QUATERNARY TECTONIC MOVEMENT DEDUCED FROM MARINE TERRACES AND NOHEJI FORMATION IN THE KAMIKITA PLAIN, SHIMOKITA PENINSULA, NORTHEAST JAPAN

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Abstract In the Kamikita Plain of the "mid-lowland" of the northeast Japan arc, the marine Pleistocene sediment "Noheji formation" consists of the basements under marine terraces as revealed by previous studies. The Noheji formation is rather thick as if this formation had accumulated in a subsiding basin. The geomorphologic and geological structures, however, reveal that the Noheji formation is an assemblage of marine-terrace deposits newly recognized in the Kamikita Plain. Because marine terraces and their deposits are generally formed by the glacial eustacy in uplifted regions, the Kamikita Plain has been uplifting on and after the accumulation of the Noheji formation. This formation didn't occur in the subsiding region, but built up with the glacial eustacy in the uplifted Kamikita Plain.

Key words: island arc, Kamikita Plain, tephra, marine terrace, Pleistocene

1. Introduction

Northeast Japan, including the Shimokita Peninsula, is a typical island arc with remarkable uplift movement and volcanic activity related to the Pacific Plate subduction at the Japan Trench (Fig. 1). In the northeast Japan arc, a distinct lowland, called the "mid-lowland" in this paper, runs from north to south along the volcanic front. Middle-to-late Pleistocene uplifts in this arc were often elucidated using the paleo-shorelines of marine terraces along the coastline (e.g. Miyauchi 1985; 1987; 1988). Nonetheless, based on geomorphologic and geological structures, no investigations of uplift and subsidence were attempted at the mid-lowland except for the northern part of the Shimokita Peninsula, the Tanabu Lowland (Kuwabara and Yamazaki 2000).

Middle-to-late Pleistocene vertical tectonic movement was generally reconstructed from the shorelines of marine terraces and the thicknesses of marine deposits, because emergence of marine terraces and thick deposits reflected vertical-movement changes. Nevertheless, in the greater part of the mid-lowland, which is the inland region, marine terraces and marine Pleistocene deposits don't exist. In the southern and northern parts of the Shimokita Peninsula, however, the mid-lowland (the Kamikita Plain and the Tanabu Lowland) are enclosed by sea. It is, therefore, possible to measure Quaternary vertical movement deduced

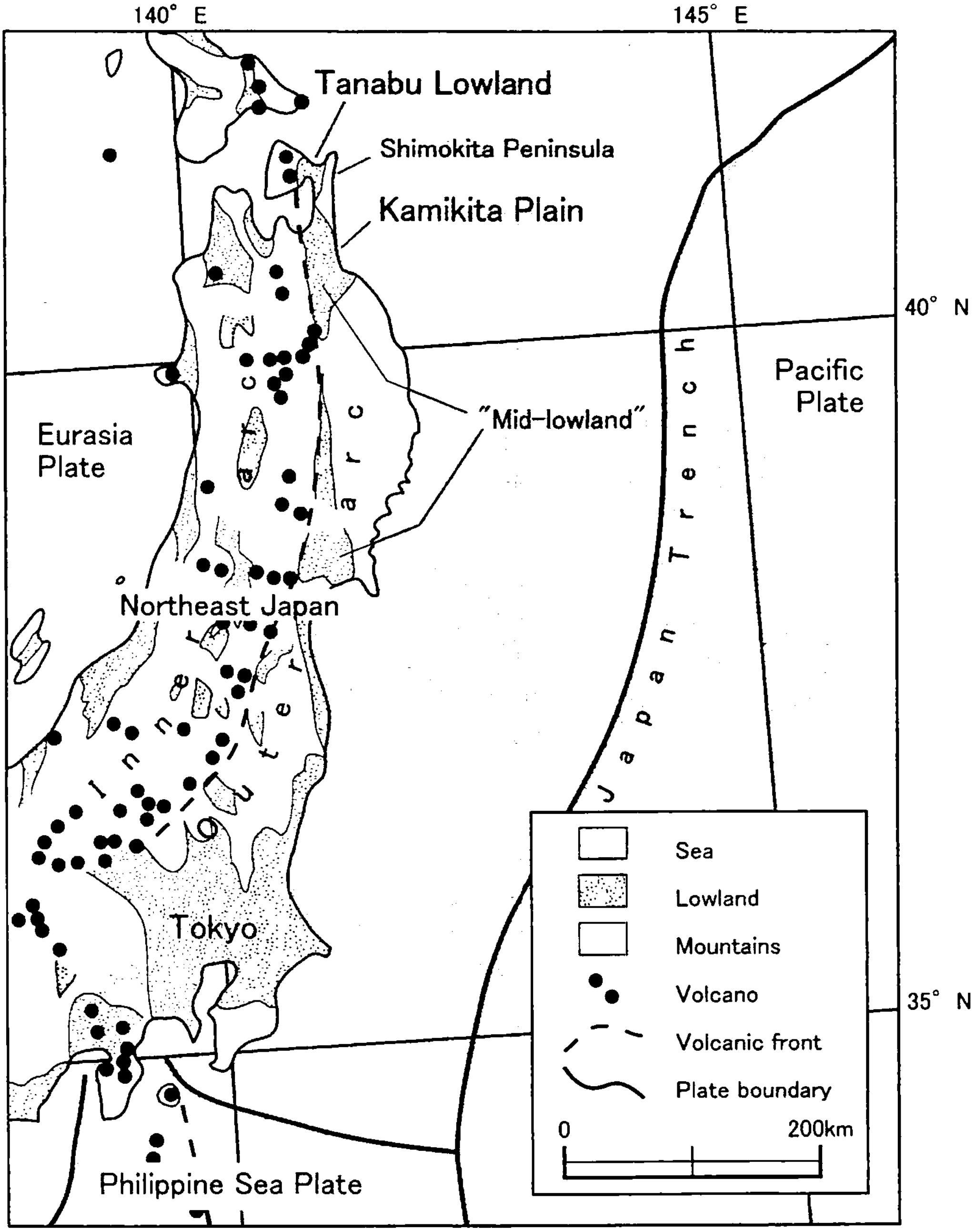

Fig. 1 Geomorphological map of northeast Japan arc.

from marine terraces and marine deposits at the Shimokita Peninsula. This study is necessary for clarifying tectonic movement of the mid-lowlands and the island arcs.

In the Kamikita Plain, Iwai (1951) subdivided the marine Pleistocene into terrace deposit and its basement, that is to say, the "Noheji formation", which unconformably overlies the Pliocene Chikagawa Group (Fig. 2). The Noheji formation is thick and reaches 140 meters in maximum thickness. Usually, marine terraces and their deposits are formed in uplifted regions; but thick marine deposits can also accumulate with subsidence of sedimentary basins. The above succession, therefore, suggests that tectonic movement had changed from subsidence to uplift at the time of the Noheji formation and terrace deposition in the Pleistocene. This abrupt change, however, was so doubtful that this author predicted that Iwai's terrace was divided into several marine terraces whose deposits constitute the Noheji formation. At the same time, the author performed field investigations to reveal the relationship between marine terraces and thick marine Pleistocene sediments. This result indicates that the Noheji formation is correlated with deposits of a few marine terraces through transgressions.

In this paper, the author outlines the stratigraphic succession and the formation processes about marine terraces and the Noheji formation, together with marine isotope stages (=MIS), which show horizons in marine isotope stratigraphy. The stratigraphic succession doesn't attribute the Noheji formation to subsidence, but the formation processes suggest that the Noheji formation had become too thick for uplift and for glacial eustasy on the Kamikita Plain.

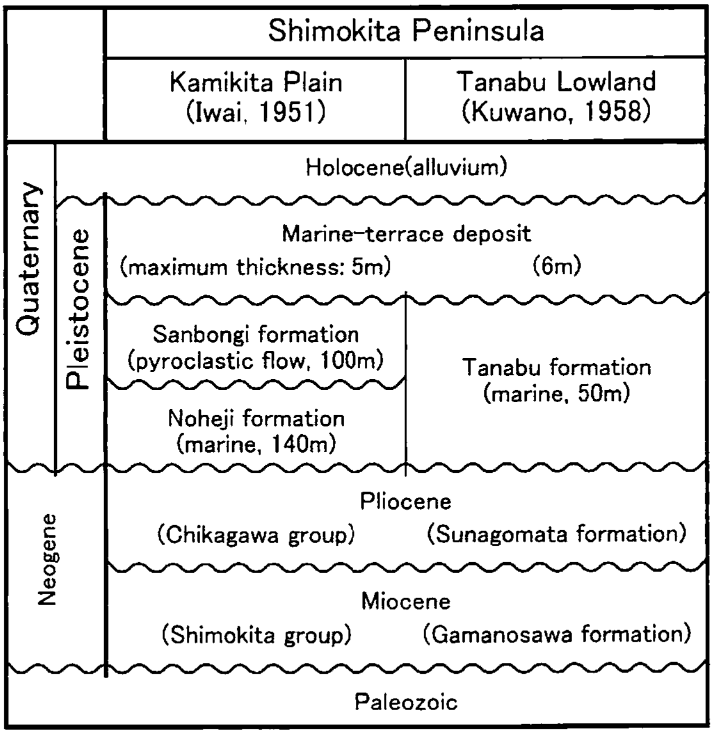

Fig. 2 Stratigraphic classification of Shimokita Peninsula by previous studies.

2. Quaternary Tectonic Movement and the Stratigraphic Succession on the Kamikita Plain

Tephrostratigraphy

The Kamikita Plain is overlain by many volcaniclastic materials (tephras) including volcanic-ash layers, pumice layers, and pyroclastic-flow deposits, because some volcanoes are located in the windward (west) of this plain (Fig. 1). The tephrostratigraphy of this area was already used for analyzing volcanic history (e.g. the Towada Volcano; Hayakawa 1985; Matsuyama and Oike 1986). Moreover, the Quaternary tectonic movement of the Kamikita Plain was estimated from deformed terraces classified by tephrochronology (Miyauchi 1985; 1987). At the stratigraphic section around Noheji (Loc. 1 in Figs. 3 and 4), alternating beds of tephras and soils are over 25 meters thick. Tephras are important for the correlation and recognition of marine terraces.

Major tephras in the Kamikita Plain are the Towada-Hachinohe, Towada-Ofudo, Towada-Red (To-H, To-Of, To-Rd; Machida and Arai 1992), Toya ash (Toya; Machida *et al.* 1987), OrP, WP (Matsuyama and Oike 1986), Fukuromachi tephra group (hereafter referred to as Fkr 13, Fkr 12...Fkr 1), and Ohira (Ohr; named here) in descending order. In particular, the Fukuromachi tephra group, underlying a reddish soil whose thickness is 6 meters up to the WP are the oldest tephras and rest upon a series of marine terraces. The Fkr 3 tephra is so thick (thickness; 275 centimeters) that it is a key marker bed on this plain. Furthermore, the Ohr is locally intercalated in the marine Pleistocene. In the above tephras, Toya ash was recognized as a late-Quaternary widespread tephra in northern Japan (Machida *et al.* 1987); and a time marker at 106ka, MIS 5d (Shirai *et al.* 1997). The characteristics of the above-mentioned tephras at the type locality (Loc. 1) are summarized in Table 1.

Marine terraces and the Noheji formation

Considering the tephrostratigraphic horizons mentioned above, the author identifies four extensive marine terraces in the Kamikita Plain (Figs. 4 and 5). The highest marine surface, the Fukuromachi terrace (named here), was previously detected as a summit plane (elevation; 140-100 meters) for hills in the western Kamikita Plain. This surface forms the watershed between Mutsu Bay and the Pacific Ocean, and runs from north to south. The Fukuromachi tephra group overlies only this surface in all terraces. Lower surfaces, the Shichihyaku and Tengutai terraces (100-60 meters, 60-45 meters; Miyauchi 1985; 1987), appear to the east of the Fukuromachi terrace. WP and OrP are restricted on three of the above surfaces. The Takadate terrace (45-10 meters; Miyauchi 1985; 1987), which is the lowest marine terrace covered by Toya ash in the Kamikita Plain, is located along the coastlines of Mutsu Bay and the Pacific Ocean.

The marine Pleistocene consists chiefly of thick soft sand and gravel sediment (thickness; > 60 meters) on this plain. Figure 6 is the generalized topographic and geologic profile from western to eastern parts of the central Kamikita Plain. This figure shows five depositional sequences, cycles Ⅰ-Ⅴ (named here) from older to younger ones. Cycles Ⅰ and Ⅱ widely accumulated in this area, but cycles Ⅲ-Ⅴ cut down deeply into older sequences. Any one sequence contains at least beach sand and gravel layer (shoreface, foreshore, and backshore deposits in ascending order) which has thicknesses ranging from a few meters to

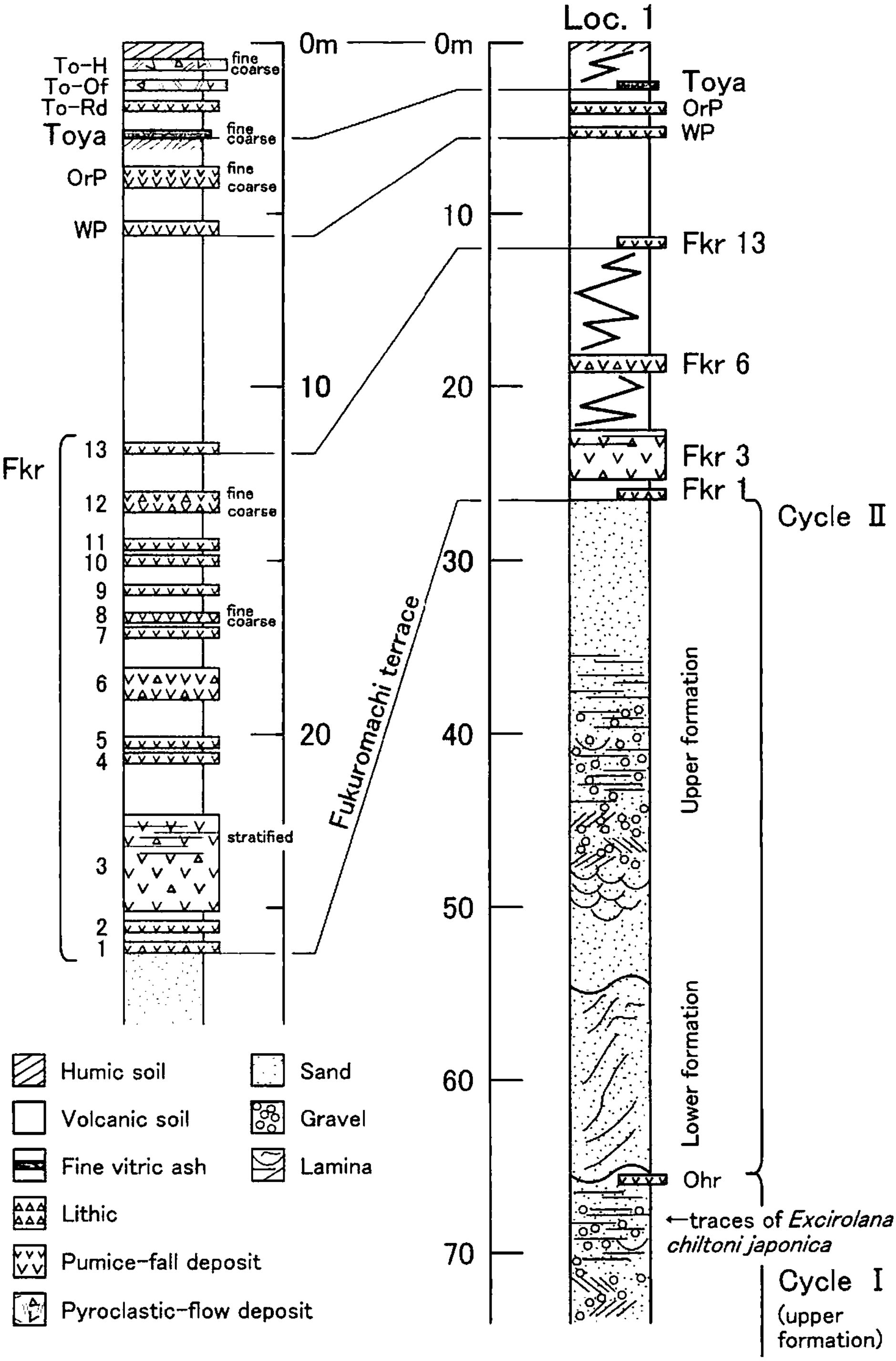

Fig. 3 Columnar section at Fukuromachi terrace around Noheji (Loc. 1 in Fig. 4).

Table 1 Characteristics of tephras at type locality (Loc. 1 in Figs. 3 and 4)

(1) tephra		(2)	(3)	(4)	(5) thick-	(6) maximum grain size (mm)		(7)	(8)	(9)
this study	Iwasaki (1983)	locality	type	color	ness (cm)	essential ejecta	lithic fragment	sorting	lithics	other remarks
To-H	H.V.A.	Loc.1	pfl	gra-ora	28	35	-	-	poor	•normal grading.
To-Of	TA 20	Loc.1	afl	ora	12	5	-	-	poor	-
To-Rd	16	Loc.1	pfa	blu-bla	7	3	-	well	poor	-
Toya	3	Loc.1	afa	yel-ora	9	1	-	well	poor	•normal grading. •vitric(pm>>bw).
OrP	TE 8	Loc.1	pfa	ora	60	8	-	well	poor	•normal grading. •ho>>cpx,opx.
WP	5	Loc.1	pfa	ora,whi	35	-	-	-	-	-
Fkr 13	NO 15	Loc.1	pfa	ora	7	2	-	well	poor	-
12	14	Loc.1	pfa	ora	55	3	3	well	abundant	•normal grading.
11	13	Loc.1	pfa	ora	18	2	-	well	poor	-
10	12	Loc.1	pfa	ora	10	2	-	well	poor	-
9	11	Loc.1	pfa	ora	30	2	-	well	poor	-
8	9,10	Loc.1	pfa	ora	24	2	-	well	poor	•normal grading.
7	8	Loc.1	pfa	ora	8	silt size	-	-	-	•qt.
6	5	Loc.1	pfa	red-ora	90	4	17	well	abundant	-
5	4	Loc.1	pfa	red-ora	10	4	-	-	poor	-
4	3	Loc.1	pfa	ora	10	5	-	poor	poor	-
3	1	Loc.1	pfa	ora	275	10	10	well	poor	•stratified(upper part). •cpx,opx.
2	-	Loc.1	pfa	ora	2	silt size	-	-	-	-
1	-	Loc.1	pfa	whi-pal	13.5	5	5	-	abundant	-
Ohr	-	Loc.1	pfa	whi-yel	4.5	3	-	well	poor	-

(2) Observed outcrop. Location is shown in Figs. 3 and 4. (3) afa: ash-fall deposit, afl: ash-flow deposit, pfa: pumice-fall deposit, and pfl: pumice-flow deposit. (4) bla: black, blu: blue, gra: gray, ora: orange, pal: pale, red: red, whi: white, and yel: yellow. (9) bw: volcanic-glass shard of bubble-wall type, cpx: clinopyroxene, ho: hornblende, opx: orthopyroxene, pm: volcanic-glass shard of pumice type, and qt: quartz.

30 meters. In beach materials, which rest upon distinct flat and smooth erosional surfaces (ravinement surfaces), parallel bedding and trough cross stratification are found. Further, beach materials occasionally contain numerous white-spot traces. These are traces of *Excirolana chiltoni japonica* which are one of the most useful indicators about tidal zones in Japan (Kikuchi 1972). Cycle Ⅲ is composed of only beach material mentioned above, however, four other sequences are accompanied by mud and sand layers or sand and gravel layers (lower formations) beneath the beach materials (upper formations). Lower formations, whose thicknesses are 15-25 meters, are associated with parallel bedding and large-scale foreset bedding. Concerning cycles Ⅳ and Ⅴ, lower formations are thickly deposited upon undulating sequence boundaries like valleys. Incidentally, the lower formation of cycle Ⅰ is so pumiceous that it is easily traced.

In addition, Fig. 6 shows that cycles Ⅱ-Ⅴ have four sequences, which comprise the Fukuromachi, Shichihyaku, Tengutai, and Takadate marine terraces. The depositional surfaces of beach materials (upper formations) are the terrace surfaces. On the other hand, the oldest-sequence cycle Ⅰ is merely covered by younger sequences, and doesn't constitute a terrace surface. Still, including the beach material of the upper formation, i.e. the indicator of emergence, cycle Ⅰ is recognized as a buried terrace deposit, which cut a marine surface before accumulating younger-sequence cycle Ⅱ (Loc. 1). Because all the basements of four marine terraces are cycles Ⅰ, Ⅱ, and Ⅳ: these three sequences, or three marine-terrace

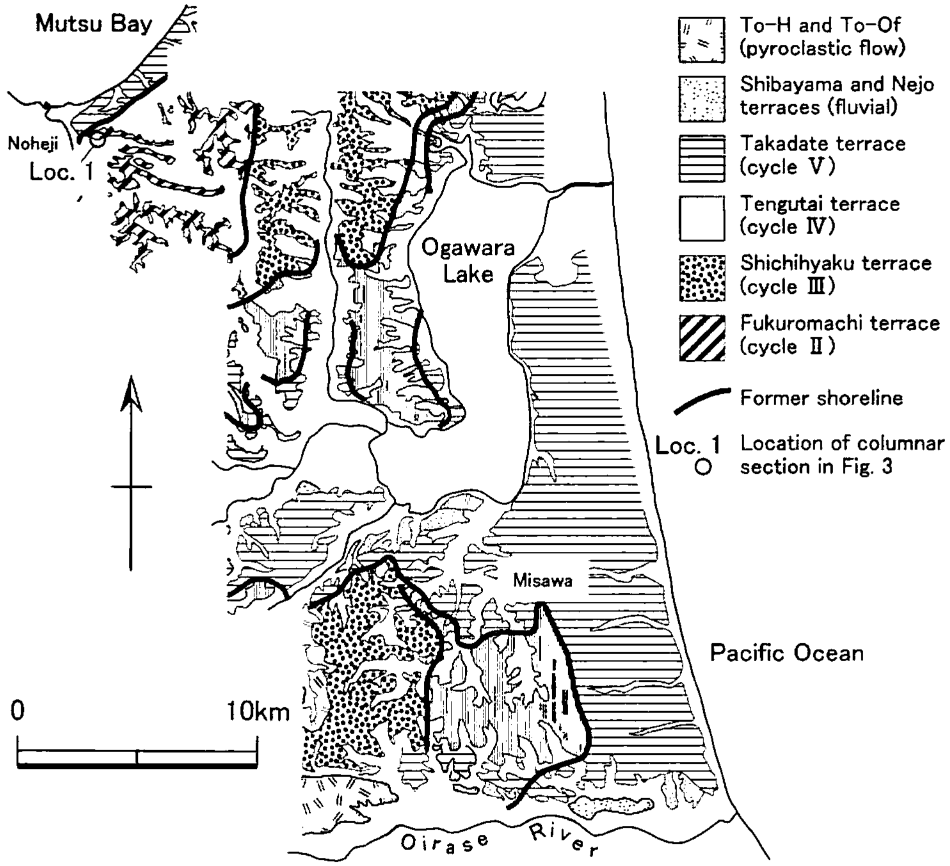

Fig. 4 Marine terraces in Kamikita Plain.

deposits, constitute the Noheji formation.

Quaternary tectonic movement deduced from the stratigraphic succession

Cycle Ⅴ emerged from the sea just before the Toya ash was deposited, because this tephra exists in the lowest horizon of alternating beds of tephras and soils above the Takadate terrace (Cycle Ⅴ). A standard curve of oxygen isotope ratios shows that the sea surface was higher at MISs 5e, 7, 9, 11, and 13 (122ka, 186-242ka, 301-334ka, 364-427ka, and 474-528ka, respectively: Bassinot *et al.* 1994) before deposition of Toya ash (MIS 5d). In general, marine terraces are formed during high sea levels. Indeed, cycles Ⅳ and Ⅴ, which were built at times of higher sea levels, are thick deposits resting on undulating sequence boundaries like valleys. Considering the vertical relationships with Toya ash, cycles Ⅰ-Ⅴ are sequences correlative with MISs 13, 11, 9, 7, and 5e, respectively (Fig. 5).

The Noheji formation consists of cycles Ⅰ, Ⅱ, and Ⅳ. It is therefore a mid-Pleistocene assemblage of marine terraces. The Kamikita Plain has been uplifting on and after the accumulation of the Noheji formation, because all of the marine terraces, whose former-

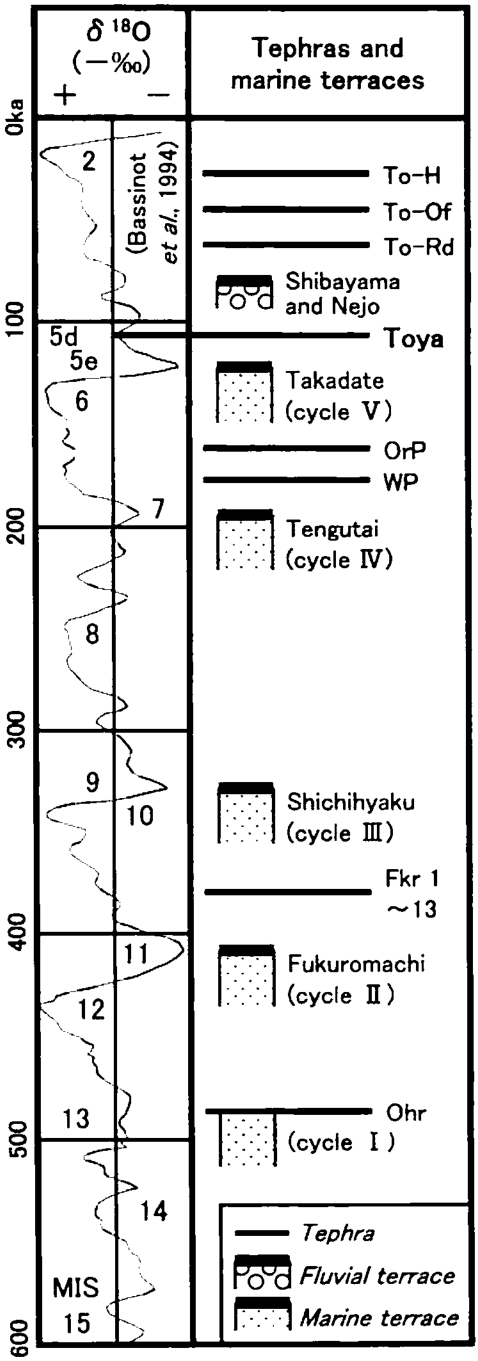

Fig. 5 Correlation of marine terraces in Kamikita Plain with marine isotope stratigraphy. The age of Toya ash is based on Shirai *et al.* (1997).

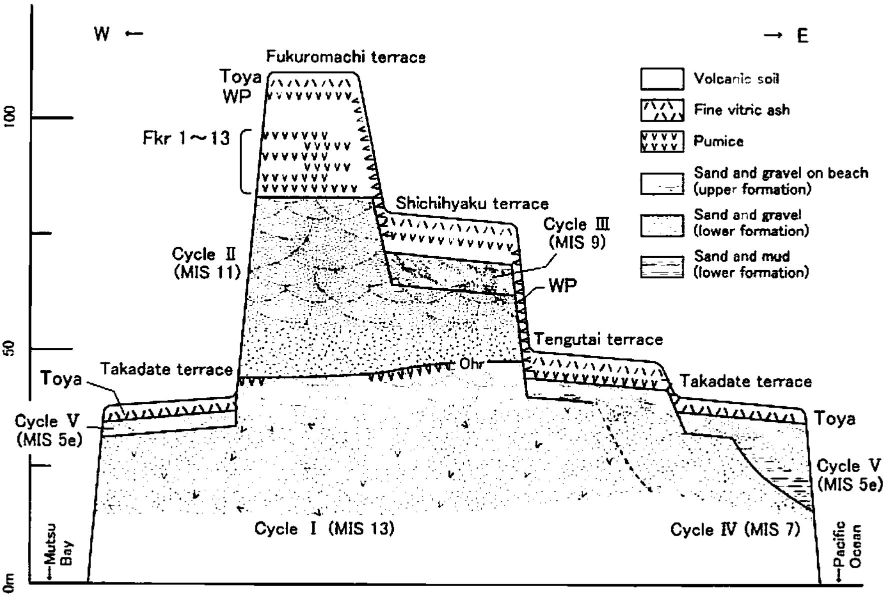

Fig. 6 Generalized section showing relationships between marine terraces and the marine Pleistocene from western to eastern parts of the central Kamikita Plain. Cycles Ⅱ-Ⅴ comprise marine terrace deposits of Fukuromachi, Shichihyaku, Tengutai, and Takadate. Noheji formation is composed of cycles Ⅰ, Ⅱ, and Ⅳ which are the basements under marine terraces.

shoreline heights are cumulative, are much higher than the current sea level in this area. In other words, there are no rapid inversions of tectonic movement from subsidence to uplift during Pleistocene.

3. Quaternary Tectonic Movement and Development of the Kamikita Plain

Cycles Ⅰ - Ⅱ

The generalized section of Fig. 6 also shows the following development of marine terraces and marine Pleistocene: demonstrating that glacial eustasy was effective against the formation of the Kamikita Plain in the middle-to-late Pleistocene. First, cycle Ⅰ commenced at MIS 13, the time of higher sea level. Because this sequence is thick and is distributed widely on the central Kamikita Plain, this plain was broadly submerged at MIS 13. The sequence was deposited when the sea-surface rose from MIS 14, at a time of lowered sea level just before this higher sea level. On the other hand, this sequence is associated with the upper formation, that is, beach material showing emergence out of water. Consequently, this plain developed entirely as the sea surface fell to MIS 12, which was the next time of the lower sea level. The sequence formed by this higher sea level is estimated to be 30 meters thick from the bottom (elevation: 15 meters) to the top (45 meters) of cycle Ⅰ.

Cycle Ⅱ corresponds to the next higher sea level, MIS 11. It is thick, widely distributed, and overlies cycle Ⅰ. In addition, the depositional surface of cycle Ⅱ, the Fukuromachi marine terrace, is the watershed between Mutsu Bay and the Pacific Ocean. Thus, the Kamikita Plain was broadly submerged again in those days, and cycle Ⅱ was deposited when the sea-level rose from MIS 12 to MIS 11. The relative height between this sequence's base (45 meters) and the Fukuromachi terrace (80 meters) shows that the thickness of the MIS 11 sequence exceeds 35 meters. The above discussions indicate that the central Kamikita Plain was largely submerged twice at the age of cycles Ⅰ - Ⅱ, and that the marine Pleistocene, with the total thickness of 65 meters, was widely deposited in enormous thickness.

Cycles Ⅲ - Ⅴ

The younger sequence cycles Ⅲ - Ⅴ, whose depositional surfaces were constructed as marine terraces of Shichihyaku, Tengutai, and Takadate, occurred one after another at MIS 9, 7, and 5e, when sea levels were higher. Cycle Ⅲ consists of a thin marine deposit, however, cycles Ⅳ and Ⅴ are very often thick and built up on sequence boundaries which undulate as valleys. These characteristics show that the sequences of cycles Ⅳ and Ⅴ accumulated when each sea-level rose just after the low sea levels (MISs 8 and 6). During these periods, the Kamikita Plain emerged above the sea surface, and valleys were formed. Both thicknesses exceed 20 meters from the base (15 meters) to each terrace's former shoreline (45 meters and 35 meters, respectively). Still, the central Kamikita Plain wasn't widely submerged at higher sea levels of cycles Ⅲ - Ⅴ, because three terraces of cycles Ⅲ - Ⅴ surround the highest surface of the Fukuromachi terrace. Besides, each fluvial terrace, which is lower than the Takadate terrace, was constructed under an intermittently falling sea-level after the appearance of cycle Ⅴ (Takadate terrace).

Quaternary tectonic movement deduced from the development of marine terraces and the Noheji formation

The above discussions show that the development of the Kamikita Plain had been sharply influenced by glacial eustasy at the mid-to-late Pleistocene. As already stated, the Noheji formation had been formed on this uplifting plain, because this formation is an assemblage of cycles Ⅰ, Ⅱ, and Ⅳ, namely, marine-terrace deposits reflecting the transgressions and the regressions. On the contrary, the Noheji formation is rather thick as if this formation had accumulated in a subsiding basin. Such a thick marine formation originated because each sequence, which is about 30 meters thick, accumulated just after a period of lowered sea level. The accumulation on this plain may have been caused by relative subsidence whose uplift rate is smaller than that of the surrounding mountains.

4. Quaternary Tectonics of Shimokita Peninsula

As stated first about the northern part of the northeast Japan arc, the mid-lowland leads from the southern part, the Kamikita Plain, to the northern part, the Tanabu Lowland, of the Shimokita Peninsula (Fig. 1). Using the stratigraphic classification of the marine Pleistocene, we can also infer tectonic movement of the Tanabu Lowland as well as the Kamikita Plain.

Kuwano (1958) subdivided the marine Pleistocene of the Tanabu Lowland into the terrace deposit and its basement, namely, the "Tanabu formation" (Fig. 2). The Tanabu formation, which unconformably covers the Pliocene Sunagomata formation, is thick with a maximum thickness of about 50 meters like the Noheji formation. This thickness suggests that the Tanabu formation was caused by subsidence, and that tectonic movement sharply reversed from subsidence to uplift just before the terrace construction in the Tanabu Lowland. Lately, Kuwabara and Yamazaki (2000) showed that the Tanabu formation was a set of old marine-terrace deposits that were excluded from the terrace deposit by Kuwano (1958). Kuwabara and Yamazaki (2000) therefore concluded that the Tanabu formation was made up by uplift and glacial eustasy like the Noheji formation of the Kamikita Plain. In other words, there were no rapid inversions of tectonic movement from subsidence to uplift in the Pleistocene on the Tanabu Lowland as well as the Kamikita Plain.

Considering the stratigraphic classification of the earlier studies about the Tanabu Lowland and the Kamikita Plain (e.g. Iwai 1951; Kuwano 1958), we may generally regard the mid-lowland as a subsiding basin even at the Pleistocene on the Shimokita Peninsula. On the other hand, Kuwabara and Yamazaki (2000) and this study imply that this mid-lowland has been uplifting since the Pleistocene. This result is important for clarifying formation process of the northeast Japan arc.

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