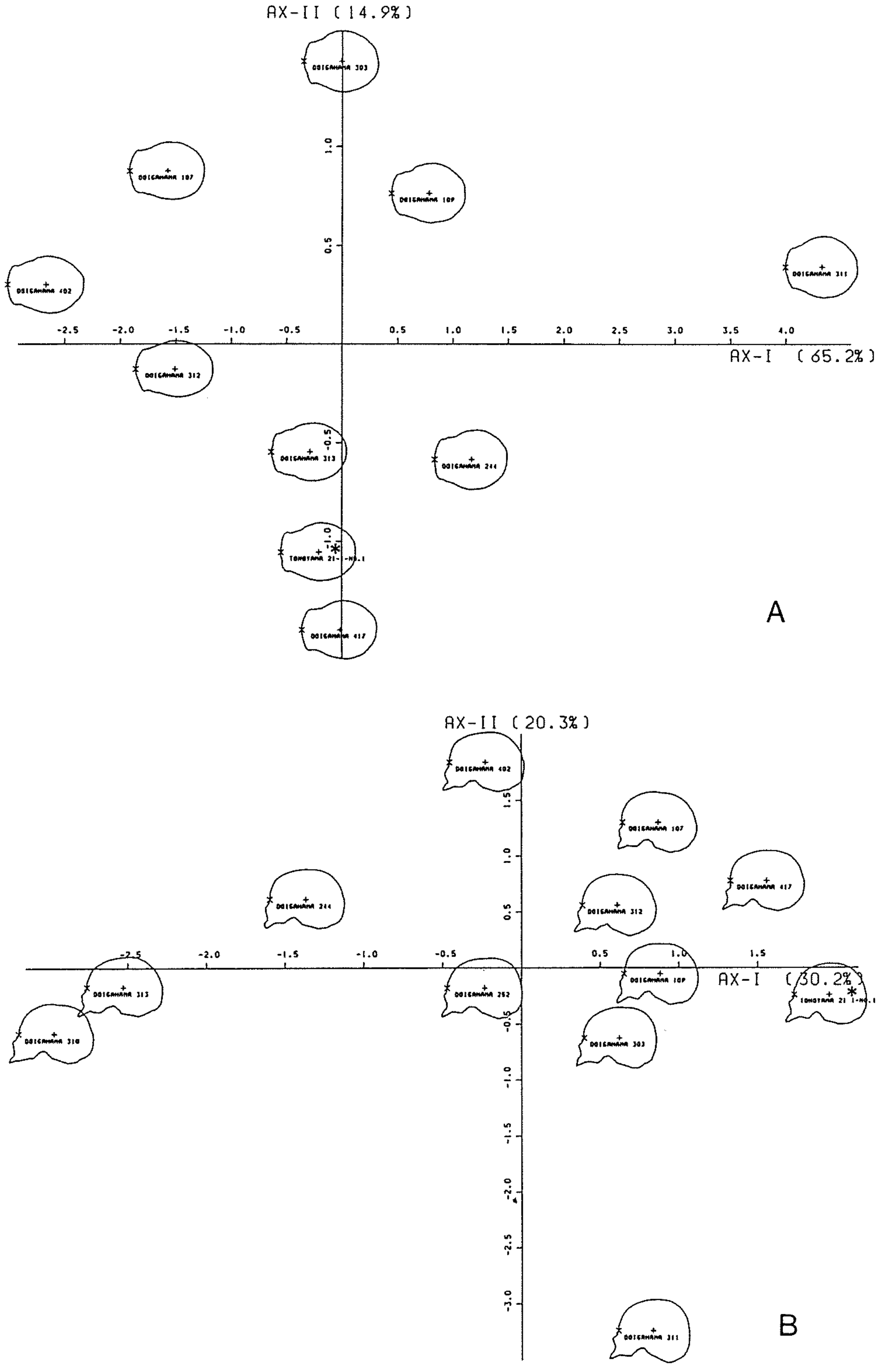


Fig. 10

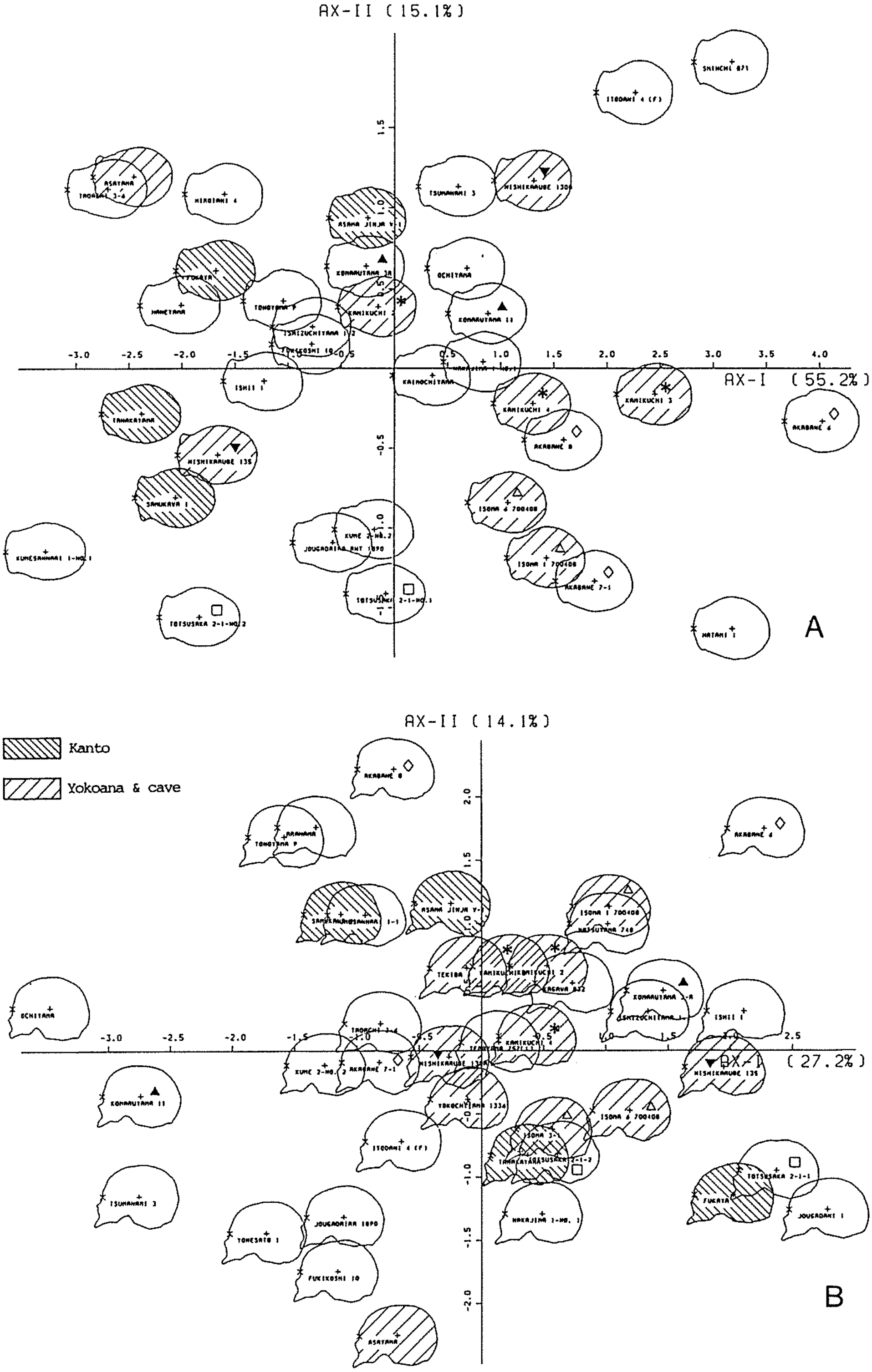


Fig. 11

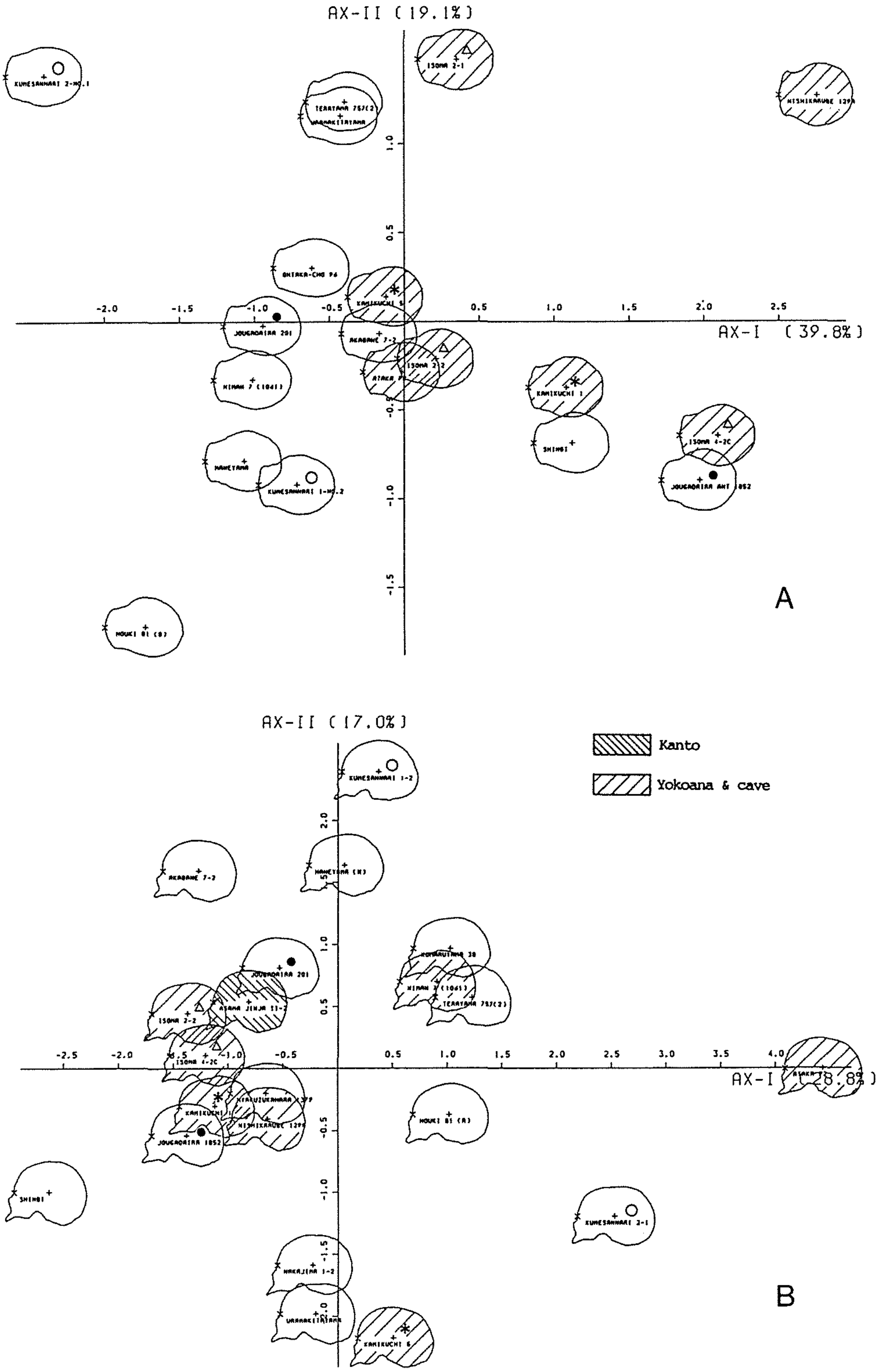


Fig. 12

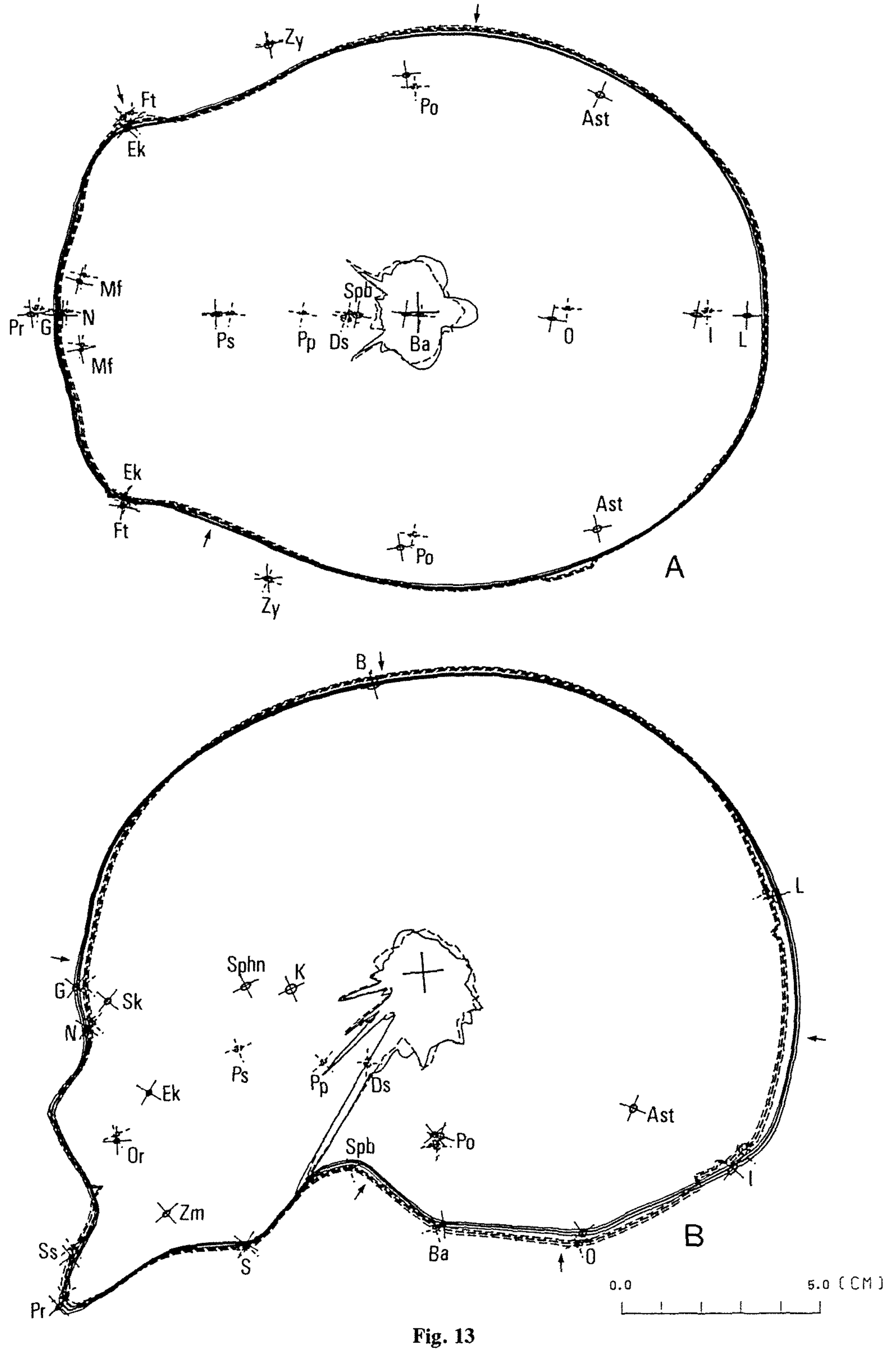

Zy
Ft
Ek
Po
Ast
Mf
Spb
Pr
G
N
Ps
Pp
Ds
Ba
O
I
L
A
B
Sphn
K
Sk
Or
Zm
Ss
S
0.0
5.0 (CM)

Fig. 13

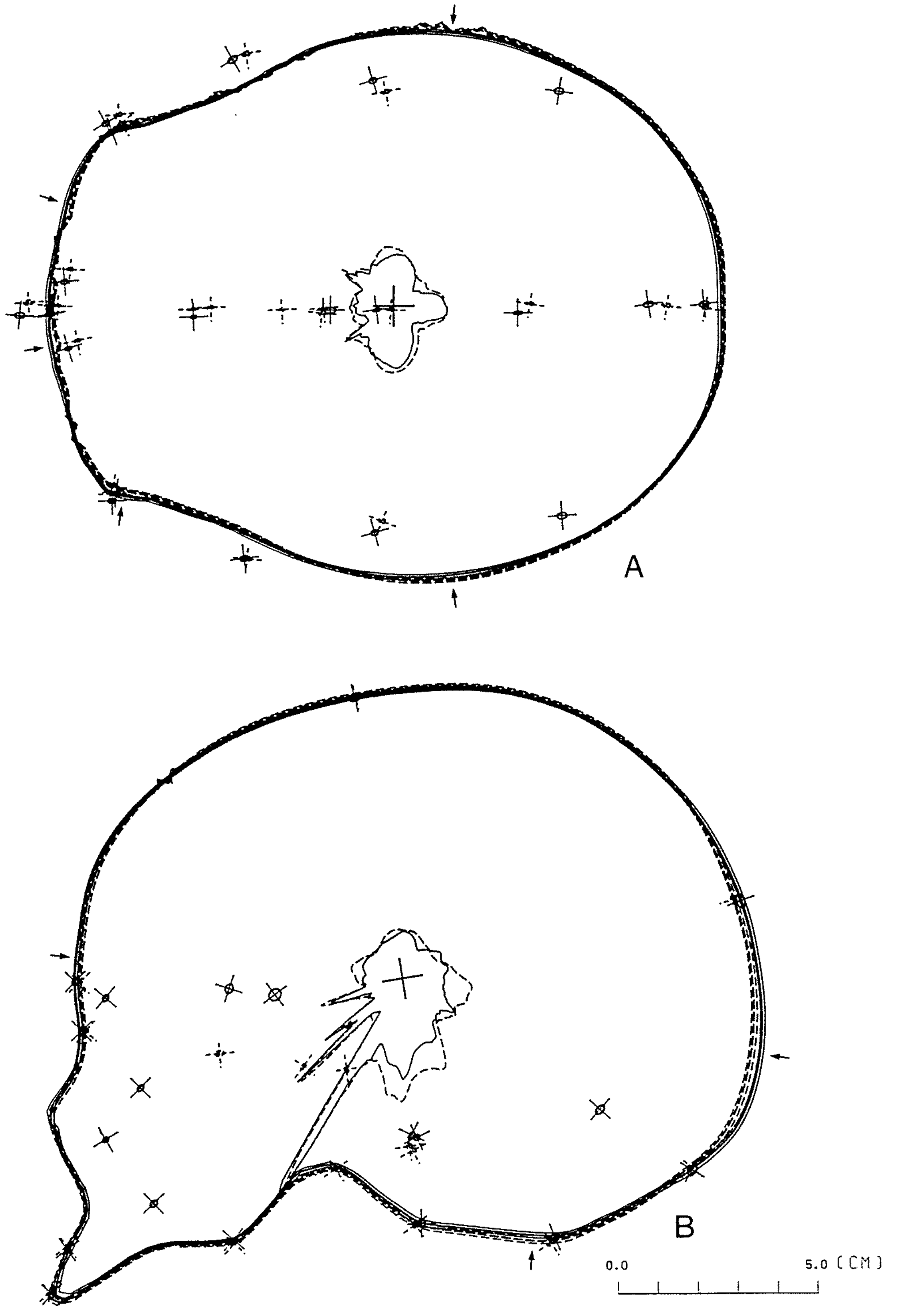


Fig. 14

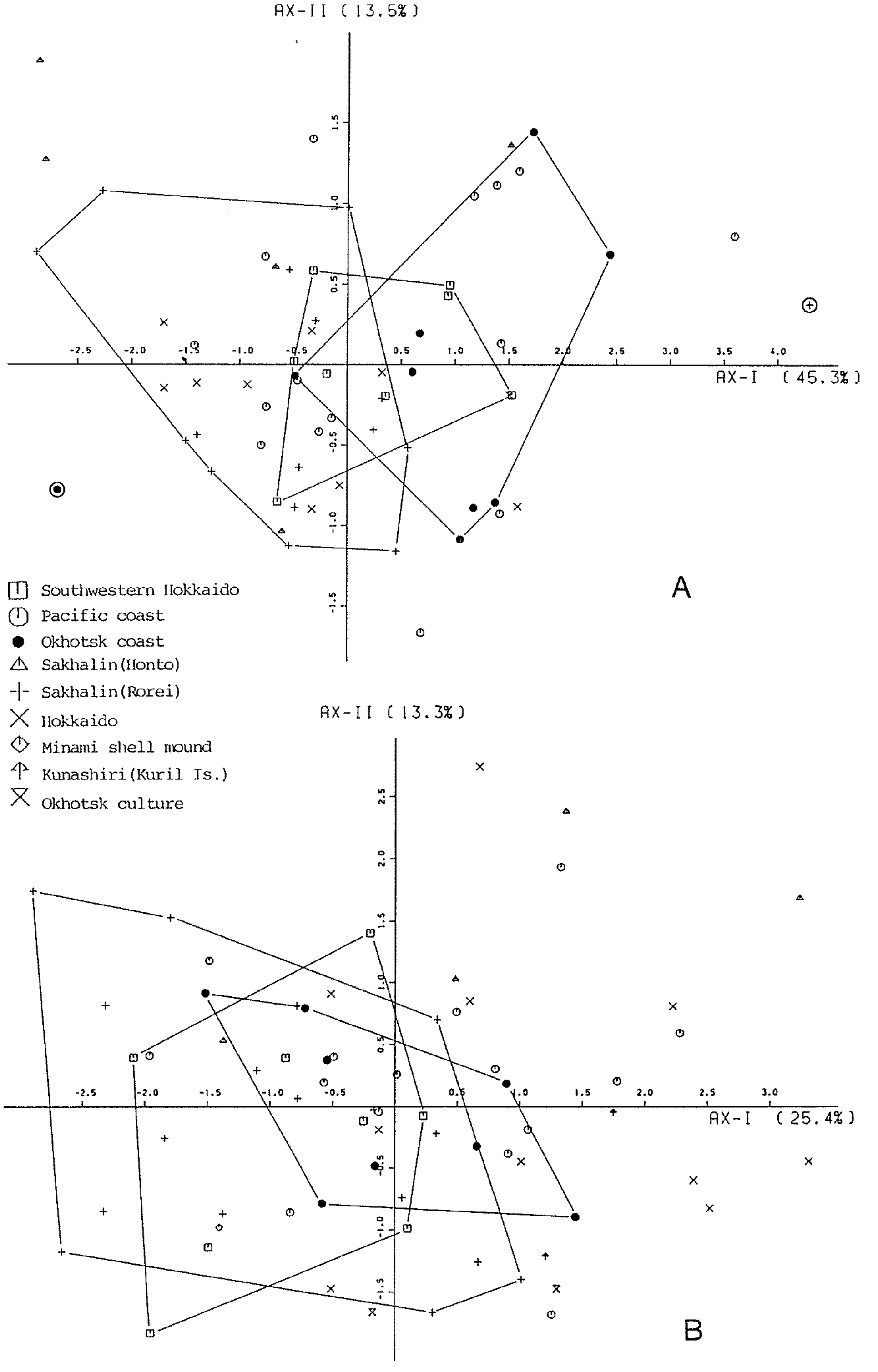
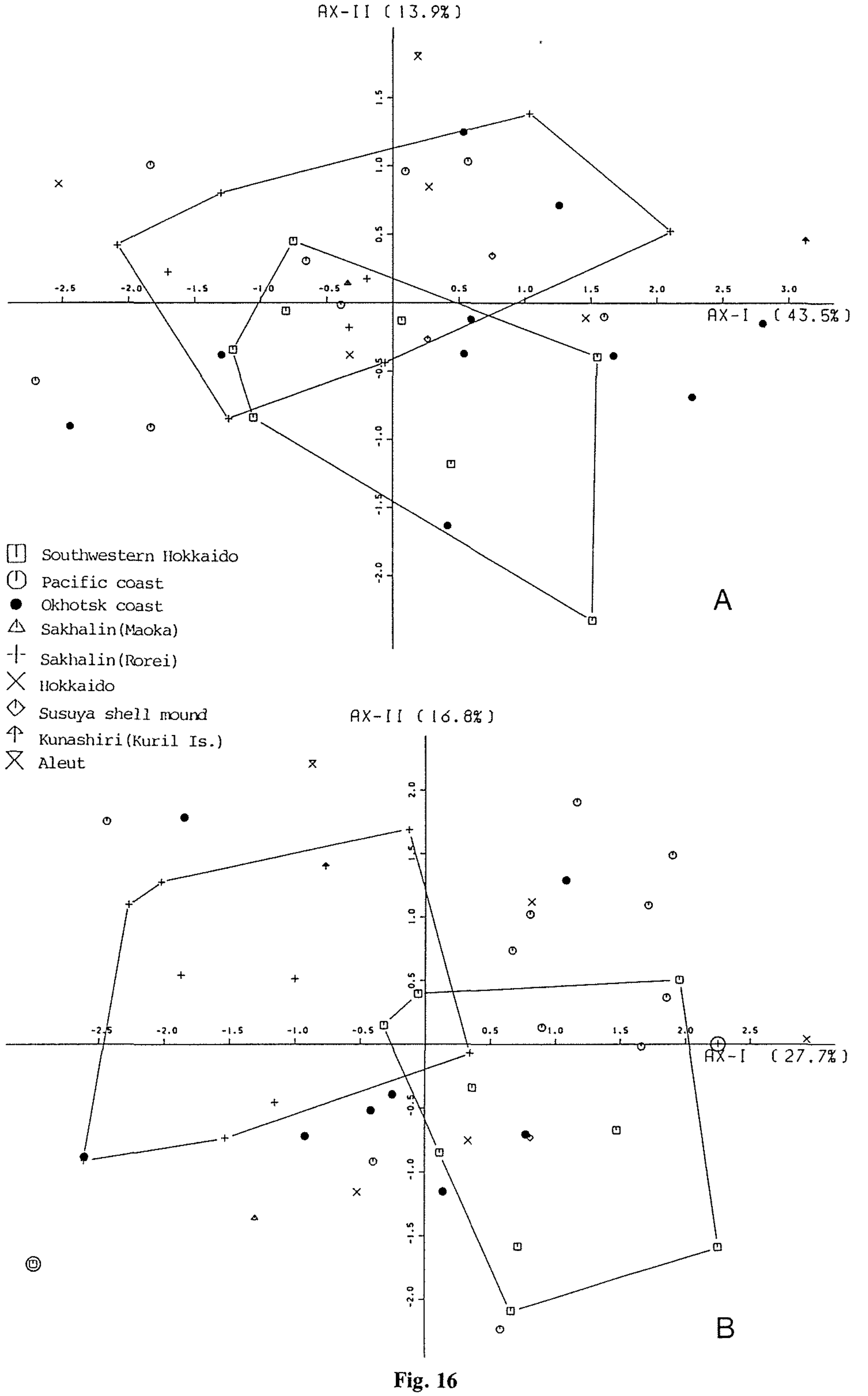

AX-II (13.5%)
AX-I (45.3%)
A
Southwestern Hokkaido
Pacific coast
Okhotsk coast
Sakhalin(Honto)
Sakhalin(Rorei)
Hokkaido
Minami shell mound
Kunashiri(Kuril Is.)
Okhotsk culture
AX-II (13.3%)
AX-I (25.4%)
B

Fig. 15



AX-II (13.9%)
AX-I (43.5%)
A
Southwestern Hokkaido
Pacific coast
Okhotsk coast
Sakhalin(Maoka)
Sakhalin(Rorei)
Hokkaido
Susuya shell mound
Kunashiri(Kuril Is.)
Aleut
AX-II (16.8%)
AX-I (27.7%)
B

Fig. 16

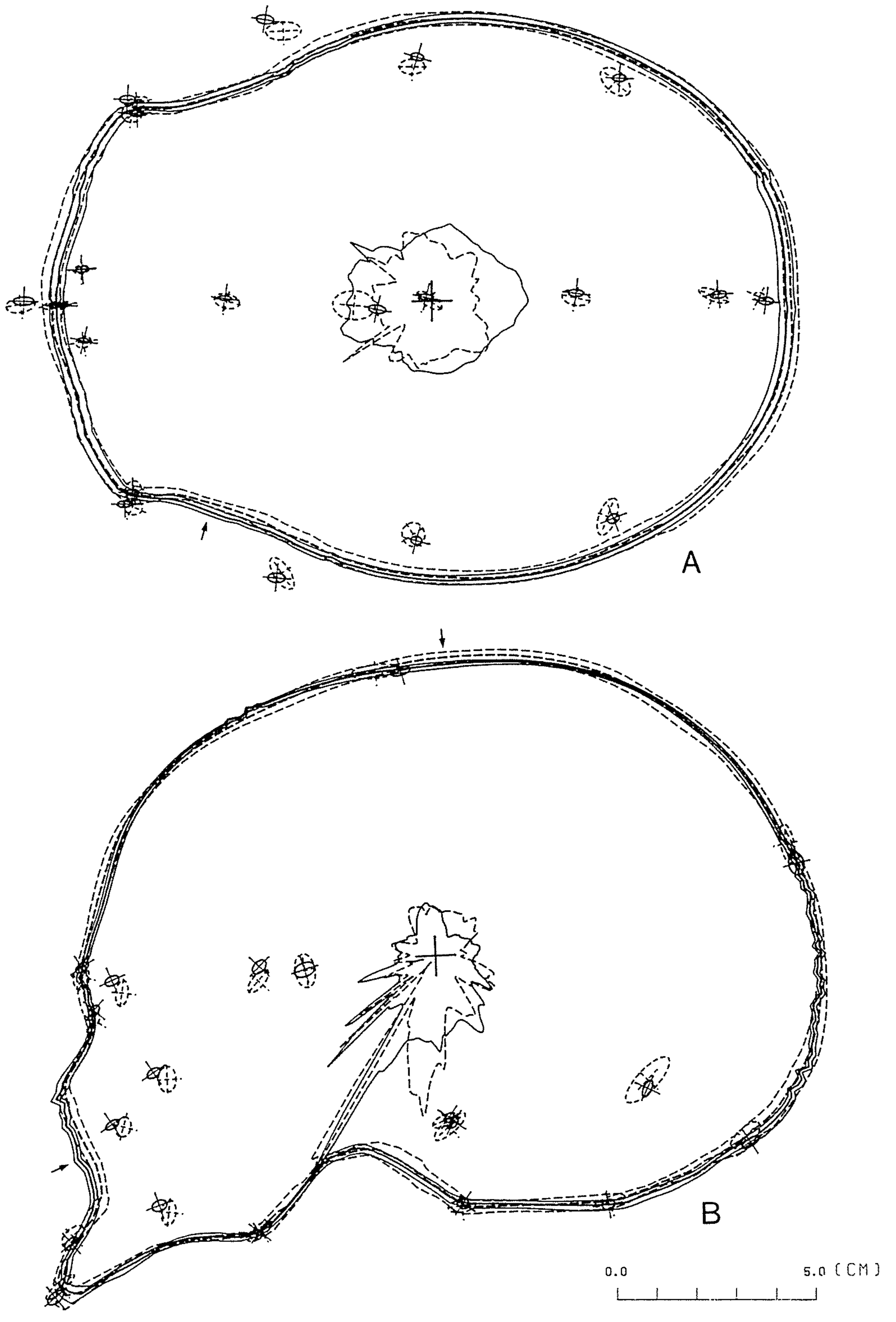


Fig. 17

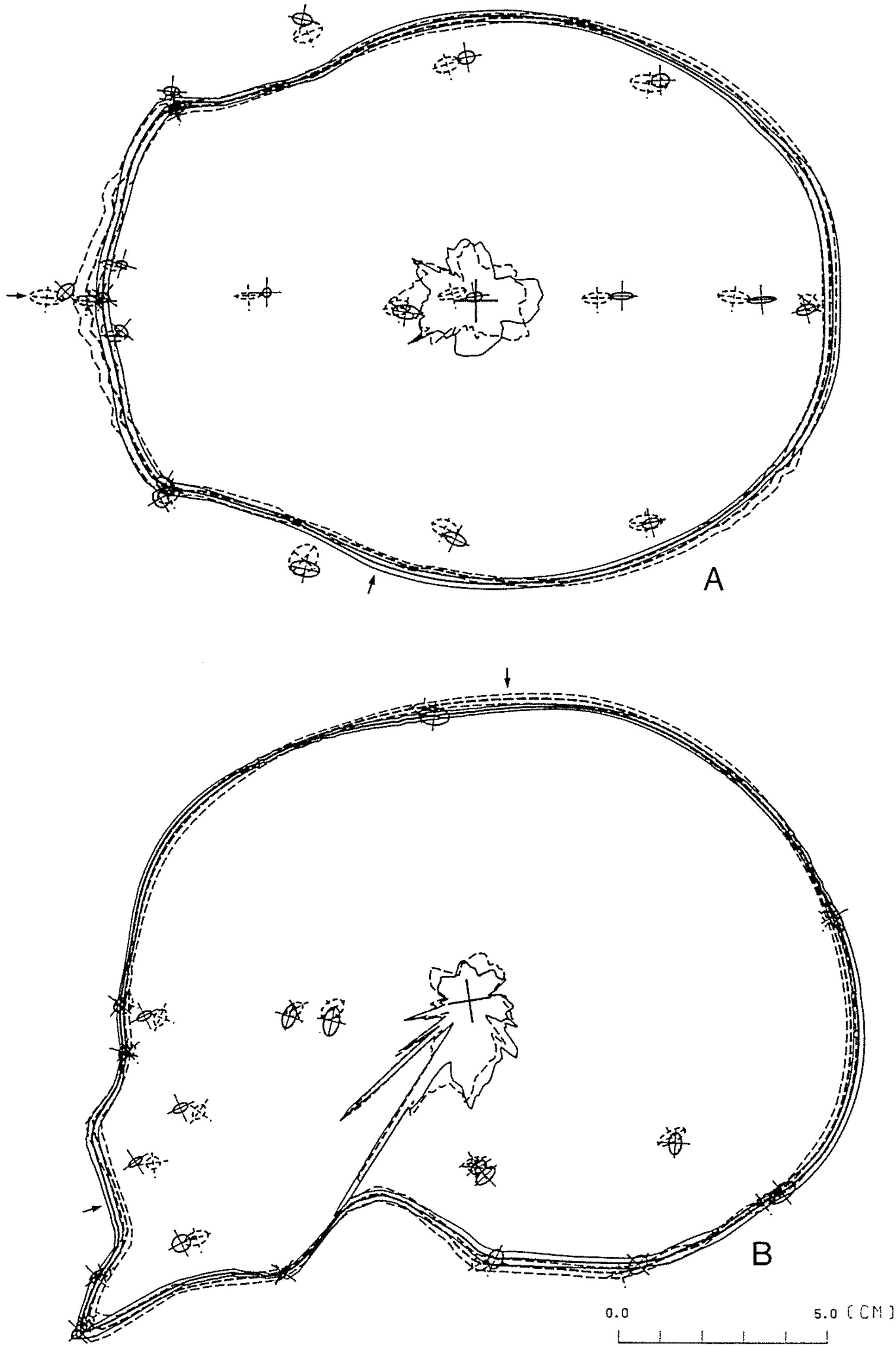


Fig. 18

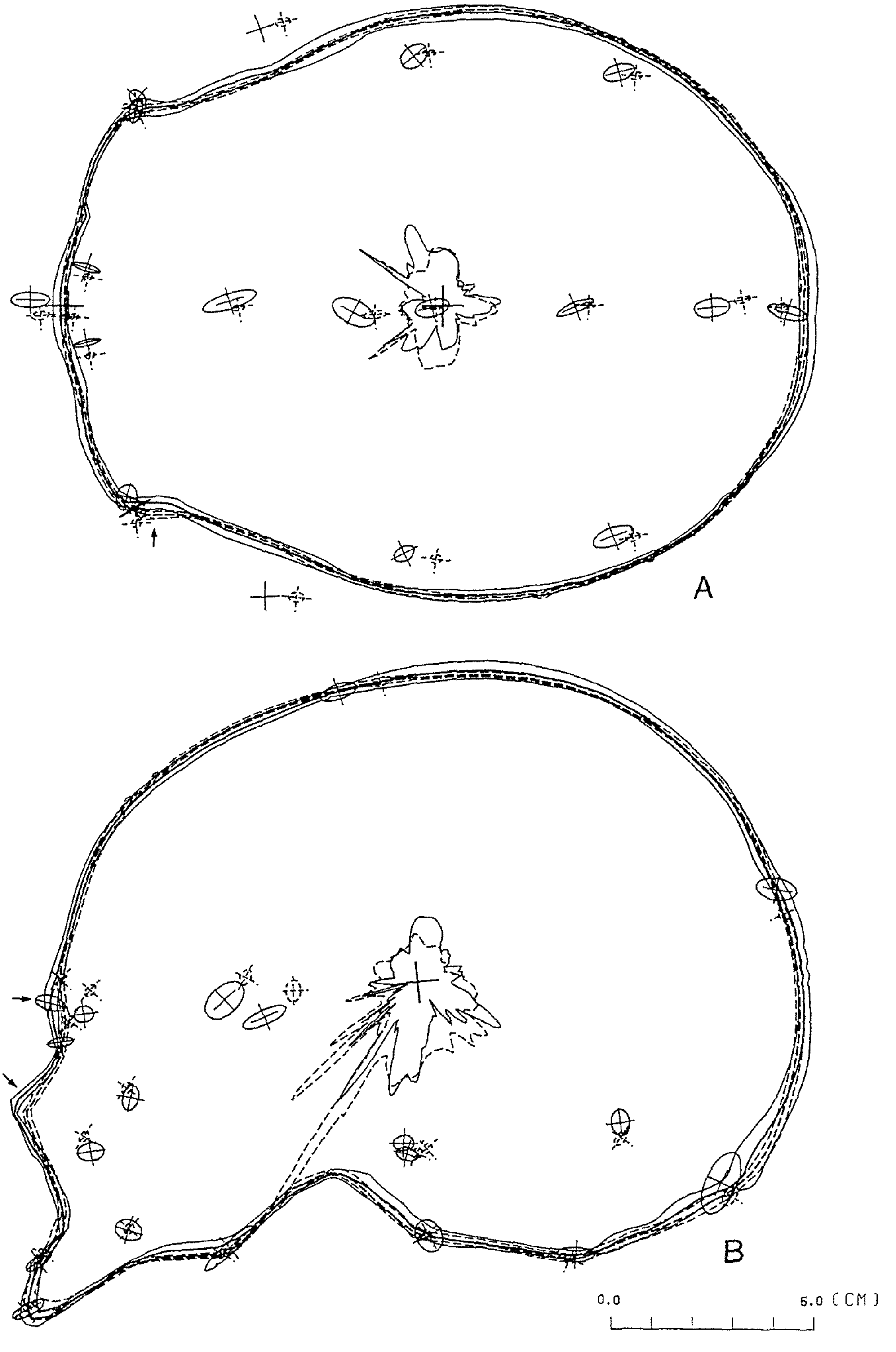


Fig. 19

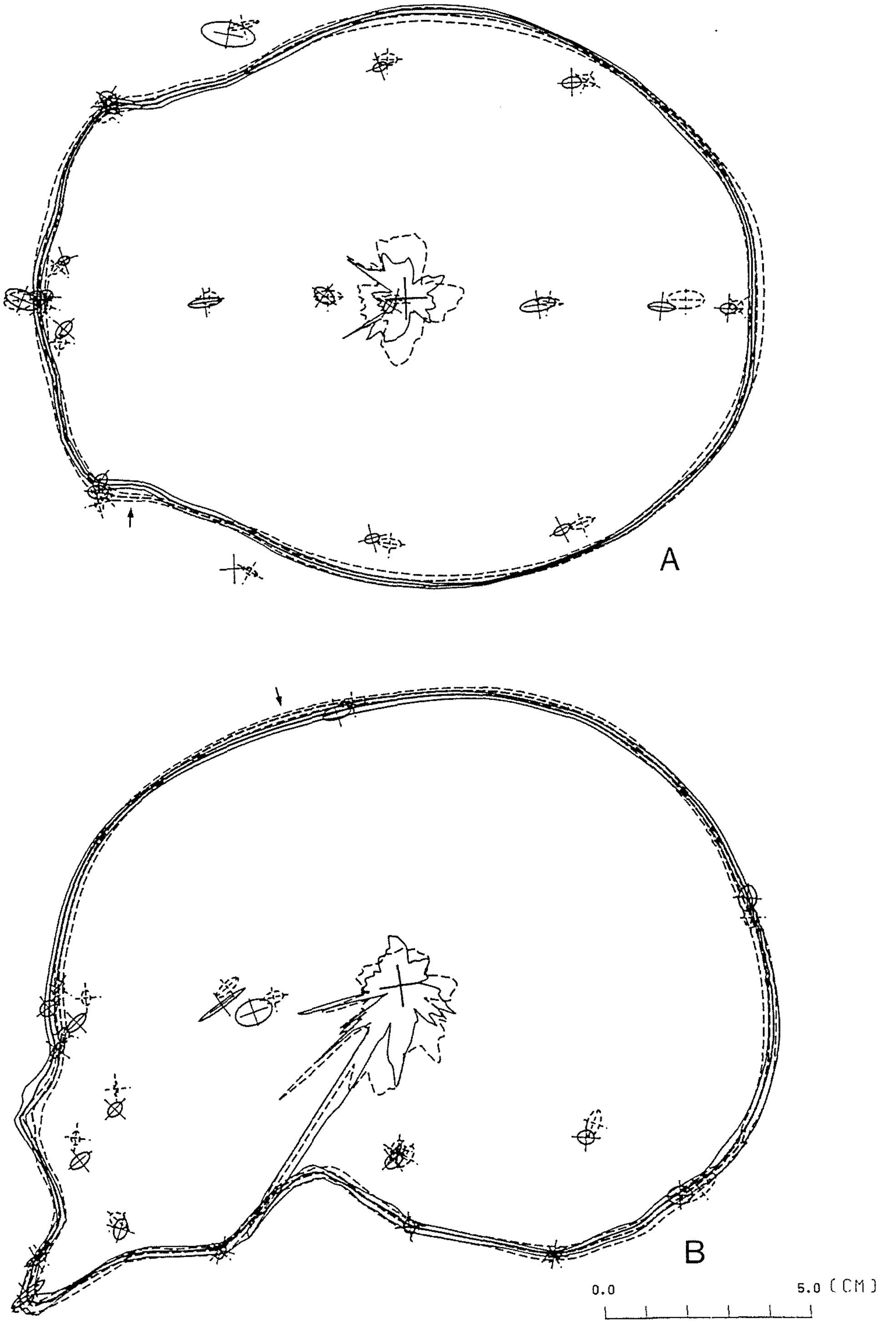


Fig. 20

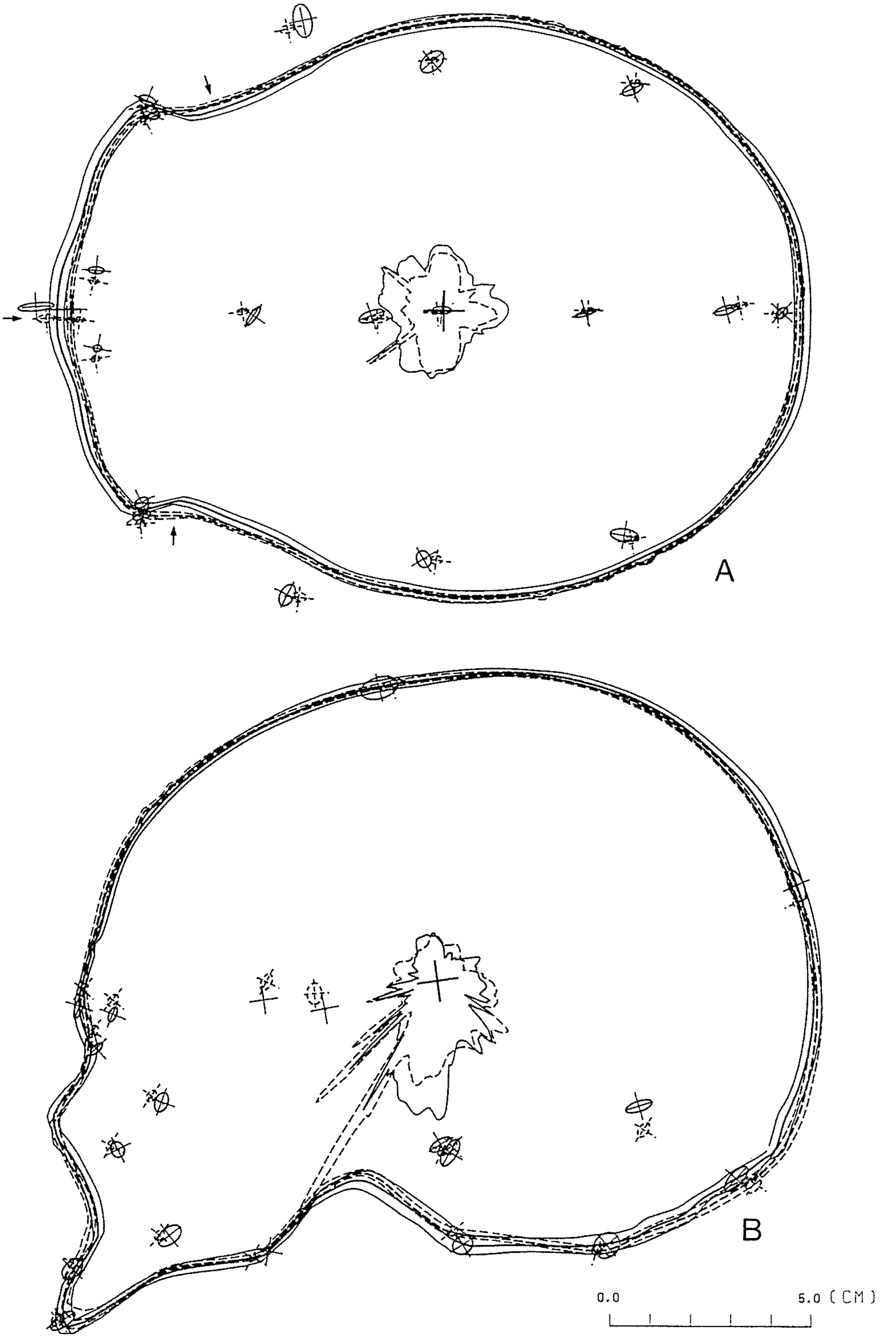


Fig. 21

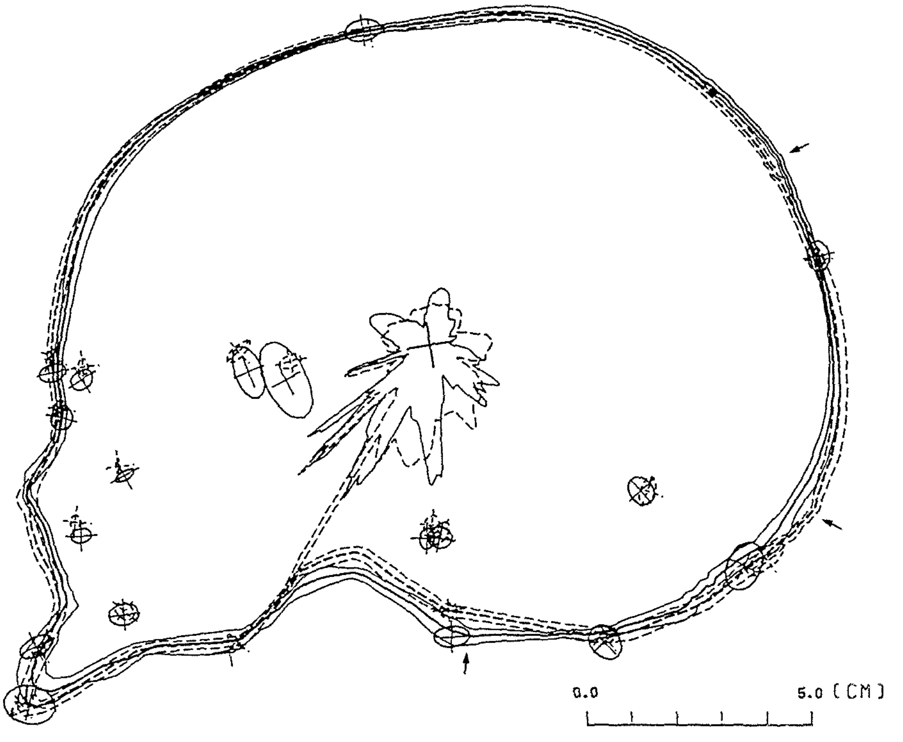


Fig. 22

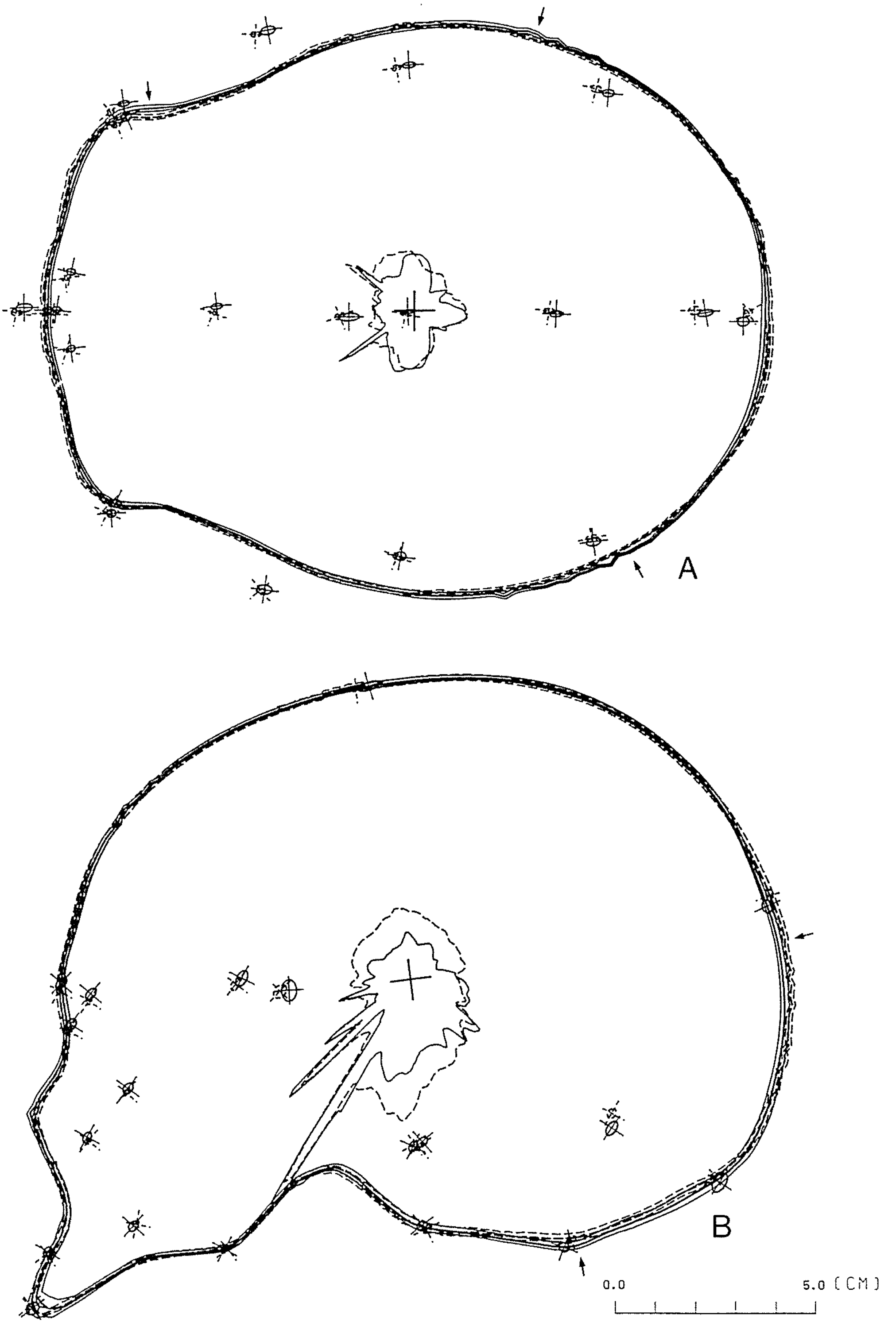


Fig. 23

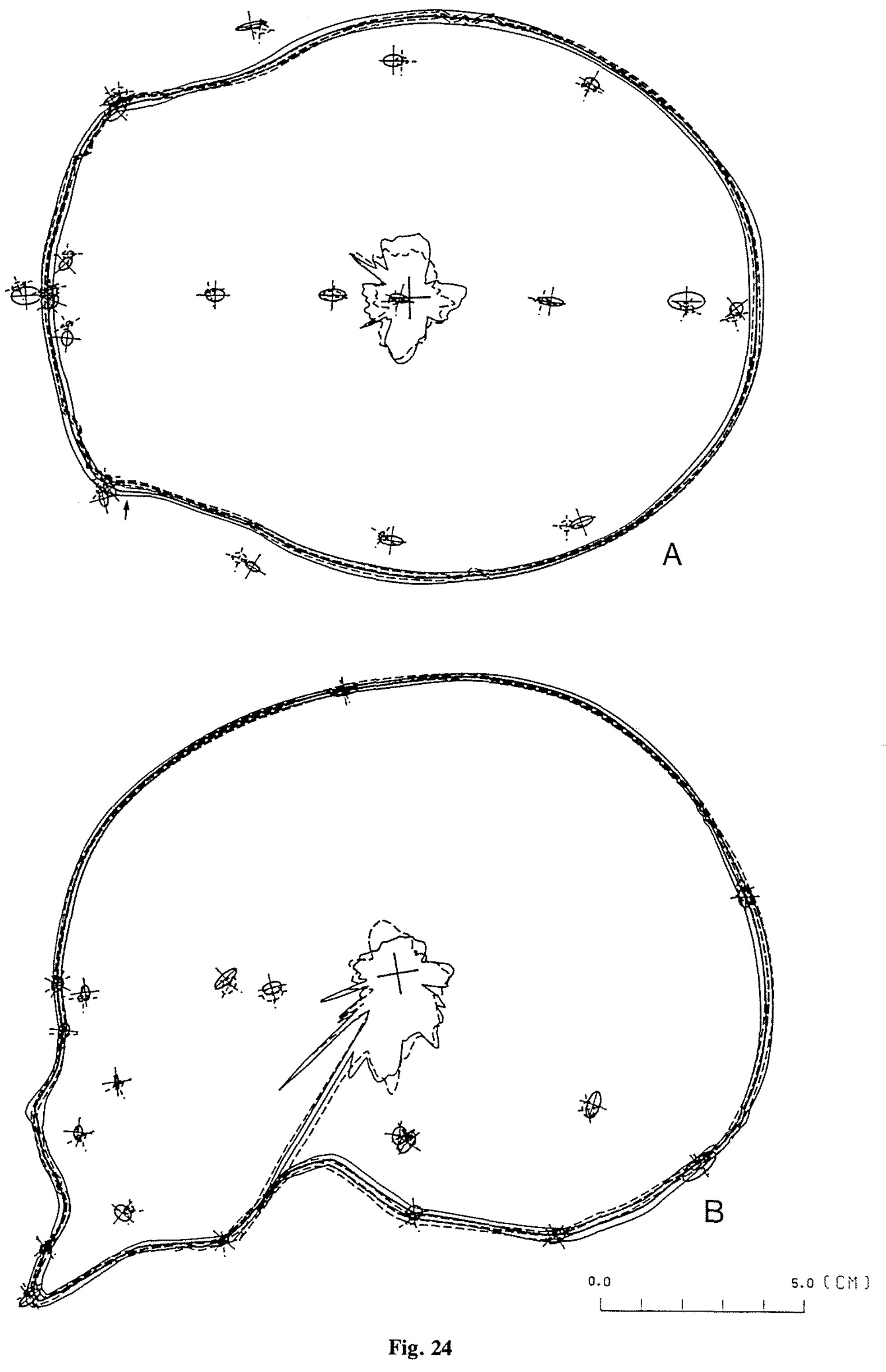


Fig. 24

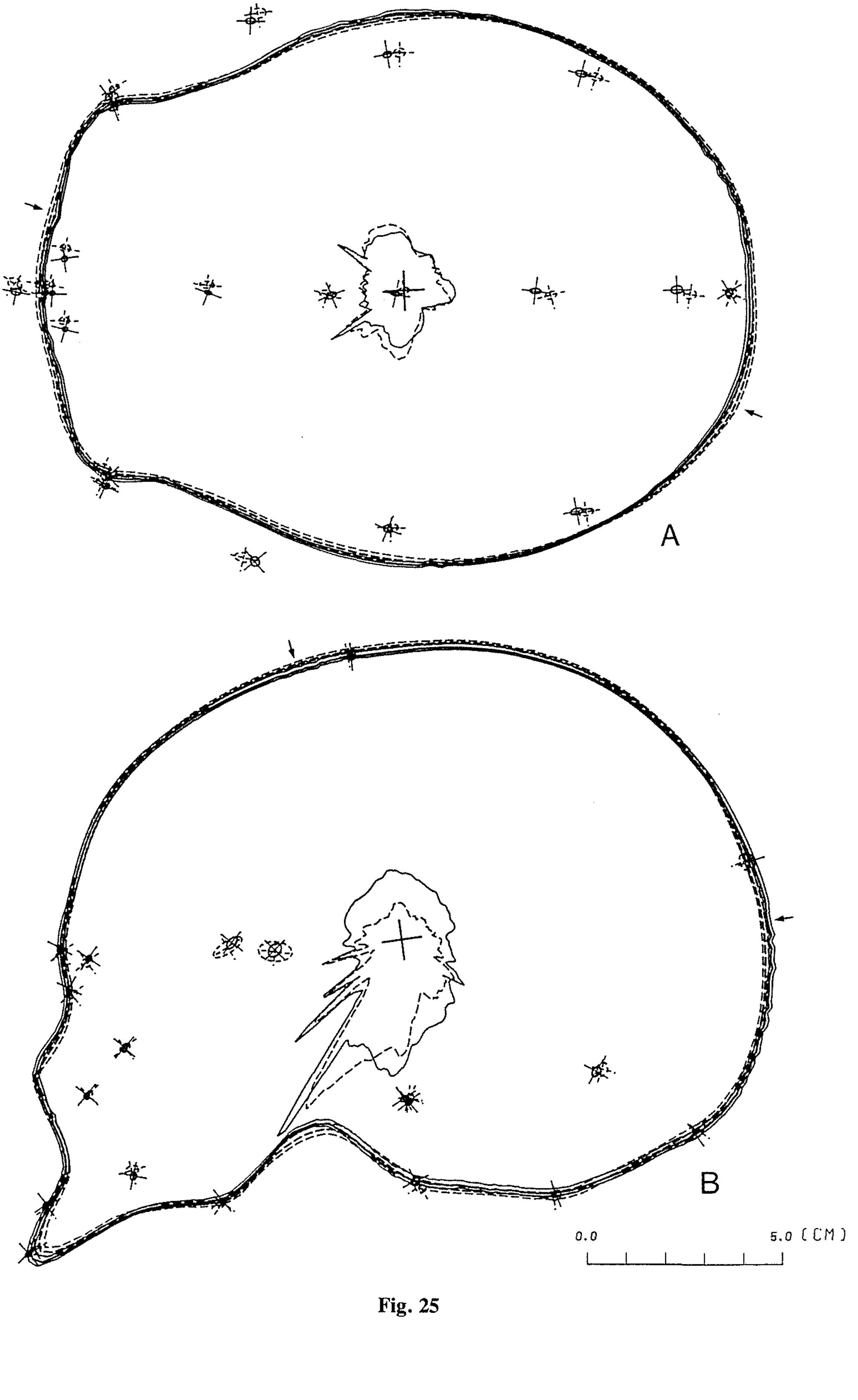


Fig. 25

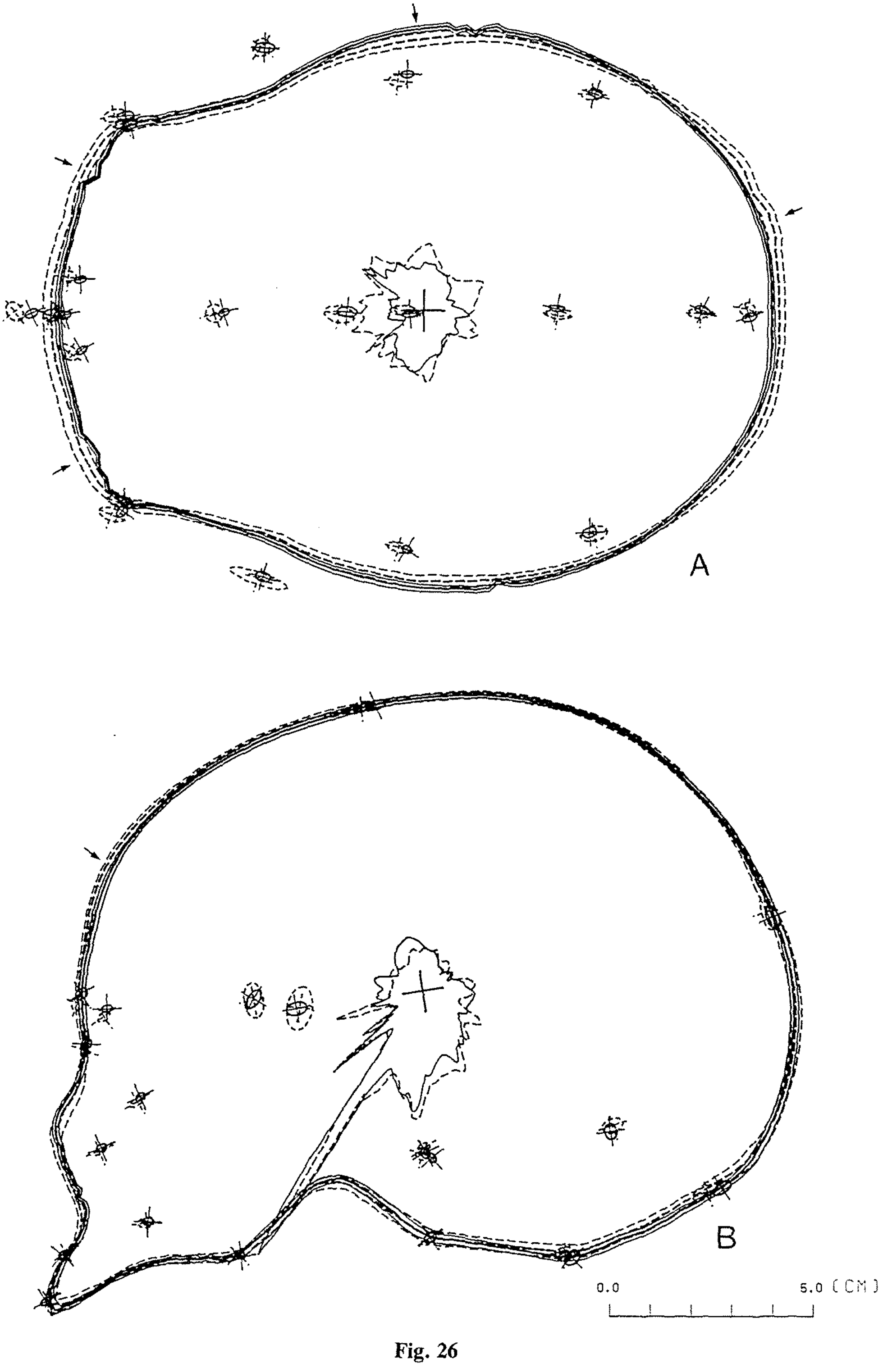


Fig. 26

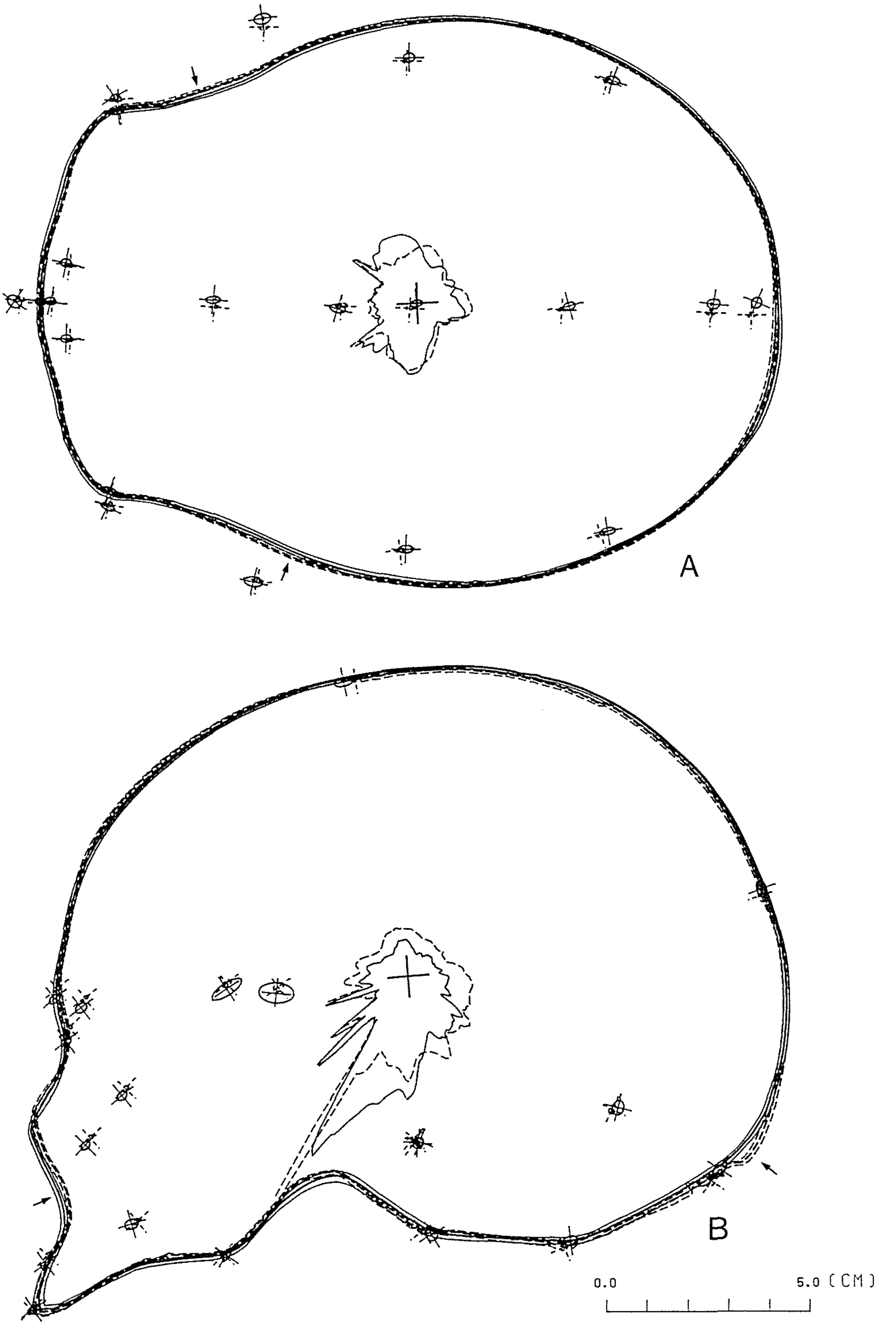


Fig. 27

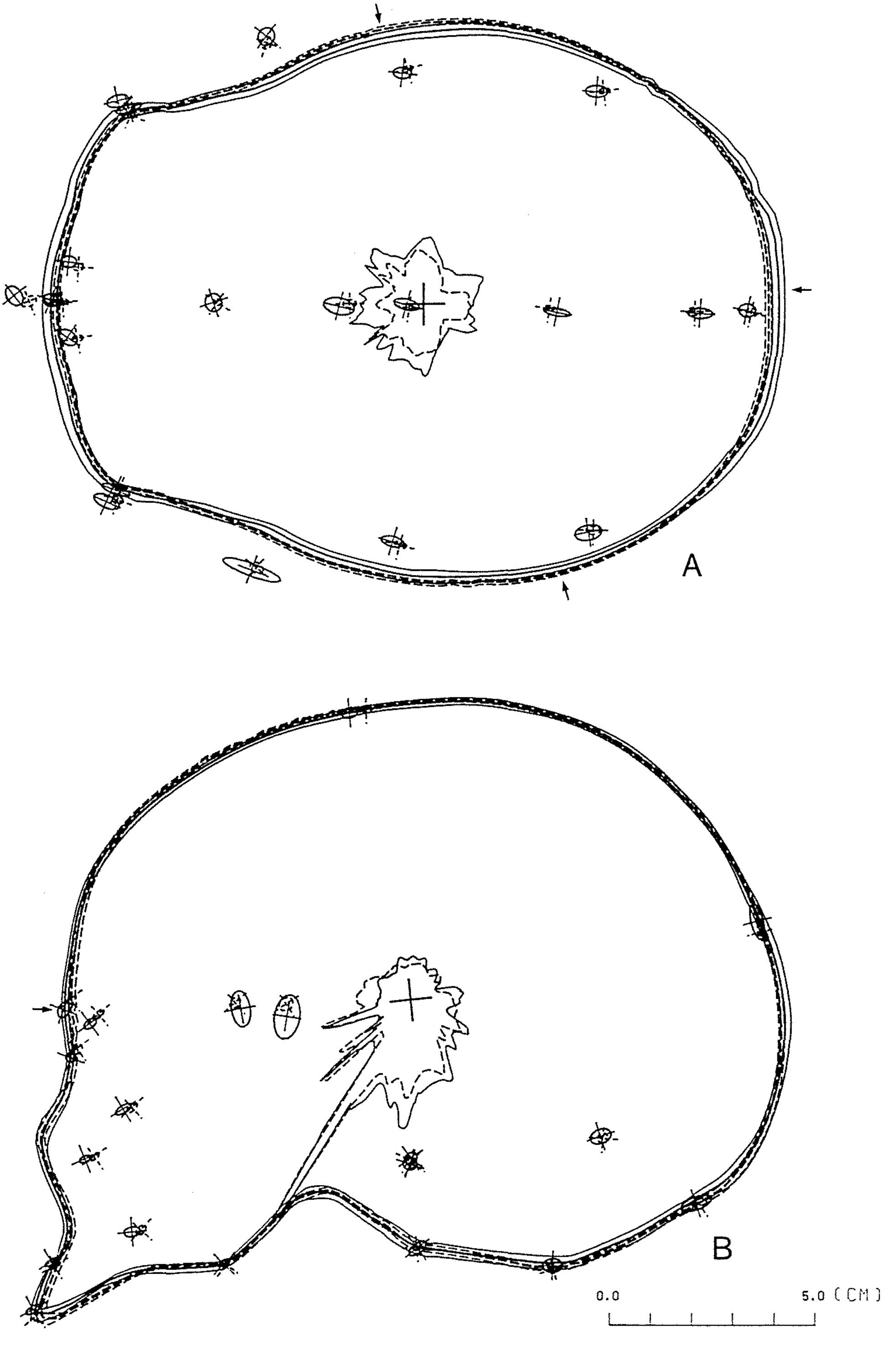


Fig. 28

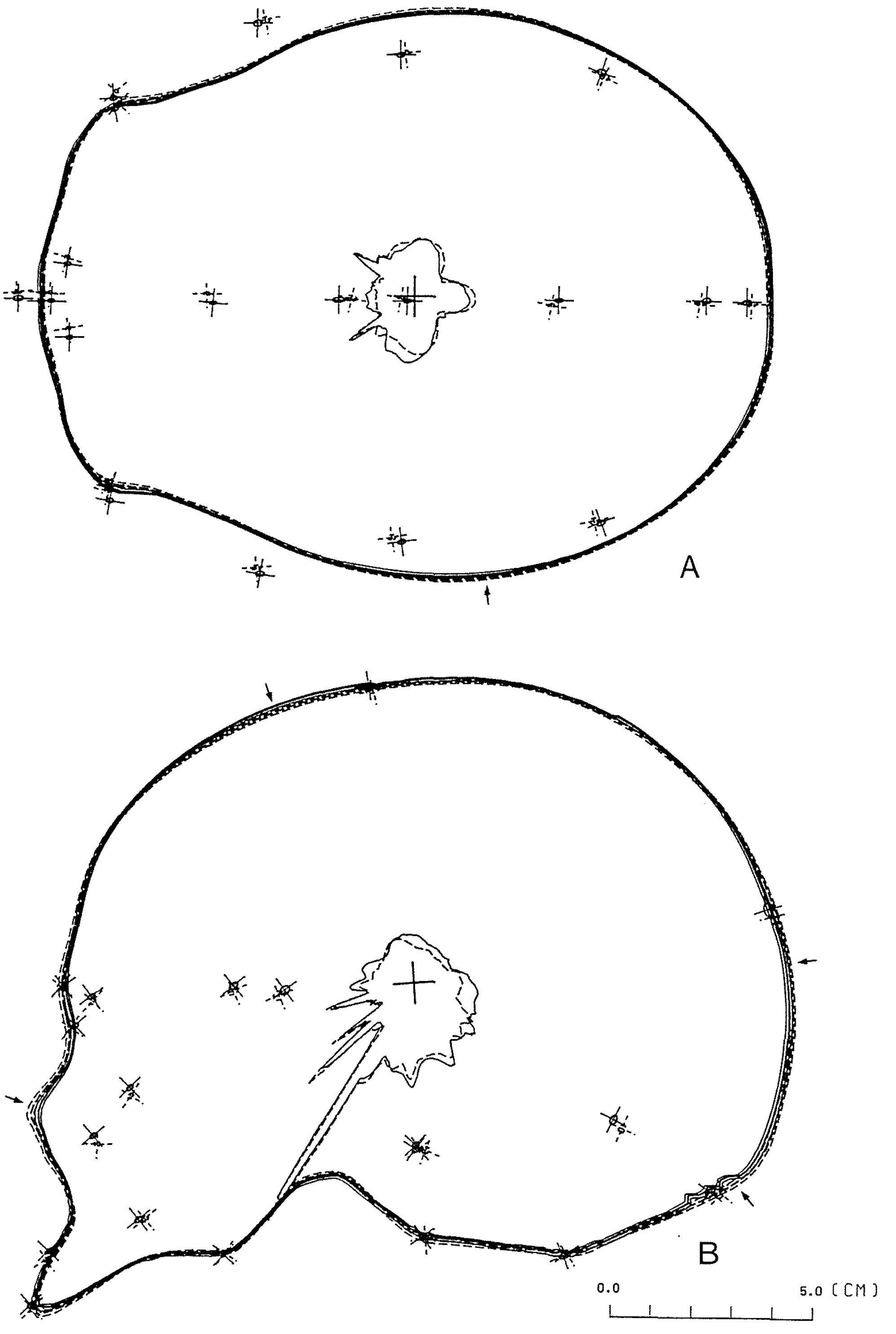


Fig. 29

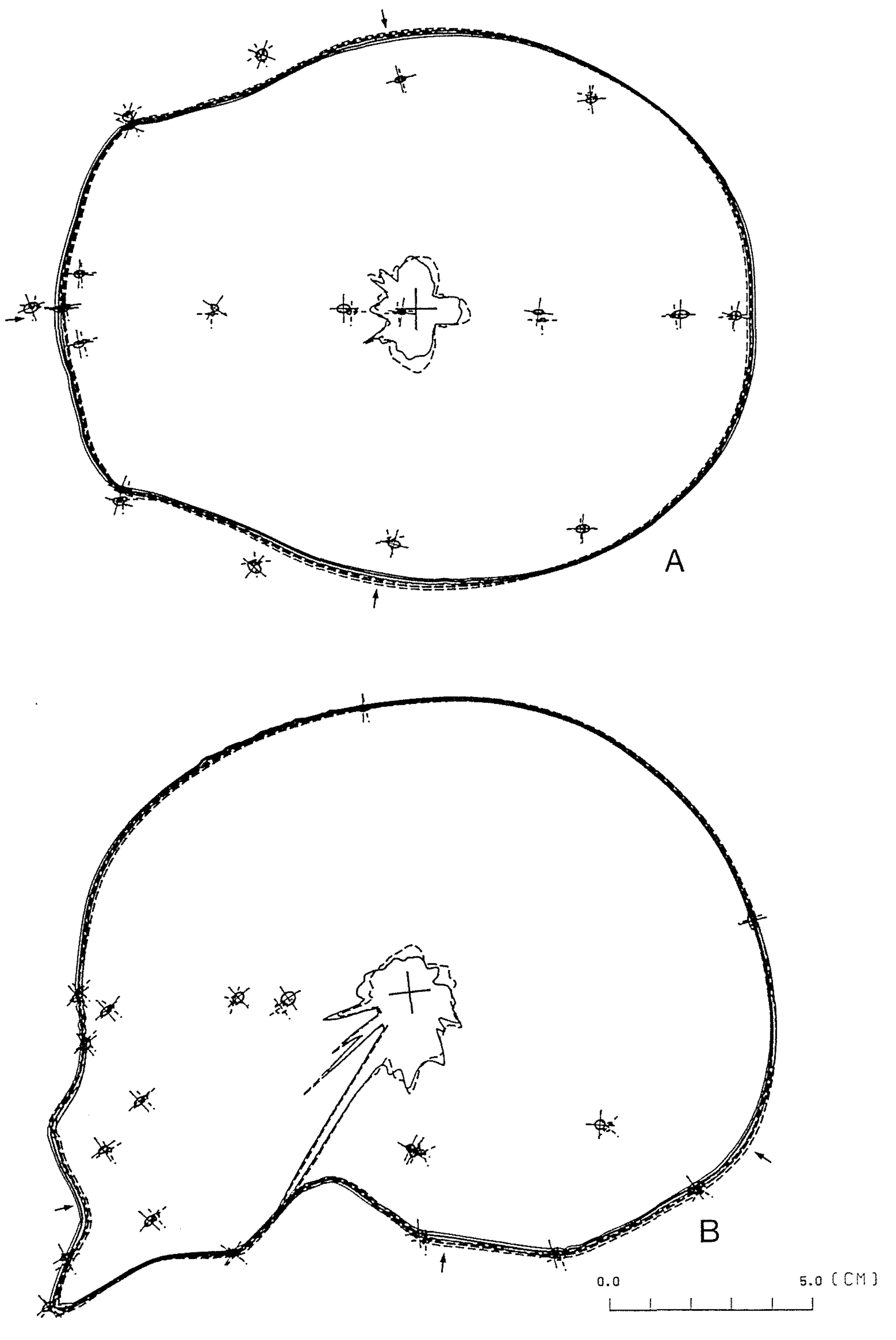


Fig. 30

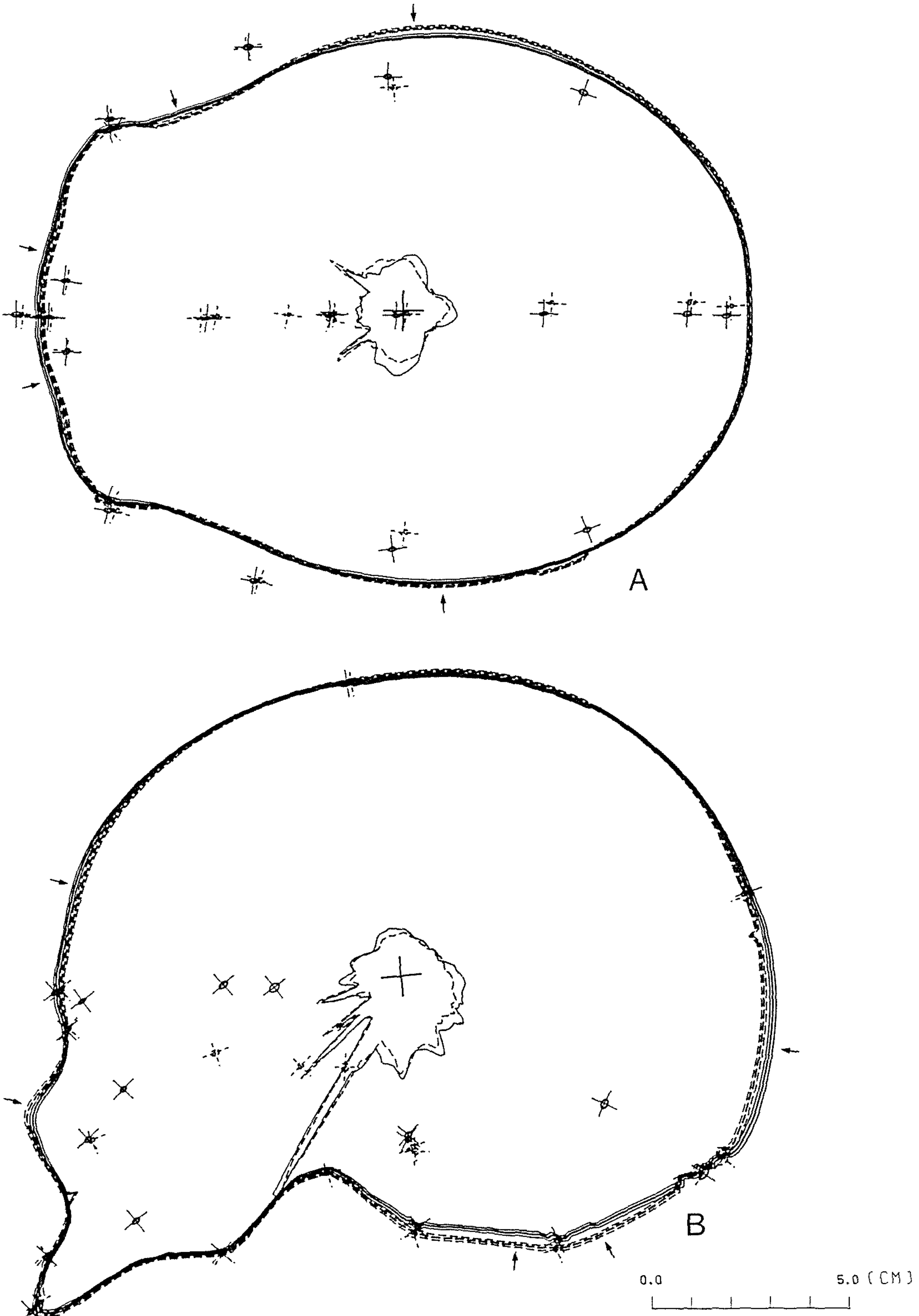


Fig. 31

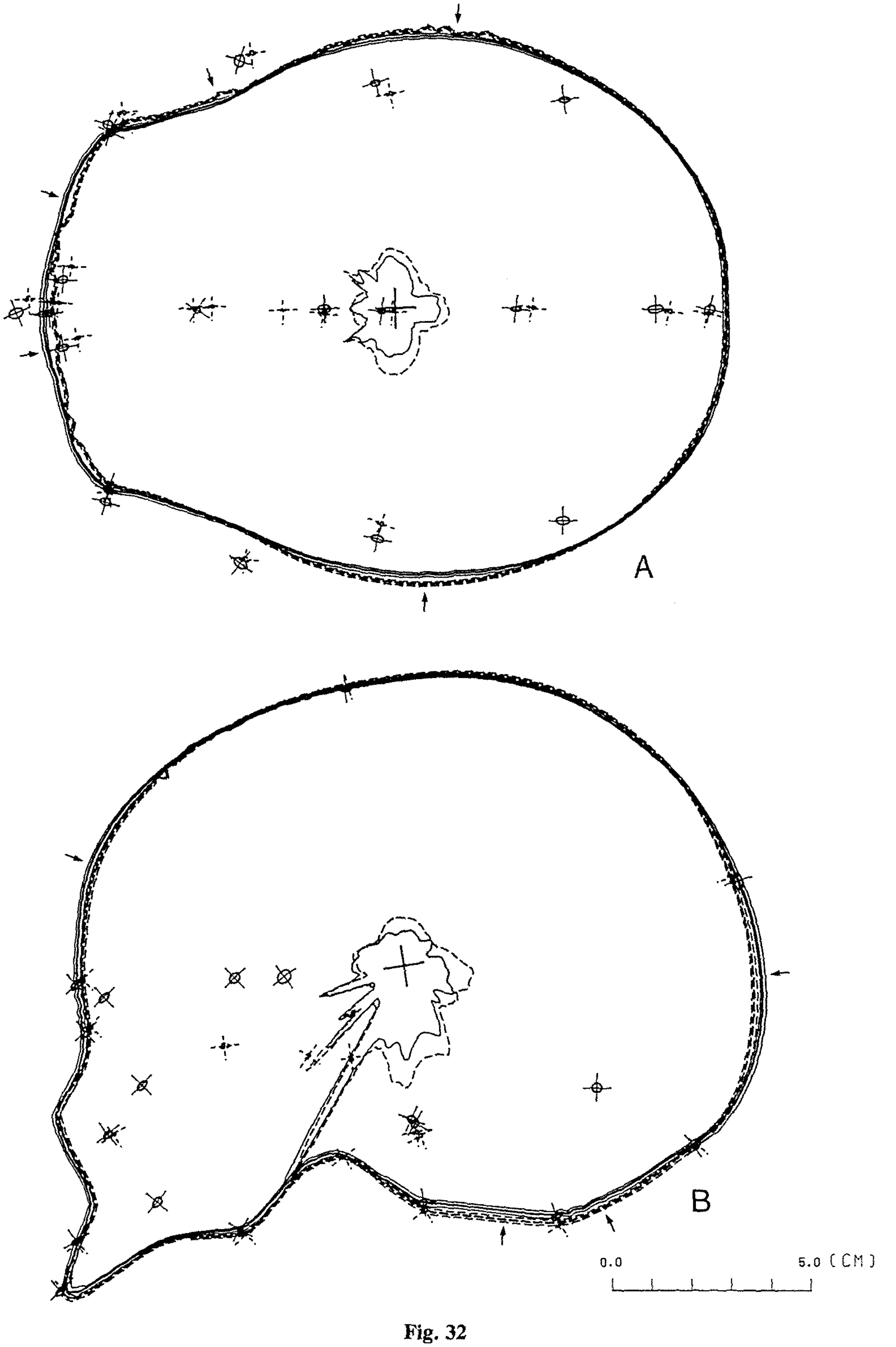


Fig. 32

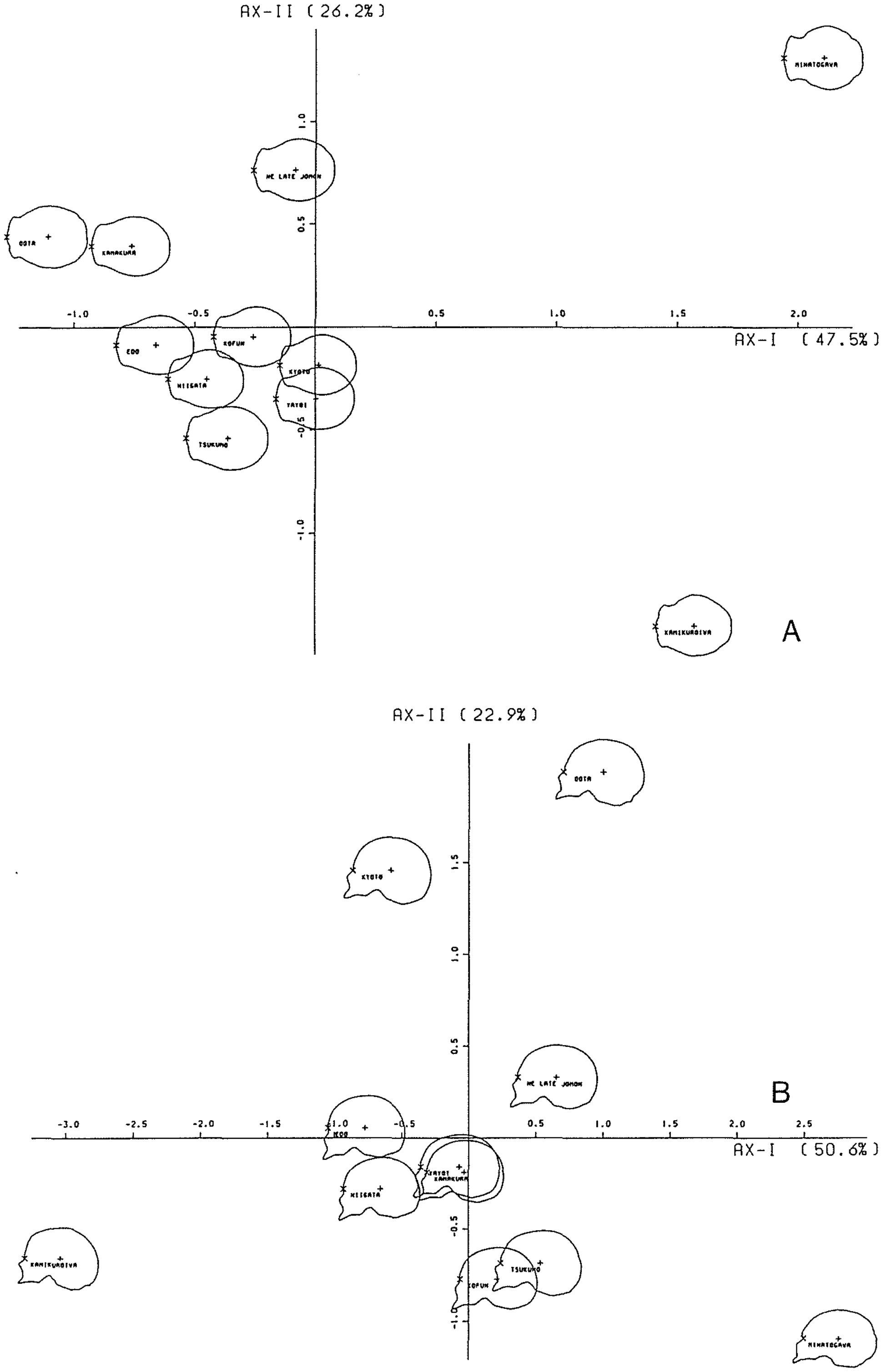


Fig. 35

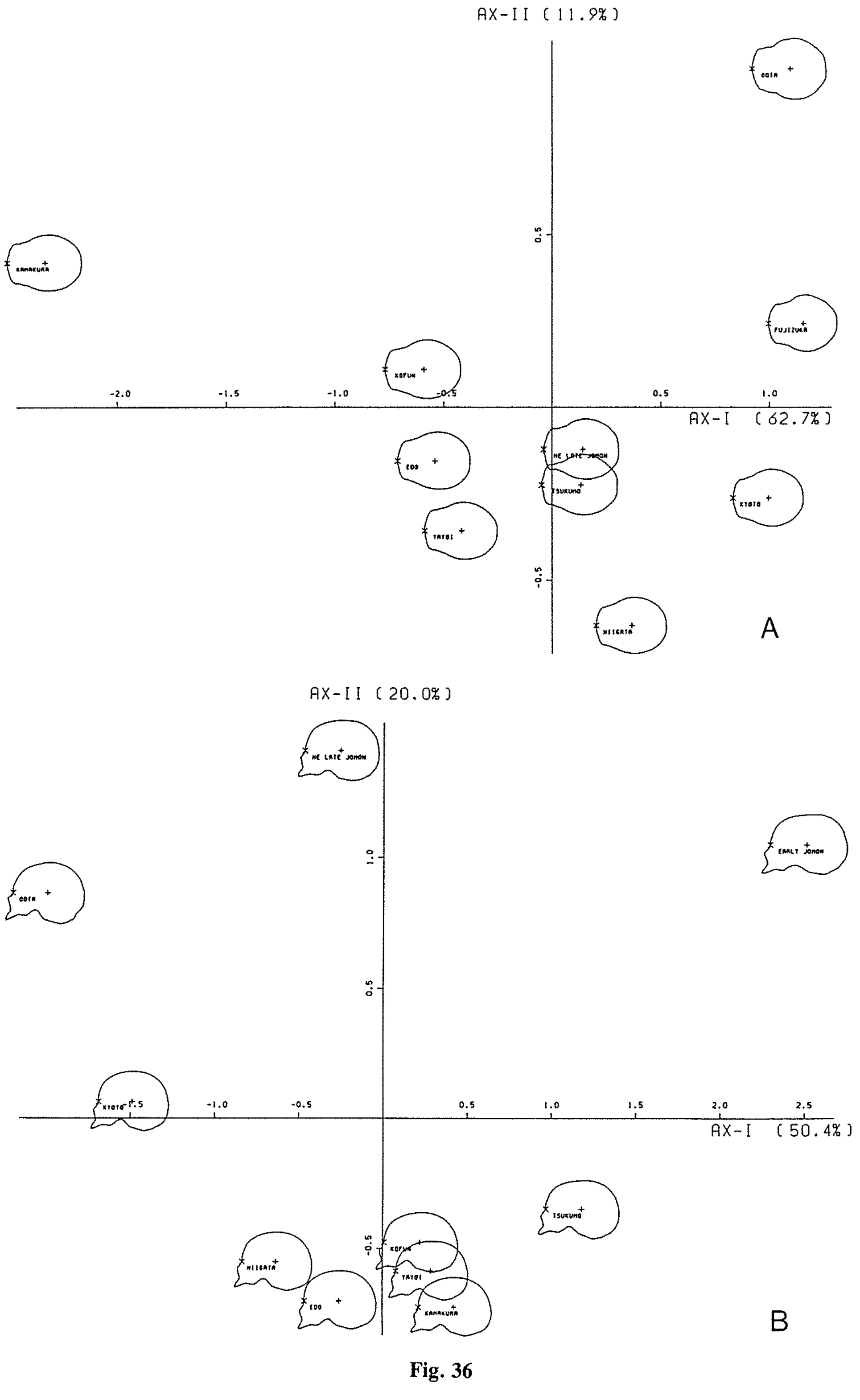

AX-II (11.9%)
AX-I (62.7%)
-2.0
-1.5
-1.0
-0.5
0.5
1.0
0.5
-0.5
A
AX-II (20.0%)
AX-I (50.4%)
-1.5
-1.0
-0.5
0.5
1.0
1.5
2.0
2.5
1.0
0.5
-0.5
B

Fig. 36

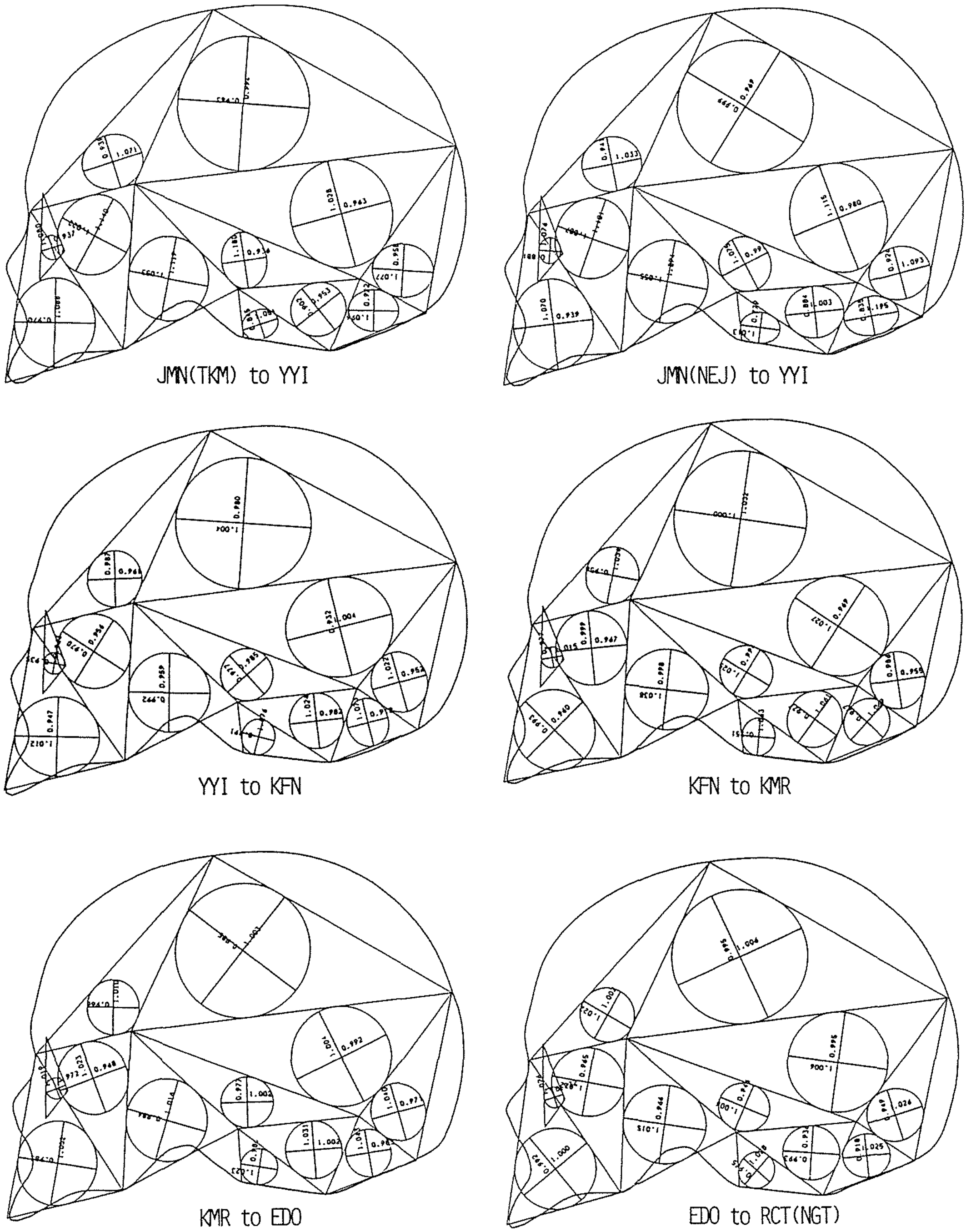

JMN(TKM) to YYI
JMN(NEJ) to YYI
YYI to KFN
KFN to KMR
KMR to EDO
EDO to RCT(NGT)

Fig. 37

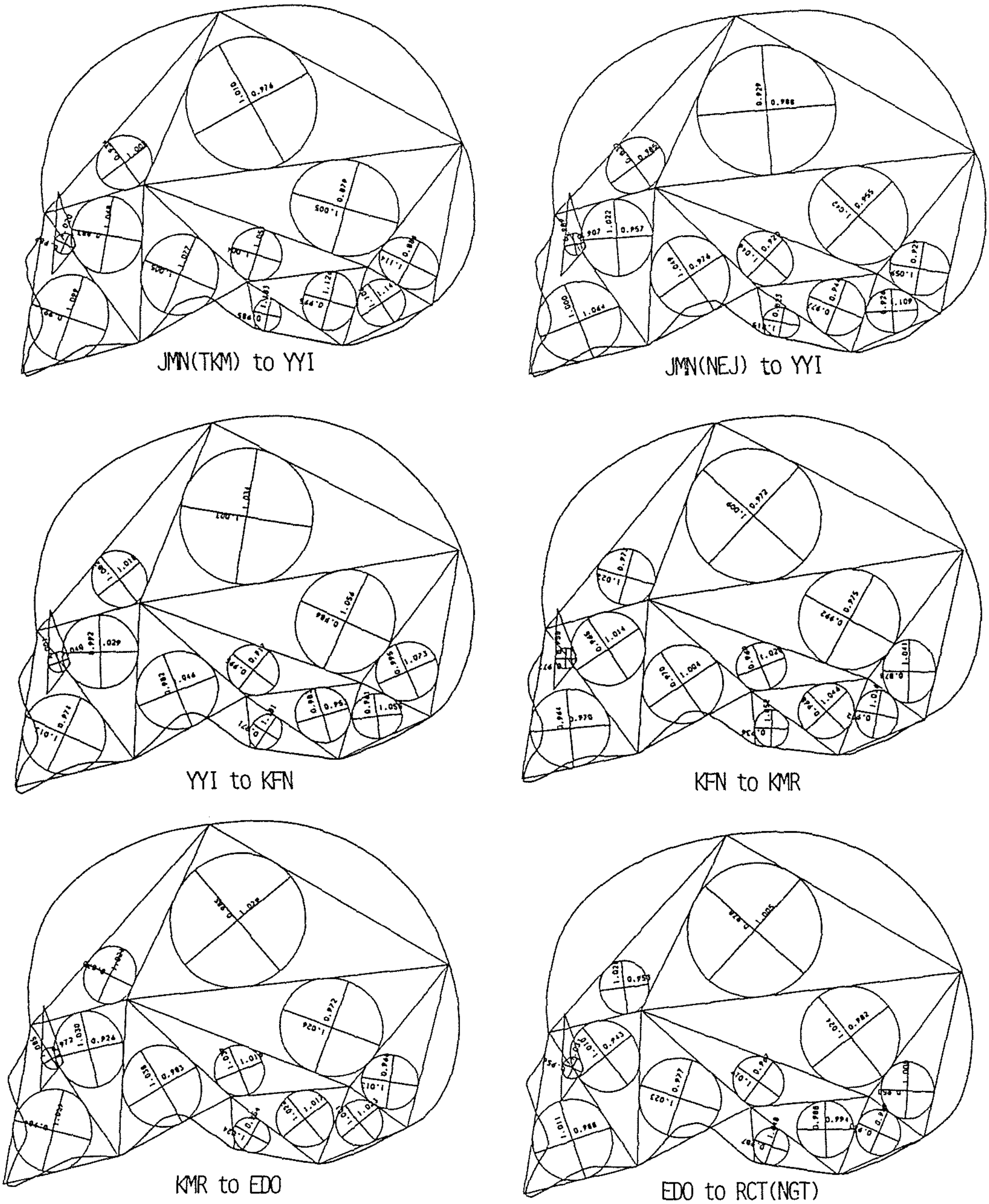

JMN(TKM) to YYI
JMN(NEJ) to YYI
YYI to KFN
KFN to KMR
KMR to EDO
EDO to RCT(NGT)

Fig. 38

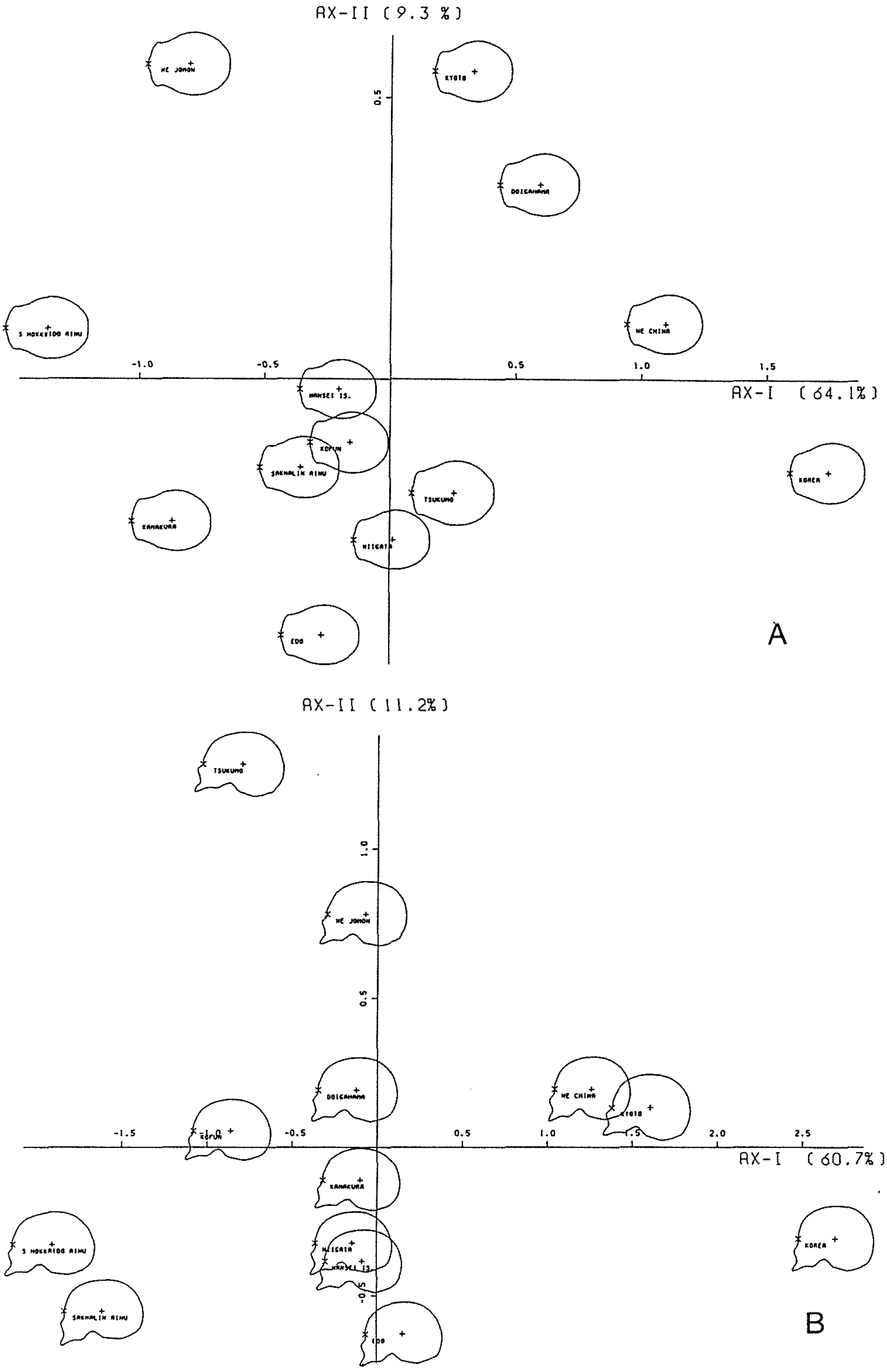

AX-II (9.3 %)
AX-I (64.1%)
NE JOMON
KYOTO
DOIGAHAMA
S HOKKAIDO AINU
NE CHINA
NANSEI IS.
KOFUN
SAKHALIN AINU
TSUKUMO
KAMAKURA
NIIGATA
KOREA
EDO
A
AX-II (11.2%)
AX-I (60.7%)
B

Fig. 42

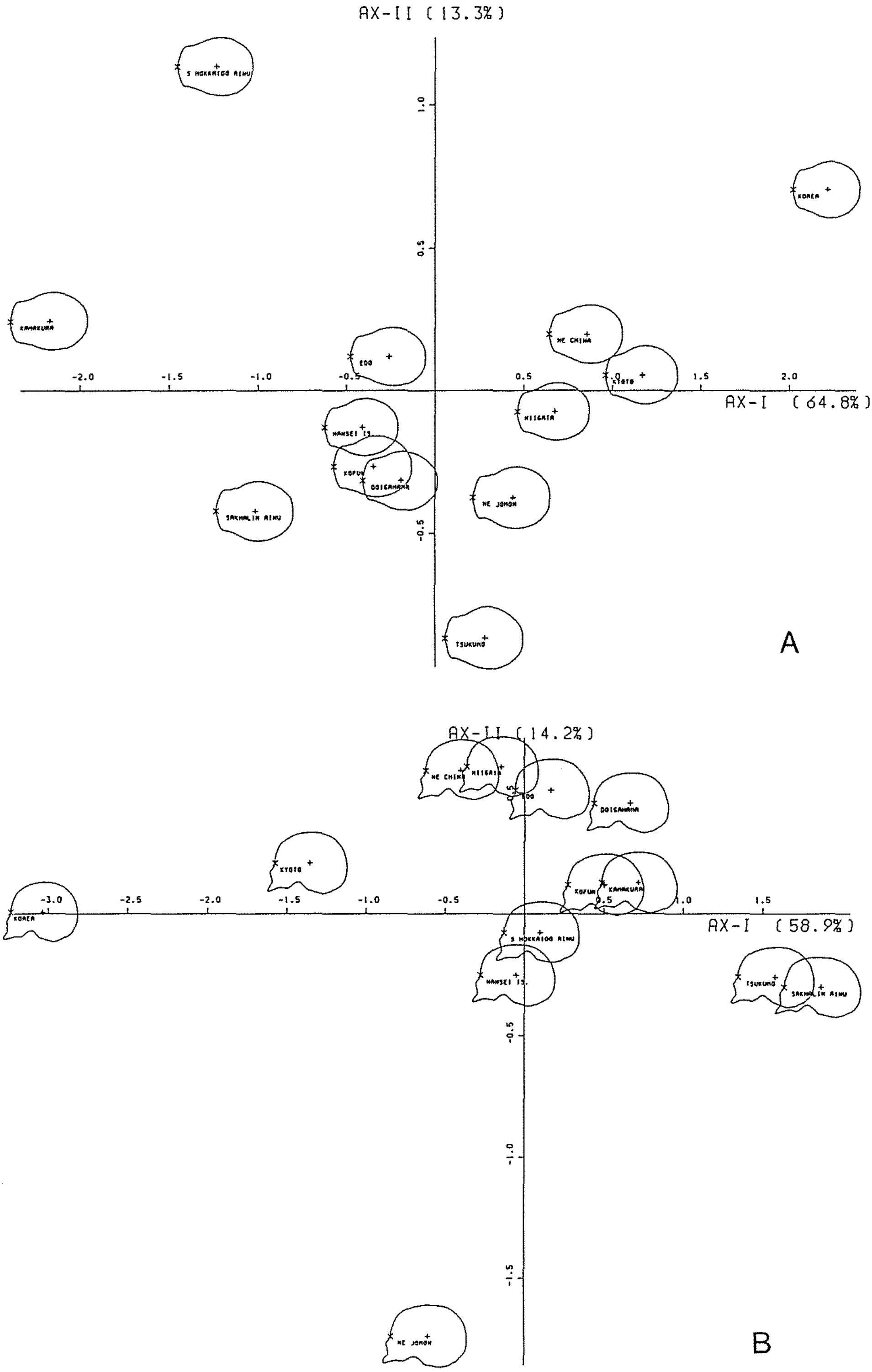

AX-II (13.3%)
AX-I (64.8%)
S HOKKAIDO AINU
KOREA
KAMAKURA
EDO
NE CHINA
KYOTO
NIIGATA
NANSEI IS.
KOFUN
DOIGAHAMA
NE JOMON
SAKHALIN AINU
TSUKUMO
A
AX-II (14.2%)
AX-I (58.9%)
B

Fig. 43