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PALEOMAGNETIC STUDY OF THE TETORI GROUP IN TOYAMA

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ABSTRACT

The present authors carried out the paleomagnetic study of the Tetori Group in Toyama Prefecture. The paleomagnetic samples are taken from 60 sites in the following three areas such as the Ohyama Area, the Arimine Area and the Nagatogawa Area. Sites in the Ohyama Area are divided into three groups of the Upper Ohyama, the Middle Ohyama and the Lower Ohyama horizon. The Middle Ohyama horizon group is the excavation site where many footprints of dinosaurs and birds were recovered.

The paleomagnetic results of the Upper Ohyama horizon group and the Nagatogawa Area show higher paleolatitude of about 47°N and 51°N, respectively, while that of the Arimine Area is as low as 32°N. The values of paleolatitude of the Middle and the Lower Ohyama horizon groups are in between the above-mentioned areas, that is, 38° and 39°, respectively.

The paleomagnetic study of the Tetori Group in Fukui and Ishikawa Prefectures revealed that the lower the stratigraphic horizon shows the lower paleolatitude. The paleolatitude of the basin varies from about 20°N at the time of the Kuzuryu Subgroup, to beyond 40°N at that of the Akaiwa Subgroup.

Comparing the present results with those in the Fukui–Ishikawa region, the Upper Ohyama horizon group and the Nagatogawa Area can be correlated to the Akaiwa Subgroup, and the Arimine Area to the Itoshiro Subgroup. The Middle and the Lower Ohyama horizon groups might be correlated to the uppermost part of the Itoshiro Subgroup (or to the lowermost of the Akaiwa Subgroup).

More than 40° differences in the paleomagnetic declinations of the same stratigraphic horizons are observed between the Fukui-Ishikawa region and the Toyama region. This fact may indicate that the differential rotation took place within the Tetori basin after its northward migration.

A clear anisotropy of the magnetic susceptibility is detected on the Middle Ohyama horizon group. The anisotropy may provide a useful tool for analyzing paleocurrent.

Key words: paleomagnetic study, paleolatitude, Tetori Group, northward migration, tectonic rotation, differential rotation, anisotropy of magnetic susceptibility, Toyama Prefecture.

広岡公夫・山口重太郎・酒井英男・溝口秀勝（2003）富山の手取層群の古地磁気学的研究．福井県立恐竜博物館紀要 2：51–61.

富山県内に分布する手取層群について３地域，60層準から古地磁気試料を採取した．恐竜足跡化石露頭とその周辺の大山地域，有峰湖周辺の有峰地域および長棟川中流域南方の長棟川地域である．大山地域は層序にしたがって，上部，中部，下部の３層準に区分した．

地域ごとの平均伏角から求めた古緯度は，大山上部層準と長棟川地域では，それぞれ約47°Nと51°Nとなり，有峰地域では32°Nとなった．大山中部および下部層準は，38°～39°Nで，上記の中間にくる．福井・石川地方の古地磁気結果と比較すると，大山上部層準・長棟川地域は赤岩亜層群に，有峰地域は石徹白亜層群に対比される．大山中部・下部層準は石徹白亜層群最上部（または赤岩亜層群最下部）に相当する．また，福井・石川と富山とでは偏角に40°を超える差異があり，堆積盆内で差動回転があった．

足跡化石露頭の地層には明瞭な帯磁率の異方性が見られ，古流向解析の有効な手段となる可能性が高い．

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INTRODUCTION

The paleomagnetic study on the dinosaur-bearing strata in Fukui and Ishikawa Prefectures was the first systematic paleomagnetic study of the Tetori Group (Hirooka et al., 2002). By this study, it is found that paleomagnetic remanence of samples collected from the Tetori Group is stable enough to discuss the paleolatitude and tectonic rotation of the Tetori basin.

The study revealed a following geotectonic history of the sedimentary basin of the Tetori Group. The sedimentary basin had initially been located in a region of very low latitude of around 24°N during the formation of the Kuzuryu Subgroup. The basin began to migrate northward and the mean paleolatitude at the time of the Itoshiro Subgroup was about 35°N. This northward migration had been continued until the sedimentation of the Akaiwa Subgroup, and the mean paleolatitude of the basin reached up to around 41°N at the time of the Akaiwa Subgroup. During this northward migration, the basin was rotated counter-clockwise by about 40°. The sedimentation of the Kuwajima Formation and the Akaiwa Subgroup were performed at this high latitude. The basin was transferred southeastward and rotated clockwise by the angle of about 80° sometime after their sedimentation, probably in the Early Miocene time when the opening of the Japan Sea took place.

Although it is rather sporadic, the distribution of the Tetori Group is ascertained in Toyama Prefecture. The present authors attempt, therefore, paleomagnetic investigation in this region to confirm the above-mentioned tectonic history of the northward migration and tectonic rotation of the Tetori Basin.

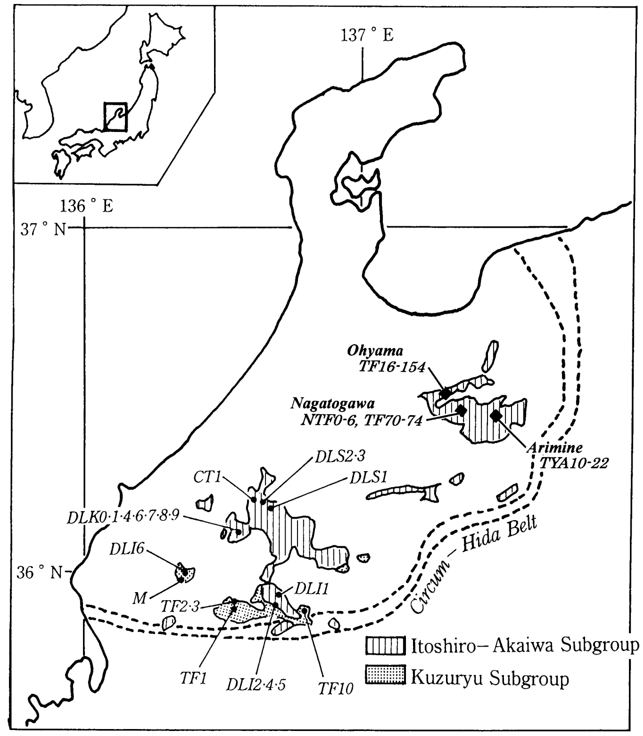

FIGURE 1. Map showing distribution of the Tetori Group and localities of the paleomagnetic sampling sites. Sampling sites of the previous study in Fukui and Ishikawa Prefectures are also plotted here.

PALEOMAGNETIC SAMPLING IN TOYAMA PREFECTURE

Paleomagnetic samplings of the Tetori Group in Toyama Prefecture are carried out in the Ohyama, the Arimine and the Nagatogawa Areas as shown in Fig. 1. The Tetori Group in Toyama is divided stratigraphically into three formations of the Higashi-Sakamori, the Nagatogawa and the Atotsugawa Formations in ascending order (Kawai and Nozawa, 1958), which are correlated with the Kuzuryu, the Itoshiro and the Akaiwa Subgroup in the Fukui–Ishikawa region, respectively. Each of the formations is composed of two members. The Higashi-Sakamori Formation is of the Makawa sandstone conglomerate and the Arimine shale Members, the Nagatogawa Formation is of the Ioridanitoge conglomerate and the Inotani alternation Members, and the Atotsugawa Formation is of the Minamimatadani conglomerate and the Wasabu alternation Members.

In the Ohyama Area, a concentrated sampling is carried out from many horizons on the sedimentary sequence at the excavation site where many dinosaur footprints were recovered. In this area, samples were also collected from nearby outcrops of the excavation site. The Tetori Group distributing in this Area is not well classified stratigraphically. There have been argued two ways to correlate the stratigraphic horizons in the Ohyama Area. One is to consider that the horizons belong to the Inotani Alternation Member (Kawai and Nozawa, 1958; Toyama Prefecture, 1970, 1992) and the other is correlating with the Wasabu Alternation Member (Maeda and Takenami, 1957; Yamada, 1988). The present authors tentatively correlate the horizons to the Wasabu Alternation Member.

Paleomagnetic samplings were carried out at 12 sites (Sites TYA10, TYA12–22) in the Arimine Area. According to the geological map of Toyama Prefecture (Toyama Prefecture, 1992), the stratigraphic horizons of the sampling sites in the Area are as follows. Site TYA17 is considered to be in the Wasabu Alternation Member and the other sampling sites are to be in the Inotani Alternation Member except Site TYA22 which is correlated with the Higashi-Sakamori Formation.

In the Nagatogawa Area, samples are collected from 11 sites (Sites NTF0–6, TF70–72, TF74). The Sites NTF0–6 are of the Wasabu Alternation Member, Sites TF70, TF71 and TF74 are of the Inotani Alternation Member, and Site TF72 is igneous sheet.

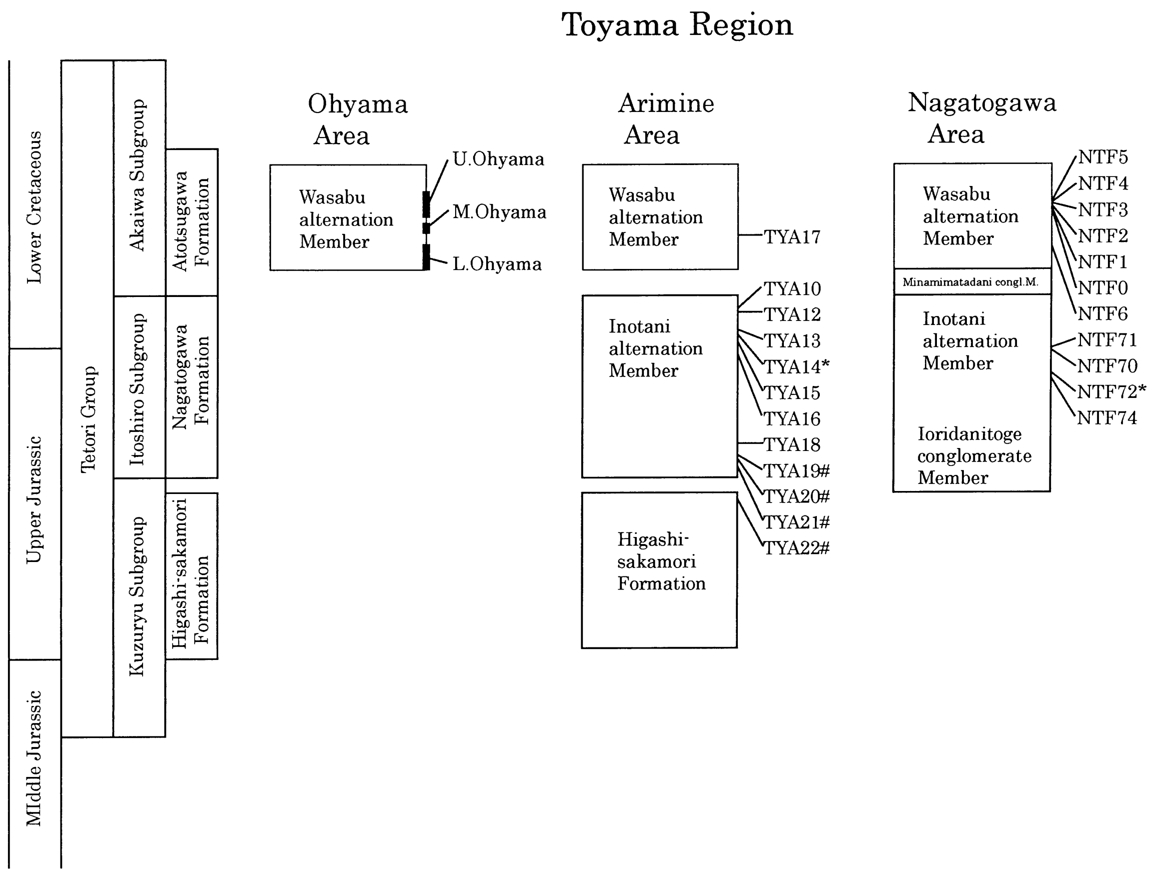

FIGURE 2. Paleomagnetic sampling horizons shown on the stratigraphic classification of the Tetori Group in Toyama Region.

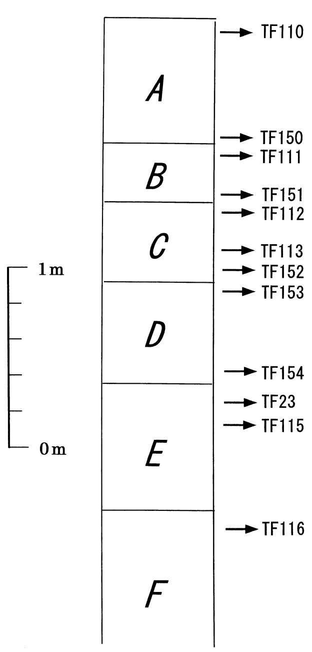

FIGURE 3. The columnar section showing the detail stratigraphic sampling horizons in the Ohyama excavation site.

The locality, stratigraphic unit, rock type, and strike and dip of bedding plane of each sampling site are tabulated in Table 1. The stratigraphic horizons of the sampling sites are shown in Fig. 2.

In the Ohyama Area, paleomagnetic samples were collected from 37 sites (Sites TF16–20, TF22–23, TF51–57, TF60–61, TF90–91, TF94–98, TF110–113, TF115–116, TF120–122, TF150–154). At the Ohyama excavation site, strata are divided into 6 layers, that is, Layer A, B, C, D, E and F in the descending order. The horizon where more than 300 dinosaur and bird footprints were discovered is on the top surface of Layer E, and whose paleomagnetic sampling horizon is Site TF23. On the top surface of Layer B, 2 footprints of an ankyrosaur were excavated. This is the first discovery of the ankyrosaur footprints in Japan (Toyama Dinosaur Research Group, 2002).

The detail stratigraphic horizons of paleomagnetic sampling sites at the Ohyama excavation site are described as follows in the descending order. Sites TF110 and TF150 are in Layer A, Sites TF111, TF151 are in Layer B, Sites T112, TF113 and TF152 are in Layer C, Sites TF153 and TF154 are in Layer D,

TABLE 1. Localities and stratigraphic information of the sampling sites.

Site	Locality		Stratigraphic unit	Rock type	Bedding	
	Lat. (N)	Lon. (E)			Strike(°)	Dip(°)
The Ohyama Area						
The Upper Horizon Group						
TF61	36° 30′	137° 11′	Wasabu alt. M.	sandstone	N 19 W	36 W
TF60	36° 30′	137° 11′	Wasabu alt. M.	sandstone	N 19 W	36 W
TF121	36° 32′	137° 17′	Wasabu alt. M.	sandstone	N 77 E	27 N
TF91	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 83 E	36 N
TF90	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 79 E	23 N
TF16	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 76 E	50 N
TF17	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 88 E	40 N
TF18	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 71 E	44 N
TF19	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 70 E	51 N
TF20*	36° 32′	137° 16′	Wasabu alt. M.	sheet(tuff?)	N 82 E	42 N
TF22	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 82 E	42 N
TF51	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 84 E	17 N
TF54	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 85 W	38 N
TF55	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 86 E	39 N
TF56	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 64 E	34 N
TF57	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 66 E	46 N
The Middle Horizon Group						
TF110	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 78 E	41 N
TF150	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 77 E	26 N
					N 88 E	45 N
TF111	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 78 E	36 N
TF151	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 73 E	38 N
TF112	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 73 E	41 N
TF113	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 74 E	35 N
TF152	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 72 E	31 N
TF154	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 57 E	31 N
TF23	36° 32′	137° 16′	Wasabu alt. M.	siltstone	N 64 E	34 N
TF115	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 72 E	34 N
TF116	36° 32′	137° 16	Wasabu alt. M.	sandstone	N 62 E	31 N
The Lower Horizon Group						
TF52	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 87 E	37 N
TF53	36° 32′	137° 16′	Wasabu alt. M.	sandstone	N 87 E	44 N
TF98#	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 85 E	31 N
TF97#	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 69 E	37 N
TF96	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 65 E	22 N
TF95	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 81 E	24 N
TF94	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 84 W	17 N
TF120	36° 31′	137° 16′	Wasabu alt. M.	sandstone	N 82 W	40 N
TF122	36° 31′	137° 17′	Wasabu alt. M.	sandstone	N 88 E	12 S

TABLE 1. (continued)

Site	Locality Lat. (N)	Lon. (E)	Stratigraphic unit	Rock type	Bedding Strike(°)	Dip(°)
The Arimine Area						
TYA17#	36° 29′	137° 27′	Wasabu alt. M.	siltstone	N 21 E	31 W
TYA10	36° 27′	137° 26′	Inotani alt. M.	sandstone	N 75 W	35 S
TYA12	36° 27′	137° 26′	Inotani alt. M.	sandstone	N 48 E	26 S
TYA13	36° 27′	137° 26′	Inotani alt. M.	sandstone	N 66 W	16 N
TYA14*	36° 26′	137° 27′	Inotani alt. M.	dike	N 18 E	19 W
TYA15	36° 26′	137° 27′	Inotani alt. M.	shale	N 30 E	18 W
TYA16	36° 25′	137° 27′	Inotani alt. M.	siltstone	N 58 E	19 N
TYA18	36° 28′	137° 29′	Inotani alt. M.	sandstone	N 29 E	19 W
TYA19#	36° 28′	137° 29′	Inotani alt. M.	sandstone	N 40 W	30 W
TYA20#	36° 28′	137° 29′	Inotani alt. M.	sandstone	N 22 W	22 W
TYA21#	36° 28′	137° 29′	Inotani alt. M.	siltstone	N 16 E	26 W
TYA22#	36° 28′	137° 29′	Higashi-Sakamori F.	sandstone	N 12 E	20 W
The Nagatogawa Area						
NTF5	36° 28′	137° 19′	Wasabu alt. M.	sandstone	N 84 W	11 S
NTF4	36° 28′	137° 19′	Wasabu alt. M.	siltstone	N 52 E	13 E
NTF3	36° 28′	137° 19′	Wasabu alt. M.	sandstone	N 80 E	10 S
NTF2	36° 28′	137° 19′	Wasabu alt. M.	sandstone	N 8 W	12 W
NTF1	36° 28′	137° 19′	Wasabu alt. M.	sandstone	N 46 W	8 S
NTF0	36° 28′	137° 19′	Wasabu alt. M.	shale	N 46 W	8 S
NTF6	36° 28′	137° 19′	Wasabu alt. M.	sandstone	N 66 E	25 N
TF71	36° 28′	137° 21′	Inotani alt. M.	sandstone	N 10 W	8 E
TF70	36° 28′	137° 19′	Inotani alt. M.	sandstone	N 10 W	8 E
TF72*	36° 27′	137° 20′	Inotani alt. M.	sheet	N 10 W	8 E
TF74	36° 27′	137° 20′	Inotani alt. M.	sandstone	N 10 W	8 E

Wasabu alt. M. : Wasabu alternation Member, Inotani alt. M. : Inotani alternation Member, Higashi-Sakamori F. : Higashi-Sakamori Formation. Asterisks(*) indicate the intrusive rock sites and sharps(#) indicate the sites which show extremely strong intensity and/or unusual remanent direction

Sites TF23 and TF115 are in Layer E, and Site TF116 is in layer F, as is shown in Fig. 3.

6 to 10 oriented hand samples were collected from each site. From each hand sample, plural cylindrical specimens (25 mm in diameter and 24 mm long) were cored out and submitted to magnetic measurement.

Sites TF72 and TYA14 are not of sedimentary strata but of igneous sheets intruded in between sedimentary layers. The age of these intrusive sheets must be younger than the sedimentary strata of the Tetori Group.

RESULTS OF PALEOMAGNETIC MEASUREMENTS

Most of the samples are so weakly magnetized that only SQUID (Superconducting Quantum Interference Device) magnetometer can detect their remanence accurately. NRM (natural remanent magnetization) intensity of core specimens is in the order of 10^{-3} Am^2. All the specimens are submitted to the progressive AF (alternating field) demagnetization and/or Th (thermal) demagnetization to eliminate stable and reliable magnetic components of the remanence.

The results of paleomagnetic study for the Ohyama Area, the Arimine Area and the Nagatogawa Area are tabulated in Tables 2, 3 and 4 respectively. Tilt corrected mean declination (D) and

TABLE 2. Site mean paleomagnetic directions of the Tetori Group in the Ohyama Area.

Site	N	ODT (°C)	ODF (mT)	D (°E)	I (°)	α_{95} (°)	K	J ($x10^{-3}$ Am^2)
The Upper Horizon Group								
TF61	9		10.0	−30.0	71.0	7.70	45.46	4.67
TF60	8		10.0	−31.3	68.0	7.24	59.44	12.6
TF121	9		NRM	34.4	61.6	7.29	50.81	8.32
TF91	9		10.0	18.1	43.1	13.39	15.74	3.42
TF90	8		7.5	26.1	53.5	6.20	80.81	6.94
TF16	7	300		−14.8	70.8	9.53	41.06	0.110
TF17	8	300		26.3	64.4	9.33	14.24	0.108
TF18	8	200		30.0	66.5	5.25	112.28	2.86
TF19	6	250		37.1	65.0	4.41	231.54	2.52
TF20*	10	250		16.1	54.8	21.65	5.94	465
TF22	6	450		69.5	49.1	4.24	64.35	4.48
TF51	8	150		43.6	56.5	5.57	99.94	11.9
TF54	7	250		71.8	50.4	3.91	283.82	22.0
TF55	8	150		48.0	68.0	7.40	56.99	4.06
TF56	8	400		35.9	73.6	3.85	207.71	5.02
TF57	8	400		18.0	68.8	7.93	49.76	1.85
The Middle Horizon Group (The Ohyama Excavation Site)								
TF110	10		7.5	22.6	58.8	14.15	12.62	4.01
TF150	8		30.0	32.9	42.9	16.73	11.92	1.60
TF111	6		15.0	32.1	60.6	8.75	59.64	3.69
TF151	8		20.0	35.3	50.4	7.97	49.32	2.67
TF112	8		7.5	17.8	51.7	7.10	61.78	6.66
TF113	9		NRM	42.2	53.8	7.19	52.22	5.19
TF152	8		7.5	24.4	57.7	11.76	23.15	3.53
TF153	6		7.5	23.9	71.7	9.19	54.07	3.13
TF154	8		15.0	24.1	63.6	6.34	77.22	5.37
TF23	5	100		23.7	56.6	6.07	159.72	1.96
TF115	7		10.0	34.6	57.3	10.45	34.35	5.91
TF116	6		7.5	24.4	61.8	4.84	192.75	6.67
The Lower Horizon Group								
TF52	8	350		48.5	63.8	6.63	70.73	3.06
TF53	7	400		46.5	61.9	4.16	211.99	3.15
TF98#	8		20.0	−59.5	−8.3	35.37	3.41	4.28
TF97#	10		20.0	−79.6	−40.6	14.84	11.55	4.15
TF96	8		NRM	−23.7	45.9	15.78	13.28	3.95
TF95	9		25.0	24.8	48.3	18.40	8.79	2.51
TF94	9		10.0	−21.1	59.5	14.05	14.38	4.32
TF120	10		5.0	24.2	43.6	8.49	33.34	6.77
TF122	9		NRM	−14.5	61.1	15.49	12.00	2.25

Following abbreviations were used, number of samples (N), optimal demagnetizing temperature (ODT), optimal demagnetizing field (ODF), tilt corrected declination (D), tilt corrected inclination (I), Fisher's confidence angle (α_{95}), Fisher's precision parameter (K), and mean intensity (J). Asterisk(*) indicates the intrusive rock site and sharps(#) indicate the sites which show extremely strong intensity and/or unusual remanent direction.

TABLE 3. Site mean paleomagnetic directions of the Tetori Group in Arimine Area.

Site	N	ODT (° C)	ODF (mT)	D (° E)	I (°)	α_{95} (°)	K	J ($x10^{-3}$ Am^2)
TYA17#	10		10.0	-77.6	-25.7	38.27	4.02	1.24
TYA10	7		15.0	155.1	62.1	32.82	4.33	10.4
TYA12	7		15.0	27.4	58.2	27.45	5.79	45.4
TYA13	7		30.0	44.7	41.0	10.43	34.43	3.04
TYA14*	6		NRM	31.0	45.5	46.80	3.00	2.51
TYA15	5		NRM	13.2	53.7	8.83	76.13	16.3
TYA16	6		15.0	-17.6	41.6	5.13	171.36	21.0
TYA18	8		NRM	-42.3	15.7	27.36	5.05	14.2
TYA19#	8		15.0	158.8	-69.5	9.87	32.48	1770
TYA20#	8		30.0	252.7	-45.5	33.98	3.61	200
TYA21#	8		7.5	-59.8	20.5	24.71	5.98	454
TYA22#	8		25.0	205.4	-57.1	9.10	38.02	1440

Abbreviations are the same as in TABLE 2.

TABLE 4. Site mean paleomagnetic directions of the Tetori Group in the Nagatogawa Area.

Site	N	ODT (° C)	ODF (mT)	D (° E)	I (°)	α_{95} (°)	K	J ($x10^{-3}$ Am^2)
NTF5	8		5.0	27.3	73.4	10.03	31.48	2.08
NTF4	8		5.0	0.2	67.3	21.21	7.77	1.19
NTF3	10		10.0	56.0	68.4	16.27	9.78	1.56
NTF2	8		5.0	269.7	72.2	32.12	3.93	1.50
NTF1	9		NRM	145.6	78.6	29.93	3.92	1.22
NTF0	10		15.0	69.4	73.4	12.43	16.05	1.95
NTF6	9		5.0	2.7	40.9	4.71	120.27	2.04
TF71	6		7.5	23.3	70.3	11.27	33.41	9.42
TF70	7		5.0	10.9	63.2	6.82	79.36	5.48
TF72*	10		5.0	26.1	62.5	2.96	268.06	100
TF74	6		25.0	-3.3	70.0	5.57	140.75	8.50

Abbreviations are the same as in TABLE 2.

inclination (I), mean intensity (J), Fisher's confidence angle (α_{95}) and Fisher's precision parameter (K) (Fisher, 1953) for each site are listed in the tables together with the number of specimens (N) and optimal demagnetizing field (ODF) or temperature (ODT). Sites in the tables are arranged in the descending order according to their stratigraphic horizons.

Asterisks (*) indicate the intrusive rock sites in the tables. It is obvious that intensity of remanent magnetization of most intrusives is about 100 times stronger than that of the ordinary sediments. The sites indicated by sharps (#) are the sites that show extremely strong remanent intensity as compared with ordinary sediments and/or very unusual magnetic directions.

In Fig. 4, the tilt corrected site mean directions of the Ohyama, the Arimine and the Nagatogawa Areas are plotted on the equal areal stereographic projections.

The mean paleomagnetic directions for all the sites and for each of areas are calculated. As for the Ohyama Area, all the sites are divided into following 3 groups according to their

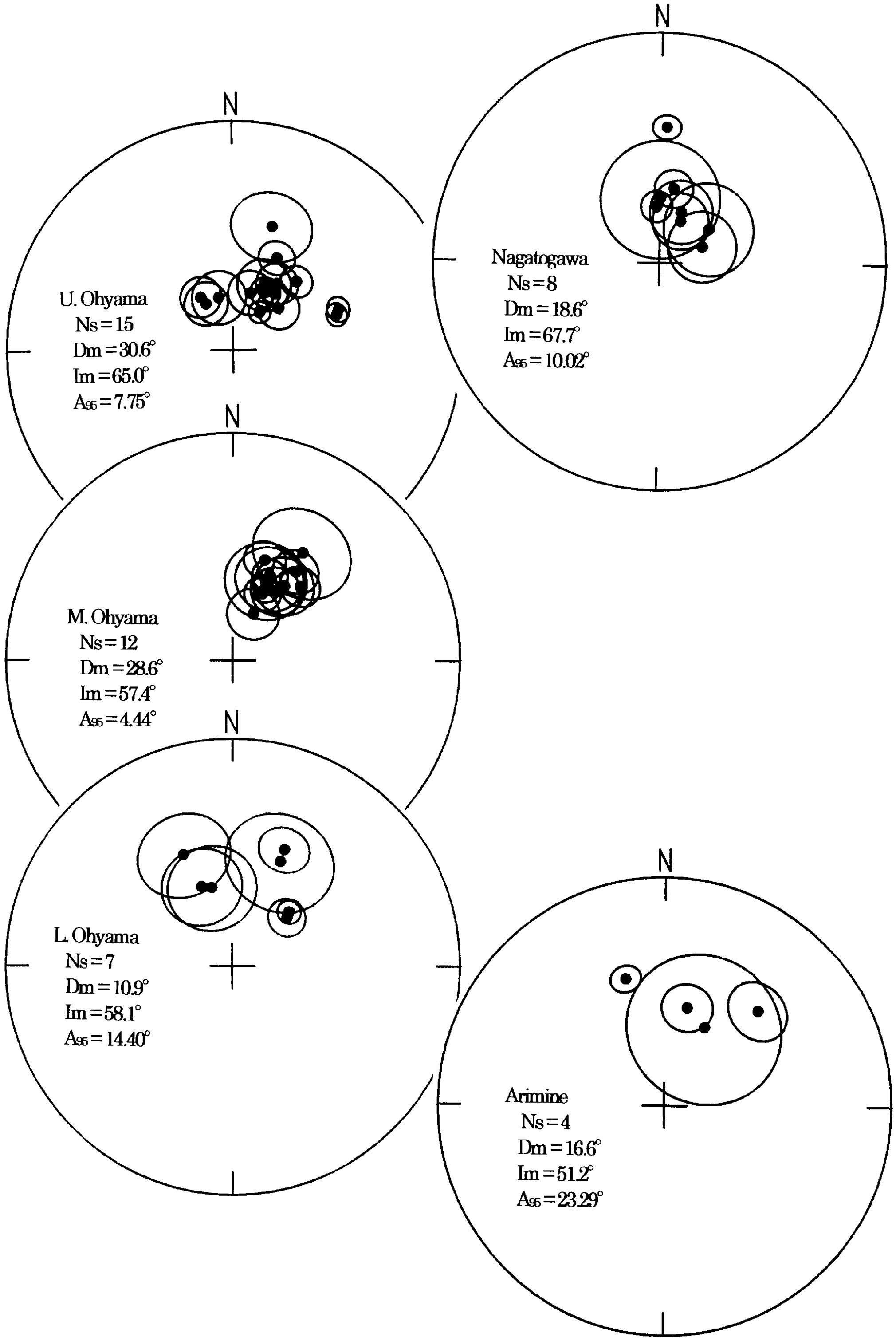

FIGURE 4. Stereographic projection of tilt corrected site mean paleomagnetic directions of the Ohyama, the Arimine and the Nagatogawa Areas. Abbreviations are same as in Table 5.

TABLE 5. Area mean paleomagnetic directions of the Tetori Group in Toyama.

Area	Ns	Dm (°E)	Im (°)	A_{95} (°)	k	δD (°)	Paleolatitude (° N)
All Sites	46	23.6	61.5	4.11	27.1	8.60	42.6
Ohyama	34	25.5	61.1	4.63	29.2	9.58	42.2
U. Ohyama	15	30.6	65.0	7.75	25.3	18.32	47.0
M. Ohyama	12	28.6	57.4	4.44	96.7	8.24	38.0
L. Ohyama	7	10.9	58.1	14.40	18.5	27.29	38.8
Arimine	4	16.6	51.2	23.29	16.5	37.17	31.9
Nagatogawa	8	18.6	67.7	10.02	31.5	26.42	50.6
Area Mean	5	20.7	60.1	7.36	109.1	14.75	41.0

Ns denotes number of sites or areas. Dm, Im, A_{95}, k and δD indicate tilt corrected mean declination, tilt corrected mean inclination, Fisher's confidence angle, Fisher's precision parameter and error angle in declination, respectively.

stratigraphy, that is, the lower Ohyama horizon group (abbreviated as 'L. Ohyama' in Fig. 2 and Table 5) from Site TF122 to Site TF52, the middle Ohyama horizon group ('M. Ohyama' in Fig. 2 and Table 5) from Site TF116 to Site TF110 (the excavation site) and the upper Ohyama horizon group ('U. Ohyama' in Fig. 2 and Table 5) from Site TF57 to Site TF61. The calculated area mean and group mean directions are tabulated in Table 5. The sites marked with asterisks and sharps in Tables 1, 2, 3 and 4 are excluded in the Area mean calculations because that their magnetizations might not be the initial magnetization but be the overprint of the secondary components added to in the later geological ages. The data of sites whose α_{95} exceed 28.0° such as TYA10, NTF2 and NTF1 are also excluded in the calculations. The mean paleomagnetic direction is computed from the data of the five Areas and groups mentioned above and listed as 'Area Mean' in Table 5. Paleolatitude computed from each mean inclination is also tabulated in Table 5.

The mean paleomagnetic declination and inclination calculated for all the sites (46 sites) excluding above-mentioned sites are 23.6°±8.6°E and 61.5°±4.1°, respectively. The shallowest inclination is observed in the Arimine Area, and the

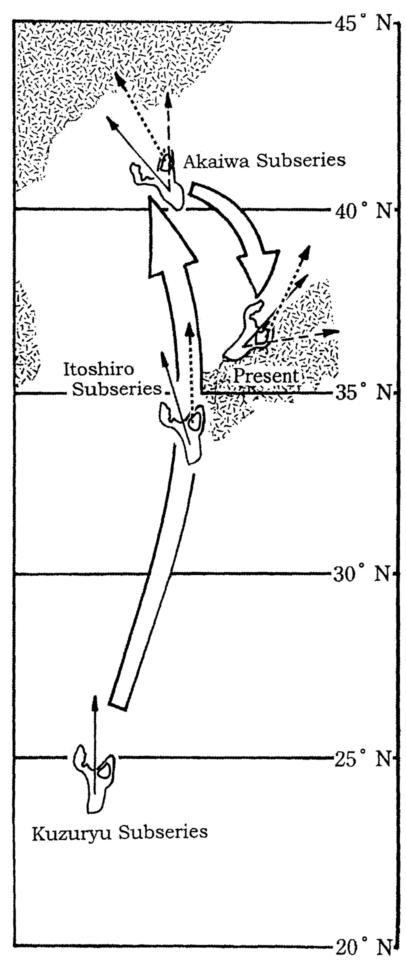

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FIGURE 5. Tectonic evolution of the Tetori Basin inferred from paleomagnetic study in Toyama. The basin performed northward migration and counterclockwise rotation at the times of the Kuzuryu, the Itoshiro and the Akaiwa Subgroups which are shown as 'Kuzuryu Subseries', 'Itoshiro Subseries' and 'Akaiwa Subseries' respectively (Hirooka et al., 2002).

deepest is in the Nagatogawa Area. The inclination of the Ohyama Area is in-between of these two Areas, and the lower horizons in the Area show the shallower inclinations.

If we could assume according to the results of the previous paleomagnetic study in Fukui and Ishikawa (Hirooka et al., 2002) that the Tetori Basin performed continuous northward migration from subtropical latitude to higher middle latitude, the fact mentioned above can indicate that the sedimentary formation in the Arimine Area is correlative to the Itoshiro Subgroup. The Lower and the Middle Ohyama horizons giving the paleolatitude around 38°N can be correlated both ways either to the Itoshiro Subgroup or to the Akaiwa Subgroup. On the contrary, as the paleolatitude both of the Upper Ohyama horizon and the Nagatogawa Area exceeds 42°N, it is obvious that those can be correlated to the Akaiwa Subgroup.

As for the declination variation, there is a recognizable trend that the easterly deflection of declination increases as the paleolatitude becomes higher. The mean declination of the Arimine Area is 16.6°E, while that of the Upper Ohyama horizons attain to 30.6°E. The same trend had been pointed out in the previous study of Fukui–Ishikawa region. But the amount of easterly deflection of declination is much smaller than that of Fukui–Ishikawa region where the declinations are varying from 38° up to 80°E. This fact seems to indicate that the clockwise tectonic rotation occurred after northward migration was not even all over the basin but differential rotation took place within the basin. The tectonic evolution such as northward migration and differential rotation of the Tetori Basin is schematically illustrated in Fig. 5.

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

Measurements of magnetic susceptibility anisotropy were carried out on rock samples obtained from Sites TF150 (Layer A), TF151 (Layer B), TF152 (Layer C) and TF154 (Layer D) at the sedimentary sequence of the Ohyama excavation site. Each of the anisotropy axes of the maximum, the intermediate and the minimum exhibit a very good convergence as clearly seen in Fig. 6. After tilt correction, both the maximum and the intermediate axes lie in the horizontal plane. The maximum and the intermediate axes point to N75°W and N15°E respectively in average. The direction of the maximum axis coincides with the direction perpendicular to the small 'ripple mark' like structure found on the top surface of Layer E. This preferred orientation of anisotropy of magnetic susceptibility would indicate the direction of paleocurrent at the site because that the orientation of the anisotropy is in accordance with E–W trend of paleocurrent deduced from the above-mentioned structure (Toyama Dinosaur Research Group, 2002).

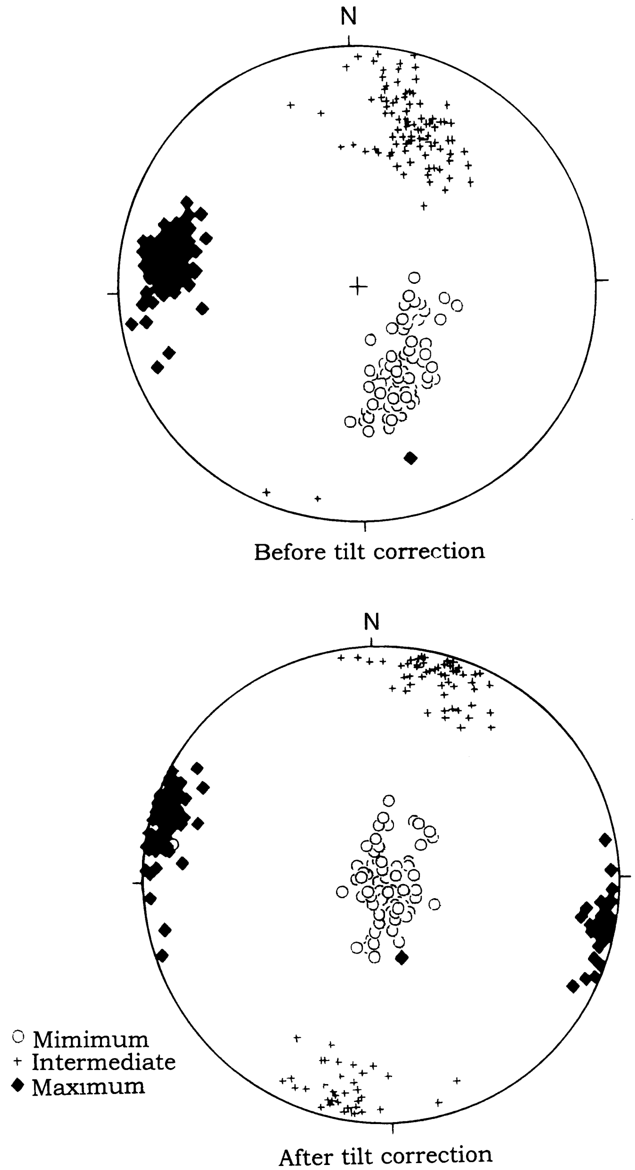

FIGURE 6. Magnetic susceptibility anomaly of the Ohyama excavation site.

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REFERENCES

Fisher, R. A. 1953. Dispersion on a sphere. Proceedings of Royal Society of London, Series A, 217: 295–305.

Hirooka, K., M. Kato, T. Morisada and Y. Azuma. 2002. Paleomagnetic study on the dinosaur-bearing strata of the Tetori Group, Central Japan. Memoir of the Fukui Prefectural Dinosaur Museum 1: 54–62.

Kawai, M., and T. Nozawa. 1958. Geological map of Japan and its explanatory text, Higashimozumi Sheet (1:50,000). Geological Survey, Japan, 86pp.*

Maeda, S., and K. Takenami. 1957. Stratigraphy and geological structure of the Tetori Group in the southern district of Toyama Prefecture. Journal of the Geological Society of Japan 63:273–288.*

Toyama Dinosaur Research Group. 2002. Report of the Dinosaur Excavation Project in 2000 & 2001. Toyama Prefecture, Japan, 60pp.*

Toyama Prefecture. 1970. Geological map of Toyama Prefecture and its explanatory text (1:150,000). Toyama Prefecture, 127pp.**

Toyama Prefecture. 1992. 1:100,000 geological map of Toyama Prefecture and its explanatory text. Toyama Prefecture, 201pp.**

Yamada, K. 1988. Tetori Group; pp. 26–37 *in* Editorial Committee of CHUBU II, Part 5 of Regional Geology of Japan (ed.), Regional Geology of Japan, Part 5, CHUBU II. Kyoritsu Shuppan Co. Ltd., Tokyo.**

* : in Japanese with English abstract

** : in Japanese

＜ 地 名 ・ 地層名 ＞

Akaiwa Subgroup	赤岩亜層群
Arimine shale Member	有峰頁岩層
Fukui Prefecture	福井県
Inotani alternation Member	猪谷互層
Ishikawa Prefecture	石川県
Kuzuryu Subgroup	九頭竜亜層群
Makawa sandstone conglomerate Member	真川砂礫層
Nagatogawa Area	長棟川地域
Ohyama Area	大山地域
Wasabu alternation Member	和佐府互層
Arimine Area	有峰地域
Atotsugawa Formation	跡津川累層
Higashi-Sakamori Formation	東坂森累層
Ioridanitoge conglomerate Member	庵谷峠礫岩層
Itoshiro Subgroup	石徹白亜層群
Kuwajima Formation	桑島層
Minamimatadani conglomerate Member	南俣谷礫岩層
Nagatogawa Formation	長棟川累層
Tetori Group	手取層群