Geomorphic Differentiation Inside the Plio-Pleistocene Sedimentary Basins in and around the Kinki Triangle, Inner Zone of Southwest Japan

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Geomorphic Differentiation Inside the Plio-Pleistocene Sedimentary Basins in and around the Kinki Triangle, Inner Zone of Southwest Japan

Hiroshi YAGI*

1 Introduction

Ranges and basins have developed since late Tertiary in the inner arc and the inner zone of Japanese island arc systems. These ranges and basins have similar size of 50 to 100 km in width. There remain many unsolved problems on the history and evolution of such ranges and basin systems. Valuable information for these problems has been acquired from ranges and basins independently. One is the geomorphological method for ranges and the other is geological for basins. From geomorphological point of view, it has been assumed that, in Japan up to two-thirds of present mountain relief had been formed in Quaternary (Research Group For Quaternary Tectonic Map 1969). But there was no concrete arguments on the process of mountain growth in Quaternary, mainly to the lack of reliable dated reference in ranges. For example, above mentioned assumption is based on a very rough estimation of the age of erosional surface to be Late Pliocene. Such roughness is inevitable if one employs erosional surfaces as a reference of crustal movement. Because they have been usually under erosional condition for time-markers to be removed.

In the late Neogene sedimentary basins, we can usually distinguish two geomorphic levels. One is the sedimentary basin floor where subsidence and consequently sedimentation are predominant. The other is a set of uplifted sedimentary surfaces which include hill summit plane and various terrace surfaces, namely hill and upland (Fig. 1). These hill and upland are composed of Pleistocene sediments and distributed in the marginal part of sedimentary basins. And, tectonic lines usually divide these hill and upland from sedimentary basin floor. Observing such topographic arrangement in Plio-Pleistocene sedimentary basins, it is assumed that tectonic differentiation inside sedimentary basins had occurred in Quaternary. The author defines the initiation of this differentiation as an evolution from the sedimentary phase to the terrace phase. Before this evolution, the contrast between ranges and basins had been very sharp to make basins subside on the whole. But after this evolution, previous basins have been differentiated into uplifted margin and continuously subsiding area (Fig. 2).

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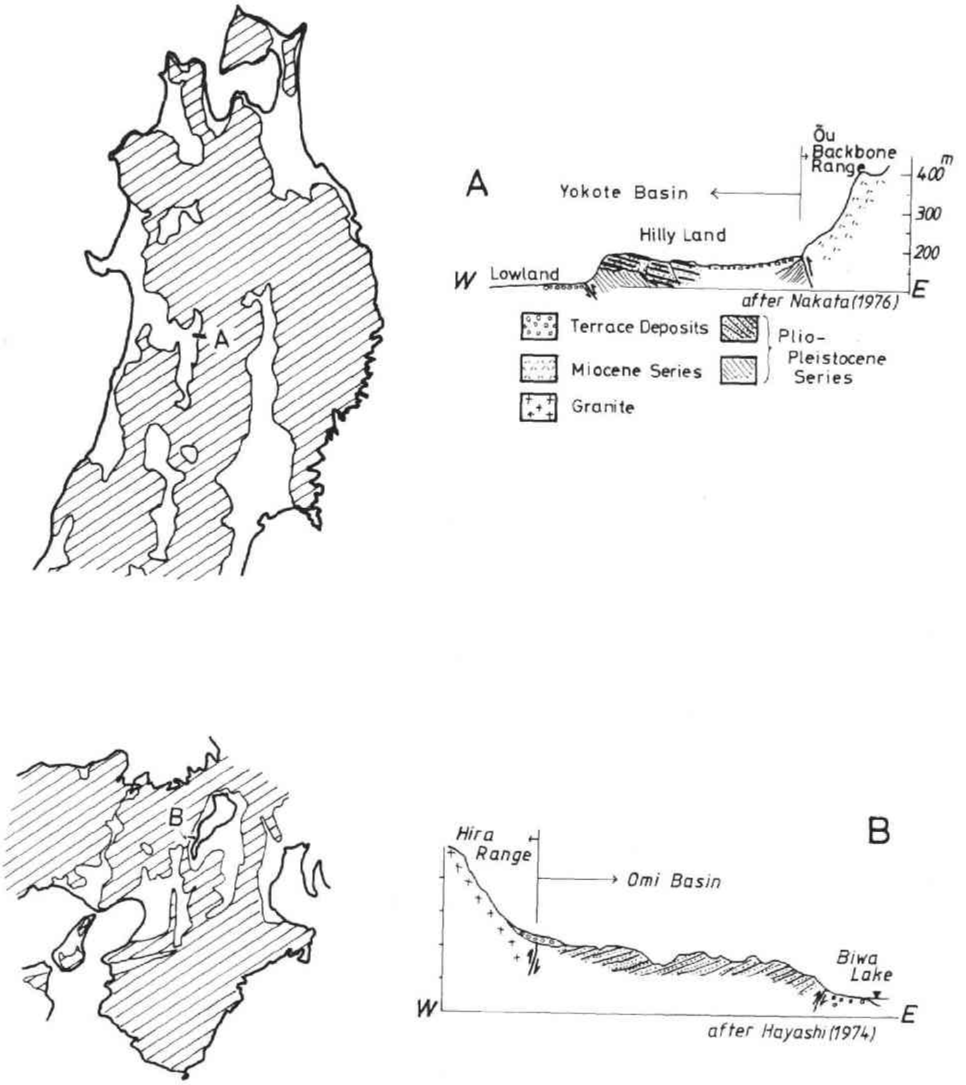


Fig. 1 Geomorphic profile across Yokote Basin, Northeast Japan and the west coast of Biwa Lake, Southwest Japan.

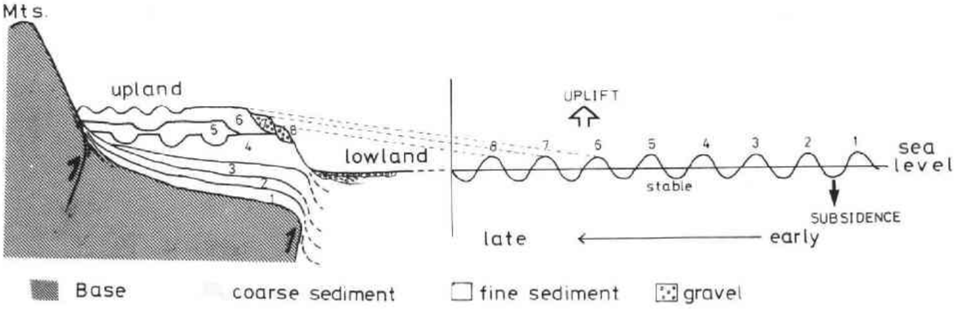


Fig. 2 Idealized diagram of geomorphic differentiation inside a sedimentary basin connected with oscillation of sea level.

This differentiation is common for the basins in the inner arc and the inner zone of Japanese islands arc system. And the timing of the evolution in each basins seems to coincide with a significant change of the crustal movement in Japan. As it is expected from former studies that this evolution had broken out not sporadically from basin to basin, but approximately simultaneously. Moreover, some diachronous extension of this evolution from region to region can be presumed.

Therefore, a regional modification of Quaternary tectonic movement will be demonstrated from the history of this evolution. It is at the same time the modification on mountain growth and basin development.

This paper aims to clarify the emergence ages of the highest geomorphic surfaces inside the Plio-Pleistocene sedimentary basins and time and space distributions of the commencement of differentiation. For the sake of this investigation, study area has been selected on the following conditions. (1) The outline of major relief is distinct. (2) The Quaternary stratigraphy and the tendency of the late Pleistocene upheaval movement can be known to some degree. Because subsidence history of basin is recorded in the Quaternary sediments, and the tendency of upheaval movement is perceived from the height distribution of late Pleistocene marine terraces inside the basin.

There are many Plio-Pleistocene sedimentary basins in the central part of the Inner Zone of Southwest Japan and the northern part of the inner arc of Northeast Japan. And they meet the requirements above. Among these basins, the author mainly takes up Kakogawa-Fukuchiyama area for a sample field (Fig. 3), where is a topographic depression along the northwestern rim of "Kinki Triangle" (Huzita 1962). In this area also, Middle Pleistocene higher terraces composed of fluvial or marine deposits have been extensively preserved.

In this study area, the emergence age of the highest geomorphic surface were successfully acquired. And then, the time lag of the geomorphic differentiation was

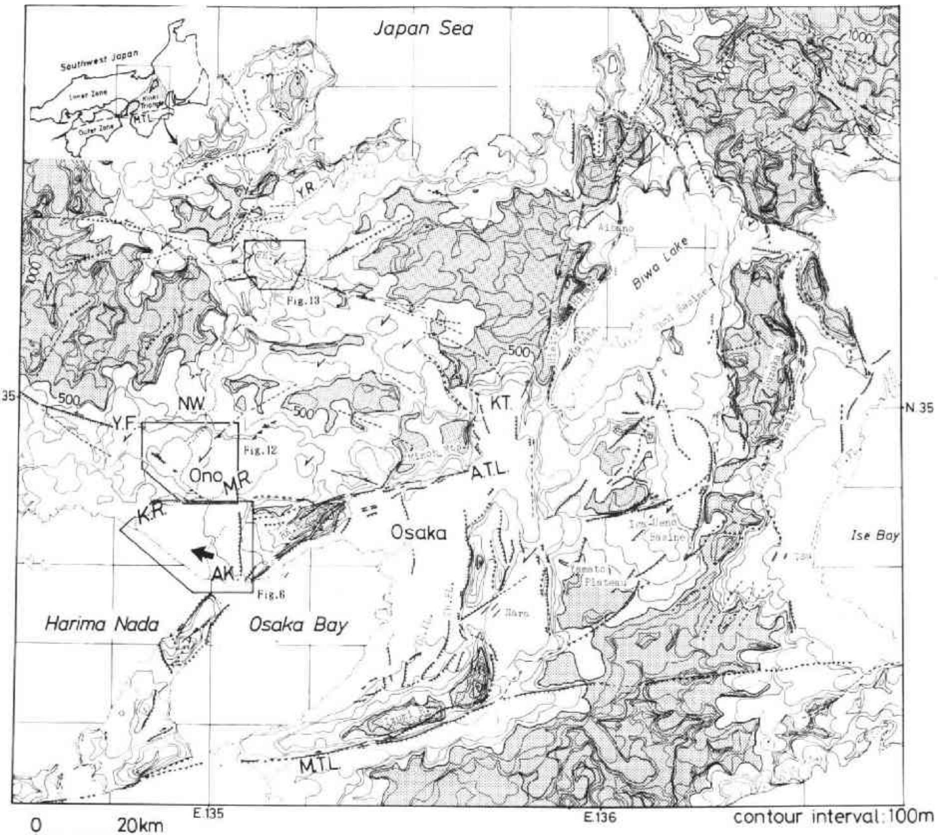


Fig. 3 Summit level map in and around the Kinki Triangle, Inner Zone of Southwest Japan. (contour interval : 100 m)
M.T.L. : Median Tectonic Line, A.T.L. : Arima Takatsuki Tectonic Line, Y.F. : Yamasaki Fault, KT. : Kyoto, AK. : Akashi, FK. : Fukuchiyama, NW. : Nishiwaki, KR. : Kakogawa River, Y.R. : Yura River, M. : Mino River.

examined among the basins in and around the Kinki Triangle, central part of the Inner Zone of Southwest Japan, based on a lot of previous studies on Plio-Pleistocene stratigraphy there.

2 Method of investigation

Stratigraphy and chronology of Quaternary System are the fundamental data for this study. In order to establish them, careful examination on tephrostratigraphy, magnetostratigraphy and paleoenvironments have been carried out. For tephrostratigraphy, microprobe technique were applied, using Energy Diffraction Spectrometry type microanalyzer for major elements. Measurement of remnant magnetization was brought about by spinner type magnetometer. Paleoenvironmental data were obtained through pollen analyses by Prof. Yamanaka., Kochi Univ. Above these analyses of Quaternary deposits, pedological evidence and geomorphological characteristics were useful in correlating terrace surfaces.

3 Pleistocene series and terrace surfaces in Kakogawa-Fukuchiyama Valley

3.1. Topographical outline of the study area

A topographic depression lower than 200 m above sea level runs from Fukuchiyama to Kakogawa with the direction of NE-SW, which constitutes the northwestern rim of Kinki Triangle. The author calls the depression Kakogawa-Fukuchiyama Valley in this paper. The valley consists of two Plio-Pleistocene sedimentary basins of Kakogawa and Fukuchiyama. They are bordering with the lowest divide in the valley from the Pacific Ocean to the Sea of Japan over the Honshu Island. Kakogawa River streams from the divide to the south through Kakogawa Basin and Yura River flows to the north through Fukuchiyama basin. Thick Quaternary deposit and a number of terrace surfaces are distributed along the middle and lower course of Kokogawa River and middle course of Yura River. Takatsukayama and Ougo faults

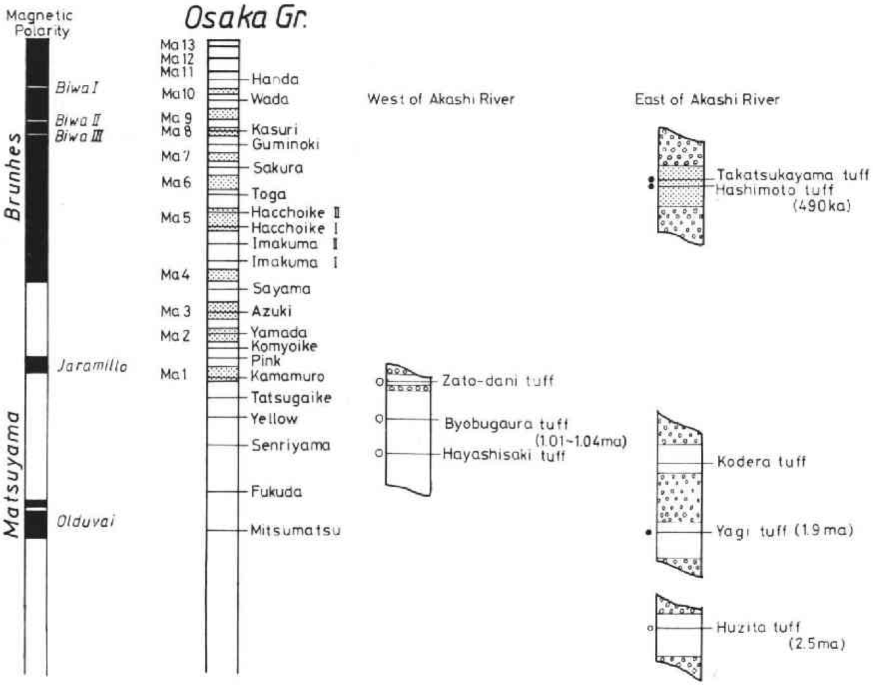


Fig. 4 Tephrostratigraphy in Akashi region and of Osaka Group.

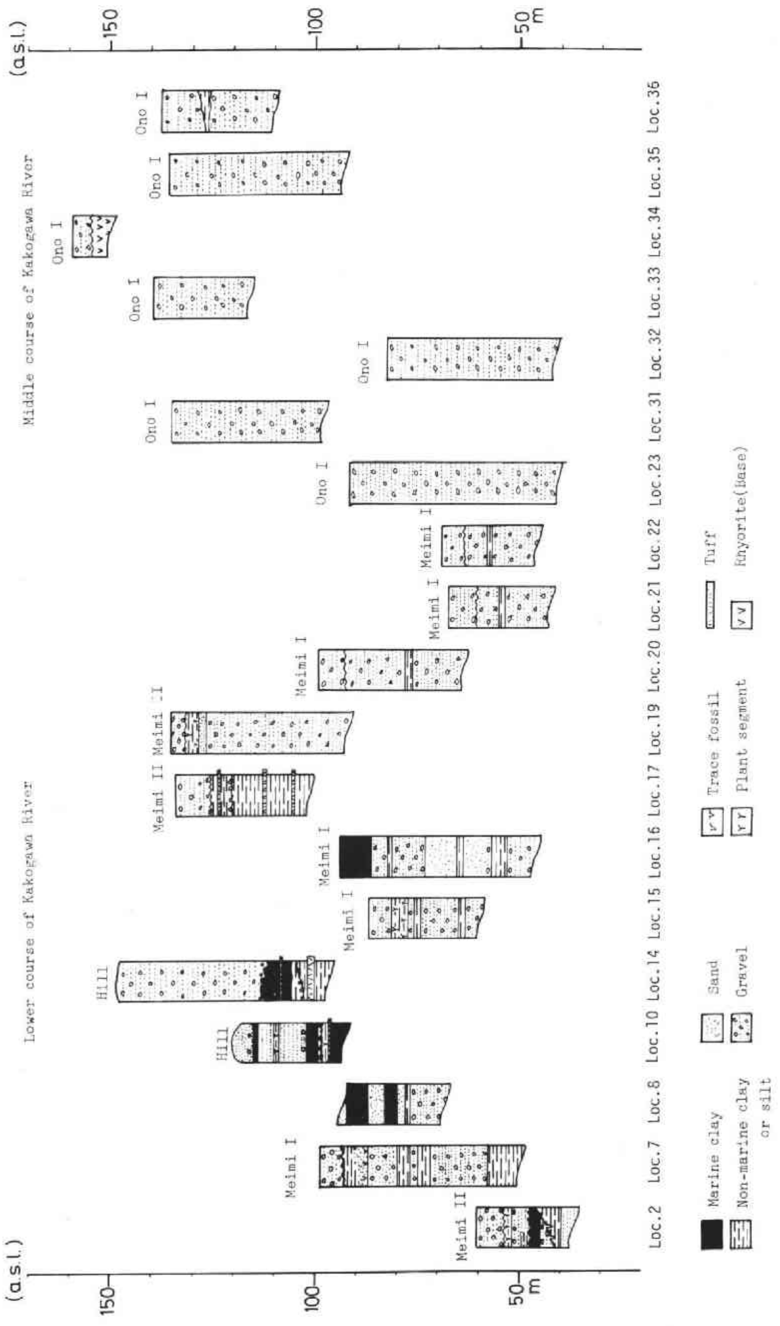


Fig. 5 Columnar sections in Kakogawa Basin.
Legend in common to Figs. 7, 8, 9 and 14.

Table 1-a Major element chemical compositions of grass shards of tephras distributed in Akashi region (WT %)

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	K_2O	Na_2O	TOTAL
Takatsukayama tuff (Loc. 11)	Mean	77.64	0.15	12.80	1.11	0.03	0.41	1.12	3.24	3.49	99.99
	S.D.	0.83	0.07	0.25	0.28	0.02	0.08	0.33	0.24	0.35	
Hashimoto tuff (Loc. 14)	Mean	74.18	0.15	15.63	1.30	0.02	0.71	1.61	3.08	3.33	100.01
	S.D.	0.30	0.02	0.09	0.05	0.01	0.07	0.14	0.09	0.23	
Zato-dani tuff (Loc. 17)	Mean	77.03	0.11	14.72	0.83	0.01	0.61	1.40	2.62	2.62	99.95
	S.D.	0.51	0.06	0.13	0.18	0.01	0.04	0.20	0.09	0.31	
Hayashisaki tuff (Loc. 29)	Mean	77.78	0.14	12.86	1.14	—	0.51	1.45	1.92	4.20	100.00
	S.D.	0.20	0.20	0.15	0.04	—	0.05	0.04	0.05	0.15	
Yagi tuff (Loc. 13)	Mean	77.10	0.12	12.61	0.96	0.02	0.52	0.80	3.73	4.14	100.00
	S.D.	0.35	0.02	0.14	0.03	0.01	0.07	0.10	0.30	0.15	
Yagi tuff (Loc. 2)	Mean	77.08	0.14	12.52	0.97	0.03	0.43	0.80	3.60	4.43	100.00
	S.D.	0.42	0.03	0.27	0.03	0.02	0.06	0.06	0.07	0.19	
Yagi tuff (Loc. 4)	Mean	77.88	0.15	12.80	1.11	0.03	0.37	0.73	3.47	3.49	100.00
	S.D.	0.38	0.02	0.16	0.02	0.00	0.07	0.02	0.22	0.33	
Huzita tuff (Loc. 14)	Mean	76.55	0.05	13.37	0.96	—	0.28	0.77	5.36	2.66	99.99
	S.D.	0.70	0.01	0.12	0.18	—	0.08	0.07	0.18	0.59	
Huzita tuff (Loc. 10)	Mean	76.39	0.05	13.45	0.76	—	0.31	0.74	5.45	2.85	100.00
	S.D.	0.55	0.01	0.12	0.31	—	0.05	0.05	0.26	0.58	

Table 1-b Major element chemical compositions of Amphibole of tephras distributed in Akashi region (WT %)

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	K_2O	Na_2O	TOTAL
Byobugaura tuff (Loc. 29)	50.22	0.62	7.44	13.09	0.73	15.74	10.52	0.15	1.50	100.00
	50.26	0.66	7.54	13.04	0.73	15.74	10.52	0.15	1.50	99.96
	49.08	0.70	8.64	13.79	0.73	15.04	10.62	0.12	1.27	100.00
	49.23	0.69	8.41	13.16	0.56	15.64	10.72	0.21	1.39	100.00
	49.69	0.65	7.71	13.83	0.81	15.34	10.47	0.10	1.42	100.01
	49.04	0.70	8.81	13.45	0.52	15.52	10.57	0.19	1.21	100.02
	49.17	0.73	8.45	13.28	0.52	15.60	10.54	0.17	1.55	100.01
	48.90	0.69	8.78	13.21	0.60	15.43	10.65	0.21	1.54	100.00
	48.22	0.78	9.63	12.89	0.41	15.64	10.72	0.26	1.47	100.01
	49.04	0.63	8.67	13.29	0.56	15.50	10.68	0.19	1.46	100.01
	49.03	7.71	8.57	13.16	0.55	15.82	10.50	0.19	1.48	100.00
Byobugaura tuff (Loc. 17)	49.70	0.69	8.05	12.91	0.53	16.12	10.31	0.18	1.53	100.00
	49.08	0.91	8.51	12.27	0.33	16.46	10.44	0.19	1.82	100.00
	48.65	0.93	9.04	12.63	0.40	16.18	10.41	0.20	1.56	100.00
	49.46	0.81	8.15	12.51	0.41	16.28	10.44	0.16	1.79	99.98
	49.70	0.73	8.08	12.65	0.47	16.34	10.28	0.19	1.40	100.00
	49.03	0.90	8.46	12.54	0.37	16.61	10.62	0.18	1.61	99.98
	49.84	0.66	8.01	12.61	0.57	16.14	10.62	0.19	1.35	99.99

which are distinct tectonic line between Kakogawa Basin and Rokko Range. General height distribution in the basin decreases from the east to the west.

3.2. Pleistocene series in Kokogawa Basin

(a) Outline of the Pleistocene series in Kakogawa Basin

Gravels with more than 50 m in thickness are extensively distributed along the middle and lower course of Kakogawa River (Fig. 4). They sometimes intercalate thin marine clay and nonmarine silt beds around Akashi City facing to the Harima-*nada*, the eastern part of the Seto Inland Sea. Such fine sediments exposed around Akashi City dip to a few degrees to the west. The author tried to correlate them with the Osaka Group by the analytical methods mentioned above.

(b) Tephras and their correlation

There are 5 tephras distributed in the east of the Akashi River. They are named Huzita tuff, Yagi tuff (Huzita and Maeda 1984), Kodera tuff, Hashimoto tuff (Huzita and Maeda 1984) and Takatsukayama tuff in ascending order (Fig. 5). There are also 3 tephras distributed in the west of the Akashi River. They are named Zato-*dani* tuff (Yokoyama *et al.* 1980), Byobugaura tuff and Hayashisaki tuff (Itihara and Oguro 1958) in descending order (Fig. 5). Some of them were dated by fission track method. Huzita tuff, Yagi tuff and Hashimoto tuff is dated as 2.5 Ma, 1.9 Ma and 490 ka respectively (Huzita and Maeda 1984). Byobugaura tuff is also dated as 1.01–1.04 Ma

Table 2 Major element chemical compositions of grass shards of middle Pleistocene tephras in Osaka Group (WT %)

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	K_2O	Na_2O	TOTAL
Handa	Mean	77.27	0.11	12.92	0.79	0.02	0.35	0.72	5.06	2.74	99.98
	S.D.	0.21	0.02	0.08	0.01	0.00	0.05	0.15	0.08	0.17	
Wada	Mean	78.19	0.11	12.98	0.81	0.02	0.43	0.68	4.85	1.93	100.00
	S.D.	0.25	0.01	0.06	0.03	0.00	0.10	0.19	0.28	0.20	
Guminoki	Mean	74.38	0.21	14.68	1.13	0.03	0.51	1.06	4.50	3.50	100.01
	S.D.	0.50	0.03	0.23	0.08	0.01	0.07	0.15	0.07	0.37	
Sakura	Mean	74.35	0.21	14.73	1.15	0.02	0.52	1.01	4.48	3.53	100.00
	S.D.	0.63	0.03	0.22	0.07	0.01	0.08	0.22	0.11	0.31	
Imakuma II	Mean	78.39	0.12	13.35	0.95	0.04	0.42	0.97	3.59	2.17	100.00
	S.D.	0.55	0.02	0.30	0.08	0.01	0.10	0.17	0.19	0.19	
Imakuma I	Mean	78.22	0.17	12.83	1.29	0.02	0.43	1.34	2.32	3.38	100.00
	S.D.	0.41	0.02	0.15	0.05	0.01	0.06	0.03	0.06	0.40	
Sayama (pumicetype)	Mean	73.35	0.41	15.43	1.72	0.04	0.79	1.61	4.29	2.36	100.00
	S.D.	0.60	0.05	0.27	0.17	0.01	0.13	0.20	0.19	0.42	
Sayama (bw type)	Mean	74.10	0.41	15.14	1.51	0.01	0.65	1.35	4.43	2.40	100.00
	S.D.	0.97	0.02	0.14	0.06	0.00	0.05	0.05	0.20	0.45	

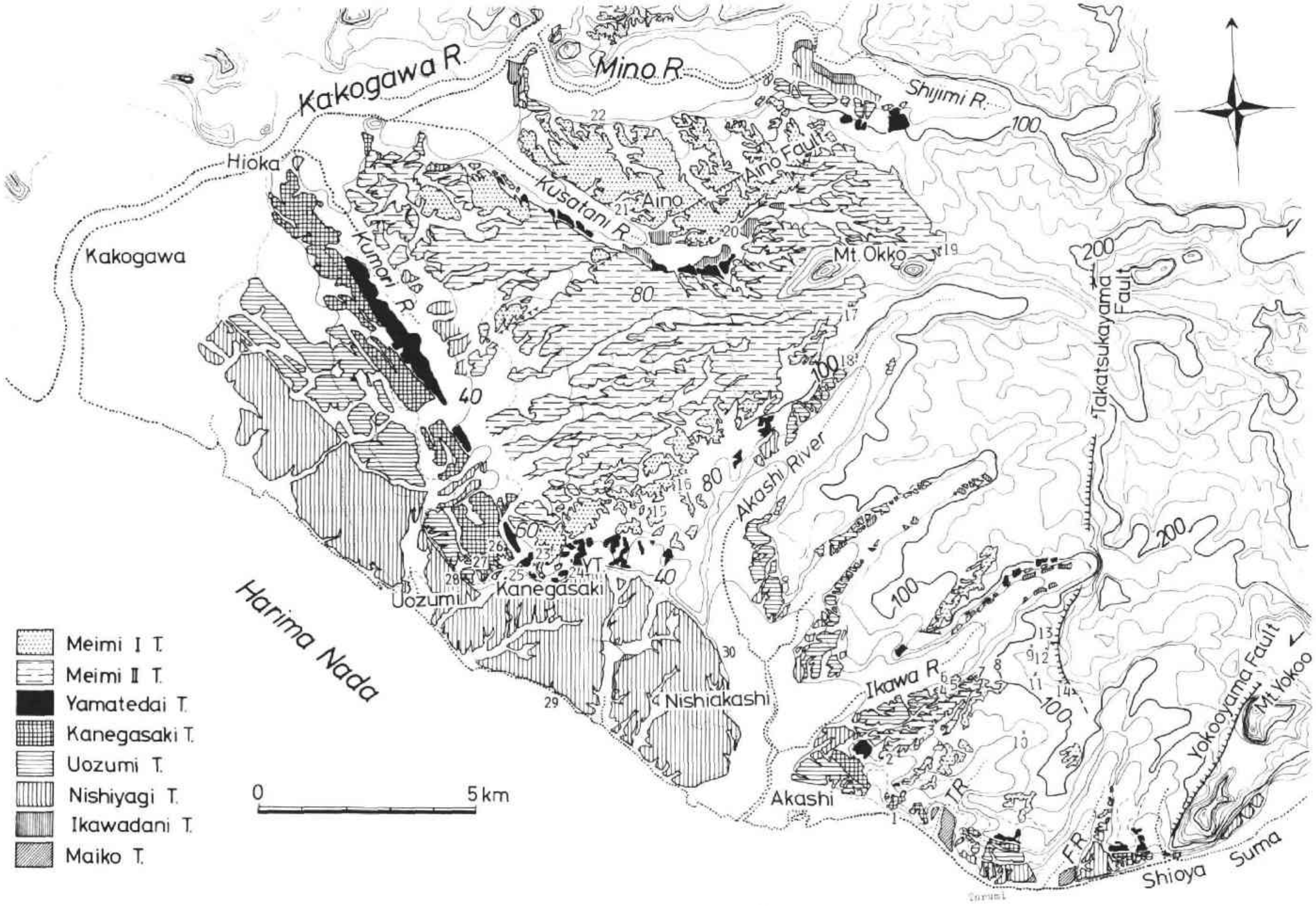


Fig. 6 Distribution of terrace surfeces along the northeast coast of Harima-*nada*, the Seto Inland Sea.
YM.: Yamatedai
The numerals are location numbers of outcrops and coincide with the sites of columnar sections in Fig. 5, 7, 8, 9, 10.

Table 3 Results of pollen analyses (Unit : %)

	Takatsukayama Section					Akashi Section					Akasaka Section		
	1	2	3	4	5	1	2	3	4	5	1	2	3
Pinus	1.0	29.0	23.1	1.0	16.4	2.1	12.0	5.4	14.2	1.7	5.9	25.7	39.1
Abies	1.0	6.7	11.8	1.0	2.1	5.0	13.2	6.1	15.0	2.4	9.7	4.1	3.9
Picea		0.3	0.5	0.2		1.0	2.8	1.9	11.0	0.2	0.9		1.1
Tsuga	2.0	11.7	7.2	3.4	8.9	5.9	7.1	1.6	14.2	3.2	1.8	1.7	1.9
Larix		0.9						1.0		0.5			
Cryptomeria	5.7	6.1	9.2	12.1	2.1	30.1	0.9	3.5	4.0	1.9	42.8	6.5	.9
Soioadopitys	1.7	4.4	6.7		4.6	1.0				0.7	0.6	0.5	0.2
Cupressaceae							0.3						
other conifers	1.3	1.2	0.5	0.5	0.2					0.7	0.3	0.7	
Fagus	32.4	8.7	3.6	36.0	3.0	2.5	0.6	0.6	2.0	43.8	.9	8.7	9.8
Quercus	7.7	2.9	2.6	5.2	3.2	19.0	4.1	1.6	3.7	2.9	19.1	21.9	37.7
Cyclobalanopsis	0.3	20.7	26.2	3.7	43.6		1.9		0.8	1.2	0.9	1.2	
Castanea		2.6	6.2	0.2	1.8	0.6			0.3	0.3			1.2
Castanopsis					7.5								
Alnus	10.7	3.8	5.1	5.4	2.5	2.5	12.3	27.4	22.9	4.9	4.7	13.0	1.8
Betula	2.3	0.3	0.5	4.9	0.5	0.6	13.2	60.1	17.8	3.6	0.6	0.2	
Carpinus	7.0	0.9		6.4	0.7	4.6	6.3	4.1	7.1	4.9	1.5	4.3	0.2
Carpinus tschonoskii	5.0	0.6		3.7	0.2	5.0				3.6	1.5	3.4	0.7
Ulmus	22.7	2.0	2.1	17.2	1.1	7.7	4.4	1.1	4.2	21.6	3.2	11.1	1.2
Zelkova	3.7		1.5		1.7	1.3		0.3	4.8		1.9		
Celtis	1.7			0.5		0.4	0.9		0.8		0.6		
Tilia						0.2	0.6	0.6		0.2	0.3	0.4	0.2
Juglans	0.3									0.2			
Pterocarya	0.7	0.3				2.1		0.6	0.3	0.5	0.9	0.4	
Aesculus							0.3	0.3					
Fraxinus	0.3	0.3		0.5		0.3	1.3		1.7	0.7	3.5	1.2	0.4
Styrax	0.3												
Mallotus					0.5								
Acer				1.5		1.3	0.6	0.6	0.6				
Vibrunum	1.0												0.2
Symplocos						0.2							
Rhus						0.2							
Salix	2.7			0.5	0.5	2.5		1.3		1.0	1.2	0.2	
Albizzia								0.6					
Lagerstroemia											0.9	1.0	0.7
Liquidambar					3.2			1.9	2.0		4.8		
Myrica							0.3	1.6					
Viburnum							0.3	1.6			0.3	0.2	0.2
Corylus	0.7	0.6		0.7	0.5		4.1	5.4				0.2	
Ilex		0.6				1.9	0.3		3.4	0.2			
Rhamnus	1.0								1.1				
Elaeagnus			0.5									0.5	
Thymelaeaceae								1.0					0.2
Ericaceae						0.2	1.3	0.6	0.8				

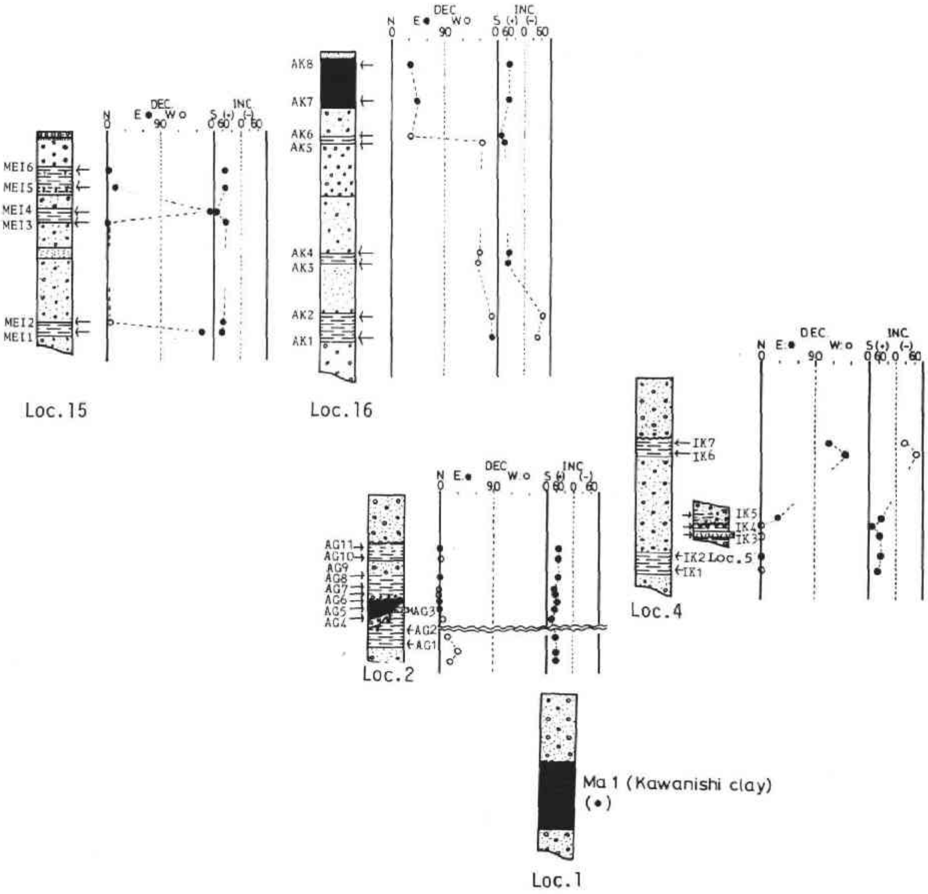
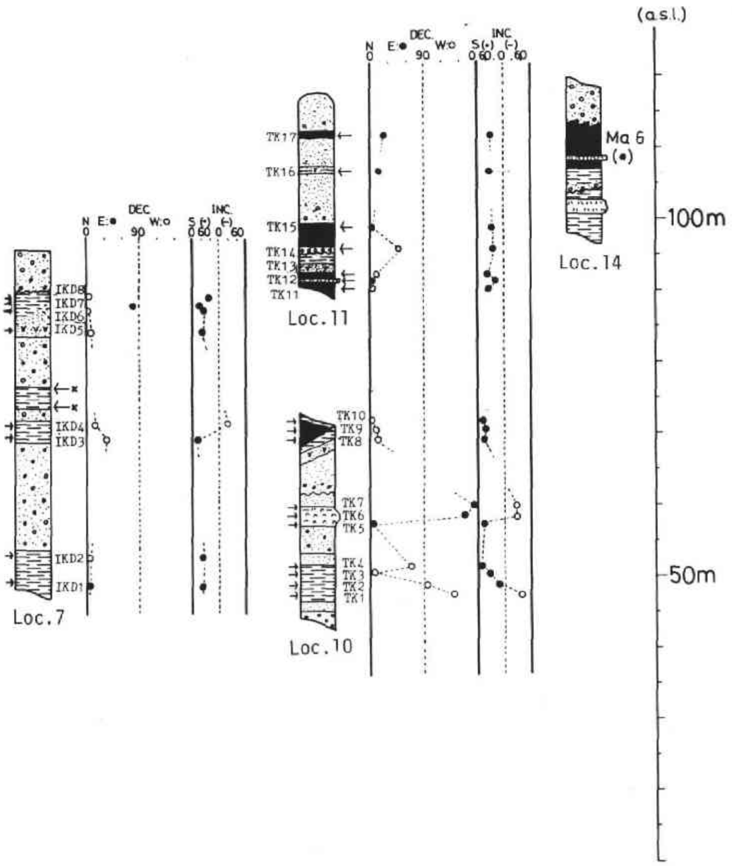


Fig. 7 Paleomagnetic results of

by fission track method (Suzuki 1987). Their major element chemical compositions of them are shown in Table 1. Huzita tuff, Yagi tuff and Byobugaura tuff were found at a few site in this study area. Hashimoto and Takatsukayama tuff were not identical with middle Pleistocene tephras in the Osaka Group (Tables 1 and 2).

(c) Magnetostratigraphy

The samples for paleomagnetic study were obtained from 6 sections consisting of 8 sites around Akashi City. These sections are named AG, IK, IKD, TK, MEI, AK. The number of sampling horizons are 57. Their locations and stratigraphic positions are shown in Fig. 6. Demagnetization was performed to all samples in a magnetic field of 200 Oe for magnetic cleaning treatment. The result are shown in Fig. 7.



sections in Kakogawa Basin.

(d) Pollen analyses

Thirteen samples for pollen analyses were collected at 7 site composing 3 sections. Their localities and stratigraphic positions are indicated in Fig. 6 and Fig. 8. The results are shown in Table 3.

(e) Correlation of the Quaternary strata in the east of the Akashi River with Osaka Group

The author tried to correlate the Quaternary strata in Akashi region with Osaka Group based on the tephrostratigraphy, magnetostratigraphy and pollen records. The topographic profile of N80°W across the Akashi River was made (Fig. 9), projecting columnar sections with the results of above mentioned analyses. This profile is

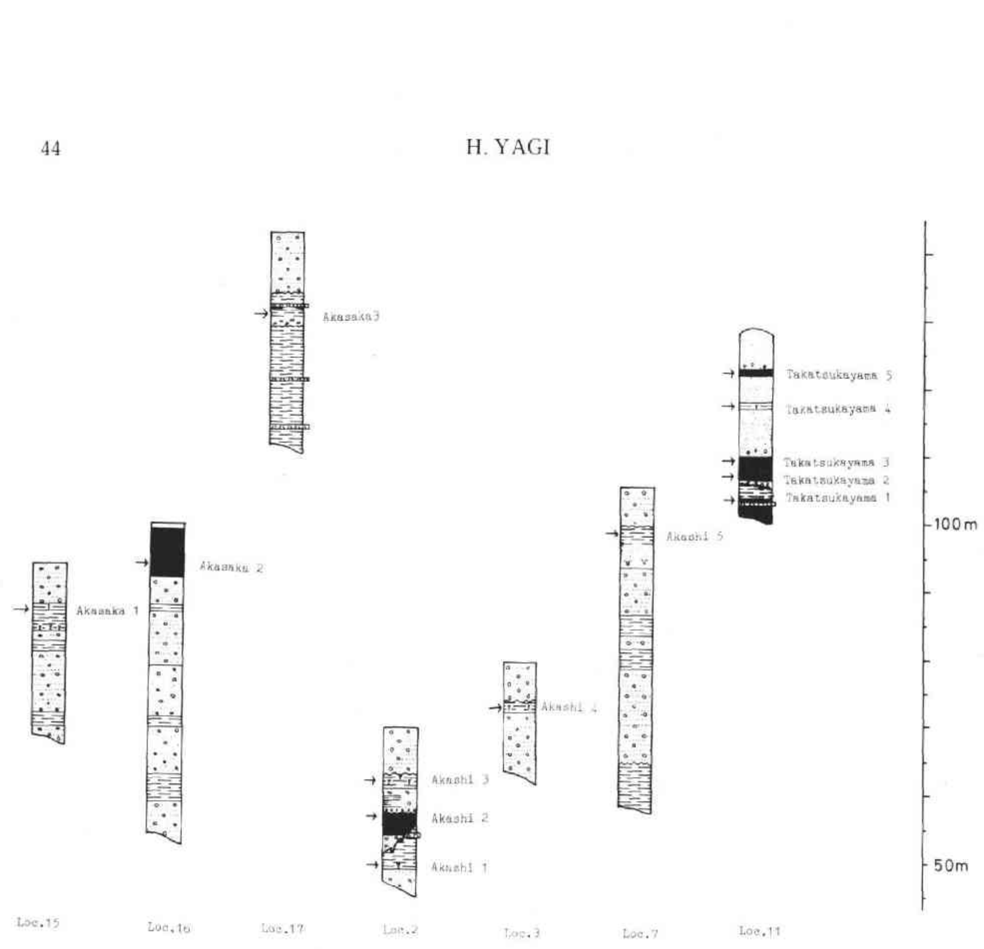


Fig. 8 Sampling site of plant remnant for pollen analyses.

parallel to the general direction of tilting in the study area.

Generally speaking, the strata younger than 0.9 Ma overlie the Plio-Pleistocene sediments before or after Olduvai Event in Matsuyama Reverse Epoch unconformably and they were successively deposited up to the Ma 9 horizon of Osaka Group in the east of the Akashi River, Akashi (Fig. 9). Ma 9 is dated as 300-270 ka (Maenaka and Yokoyama 1977).

Upper Pliocene and Lower Pleistocene

Consolidated non-marine bluish clay are distributed around Akashi. This non-marine clay has been called Osawa clay (Itihara *et al.* 1958). Huzita tuff appears at Loc. 10 and 14 within this non-marine clay.

Yagi tuff occurs at Loc. 2, 4, 12 and 13 above the horizon of Huzita tuff (Fig. 9). Major element chemical composition of Yagi tuff obtained from Loc. 2, 4 and 13 are shown in Table 1. Very small grain size of Taxodiaceae that is thought *Metasequoia* is quite dominant at the horizon of Akashi-1 below Yagi tuff at Loc. 2 (personal communication from Prof. M. Yamanaka, Kochi Univ.). Though Yagi tuff is dated as

1.9 Ma by fission track method, the thick non-marine bluish clay intercalating Yagi tuff from the horizon of AG-1 to AG-3 has normal polarity (Figs. 7, 9). These evidences supports that Yagi tuff coincides with Olduvai Event in Matsuyama Reverse Polarity Epoch. A bed of marine clay which appears at Loc. 1 near Asagiri Station is called "Kawanishi Clay" and correlated with Ma 1 of Osaka Group because it yields *Metasequoia* and its paleomagnetic polarity is normal (Ishida 1970). The age of Ma 1 coincides with the Jaramillo Event in Matsuyama Reverse Polarity Epoch about 0.9 ka.

Middle Pleistocene

The non-marine clay is overlain by the alternating beds of gravels, marine clay and non-marine silt with the obvious unconformity. They are the middle Pleistocene deposits because their paleomagnetic polarities are normal and they don't yield *Metasequoia*. Akashi-2 at Loc. 2 was identified with Ma 6 of Osaka Group because pollen of *Tsuga* and *Pinus* are predominant at this horizon as to be correlated with Tsuga-Conifer pollen Subzone (Nasu 1970).

Non-marine silt of Akashi-3 at Loc. 2 yields the subarctic or the subalpine flora typified by *Betula ermanii*. Consequently the horizon of Akashi-3 is correlated with Manchidani stage the flora of which indicates the coldest climate in the middle Pleistocene (Miki 1937, Huzita *et al*. 1971). And the stratigraphic position is between Ma 6 and Ma 7 in Osaka Group (ca 480 ka : Maenaka and Yokoyama 1977).

Osawa Clay is directly overlain by deposits younger than the Ma 1 horizon of Osaka Group with unconformity at Loc. 4, 10, 12, 13, 14 as well as at Loc. 2. Marine sediments corresponding to Ma 6 of Osaka Group had been discovered at Loc. 9, 14 (Huzita and Maeda 1984). Ma 6 successively appears from Loc. 14 to Loc. 11. The beds of Takatsukayama-2, 3 and 5 above Ma 6 at Loc. 11 yield flagellates that is the evidence of marine sediment. *Cyclobalanopsis* and *Pinus* are quite dominant and *Castanopsis* and *Liquidambar* are found in the bed of Takatsukayama-5. The result of pollen analysis shows that the bed of Takatsukayama-5 deposited during the warmest stage among the Takatsukayama section at Loc. 11. The author, therefore, correlates the bed of Takatsukayama-5 with the Ma 8 horizon of Osaka Group because the paleoclimatic at the age of Ma 8 is known as the most distinct warm or subtropical stage in the middle Pleistocene (Huzita 1954, Itihara *et al*. 1966, Huzita and Kasama 1982, Fukuma and Huzita 1986). Ma 8 of Osaka Group has been dated as 380-350 ka by fission track method (Maenaka and Yokoyama 1977). Three marine clay beds corresponding to the Ma 6, 7, 8 horizons of Osaka Group occur at Loc. 11. Pollen compositions of Takatsukayama -1 and 4 among these marine strata show cooler climate. The horizons of these cooler stages are thought to correspond to the regressional stages between Ma 6 and Ma 7 and between Ma 7 and Ma 8 in Osaka Group. Sand and gravel layer of 15-20 m in thickness overlies the horizon of Takatsukayama-

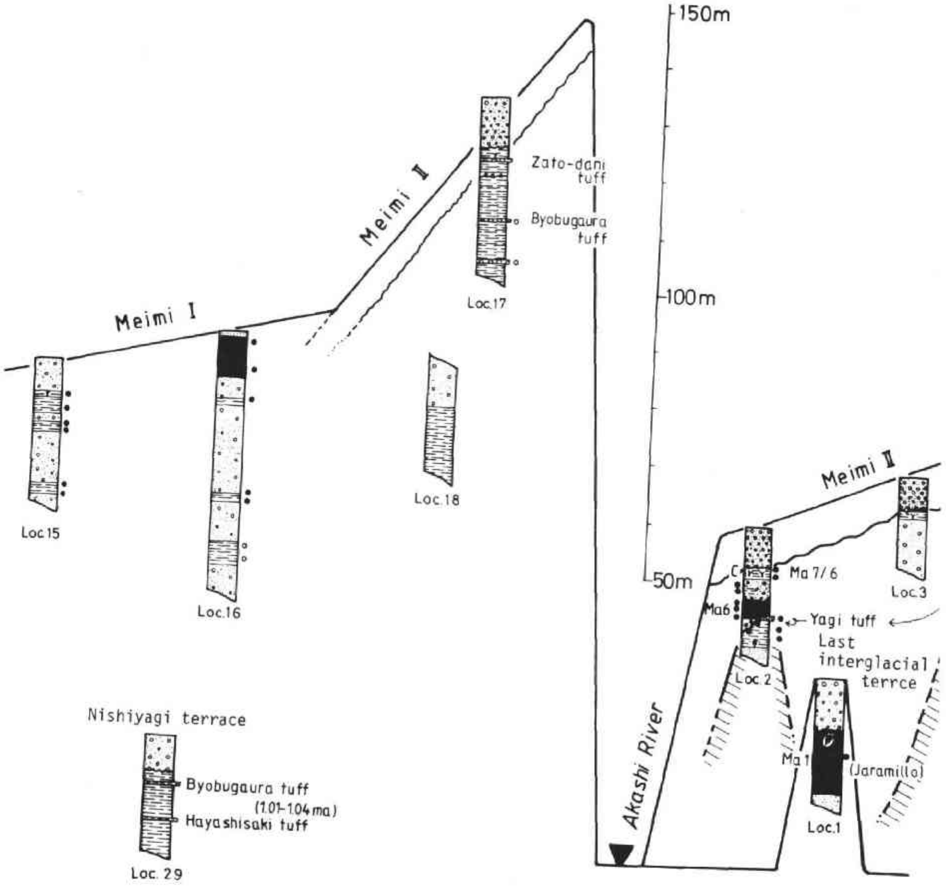
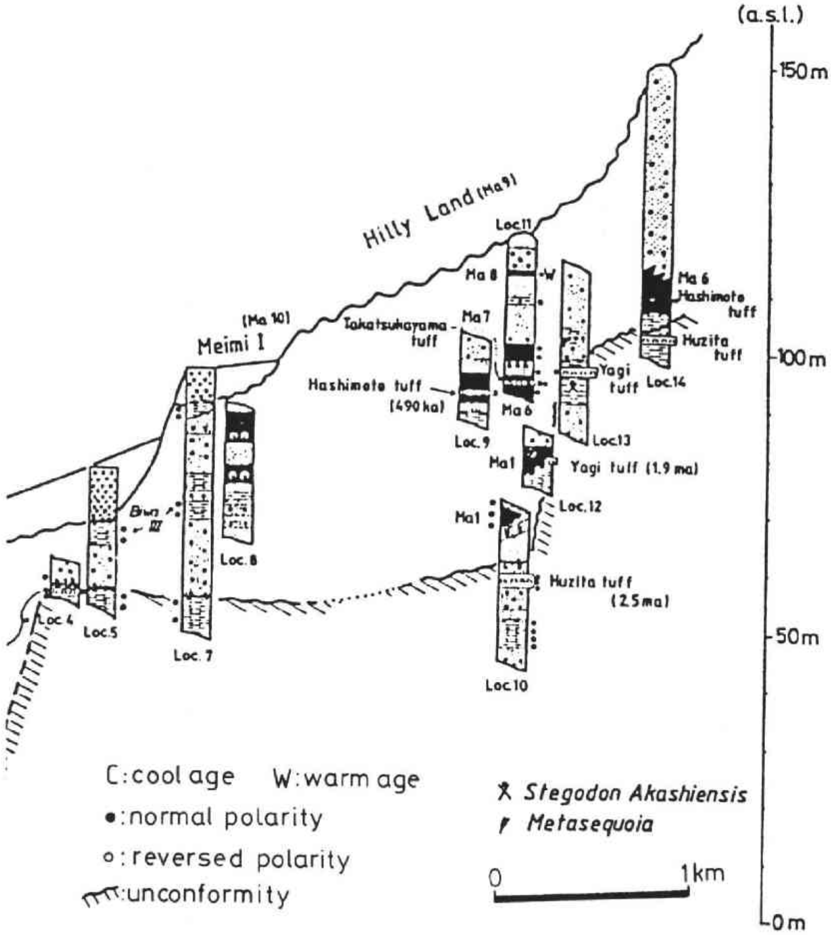


Fig. 9 Geomorphic and geologic section across the

5 at Loc. 11 and is presumed to be the Ma 9 horizon of Osaka Group. Its depositional surface has been dissected to become the summit plane of the hills.

IK-6 at Loc. 5 and IKD-4 at Loc. 7. show reverse polarity. This reversal can be correlated with Biwa III Event in Brunhes Normal Polarity Epoch, considering their stratigraphic position among the middle Pleistocene deposit in adjacent area. Biwa III occurred just below the Ma 8 horizon of Osaka Group.

Putting descriptions above mentioned in order, the strata younger than 0.9 Ma overlie the Plio-Pleistocene sediments before or after Olduvai Event in Matsuyama Reverse Epoch unconformably and they were successively deposited up to the Ma 9 horizon of Osaka Group around Akashi. It is dated as 270-300 ka (Maenaka and



Akashi River in southeastern part of Kakogawa Basin.

Yokoyama 1977). The top surface of hilly land developed in the eastern margin inside the Kakogawa Basin is composed of the strata younger than 300 ka.

(f) The Quaternary strata in the west of the Akashi River

Consolidated bluish clay embedding Byobugaura tuff, the age of which is dated as 1.01 and 1.04 Ma by fission track method (Suzuki 1987), appears at Loc. 16, 17, 18, 38 on the west side of Akashi River. This bluish clay is overlain by sand and gravel layers up to 40 m in thickness called "Meimi Gravels". They are presumably the middle Pleistocene in age because intercalating thin silt beds have normal magnetization (Fig. 7). The top horizon of them forms the higher marine terrace surface (Figs. 4, 9).

(g) The Quaternary strata in the middle course of the Kakogawa River

Thick accumulations composed of gravels called "Miki Gravels" are widely distributed in the middle course of Kakogawa River north of Mino River (Fig. 4). Their facies are very similar to "Meimi Gravels" in the lower course of Kakogawa River. The higher terrace is the depositional surface of "Miki Gravels".

3.4. Terraces in Kakogawa Basin

Classification of terrace surfaces was done by aerial photo interpretation. The aerial photo are in scale of 1/10,000 taken by U.S. Air Force in 1946 and 1/40,000 taken by the Topographical Institute of Japan in 1960. In case of recognizing the marine terraces, the author put great emphasis on the continuity of shore line angles.

(a) Marine and fluvial terraces in the lower course of the Kakogawa River

Six levels of marine terrace surfaces have developed in the lower course of the Kakogawa River. They are named as Meimi I, Yamatedai, Kanegasaki, Uozumi, Nishiyagi and Maiko terraces in descending order (Fig. 6). Fluvial terraces of two levels have also developed in this region. They are Meimi II and Ikawadani terraces (Fig. 6).

The Meimi I terrace has been heavily dissected, and remaining surface shows the shape of veins of leaf. Red weathered soil patched in red and white colors have developed on the surface. At Loc. 16 the Meimi I terrace is the depositional surface of marine clay which is the upper most horizon of the middle Pleistocene series distributed in the west of the Akashi River. The Meimi I terrace has developed in front of hilly land facing to the sea in the east of the Akashi River. The horizon of the terrace deposit is correlated with Ma 10 of Osaka Group, considering that it overlies the strata composing the hilly land (Fig. 9). Ma 10 of Osaka Group is the uppermost marine sediment in the middle Pleistocene (Huzita and Maeda 1984). And the next transgressional stage is the last interglacial age. So, the age of the Meimi I terrace can be correlated with the stage 7, about 250–200 ka, in oxygen isotopic curve issued by Emiliani (1975). The Yamatedai terrace has developed below the Meimi I terrace and its shoreline angle is parallel to the present coastline. It consists of a thick transgressional deposit with a buried valley and has a red weathered soil on the terrace surface (Fig. 10). The formative age of the Yamatedai terrace is estimated to be the culmination of the last interglacial age, about 125 ka, considering it's geological and pedological characteristics and the sequence of geomorphological development in the northeast coast of the Harima-*nada*.

The Nishiyagi terrace is dated as 54 ka by radio carbon dating using an accelerator mass spectrometry technique (Kobayashi *et al.* 1987). An elephantid tusk specimen from the Nishiyagi terrace deposit has been dated as 55–90 ka by aspartic acid

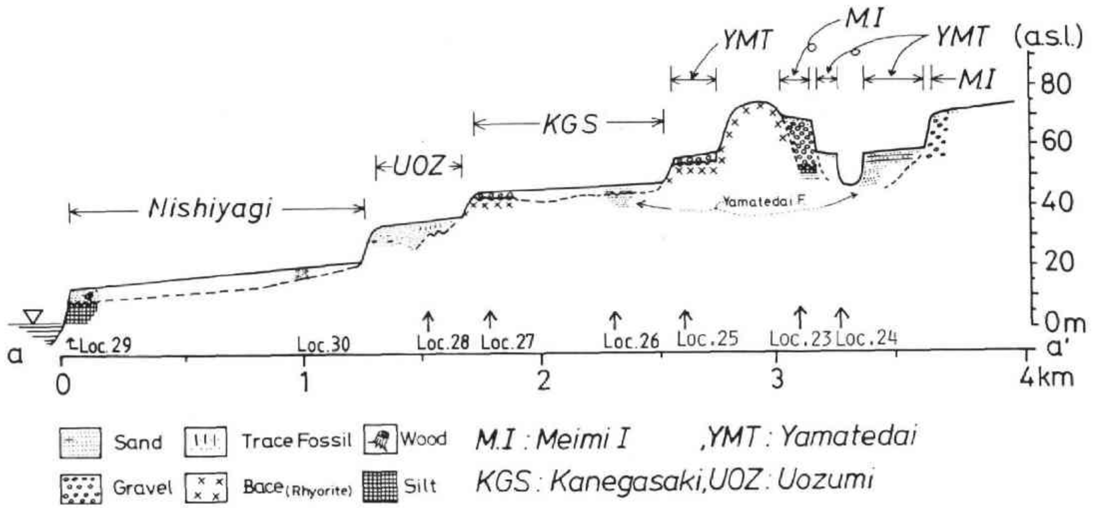


Fig. 10 Geomorphic and geologic section across the late Pleistocene marine terraces in the west of the Akashi River.

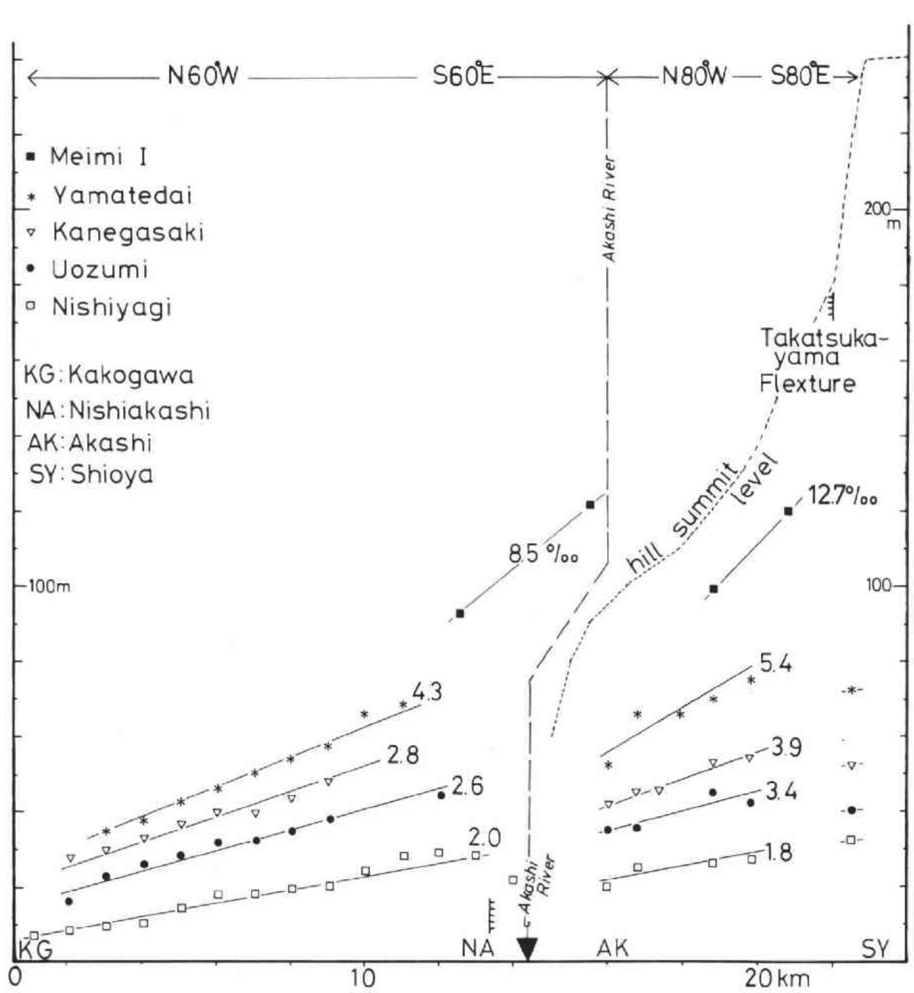


Fig. 11 Distribution of the heights of former shorelines projected onto vertical planes trending N60°W and N80°W.

racemization analysis (Matsu'ura 1987).

The Kanegasaki, Uozumi and Nishiyagi terraces were, therefore, formed during interstadials in the late Pleistocene. These late Pleistocene marine terraces arranged in tiers stepped by scarps parallel to the present shore line. Relative heights of those scarps range within 5 to 10 m. The elevations of their shore line angles decrease from the east to the west, indicating the tilting of this area towards the west (Fig. 11). The Maiko terrace is presumably the Holocene in age judging from it's distribution height up to 6 m a.s.l..

The fan shaped development of the Meimi II terrace indicates that this terrace is

Fig. 12 Distribution of fluvial terrace surfaces in the middle course of the Kakogawa River.

a fluvial terrace. The Meimi II terrace was formed during the regressional period toward the low stand of sea level during the period between 200–125 ka. The Ikawadani terrace is dated back to ca 10 ka in radio carbon age.

(b) Fluvial terraces distributed in the middle course of Kakogawa River

Fluvial terraces with 8 levels have developed in the middle course of the Kakogawa River. They are named Ono I- Ono VIII terrace in descending order (Fig. 12). The Ono I terrace is the depositional surface of thick gravels called as "Miki Gravels" corresponding to Meimi Gravels (Fig. 4). Although no material for dating was discovered from Miki Gravels, the emergence age of the Ono I terrace is presumed to be ca 250 ka that is the horizon between Ma 9 and Ma 10 of Osaka Group. Because the elevation of the Ono I terrace is higher than that of the Meimi I terrace, and no terrace surface consisting of Ma 9 of Osaka Group is preserved around Akashi City (Figs. 4, 9). Terraces below the Ono I are fill strath terraces. Red weathering crust has been formed on the surfaces higher than Ono V terrace. They are, therefore, formed in the middle Pleistocene up to the last interglacial age. The Ono VIII terrace is covered with Aira-Tanzawa(AT) tephra of 21-22 ka which is one of the widespread tephra over Japan (Naruse 1985).

3.5. Distribution of the higher terrace and its formation in Fukuchiyama Basin

Heavily dissected higher terrace is distributed in Fukuchiyama Basin (Fig. 13). There is a red weathered soil on the surface. It is the depositional surface of "Fukuchiyama Formation" (Fukuma and Huzita 1986) that is the thick accumulation of gravels, sand and clay up to 50 m in thickness (Fig. 14). Plants fossils in the lower part of "Fukuchiyama Formation" indicate warmer and subtropical climate (Fukuma and Huzita 1986). That fossil bed is called the Sabia bed and is correlated with the Ma 8 horizon of Osaka Group (Fukuma and Huzita 1986). A brief reverse polarity event was found in the upper part of Fukuchiyama Formation (Fukuma and Huzita 1986). The reversal is presumably the Biwa I event or the Biwa II event, because of its stratigraphic relation with the Sabia bed. The Biwa I event and the Biwa II event were dated as ca 170 ka and ca 300 ka (Kawai *et al.* 1972, Manabe 1980). According to these chronological data, the emergence age of the higher terrace in Fukuchiyama Basin is estimated to be younger than 300 ka.

Fig. 13 Distribution of fluvial terrace surfeces in Fukuchiyama Basin.

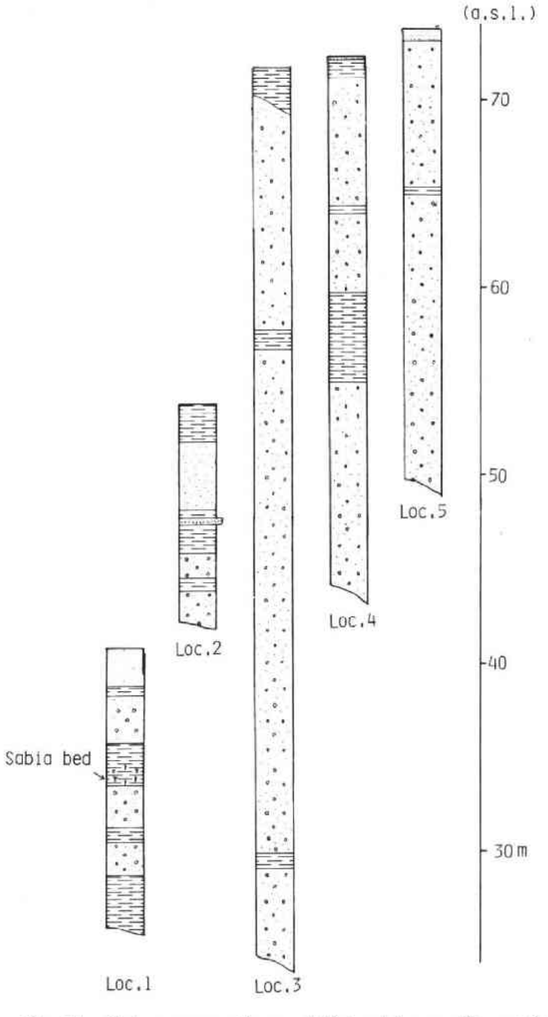


Fig. 14 Columnar sections of Fukuchiyama Formation. After Fukuma and Huzita (1986).

4 Geomorphic differentiation in Kakogawa-Fukuchiyama Valley

Both Kakogawa basin and Fukuchiyama basin are filled with thick accumulations of gravels, sand and clay more than 50 m in thickness. They are Meimi Gravels, Miki Gravels and Fukuchiyama Formation. They are correlated with the middle Pleistocene. The uppermost parts of them are composing higher terraces or hilly lands in the Basins. In other wards, the higher terrace surfaces are depositional surfaces of the middle Pleistocene series. These thick sediments have filled up the valley as a

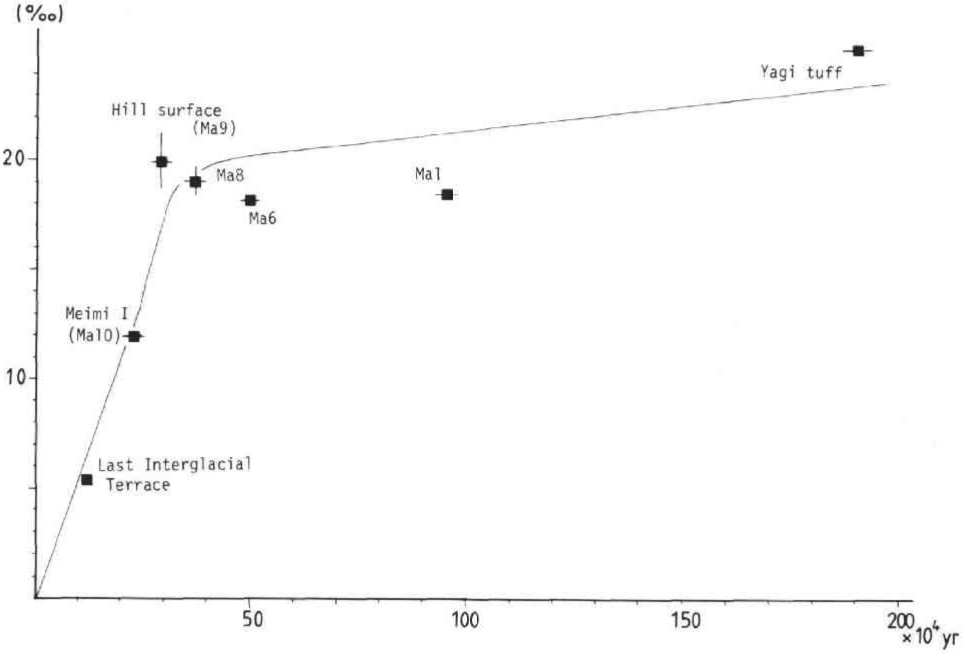


Fig. 15 Change of tilting rate in Quaternary.

whole. And just after the deposition, geomorphic differentiation in Kakogawa-Fukuchiyama Valley was initiated. Therefore, the emergence of these higher terraces indicate the timing of the evolution. The age is between 300 ka to 170 ka.

The tilting rate between two successive references are calculated from Yagi tuff to last interglacial marine terrace (Fig. 15). They are Yagi tuff, Ma 1, Ma 6, Ma 8, hill surface (Ma 9), Meimi I terrace (Ma 10) and Last Interglacial terrace. The result clearly indicates the abrupt acceleration after about 300 ka, and the rate has been constant after the Meimi I terrace of 200-250 ka. In conclusion the terrace phase in Kakogawa-Fukuchiyama Valley has occurred since 300-170 ka.

5 Geomorphic differentiation inside the Plio-Pleistocene sedimentary basins in and around the Kinki Triangle

In order to demonstrate the tectonic conversion from subsiding to uplifting inside the sedimentary basins in time series and a wide area, a distribution map of the uppermost horizons of the Plio-Pleistocene series composing hilly lands and higher terraces in and around Kinki Triangle has been made (Fig. 16). The Plio-Pleistocene series are classified into the following three age categories, Pliocene, lower Pleistocene, middle Pleistocene.

Fig. 16 Distribution of Plio-Pleistocene composing hill surfaces and higher terraces in and around the Kinki Triangle.

Some of the higher terraces are the depositional surface of the uppermost part of middle Pleistocene series. Stratigraphic data are based on geological maps and former geological studies (Itihara 1960, Oka 1961, Takehara 1961, Yokoyama 1969, Yosikawa 1973, 1984, Hayashi 1974, Tamura *et al.* 1977, Sangawa 1977, Huzita 1980, Takemura 1984, Sangawa *et al.* 1985). Precisely speaking, depositional surfaces do not always remain on the hills. But the uppermost stratum composing the hills should

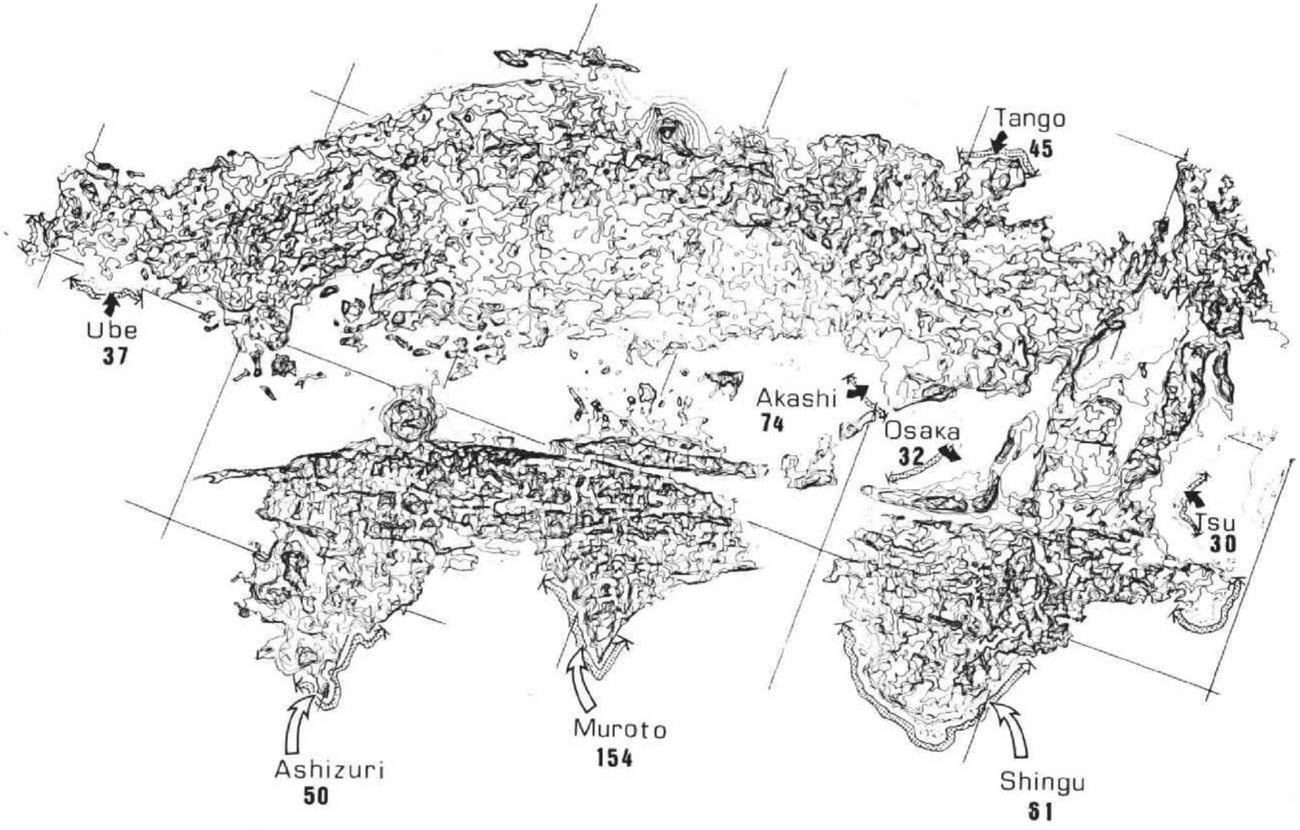


Fig. 17 Distribution of Last Interglacial marine terrace in Southwest Japan.
Coasts along which Last Interglacial marine terrace are distributed are indicated by shaded band.
Numerals are elevations of former shorelines.

a

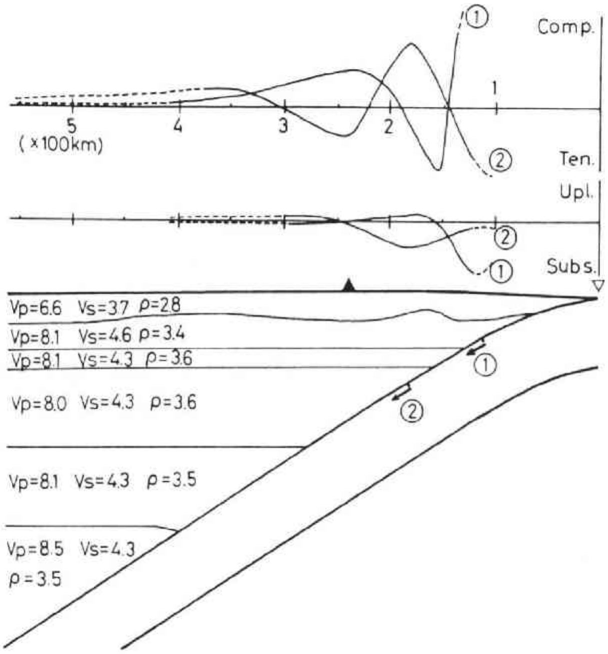


Fig. 18-a Effect for horizontal stress and vertical movement caused by compulsory deformation of coupling boundary.
Results of computation in case compulsory deformation are given at 1 and 2.
After Otsuki (1982) and Shimazaki (1974)

b

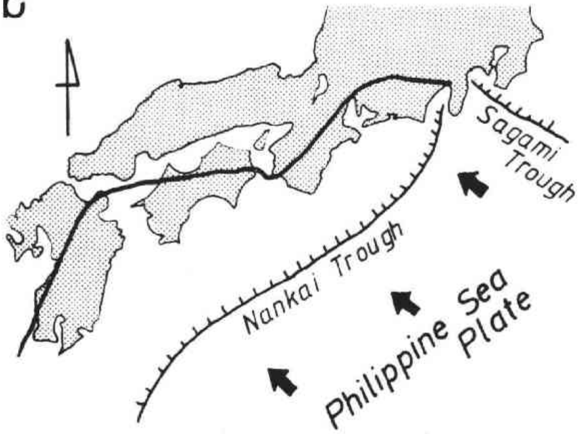


Fig. 18-b Spatial relation between the underthrusting Philippine Sea Plate and the Nankai Trough.
Modified Shinon (1980)
Solid line: leading edge of Philippine Sea Plate

not to be much older than the emergence of depositional surface. The age at which the differentiation broke out get younger from eastern part to the western part in the Kinki Triangle (Fig. 16). It is to say, the evolution first broke out in the east and gradually propagated northwestward. At first it occurred in the western coast of Ise Bay before Early Pleistocene. Subsequently it began in the eastern coast of Biwa Lake during Early Pleistocene. Basins where the highest geomorphic surfaces initiated to emerge in Middle Pleistocene are distributed to the west of Biwa Lake. And Nara basin, also since Middle Pleistocene. In Kakogawa-Fukuchiyama Valley it has occurred since 300-170 ka, as was described in chapter 3. The higher marine terrace as a depositional surface of middle Pleistocene series is most widely distributed in this valley among the basins in the central part of the Inner Zone, Southwest Japan.

On the contrary to the west of Kakogawa basin, no marine terrace including Holocene terrace appears along the coast of Seto Inland Sea as far west as Ube, western part of Southwest Japan (Fig. 17). In this region no inclination of upheaval movement after the middle Pleistocene is recognized. These mean that the conversion of tectonic movement from subsidence to uplifting in a basin has finally occurred in Kakogawa-Fukuchiyama Valley and that the tectonic evolution has not extended to the west of Kakogawa Basin yet.

The author attributes this regional characteristics of geomorphic evolution to the commencement and propagation of subduction of Philippine Sea Plate that has a great influence upon the tectonism of Southwest Japan. It is genarally accepted that Philippine Sea Plate initiated to subduct along the Nankai Trough in 5 to 3 Ma (Shiono 1980). The tectonic stress province in southwestern Japan (Okada 1980) is thought to be caused by coupling boundary effect (Shimazaki 1974, Otsuki 1982) between Eurasian Plate and Philippine Sea Plate. Coupling boundary effect has gradually propagated to the continental side with the lapse of time, in proportion to the advance of underthrusting slab of Philippine Sea Plate after 5-3 Ma obliquely to the Southwest Japan Arc (Fig. 18).

Comparing elevations of former shorelines of the last interglacial marine terraces distributed in and around the Kinki Triangle (Fig. 17), much difference in uplift rate between eastern part and western part of it is not found. Therefore geomorphic evolution in the easten part of the Kinki Triangle had proceeded slowly in its early stage and accelated after the middle Pleistocene.

6 Concluding remarks

It has been assumed that present mountain relief of the Japanese Islands has been obtained by the Quaternary tectonic movement. This study clarified the regional characteristics of Quaternary tectonism with the lapse of time from the view point of geomorphic differentiation in Plio-Pleistocene sedimentary basin in and around Kinki

Triangle, Inner Zone of Southwest Japan. An evolution common to the basins in and around the Kinki Triangle was recognized as a turning point from the sedimentary phase to the terrace phase, or as the initiation of geomorphic differentiation inside the basins. Through detailed examination on the time and space distribution of this evolution, the northwestward propagation of the evolution was recognized. The age of the evolution ranges from Late Pliocene to Middle Pleistocene. It had begun at the eastern end of the Kinki Triangle and extended to northwestward to be terminated in Kakogawa-Fukuchiyama Valley.

Tectonic development of ranges and basins around the Kinki Triangle had been altered since this evolution. And the new phase, namely terrace phase, is now prevailing in the Kinki Triangle.

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