LATE QUATERNARY CRUSTAL MOVEMENTS DEDUCED FROM MARINE TERRACES AND ACTIVE FAULTS, JOBAN COASTAL REGION, NORTHEAST JAPAN

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Abstract In the Joban coastal region facing the Pacific Ocean, the former strandline elevation of the marine terrace formed during the Last Interglacial is from 32 m to 78 m above sea level. This shows that the coastal region has undergone an absolute uplift. In the northeastern part of the Kanto Plain, the former strandlines reveal southwestward tilting resulted from the movement of the Kanto Tectonic Basin. Along the eastern foot of the southern Abukuma Mountains, the former strandlines reveal southward and/or westward tilting, while along the eastern foot of the northern Abukuma Mountains they slope markedly to the north, expressing an intensive northward tilting. These facts indicate the pattern of uplift of the Abukuma Mountains. The average rate of the vertical displacement (west-side-up) across the Futaba Fault Zone, which stretches along the eastern margin of the northern Abukuma Mountains, decreases southward.

Key words: Last Interglacial marine terrace, active fault, crustal movement, Joban coast

1. Introduction

Marine strandlines are a most convenient reference for detecting the vertical crustal movement during the late Quaternary. Therefore, a lot of studies of the crustal movement on the basis of the analysis of the Pleistocene marine terraces have been carried out along the coasts of Japanese Islands. On the Joban coastal region facing the Pacific Ocean in the northeastern Japan, marine terraces have been studied by several authors (*e.g.* Nakagawa, 1961; Ota, 1975; Oka *et al.*, 1981). Among others, Ota (1975) suggested that the former strandlines have been very gently warped with a long wave length longer than 100 km. However, ages and elevations of the marine strandlines are not yet described in detail. Furthermore, the rate of fault movement, which probably deforms strandlines, remains unknown. In this paper, the author first presents the elevations of tephrochronologically dated strandlines and the rate of fault movement, and then discusses the crustal movement.

The investigated region extends about 200 km from the south to the north, and is 60-120 km away from the volcanic front (Fig. 1). The southern part of this region occupies the northeastern part of the Kanto Plain consisting Neogene sediments up to 3,000 m in

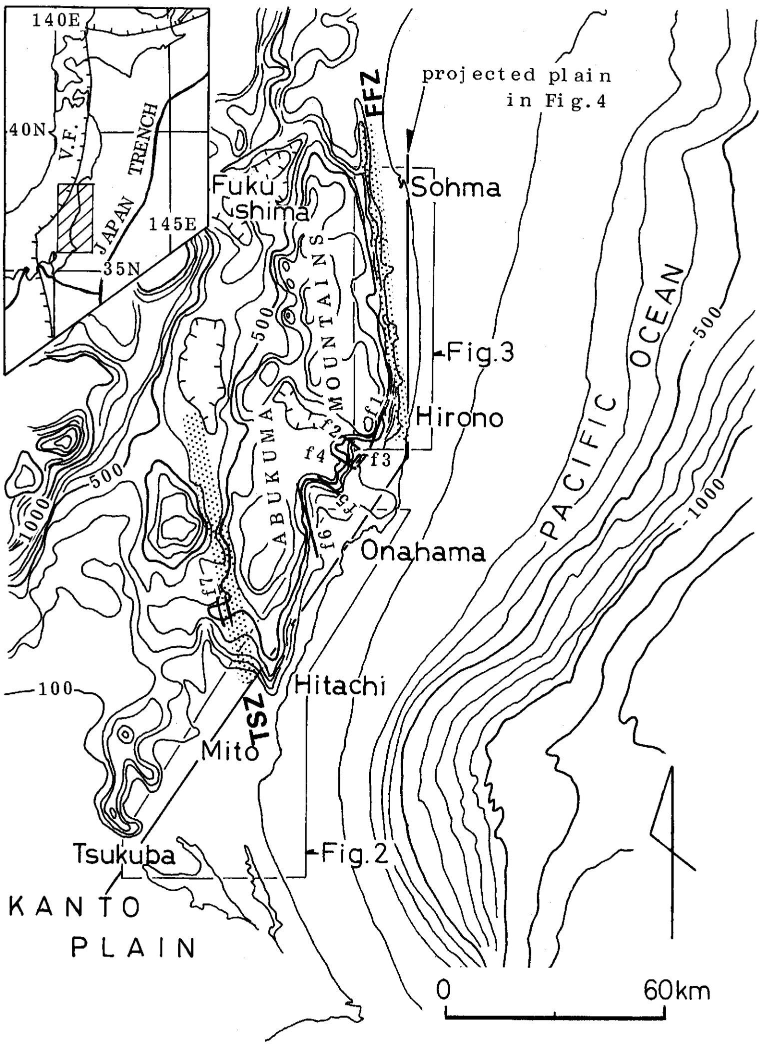

Fig. 1 Topography of Abukuma Mountains and its surroundings contour interval: 100 m; f1-f7 are shown in Table 2; FFZ: Futaba Fault Zone; TSZ: Tanakura Sheared Zone; V.F.: Volcanic front

thickness. The northern part of the region extends along the eastern foot of the Abukuma Mountains composed of pre-Neogene sedimentary rocks, granitic and metamorphic rocks.

2. Last Interglacial Marine Terrace

Northeastern part of the Kanto Plain

Marine terrace formed during the Last Interglacial at *ca.* 130,000-80,000 years ago are extensively developed in this region. It is named as the *"Ni-ihari Daichi", "Higashi-ibaraki Daichi",* and *"Naka Daichi"* (Fig. 2). *"Daichi"* means a terrace landform in Japanese. These Daichi-surfaces consist of shallow marine sands named the Upper Part of the Miwa Formation by Sakamoto *et al.* (1972). Four water-laid tephra layers are found in the sands; *i.e.* the Miwa-U, Miwa-M and Miwa-L pumices, and the K-Tz ash (Fig. 2; Suzuki, 1989). The Miwa-M pumice is chemically and petrographically identified (Suzuki, 1989) with the KlP-7 pumice (Machida, 1971; Machida and Suzuki, 1971) derived from the Hakone volcano in southern Kanto at *ca.* 130,000 years ago. The K-Tz ash is a wide-spread tephra erupted at 75,000-80,000 years ago in the southern Kyushu (Machida, 1984). These tephras in the sands show that the marine sands have been formed between 130,000 and 80,000 years ago. It can be concluded that the strandline of the marine terrace was formed during the Last Interglacial culmination.

The former strandline elevation of the Last Interglacial terraces ranges from 35 m (Tsukuba) to 50 m above sea level (Naka Daichi Surface) (Fig. 2), smoothly downsloping to the southwest. There are no vertical discontinuities expressing fault movements in the longitudinal profile of strandlines.

Eastern foot of the southern Abukuma Mountains

In this region, marine and fluvial terraces unconformably overlying the Tertiary sedimentary rocks are distributed in the belt of less than 10 km wide between the Abukuma Mountains and the Pacific Ocean. Marine terraces formed during the late Pleistocene can be divided into two surfaces, the Tajirihama I and Tajirihama II surfaces in descending order (Fig. 2). Since the Tajirihama I surface is covered with the Miwa-U

Table 1 Classification and correlation of the terraces in the Joban coastal region

<table>
<tr><td colspan="2">South part</td><td colspan="4">North part</td></tr>
<tr><td colspan="2">this paper</td><td>this paper</td><td>Oka et al. (1981)</td><td>Nakagawa (1961)</td><td>Okura (1958)</td></tr>
<tr><td colspan="2" rowspan="3">fluvial terraces
post interglaciation</td><td rowspan="2">lower surfaces</td><td>5th</td><td>V</td><td>5</td></tr>
<tr><td>4th</td><td>IV</td><td>4</td></tr>
<tr><td>Moto-oka surface</td><td>3rd-a</td><td rowspan="3">III</td><td rowspan="3">3</td></tr>
<tr><td rowspan="2">Ni-ihari Daichi S.
Higashi-ibaraki Daichi S.
Naka Daichi S.</td><td>Tajirihama II</td><td>Yonomori surface</td><td rowspan="2">3rd</td></tr>
<tr><td>Tajirihama I</td><td>Kobama surface</td></tr>
<tr><td colspan="2" rowspan="2"></td><td rowspan="2">Higher surface</td><td>2nd</td><td>II</td><td>2</td></tr>
<tr><td>1st</td><td>I</td><td>1</td></tr>
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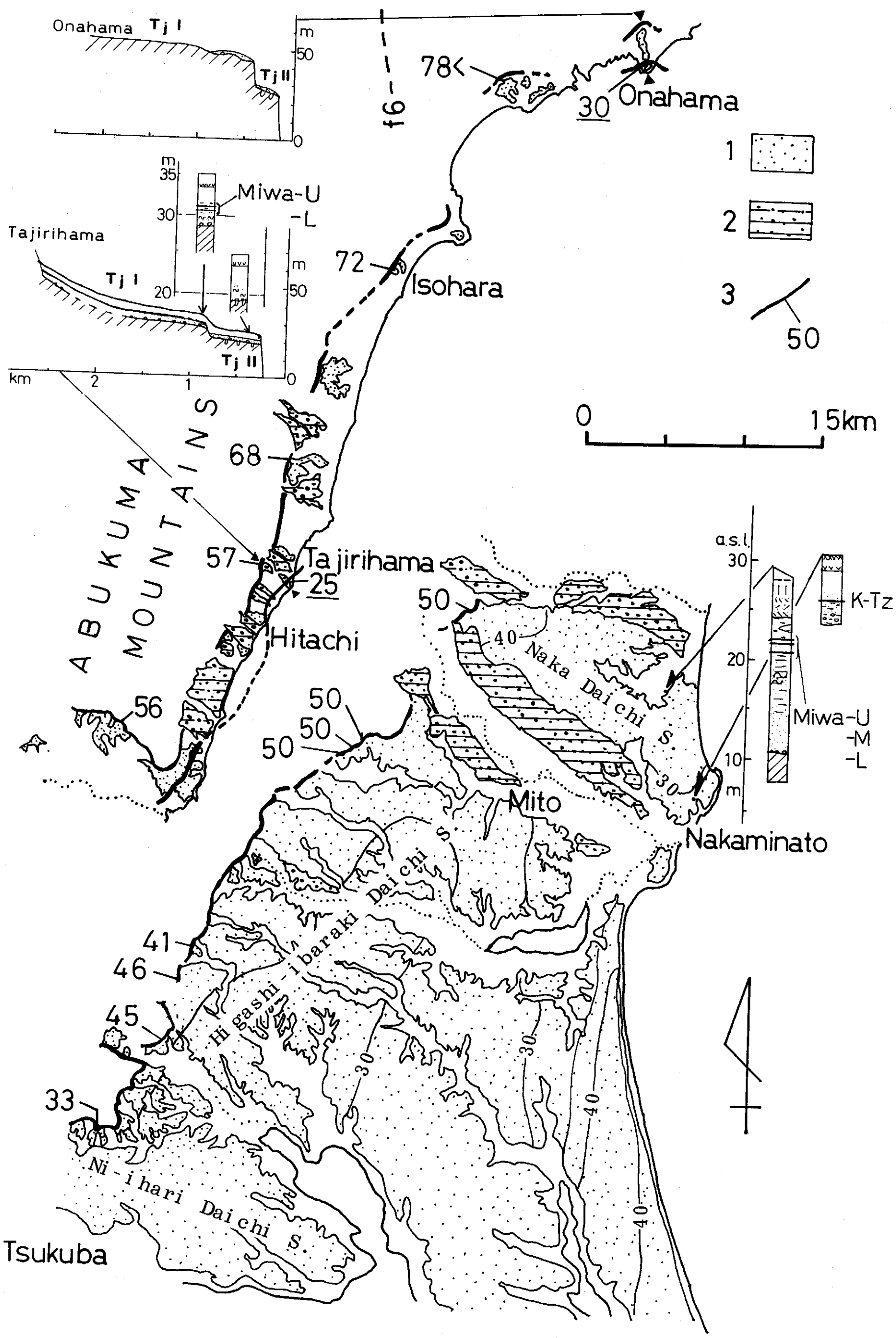

Fig. 2 Distribution of terraces and topographic and geological sections in the southern Joban coastal region
1: marine terrace formed in the Last Interglacial; 2: fluvial terraces formed after the Last Interglacial; 3: former strandline and its height in meters

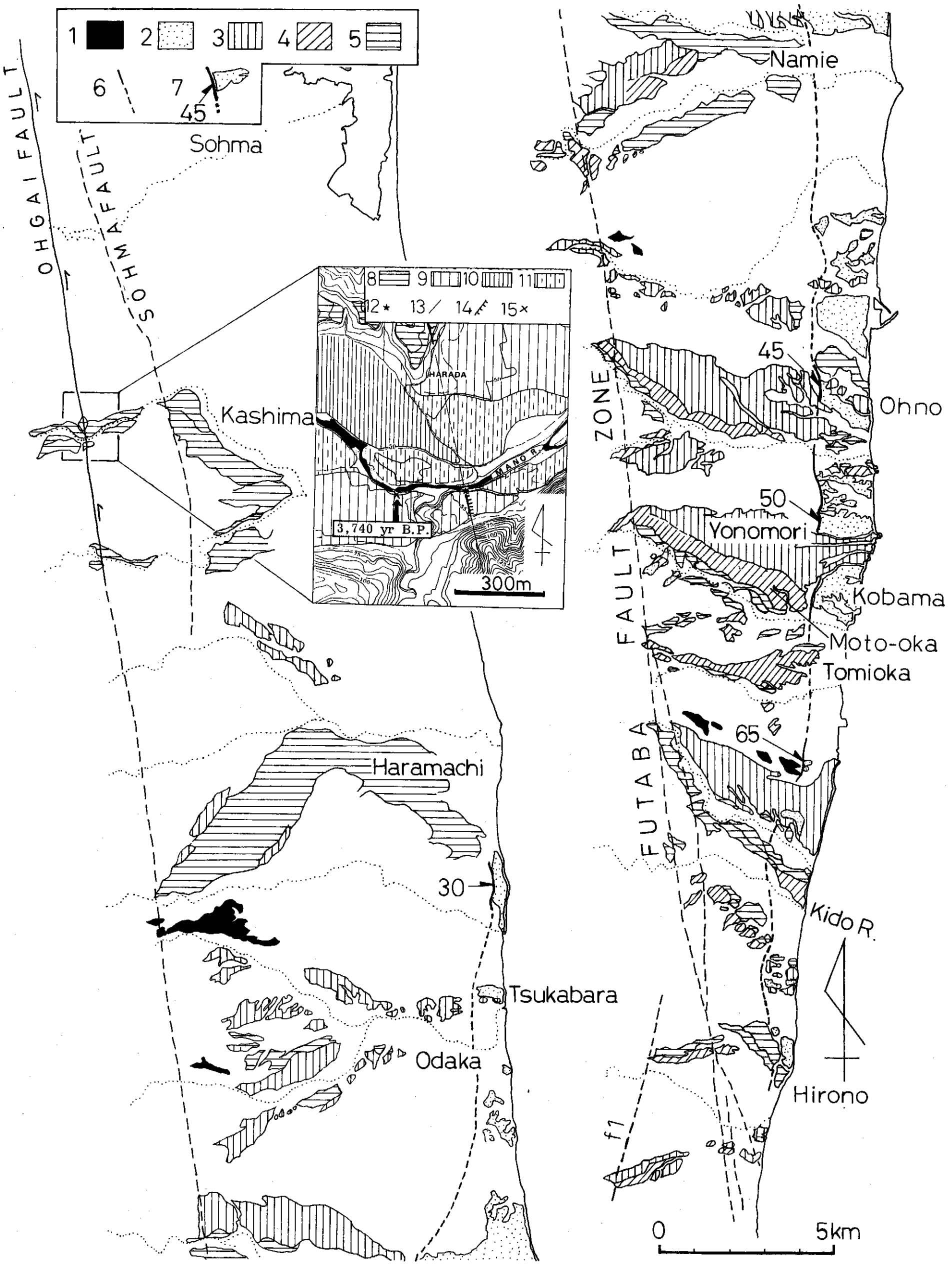

Fig. 3 Distribution of terraces in the northern Joban coastal region
1: higher terraces; 2: Kobama surface; 3: Yonomori surface; 4: Moto-oka surface; 5: lower surfaces; 6: fault; 7: former strandline and its height in meters; 8: lower terrace I; 9: lower terrace II; 10: lower terrace IV; 11: lower terrace V; 12: fault outcrop; 13: fault; 14: fault scarp; 15: sampling locality for C-14 dating

and Miwa-L pumices, which are stratigraphically just above and below the KlP-7 pumice (*ca.* 130,000 years ago) respectively, the surface was formed in the culmination of the Last Interglacial. The lower Tajirihama II surface was probably formed at *ca.* 80,000 years ago, because it is not covered with these tephras.

In the region between the Hitachi City and the Isohara Town the strandline elevation of the Tajirihama I surface ranges from 56 m to 72 m above sea level, and increases northward (Fig. 3). However, it is impossible to measure strandline elevations in the region between the Isohara Town and the Hirono Town, because the terrace surface is not well preserved. Nevertheless, the presence of marine deposits consisting of the Tajirihama I surface at 78 m above sea level around the Onahama Town (Fig. 2) apparently indicates that the former strandline of the Tajirihama I surface is higher than 78 m. The strandline of the Tajirihama II surface increases the height northward, like that of the Tajirihama I surface (Fig. 4).

Eastern foot of the northern Abukuma Mountains

In this region, fluvial and marine terraces truncating the Pliocene sedimentary rocks occupy the eastern area of the east-facing fault scarp of the Futaba Fault Zone (FFZ) running along the eastern margin of the Abukuma Mountains (Fig. 3). Four terrace surfaces named the Higher, Kobama, Yonomori and Moto-oka surfaces in descending order are distributed (Fig. 3, Table 1). While the Higher surface is strongly dissected, the other younger terrace surfaces are well preserved.

Nakagawa (1961) correlated the Kobama surface with the Shimosueyoshi surface, the Last Interglacial marine terrace in the southern Kanto, on the basis of the morphological characteristics of the surface. Manabe (1974) found a reversed polarity interval correlated with the Blake event (108,000-114,000 yrB.P.; Smith and Foster, 1969) in the deposit at

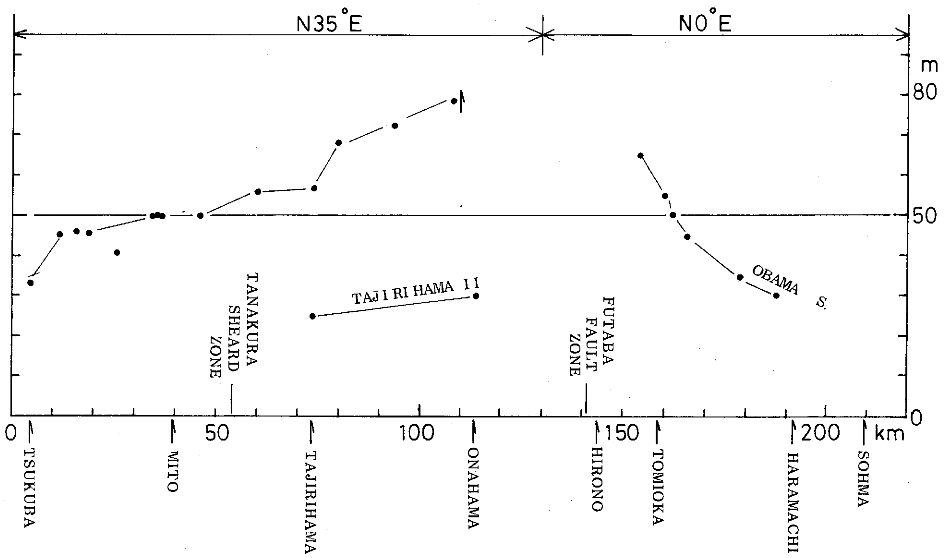

Fig. 4 Projected elevations of former strandlines

Tsukabara. These facts suggest that the high sea level during the formation of the surface should correspond to the Last Interglacial culmination.

Because the Kobama surface has been partly cut by fluvial terraces, the longitudinal profile of strandlines of the surface is discontinuous. The strandline elevations of the Kobama surface from four points are 30 m (Haramachi), 45 m (Ohno), 50 m (Yonomori) and 65 m (Tomioka) above sea level, respectively (Fig. 4). Thus the strandline elevations increase southward.

3. Active Faults around the Abukuma Mountains

Around the Onahama Town six active faults categorized in certainty II (Figs. 1, 2 and 3, Table 2) have been reported by the Research Group for Active Faults (1980). Because none of the faults extend to the coastline, the displacement rates for the faults cannot be determined by means of the deformation of strandline. In the longitudinal profile of strandlines there are no disconitinuties showing the fault movements in the southeastern extension of the f2, the f4, and the f5, and southern extension of the f6. There is no evidence to indicate an offset on the Moto-oka and lower surfaces, where the f1 stretches.

The FFZ extends 55 km along the eastern flank of the Abukuma Mountains. The northern part of the FFZ, from the northwestern side of the Sohma City to 5 km southeast of the Kashima Town, was categorized in certainty I by the Research Group for Active Faults, (1980) (Table 2). It consists of two faults; the Ohgai and the Sohma fault as shown in Fig. 3. Tectonic landforms produced by a faulting are observed only along the Ohgai fault (*e.g.* Otsuki *et al.*, 1977; Suzuki and Koarai, 1989). They are represented by left-lateral offset streams and east-facing fault scarps on fluvial surfaces, indicating the west-side-up and left-lateral displacement. The youngest surface displaced by the Ohgai fault is the Lower III surface in the Kashima Town area. The buried soil, which covers just above the gravels constructing this terrace, is dated at 3,740 yrB.P. (GaK-14239) by ^{14}C dating (Fig. 3). Therefore, it can be concluded that the Lower III surface was formed at *ca.* 3,700 years ago. The vertical component of displacement of the surface is 1.2 m, which is obtained from the height of the fault scarp, probably associated with the last fault movement (Suzuki and Koarai, 1989). The average rate of vertical displacement across the fault is 0.3 mm/year, on the assumption that the recurrence interval of faulting is *ca.* 4,000 years. Otsuki *et al.* (1977) proposed the average rate of left-lateral displacement, about 0.3-0.5 mm/year, assuming that the FFZ began to play a left-lateral faulting about 450,000 years ago.

The FFZ from the Haramachi City to the Hirono Town has been categorized in certainty II (Research Group for Active Faults, 1980). In the longitudinal profile of strandlines (Fig. 4), the displacement by the FFZ cannot be directly clarified because of the dissection of marine terraces around the Hirono Town. However, there is no evidence to show the offset on the Yonomori, Moto-oka, and lower surfaces stretched by the FFZ (Fig. 3). Therefore, the FFZ has been inactive during the late Pleistocene in this region.

Table 2 Characteristics of active faults

1 Fault	Name in Fig. 1	2[1) Certainty	3 Length (km)	4 Strike /Dip	5[2) Tectonic landform	6[3) Displacement rate (mm/y)
Futaba fault zone	FFZ					
Ohgai F.		I	23	NNW	fsf os(L)	V:0.3> L:0.3-0.5(Otuki et al, 1977)
(southern part)		II	37	NNW	fsl	
Osaka -Asizawa F.	f1	II	10	NNE	fss	
Futatsuya F.	f2	II	6	NW WNW/S	fss	
Ohkura F. Group	f3	II	2	NE	fsl	
Akai F.	f4	II	5	NW NW/S	fss	
Yunotake F.	f5	II	6	NW/S	fsl	
Idosawa F.	f6	II	10	NNW	fss os(R)	
Tanakura sheard zone	f7	III	7	NNW/V	fsl	

1, 2, 3, 4 and 5 are after Research Group for Active Faults (1980).

1) certainty I: when it is certain beyond doubt that the fault was active during the Quaternary; certainty II: when it is not definitely certain that the fault was active during the Quaternary, yet it is possible to infer the sense of the displacement; certainty III: when a fault is a mere lineament suspected to be active during the Quaternary
2) fsf: fault scarp on a fluvial surface; fss: fault scarp on a slope; fsl: fault scarp on a low-relief erosional surface; os: offset stream
3) v: vertical displacement; l: lateral displacement (L and R are left and right-lateral, respectively)

4. Discussion

It has been widely accepted that the sea level in the Last Interglacial culmination was 5-6 m higher than that of the present (*e.g.* Bloom and Yonekura, 1985). Accordingly, the Joban coast should have absolutely uplifted at a rate of more than 0.2 mm/year, because the Last Interglacial strandline is now situated between 30 m and 80 m above sea level.

In the northeastern part of the Kanto Plain, the longitudinal profile of the Last Interglacial strandline indicates a moderate southwestward tilting at a rate of 2.3×10^{-9}/year (Fig. 5). It is known that the center of the less-rapid uplifted area in the Kanto Plain locates *ca.* 30 km southwest from the Tsukuba City (Fig. 5; Kaizuka *et al.*, 1977). Therefore, this tilting is probably resulted from the movement of the Kanto Tectonic Basin.

No vertical discontinuities are found in the longitudinal profile of the height of former

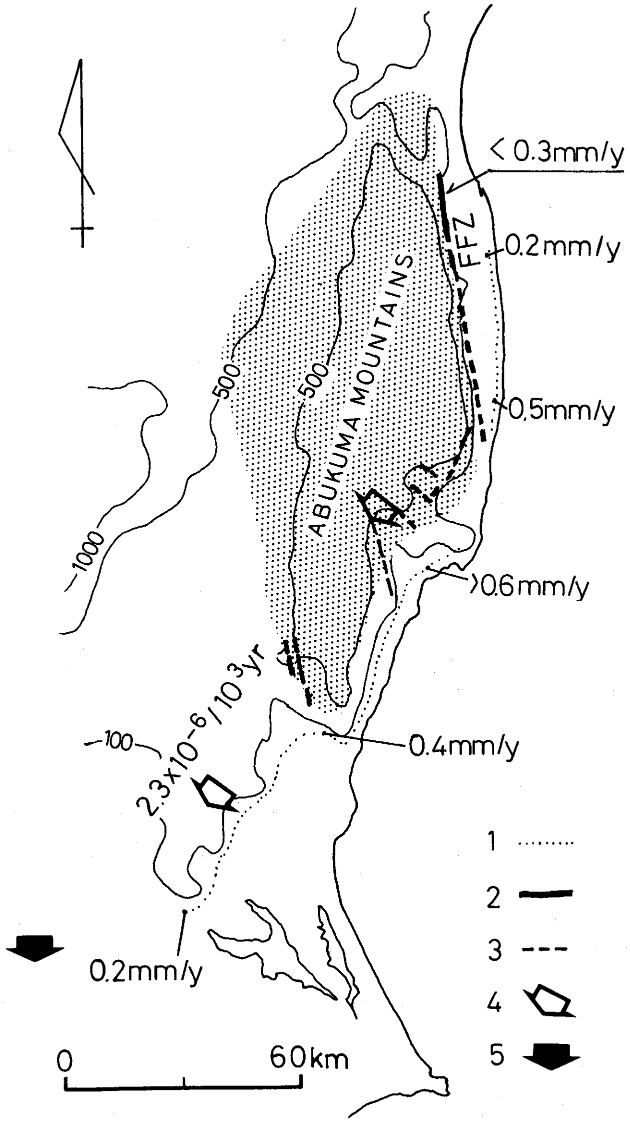

Fig. 5 Late Pleistocene tectonics of the Abukuma Mountains and the Joban coast
1: strandline; 2: active fault during the late Pleistocene; 3: fault suspected to be in active during the late Pleistocene; 4: direction of tilting; 5: center of the area with less-rapid uplift or relatively stable area shown by Kaizuka *et al.* (1977).
Figures indicate the average rates of uplift and tilting except that with underline indicating the average rate of vertical displacement of fault.

strandlines, although it stretches across the southeastern extension of the Tanakura Sheared Zone (TSZ, Fig. 4). This suggests that the TSZ has been inactive, and this is concordant with the estimation of the Research Group for Active Faults (1980) that gave the lineaments (f7) along the TSZ the certainty III (Table 2).

The elevation of the former strandline formed during the Last Interglacial culmination varies from 50 m (Naka Daichi) to 72 m (the Isohara Town). The elevation of the Tajirihama II (*ca.* 80,000 years ago) strandline also increases northward. This deformation pattern is most likely associated with the uplift of Abukuma Mountains, which should be a very gentle undulatory movement. Therefore, the deformation pattern reveals that the uplift of Abukuma Mountains has been accompanied by the southwestward and/or westward tilting during the late Pleistocene. This appears to be concordant with the westward tilting deformation pattern of erosion surfaces on the Abukuma Mountains (Koike, 1968).

The rate of the vertical displacement of the FFZ and the rate of the uplift estimated from the former strandline show the pattern of the crustal movement of the northern Abukuma Mountains. The average rate of uplift derived from the elevation of former strandline during the late Pleistocene increase southward from 0.2 mm/year in the Haramachi City to 0.5 mm/year in the Tomioka Town areas (Fig. 5). On the contrary, the rate of vertical displacement of the FFZ decreases southward. That is, the vertical displacement of the fluvial surfaces gives a rate of 0.3 mm/year in maximum in the Sohma City area, and that of 0 mm/year in the southern part of the FFZ.

The average rate (0.5 mm/year) of uplift obtained from the strandline elevation of the Tomioka Town area probably implies a similar uplift of the Abukuma Mountains, just west of the Tomioka Town area. On the other hand, the average rate of uplift of the Abukuma Mountains near the Sohma City cannot be directly calculated from the elevation of the former strandline. If the average rate of displacement of the FFZ is assumed to be 0.3 mm/year, the average rate of uplift of the northern Abukuma Mountains (0.5 mm/year) must be accompanied with the uplift derived from the dislocation of strandline in addition to the displacement of the FFZ under the assumption that there are no tilting and/or folding between the former strandline and the FFZ. Consequently, the rate of uplift of the Abukuma Mountains near the Sohma City (0.5 mm/year) seems to be the same as that of the Abukuma Mountains near the Tomioka Town (0.5 mm/year). This shows that a northward tilting dose not occurs but probably westward and/or southwestward tilting occur, in the northern Abukuma Mountains, like the crustal movement in the southern Abukuma Mountains.

5. Conclusion

Crustal movements during the late Pleistocene in the Joban coastal region were discussed, using data of the marine terrace deformation and the active faults. The major results can be summerized as follows:

1) The elevations of the Last Interglacial strandlines (>78-30 m above sea level) reveal an absolute uplift of the Joban coastal region.

2) In the northeastern part of the Kanto Plain, southwestward tilting associated with the movement of the Kanto Tectonic Basin has occurred.
3) The uplift of the Abukuma Mountains has caused the westward and/or southwestward tilting.
4) In the coastal region, only the northern part of the Futaba Fault Zone has been probably active through the late Pleistocene.

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