Buried Terraces in the Lower Sagami Plain, Central Japan : Indicators of Sea Levels and Landforms during the Marine Isotope Stages 4 to 2 (Part IV)

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6. Discussions

On the basis of identified and correlated buried terraces and deposits in the lower Sagami Plain, the author discusses on following points : 1) Geomorphological features of each buried terrace, 2) Correlation of buried terraces with those in other areas, 3) Reconstruction of sea-level changes, and 4) Reconstruction of landform changes.

6. 1 Geomorphological features of buried terraces in the lower Sagami Plain

The author identified buried terraces corresponding to the MISs 5a, 4, 3 and 2 in the lower Sagami Plain. Geomorphological features of each terrace and deposit are discussed below.

1) Buried terraces and deposits corresponding to the MIS 5a

In the present study, the S3 terrace can be correlated with the MIS 5a in the lower Sagami Plain.

The subaerial S3 terrace occurs on the western side of Koza Upland. A marker tephra, Hk-AP, can be recognized at the bottom of the tephra group covering this terrace deposits. Except for the Okada terrace, the terrace surface submerges into the alluvial plain near Samukawa, 7 km upstream from the present river mouth (Figs. 5.1 and 5.4).

The thickness of this buried terrace gravel reaches about 20 m in the lower reaches. The height of the gravel top in the lowermost part (at the portion of borehole, 2.5 km upstream from the present river mouth) is -25 m a.s. l.

This is a fluvial terrace which was formed during the relative stable sea-level period of the MIS 5a. This terrace has a gentle gradient of the longitudinal profile, and occurs in a wide area in the left bank. The width of the plain was at least 5 km, at the distance 2 km from the present river mouth. Therefore the author suggests the existence of a fan-delta from Samukawa to Chigasaki at the culmination of the MIS 5a. It is not clear where the former river mouth was at this stage; however, it could have been located slightly more offshore than the present.

2) Buried terraces and deposits corresponding to the MIS 4

S4 and S5 terraces show patchy occurrences around the present river mouth. This limited extension and their thin formation may indicate that they are non-cyclic fluvial terraces in the phase of downcutting after the emergence of the S3 terrace. This downcutting is possibly correlated with the rapid sea-level drop that might have occurred in the period of transition between the MISs 5a and 4.

The author then considers that the indicator of the lowest sea level during the MIS 4 may be the basal layer of the buried Nakatsuhara Terrace formation. As mentioned earlier, the Nakatsuhara Terrace has relatively thick fluvial deposits (12-18 m), and the base of deposits can be seen at -90 m a.s.l. at the present river mouth. It is deeper than those of S4 and S5 deposits. Further data on the heights of marine deposits will confirm the paleo sea level.

Accordingly, a deep valley would have been formed near the present river mouth in the culmination of the MIS 4. The valley bottom was more than 50 m lower than the previous MIS 5a stage plain (S3). The height and gradient were nearly the same as the basal level of BG (Basal Gravel of the Recent deposits). The width of the valley bottom seems to be 2-2.5 km at the present river mouth.

3) Buried terraces and deposits corresponding to the MIS 3

Nakatsuhara terrace was formed during this stage. This terrace surface submerges into the alluvial plain near the city of Atsugi, 14 km upstream from the present river mouth. Both subaerial and buried terraces extensively occur in the lower Sagami Plain. The existence of the Buried Nakatsuhara Terrace is confirmed in Hiratsuka City and near the present river mouth, since the author found tephras containing AT covering the terrace gravel bed near the present river mouth.

Nakatsuhara terrace has a wide distribution in the lower Sagami Plain. This terrace is also seen along the Nakatsu, Tamagawa (west of Atsugi), and Kaname rivers. Accordingly, the lower Sagami Plain in this stage can be reconstructed as a compound fan plain. However near the present river mouth, it was a narrow valley plain bordered by S3 and S4 terraces on its both sides.

Thick formation of this terrace suggests that a sea-level rise after the low sea-level period of the MIS 4. The surface of deposits seen -75 to -65 m at the present river mouth may indicate the 15 to 25 m sea-level rise and the succeeding stagnation because the fluvial plain has been widened during the MIS 3.

The Tanahara-1 Terrace was formed in the latest period of the MIS 3 because this terrace emerged just before the AT fall. The gradient of this terrace is almost the same or slightly gentler than that of Nakatsuhara Terrace, indicating relatively minor changes of the base level.

4) Buried terraces and deposits corresponding to the MIS 2

Kaizuka and Moriyama (1969) mentioned that 'Mochi (Mm)' terrace (the steepest one) of Minahara terrace group, possibly corresponds to the BG (Basal Gravel). It might have been formed during the lowest sea-level period. The bottom height of the BG is about -100 m a.s.l. at the present river mouth. The estimated age of this lowest sea-level period is centered around 20-17 ka.

The present study has no additional data on the basal depth of the BG at the present river mouth; therefore, it employs previous data. Machida *et al.* (1990) estimated the age of this lowest sea-level period about 22 ka to 14 ka. They estimated the age of the F-S (Fuji-Sagami River Mudflow), which is seen in the Minahara Terrace deposits as 17 to 14 ka.

A deep and narrow valley was formed during the MIS 2. The width of the buried valley is estimated to be 1.5 km at the present river mouth. This valley bottom can be traced to the subaerial Minahara terrace deposits in the upper reaches.

6.2 Correlation of buried terraces in the lower Sagami Plain with those in the Paleo-Tokyo River basin

Buried terraces have also been described in the Paleo-Tokyo River basin in the Tokyo-Yokohama area, south Kanto (*e. g.*, Matsuda, 1973, 1974; Kaizuka *et al.*, 1977; Endo *et al.*, 1983; Matsuda, 1993). The Paleo-Tokyo River is a prolonged river system in the present Tokyo Bay caused by the sea-level drop during the Last Glacial period. The author attempts to correlate these terraces with those in the lower Sagami Plain by using data she collected. Detailed data will be shown in another paper.

1) Distribution of buried terraces

The lower Tama river plain : The author subdivides the sub-aerial 'Tachikawa terrace' (Juen, 1966) in the Musashino upland into the older Tc1, and the younger Tc2 terrace (Fig. 6.1). The Tc1 terrace submerges into the alluvial plain and continues to the extensive buried terrace in the lower

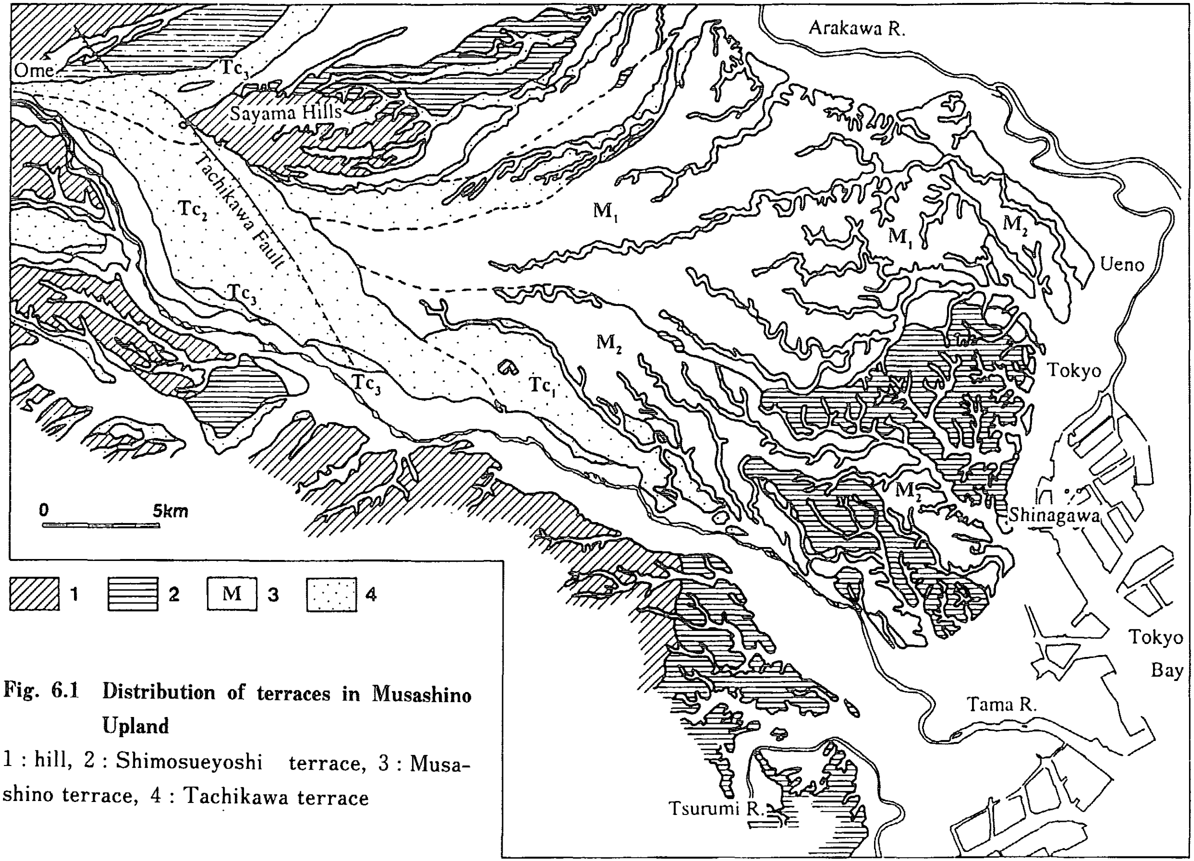

Fig. 6.1 Distribution of terraces in Musashino Upland

1 : hill, 2 : Shimosueyoshi terrace, 3 : Musashino terrace, 4 : Tachikawa terrace

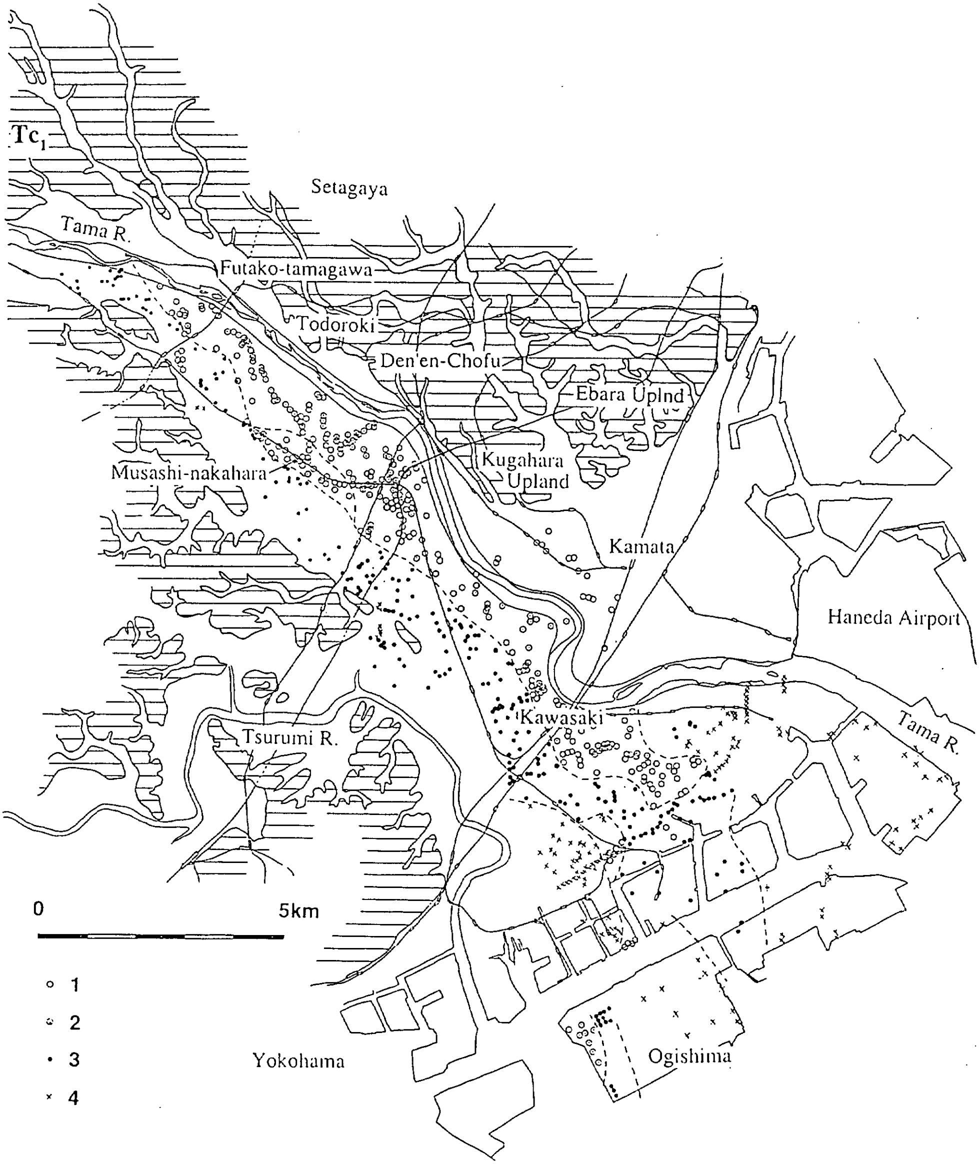

Fig. 6.2 Buried landforms along the lower Tama River Plain
1 : Tachikawa gravel, 2 : Tachikawa gravel covered with tephras,
3 : BG, 4 : abrasion platform etc.

reaches (Fig. 6.2). It is covered with a-few-meters-thick tephra. The eastern margin of this terrace occurs around 2 km east of Kawasaki Station. Altitudes of the surface of the gravel bed are about -25 to -27 m a.s.l. This Tc1 terrace can be correlated with Nakatsuhara Terrace in the Sagami Plain because the equivalent tephra sequence covers the terrace surface. The Tc2 terrace occurs fragmentary in the deeper parts.

The Tokyo Lowland : The well-described 'Honjo Buried Terrace' occurs in the western part of the Tokyo Lowland. It is also possible to correlate it with the buried Tc1 terrace (Matsuda, 1974). Though Endo *et al.* (1988) correlated the whole 'Honjo Buried terrace' with Tc2, the author considers that the 'Honjo Buried terrace' consists of both Tc1 and Tc2. This is because she found the western part of the 'Honjo buried terrace', covered with tephras containing AT ash (at -29 m a.s.l. in Kinshicho, Sumida Ward). This suggests it is the Tc1 terrace. The buried Tc2 terrace seems to exist in the deeper part, such as in the southwestern part of the Katsushika Ward (Kubo, 1988b). Thus most of the 'Honjo buried terrace' corresponds to Tc1.

2) Remnants of buried terraces in Tokyo Bay

Kaizuka *et al.* (1977) mentioned that the Nakanose bank in Tokyo Bay (height -15 to -20 m) might be a submerged terrace of the late Pleistocene. According to the occurrence, it may be correlated with the M2 terrace (Fig. 6.3).

Recently Matsuda (1993) showed a geological cross section along the Trans-Tokyo Bay Road, connecting Kawasaki with Kisarazu. A gravel bed about 8 m thick covered with tephras 2-3 m thick is seen in this section at a depth of about -60 m. He described these deposits as that of a buried fluvial terrace, but no detailed explanation was given. This terrace can be correlated with one of the buried Tachikawa terraces.

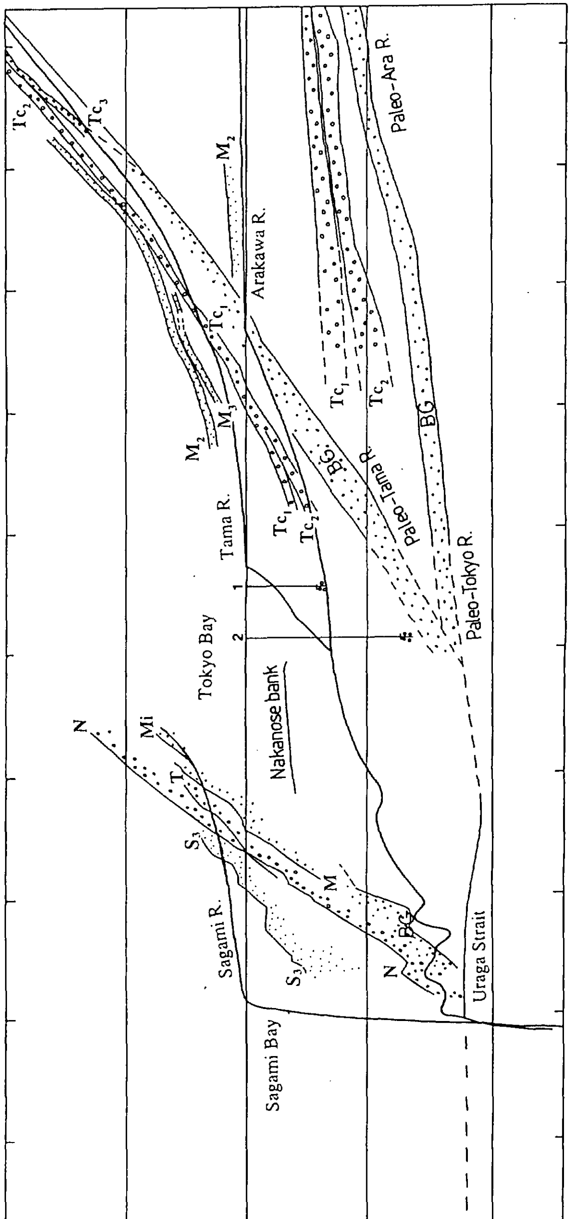

Fig. 6.3 Longitudinal profiles of rivers and buried terraces in the lower Paleo-Tokyo River, compared with the lower Sagami River

Distance of each river is shown from the edge of continental shelf.

3) Sea-level evidence in the MIS 3

The plain of the Tc1 stage seems to have been wide in the lower Tama Plain and the Tokyo Lowland. This condition is similar to the lower Sagami Plain. This may support the view of sea-level stagnation during the MIS 3 as suggested in the lower Sagami Plain.

Because of the longer distance from the edge of the continental shelf, buried terraces in the Paleo-Tokyo River basin discussed above occur at shallower levels than those in the lower Sagami Plain. They seem to be fluvial terraces, and the lowermost parts of buried terraces in the Tama River Plain and the Tokyo Lowland are some 40-60 km from the edge of continental shelf (Fig. 6.3).

Though data obtained from the Paleo-Tokyo River basin seem insufficient for sea level reconstruction, they partly support the results of the lower Sagami Plain for the MIS 3.

6.3 Sea-levels during the MIS 5a to 2

The observed height of the past sea level is a compound of the tectonic and glacial-eustatic components in tectonically active areas (*e. g.*, Nakada *et al.*, 1991). Therefore, the evaluation of tectonic deformation is a fundamental process to reconstruct the paleo sea levels. As south Kanto contains one of the most intensely uplifted areas through the Quaternary in Japan, the author attempts to evaluate the average uplift rate at the mouth of the Sagami River, and then calibrates the sea levels in each stage.

1) Outline of crustal movement in and around the lower Sagami Plain

The Oiso Hills, west of Sagami Plain, is the place of strong uplift with many active faults. The mean uplift rate is about 3 m/ky in the Holocene (Yonekura *et al.*, 1968; Yamazaki, 1992) along the southern coast of the Oiso

Hills. This was derived from the height of the well-dated Holocene shoreline in the Nakamurahara terrace (shown in Fig. 4.8).

On the other hand, there is no strongly uplifted shoreline to the east of the Oiso Hills. Matsuda *et al.* (1988) found the transition of marine to fresh-water deposits of about 6 ka, in drilling cores near the Isehara Fault. The levels were -2.16 m and -0.91 m (the difference in height indicates dislocation by the faulting). Ota and Seto (1968) reported the radiocarbon date of 1950 ± 90 yBP on drifted wood that occurs in beach pebbles 2 m a.s.l. at Hiratsuka Station. Moreover, the southern rim of the Koza Upland is a former coastal cliff, which was formed during the Holocene transgression. Sand bars and sand dunes develop from the foot of this cliff to the south. This evidence does not suggest an uplift in this area.

The author supposes an active N-S fault, with its western side upthrown, divides the Oiso Hills from the Sagami Plain. This can be supported by the depth of basement rock, which abruptly increases at the western rim of the plain (see Fig. 5.3).

Kaizuka and Moriyama (1969) estimated the rate of tectonic uplift of about 1.4 m/ky near the present Sagami River mouth. This area was uplifted about 1 m in the Great Kanto Earthquake in 1923. They estimated the recurrence interval of large earthquakes as 140 years, and the net uplift during each interval of large earthquakes as 0.2 m.

If the above uplift rate (1.4 m/ky) has been uniform, the shoreline at the time of the Holocene transgression peak, 6 ka, is to be seen at 8.4 m (1.4 * 6) at the present river mouth. This seems to be unrealistic because there is no evidence of uplift near the present river mouth.

Machida (1973) suggested that the present mouth of the Sagami River is a relatively subsiding area, when it is compared with surrounding areas on the heights of the Shimosueyoshi (the MIS 5e) surfaces. He also demonstrated

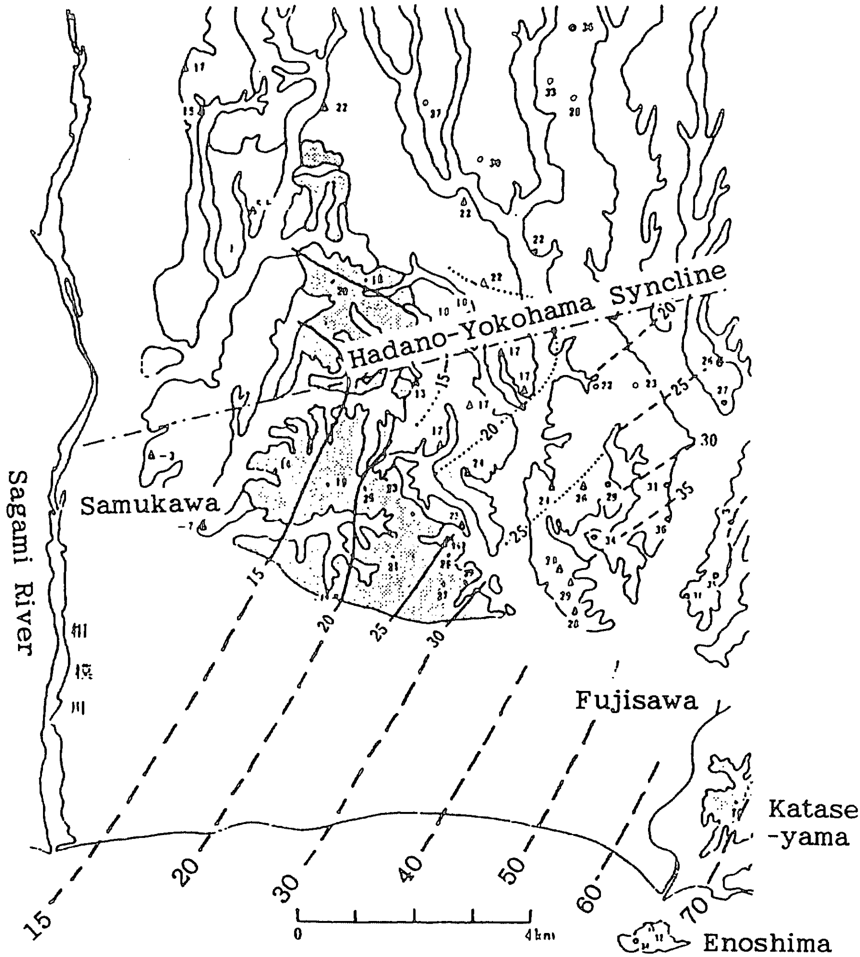

Fig. 6.4 Extrapolated heights of the former shoreline of MIS 5e in the lower Sagami Plain (modified from Machida, 1973)

the northwestward constant tilting of the southern half of the Koza Upland during the last 10^5 years (Fig. 6.4).

The author estimates the average uplift rate near the present Sagami River mouth as follows. Since the height of the MIS 5e deposits in the Koza Upland tilts northwestward (shown in Fig. 6.4), the author extrapolated the height to the present Sagami River mouth at about 15 m. The sea level of the MIS 5e may have been slightly higher than this altitude at the present river mouth. On the basis of the assumed paleo sea level of the MIS 5e (+6 m, *e. g.*, Bloom and Yonekura, 1985), the average uplift rate is estimated to be at least 0.07 m/ky (15 minus 6 m/ 125 ky). This rate is much smaller than that of Kaizuka and Moriyama (1969).

2) Estimation of past sea levels by subtracting tectonic components

To estimate former sea levels, we need to subtract the tectonic components from the observed sea levels. Kaizuka and Moriyama (1969) estimated the paleo sea level at the peak of the MIS 2 as follows. The Sagami River mouth of the valley buried under the Recent deposits seems to have lain at the edge of the continental shelf, whose present depth is about -110 to -120 m. They suggested that a wave-cut platform existed there and estimated the former shoreline was some 20 m higher : at around -90 to -100 m. Assuming the uplift rate of 1.4 m/ky, they suggested that the sea level of 20 ka was -120 to -130 m.

The author, however, proposes to revise the uplift rate as mentioned above (<0.07 m/ky), and estimates sea levels of each culmination of the MIS 5a to 2. The observed height of deposits of the MIS 5a was -25 m (S3 : 80 ka) in the lowermost part. It contains a 5.6 m of tectonic component, which must be subtracted from the observed height. The result is c. -31 m. However, the deposits appear to be fluvial, showing that is the highest estimate of the sea

Table 6.1 Tectonic correction for sea-level estimates on the assumption of average uplift rate

isotope stage (age)	observed altitude of deposits	extrapolated hight at the edge of continental shelf	vertical displace-ment	calibrated altitude
MIS 5a (80 ka)	S3 (top) : −25 m	−34 m	5.6 m	<−31 to −40 m
4 (65 ka)	N (base) : −90	−104	4.6	<−95 to −109
3 (50 ka)	N (top) : −75	−86	3.5	<−79 to −90
2 (20 ka)	BG (base) : −100	−100	1.4	<−101 to −111

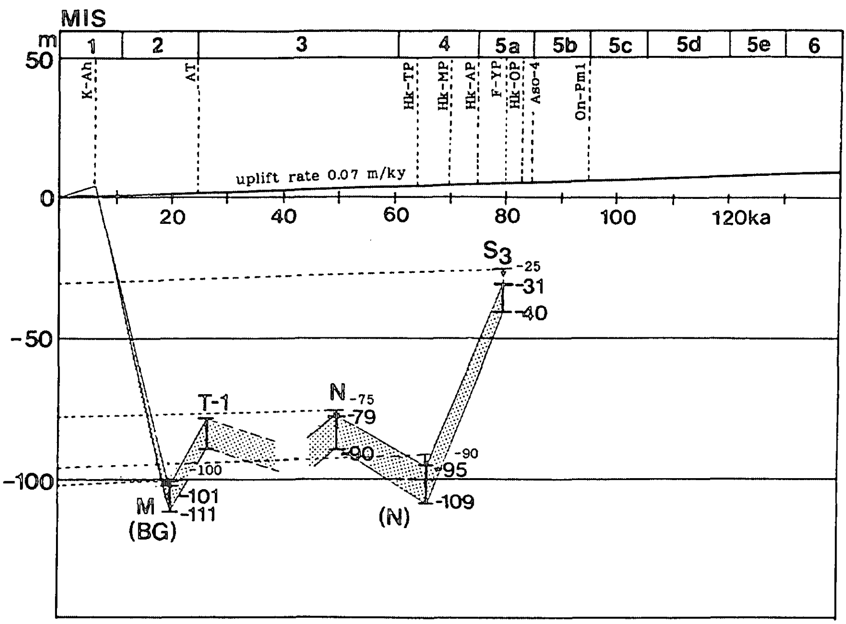

Fig. 6.5 Sea-level changes during the Last Glacial Cycle reconstructed from buried terraces and deposits in the lower Sagami Plain

level. To estimate the lowest value, the terrace profile was extrapolated to the edge of the continental shelf (-34 m; see Fig. 5.4c). Then the tectonic component (5.6 m) was subtracted (the result : c.-40 m).

In the same way, the uplifted heights, 4.6 m, 3.5 m and 1.4 m, were subtracted from observed heights that correspond to the peaks of MISs 4, 3 and 2. These results are between -95 m and -109 m for the MIS 4 (65 ka); between -79 m and -90 m for the MIS 3 (50 ka); and between -101 m and -111 m for the MIS 2 (20 ka), respectively (Table 6.1).

Figure 6.5 is a reconstructed sea-level change during the Last Glacial Cycle derived from buried landforms in the lower Sagami Plain. Attention must be paid so that the result of each sea level has a range because they came from mainly fluvial terraces, and time controls were given mainly by tephrochronology. The results suggest an extensive sea-level drop during the MIS 4, and sustained low sea level for the MIS 3.

6.4 Comparison with the previous results

1) Comparison with isotopic results

Table 6.2 shows estimated sea levels of this study and previous ones. The sea levels indicated by the oxygen isotope study by Shackleton (1987, Fig. 2.1) is comparable with the results from the Sagami Plain in each peak. The recent results derived from coral reefs (*e. g.*, Bard *et al.*, 1990b and Chappell *et al.*, 1994) also support this isotopic result.

The estimated sea level at the peak of the MIS 5a (-40 to -31 m) is slightly lower than that of Shackleton (1987), which is -25 m.

The estimated sea level for the minimum peak of MIS 4 (-109 to -95 m) is 15 to 29 m lower than that of Shackleton (1987). However, the difference of sea levels between the MISs 5a and 4 is about 60 m. It is almost the same as that of Shackleton (1987). It is clear that a significant sea-level drop

Table 6.2 Comparison of estimated sea levels with previous works shown in Table 2.1.

researcher	MIS 5e	5c	5a	4	3	2	material
this study			−31 /−40	−95 /−109	−79 /−90	−101 /−111	Sagami R. terrace
Broecker *et al.*, 1968	+6*	−13	−13				Barbados corals
Shackleton & Opdyke, 1973				−80		−120	Pacific ^{18}O
Bloom *et al.*, 1974	+6*	−15	−13		−28 to −41		New Guinea corals
Konishi *et al.*, 1974	+6*	−10**	−15**		−20 to −40**		Kikai corals
Fairbanks & Matthews, 1978	+5	−43	−45				Barbados corals
Aharon & Chappell, 1986		−12	−19		−28 to −44		New Guinea corals/shells
Shackleton 1987	+5	−20	−25	−80	−50 to −90	−125	Pacific ^{18}O
Bard *et al.*, 1990b				<−70	<−80		Barbados corals
Chappell *et al.*, 1994					−38 to −91		New Guinea corals

*assumed value
**shown in Figure

seems to have occurred in the MIS 4.

The estimated sea-level peak in the MIS 3 (-90 to -79 m) is lower than the peak in the MIS 3 of Shackleton (1987), that is -50 m. The estimated paleo sea-level minimum of -111 to -101 m in the MIS 2 is some 10-20 m higher than that of Shackleton (1987).

The systematically lower estimated sea levels in the peaks of the MISs 5a, 4 and 3 may suggest subsidence around the present river mouth, rather than uplift, but the estimated sea level in the peak of the MIS 2 is excluded.

Nakada *et al.* (1991) showed about a 30 m spatial difference of the predicted maximum sea-level drop at 18 ka, based on the geometric effect in the

Japanese islands and mantle viscosity models. According to their results, relative sea level at 18 ka was around -110 to -100 m along the Sagami Bay coast. The result of this study agrees with this at least in the MIS 2.

Considering the uncertainty involved in the estimation of tectonic component, the buried terraces in the lower Sagami Plain generally support the sea-level history derived from oxygen isotope records.

2) Some problems concerning the MISs 4 and 3

The buried terraces in the lower Sagami Plain suggest a low sea level in the MIS 4, which is nearly the same as that of the MIS 2. The result suggest the extensive advance of continental ice sheet during the MIS 4. However, the scale of ice is highly controversial in the present situation.

In a regional scale, the low sea level during the MIS 4 may have caused the blockage of the Japan Sea as same as in the MIS 2. This condition affects the paleoenvironments in Japan such as winter precipitation, glacial advance in Japan Alps and the vegetation.

The buried terraces in the lower Sagami Plain suggest a low sea level sustained for relatively long period in the MIS 3. The buried terraces in the Paleo-Tokyo River basin also support this result. This result suggest the survival of ice in North America during the MIS 3.

However, it has been argued that the decay of ice sheet occurred in the MIS 3 in North America. Though one or two periods of interstadial warmth appear to have taken place in north America during the MIS 3 (Dawson, 1992), inferred global ice volume changes remain uncertain.

Some warm periods suggested in the MIS 3 have uncertainties of age dating. The author hesitates to give ages older than 40,000 yBP by the ^{14}C method for materials that possively correspond to the MIS 5a and 5c. It is necessary to solve the problems with various independent data on paleoenvironments.

Table 6.3 Estimated age and duration of each stage/substage (Martinson *et al.*, 1987)

stage/substage	from	to	duration
Event 5.5(5e)	129,700	122,560	7,140
Event 5.4(5d)	122,190	110,790	11,400
Event 5.3(5c)	107,550	96,210	11,340
Event 5.2(5b)	94,060	90,950	3,110
Event 5.1(5a)	90,100	79,250	10,850
Event 4	73,250	58,960	14,300
Event 3	58,930	24,110	34,820
(3.3)	(58,930)	(50,210)	(8,720)
(3.1)	(48,900)	(25,420)	(23,480)
Event 2	23,930	12,050	11,880

According to Shackleton (1987), the MIS 3 is relatively long in duration with a wide range in sea levels. Martinson *et al.* (1987) presented a precise chronology on stacked oxygen isotope records of deep sea cores using 'orbital tuning'. According to their result, the MIS 5e lasted only 7.1 ky; 5d, 5c and 5a lasted about 10 ky; the MIS 5b lasted only 3 ky; and the MISs 4 and 2 lasted 14 and 12 ky respectively. The culminating period in each stage should be shorter. Instead the MIS 3 lasted much longer, nearly 35 ky, and was subdivided into the MISs 3.1 to 3.3 (Table 6.3).

Since the duration of the MIS 3 is much longer than those of other stages, there still remain unexplained problems. For instance, the range of sea levels (or ice volume) during this stage. Greenland ice core records suggest an unstable climate during the MIS 3 with 20 interstades (Dansgaard *et al.*, 1993).

Emerged coral reefs show some periods of relative high sea-level stand in the MIS 3 (*e. g.*, Bloom *et al.*, 1974; Aharon and Chappell, 1986). However, Chappell *et al.* (1994) revised the sea levels at between 70 and 30 ka. They demonstrated relatively high sea-level periods at 60 ka, 52 ka and 46 ka (by U-series dating) with estimated sea levels -69 to -60 m, -52 to -42 m and -53 to -38 m. These new results overlapped the isotopic results of Shackleton (1987).

The buried terraces in the lower Sagami Plain fail to show such instability of sea levels of the MIS 3, but, small fluctuation may be suggested by the emergence of fluvial N and T-1 terraces within the stage. Though compared with coral growth or ice core records, it is not easy to recognize short duration events from borehole logs, this study offers independent data of sea-level changes to examine the above problems.

6.5 Landform reconstruction during the MIS 5a to 1

Figure 6.6 tentatively shows reconstructed landforms of the lower Sagami Plain for the MIS 5a to 1.

The MIS 5a : A fan-deltaic plain was formed along the present Sagami River. The fan is composed of some 20 m thick gravel in Chigasaki. The plain has a gentle gradient, and is well developed. The width of the plain was large, at least 5 km near Chigasaki.

The MIS 4 : A deep (relative height of about 55 m from the MIS 5a terrace surface near the present river mouth) and narrow valley was formed under the present Sagami River. The width of this valley bottom was about 2 km at the present river mouth. The S3 surface emerged to form a wide terrace in the left bank. Hk-TPfl (pumice flow) flowed into the valley and remained on the higher terraces.

The MIS 3 : An extensive fan plain developed in the right bank, from Atsugi to Hiratsuka. Its surface might have been enlarging for a relatively long period. It was a plain of compound fans of the Sagami, Nakatsu and other rivers. Sand and gravel filled up the deep valley formed during the MIS 4. However, a narrow outlet might have remained at the coast. The width was restricted by S3 and S4 terraces on both sides. The base level

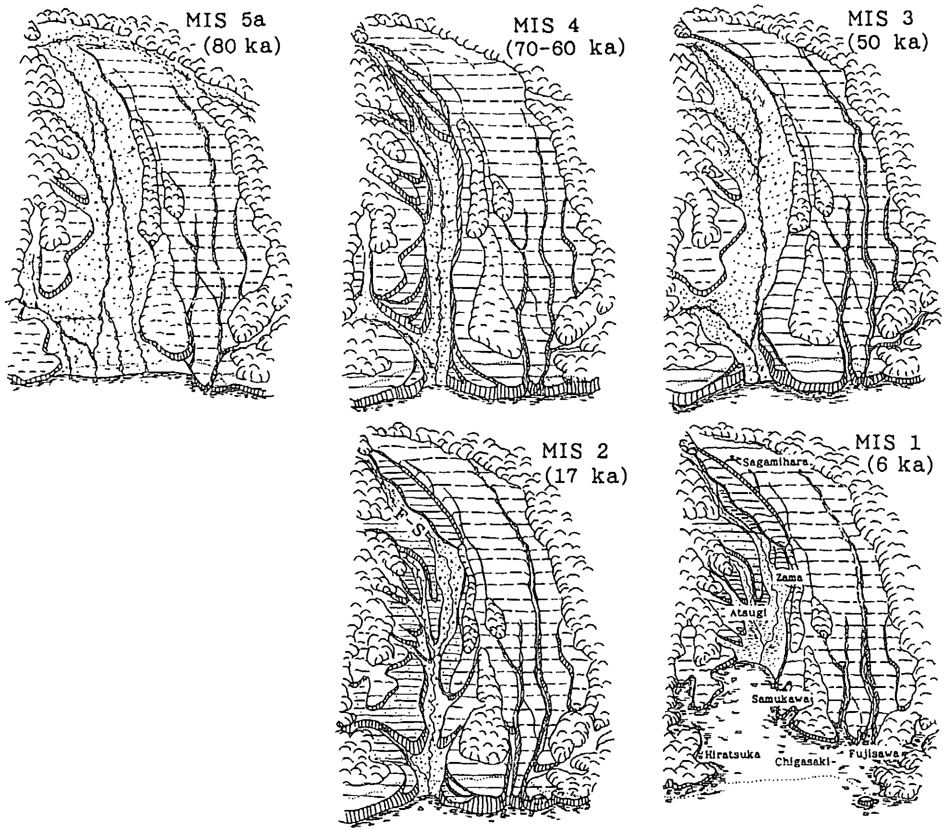

Fig. 6.6 Paleo-landforms in the lower Sagami Plain in the Last Glacial Cycle

was sustained until the Tanahara-1 stage.

The MIS 2 : A flight of terraces (Minahara terraces) was formed in Sagamihara, while a valley indicated by BG (Basal Gravel of the Recent deposits) was formed in the lower Sagami Plain due to the low stand of sea level. This valley bottom was narrow, about 1.5 km wide at the present river mouth.

The MIS 1 : The figure demonstrates the landforms at the culmination of the Holocene transgression. The Inner Sagami Bay was formed due to the transgression. This is the only period that the Sagami Bay penetrated into the lower Sagami Plain since the MIS 5e.

7. Concluding Remarks

The author focused on the buried landforms and deposits in south Kanto and discussed the changes of sea level and landforms during the MISs 5a to 2.

She investigated the buried terraces particularly in the lower Sagami Plain. The lower Sagami Plain was the most suitable area to distinguish and identify each buried terrace corresponding to the MISs 5a to 2. The reasons are : 1) As there is no distinct continental shelf at the river mouth, sea-level changes, when they occur, must directly affect the river regime, and form a flight of terraces. 2) This area is totally covered by Late Quaternary tephra layers which were supplied from Fuji, Hakone and other volcanoes to the west, and provide significant time markers for terrace sequencing. Also, air-laid tephra is useful for the recognition of the emergence of each terrace and consequently for their identification.

The main results are as follows.

1) The author identified buried terraces corresponding to the subaerial Sagamihara (S3-5), Nakatsuhara, Tanahara and Minahara terraces in the

lower Sagami Plain. Each buried terrace is correlated with a subaerial terrace on the basis of the continuity of terrace deposits and the thickness of tephras covering the terrace surface.

2) The Sagamihara-3 (S3) terrace corresponds to the MIS 5a (80 ka), because the equivalent tephra sequence covers the marine Misaki Terrace in Miura peninsula, which was assigned to the MIS 5a. The base of Nakatsuhara terrace deposit coincides with the MIS 4 (70-60 ka). It is supported by pollen and tephra stratigraphy. The Nakatsuhara terrace (c.50 ka) and Tanahara terrace (c.25 ka) correspond to the MIS 3. Their ages are estimated by the accumulation rate of 'loam'. Both the Minahara terrace and the base of the Recent deposits in the lower reaches correspond to the MIS 2, because they show the lowest sea-level stand.

3) The heights of buried terraces and/or deposits near the present river mouth are as follows. The buried S3 terrace deposits (MIS 5a) occur -25 m a.s.l. at the lowermost part, 2.5 km upstream from the present river mouth. The sea level at that time must have been lower than that because the deposits are of fluvial origin. The non-cyclic S4 and S5 terraces, occuring in deep levels and being fragmentary, suggest sea-level fall during the transition of MISs 5a/4.

The deposits of the buried Nakatsuhara Terrace near the present river mouth is composed of relatively thick sand and gravel. It is possible to assign the base of this terrace to the MIS 4. The base of the Nakatsuhara deposits can be seen -90 m a.s.l. near the present river mouth. There was a deep valley in this stage, likely in the MIS 2.

The Nakatsuhara terrace surface, corresponding to the MIS 3, occurs in a broad area. Its surface exists -75 m a.s.l. near the present river mouth. Tanahara-1 terrace seems to converge with the Nakatsuhara terrace in the lowermost part. This terrace was also formed in the latest period of MIS 3.

The stagnation of sea level during the MIS 3 may have caused the formation of the broad terrace.

The Minahara terrace deposits can be traced to the Basal Gravel of the Recent deposits (BG), and they are correlated with the MIS 2. The bottom of BG can be seen c.-100 m a.s.l. near the present river mouth. The distribution of BG suggests the existence of a deep and narrow valley.

4) The correlation of buried terraces in the lower Sagami Plain yields the revision of those in the Paleo-Tokyo River basin. The occurence of buried Tachikawa-1 terrace is dominant in the Paleo-Tokyo River basin, and it also supports the stagnation of sea level in the MIS 3.

5) As the observed sea levels include glacio-eustatic and tectonic components, evaluation of a tectonic factor would be indispensable for obtaining a relative sea-level curve.

The author estimates the average uplift rate, 0.07 m/ky near the present Sagami River mouth, from an extrapolation of the heights of Koza Upland deposits (the MIS 5e surface), which is tilting towards the northwest. As a result, the estimated sea levels corresponding to each culmination are : <-31 m in the MIS 5a, <-95 m in the MIS 4, <-79 m in the MIS 3, and <-101 m in the MIS 2, respectively. The relatively low sea level was sustained throughout the MIS 3.

These results suggest the extensive sea-level drop in the MIS 4, and the relatively low stagnated sea level during the MIS 3. Although they are independent from oxygen isotopic records, they are generally in accordance with the sea-level curve shown by isotopic records of Shackleton (1987). However, there is more to debate on sea level or ice volume in the MIS 3 when compared with other data.

6) The reconstructed changes of landform in the lower Sagami Plain are as follows. A broad fan-deltaic plain was formed during the MIS 5a. A deep

valley was formed during the MIS 4 due to the sea-level drop. This deep valley was filled, and relatively wide compound fans were formed during the MIS 3. A deep valley was formed again in the MIS 2.

The coastline was located around the present river mouth during the MISs 5a to 2. The transgression of Sagami Bay has occured only in the MISs 5e and 1.

7) The buried terraces in the lower Sagami Plain provided much information on changes of sea levels and landforms during the Last Glacial Cycle. This study will improve the chronostratigraphy of the Late Quaternary sequence in Japan. Results of this study also show land-based chronology of sea-level changes. The data may be used to evaluate the validity of the "orbitally tuned" chronology of marine and/or ice cores.

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【要　旨】

相模川下流平野の埋没段丘により示される酸素同位体ステージ4-2の海水準変化と平野の地形変化

久保　純子

本研究は，酸素同位体ステージ4から2までの期間の環境変化，とくに海水準変化と平野の地形変化過程を明らかにすることを目的とする．従来この期間の環境変化は深海底コアや氷床コアの酸素同位体比により示されてきたが，陸上の堆積物や地形による証拠は少なかった．この目的のため，筆者は相模川下流部の平野の地下に埋没した段丘地形に着目した．現海岸に近いところの埋没段丘は，現在より低い海水準に対応して形成され，それらの地形や堆積物が保存されているため，地盤変動量が既知の場合，過去の海水準の指示者として利用できる．

相模川下流平野は最新氷期サイクルにおける埋没段丘の研究を行なうのに適した条件を備えている．相模川の河口沖は大陸棚を欠き，急勾配で相模トラフへと水深を増すため，海水準変化が相模川河床の侵食・堆積を速やかにひきおこし，段丘や谷が形成される．さらに，噴出年代が知られている富士火山や箱根火山などのテフラが段丘上に厚く堆積しているため，埋没段丘の識別と，それらの陸上の段丘との対比が可能である．

相模川下流平野における埋没段丘の認定・区分はボーリングデータの解析により行なった．埋没段丘と陸上部の段丘面との対比には，段丘地形の分布や縦断方向における連続性と，テフラを用いた．

南関東地域のテフラ層序と主要な指標テフラの年代値（放射年代値および「ローム」の堆積速度による推定）をもとに，相模野地域の編年の枠組みを設定した．相模川下流平野には何段もの段丘が発達する．それらは相模原段丘群

(S1-S5)，中津原段丘（N)，田名原段丘群（T-1，T-2)，陽原段丘群（M）に区分される．これらの段丘や堆積物は，その地形地質的特性に加えて，海域と陸域を結ぶ主要テフラ，花粉層序および各地の層序との関係などにより編年が行なわれてきた．相模野地域の段丘とテフラ層序と，酸素同位体ステージ（MIS）の対比の結果，これらの段丘および堆積物はそれぞれ，S1-S3 段丘 : MIS 5c-5a（100-80 ka)，N および T-1 段丘 : MIS 3（60-25 ka)，M段丘 : MIS 2（17-14 ka）に対比される．

ボーリングデータの解析による埋没段丘の検出と，それらの陸上の段丘との対比の結果，相模川下流部の埋没段丘は S3-5，N，T-1および M に対比される．また，相模川下流の埋没段丘と古東京川水系の埋没段丘とを対比した結果，最も広く分布する立川 1 段丘（Tc1）と相模川下流の中津原段丘(MIS 3）が対比された．

埋没段丘の情報をもとに，現河口付近での地殻運動による変形を差し引いて，海水準変化の考察を行なった．現在の相模川河口部における平均地盤隆起速度は，高座台地（MIS 5e）の傾動を河口方向に外挿して 0.07 m/ky と見積もった．平野の最下流部において推定された各時期の海水準（括弧内は現在の上限高度と下限高度）は，MIS 5a : -31～-40 m（-25～-34 m)，MIS 4 : -95～-109 m（-90～-104 m)，MIS 3 : -79～-90 m（-75～-86 m)，MIS 2 : -101～-111 m（-100～-110 m）となった．MIS 3 の時期には，相対的に低い海水準が持続した．以上の成果は酸素同位体ステージの 4 および 3 の時期の低海水準を示し，それらは酸素同位体による結果ともおおむね一致した．

相模川下流部における MIS 5a から 1 までの地形変化は以下のように復元された．MIS 5a には広い臨海扇状地が形成されたが，MIS 4 には海水準の低下により深い谷が形成された．この谷は次の MIS 3 の期間に埋積され，複合扇状地平野が形成された．このことは MIS 3 の海水準が相対的に長い間一定のレベルにあったことを示す．MIS 2 には再び下刻に転じ，MIS 4 の時期と同様の谷が再び形成された．相模湾が内陸まで進入した時期は，最終間氷期（MIS 5e）を除くと MIS 1（完新世）のみである．

以上のように，相模川下流平野の埋没段丘は最新氷河サイクルにおける古環境データ，特に従来不明な部分が多かったMIS 4から2の時期の海水準や，当時の平野下流部の地形について多くのデータを提供した．とくに，MIS 4の海水準がMIS 2に匹敵すること，MIS 3の時期に海水準が相対的に低いまま持続したことが提示された．これらの成果は，氷床規模の見積もりをはじめ，最新氷期サイクルにおける古環境復元のさいに重要であり，日本列島の古環境を考察するうえでも，日本海の閉塞などの問題と関連し，今後追試されるべきものといえる．

付記：本論文は1995年に東京都立大学へ提出した学位請求論文の全文であるが，『人間・自然論叢』ページ数制約のため以下の通り4分割したことをお断りする．

Part Ⅰ 第6号（1997年7月）

Part Ⅱ 第7号（1997年12月）

Part Ⅲ 第8号（1998年7月）

Part Ⅳ 本号

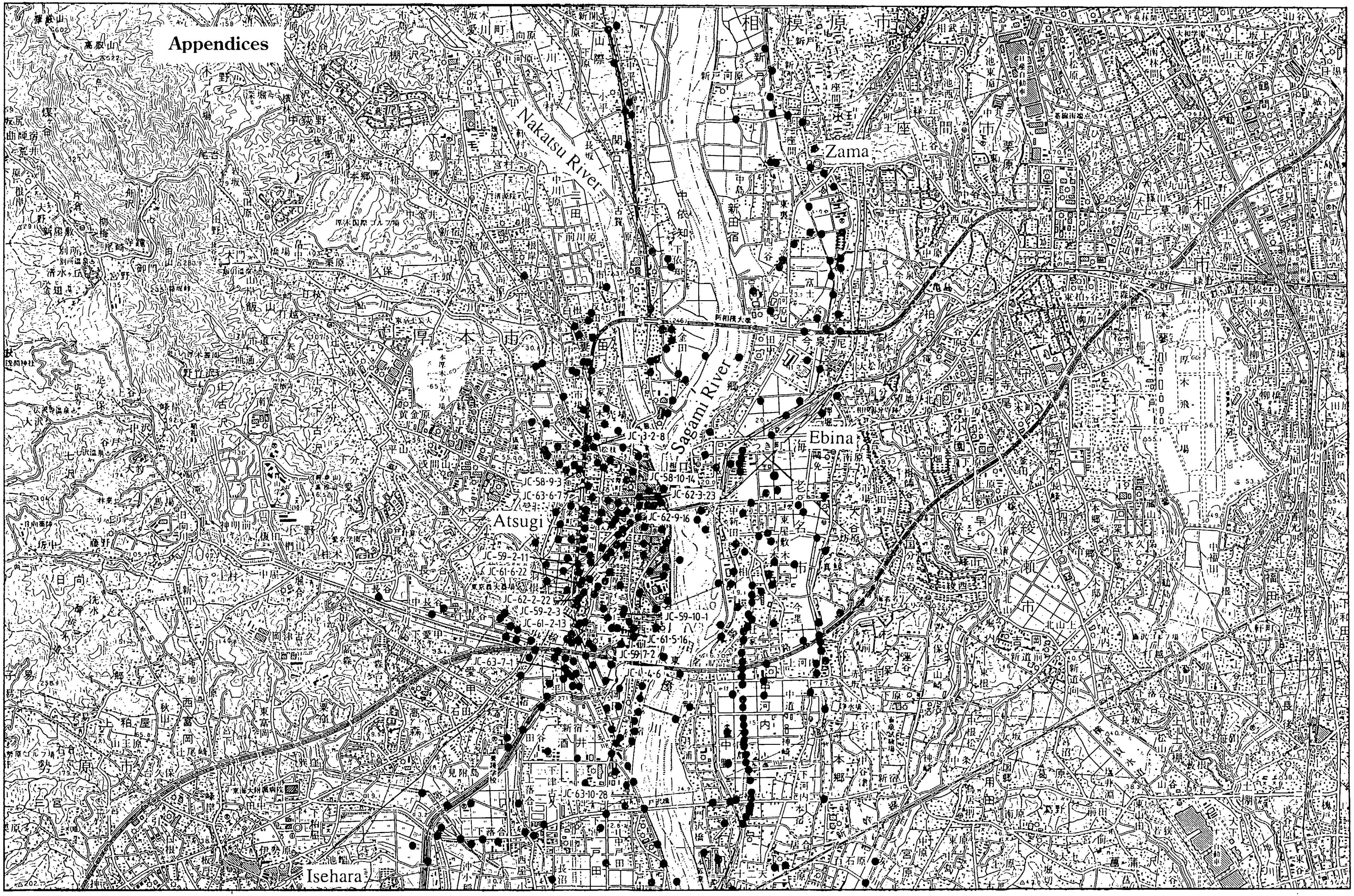

Fig. A-1a Distribution of collected borehole logs in the lower Sagami Plain(north).

Base map : GSI Topographic Map "Fujisawa" (S=1/50,000×0.8)

Fig. A-1b Distribution of collected borehole logs in the lower Sagami Plain (south).

Base map : GSI Topographic Map "Fujisawa" and "Hiratsuka" (S=1/50,000×0.8)

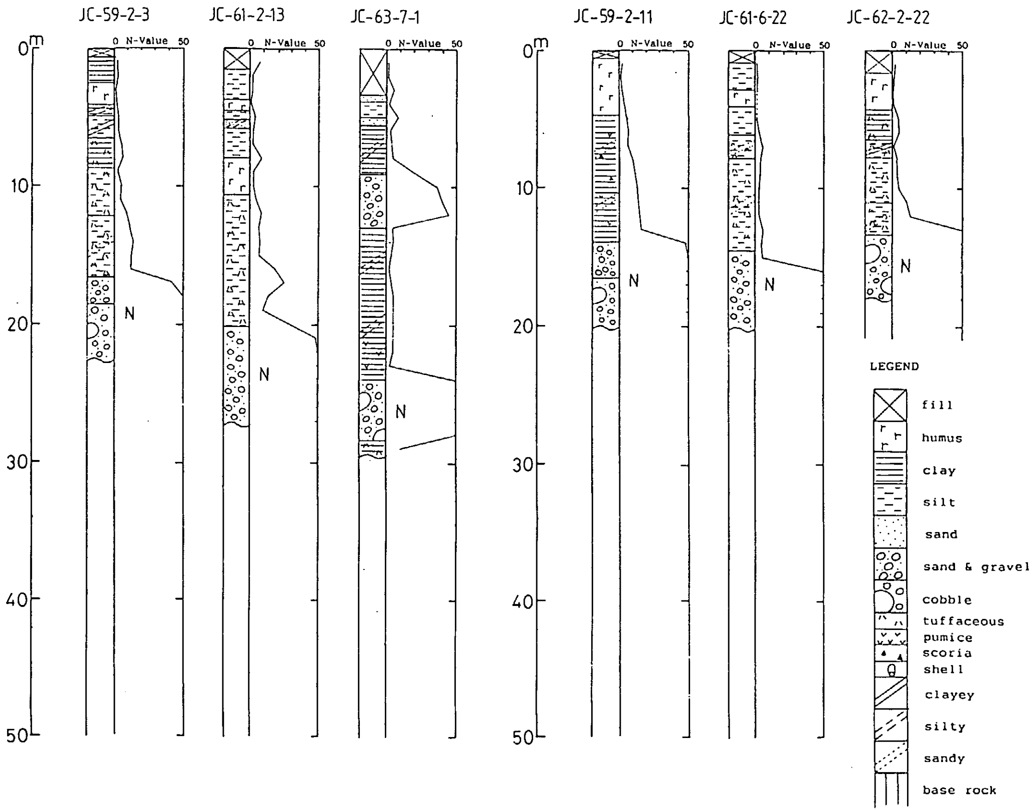

Fig. A-2a Representative borehole logs of buried terraces in the lower Sagami Plain (near Atsugi)
Localities are shown in Fig. A-1a. N : Nakatsuhara terrace deposits

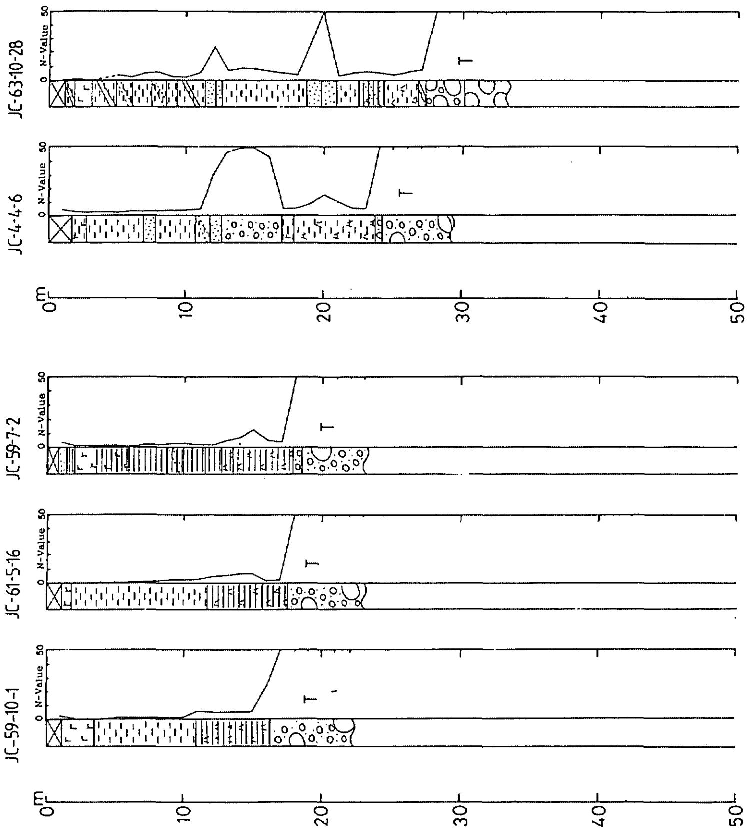

Fig. A-2a (cont.)   T : Tanahara terrace deposits

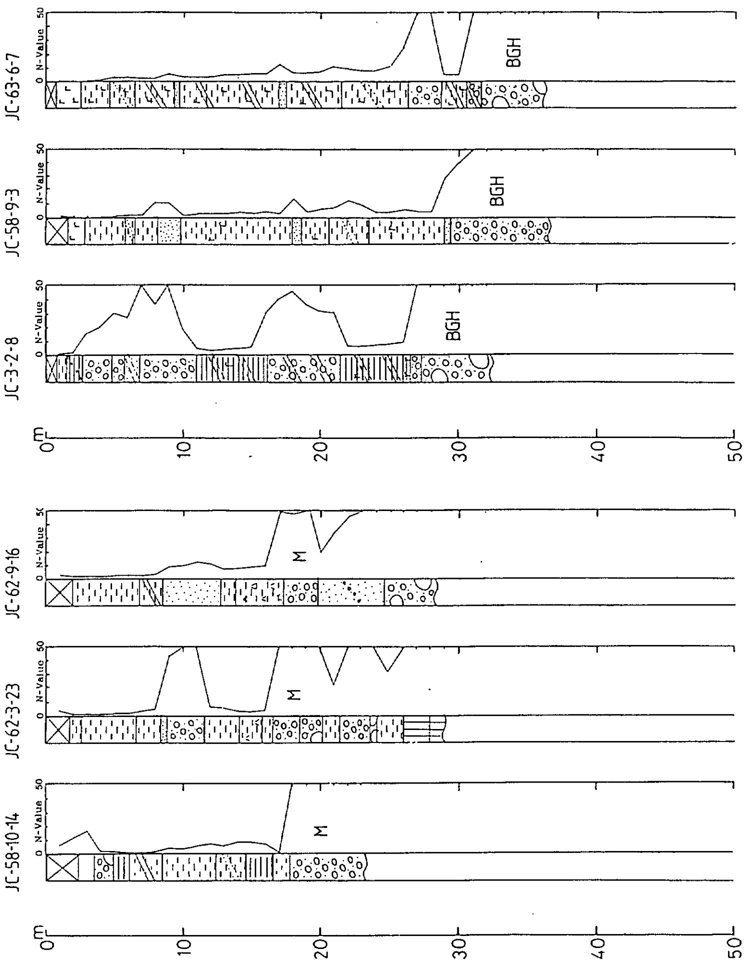

Fig. A-2a (cont.) M : Minahara terrace deposits, BGH : Basal Gravel of the Recent deposits in the upper reaches

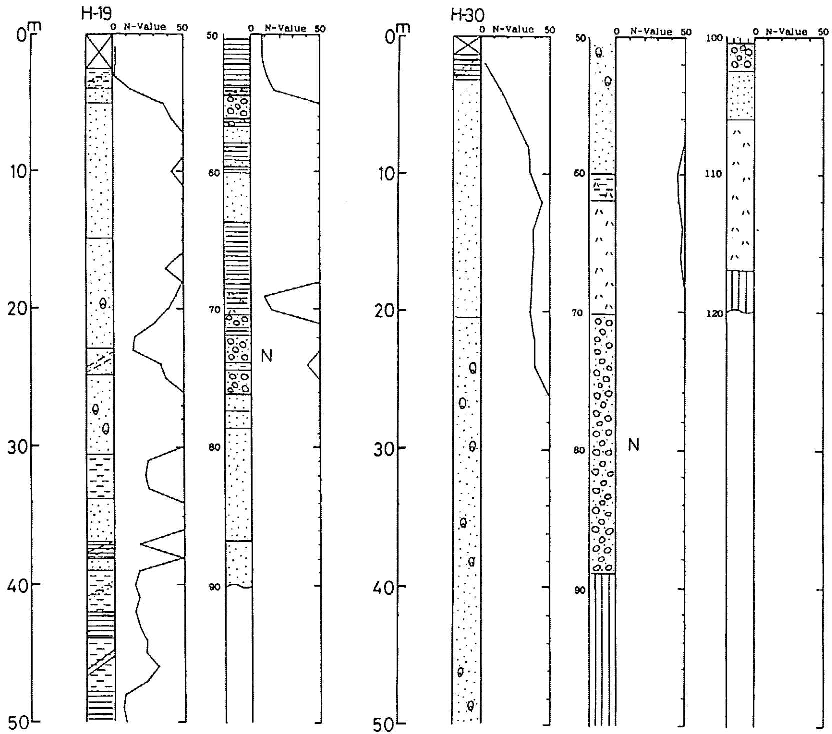

Fig. A-2b Representative borehole logs of buried terraces in the lower Sagami Plain (near Hiratsuka and Chigasaki)

Localities are shown in Fig. A-1b N : Nakatsuhara terrace deposits

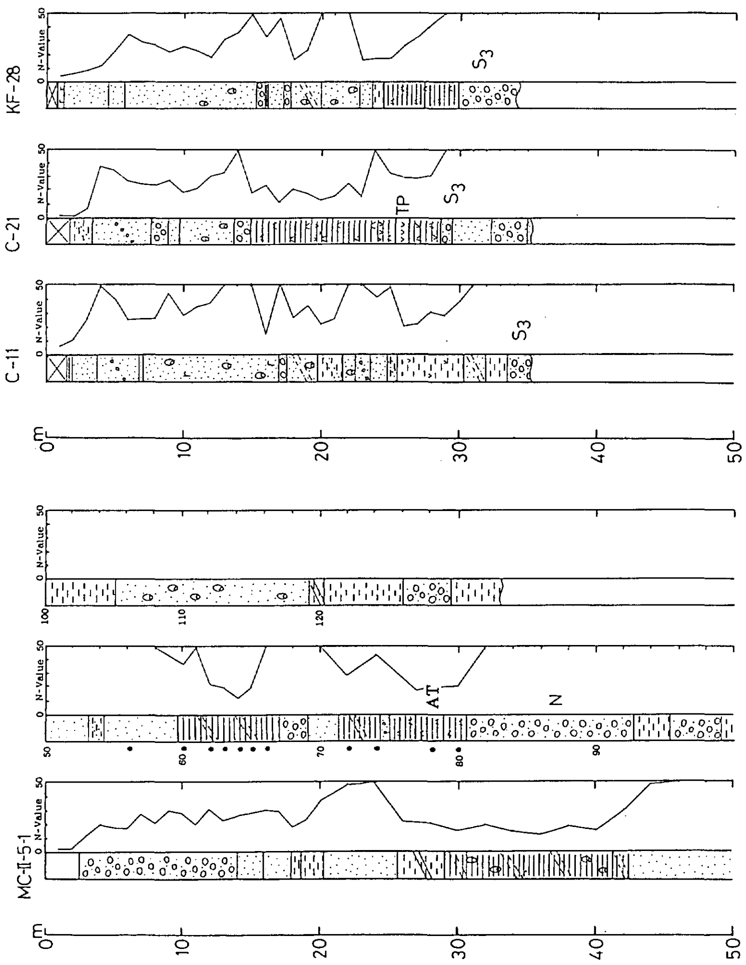

Fig. A-2b (cont.)

S_{3-5} : buried terrace deposits

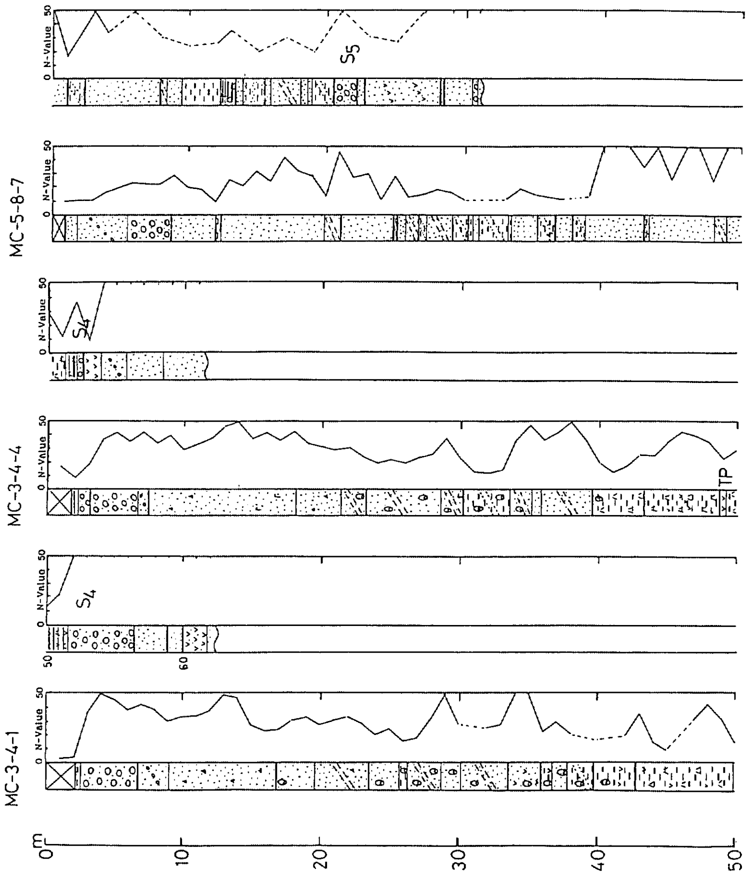

Fig. A-2b (cont.)

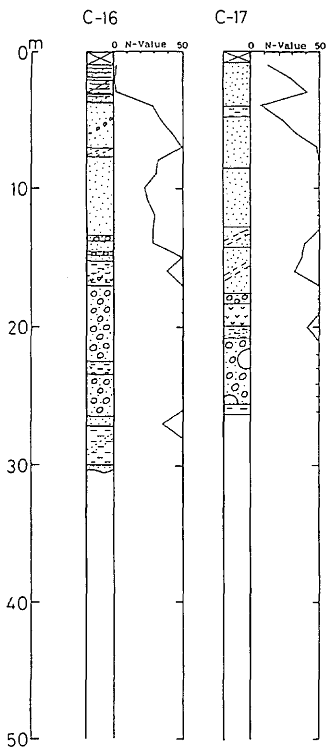

Fig. A-2c Representative borehole logs in the 'Tsujido Buried wave Cut Platform'
Localities are shown in Fig. A-1

*** Original Data Sheet ***

94/12/20
23:17:34

Series Name : sagami (Kubo)
Sample Name : 2-5-1-10 (-78m)
Analist : Y.Yoshida
Material : glass
Immersion Oil: No.3.8 (Nd=1.51907-0.000393·t)

(Ascent+Descent)/2

1.5010	1.5009	1.5008	1.5006	1.5003	1.5001	1.4999	1.4996	1.5014	1.5013
1.5011	1.5010	1.5008	1.5007	1.5004	1.5003	1.5017	1.5017	1.5013	1.5012
1.5010	1.5008	1.5006	1.5003	1.4995	1.4997	1.4998	1.4999	1.5001	1.5003
1.5007	1.5008	1.5019	1.5018	1.5018	1.5017	1.5015	1.5014	1.5011	1.5011

		count	min.	max.	range	mean	st.dev.	skew.
Total	:	40	1.4995	1.5019	0.0024	1.5008	0.0007	-0.1697

*** Histogram *** * = 1

```
                          0         10        20        30        40        50        60
--------------------------+---------+---------+---------+---------+---------+---------+
 1.490 =<Nd< 1.491       0|
 1.491 =<Nd< 1.492       0|
 1.492 =<Nd< 1.493       0|
 1.493 =<Nd< 1.494       0|
 1.494 =<Nd< 1.495       0|
 1.495 =<Nd< 1.496       0|
 1.496 =<Nd< 1.497       0|
 1.497 =<Nd< 1.498       0|
 1.498 =<Nd< 1.499       0|
 1.499 =<Nd< 1.500       6|******
 1.500 =<Nd< 1.501      16|****************
 1.501 =<Nd< 1.502      18|******************
 1.502 =<Nd< 1.503       0|
 1.503 =<Nd< 1.504       0|
 1.504 =<Nd< 1.505       0|
 1.505 =<Nd< 1.506       0|
 1.506 =<Nd< 1.507       0|
 1.507 =<Nd< 1.508       0|
 1.508 =<Nd< 1.509       0|
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 1.513 =<Nd< 1.514       0|
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 1.526 =<Nd< 1.527       0|
 1.527 =<Nd< 1.528       0|
 1.528 =<Nd< 1.529       0|
 1.529 =<Nd< 1.530       0|
--------------------------+---------+---------+---------+---------+---------+---------+
```

Fig. A-3 Refractive indices of volcanic glass in sample No.10 (-78 m) of MC-II-5-1 core