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# Middle Miocene to Pliocene sedimentary basin analysis of vertical movements in Hokkaido, Japan

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## ABSTRACT

*Neogene Tertiary sequences are widely represented in the Japanese Islands. Sediments of Neogene Tertiary are particularly well represented in Hokkaido, the northernmost part of Japanese Islands. Detailed Neogene Tertiary stratigraphy provides regional context for correlation with Tertiary in the Honshu, the main land of Japan, and the Sakhalin and Kamtschatka regions of Russia. Paleo-sea level was reconstructed, based on four sedimentary facies, for 27 of 31 basins studied. Unconformities indicate exposure of land surface during regression, whereas the facies of conglomerate, sandstone, siltstone, and mudstone represent sedimentation under changing sea levels during transgression. 31 basins studied represent nine types of vertical movements. Subsidence rates for the late Miocene, early early Pliocene and late early Pliocene show a tendency to become faster as geologic ages become younger.*

*Keywords: Neogene, basin analysis, vertical movement, Hokkaido*

## RESUMEN

*Las secuencias del Terciario Neógeno se encuentran ampliamente representadas en las Islas Japonesas. Los sedimentos del Terciario Neógeno se encuentran particularmente bien representados en Hokkaido, la parte más septentrional de las Islas Japonesas. La estratigrafía detallada del Terciario Neógeno proporciona un contexto regional para establecer una correlación con el Terciario en Hanshu, la región principal de Japón y las regiones Sakhalin y Kamtschatka de Rusia. Sobre la base de cuatro facies sedimentarias, se reconstruye el nivel paleo-marino para 27 de las 31 cuencas estudiadas. Las discontinuidades indican exposición de superficie terrestre durante la regresión, mientras que las facies de conglomerados, areniscas, lutitas, y lodolitas representan sedimentación bajo condiciones cambiantes del nivel marino durante la trasgresión. Las 32 regiones estudiadas representan 9 tipos de movimientos verticales. Las tasas de subsidencia para el Mioceno tardío, inicios del Plioceno temprano, y finales del Plioceno temprano muestran una tendencia a ser más rápidas a medida que disminuye la edad geológica.*

*Palabras clave: Neógeno, análisis de cuencas, movimientos verticales, Hokkaido.*

## INTRODUCTION

The Japanese Islands are located in eastern margin of the Asian continent, and have experienced considerable volcanic activities and crustal movements. The Neogene Tertiary is widely represented within the islands and in the circum-Pacific. The Neogene Tertiary on Hokkaido is much productive and the island is one of the type localities for the Neogene Tertiary. Neogene Tertiary stratigraphy in Japanese Islands, situated in middle latitudes, is necessary for correlation with stratigraphies in the low and high latitude areas of the circum-Pacific (Tanai, 1981). Both marine and continental sediments of Neogene Tertiary are widely distributed in Hokkaido, and detailed Neogene stratigraphy for Hokkaido is also necessary for the correlation with the Tertiary in the Honshu, Sakhalin and Kamtschatka regions.

Based on seismic stratigraphy, Vail *et al*. (1977) and Haq *et al.* (1987, 1988) presented the sea-level curves back to the Cryptozoic eons. It has been a critical research topic to establish the relationship between the fluctuations in global sea level and the development of sedimentary basins in Japan (Saito, 1983).

This paper provides information on the vertical movements in sedimentary basins during late Miocene to Pliocene based on detailed assessment and dating of the Neogene Tertiary stratigraphy.

## NEOGENE STRATIGRAPHY

Tanai (1977) discriminated six sedimentary provinces based on geologic characteristics (Figure 1):

(1) The Oshima Province is located to the west of the Ishikari Lowland and represents part of the green tuff region over the western Hokkaido. Since stratigraphic facies and scale of sedimentary basins are similar to those in the northern part of Honshu, the Oshima Province is regarded as its northern extent . In the western part of the province, west of Kuromatsunai Lowland, there are a number of small basins consisting dominantly of sedimentary rocks (mudstone, sandstone and conglomerate) with a few volcanic rocks (andesite and basalt). On the other hand, volcanic rocks are dominant only in the eastern half of southern Hokkaido.

(2) The Central Province extends west to the axial zone of Hokkaido and includes the Hidaka mountain range and is regarded as stratigraphically equivalent to the Sakhalin sequences. In each sedimentary basin, generally larger than basins in the Oshima Province, the Neogene Tertiary consists mainly of sandstones and mudstones, and becomes younger westwards.

(3) The Eastern Province extends east to the axial zone consisting mostly of mudstones which overlie Cretaceous or Paleogene basement rocks. Pyroclastic rock dominates in the northern part of the province, and fine clastic rock (mudstone) dominates in the southern part. Stratigraphy and facies of the province are similar to those of the central province.

(4) The North-Central depression extends from Nayoro to Kitamiesashi and represents part of the green tuff region over the eastern Hokkaido. The depression consists of neritic to continental sedimentary rocks, andesitic pyroclastic rock, sandstones and conglomerates, with lignite beds overlying Upper Cretaceous and pre-Cretaceous basement rocks.

(5) The Northeastern Province extends from Monbetsu to Nukabira, and represents part of the green tuff region. Neritic sedimentary rocks (sandstones and conglomerates), pyroclastic rocks and lacustrine sedimentary rocks are distributed over the pre-Cretaceous basement. That indicates an invasion of the paleo-sea from the north to this province and to the North-central depression (Tanai, 1977).

(6) The Shiretoko Province includes the Shiretoko Peninsula and the area including Teshikaga. The Neogene Tertiary units of this province consist of (a) green tuffs, (b) propyrite and mudstone with pyroclastic rocks, (c) tuff breccia, and (d) sandstone and conglomerate, in ascending order. The provinces are sub-divided into 31 sedimentary basins as shown in Figure 1: 10 in the Oshima Province; 8 in the Central Province; 7 in the Eastern Province; 2 in the North-Central Depression; 2 in the Northeastern Province; and 2 in the Shiretoko Province (Figure 1).

Detailed stratigraphy for each basin has been provided by diatom stratigraphy and radiometric ages (Sagayama, 2000).

## PALEO-SEA LEVEL

The third order of the sea-level curve by Haq *et al.* (1988) for the Neogene Tertiary shows stages of remarkably low sea levels at 10.5 Ma (-80m), 5.5 Ma (-50m), and 3.8 Ma (-30m) and of high sea-level stages before 10.5 Ma, and during 5.5 to 3.8 Ma.

The fluctuations of the sea level strongly influenced the formation of sedimentary facies. Four sedimentary facies observed in the geological sections from the above mentioned basins, conglomerate, sandstone, siltstone, and mudstone, in ascending order, seem to represent four paleo-sea levels (Figure 2). The basal boundary of formation corresponds to low sea-level stages in the paleo sea-level curve by Haq *et al.* (1988), and the sedimentary units within the formation correspond to the high stages.

Geologic evidences for low sea-level stages are distributed as follows: evidences for 10.5 Ma in Muroran, Western Sapporo, and Atsunai; for 5.5 Ma, in Haboro, Southern Kabato, Kumaishi-Esashi, Imagane, and Shiretoko; for 3.8 Ma, in Tenpoku coal field, Haboro, Tate, Taiki, and Shiretoko.

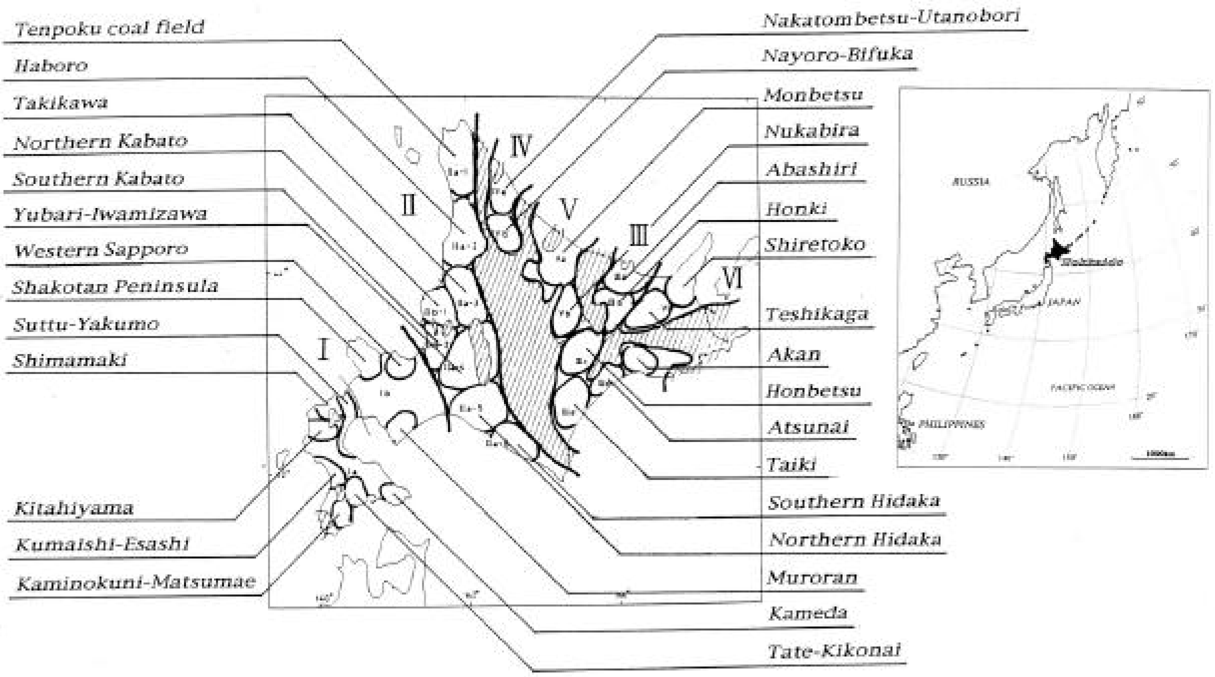


Figure 1. Six sedimentary provinces and thirty one sedimentary basins of Neogene Tertiary in Hokkaido (adapted from Tanai, 1977). I: Oshima province; II: Central province; III: Eastern province; IV: North-central depression; V: Northeastern province; VI: Shiretoko province.

## VERTICAL MOVEMENT OF SEDIMENTARY BASINS

Based on the stratigraphy and correlated sea level for the late Miocene to Pliocene represented in each sedimentary basin, this paper examines the vertical movement within 27 of the 31 basins (Geologic data in 4 basins are insufficient).

We infer that the basal unconformity and hiatus in the sedimentary sequences prove that surface of the basin was at higher level than sea surface when sedimentation occurred, while successive strata suggest sedimentation during transgression. Differences between the measured stratigraphy and the sea-level curve of Haq *et al.* (1988) are inferred due to the crustal movement in the studied region. Fluctuations in the sea level and correlated vertical movement of the basin surface can be classified into nine types (Figure3; Table 1): a) approximately stable (little change); b) constantly rising; c) Rise to radically fall around 6 Ma; d) radically rise around 5.5 Ma; e) gently falling after 5.5 Ma; f) Rise to radically fall around 4.5 Ma; g) Rise and then fall around 4.5 Ma; h) Rise around 4.5 Ma; and i) Rise around 4 Ma.

In the southwestern part of Hokkaido, including the Oshima Province, sedimentation in the areas facing to the Sea of Japan experienced movement of (g) type, while in the areas facing Funka-wan, movements of various types occurred. By contrast, in all the basins of the southeastern part of Hokkaido, sedimentation patterns throughout the region suggest a certain crustal movement all at once.

In Central Hokkaido, Southern Kabato experienced movement of (i) type, while northern Kabato experienced movement of (h) type indicating that Kabato mountain district had crustal movements at different times. The types of vertical movement seem to be distributed symmetrically: Takikawa, west of the axial zone, experienced movement of (b) type; Haboro and Yubari-Iwamizawa, located on either side of Takikawa, experienced the movement (a); and areas further outside, including the Tenpoku coal field and Hidaka, experienced the movement (g). This suggests that areas in both ends of the Central Province were uplifted after the central areas had been uplifted.

In the Eastern Province of Hokkaido, all of the basins, except the Taiki and Akan, are located along the Abashiri tectonic line which extends northwards to the reverse fault, in the west margin of the Kitami-Yamato bank, and reaches the Kushiro submarine canyon in its southern end. Yamamoto (1983) suggests that the Kitami-Yamato bank rose during the late Miocene to Pleistocene. Sakurai *et al.* (1974) demonstrates, on the other hand, that the submarine canyon was formed after the middle of the Neogene Tertiary and that a part of its southern end, around the Erimo cape and continental shelf off the Akkeshi, are now sinking or tilting. These

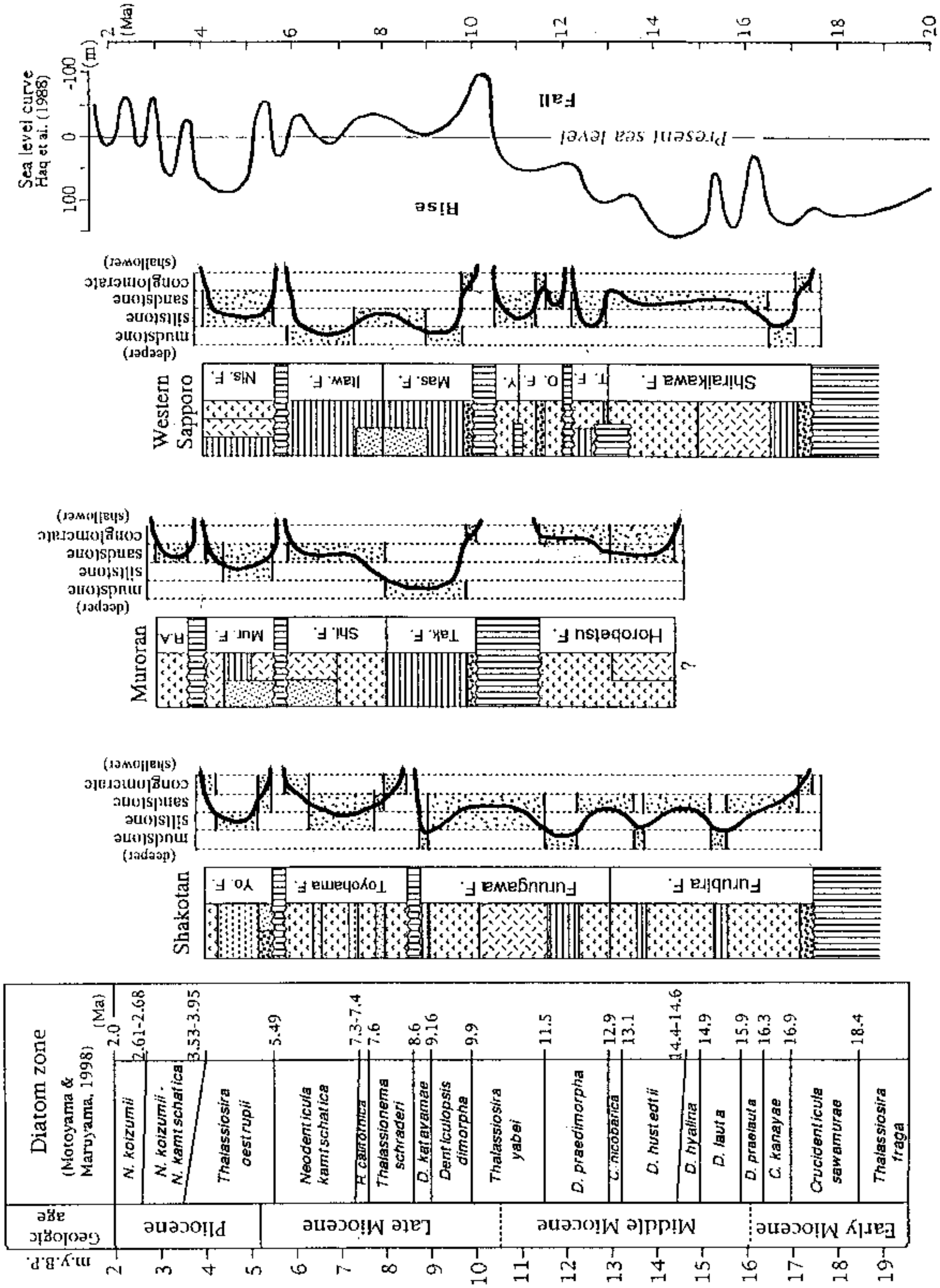


Figure 2a. Sea level curve of sedimentary basins.

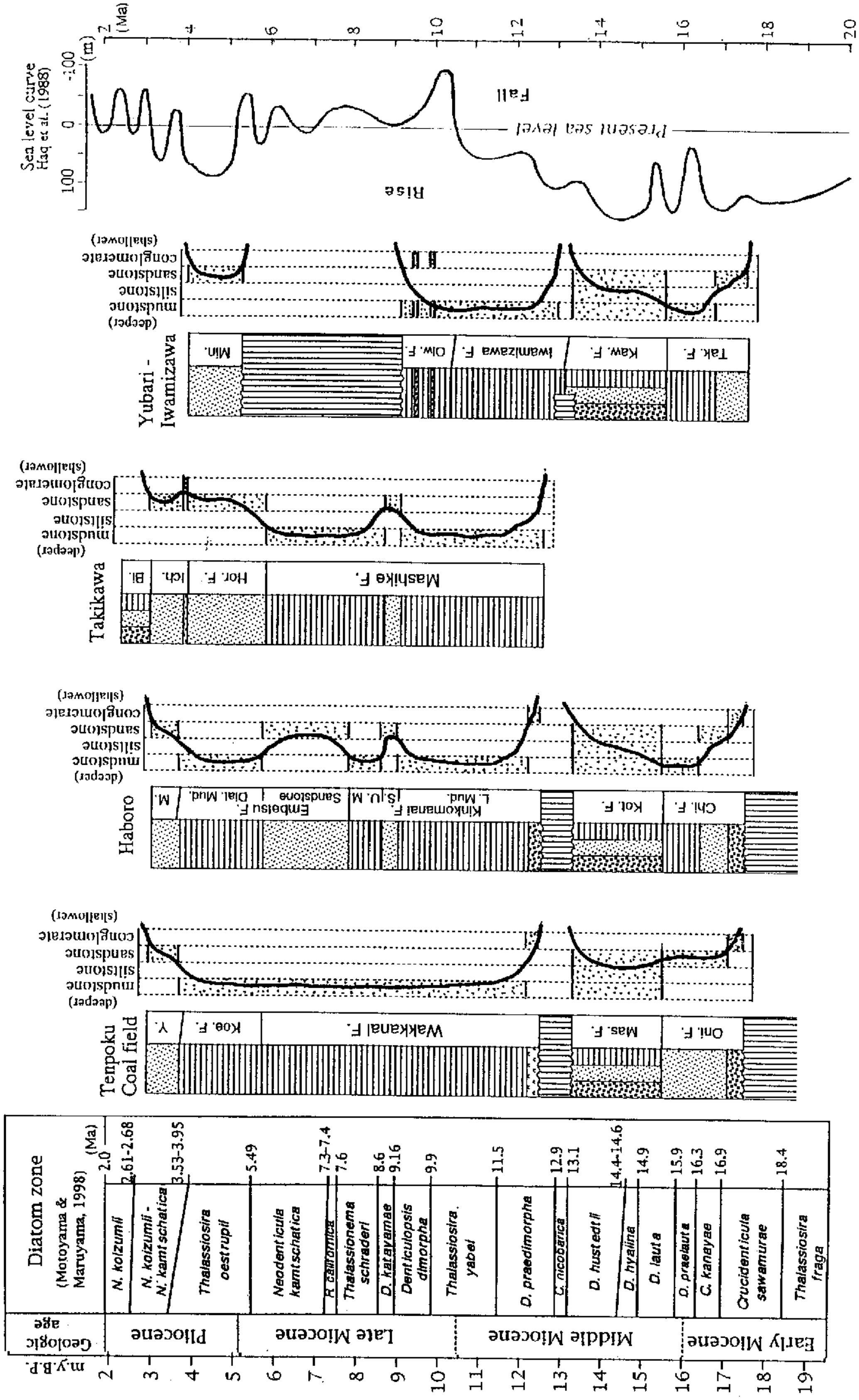
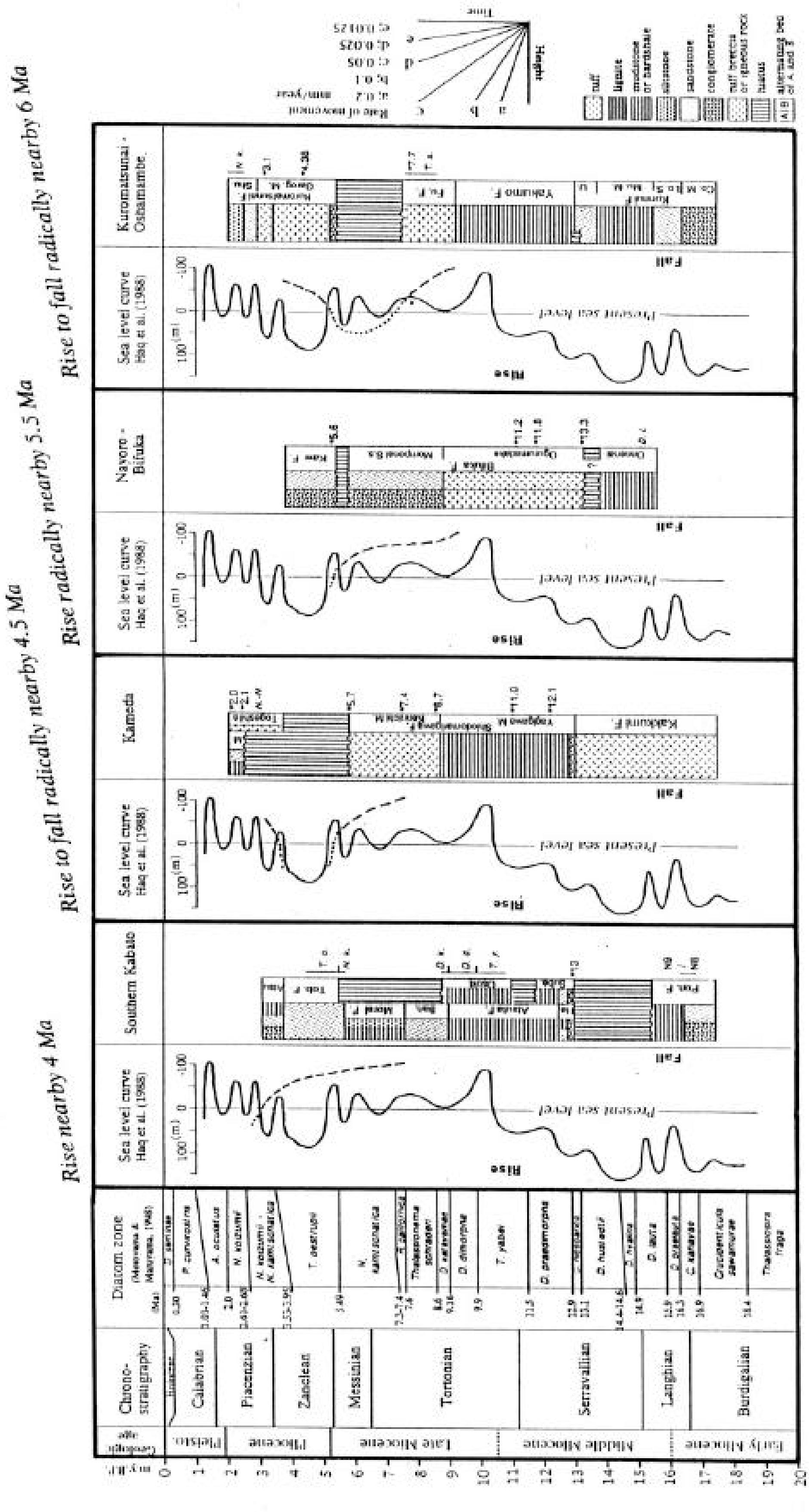
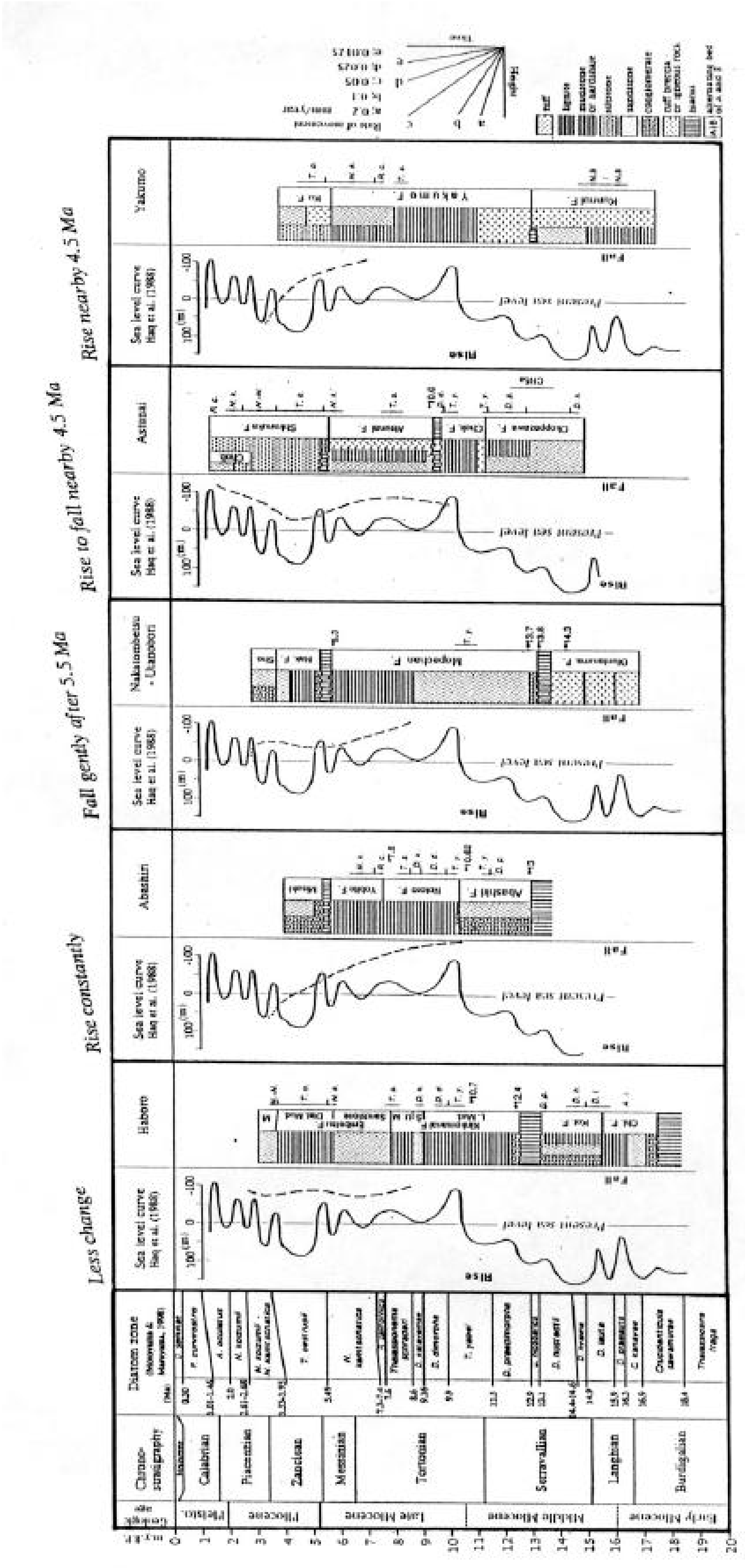


Figure 2b. Sea level curve of sedimentary basins.



Figures 3a . Change curve of sedimentary surface.



Figures 3b . Change curve of sedimentary surface.

Table 1. Classification of change curve of sedimentary surface.

| Type of vertical movement | Sedimentary basin | | | Maximum rate (m/1,000 years) |
|---|---|---|---|---|
| | **Oshima province** | **Central province** | **Eastern province** | |
| *Rise nearby 4 Ma* | | South. Kabato | | 0.2 (rise) |
| *Rise nearby 4.5 Ma* | Yakumo | North. Kabato | | 0.13~0.15 (rise) |
| *Rise to fall nearby 4.5 Ma* | Tate-Kikonai<br>Kumaishi-Esashi<br>Kitahiyama | Tenpoku<br>North. Hidaka<br>South. Hidaka | Atsunai<br>Taiki | 0.025 (rise)<br>0.05 (fall) |
| *Rise to fall radically nearby 4.5 Ma* | Kameda | | | 0.25 (rise) |
| *Fall gently after 5.5 Ma* | | Nakatombetsu-Utanobori | Shiretoko<br>Teshikaga | 0.02 (rise)<br>0.02 (fall) |
| *Rise radically nearby 5.5 Ma* | Kuromatsunai-Oshamambe | Nayoro-Bifuka | | 0.25 (rise) |
| *Rise to fall radically nearby 6 Ma* | Kuromatsunai-Oshamambe | | | 0.13 (rise)<br>0.2 (fall) |
| *Rise constantely* | Shimamaki<br>Shakotan Pen.<br>Muroran<br>Western Sapporo | Takikawa | Abashiri<br>Honki<br>Akan | 0.04~0.13 (rise) |
| *Less change* | | Haboro<br>Yubari-Iwamizawa | | |

observations are in agreement with the crustal movement after 4.5 Ma, uplift (sea-level fall) in the northern area and down-warping (sea-level rise) in the southern area.

## SUBSIDENCE RATE OF THE SEDIMENTARY BASIN

As shown in Figure 4, sedimentation rates within the formations *A*, *B* and *C* are assumed to be constant. The curved line *S* indicates that depth of the basin decreased due to the supply of clastics. A reference point $P_b$ from formation *A* in figure 4 is assumed to subside with accumulation of the sediments in formation *B* (transition of $P_b$ to $P_b'$). The associated thickness $t_b$ is the thickness of the formation *B*, and $t_b'$ shows increasing elevation of the basin surface during deposition of the formation *B*. The thickness between $t_b'$ and $t_b$ is an amount from the basin surface $P_b$ to the subsided basin surface $P_b'$. As this subsidence took place during the period of $T_b$ (the deposition time of the formation *B*), the subsidence rate (m/1000 years) of the formation *B* is computed by the formula, $t_b$-$t_b'$ / $T_b$.

Subsidence rates in twenty-five sedimentary basins were estimated for the late Miocene (5.5 to 10.5 Ma), early early Pliocene (3.8 to 5.5 Ma), and late early Pliocene (2.9-3.0 to 3.8 Ma) (Table 2). The rate shows a tendency to increase as geologic ages descend. During the late Miocene subsidence rates are inferred to have

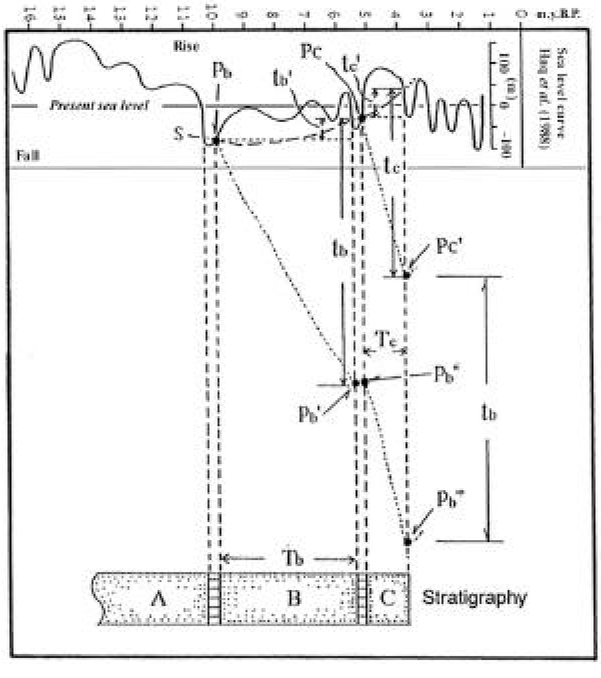
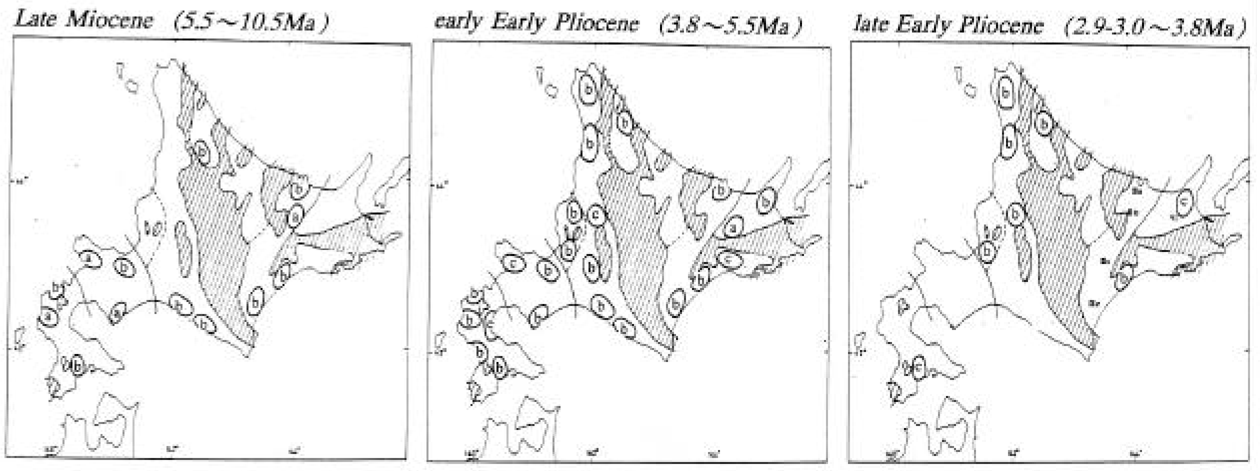


Figure 4. Relation between movement of the surface and subsidence in the sedimentary basin. *S*: vertical-change curve of sedimentary surface; $T_b$: time of sedimentation of formation *B*; $t_b$: thickness of formation *B*; $t_b'$: difference between the beginning and the end of vertical-change curve of depositional surface of formation *B*; $T_c$: time of sedimentation of formation *C*; $t_c$: thickness of formation *C*, $t_c'$: difference between beginning and end of vertical change curve of depositional surface of formation *C*.

Table 2. Subsiding rate of sedimentary basin in Late Miocene to Pliocene.

| **Province** | | **Area** | **Standard point on sedimentary basin; subsidence rate (m/1000 years) of sedimentary basin (Objected formation)** | | |
|---|---|---|---|---|---|
| | | | **Late Miocene (5.5 - 10.5Ma)** | **early early Pliocene (3.8 - 5.5Ma)** | **late early Pliocene (2.9-3.0 -3.8Ma)** |
| Western Hokkaido | Oshima | Tate - Kikonai | Upper limit of Kikonai F.; 0.30 (Assabu F.) | Upper limit of Assabu F.; 0.10 (Yosumizawa M. of Tate F.) | Upper limit of Yosumizawa M.; 0.83 (Nukano M. - Suga M.) |
| | | Kumaishi - Esashi | | Upper limit of Esashi F.; 0.26 (Tate F.) | |
| | | Kitahiyama | Upper limit of Babagawa F.; 0.03 (Mujinatai F.) | Upper limit of Yakumo F.; 0.38 (Siltstone M. of Kuromatsunai F.) | |
| | | Shimamaki | Upper limit of lower part of Orikawa F.; 0.10 (Upper part of Orikawa F.) | Upper limit of Orikawa F.; 0.32 (Honme F.) | |
| | | Yakumo | | Upper limit of Yakumo F.; 0.56 (Kuromatsunai F.) | |
| | | Shakotan Penn. | Upper limit of Furuugawa F.; 0.03 (Toyohama F.) | Upper limit of Toyohama F.; 0.50 (Yobetsu F.) | |
| | | Muroran | Upper limit of Horobetsu F.; 0.09 (Takinokawa F. - Shikanosawa F.) | Upper limit of Shikanosawa F.; 0.14 (Muroran F.) | |
| | | Western Sapporo | Upper limit of Yuuhizawa F.; 0.31 (Masunosawa F. - Itawarizawa F.) | Upper limit of Itawarizawa F.; 0.21 (Nishino F.) | |
| Central Hokkaido | Central | Tenpoku coal field | | Upper limit of Wakkanai F.; 0.24 (Koetoi F.) | Upper limit of Koetoi F.; 0.33 (Yuchi F.) |
| | | Haboro | | Upper limit of Kinkomanai F.; 0.20 (Embetsu F.) | Upper limit of Embetsu F.; 0.25 (Mochikubetsu F.) |
| | | Takikawa | | Upper limit of Mashike F.; 0.60 (Horokaoshirarika F.) | Upper limit of Horkaoshirarika F.; 0.19 (Ichinosawa F.) |
| | | Yubari-Iwamizawa | | Upper limit of Oiwake F.; 0.16 (Minenobu F.) | |
| | | Northern Hidaka | Upper limit of Nibudani F.; 0.27 (Nina F.) | | |
| | | Southern Hidaka | Upper limit of Motokanbe F.; 0.34 (Atsuga F.) | | |
| | | Northern Kabato | | Upper limit of Mashike F.; 0.13 (Rumoi F.) | |
| | | Southern Kabato | | Upper limit of Morai F.; 0.48 (Tobestu F.) | Upper limit of Tobetsu F.; 0.36 (Atsukaruushinai F.) |
| | North-central depression | Nakatombetsu-Utanobori | | Upper limit of Mopechan F.; 0.21 (Nakatonbetsu F.) | Upper limit of Nakatonbetsu F.; 0.41 (Shotonbetsu F.) |
| | | Nayoro-Bifuka | Upper limit of Ogurmadake agglomerate M.; 0.30 (Momponai Sandstone M.) | | |
| Eastern Hokkaido | Eastern | Abashiri | Upper limit of Abashiri F.; 0.17 (Notoro F. - Yobito F.) | Upper limit of Yobito F.; 0.10 (Misaki F.) | |
| | | Honki | Upper limit of lower part of Mito F.;<br>0.06 (upper part of Mito F.) | | |
| | | Atsunai | Upper limit of Chokubetsu F.; 0.11 (Atsunai F.) | Upper limit of Atsunai F.; 0.21 (Shiranuka F.) | |
| | | Akan | | Upper limit of Atsunai F.; 0.82 (Kotan F.) | |
| | | Taiki | Upper limit of Oikamanai F.; 0.19 (Taiki F.) | Upper limit of Taiki F.; 0.12 (Nukanai F.) | |
| | Shiretoko | Shiretoko | | Upper limit of Koshikawa F.; 0.37 (Ikushina F.) | Upper limit of Ikushina F.; 0.63 (Rikushibetsu F.) |
| | | Teshikaga | | Upper limit of Yubaegawa F.; 0.04 (Shikerepenpetsu F.) | |
| Average | | | *0.18* | *0.29* | *0.4* |



$a < 0.1 \leqq b < 0.5 \leqq c$ m / 1000 years

Figure 5. Distribution of subsidence in sedimentary basin during late Miocene to Pliocene.

been relatively fixed without much regional variations. The early early Pliocene stage indicates more active movement, and in the area west to the axial zone of the Hokkaido subsidence rates are higher than in the other one. The late early Pliocene stage indicates the most active movement in the three stages.

According to Matsuda (1975), classification of Quaternary faults, based on long-term rates of displacement, the rate $S$ (m/1000 years) of each class is: $1<S<10$ for *A*, $0.1<S<1$ for *B*, and $0.01<S<0.1$ for *C*. *B* was further subdivided into $a<0.1<b<0.5<c$ (m/1000 years) and classified in three stages, late Miocene, early early Pliocene and late early Pliocene in terms of the rates of displacement (Figure 5).

In late Miocene, eight basins are classified as "*b*" in the subsidence rate, and four basins as "*a*", suggesting that regional differences in diastrophism of Hokkaido were weaker than in following stages. In early early Pliocene, three basins are inferred to have experienced a subsidence classified as "*c*", one basin as "*a*" and other 17 as "*b*". Diastrophism in this stage is inferred to be more active than in late Miocene. In late early Pliocene, it is assumed that the most active diastrophism among the three stages occurred.

## CONCLUSIONS

1. Thirty-one sedimentary basins are distinguished on the basis of the distribution of Neogene formations, detailed stratigraphy of diatoms and of others, and radiometric ages.

2. Paleo-sea level curve was reconstructed based on four sedimentary facies observed in the geological columnar sections: conglomerate, sandstone, siltstone, and mudstone, each of which is assumed to represent a transgressive sea-level sequence.

3. Based on that unconformities we conclude that the surface of the sedimentary basin was higher than sea level at that time, and that successive strata indicate sedimentation during submergence and during sea-level rise; nine types of vertical movement in the basins are defined.

4. Subsidence rates, based on the relationship between vertical movement in the basin surface and thickness of formation, indicates a tendency to become faster as geologic ages become younger. The late Miocene was a comparatively uniform stage without strong regional differences in the subsidence, early early Pliocene was more active, and late early Pliocene was the most active in the three stages.

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