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Miocene lateral bending of central Japan — Intra-arc deformation at arc-arc collision zone —

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TAKAHASHI Masaki (1994) Miocene lateral bending of central Japan — Intra-arc deformation at arc-arc collision zone —. *Bull. Geol. Surv. Japan*, vol. 45 (8/9), p. 477-495, 10figs., 1table.

Abstract : Recent paleomagnetic studies in the Kanto Mountains, central Japan, haverevealed the Miocene clockwise rotation of the east-wing of the sharp bent structure of pre-Neogene geologic terranes (Kanto Syntaxis). More than 90° clockwise rotation of the Kanto Mountains took place between 15 and 6Ma. About a half of its overall rotation probably occurred at around 15Ma in association with the rapid clockwise rotation of Southwest Japan. The rest rotation occurred till 6Ma, resulting the sharp bent structure of the Kanto Syntaxis. The Izu-Bonin arc has been colliding with central Japan since Middle Miocene, which may be the cause of this intra-arc deformation.

1. Introduction

The Japanese Islands are situated on the eastern margin of the Eurasian Plate where both the Pacific and Philippine Sea Plates are subducting. One of the most characteristic geological features of the Japanese Islands is the zonal distribution of pre-Neogene terranes as shown in Fig. 1. This zone comprises three belts (Sanbagawa, Chichibu and Shimanto Belts) and can be traced from Kyushu to central Japan. While the trend of this zonal structure is parallel to the axis of the island arc in Southwest Japan, this zone is sharply bent at central Japan, which is called the Kanto Syntaxis. Detailed timing of the formation of this bend has been controversial since the last century.

The South Fossa Magna region is located at central Japan where the Izu-Bonin arc on the northwestward migrating Philippine Sea Plate is colliding (Fig. 2). Recently, field investigations revealed that two or more exotic blocks of the Izu-Bonin arc had collided since Middle Miocene (Niitsuma and Matsuda, 1985; Koyama, 1991 ; Amano, 1991). Thick conglomerate overlying abyssal mudstone distributed between collided blocks seems to represent the timing of the collision. The collision of the Izu-Bonin arc with central Japan may be the cause of the northward-convex structure of pre-Neogene terranes.

This paper presents the paleomagnetic results of the Kanto Mountains and adjacent areas to show the block rotation within the island arc. The collision tectonics between the Izu-Bonin arc and central Japan at the South Fossa Magna region is also reviewed. The interrelations among the rotations of Southwest and Northeast Japan arcs, collision tectonics in central Japan and lateral bending of the Kanto Syntaxis are also discussed. The synthesis of Neogene tectonic development of the Japanese Islands is proposed based on many kinds of geological data and the geophysical constraints.

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Keywords : tectonic rotation, intra-arc deformation, paleomagnetism, Miocene, collision tectonics, Kanto Syntaxis, central Japan

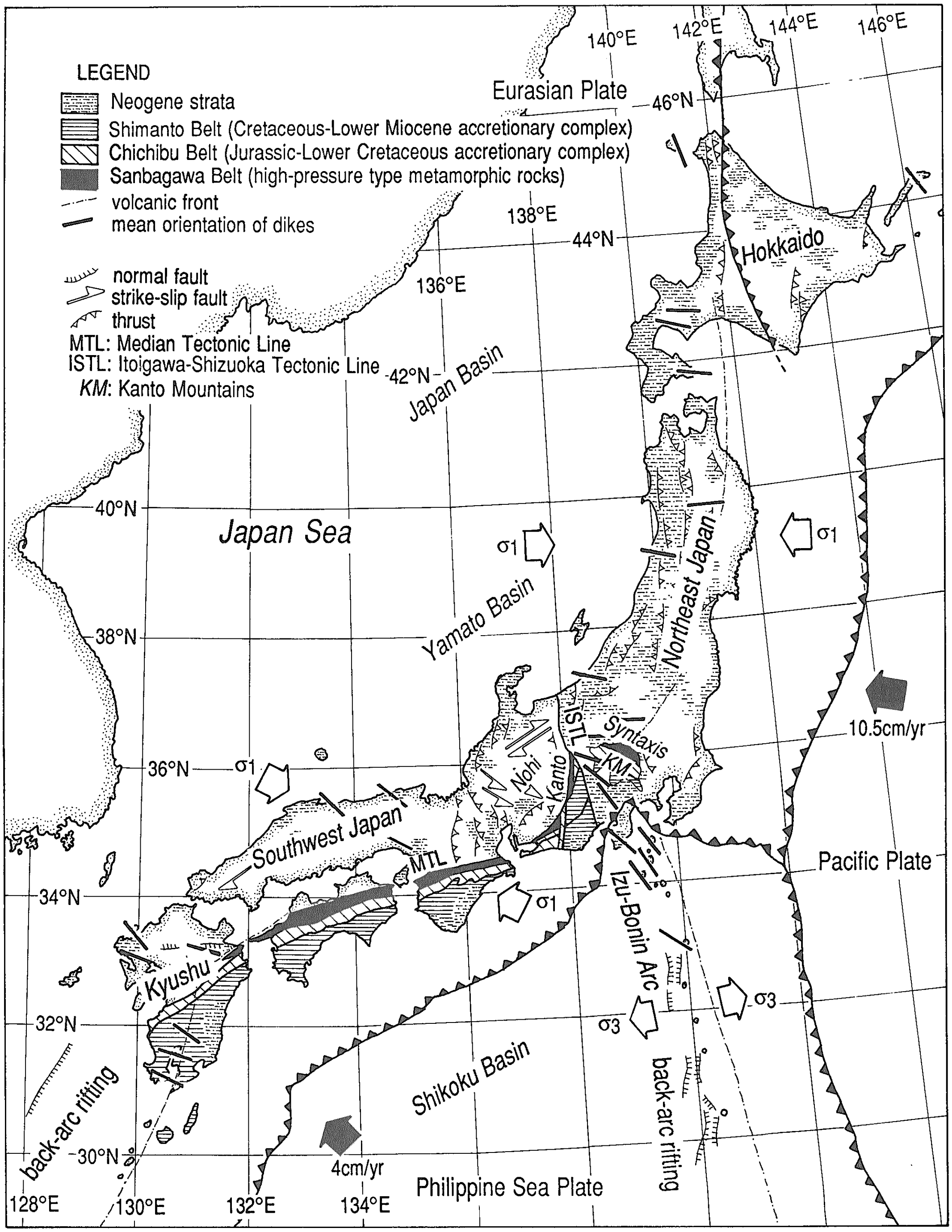

Fig. 1 The present tectonic sketch of the Japanese Islands. The solid arrows indicate the present plate motions relative to the Eurasian Plate (Minister and Jordan, 1978, 1979). The Japanese Islands have been under compressional tectonic regime since 3Ma (Sato and Amano, 1991). The Izu-Bonin arc collides with central Japan where zonal distribution of the pre-Neogene geologic terranes is sharply bent.

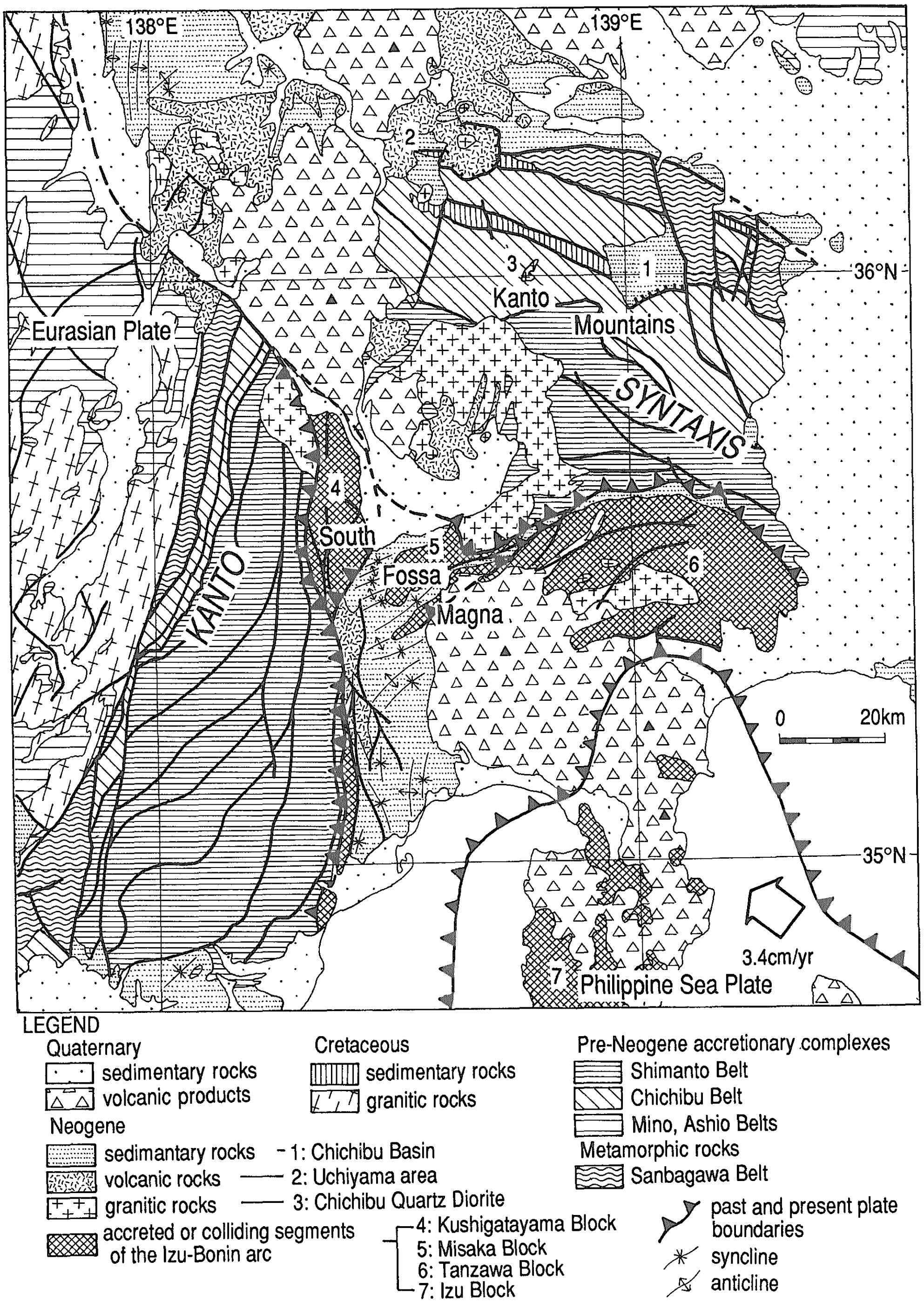

Fig. 2 Detailed geological map of central Japan modified from Geological Survey of Japan (1992). Collisions of the Kushigatayama and Misaka Blocks probably took place at 12Ma and 9-7Ma, respectively. The Tanzawa Block collided at 5-3Ma and the Izu Block commenced to collide at 1Ma (Amano, 1991).

2. Tectonic rotation of the Kanto Mountains

Paleomagnetic investigations are indispensable for studying island arc tectonics of Japan, where rotational motions are common as well as vertical movements. The zonal distribution of the pre-Neogene terranes in the Kanto Mountains has a different trend from in Southwest Japan, suggesting an occurrence of a differencial rotation as a part of the intra-arc deformation. As the Kanto Mountains are located on the east-wing of the Kanto Syntaxis, the difference of the paleomagnetic directions between the Kanto Mountains and the adjacent areas represents a deformation history of the Kanto Syntaxis. At first, the paleomagnetic directions with ages of three areas (Chichibu Basin, Uchiyama area and the Chichibu Quartz Diorite) in the Kanto Mountains are reviewed in detail to show a clockwise rotation of the east-wing of the Kanto Syntaxis (Table 1).

2.1 Chichibu Basin

The Miocene Chichibu Basin is located at a central part of the Kanto Mountains (Fig.2), where more than 5000m-thick sediments were deposited in spite of its small areal extension (about 160km^2). Sedimentary rocks in the Chichibu Basin consist of conglomerate, sandstone and siltstone with thin tuff layers. Hyodo and Niitsuma (1986) measured the paleomagnetism of the sedimentary rocks in the Chichibu Basin in an effort to clarify the timing of the bending of the Kanto Syntaxis. Although they collected paleomagnetic samples from 133 sites in the basin, only 58 specimens of 11 sites showed stable paleomagnetic directions by the stepwise alternating field (AF) and thermal (Th) demagnetizations.

Fig.3 indicates each tilt-corrected paleomagnetic direction of 11 sites in the Chichibu Basin. Each solid arrow is for the normal polarity and the open arrow shows reversed polarity with opposite direction. A mean paleomagnetic direction of the Chichibu Basin is D=93.7° and I=52.7° with the radius of 95% confidence circle (α_{95}) of 8.3°, after the inversion of the reversed polarity directions to the normal polarity. While the mean inclination is not significantly different from that of geocentric axial dipole field (56°), the mean declination is deflected easterly from north. As these 11 sites comprise both normal and reversed polarities which represent a sufficiently long period to average the geomagnetic secular variation, Hyodo and Niitsuma (1986) concluded that the eastward paleomagnetic declination is probably caused by the clockwise rotation of the Kanto Mountains.

The geologic age of the Chichibu Basin is zone N8 (Blow, 1969) based on the planktonic microfossils (Takahashi *et al.*, 1989 ; Takahashi, 1992). Therefore the paleomagnetic polarity sequence of the Chichibu Basin can be correlated with Chron C5B (Berggren *et al.*, 1985). The duration of the zone N8 is calibrated to be 16.6 - 15.2 Ma after Berggren *et al.* (1985). Consequently, more than 90° clockwise rotation of the Kanto Mountains took place since 15.2Ma.

2.2 Uchiyama Area

Fig.4 shows the geologic map of the Uchiyama area with paleomagnetic data measured by Takahashi and Watanabe (1992). In the Uchiyama area, northwestern corner of the Kanto Mountains (Fig. 2), several facies of volcanic rocks and intrusions are distributed. Among all, the Yaekubo Formation is a good target for paleomagnetic study, considering intercalating many fresh andesite lava. The paleomagnetism of the small intrusion (Takonomine Porphyrite) was also measured. The K-Ar ages of the andesite lava (11.9±0.9Ma, 12.2±0.4Ma, 12.4±0.4Ma) and of the Takonomine Porphyrite (12.5±0.4Ma) suggest the close relations between the intrusion of the porphyrite and the eruption of the andesite lava (Nomura and Kosaka, 1987 ; Nomura and Ebihara, 1988).

Paleomagnetic sampling was carried out at 9 sites for the andesite lava of the upper Yaekubo Formation and at 2 sites for the Takonomine Porphyrite. The total number of samples and specimens are 47 and 271, respectively. By the careful treatment of the Th and/or AF demagnetizations, reliable paleomagnetic directions were obtained from all samples.

Each arrow in the Fig.4 shows site-mean direction which are calculated from the

Table 1 Paleomagnetic directions obtained from the Chichibu Basin, Uchiyama area and the Chichibu Quartz Diorite. Some important planktonic microfossils and radiometric data are also listed. N and n are the number of the samples and specimens, respectively ; Jn is intensity of natural remanent magnetization (NRM) ($\times 10^{-3}$emu/cm^3) ; Demag. is demagnetization level ; Dec. and Inc. are declination and inclination of remanent magnetization after alternating demagnetization ; Dec.* and Inc.* are declination and inclination after tilt-correction ; α_{95} is radius of 95% confidence limit in degrees ; k is precision parameter ; Lat. (N) and Long. (E) are latitude and longitude of virtual geomagnetic pole (VGP).

Site	N	n	Jn	Demag. (mT)	Dec. (°)	Inc. (°)	Dec.* (°)	Inc.* (°)	α_{95} (°)	k	Lat.(N) (°)	Long.(E) (°)	lithology, key	microfossils & radiometric age
Chichibu Basin (Hyodo & Niitsuma, 1986)														
CB48	3			10	68.2	59.9	93.7	63.6	16.5	56.8	22.9	171.9	sandstone	*Orb. suturalis*
OG28	5			20	29.8	51.8	70.4	63.6	3.7	424.2	37.5	164.3	tuff	*Gds. sicanus*
OG12	5			15	-135.4	-57.4	-105.1	-61.4	12.3	39.6	33.5	162.4	sandstone	*Grt. peripheroronda*
OG32	5			25	-124.1	-57.5	-99.7	-44.6	15.9	24.3	22.5	147.9	sandstone	*Pro. glomerosa curva*
OG40	5			20	3.9	-63.1	-110.6	-40.2	8.5	81.3	29.4	139.2	tuffaceous sandstone	*Pro. transitoria*
OG35	5			20	14.8	-51.5	-80.4	-49.6	18.1	18.7	10.4	161.1	tuffaceous sandstone	
HK16	4			25	-101.7	-42.7	-75.8	-39.4	12.9	51.8	2.3	157.2	tuffaceous sandstone	
HK19	5			25	-102.1	-56.4	-52.6	-56.6	5.8	173.1	2.1	178.3	tuffaceous sandstone	*Pro. glomerosa curva*
HK13	6			20	-89.1	-50.2	-83.2	-55.6	16.6	17.3	15.6	164.6	tuffaceous sandstone	*Gds. sicanus*
HK12	5			25	-109.5	-56.6	-78.0	-44.0	8.8	76.8	6.0	158.7	sandstone	*D. deflandrei*
HK04	5			15	-92.0	-33.0	-73.8	-40.5	19.7	16.0	1.3	158.9	sandstone	*S. heteromorphus*
mean					80.0	61.4			16.2	8.9	30.0	-164.0		
mean*							**93.7**	**52.7**	**8.3**	**31.4**	**15.8**	**-160.1**		**zone N.8 (16.6-15.2Ma)**
Uchiyama Area (Takahashi & Watanabe, 1993)														
TK-1	3	14	0.62	10	22.8	49.1			2.6	2206.4	70.0	-121.0	porphyrite	12.5±0.4Ma
TK-2	3	14	0.62	10	34.0	63.1			2.4	2737.8	62.9	-161.1	porphyrite	
YK-1	5	44	9.95	20	-123.4	-45.7	-134.3	-41.8	9.1	71.5	49.1	-127.3	andesite lava	11.9±0.9Ma
YK-2	4	16	1.76	20	-127.4	-43.3	-139.9	-55.3	6.0	233.0	57.8	-142.9	andesite lava	12.2±0.3, 12.4±0.4Ma
YK-3	4	28	4.97	20	-101.4	-63.8	-147.4	-56.7	5.8	252.8	64.0	-143.6	andesite lava	
YK-4	4	18	8.62	20	-140.8	-47.8	-149.3	-48.5	9.8	88.3	63.5	-125.6	andesite lava	
YK-5	4	17	5.89	20	-115.9	-51.1	-142.5	-55.0	15.0	38.4	59.8	-141.4	andesite lava	
YK-6	5	34	2.89	20	-146.6	-47.1	-157.5	-48.5	8.5	82.2	70.0	-118.1	andesite lava	
YK-7	4	26	0.61	20	-139.9	-49.5	-151.7	-49.9	3.5	698.0	65.8	-126.4	andesite lava	
YK-8	6	22	8.17	20	-119.9	-62.8	-145.4	-56.4	7.9	72.5	62.4	-143.4	andesite lava	
YK-9	5	22	7.04	20	-111.7	-54.4	-140.8	-47.3	10.8	51.2	56.2	-129.5	andesite lava	
mean					-126.7	-52.5			7.3	50.1				
mean*							**34.7**	**51.2**	**4.4**	**141.0**	**61.1**	**-133.1**		**12.4-11.9Ma**
Chichibu Quartz Diorite (Takahashi & Nomura, 1989)														
1	1	7	0.34	20	-21.0	72.5			8.1	56.0	64.2	112.8	quartz diorite	
2	1	8	0.29	20	34.4	76.5			1.8	964.6	55.0	164.0	quartz diorite	
5	1	6	0.035	20	170.4	-57.4			5.8	132.4	82.1	66.4	porphyrite	
8	1	8	0.77	20	-170.0	-69.9			1.9	900.6	70.9	157.1	quartz diorite	6.6±0.3Ma
11	1	8	0.11	20	-173.0	-55.6			9.1	37.8	84.3	-134.7	quartz diorite	
12	1	9	0.065	20	-154.8	-38.9			3.0	294.7	64.0	-105.4	quartz diorite	
14	1	7	0.070	20	-170.8	-59.6			5.3	129.9	81.5	-165.5	quartz diorite	
15	1	4	0.20	20	-41.4	-50.5			1.0	9306.9	55.5	53.1	quartz diorite	
26	1	6	0.20	20	0.5	76.9			8.0	71.9	61.0	139.2	quartz diorite	5.9±0.3, 6.1±0.7Ma
27	1	5	0.31	20	28.4	70.5			3.1	593.0	63.0	176.1	quartz diorite	
28	1	8	0.69	20	3.3	65.8			1.8	921.5	77.7	149.2	quartz diorite	
30	1	6	0.34	20	1.8	66.6			4.1	270.2	76.8	144.0	quartz diorite	
31	1	6	0.17	20	171.3	-71.8			1.1	3459.5	68.5	125.7	quartz diorite	
32	1	5	0.14	20	8.4	70.7			1.2	4128.3	70.1	153.1	quartz diorite	
36	1	6	0.015	20	11.7	75.6			5.2	164.6	62.2	150.3	quartz diorite	
38	1	3	0.32	20	-1.0	57.7			3.5	1262.2	87.5	120.3	quartz diorite	
39	1	9	0.14	20	12.2	67.4			1.4	1346.5	73.3	166.8	quartz diorite	
42	1	5	0.11	20	18.9	61.8			1.6	2392.6	73.9	-162.7	quartz diorite	
43	1	4	0.067	20	9.3	51.6			5.1	326.9	81.4	-107.9	quartz diorite	
50	1	5	0.29	20	176.2	-64.7			6.4	144.1	79.0	125.0	quartz diorite	
51	1	9	0.47	20	174.3	-48.1			6.7	59.4	81.6	-4.7	quartz diorite	
mean					**3.5**	**64.4**			**5.1**	**40.2**	**79.4**	**152.1**		**6.6-5.9Ma**

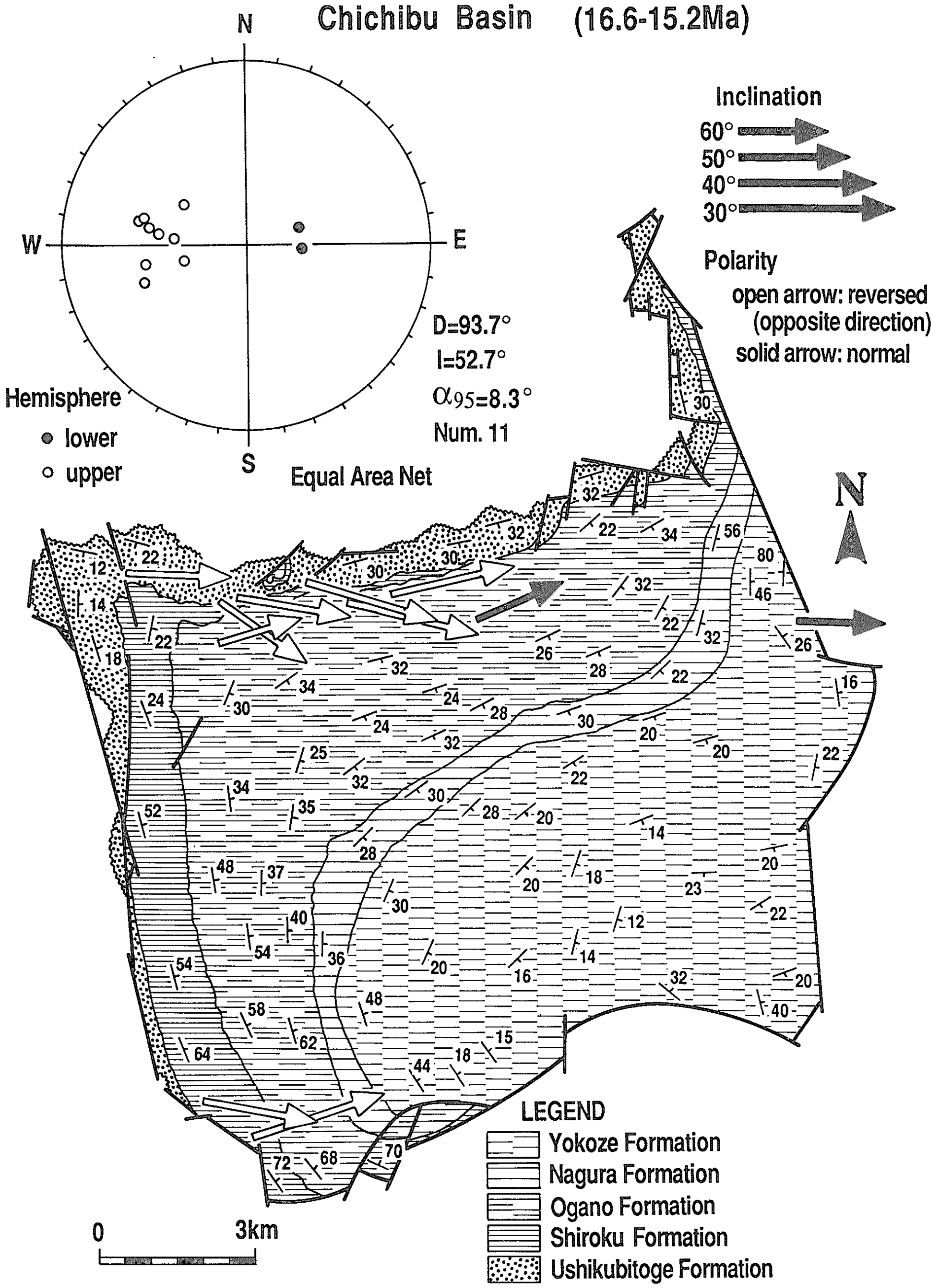

Fig. 3 Paleomagnetic result of the Chichibu Basin. Each arrow represents tilt-corrected site-mean direction (Hyodo and Niitsuma, 1986). Geological map and stratigraphic division are after Takahashi (1992). The easterly deflected directions suggest the clockwise rotation of the Chichibu Basin after 15.2Ma.

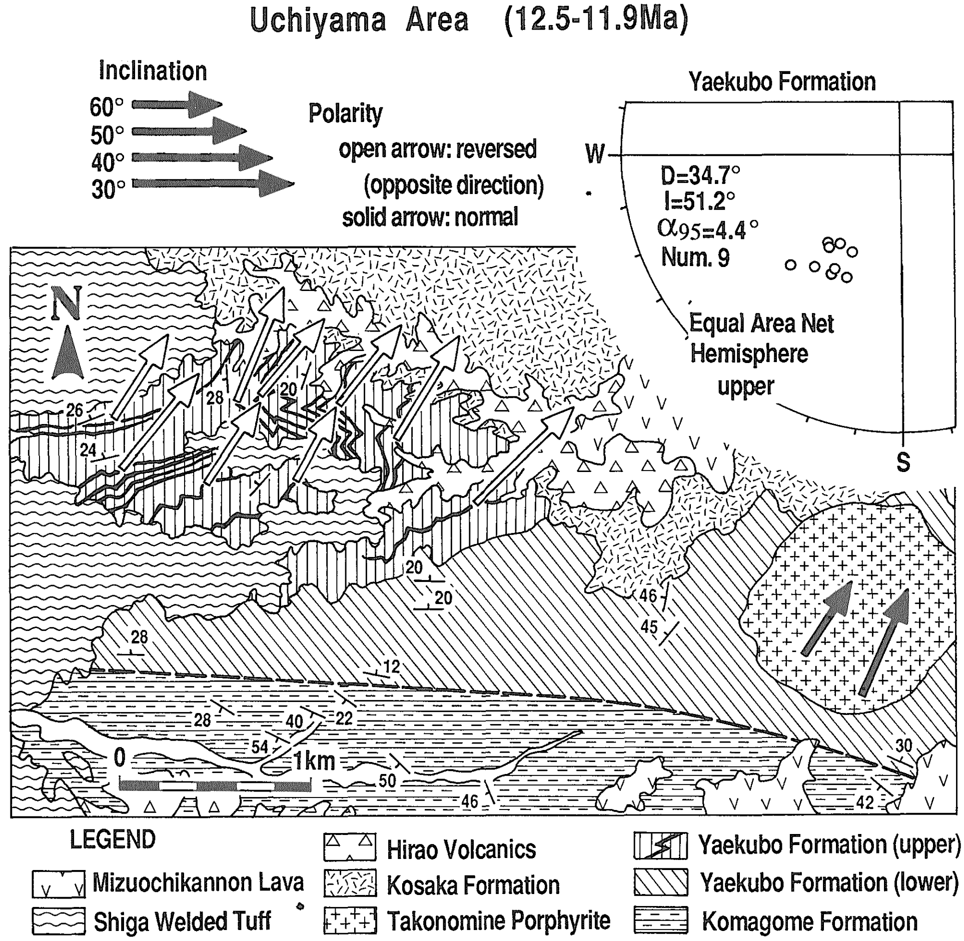

Fig. 4 Paleomagnetic result of the Uchiyama area modified from Takahashi and Watanabe (1993). The eastward deflected directions of the Takonomine Porphyrite (normal polarity) are in concordant with those of the Yaekubo Formation (reversed one). Base on the radiometric ages of these igneous rocks, about 35° clockwise rotation occurred after about 12Ma.

sample-mean directions. While the arrows of the andesite lava are tilt-corrected, the paleomagnetic directions of the porphyrite are in-situ directions. As the lava beds often have an initial dip, these paleomagnetic directions were tilt-corrected based on the bedding plane of intercalated sandstone or tuff layers. The formation-mean direction, D=-145.3°, I=-51.2°, α_{95}=4.4°, was then given by the tilt-corrected site-mean directions of the 9 sites.

Despite there are no micropaleontological data for the Yaekubo Formation, the radiometric ages of both the lowest and the upper ande site lava are approximately 12Ma with small error. Based on these radiometric data and the paleomagnetic polarity, the upper Yaekubo Formation can be correlated with the Chron C5 A of Berggren *et al.* (1985).

The paleomagnetic direction of the Yaekubo Formation shows eastward deflection after inversion of the reversed polarity direction to a normal one, which strongly suggests the clockwise rotation of the study area since 12Ma. The Takonomine Porphyrite (12.5Ma) also has a eastward deflected declination with normal polarity, which is concordant with that of the

Yaekubo Formation. Consequently, it can be concluded that about 35° eastward deflected direction is probably due to the post-12Ma clockwise rotation of the Kanto Mountains.

2.3 Chichibu Quartz Diorite

The Chichibu Quartz Diorite intruded into the pre-Neogene rocks of the Chichibu Belt at the central part of the Kanto Mountains (Fig. 2). This igneous rock is a stock of medium-grained massive quartz diorite with small dikes of quartz porphyry and porphyrite. Paleomagnetic direction of the Chichibu Quartz Diorite was measured by Takahashi and Nomura (1989). Total number of oriented hand samples and specimens are 51 and 304, respectively. By the careful treatment of AF demagnetization, reliable paleomagnetic directions were obtained from 21 samples as shown in Fig. 5.

Paleomagnetism of the northern part of the Chichibu Quartz Diorite shows reversed polarity. On the other hand, its southwestern body includes both normal and reversed polarities. The litofacies of the Chichibu Quartz Diorite is not significantly heterogeneous, implying a monogenic origin. The fact that the reversed polarity is recognized only near the margin of the diorite body suggests a change in geomagnetism during the period of cooling of the quartz diorite.

Mean paleomagnetic direction of the Chichibu Quartz Diorite (D=3.5°, I=64.4°, α_{95}=5.1°) is calculated after inversion of the reversed polarity directions to a normal one. Paleomagnetic directions of reliable 21 samples show both normal and reversed polarities and are distributed in antipodal directions, which signifies that the measured directions represent magnetic fields of a sufficiently long period to average geomagnetic secular variations. The obtained direction of the Chichibu Quartz Diorite can be assumed to represent an average dipole field.

The paleomagnetic declination shows no significant deflection from the north as shown in Fig. 5. While each arrow indicates an in-situ direction because of the intrusive origin, no deflected directions strongly suggest that the rotational motion of the Kanto Mountains after the intrusion of this diorite is negligibly small. The radiometric ages of this diorite (6.6±0.3 Ma, 5.9±0.4Ma : Ueno and Shibata, 1986) may represent the latest timing of the cease of the rotation.

3. Differential rotation within island arcs

Fig. 6 shows stratigraphic positions of the Neogene rocks of the Chichibu Basin, Uchiyama area and the Chichibu Quartz Diorite. Also shown are the time constraints based on the radiometric ages or planktonic microfossils as well as paleomagnetic directions. As the late Tertiary paleomagnetic poles of Eurasia almost coincide with the present geographic pole (Irving and Irving, 1982), the deflections in declination of the Chichibu Basin, Uchiyama area and the Chichibu Quartz Diorite represent the sum of clockwise rotation angles of the Kanto Mountains after 15, 12 and 6Ma, respectively. Therefore, the Kanto Mountains rotated about 60° clockwisely relative to the geomagnetic north between 15 and 12Ma, then most of the rest angle (31°) is attributed to the period between 12 and 6Ma, because the rotation since 6Ma is negligibly small.

Fig. 7 indicates the paleomagnetic declination values during the Tertiary obtained from Southwest Japan, Nohi area, Northeast Japan and the Kanto Mountains. The changes in paleomagnetic direction of these areas represent each history of tectonic rotation relative to the magnetic north, so that we can know the differential rotation by the comparison among them.

It became apparent in the last decade that Southwest Japan experienced a large clockwise rotation concurrent with the Japan Sea opening. (Otofuji and Matsuda, 1983, 1984, 1987 ; Otofuji *et al.*, 1985a, b, c ; Hayashida and Itoh, 1984; Hayashida, 1986 ; Hayashida *et al.*, 1991). Based on a data set obtained from Southwest Japan since 1982, Otofuji *et al.* (1985a) estimated the amount of clockwise rotation as 47°. They obtained the timing of this rotation using best fitting curves for rotation on the plots of declination against age data ; the climax of rotation is at 14.9Ma. Recently, Otofuji *et al.* (1991) measured K-Ar ages as well as paleomagnetism of Miocene volcanic rocks in Southwest Japan to elucidate the duration of the rotation.

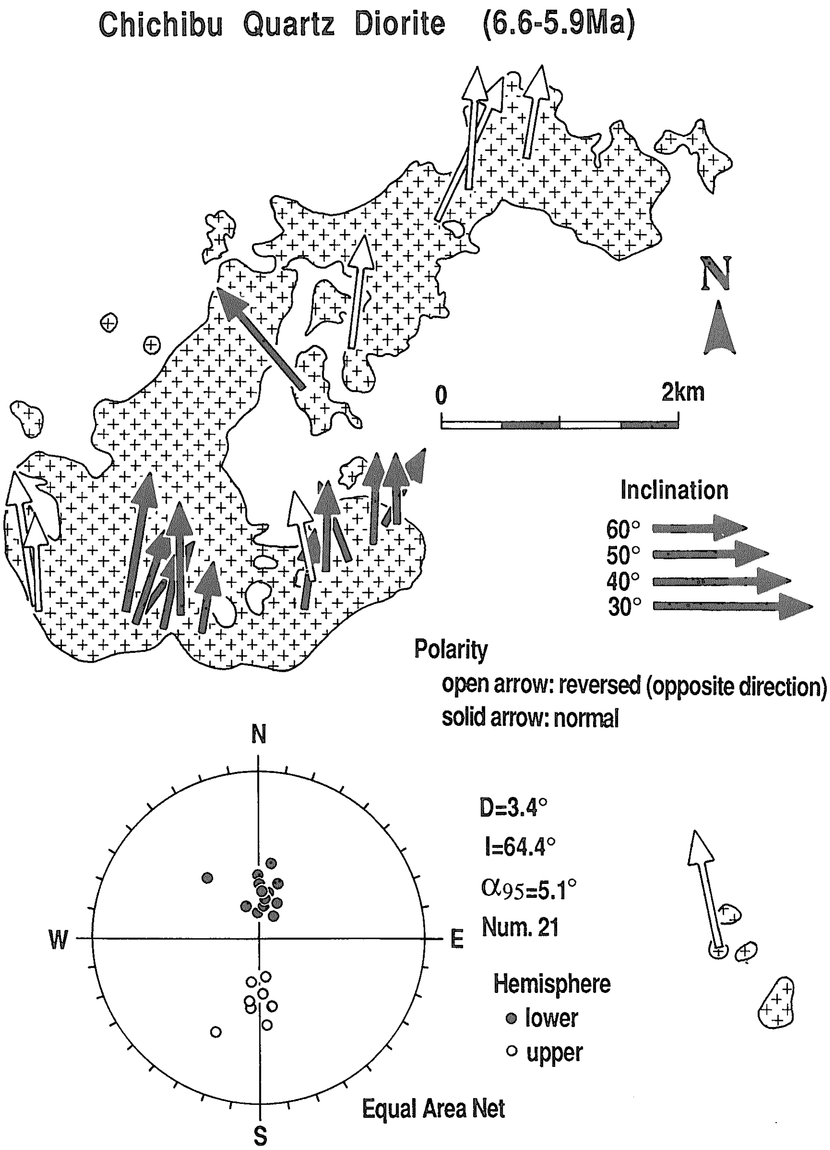

Fig. 5 Paleomagnetic result of the Chichibu Quartz Diorite partly modified from Takahashi and Nomura (1989). Although these paleomagnetic directions are in-situ ones, antipodal distribution with N-S trend signifies that the rotation of the Kanto Mountains after intrusion of this body is negligibly small.

Their data show that more than 80% (39°) of the overall rotation (47°) of Southwest Japan occurred between approximately 16 and 14Ma, which represents the rapid rotation of Southwest Japan (20°/m. yr.).

There are, however, some paleomagnetic data suggesting much smaller rotational angles obtained from Nohi area, located on the eastern part of Southwest Japan (Itoh, 1986, 1988). Since the Nohi area is located on the west-wing of the Kanto Syntaxis (Fig. 1), the paleomagnetic results should represent a rotation of the west-wing of the Kanto Syntaxis. Itoh (1988) showed the paleomagnetic properties of Late Cretaceous and Miocene rocks in the Nohi area, which indicated a slight deflected declination

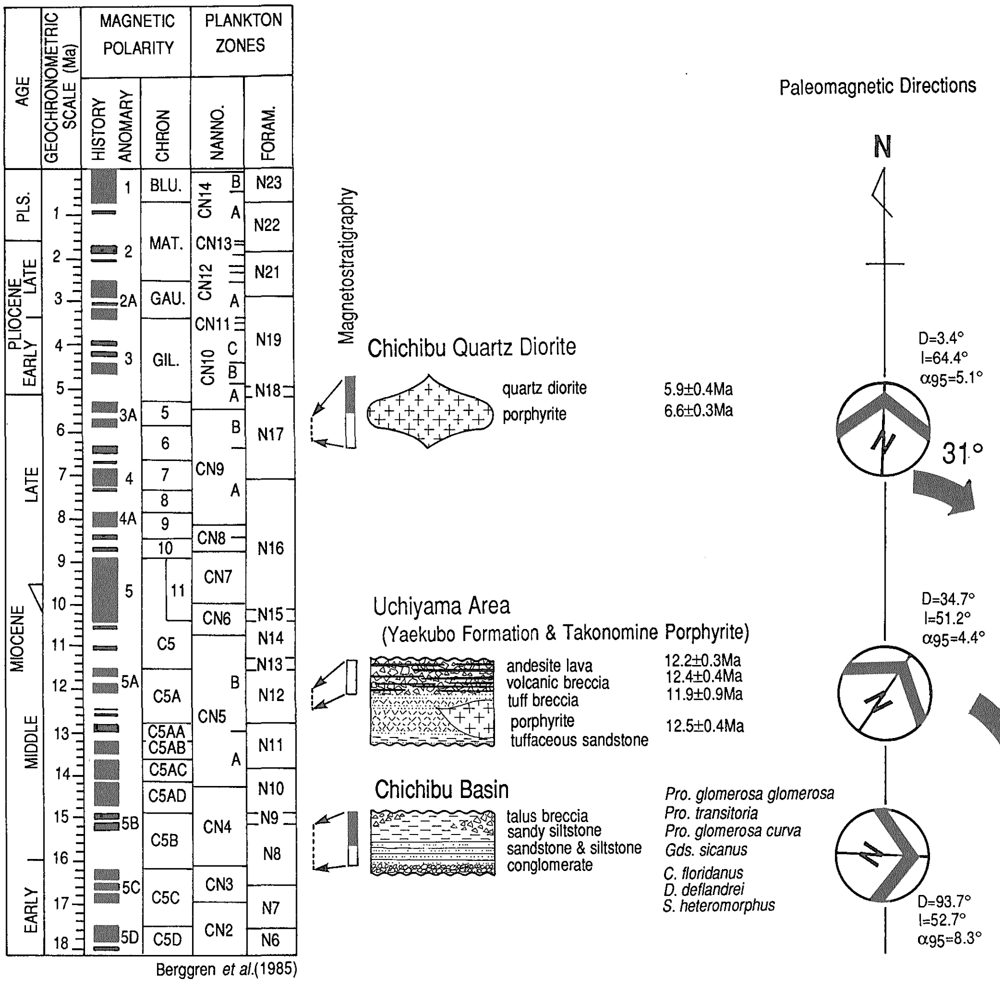

Fig. 6 Summary of the paleomagnetic results in the Kanto Mountains. The sequential shift of the paleomagnetic declination represents the clockwise rotation of the Kanto Mountains.

(13-17°). These paleomagnetic data infer that the west-wing of the Kanto Syntaxis rotated more than 30° counter-clockwisely relative to the main part of Southwest Japan between 15-12Ma. The northward bending of the zonal structure at the Nohi area is interpreted to have been formed by the left lateral plastic deformation at eastern end of the rotating Southwest Japan, based on the geologic features of central Japan as well as paleomagnetic data.

There have been only few paleomagnetic works on the late Tertiary rocks in Northeast Japan (Otofuji *et al.*, 1985; Tosha and Hamano, 1986, 1988, Nishitani and Tanoue, 1988, Yamazaki, 1989). Otofuji *et al.* (1985c) reported paleomagnetic data from a wide area of Northeast Japan and concluded that Northeast Japan had rotated counter-clockwise through 47° between 21 and 11Ma. They attributed the differential rotations between Southwest and Northeast Japan arcs to the back-arc opening of the Japan Sea with a double-door mode. Tosha and Hamano (1986, 1988) revealed that Northeast Japan was situated along the east coast of the Asian continent since Early Cretaceous and rotated between 22 and 15Ma. The estimated

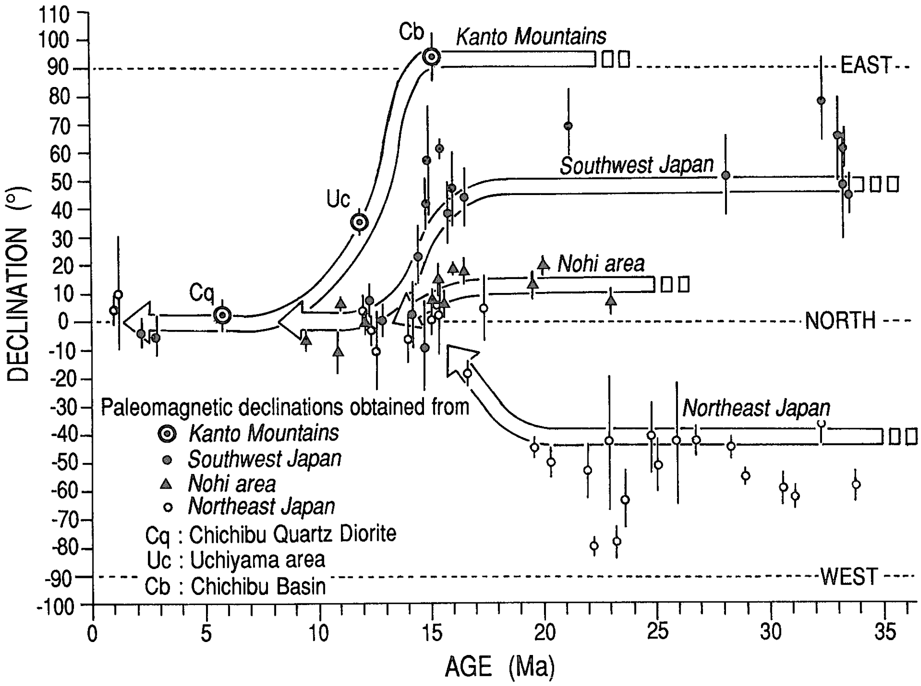

Fig. 7 Declination versus age for the Kanto Mountains (Hyodo and Niitsuma, 1986 ; Takahashi and Nomura, 1989 ; Takahashi and Watanabe, 1993), Southwest Japan (Otofuji *et al.*, 1985a), Nohi area (Itoh, 1986, 1988) and Northeast Japan (Otofuji *et al.*, 1985c ; Nishitani and Tanoue, 1988, Yamazaki, 1989 ; Hoshi *et al.*, 1992) partly modified from Takahashi (1994). Each error bar is the radius of 95% confidence circle (α_{95}).

amount of the rotation was somehow small (roughly 20°) than the previous estimation (Otofuji *et al.*, 1985c). Nishitani and Tanoue (1988) also determined the paleomagnetism of Northeast Japan to reconstruct the paleo-position and to elucidate the timing of the rotational motion. Their paleomagnetic results showed that the counter-clockwise rotation took place between 23 and 13Ma, which represents a long duration of rotation relative to Southwest Japan. Recently, Yamazaki (1989) performed a paleomagnetic study of the Neogene rocks along the Pacific side. He showed that the rotation of Northeast Japan had ceased before 16Ma, which suggests the difference in time of rotations between Southwest and Northeast Japan arcs.

4. Collision tectonics at central Japan

The South Fossa Magna is thought to be a Neogene collision zone between the Izu-Bonin arc on the Philippine Sea Plate and central Japan on the Eurasian Plate (Figs. 1, 2). After Sugimura (1972) pointed out that the boundary between the Philippine Sea and Eurasian Plates was located in the South Fossa Magna, it has been believed that the collision of the Izu-Bonin arc had caused the cusp structure of pre-Neogene terranes (Matsuda, 1978, 1984 ; Niitsuma, 1982, 1989). In recent years, detailed investigations on the geology and geophysics of the South Fossa Magna revealed the tectonic history of this arc-arc collision zone. Since such collision is expected to have caused a strong deformation in and around the colliding block, brief reviews of the collision tectonics at central Japan are shown here.

The tectonics of central Japan are related to the Eurasian, Philippine Sea and Pacific Plates as shown in Fig. 1. The Pacific Plate subducts beneath both the Eurasian and Philippine Sea

Plates. Then the Philippine Sea Plate also has a subduction boundary with the Eurasian Plate, while a northern tip of it collides with central Japan on the Eurasian Plate (Fig. 2). The subduction boundary between the Eurasian and Philippine Sea Plates can be traced onshore at the South Fossa Magna where the boundary nature changes to a collisional one. The collision of the Izu-Bonin arc with central Japan may be attributed to the buoyant nature of the active island arc.

Recently, Amano (1991) identified four exotic blocks in the South Fossa Magna (Fig. 2) ; Kushigatayama (Kg), Misaka (Ms), Tanzawa (Tz) and Izu (Iz) Blocks. These blocks are composed of thick piles of submarine volcanics and pyroclastics which are exceedingly deformed and altered. Based on the lithological characters, these four blocks are regarded as the tectonic segments of the Izu-Bonin arc, which collideded northward with central Japan. The ages of their volcanic activities are Early to Middle Miocene. The thick piles of detritus covering these four exotic segments are distributed along the margins between the blocks. These sediments shows generally upward-coarsening nature and is probably representing the collision-related sequences. For example, the Jike Mudstone, distributed along the northern margin of the Tanzawa Block, is thought to have been deposited on the trough slope or on the trough bottom, in front of the northward migrating Tanzawa Block as shown in Fig. 8 (Niitsuma and Akiba, 1985). The Ochiai Conglomerate, overlying the Jike Mudstone, is composed of coarse-grained detritus of fan-deltas derived from the Kanto Mountains, which filled up a deep trough rapidly. The buoyant nature of colliding Tanzawa Block was the cause of abrupt uplifting of the Kanto Mountains which supplied the coarse-grained clastics to the deep trough rapidly. Thus the upward coarsening sequence is thought to be a good indicator when the block collided. Therefore, the Tanzawa Block initiated to collide with central Japan at 5Ma. Based on the bio-and lithostratigraphy of the conglomerate dominated horizons, Amano (1991) concluded the timings of the collision of the Kushigatayama, Misaka, Tanzawa and Izu Blocks at 12Ma, 9-7 Ma, 5-3Ma and 1Ma, respectively. These collisions are expected to cause strong deformations in and around the South Fossa Magna.

5. Lateral bending of central Japan

Based on the accumulated results of paleomagnetic research, which can detect directly a component of large latitudinal drift as well as rotation, idealized reconstructions of the tectonic history of the Japanese Islands are shown in Figs. 9 and 10.

The Japanese Islands were located along the eastern margin of the Asian continent before the Japan Sea opening. It is clear that the zonal structure of the pre-Neogene geologic terranes was almost in linear trend in Early Miocene time as reconstructing by the paleomagnetic data. This implies that the sharp bent structure did not exist before the Japan Sea opening. Back-arc spreading of the Shikoku Basin started at 25 Ma (Kobayashi and Nakada, 1978), and its active spreading center and the newly formed oceanic lithosphere on the both sides also subducted beneath the Japanese Islands. About 47° clockwise rotation of Southwest Japan took place at around 15Ma and the Kanto Mountains (east-wing of the Kanto Syntaxis) probably rotated clockwise, while the west wing of the Kanto Syntaxis (Nohi area) migrated with only slight rotation, resulting the bending structure of the Kanto Syntaxis.

During this period (late Early Miocene to earliest Middle Miocene), a great number of half grabens were formed especially in the Japan Sea side of Northeast Japan (Yamaji, 1989, 1990), which indicates that Northeast Japan was subjected to extensional tectonics (Yamaji and Sato, 1989). Based on the stratigraphic constraints, it can be concluded that the interval of this extensional deformation continued from 18 to 15Ma. The formation of many half grabens and abrupt subsidence are thought as a response to the stretching and rifting of the lithosphere of the arc (Takeshita and Yamaji, 1990). Although the detailed timing of the rotation of Northeast Japan is still obscure owing to scarceness of paleomagnetic data, it is reasonable to assume

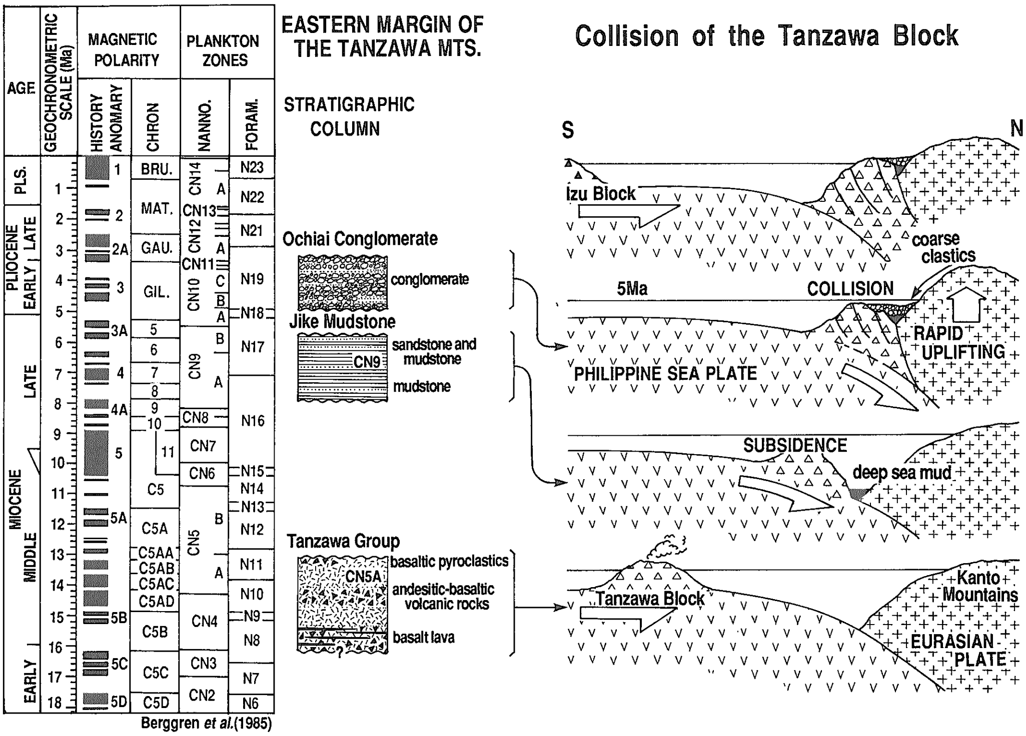

Fig. 8 Schematic diagram showing four stages during the Miocene and Pliocene collisional history of the Tanzawa Block with the Kanto Mountains (Takahashi, 1994). The Jike Mudstone deposited in the deep trough between the Kanto Mountains and the Tanzawa Block, and overlying coarse clastics (Ochiai Conglomerate) abruptly filled up the trough, which may be associated with the collision and accretion of the Tanzawa Block.

that the counter-clockwise rotation occurred during that time, that was probably caused by the opening of the Japan Sea.

Drastic events was suddenly stopped at the end of the rotation of Southwest Japan (ca. 14 Ma). Since then, the Japan arc got into a tectonically quiet state except for central Japan. Northeast Japan subsided gently and intra-arc deformation was small since 14Ma. The stress field deduced from dikes, veins and minor faults shows that Northeast Japan were under weak compressional or neutral regime till Early Pliocene. On the other hand, the compressional deformation took place in central Japan at 14Ma (Oishi and Takahashi, 1989), suggesting that the collision of the Izu-Bonin arc initiated at that time. The about 30° additional rotation of the Kanto Mountains occurred between 12 and 6Ma, resulting the cusp shape structure of the Kanto Syntaxis. It is likely that this rotation was caused by the collisions of the Kushigatayama and Misaka Blocks against the Kanto Mountains.

The tectonic regime of the Japanese Islands was neutral or weak compressional in Late Miocene (Amano, 1980 ; Sato *et al.*, 1982 ; Sato, 1986 ; Otsuki, 1990b). Many caldera structures related to felsic subarial volcanisms were formed in Northeast Japan. Although the Tanzawa Block collided at 5Ma, the rotation of the Kanto Mountains after 6Ma was not more than 10° (Fig. 5), which signifies that the collision of the Tanzawa Block did not play an important role in formation of the Kanto Syntaxis. The colliding Tanzawa Block seems to have deformed only Neogene strata in the South Fossa Magna area.

Since ca. 3Ma, the Japanese Islands have

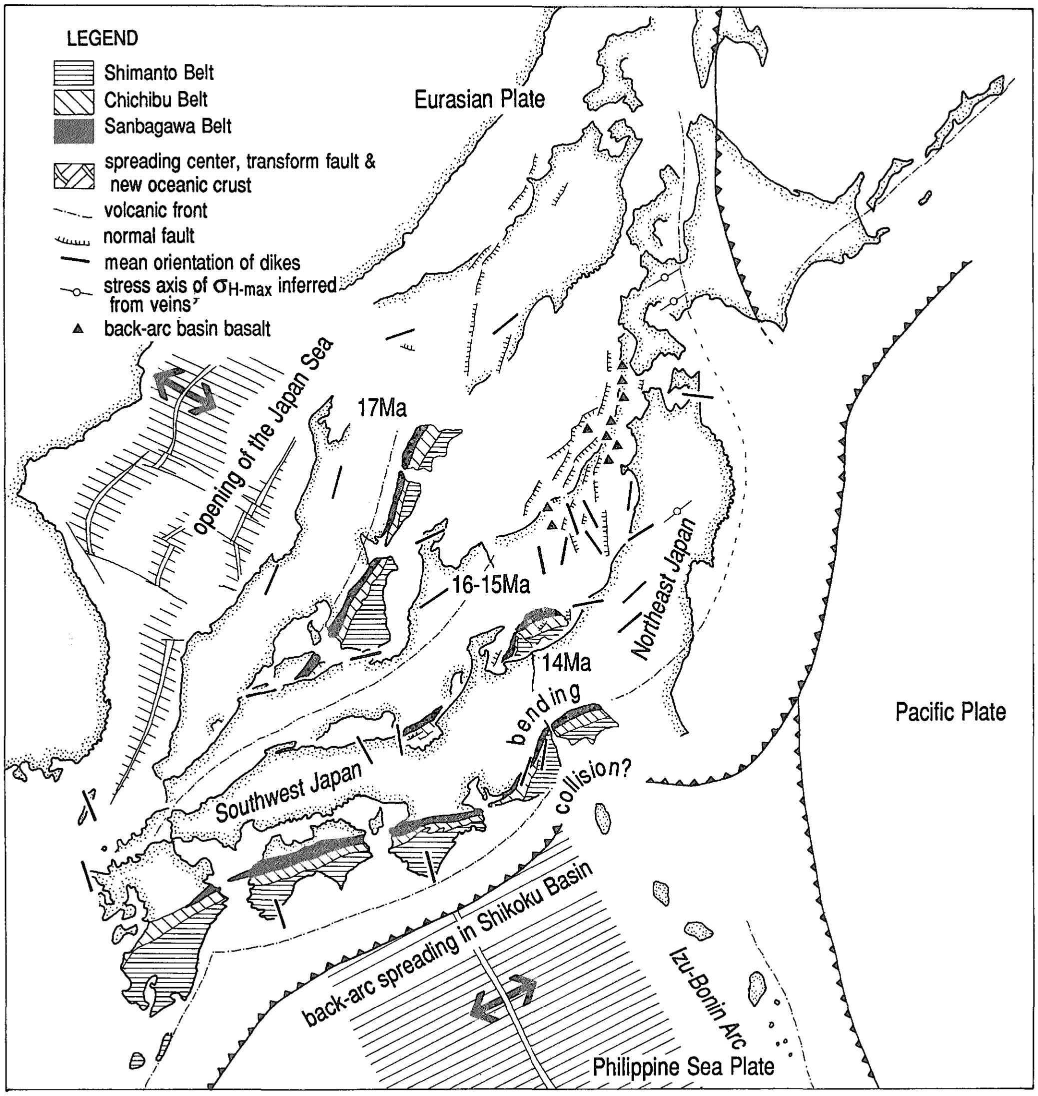

Fig. 9 Paleogeographic map of the Japanese Islands in the latest Early Miocene to early Middle Miocene. The stress axes of $\sigma_{H\text{-}max}$ inferred from dikes (Yamamoto, 1991) and veins (Otsuki, 1989, 1990b) are also shown. The reconstructed plate boundaries, as well as off shore area, are partly modified from Otsuki (1990a). The zonal structure of pre-Neogene terranes was almost in linear trend before the Japan Sea opening. This period is characterized by the extensional tectonics and oceanward drifting with rotation of the Japanese Islands.

been suffering the compressional deformation as shown in Fig. 1. Many boundary normal faults of the Early Miocene half grabens have reacted as thrusts where thick Neogene strata are strongly folded. The reconstructed stress field suggests that the maximum principal stress is oriented horizontally. The direction of the $\sigma 1$ is almost normal to the trench in Northeast Japan, while the $\sigma 1$ trend in Southwest Japan is diagonal to the relative motion of the Philippine Sea Plate. Thus the stress field in Southwest Japan may have been subjected to both the westward migration of the Pacific Plate and northwestward motion of the Philippine Sea

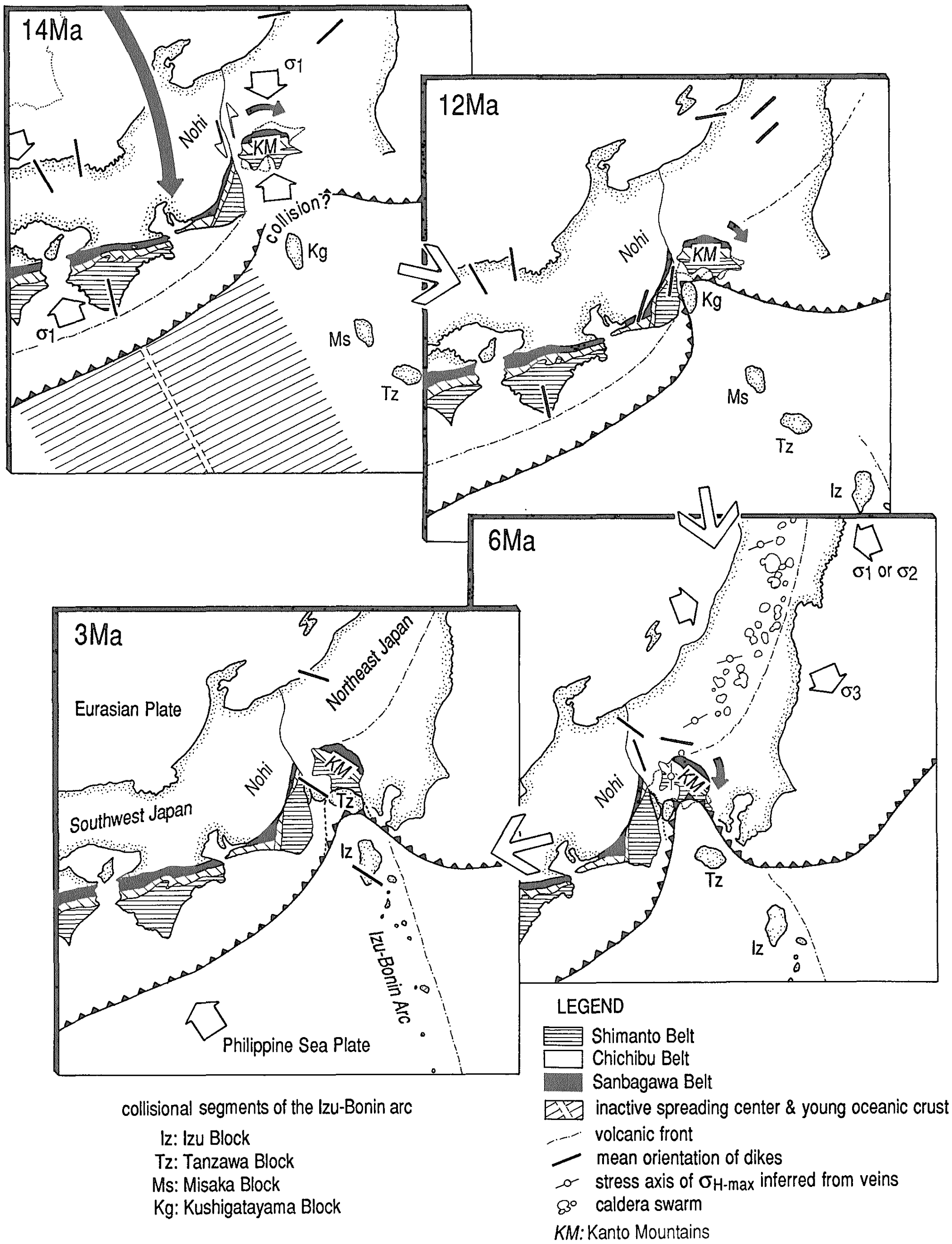

Fig. 10 Paleogeographic maps of central Japan in Middle Miocene to Early Pliocene time. The major rotations of Southwest and Northeast Japan arcs ceased at 14Ma, while the Kanto Mountains rotated till Late Miocene. The Kushigatayama, Misaka and Tanzawa Blocks have collided and accreted at the South Fossa Magna region in succession. The additional rotation of the Kanto Mountains, probably caused by the collision of the Izu-Bonin arc, resulted in the sharp bent structure of the Kanto Syntaxis.

Plate. As for the central Japan, the Izu Block initiated to collide at 1Ma (Amano *et al.*, 1986) and the reconstructed principle stress axes are almost equal to the relative motion of the Philippine Sea Plate (Amano, 1991). The tectonics of central Japan have been dominated by the collision of the Izu-Bonin arc since Middle Miocene.

6. Conclusions

1. The zonal distribution of the pre-Neogene terranes was almost in linear trend before the Japan Sea opening, that is, the cuspate structure of the Kanto Syntaxis at central Japan did not exist then.
2. The lateral bending of the Kanto Syntaxis firstly occurred at around 15Ma by the differential rotations at central Japan in association with the rapid clockwise rotation of Southwest Japan.
3. The Kanto Mountains, on the east-wing of the Kanto Syntaxis, rotated till Late Miocene, resulting a sharp bend at central Japan. Probable cause of this additional rotation was the collision of the Izu-Bonin arc on the northwestward migrating Philippine Sea Plate.

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中新世における中部日本の折れ曲がり
ー島弧ー島弧衝突域における弧内変形ー

高橋雅紀

要　旨

典型的島弧である日本列島の中部域は，複数の島弧(東北日本弧・西南日本弧・伊豆ー小笠原弧)が会合し，複雑な地史を経てきたと推察される．実際，九州から西南日本外帯に連続して追跡される先中新統の帯状配列は，中部日本において著しく北西方向に湾曲し，関東対曲構造(Kanto　Syntaxis)として前世紀よりその形成時期および成因が議論されてきた．

このような島弧規模の変形過程を把握するために，地質体の回転量を定量的に表わす古地磁気データを時間軸にそってブロック毎にまとめ，さらに屈曲構造形成に大きく関与したと考えられる伊豆ー小笠原弧の衝突と関連させて，中部日本の変形史を考察した．その結果，前期中新世の日本海の拡大にともない，時計回りに回転した西南日本の東端において湾曲構造が形成されたことが強く示唆された．そしてその後のフィリピン海プレートの北西方への沈み込みにより，伊豆ー小笠原弧が南部フォッサマグマにおいて衝突し，湾曲構造の東翼である関東山地がさらに回転した結果，より屈曲した構造が6Maまでに形成されたことが判明した．