ON THE FORMATION OF THE COAL-BEARING DEPOSITS IN NORTHEASTERN HONSHU, JAPAN

— The Distribution and the Stratigraphical Relationships of the Coal Fields —

By

Toshimasa TANAI

Contributions from the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, Sapporo; No. 757.

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I. Introduction

The productive coal fields in Japanese mainly located in Hokkaidô and Kyûshû, with scarcely any in Honshû except the Ube and Jôban fields. In northeastern Honshû, many small coal deposits are scattered throughout the area; total area of lignite fields in this province occupies about 50 per cent of the total Japanese lignite fields.

The coals in northeastern Honshû are generally of low grade in quality with some exceptions, and are used only for domestic heating in the vicinity of each field. But some fields may be more exploited in future, if the utilization of low-grade coals should be promoted. In the

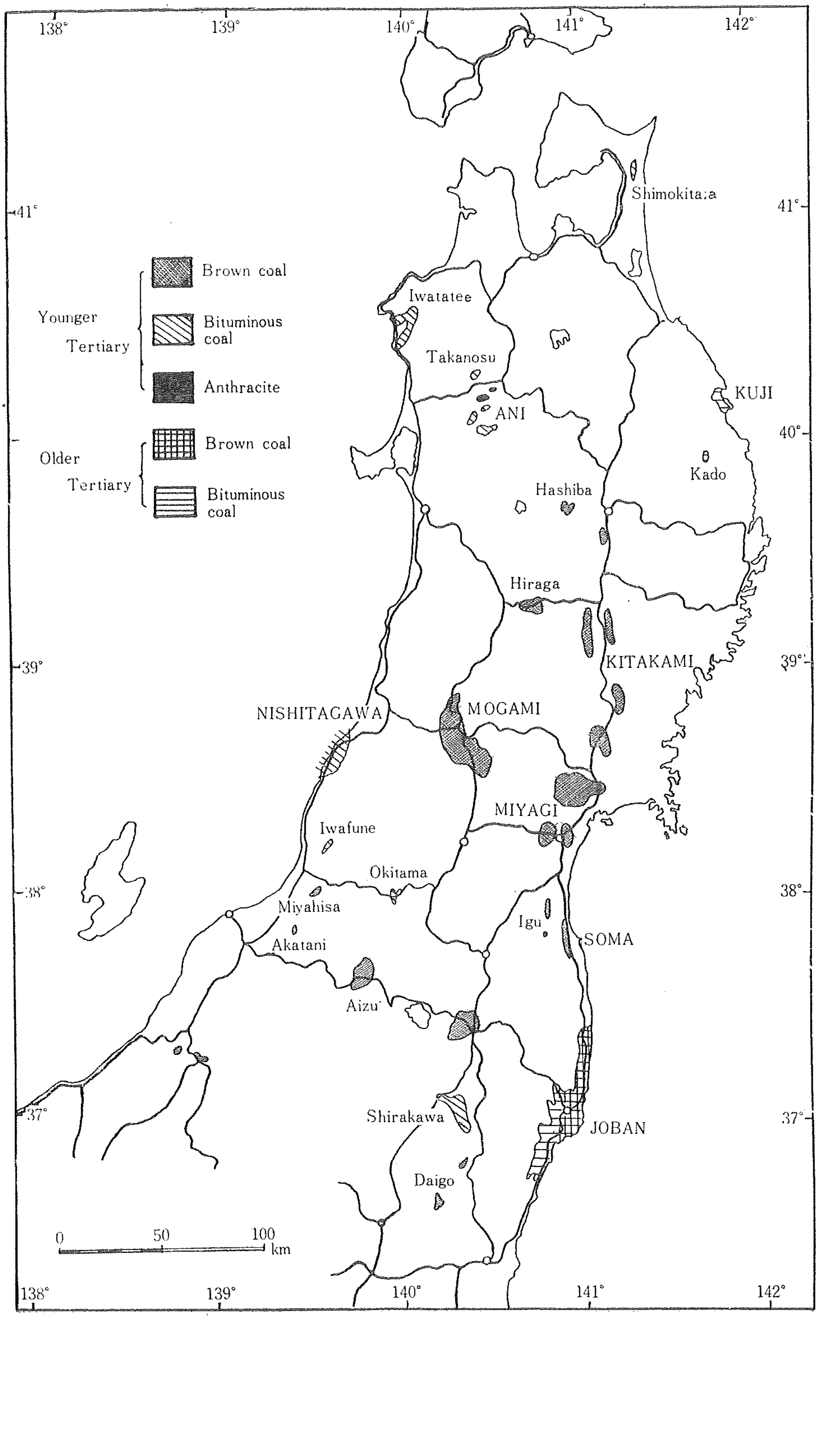
Brown coal
Younger Tertiary
Bituminous coal
Anthracite
Brown coal
Older Tertiary
Bituminous coal
Shimokita:a
Iwatatee
Takanosu
ANI
KUJI
Kado
Hashiba
Hiraga
KITAKAMI
MOGAMI
NISHITAGAWA
MIYAGI
Iwafune
Okitama
Miyahisa
Akatani
Igu
SOMA
Aizu
Shirakawa
JOBAN
Daigo
0 50 100 km
138° 139° 140° 141° 142°
41° 40° 39° 38° 37°

Fig. 1. Geographic and Geologic Distribution of Coal-bearing Deposits in Northeastern Honshu.
The coal fields are shown by all capital letters, and the others are the coal-bearing areas.

consequence of the progress of the geological survey, the coal deposits in northeastern Honshû are comparitively well-known in their distribution and stratigraphical positions.

The writer has studied the coal-bearing formations and the fossil floras in northeastern Honshû with an interest in clarifying the problem of the vegetable matter from which they originated. In this paper the writer summarizes the geological characteristics of the coal deposits and affords some considerations on the historical process of their deposition.

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II. The Distribution of the Coal Fields in Northeastern Honshu

The coal deposits are distributed in all parts of this province; their distribution and the quality of coals are shown in Fig. 1. Among these deposits the Jôban and Kuji fields and the Kado coal-bearing area are older Tertiary in age; the others were formed in younger Tertiary or Quaternary times.

Considering their geological characteristics, the coal fields in northeastern Honshû are distributed in the following four groups:—

A) Coal fields distributed along the Pacific coast,
B) Coal fields distributed in the oil-bearing zone,
C) Coal fields distributed in the interior basins,
D) Coal fields distributed in the lowland area between the Kitakami and central mountain-ranges.

Among these groups the coal fields belonging to each type have many common characteristics respectively in their stratigraphy, lithology, structures and fossil floras or faunas. Furthermore, each group of fields arrange in North-South direction, and their directions are almost parallel to an elongated arc. These facts are considered to suggest that the tectonic framework and palaeogeographic development in northeastern Honshû had some orientation and uniformity in Tertiary time. There are, of course, found some exceptions which do not belong to any of the four groups, but such fields have some geological significance respectively.

The writer considers that many Cenozoic coal deposits of Japan are caused by fluctuation during early time of transgression or regression in the depositional basin. Among the above-mentioned four groups the first and second belong to the transgression-type, and the third and fourth to the regression-type.

III. Geological Characteristics of Each Group of Coal Fields

Each group of coal-bearing deposits have alike characters respectively in geological and palaeontological characteristics; these are briefly described as follows:—

1. Coal fields distributed along the Pacific coast.

The Jôban and Kuji coal fields are distributed along the Pacific coast; the former is most productive field in northeastern Honshû. These older Tertiary coal-bearing formations cover unconformably the Late Cretaceous (Cenonian) and the Palaeozoic deposits or grano-diorite. The existence of basement of Cretaceous rocks is one of the characteristics. Though considered to belong to this group on account of the common characteristics.

These coal-bearing formations dipping gently to eastward were displaced by many faultings, but the field seems to have once shown an elongated basin structure. Only the coal-seams on the west side of the synclinal structure are worked now, and those of the east side under the sea may be exploited in future. The coal-bearing formation contains one to three workable coal seams. It occupies the lower part of the older Tertiary sediments, of which the upper part is of marine origin; the upper part include many marine molluscs such as *Papyridea harrimanni* (DALL), *Nemocardium iwakiense* (MAKIYAMA), *Clinocardium asagaiense* (MAKIYAMA), *Mya grewingki* MAKIYAMA, *Periploma besshoensis* (YOKOYAMA), *Turritella tokunagai* YOKOYAMA, *Yoldia*, *Buccinum*, *Neptunea*, etc. From the coal-bearing formations many plant fossils are found the common ones being as follows: *Equisetum arcticum* HEER, *Osmunda japonica* THNB. fossilis, *Metasequoia occidentalis* (NEWBERRY) CHANEY, *Glyptostrobus europaeus* (BRONG.) HEER, *Alnus gracilis* UNGER, *Cercidiphyllum arcticum* (HEER) BROWN, *Crataegus antiqua* HEER, *Acer arcticum* HEER, *Marlea basiobliqua* OISHI et HUZ., *Nordensköldia* sp, etc.

The coal is generally of sub-bitumious to lignite rank (JIS E and F_1 class), and in the Jôban Field partly bituminous (B_2—C class).

The Cretaceous sediments under the older Tertiary coal-bearing formations have frequently some thin coal seams*, which were once mined.

2. Coal fields distributed in the oil-bearing zone.

In the inner zone of northeastern Honshû the so-called "green tuff" formation is widely distributed as the basal part of the younger Tertiary sediments.

The middle part of younger Tertiary sediments in this region is one of the main oil-bearing horizons in Japan. The so-called "green tuff" formation frequently contains small coal deposits, which are comparatively high-graded in quality. The Iwatate, Ani, Nishitagawa, Iwafune and Miyahisa coal fields are grouped as this type; besides them several coal-bearing fields are known in the so-called "green tuff region."

This region belongs to the so-called "Uetsu folded zone", and the coal-bearing formations are generally disturbed by considerable folding, faulting and igneous intrusion. Accordingly, the thickness of seams and quality of coal are considerably variable, and many unstable conditions of coal make impede the exploitation of these fields. Coals are generally sub-bituminous, and occasionally high-grade as a result of complicated structure or igneous intrusion. For instance, the coal in the northern part of the Nishitagawa field is strong-coking and bituminous, while in the Ani field it is anthracite.

The coal-bearing deposits belonging to this group, occupy generally the middle part of the "green tuff" formation, namely the uppermost of the Monzen stage (Early-Middle Miocene). They include many well-preserved plant fossils such as *Metasequoia occidentalis* (NEWB.) CHANEY, *Glyptostrobus europaeus* (BRONG.) HERR, *Pterocarya asymetrosa* KONNO, *Ulmus miodavidiana* TANAI, *Betula uzenensis* TANAI, *Betula mioluminifera* HU et CHANEY, *Carpinus subcordata* KONNO, *Fagus Antipofi* (ABICH.) HEER, *Zelkova Ungeri* (ETTING.) KOVATS, *Cercidiphyllum crenatum* (UNGER) BROWN, *Acer subpictum* SAPORTA, *Acer ezoanum* OISHI et HUZ., *Aesculus majus* (NATHORST) TANAI, *Marlea aequalifolia* (GOEPPERT) OISHI et HUZ., *Hemitrapa borealis* (HEER) MIKI., etc.

The marine sediments overlying these coal-bearing deposits are widely distributed in this region; in them many molluscan fossils such as *Luci-*

* In Japan the Late Cretaceous sediments intercalate frequently some coal seams, but they are too thin and variable in thickness to be mined. In Hokkaidô the Hakobuchi group has several coal seams, of which some are mined on a small scale in the Hidaka coal field.

noma acutilineata (CONRAD.), *Clinocardium shinjiense* (YOK.), *Phaxus izumoensis* (YOK.), *Vicarya yokoyamai* TAKEYAMA, *Chicoreus tiganouranus* (NOMURA), *Joannisiella takeyamai* OTUKA, *Clementia papyracea* GRAY, *Apolymetis* (*Leporimetis*) *nipponica* OYAMA, *Angulus* (*Moerella*) sp., etc. From the lacustrine or littoral deposits which are close stratigraphically to this marine formation many plant fossils are also found. Common are *Myrica* (*Comptonia*) *Naumanni* (NATHORST) TANAI, *Carya miocathayensis* HU et CHANEY, *Carpinus miocenica* TANAI, *Castanea Ungeri* HEER, *Quercus subvariabilis* TANAI, *Cyclobalanopsis Mandraliscae* (GAUDIN) TANAI, *Ulmus protoparvifolia* HU et CHANEY, *Liquidambar mioformosana* TANAI, *Cinnamomum oguniense* MORITA, *Dodonaea japonica* (MORITA) TANAI, *Rhus miosuccedanea* HU et CHANEY, *Smilax minor* MORITA, etc.

The fossil flora termed the "Daishima-type", have the floristic composition of a warm region; it was affected by the influence of warm sea current as is indicated by the above-described fauna.

3. Coal fields distributed in the interior basins.

Between the central and the Dewa mountain ranges several interior basins arrange in the direction of North-South.

The coal-bearing deposits are distributed in the marginal montane areas of these basins, where several coal seams are mined on a small scale. The following coal fields belong to this group: the Hashiba, Hiraga, Mogami, Okitama and Aizu fields. These fields are different more or less in their scale, but they have many common characteristics in stratigraphy, lithology, structure and fossil flora or fauna.

These coal fields have generally the coal-bearing formations of two horizons, of which the lower formation overlies the "siliceous shale formation*" or sandstone formation. (Fig. 2) This sandstone formation is contemporaneous with the "black shale formation*" or partly even with the siliceous shale formation, in the inner zone and contains many marine molluscan fossils** such as *Portlandia* (*Megayoldia*) *thraciaformis* (STOR.), *Serripes fujinensis* (YOK.), *S. yokoyamai* OTUKA, *Lucinoma acutilineata* (CONRAD), *Thyasira bisecta* CONRAD, *Macoma tokyoensis*

* In the oil fields of the inner zone, these argillaceous sediments develop thickly upon the "green tuff" formation, among which the lower, the Onnagawa formation consists mainly of siliceous shale. The Funakawa formation of the upper consists of black shale, which is considered as the main mother rock of oil-bearing formations.

** This fossil fauna is called the "Yama fauna" by Y. OTUKA, and considered to be Late Miocene in age.

MAKIYAMA, *Sanguinolaria* sp., *Mya cuneiformis* (BÖHM), *Neptunea* sp., etc.

In the lower coal-bearing formation well-preserved plant fossils are contained plentifully; common ones are: *Dryopteris* sp., *Sequoia sempervirens* ENDL., *Glyptostrobus europaeus* (BRONG.) HEER, *Metasequoia occidentalis* (NEWB.) CHANEY, *Populus aizuana* HUZ. et SUZ., *Pterocarya nipponica* TANAI et ONOE, *Fagus palaeocrenata* OKUTSU, *Quercus miocrispula* HUZIOKA, *Q. protodentata* TANAI et ONOE, *Q. protoserrata* TANAI et ONOE, *Betula protoermanni* ENDO, *Alnus protohirusuta* ENDO, *Carpinus protojaponica* ENDO, *Zelkova Ungeri* (ETTINGS.) KOVATS, *Magnolia* sp., *Sassafras subtriloba* (KONNO) TANAI et ONOE, *Liquidambar mioformosana* TANAI, *Prunus protossiori* T. et O., *Ilex cornuta* LINDL. et PAX., *Acer palaeodiabolicum* ENDO, *A. palaeorufinerve* T. et O., *A. protosieboldianum* T. et O., *Styrax protoobassia* T. et O., *Viburnum* cfr. *furcatum* BLUME, etc.

In the upper coal-bearing formation there occur also many fossil leaves, fruits, seeds or nuts, which are comparatively poor in preservation. Common fossils are *Metasequoia occidentalis* (NEWB.) CHANEY, *Picea Maximowiczii* REGEL, *Myrica (Comptonia) Kidoi* ENDO, *Juglans cinerea* L. var. *megacinerea* (CHANEY) MIKI, *Alnus japonica* S. et Z., *Fagus palaeojaponica* T. et O., *Cyclobalanopsis stenophylla* MAKINO, *Brasenia Schreberi* GMELIN, *Magnolia Kobus* D. C., *Ilex cornuta* LINDL., *Styrax japonicum* S. et Z., *Stewartia pseudocamellia* MAXIM., *Trapa mamilifera* MIKI, *Carex* sp., etc.

These lower and upper coal-bearing formations are a series of continuous sediments, between which formations a marine formation is intercalated in a large depositional basin such as the Mogami field. The coals of these formations are generally brown coal in quality, and 4,000 to 5,000 calories in calorific value. The coal of the upper formation is generally of poorer grade than that of the lower.

In these coal fields the coal-bearing deposits are folded considerably along with other Tertiary sediments, and their general folding axes have the direction of North-South. The areas in the western half of each of these fields were especially affected by considerable folding and faulting movements, while, on the contrary, the eastern half shows a gentle folding structure.

4. Coal fields distributed in the lowland area.

In the lowland area between the Kitakami and central mountain ranges the marginal montane or hilly areas have a distribution of lignite-bearing deposits. The Kitakami, Miyagi and Kamikita lignite fields belong to this group. The lignite-bearing formations are observed to show two horizons, of which the lower is generally correlated with the upper horizon of the above-described interior basins; the upper horizon of this group is Pleistocene in age. Among these two lignite-bearing formations some fields have any only one horizon, for instance, in the Kamikita field the upper horizon only is observed. On the contrary, the Miyagi field has additionally a lignite-bearing horizon between those two horizons, and even marine deposits are intercalated among each formations.

These coal-bearing formations are dipping very gently or almost horizontal, and have several coal seams. The coals are of low-grade and 3,500 to 4,200 calories in calorific value. But, they are used for domestic fuel in their vicinities owing to ease in mining and facility in transportaton.

The lower coal-bearing formation has many plant fossils such as leaves, fruits, nuts, seeds and cones. Typical plants are as follows: *Metasequoia occidentalis* (NEWB.) CHANEY, *Juglans cinerea* L. var. *megacinerea* (CHANEY) MIKI, *Alnus japonica* S. et Z., *Acer Nordenskilöldia* NATH., *Prunus Haussknechtii* SCH., *Magnolia Kobus* DC., *Gleditishia japonica* MIQ., *Styrax japonicum* S. et Z., *Vitis Thunbergi* S. et Z., *Trapa mammilifera* MIKI, *Paliurus nipponicus* MIKI, etc. This flora is closely similar to that of the upper coal-bearing formation in the interior basin.

The coal-bearing formation of the upper horizon has also many plant fossils, which are abundant in seeds, fruits or nuts and rarely in leaves. Their common plants are *Picea jessoensis* CAR., *Juglns Sieboldiana* MAX., *Salix* sp., *Fagus crenata* BLUME, *Alnus japonica* S. et Z., *Menyanthes trifoliata* L., *Trapa macropoda* MIKI, *T. mamilifera* MIKI, *Brasenia Schreberi* GMELIN, *Wistaria* sp., etc. This flora is Early Pleistocene in age, and in number of species as compared to the abundance of specimens.

In the area to the eastward of the central mountain ranges some coal-bearing deposits are frequently distributed, which are contained in the lower part of Miocene sediments. The Shimokita, Igu and Shirakara coal-bearing fields belong to this type. These coal-bearing formations are considered to be formed as the result of fluctuation in the early stage of Miocene transgression, but they are upper in horizon than those of the above-described oil-bearing zone. They are abundant in plant fossils such as *Myrica* (*Comptonia*) *Naumanni* (NATH.) TANAI, *Cyclobalanopsis Mandraliscae* (GAUDIN) TANAI, *Quercus subvariabilis* TANAI, *Castanea Ungeri* HEER, *Carpinus subcordata* KONNO, *Liquidambar mioformosana* TANAI, etc. The flora belongs to the so-called "Daishima-type".

Several thin coal seams are intercalated in the formations, and generally are variable in thickness. The coals are generally low-grade in quality and of lignite rank.

In many coal fields of northeastern Honshû, the stratigraphical distribution and horizon of their coal-bearing deposits are shown in Table 1.

IV. Palaeogeography and Coal Formation in Northeastern Honshu

It is generally considered that plant remains which made the coals were deposited on swampy areas of fluvial, lacustrine, or coastal plains of comparatively great extent. Yet, it is suggested by occasional intercalation of marine strata, by substrata of marine deposition, or by covering with some marine formation that most of the coal swamps were coastal or adjacent to the sea.

How the coal-bearing deposits seem to have originated and to have developped to the present condition in northeastern Honshû, is presented here briefly. Namely, for this region an attempt is made to present a palaeogeographic history of conditions under which the coal-bearing deposits were formed.

1. Oligocene transgression.

The distribution of the older Tertiary sediments coincides almost with that of the Upper Cretaceous in northeastern Honshû; the former unconformably covered the latter. Oligocene transgression was related to Late Cretaceous sea, and invaded only into the outer zone of this region, especially along the present Pacific coast. The outer zone being a geosynclinal area since Jurassic time, was gradually filled up with sediments as M. MINATO et al. (1956) have already described, and consequently the depositional area was differentiated to some depositional basins. After deposition of the Upper Cretaceous the depositional area was uplifted, and had a rugged surface owing to land-erosion. In Early Oligocene time the sea again invaded such basins, while, the inner zone of this region always remained above the sea as an erosional area throughout Mesozoic to Early Tertiary time.

In the early stage of the Oligocene transgression* the fluctuating movement of the basement caused the deposition of some coal-bearing

* This transgression covered Japan with a comparatively wide extention. For instance, in Hokkaidô it caused the Kushiro coal field to form, and also the depositional basin of the Ishikari field extended widely at this time. In northern Kyûshû the Eocene coal-bearing formations were covered extensively by the marine or brackish sediments due to this transgression.

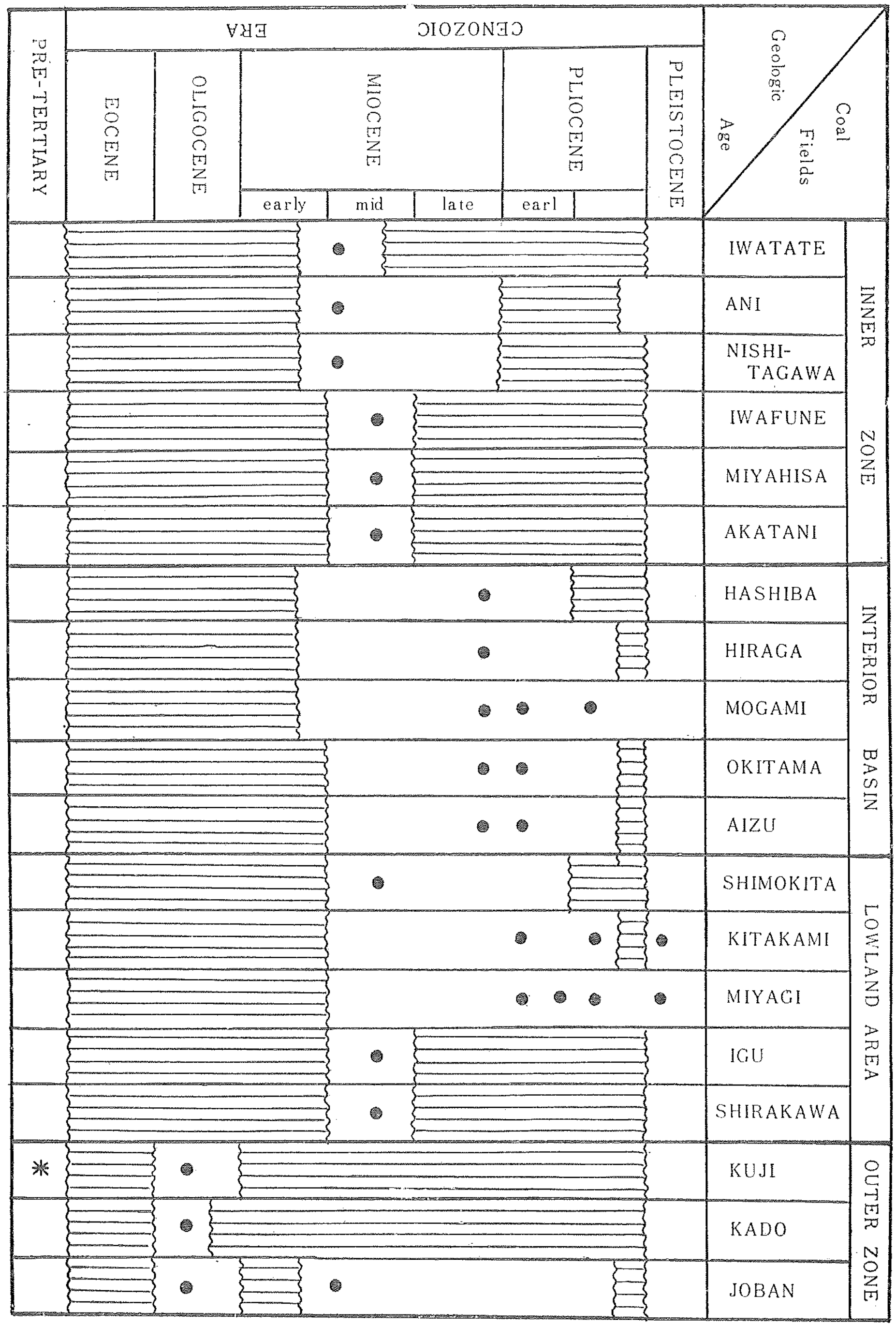

CENOZOIC ERA
PRE-TERTIARY
EOCENE
OLIGOCENE
MIOCENE
PLIOCENE
PLEISTOCENE
early
mid
late
earl
Geologic Age
Coal Fields
IWATATE
ANI
NISHI-TAGAWA
IWAFUNE
MIYAHISA
AKATANI
INNER ZONE
HASHIBA
HIRAGA
MOGAMI
OKITAMA
AIZU
INTERIOR BASIN
SHIMOKITA
KITAKAMI
MIYAGI
IGU
SHIRAKAWA
LOWLAND AREA
KUJI
KADO
JOBAN
OUTER ZONE
*

TABLE 1. Stratigraphic Distribution and Horizon of the Coal-bearing Deposits in Northeastern Honshu.

||||| lacking of sediments ● coal-bearing formation

* frequently contains several workable coal seams in the Late Cretaceous rocks

formations in northeastern Honshû; such coal basins are the Kuji and Jôban fields. As Oligocene transgression progressed still continuously after formation of the coal-bearing deposits, the sea having the Asagai fauna invaded not only the Jôban field, but spread to the northern part of the Kwanto region.

In the Jôban field the subsidence accompanying some fluctuation progressed gradually, and brought about swampy area comparatively available to form coal-bearing deposits, especially in the central part of this field, the Iwaki district, where coal seams were developed sufficiently for minable value. Toward the marginal area of this field, the coal-bearing formation is thinner or coarser in material, and overlaps gradually on the basement rocks. Especially, in the northern part, the Futaba district, where the coal-bearing deposits were overlaid upon the Upper Cretaceous, the sediments are dominant in conglomerate, and poor in devolopment of coal seams. Accordingly, the subsidence in the Jôban basin was more considerable in the central district than other districts. On the contrary, the Kuji field was smaller in its depositional basin than the Jôban field, and rapidly filled up with sediments as indicated by the coarse materials. The coals of this field are poorly developed, and also low-grade in quality.

The older Tertiary sediments in the Kuji field always overlay the Cretaceous, while no Cretaceous sediments are found in the central or southern part of the Jôban field, where the older Tertiary covers the Palaeozoic sediments or granite. It is considered that the subsidence in the older Tertiary depositional area, where the Cretaceous sediments had been distributed, was not so considerable as the other area where the basement consisted of older rocks.

Such older Tertiary depositional basins gradually became higher according to their being filled up with sediments, and became land by and by.

2. Birth of the geosyncline in the inner zone.

The considerable younger Tertiary transgression commenced at Early Miocene time, covered again almost the whole of northeastern Honshû except the Kitakami and Abukuma massifs. The eastern region from the Kitakami-Shirakawa lowland area developed as a tilted area, and had only younger Tertiary sediments. While, the western region, which had been land throughout Mesozoic to older Tertiary, became a geosynclinal area with considerable vulcanism accompanying, and was overlaid by very thick sediments. The boundary between the two regions is considered a tectonic line at present, which was partially active in Pliocene or Pleistocene time. For instance, the Tanagura-Shirakawa sheared zone (OMORI, 1958) observed in the western margin of the Abukuma massif, may be a symptom of this tectonic line, though it is oblique to the latter line in general direction.

Early Miocene transgression invaded at first in the western geosynclinal area, and due to considerable vulcanism much of the pyroclastic materials such as the so-called "green tuff" formation consist of propylite, andestic lava or tuff and many other volcanic rocks. Consequently, the depositional area having a rugged relief was gradually filled with such pyroclastic sediments. But in the early time of Miocene age this area was not entirely submerged under the sea, and there were many embayments or inland seas. The successive deposition of enormous quantities of pyroclastic materials promoted such topographic unevennes in this depositional area, while the considerable vulcanism caused also the promotion of the next transgression. Thus, in the next stage (the Monzen stage) the sea spread over the inner zone of northeastern Honshû to a greater extent than in the previous stage. And also, this Miocene transgression commenced to invade into the southeastern margin of the Abukuma upland.

Some fluctuative transgressions in Early-Middle Miocene time was resulted in the formation of coal seams under the above-mentioned physiographic condition of this region. In the hinter land at this time was grown cool-temperate flora which consisted mainly of many deciduous broad-leaved trees and some conifers as shown by the Aniai-type flora. The coal-bearing deposits at the base of the Monzen stage were formed under such an environment; they belong to the second group as previously stated.

Toward the south, the "green tuff" formation is also distributed across Honshû along the "Fossa-Magna", and passes through the Izu Peninsula. The green tuff formation in the "Fossa-Magna" region has also small coal-bearing deposits intermittently. The Uenohara, Minobe and Tone coal-bearing fields correspond to the second group of the inner zone, and are almost similar in the general condition of coal seams and quality.

3. Middle Miocene marine transgression.

Succeeding the previous stage, a very extensive transgression took place over the most of lowland areas of Honshû in Middle Miocene time, and the sea almost covered northeastern Honshû except the Kitakami, Abukuma and other small uplands. At early time of this stage there were formed frequently terrestrial or littoral deposits, which have warm fossil flora as shown by the Daishima-type flora. These terrestrial deposits are overlaid by thick marine deposits which consist mainly of pyroclastic materials. The sea-invasion occurred so rapidly on the land area that almost no coal-bearing deposit have occasionally some coal seams in the inner land area to which this Miocene transgression reached at this time. The Akatani in the inner zone, and the Shimokita, Igu, Daigo and Shirakawa coal-bearing fields in the outer zone, were formed under such depositional condition. Accordingly, in these fields almost lacking any deposits from the previous Monzen stage, the coal-bearing formation overlay directly on the basement rocks.

During Middle Miocene time, the Japanese islands were influenced by a warm current under which such foraminiferas as *Lepidocyclina, Miogypsina, Operculina,* etc. flourished. And also, *Vicarya, Vicaryella, Chicoreus, Geloina,* etc., flourished in the inland sea or embayments, while *Lucinoma, Chlamys, Dosinia, Cardium,* etc. lived in the open sea. The sea covered the greater part of northeastern Honshû at this stage, communicating freely from the Japan sea to the Pacific Ocean.

Due to the further development of geosynclinal movement, the inner zone was subjected next to a considerable and extensive submergence, and there were deposited thick marine argillaceous sediments such as the Onnagawa and Funakawa shale formations. These two formations are considered to be of deep-sea origin. At the same time, in the outer zone —the eastern area from the Kitakami-Shirakawa lowland, the epeirogenic subsidence caused the deposition of marine, littoral or lake thin sediments at that time.

4. Differentiation of the geosyncline in the inner zone.

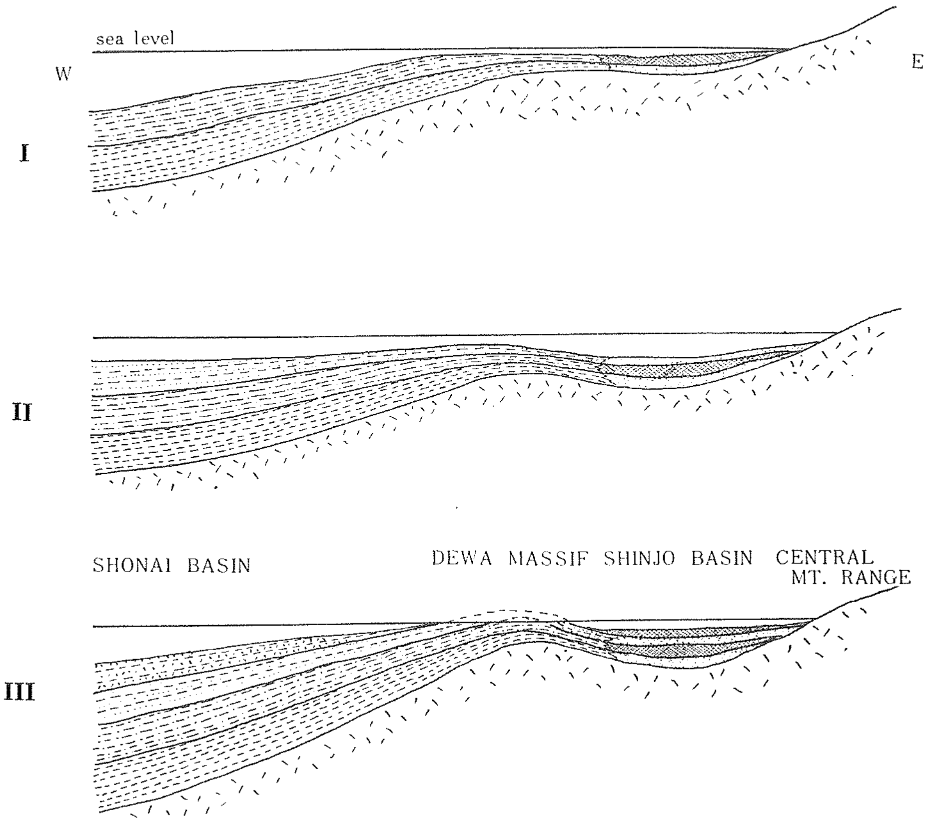
In the geosynclinal area of northeastern Honshû, the western half along the Japan Sea has thick argillaceous sediments upon the "upper green tuff" (Daishima and Nishikurosawa formations), while in the eastern half a considerable vulcanism succeeded from the previous stage. These argillaceous sediments intercalated with thick layers of tuff, tuff-breccia, agglomerate, etc., or frequently their place was taken by pyroclastic materials. Near the close of Miocene time (after or during deposition of the Onnagawa formation, the present Dewa massif commenced gradually to uplift in the geosynclinal area. As the emergence was gradually larger towards the south, the Dewa massif tended to become an elongated peninsula* extending to the north from the south. Accordingly, this geosynclinal sea differentiated gradually to several depositional areas.

In the western depositional basin the thick marine sediments piled up in succession until Middle Pliocene time (Funakawa-Kitaura-Wakimoto stages). Whereas, the eastern depositional basin became gradually to be shallow, and also a deeply-curved-in or enclosed basin, where continental or littoral deposits were dominant. Such shallowing of the depositional basin, namely regressive fluctuation since Late Miocene time, caused the coal-bearing deposits to form in the interior region of northeastern Honshû. These are the above-mentioned 3rd-type coal fields. This interior region, however, did not become monotonously shallow in the depth of basin, but fluctuating movement was repeated sometimes. Consequently, there are observed generally two horizons of coal-bearing formations in the interior basin region, between which formations a marine invasion is observed in the Mogami coal field.

In short, the geosynclinal basin of the inner zone differentiated gradually to several basins since the begining of Late Miocene time owing to local emergence** of the basement rocks. During Late Miocene time, a comparatively deep marine condition succeeded in the western depositional basin along the Japan Sea, where thick argillaceous sediments were deposited. In the later stage (Funakawa stage) of this deposition black shale was formed there. It is the main mother rock of oil in this region. On the contrary, in the eastern interior basin littoral or continental condition led gradually to the deposition of coarser sediments, and shallowing of the basin brought formation of coal deposits.

* This penisula was not always completely above sea-level in the beginning of Late Miocene time, and at least might have been a series of islands arranged within the depositional basin. M. MINATO et al. (1956) stated that the Dewa massif is one of the horst which was formed at the beginning of Miocene age. However, they cited no tectonic facts in positive support of Early Miocene or pre-Miocene faulting in this area; actually no such evidence exists there. Between the eastern and western sides of the Dewa massif no faunal difference is found during Middle Miocene time.

** The regional emergence since Late Miocene took place over the whole of Japan, and consequently the sea which reached its climax of transgression in Middle Miocene time gradually differentiated to many depositional provinces. Though most of the upper Miocene deposits in Japan are generally dominant in marine argillaceous facies, the lacustrine or lake deposits are also distributed locally in various districts. Accordginly, local unconformities are observed everywhere in this horizon of Japanese Tertiary section owing to the regional movement.



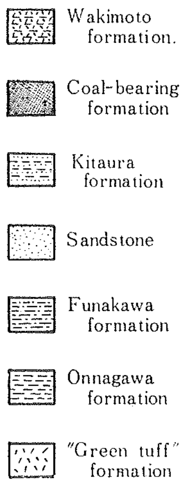


Fig. 2. Schematic Diagram of Younger Tertiary Deposition on East-West Direction along the Mogami River, Yamagata prefecture.
I. Middle—Late Miocene
II. Late Miocene—Early Plicene.
III. Pliocene.

Such environmental differnces are evidenced not only by the lithology, but by the palaeontologic data. The western argillaceous sediments are abundant in minor foraminiferas such as *Cyclammina*, *Ubigerina*, *Hopkinsina*, *Haplophragmoides*, etc., and scarce in molluscan fossils. On the contrary, the interior arenaceous sediments contain many molluscan fossils, which are represented by the "Yama fauna." It is considered at present by many geologists that the western argillaceous sediments are lower in horizon than the eastern arenaceous sediments. Though the former underlies actually the latter in many areas, the former is gradually thinner eastward in thickness, while the latter is thinner to the westward. Accordingly, the writer considers that the both sediments are partly contemporaneous in age and the upper half of the argillaceous is equivalent to the arenaceous or even lower coal-bearing deposits. Such stratigraphical and lithological relationships between the eastern and western areas are shown schematically in Fig. 2.

5. Late Miocene Lake.

As already mentioned, the regional emergence since Late Miocene time did not bring only the coal-bearing deposits in the interior basin area of northeastern Honshû, but the lacustrine deposits in other various areas which were near the hinter land. Due to the uplift of central mountain range commencing since Late Miocene time, the eastern sea from this range became gradually to be isolated from the main sea of the inner zone. Pyroclastic materials are abundantly contained in the Late Miocene sediments in the marginal area of the geosynclinal sea. Namely, considerable vulcanism continuing during Middle-Late Miocene time in this region progressed, also shallowing of the depositional basin resulted from the supply of pyroclastic materials. Consequently, between the central ranges and the Kitakami-Abukuma massifs an elongate lacustrine basin was formed along the present Kitakami-Shirakawa lowland area, which lake is called the "Paleo-Sendai Lake"* by S. HANZAWA (1950). Beside this, such Late Miocene emergence and considerable vulcanism brought about several lacustrine deposits around the Tsugaru-Ugo Massifs.

These lacustrine deposits consisting mainly of finely-bedded tuffaceous shale and sandstone, have no or few coal seams, but contain abundant plant fossils. These fossil floras indicates a cool-temperate climate, and are equivalent to those of the lower coal-bearing formations in the interior basins. These lacustrine deposits along with the lower coal-bearing deposits were not formed above the Onnagawa and Funakawa formations, but they are almost equivalent in age. Namely, because of regional emergence during Late Miocene time, marine facies form interfingers with the terrestrial facies in the marginal area of the gosynclinal basin, and also even the lake deposits are distributed intermittently in

* This Palaeo-Lake is considered by him to have been formed in the graben which was caused by faulting in Late Miocene time. However, the writer considers that Late Miocene faulting forming such lake did not always occur.

various areas.

6. Pliocene transgression.

The Late Miocene depositional area tends to differentiate locally into some basins, and such tendency increased in Pliocene time. In the inner zone the Dewa and Tsugaru-Ugo Massifs uplifted in succession from late Miocene time, and the depositional basin which had been once a geosyncline along the Japan Sea was confined in the Akita-Yamagata and Tsugaru areas. These main basins were gradually filled up with marine sediments, which are of shallow sea origin as is indicated by their coarser materials or fossil fauna. The transgression re-occurred more or less at the beginning of Pliocene time, and the Early Pliocene sea invaded partially into the interior basins along the present course of the Mogami River. Consequently, the Pliocene marine sediments were superposed upon the Late Miocene coal-bearing formations in the Shinjô basin. But the Pliocene depositional basin of the inner zone was filled up gradually with sediments. In Late Pliocene time there existed several marshy areas or lakes, where lignite seams were formed. The lignite-bearing formations of the Takanosu field and the interior basin area (upper horizon) were formed under such a condition.

Early Pliocene transgression took place also in the outer zone, and sea-invasion attained to the neighbourhood of Morioka City from the south along the present course of the Kitakami River and from the north along the present Sannoe lowland. Consequently, Pliocene marine sediments are distributed intermittently through the Kitakami-Shirakawa lowland area at present. This sea regressed gradually in Late Pliocene time, and regressive fluctuation brought some lignite-bearing deposits in the lowland, which are of the 4th type as already described.

In short, regression at the close of Pliocene time brought about many brackish or marshy environments in the depositional area of northeastern Honshû, and many lignite-bearing formations were deposited in deeply-curved-in basins. Between the eastern and western sides of the central mountain range the Pliocene depositional basins were separated completely from each other, and the two seas could not communicate entirely. This fact is indicated distinctly by the difference of the respective faunal characters.

The crustal deformation of northeastern Honshû during Tertiary time commenced from Late Miocene regional emergence, and attained its climax at the close of Pliocene time. Accordingly, in northeastern Honshû, Pleistocene deposits were superposed with unconformity upon the Tertiary sediments which were considerably affected by folding and faulting during Pliocene time.

V. Outline of Tertiary Floral Change in Northeastern Honshu

In northeastern Honshû, Oligocene to Pliocene floras occur abundantly in various localities; they are preserved in good condition in lacustrine or littoral deposits. Tertiary floras known at present in this region are shown in Fig. 3. As Pleistocene flora is not known so distinctly, Tertiary floral change in northeastern Honshû is summarized as follows.

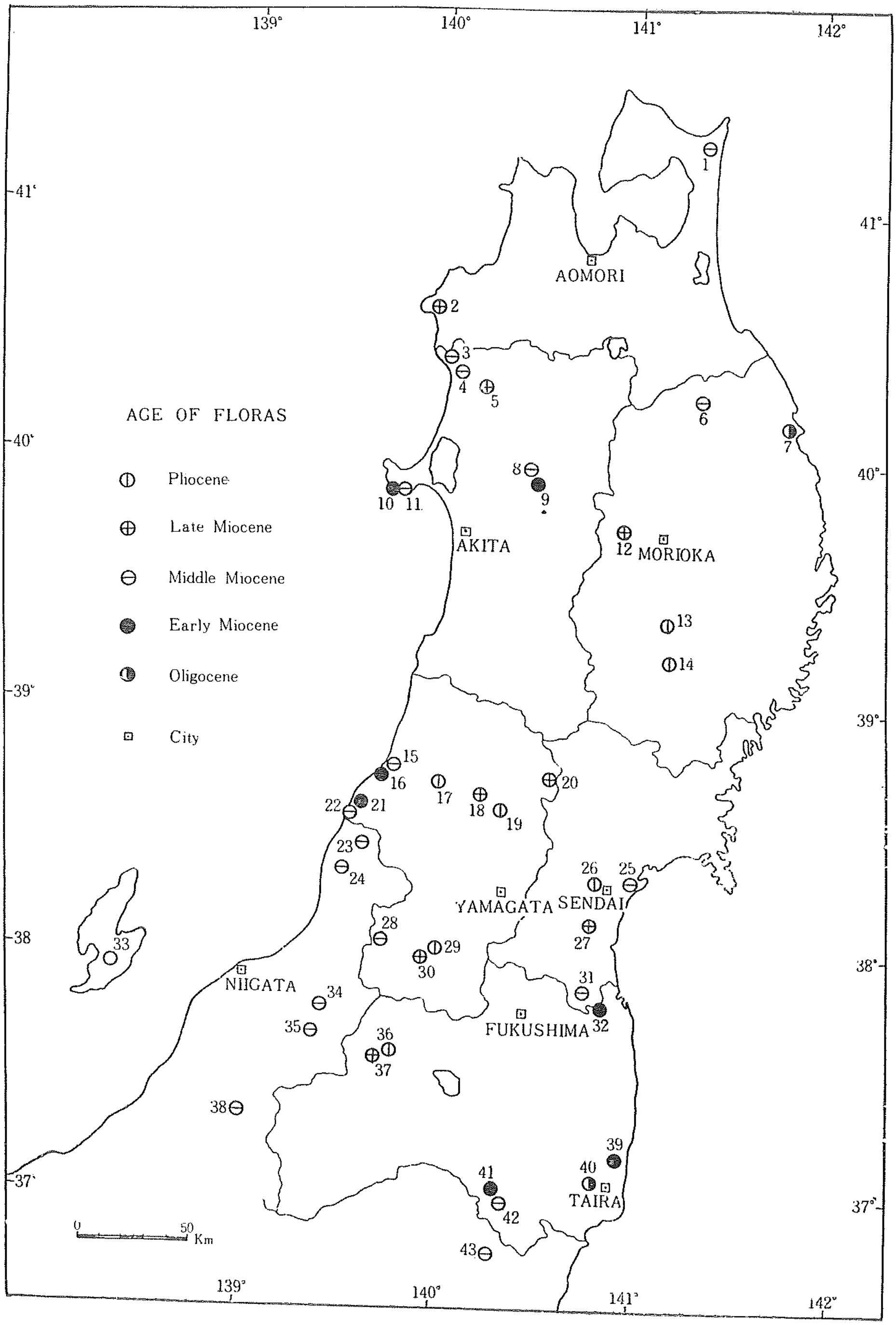
In Japanese islands a land condition prevailed in the Cretaceous-Tertiary interval, and then older Tertiary transgression progressed gradually with eustatic movement in various areas, to which movement was due older Tertiary coal formation in many main coal fields of Hokkaidô, Honshû and Kyûshû. Oligocene transgression accompanied by the Asagai-Poronai fauna, succeeded from the latest stage of coal formation in older Tertiary time, in which stage Oligocene flora of northeastern Honshû supplied the vegetal materials for the Jôban and Kuji coal fields. These Oligocene floras consist mainly of temperate or warm-temperate trees such as *Metasequoia, Glyptostrobus, Cephalotaxus, Salix, Populus, Quercus, Platanus, Acer, Crataegus, Smilax,* etc. (ENDO, 1950; TANAI, MS.), and seem to have grown under warm-temperate climate which was more or less affected by sea influence. These floras are closely similar to the Ashibetsu flora of the Ishikari coal field and the Yûbetsu or Tenneru flora of the Kushiro coal field, Hokkaidô, in their floristic components.

In younger Tertiary age the major depositional site removed to the inner zone of northeastern Honshû as described in the previous discussion. Early-Middle Miocene transgression prevailed gradually in its area, where many Early-Middle Miocene floras remain in the coal-bearing deposits. These floras, which are called the Aniai-type, consist mainly of coniferous trees such as *Metasequoia, Glyptostrobus, Taxodium, Picea, Abies,* and also abundantly of temperate deciduous broad-leaved trees such as *Betula, Carpinus, Ulmus, Zelkova, Acer, Tilia,* etc. As already reported in detail by the writer (TANAI, 1955), those floras are closely similar to the mountain-slope forest of the present northern Honshû, and grew probably under a cool-temperate climatic condition, which was rather slightly influenced by the sea. Namely, the cool-temperate climate in this stage brought out a luxuriant growth of temperate deciduous trees survived or evolved from older Tertiary flora, though there are observed their specific renewals. Thus, Miocene coals which are comparatively minable in this region, were probably originated from the above-described temperate trees.

The succeeding Miocene transgression prevailed with a wide extension in northeastern Honshû, and exerted marine influence upon the flora of this age. Middle Miocene flora preserved in lacustrine or littoral deposits is called the Daishima-type. It consists mainly of warm-temperate or subtropical broad-leaved trees such as *Cinnamomum, Machilus, Quercus, Cyclobalanopsis, Liquidambar, Castanea, Dodonaea,* etc. and temperate deciduous trees such as *Betula, Alnus, Acer, Carpinus* etc. The warm-temperate ever-green trees occupy usually about 50 per cent of the total, and also the seaside trees are abundantly contained. This flora was distinctly influenced by a warm sea current, and seems to have grown under warm or warm-temperate and slightly humid climatic conditions. That is to say, the flora of this time was most sensitively affected by marine influence among younger Tertiary floras, and it took the place of the cool-temperate flora of the previous stage. In place of cool-temperate deciduous trees, the southern warm elements grew luxuriantly in this stage; their close modern equivalents are living now in southern China and Formosa.

Younger Tertiary transgression in this region attained its climax at the close of Middle Miocene time, and the upper part of Miocene sediments consists mostly of marine argillaceous rocks in most areas. These marine sediments have frequently well-preserved plant fossils such as *Cyclobalanopsis, Myrica (Comptonia), Carpinus, Quercus, Cinnamomum,* etc., which were probably survivals of the previous Daishima-type elements. However, they are considered as drifted plant materials, and so may have scarcely any stratigraphical significance.

Whereas, the lacustrine or littoral sediments which are probably contemporaneous to Late Miocene marine sediments in age, stored frequently abundant plant fossils. These floras consisted predominantly of temperate deciduous broad-leaved trees such as *Zelkova, Ulmus, Betula, Alnus, Fagus, Quercus, Acer, Tilia,* etc., and commonly include coniferous trees such as *Metasequoia, Glyptostrobus, Sequoia, Picea,* etc. They have also commonly warm elements such as *Liquidambar, Sassafras, Liriodendron, Magnolia,* etc. That is, Late Miocene flora is characterized by mixed composition of warm and cool-temperate elements, though the latter exhibits a larger number of species and specimens. Considering from the floristic composition that flora seems to show a mixture of the two contrasting floras grown in the previous stages, although their components



139°
140°
141°
142°
41°
40°
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38°
37°
AGE OF FLORAS
Pliocene
Late Miocene
Middle Miocene
Early Miocene
Oligocene
City
AOMORI
AKITA
MORIOKA
YAMAGATA
SENDAI
NIIGATA
FUKUSHIMA
TAIRA
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Fig. 3. Geographic Occurrence of Tertiary Floras in Northe astern Honshu.

Fossil Floras

1. Shimokita
2. Fukaura
3. Iwatate
4. Hachimori
5. Noshiro
6. Yotsuyaku
7. Minato (Kuji)
8. Uttô
9. Aniai
10. Sugoroku
11. Daishima
12. Gosho
13. Hanamaki
14. Ichinoseki
15. Kamigo
16. Aburato
17. Tachiyazawa
18. Matsuhashi
19. Mogami
20. Akakura
21. Iragawa
22. Nezugaseki
23. Nakamata
24. Iwafune
25. Shiogama
26. Sendai
27. Nenoshiroishi
28. Oguni
29. Tamaniwa (Okitama)
30. Takamine
31. Ouchi
32. Soma
33. Seki (Sado)
34. Sasaoka
35. Akatani
36. Izumi
37. Fujitog'e-Shiozubo
38. Irihirose
39. Shichiku
40. Shiramizu (Jôban)
41. Tanakura (coal-bearing formation)
42. Tanakura
43. Asakawa

were modernized. In Late Miocene time the physiographic conditions were probably more complicated than in the previous stage, due to regional emergence and submergence as previously discussed. Accordingly, the floristic components of each flora are more or less different respectively in their localities or occurrences. It is, however, a common characteristic that they are dominant in cool-temperate deciduous trees accompanied with several warm elements.

The closest modern equivalents of their temperate elements now grow luxuriantly in Japan, also extending to Central or North China, Korea, Manchuria, etc. Late Miocene marine fauna which occurred in this region is considered to have flourished in a cool or even cold current, and this cold current probably caused a lowering of temperature. Such decline of temperature at that time brought out a luxuriant growth of cool-temperate elements taking the place of the warm Middle Miocene flora. However, it was probably so mild that the warm elements of *Liquidambar*, etc. were able to over-winter.

Following Late Miocene time, Pliocene depositional sites differentiated still more into small basins. Early Pliocene sediments in many areas of this region are mostly of marine origin, but sometimes lacustrine or continental sediments accompanied by fossil floras are locally distributed in interior basin areas and others: for instance, Sendai area (ENDO, 1938; OKUTSU, 1955), Aizu lignite field (SUZUKI, 1951: 1958) Mogami lignite field (TANAI, 1952) etc. Early Pliocene flora consists abundantly of *Metasequoia, Glyptostrobus, Sequoia, Picea, Pinus, Thuja,* etc., and also commonly of temperate deciduous trees such as *Myrica* (*Comptonia*), *Juglans, Pterocarya, Salix, Fagus, Betula, Alnus, Ulmus,* etc. It is characteristic in the flora of this age that coniferous trees increased gradually in number of species and specimens, while on the contrary warm elements decreased considerably. Such tendency of floristic change seemed to be especially considerable in the interior basin area. Namely, temperature seemed to decrease gradually during Pliocene age succeeding from Late Miocene time, and at the same time floral distribution differentiated locally.

At last, the younger Tertiary sea regressed gradually from this region, and performed the finable of its rôle at the close of Tertiary time. Late Pliocene regression resulted in many lignite-bearing sediments in various areas, which have many plant fossils. Late Pliocene flora is mostly similar to the above-described Early Pliocene flora in composition and components, but contains cool or cold species such as *Menyanthes, Picea, Larix,* etc. Namely, Pliocene floras in this region are much more abundant in cold elements than the floras of central and western Japan, which still contain such elements as *Liquidambar, Ilex, Parabenzoin,* etc. as reported in detail by MIKI (1941, 1950, etc.).

In short, corresponding with change of physical condition, the warm and cool-temperate floras appeared alternately in luxuriant growth during Tertiary time in northeastern Honshû. Both floras in Early-Middle Miocene time showed great contrast in their floristic composition, but the difference of their composition became gradually obscure. That is to say, Tertiary climate in this region indicated by the flora changed gradually from warm to cool-temperate or cold condition, though there were some fluctuations in the change. Moreover, the climate in Tertiary age was generally affected by sea influence which was especially considerable in Middle Miocene time.

VI. Conclusion

In northeastern Honshû many coal-bearing deposits being ranged from Oligocene to Pleistocene in age are scattered through the whole area, though most of the coals are of low-grade quality and small in scale with some exceptions. From the viewpoint of palaeogeography, most of their coal-bearing deposits were formed in the earlier or later stage of some transgression or regression. In such stage a swampy area being suitable for coal formation was probably formed in the lowland near the depositional basin. Among the coals of each stage, the coal formed as products of transgression are generally superior in quality and in their development to those of regression. The coals of this region are, in general, considered to have originated mainly from coniferous and deciduous broad-leaved trees grown under temperate climate, and only a slightly from ever-green trees grown under warm climatic condition.

In the progress of research of the so-called "green tuff" formation, the tectogenesis of the Tertiary system in Northeastern Honshû has been lately discussed by many geologists (OTSUKA, 1940; TANAI, 1951; MINATO, 1952, 1956; HUZIOKA, 1956; KATO, 1955; KITAMURA, 1958; OMORI, 1958; etc.) It is clearly observed that the general trend of pre-Tertiary rocks are from Northwest to Southeast in this region, and they are oblique to the major direction of the Tertiary structure. Some geologists have emphasized that the NW-SE direction of basement rocks played a main rôle in Late Tertiary tectogenesis of this region. However, the writer considers that geotectonic movements in this region were rather active in North-South direction, and that most of their trends are generally parallel to main faults and folding axes. The structural movements of NW-SE direction are considered to have had rather a subordinate rôle in the Tertiary history of this region.

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