

Geology and Palynology of the Hilly Area Southeast of Ichinoseki City, Iwate Prefecture, Japan

著者	Takeuti Sadako
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Sadako Takeuti

ABSTRACT

Stratigraphical and palynological studies on the Cenozoic deposits of the hilly area southeast of Ichinoseki City, Iwate Prefecture, were undertaken to determine the biostratigraphy based upon the pollen grains, the geological ages of the stratal units based upon the fossil pollen, the conditions under which the sedimentary basin was developed, and the relationship between transportation and deposition of the pollen. The stratigraphical sequence of the vertically and laterally variable lithofacies was determined, the geological structure of the sedimentary basin analysed, and the relationship between lithofacies and pollen-content interpreted from the viewpoint of aqueous and wind transportation. The paleoclimatic conditions during the ages of the different formation was worked out, and consideration was given to the features of the hinterland during deposition of the respective formations. Concerning the palynological study, the procedure, descriptions and interpretations are given in detail. A total of 9 species of pollen distributed among 34 genera were determined from the Pliocene and Early Pleistocene sediments of the area. Among them 4 species are considered new form-species or species.

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INTRODUCTION

The hilly area southeast of Ichinoseki City, Iwate Prefecture is interesting because of the development of terrestrial and marine facies, the former for the yield of lignite that has been worked on small scale and the latter for the marine fossils characteristic of both Miocene and Pliocene ages. However, details of the geology have remained unknown owing to that the vertical and lateral changes in lithofacies particularly of the terrestrial deposits has made stratigraphic work difficult, and on the other hand, the yield of fossils from such deposits are but few, thus paleontological evidence for age determination, correlation and other purposes had remained untouched in detail. For such reasons the writer has been engaged in studies of the geology and palynology of the area since many years ago, and the present work is the result of the studies.

Although not well preserved, leaves and drift woods have been reported from the Pliocene deposits of the hilly area, these have proved to be of little value for age determination, correlation and as evidence for paleocological considerations. The marine fossils from the lower part of the Pliocene rocks distributed in part of the present area have also remained untouched so far as a paleontological study is concerned.

Owing to the problems still remaining as mentioned above, the writer has found it necessary to make a paleontological investigation based upon the pollen grains by a method in which biostratigraphy and paleontology involve the usage of form species, consideration of crustal movements with transportation and deposition based upon frequency changes in lateral as well as vertical sequences from the geographical consideration. By the application of the methods just outlined she desires to point out their value in the present area and also to give suggestions for future work along advanced lines.

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PREVIOUS WORKS ON THE GEOLOGY AND PALEONTOLOGY OF THE HILLY AREA SOUTHEAST OF ICHINOSEKI CITY

The first stratigraphical study of the Cenozoic sediments of the hilly area southeast of Ichinoseki, Iwate Prefecture, was undertaken by Saito (1928, 1929) who described a part of the Tertiary sediments distributed in the eastern part of the present area on the occasion of his geological investigations in the vicinity of Usuginu, Iwate Prefecture. In his works he subdivided the Tertiary rocks into two formations of Miocene and Pliocene. Subsequently Noda (1934) mentioned on the Tertiary sediments in the area, when he made a geological investigation of the Paleozoic rocks distributed in the vicinity of Nagasaka, Iwate Prefecture.

Concentration on the Cenozoic sediments in the present area was first carried out by Shimakura and Tsuchida (1939) who described in detail the geology of the area bordering the Kitakami River, extending from the Hanamaki area at the north to the Ishinomaki area at the south. They subdivided the Cenozoic rocks into some formations and proposed the first stratigraphic sequence of the present area. Since then, stratigraphical investigations in the vicinity of Ichinoseki City were undertaken by Yamamoto (1941), Matsuno (1947) and Onodera (1951), but their works were for their graduation thesis of the Tohoku University and thus remained in manuscript form.

The stratigraphical works mentioned above were summarized by Hayakawa *et al.* (1954), Yabe *et al.* (1939), and Nakagawa *et al.* (1961). According to them, the stratigraphic sequence of the Ichinoseki area is as follows; the Pliocene Kitakamigawa Group is underlain by the Miocene and Pre-Miocene rocks with unconformity. The Kitakamigawa Group was classified into, from the lower to upper, the Ariga, Yushima, Kazawa and Mataka formations. The Lowest Pleistocene Takizawa Formation overlies the Upper Pliocene Mataka Formation with unconformity. The Pliocene-Pleistocene boundary of the present area was discussed by the Tohoku Region Quaternary Research Group (1969). Onuki (1966, 1969) pointed out the importance of the geological structure of the present area in connection with the geological history of the Tertiary Period.

Paleontological works on the marine and non-marine fossils from the Late Cenozoic sediments of the present area are few. Hatai and Yamamoto (1940) wrote on the significance of the molluscan fauna from the Yushima Formation near Ichinoseki City. According to them, the Yushima molluscan fauna is of the Tatsunokuchi fauna, and is Lower Pliocene in age. Onodera (1957) described the *Desmostylus* from the Miocene Shimokurosawa Formation at Mashiba, Ichinoseki City. Other records of fossils, mainly lists, are found in the reports on the stratigraphy, geology or geomorphology of the area in question. The present writer (1963, 1970, 1972) has carried on palynological studies of the Upper Pliocene and Lowest Pleistocene deposits of the area. As a result of the writer's study, knowledge concerning the pollen flora according to horizon, paleoclimatological conditions, sedimentary environment, and biostratigraphical evidence by the fossil pollen of the Late Cenozoic period of the present area has progressed.

GEOLOGY OF THE HILLY AREA SOUTHEAST OF ICHINOSEKI CITY

The hilly area southeast of Ichinoseki City consists of Pliocene and Pleistocene formations, underlain with unconformity by the Paleozoic rocks on the eastern side and westwards the Lower Pliocene and Miocene formations are distributed to the eastern foot

of the Backbone Range.

Though the purpose of the present study is concerned with the Pliocene and Pleistocene formations, brief accounts will be given to the pre-Pliocene formations distributed in the neighboring area because they form the basement of the Pliocene formations and are related closely with the deposition of the younger formations. Within the area studied, there have been distinguished the stratigraphic units given in Table 1.

Table 1. Stratigraphic sequence of the Tertiary formations in the hilly area southeast of Ichinoseki City (after Hayakawa *et al.*, 1954; Nakagawa *et al.*, 1961)

Geological age	Formation name	
Pleistocene	Terrace deposits	
	Takizawa Formation	
Pliocene	Kitakami Group	Mataki Formation
		Kazawa Formation
		Yushima Formation
		Ariga Formation
Miocene	Genbi Formation	
	Shimokurosawa Formation	
Permian	Toyoma Formation	

A. Basement Rocks

Each of the stratigraphic units is summarized briefly according to the previous works.

a. Toyoma Formation

The Permian Toyoma Formation is characterized by black slate intercalated with the two different types of conglomerate in the area. One of the conglomerates is called the Usuginu Conglomerate and the other is the Yamada Conglomerate. The formation is distributed east of the line drawn from Kozenji to Hinata via Yasakae, and forms the western margin of the Kitakami mountains.

b. Miocene Formations

The Miocene formations were classified into, the Shimokurosawa and Genbi formations in ascending order.

b-1. Shimokurosawa Formation

The type locality is the vicinity of Shimokurosawa along the Iwai River, west of Ichinoseki City. The Shimokurosawa Formation is distributed continuously from the drainage area of the Iwai and Kubo rivers to Kannari Town, Kurihara-gun, Miyagi Prefecture, west of the Tohoku Railway Line. The formation attains more than 300 meters in thickness. It is subdivided into lower and upper parts from the lithofacies. The lower part comprises an alternation of tuffaceous sandstone, pumiceous sandstone, tuffaceous siltstone, tuff breccia, pumiceous tuff and coarse grained sandy tuff, and has yielded a shallow water marine fauna mainly of molluscs among which some plant fossils are inter-

mingled. The uppermost part of the lower division is characterized by pyroclastic facies of tuff breccia, pumiceous tuff or sandy coarse grained tuff. The upper part comprises mainly massive dark green tuffaceous fine grained sandstone with interbedded thin pumice layers and sandy nodules, and has yielded a shallow water marine fauna mainly of molluscs and intermingled are some plant fossils. From this part, *Desmostylus* cf. *japonicus* Tokunaga and Iwasaki has been reported by Onodera (1957). The upper part of the upper division consists of cross-laminated yellowish brown coarse grained sandy tuff.

The important molluscan fossils from the Shimokurosawa Formation are: *Clinocardium shinjiense* (Yokoyama), *Trachycardium narusawaense* (Nomura), *Dosinia kaneharai* Yokoyama, *Dosinia odosensis* Nomura, *Lucinoma acutilineatum* (Conrad), *Macoma* cfr. *calcareo* (Gmelin), *Mastra kurikoma* Nomura, *Panomya simotomensis* Otuka, *Cultellus izumoensis* Yokoyama, *Serripes yokoyamai* Otuka, *Conchocele nipponica* (Yabe and Nomura), *Thracia hitosaoensis* Nomura, *Buccinum leucostoma* Lischke, *Natica janthostoma* Deshayes, *Neptunea koromogawana* Nomura and *Dentalium yokoyamai* Makiyama (Yamamoto, 1941; Matsuno, 1947; Onodera, 1957). The plant fossils from the formation are; *Sequoia* sp., *Abies* sp., *Populus balsamoides* Göppert, *Salix* sp., *Pterocarya rhoifolia* Siebold et Zuccarini, *Castanea* sp., *Fagus antipofi* Heer?, *Quercus* sp. and *Ulmus* sp. (Onodera, 1957).

b-2. Genbi Formation

The type locality is around Itsukushi, Genbi-machi, Ichinoseki City. The Genbi Formation is distributed from the drainage area of the Iwai River to the northern part of Miyagi Prefecture, west of the Tohoku Railway Line. The thickness of the formation is estimated to be about from 40 to 100 meters. The main part of the formation comprises dacitic welded tuff, whereas the lower part of the formation is composed of an alternation of tuffaceous sandstone and shale intercalated with several lignite seams, and the alternation changes laterally into cross-laminated sandstone in some cases. The formation with basal conglomerate overlies the Shimokurosawa Formation with unconformity.

The plant fossils from the basal part of the formation at Osawa in Hagisho, Ichinoseki City are; *Fagus palaeocrenata* Endo et Okutsu and *Acer palmatum* Thunberg (Onodera, 1951).

B. Pliocene and Pleistocene Formations

a. Kitakamigawa Group

The name of Kitakamigawa Group was proposed by Hayakawa *et al.* (1954) for the Pliocene System in this area. This group, bounded above and below by unconformities, is classified into four formations, from the older to the younger, the Ariga, Yushima, Kazawa and Mataka formations. The group is distributed in the hilly area southeast of Ichinoseki City and its environs. It lies with unconformity on the older rocks, such as of the Toyoma, Shimokurosawa and Genbi formations.

a-1. Ariga Formation

The type locality is around Ariga, Wakayanagi Town, Kurokawa-gun, Miyagi Prefecture. The formation is about 30 meters in thickness. It comprises an irregular alternation of sandstone, siltstone and sandy siltstone intercalated with lignite beds and conglomerate. The sandstone is coarse grained, quartz-rich and remarkably cross-bedded. The siltstone and sandy siltstone layers are bluish gray in color and contain fragments of natural charcoal. The siltstone layers have several lignite layers. The basal conglomerate of the Ariga Formation is 3 to 20 meters thick, but only 2-3 meters in the northern area, it rests upon the Miocene Genbi Formation with distinct unconformity.

The plant fossils reported by Yamamoto (1941) from the siltstone and sandy

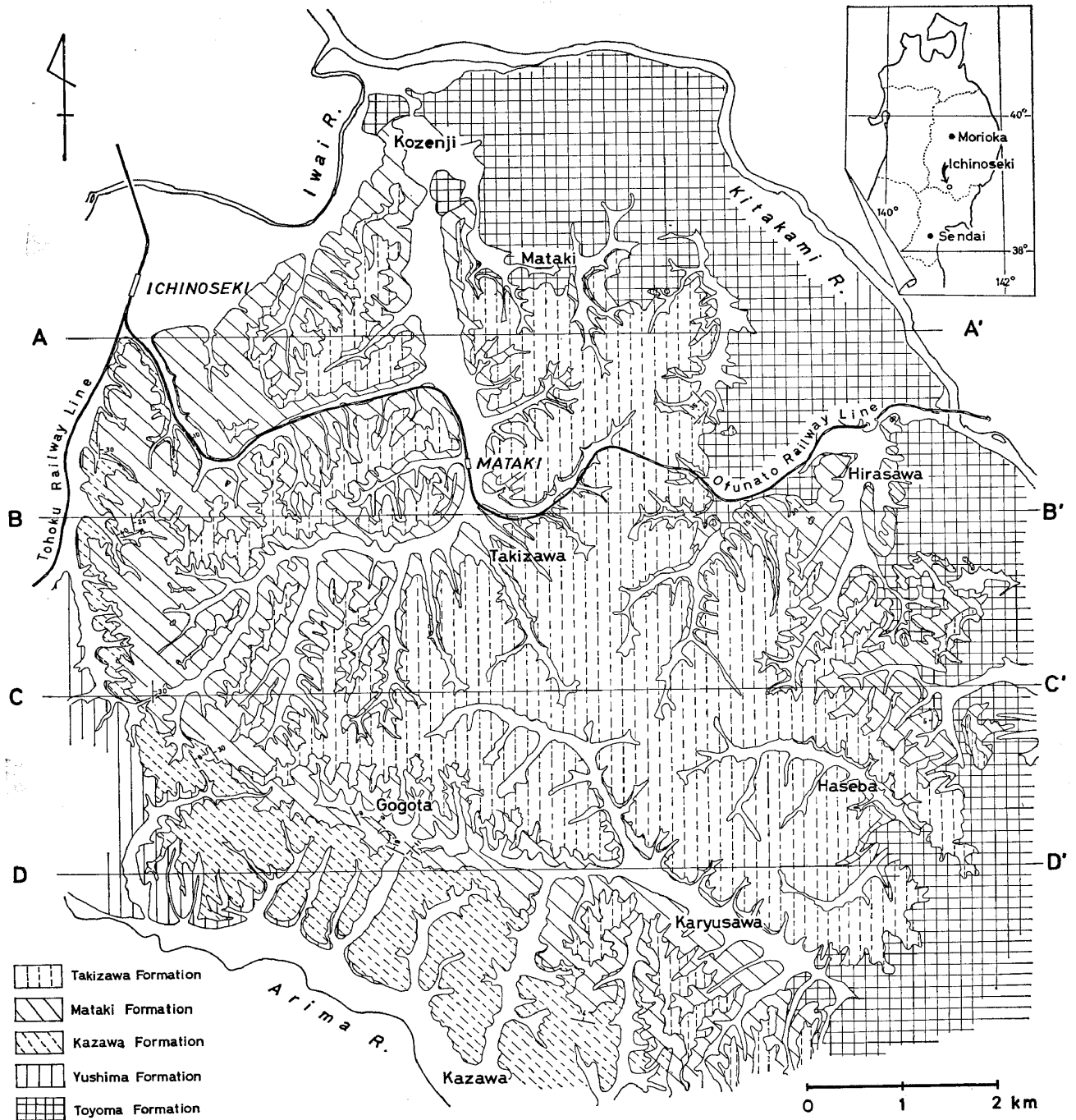


Fig. 1 Geological map of the hilly area southeast of Ichinoseki City, Iwate Prefecture.

siltstone layers of the formation are: *Fagus crenata* Blume, *Sequoia sempervirens* Endl., *Taxodioxydon sequoianum* Gothan, *Zelkova serata* Makino, *Acer pictum* Thunberg, *Sassa borealis* Makino and Shibata, and *Cryptomeria japonica* D. Don.

a-2. Yushima Formation

The type locality of the formation is around Yushima, Hanaizumi Town, Nishi-iwai-gun, Iwate Prefecture. The entire thickness of the formation is about 40 meters. It comprises mainly tuffaceous siltstone, bluish gray siltstone, bluish gray tuffaceous

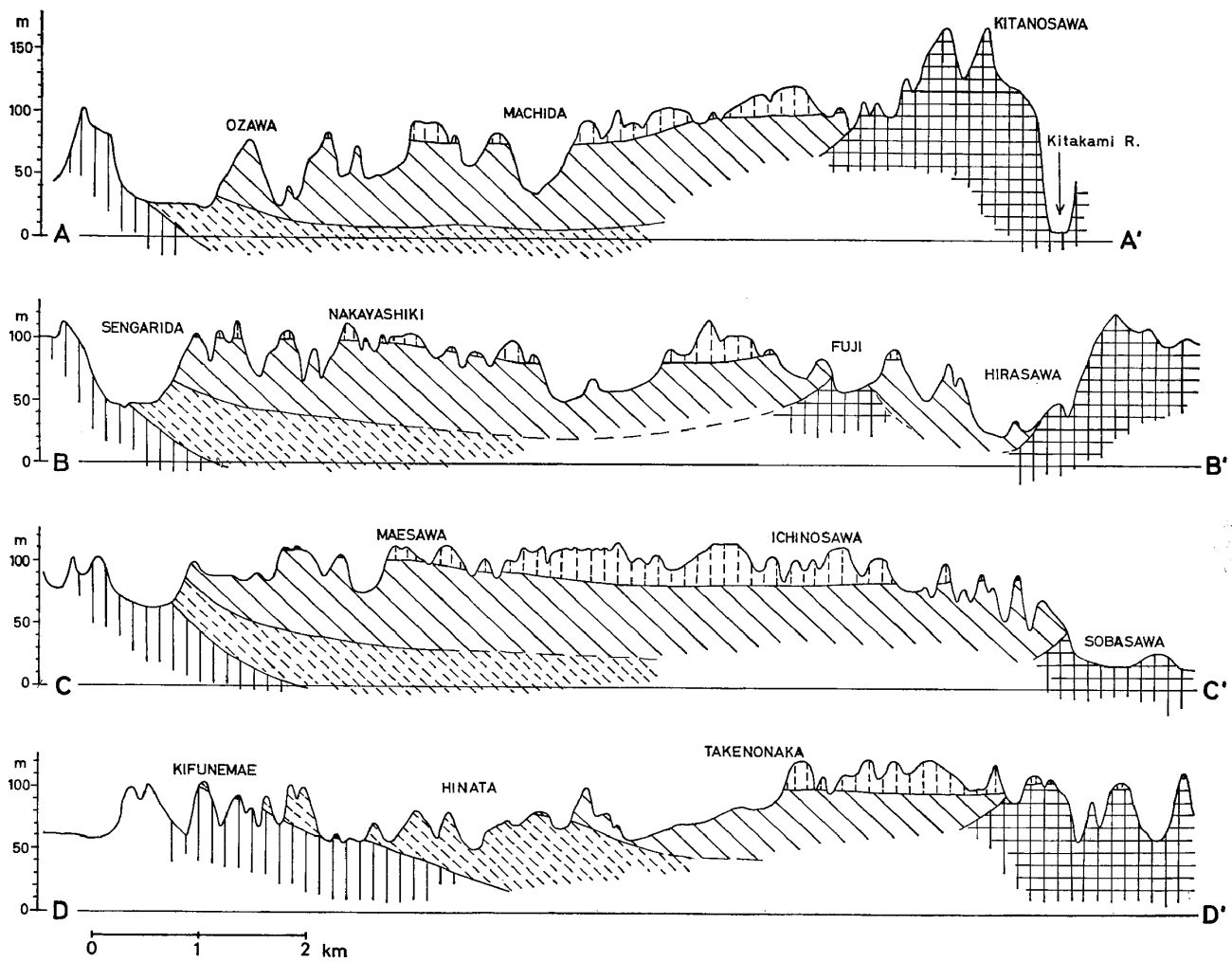


Fig. 2 Stratigraphic cross sections of the hilly area southeast of Ichinoseki City.

fine grained sandstone and coarse to very coarse grained sandstone. The tuffaceous siltstone occupies the rather upper part of the formation and is characterized by the development of laminations. The bluish gray siltstone, which yields abundant marine fossil molluscs, changes laterally into bluish gray fine grained sandstone with mica flakes and fragments of natural charcoal.

The Yushima Formation lies upon the Ariga Formation with conformity.

From the Yushima Formation, Shimakura and Tsuchida (1939) reported on the occurrence of the following fossil molluscs, namely; *Clinocardium californiense* (Deshayes), *Cardium* sp. indet., *Lucinoma acutilineatum* (Conrad), *Lucina* sp. indet., *Macoma tokyoensis* Makiyama, *Macoma praetexta* (v. Martens), *Macoma incongrua* (v. Martens), *Mya arenaria* Linné, *Ostrea gigas* Thumberg, *Fortipecten takahashii* (Yokoyama), *Pecten* sp. indet., *Panopaea japonica* (A. Adams) and *Peronidea venulosa* (Schrenck). Besides, from the formation some other fossils of particular interest, such as *Anadara tatsunokutiensis* (Nomura and Hatai), *Pitar sendaica* Nomura, *Pitar sendaica monstrosa* Nomura and *Polinices kiritaniana* Yokoyama, var., were found by Hatai and Yamamoto (1940) near Ishikoshi, Wakayanagi Town, Miyagi Prefecture. These fossils are typical of the Tatsunokuchi Formation in and around Sendai City.

According to Hatai and Yamamoto (1940), "The Yushima fauna can be briefly

characterized as, 1) nearly total absence of gastropods; this may be due to the bottom control, 2) large number of species in common with the Tatunokuti beds in the vicinity of Sendai; this suggests that the Yushima fauna lived in the same sea, 3) decidedly northerly aspect of the whole fauna, without a single typical southern form intermingled, 4) the majority of the bivalves are provided with very thick and heavy tests and show very good development in growth, 5) fauna consisting essentially of shallow-water species with some brackish-water forms, 6) water-worn shells were not found; this suggests that the fossils were embedded *in situ*, 7) where the *Ostrea*-bed occurs other forms of molluscan shells are nearly absent; this indicates unfavorable bottom control and environmental conditions for shells other than oysters, 8) small number of species but rather large individual, and, 9) species typical of sandy or other coarse materials are not found in the fauna. As to the age of the Yushima fauna, it is evident that Lower Pliocene may be accepted."

The Yushima Formation is distributed in a narrow strip along the western marginal part of the present area. In this narrow strip the Yushima Formation comprises mainly tuffaceous siltstone and sandstone, and marine fossils occur only in a small patch in the southwestern part of the field, elsewhere no fossils have been found.

Upwards the Yushima grades into the Kazawa Formation, which has different lithofacies according to places. In the northwestern margin of the field the Kazawa possesses conglomerate at the base, whereas in the central part of the western margin the base consists of tuffaceous sediments that rest upon the siltstone of the uppermost part of the Yushima Formation. In the southwestern corner of the field the Yushima Formation has siltstone at its top and this is covered by the conglomerate at the basal part of the Kazawa Formation. In the southern part of the field, the uppermost part of the Yushima consists of an alternation of sandstone and siltstone and this is covered by conglomerate of the basal part of the Kazawa.

Although no erosional surface was recognized between the two formations, the basal part of the Kazawa Formation lies upon different parts of the subjacent Yushima Formation, thus indicating that an unconformity exists between the two formations.

a-3. Kazawa Formation

The stratigraphic units, because of progressed field work, require certain emendations such as 1) designation of a new type locality, 2) definition of the lithology of the formation, 3) stratigraphic relationship with the super- and subjacent lithologic units and, 4) geographic distribution.

The type locality of the Kazawa Formation is the cliffs extending from Iikura to Hinata in Kazawa, Hanaizumi Town, Nishiiwai-gun, Iwate Prefecture.

At the type locality, the formation comprises, from the lower, a 25 m thick alternation of conglomerate, tuffaceous cross-bedded sandstone and siltstone intercalated with tuff and lignite layers, 8 m thick brown medium grained sandstone, 11 m thick siltstone with interbedded a thin tuff layer, 13 m thick thin alternation of tuff and tuffaceous siltstone intercalated with several lignite seams.

The thickness of the formation is estimated to be from 40 to 60 meters, and it can be subdivided into the lower and upper parts from lithofacies.

The lower part comprises an alternation of conglomerate, sandstone, and siltstone intercalated with tuff and lignite layers in part. The facies of the alternation changes laterally; it comprises mainly siltstone in the vicinity of Sengarida in Ichinoseki City, towards the south it becomes dominated in sandstone and conglomerate, it consists of an alternation of coarse grained sandstone and siltstone at the south of Higashizawa in Ichinoseki City, and comprises an alternation of conglomerate, sandstone and siltstone, or conglomerate and sandstone in the vicinity of Daimon in Hanaizumi Town. The facies

changes not only towards the south but also to the east. At the east of Uchizawa in Hanaizumi Town, it comprises mainly conglomerate, grading upwards into sandstone and siltstone.

The several lignite seams or coaly siltstones interbedded in the siltstone layers, are not continuous, but thin out laterally and form lenticular structures of various shapes and sizes. The columnar sections of the lower part of the Kazawa Formation taken at many different localities show the number of lignite layers, the differences in their thickness and the stratigraphic horizons at which they occur. In the vicinity of Sengarida, the siltstone in the lower part of the formation has four lignite seams. The lowest one occurs at 6 m from the base of the formation; it is about 1.5 m thick and of rather coaly siltstone; the next one is 3 m above the first, 50 cm in thickness and of coaly siltstone, the third one occurs at 6 m above the second, is 80 cm thick lignite seam and intercalated with 10 cm thick sandy tuff, and the fourth lignite seam measures 110 cm in thickness, its lower part (50 cm thick) is of coaly siltstone and westwards it dies out within about 10 m distance. South of Higashizawa in Ichinoseki City, two siltstone layers alternate with coarse grained sandstone and intercalate lignite seams. The lower seam is 45 cm in thickness and grades upwards into coaly siltstone, and the upper one is 50 cm thick and dies out in lenticular form within a short distance. At Hinata in Hanaizumi Town, the uppermost siltstone layer has only one lignite seam, it is woody and dies out into a siltstone covered with white tuff.

The upper part of the Kazawa Formation comprises from the lower, conglomeratic sandstone, sandstone, siltstone and an alternation of tuff and tuffaceous siltstone intercalated with lignite seams. The lower conglomeratic sandstone often contains siltstone patches at the basal part. The succession from the lowermost conglomeratic sandstone to the uppermost tuff with lignite seams is recognized throughout the area of distribution of the formation from the western to southern parts of this area, whereas generally it comprises mainly conglomerate at the east of Uchizawa in Hanaizumi Town.

The uppermost part of the upper division of the Kazawa Formation is characterized with an irregular alternation of tuff and tuffaceous siltstone, of about 10 meters in thickness, grayish white or white in color and has several lignite or coaly siltstone layers, that can be traced nearly throughout the distribution of the formation. Though each of the lignite or coaly siltstone layers intercalated in the uppermost part is thin and non-continuous, wherever the alternation is developed, one to six layers are intercalated.

The Kazawa Formation is distributed in the western part of the field also in rather narrow belt form being narrow in the northwestern part and becoming broader southwards because the dip is steeper at the north and low at the south. Within this narrow belt area the Kazawa shows certain differences in lithofacies, comprising mainly siltstone at the northwestern part, siltstone and gravelly sandstone at the central part, and of an alternation of sandstone, siltstone and gravelly sandstone at the southwestern part. The change in lithofacies in north to south direction and also in west to east direction is recognized, but in the uppermost part of the formation there is developed an alternation of tuff and siltstone distributed from the northern to southern part of distribution of the formation.

Throughout the distribution of the Kazawa Formation the grain size of the sandstone facies is generally of medium to coarse grained, in the case of siltstone the facies becomes tuffaceous to almost pure siltstone, and the conglomerate layers are developed in the southern to central part of distribution of the formation and number about three to four, each measuring about one meter in thickness and showing no grading. Where sandstone facies overlies the conglomerate, the gravels gradually give way to the sandstone facies.

In general the gravels of the conglomerate are mostly platy in the northern part but rounded elsewhere, rather densely arranged in the sandstone matrix, however, upwards the density of the gravels decrease.

The plant fossils from a tuffaceous siltstone layer in the upper part of the Kazawa Formation at Hinata in Hanaizumi Town are: *Sassa* sp. and *Phragmites* sp. (Yamamoto, 1941), and from the same formation other plant fossils are known to occur; *Glyptostrobus* sp., *Fagus* sp., *Acer* sp. and *Trapa* sp. (Onodera, 1957).

a-4. Mataki Formation

Upwards the Kazawa Formation is superposed by the Mataki Formation with conformity. The Mataki Formation is distributed on both sides of the basin, occupying only the marginal part at the east and a rather broad area at the west, whereas at the north and south the area of distribution becomes narrower (Fig. 1).

The type locality is in the vicinity of Gogota in Hanaizumi Town, Nishiiwai-gun, Iwate Prefecture.

At the type locality, the Mataki Formation comprises in ascending order, 3.8 m thick pebble to granule conglomeratic cross-bedded sandstone intercalated with a 30 cm white pumiceous coarse grained tuff, 1.5 m thick coarse grained tuff, 1.8 m thick tuffaceous very coarse grained sandstone grading upwards into tuffaceous very coarse grained sandstone intercalated with thin siltstone layers, 1 m massive siltstone, 3 or 4 m thick pebble to granule conglomeratic sandstone, 2 or 3 m thick sandy siltstone grading upwards into siltstone, 3 or 4 m thick very coarse grained cross-bedded sandstone grading upwards into 1 m thick sandstone, 6 m thick grayish violet silty tuff grading upwards into pumiceous tuff intercalated with coaly siltstone, 1.5 m thick yellowish white pumice-flow tuff, 9.7 m thick grayish white tuff intercalated with pumice and pisolite layers and grading upwards into laminated silty tuff, 5 m thick massive pumiceous tuff, 50 cm thick siltstone intercalated with a coaly siltstone layer, 13.8 m thick pumiceous tuff intercalated with silty tuff and sandy tuff layers and a 4.5 m thick tuffaceous siltstone.

The thickness of the formation is from 45 to 65 meters. In the area studied, the Mataki Formation is composed roughly of two cyclothems, comprising from the lower upwards, conglomeratic sandstone or sandstone, siltstone and tuff, and can be subdivided into the lower and upper parts.

The lower part of the formation comprises brown conglomeratic very coarse grained sandstone intercalated with siltstone and tuff layers in the lower, grading upwards into siltstone or tuff. The conglomeratic sandstone often contains siltstone patches.

At the west of Sawa in Ichinoseki City, the lower part of the Mataki Formation comprises from the lower, a 14 m thick cross-bedded conglomeratic sandstone, 4 m thick sandstone intercalated with thin siltstone layers, 1 m thick tuff and a 3 m thick silty tuff. The lowermost conglomeratic sandstone is thinner at the south, in the south of Sawa it becomes 3 m thick, and is overlain with a 10 m thick silty tuff of which the uppermost part has a coaly tuffaceous siltstone layer of lenticular form. At the south of Higashizawa in Ichinoseki City, conglomeratic sandstone becomes again thicker, attains 11.5 m in thickness and intercalates an about 3 m thick silty tuff layer.

The upper part of the Mataki Formation consists of, from the lower, conglomeratic sandstone, tuffaceous siltstone and grayish white tuff intercalated with pumice and silty tuff layers in the vicinity of the type locality. The upper grayish white tuff was named "Gogota tuff" by Yamamoto (1941), and intercalates a more than 1 m thick yellowish white pumice-flow tuff in the lower part under which is a lignite or coaly tuffaceous siltstone layer. In this area a 5 to 65 cm thick lignite layer is intercalated in the upper part of the grayish white tuff.

The rock facies and thickness of the upper part of the Mataki Formation changes laterally. In the belt zone trending in about NNW-SSE direction, from around Sawa in Ichinoseki City, to around Gogota in Hanaizumi Town via Magisawa, it shows a succession from the lower, conglomeratic sandstone, tuffaceous siltstone and grayish white tuff intercalated with pumice-flow tuff and silty tuff layers with lignite seams. On the eastern side of this zone, it comprises an alternation of tuffaceous cobble to pebble conglomeratic sandstone and siltstone or tuffaceous siltstone intercalated with thin tuff layers. The siltstone layers often have thin and non-continuous lignite seams. At Tateshita in Ichinoseki City, it comprises from the lower, an about 5 m thick conglomeratic sandstone, 2 m thick gray siltstone, 1.5 m thick pebble to granule conglomeratic sandstone grading upwards into sandstone, 1.5 m thick tuffaceous siltstone, 20 cm thick lignite seam, 5 m thick cross-bedded granule conglomeratic sandstone grading upwards into sandstone, 2 m thick silty tuff, about 2 m thick laminated sandy tuff, 4 m thick pebble to cobble conglomerate with sandstone lenses and an about 4 m thick sandstone grading upwards sandy siltstone. In the southwest of Hirasawa, Yasakae and Kamifuji, in Ichinoseki City, at the northeastern margin of the distribution of the formation, it again becomes dominant in tuffaceous siltstone or tuffaceous sandstone intercalated with thick tuff with woody lignite seams.

The Mataki Formation overlies the subjacent Kazawa Formation with conformity.

The following fossil woods were collected from the Mataki Formation at Fuji in Ichinoseki City by Shimakura and Tsuchida (1939), and identified by Shimakura; *Cedroxylon* (*Abies*) sp., *Cupressinoxylon* sp., *Taxodioxyton Sequoianum* Gothan and *Gleditschia* sp. Onodera (1957) reported on the occurrence of such fossils as *Sequoia* sp., *Fagus* sp., *Quercus* sp., *Zelkova* sp., *Acer* sp. and *Trapa* sp. from the formation.

The dips of the Mataki Formation at the eastern marginal part of the basin show a general westward yet low inclination, whereas along the western margin of the basin the Mataki dips eastwards, at the northwestern to northern parts of the field the formation dips northwards and at the southern part of the field the formation shows a gradual north-early dip, suggesting a basin structure of low dips (Figs. 1, 2).

The Mataki Formation is overlain by the Takizawa Formation with unconformity. The Takizawa shows rather broad distribution, especially because it covers the Mataki and occupies the central part of the field.

The Neogene formations in the area studied comprise the Yushima, Kazawa and Mataki formations, and these are overlain with unconformity by the Quaternary deposits here represented by the Takizawa Formation. As shown in the geological map of the area, the unconformity separating the Quaternary Takizawa Formation from those of the Neogene is quite significant. Other deposits of Quaternary age are the terrace deposits but these are not included in the present paper.

b. Takizawa Formation

The type locality of the Takizawa Formation is the cliffs at Takizawa in Ichinoseki City, Iwate Prefecture.

The thickness of the formation is about 40 meters. It comprises from the lower upwards, conglomerate, sandstone, clayey siltstone and tuff intercalated with peaty layers. The lower conglomerate is the thickest in the area, extending from the Mataki Station along the Ofunato Railway Line to Uetate-toge in Hanaizumi Town via Takizawa. Here, the sequence of the formation from the lower is about 15 m thick conglomerate intercalated with cross-bedded sandstone and peaty clay layers in part, overlain with an about 10 m thick coarse grained cross-bedded sandstone with clay layers, superposed with siltstone or tuff. The lower conglomerate often contains siltstone boulders and tuff patches. At

Shimoterada in Ichinoseki City, the siltstone layer lies upon the lower conglomerate directly. The lower conglomerate layer becomes thinner towards the west. At Nakayashiki in Ichinoseki City, the formation comprises from the lower, a 2.5 m thick conglomerate, 1.5 m thick coarse grained sandstone, 3.5 m thick tuffaceous clayey siltstone with peaty layers and an about 5 m thick conglomeratic cross-bedded sandstone. At Doshin-zukasugi in Ichinoseki City, it comprises from the lower upwards, a 6 m thick conglomerate intercalated with sandstone layers, 1.5 m thick pumiceous tuff, 2 m thick very coarse grained cross-bedded sandstone, 2 m thick pumiceous tuff, 2 m thick gray siltstone and a 5 m thick sandy tuff.

The Takizawa Formation lies upon the Mataka Formation with unconformity. The basal conglomerate of the Takizawa Formation lies upon the eroded surface of the Mataka Formation at Nakayashiki, Shinden and at Ichinosawa, whereas at both Kinokawa and Kusakariba the contact of the Takizawa with the underlying Mataka Formation seems to be a conformity. Southeast of the hilly area, the Takizawa Formation lies upon the Toyoma (Permian) Formation with unconformity.

RELATIONSHIP BETWEEN THE BASIN STRUCTURE AND LITHOFACIES

As already mentioned above, a basin structure can be recognized in the area studied, the Yushima and Kazawa formations occupying mainly the western marginal part of the field, whereas the next younger Mataka is distributed along both western, northern, southern and eastern parts of the field, and the youngest Takizawa Formation is distributed in the central part of the basin.

The basin structure is in good accordance with the lithofacies changes of the Kazawa, Mataka and Takizawa formations. In fact, the lateral lithofacies change of the Mataka Formation is the most remarkable and significant.

At the western part of the field tuffaceous sediments predominate, and these in eastward direction change into sandy facies and then to a facies of sand and gravels, then to predominantly of gravels at the central part. The latter mentioned gravelly facies in north to south direction, suggesting drainage along that direction. The gravels distributed in north to south direction are also significant because of exhibiting rounded shapes among which sometimes platy siltstone gravels showing imbrication can be observed. From the imbricated structure it is inferred that the drainage was varied, flowing at one time from south to north, but at another time from north to south as can be judged from the directions shown by the cross-bedding structures. Along the western margin of the field the dips of the cross-bedding is towards the east and at the eastern margin of the basin, there is a vague westward trend of the cross-bedding structures. Contrary to the cross-bedding structures, the imbricated structures are recognized at the northwestern marginal part of the field.

From the cross-bedding structures and imbrications it is inferred that drainage in the present area was somewhat varied, being from the margins towards the central part during the early phase of the Mataka time, but from north to south locally during a later phase.

The varied movements of water flowage during the time of Mataka deposition had relation with the distribution of the pollen grains and also probably with the movements leading to the development of the basin structure. In other words, gradual uplift of the marginal parts and subsidence of the central parts resulted in the development of the basin structure and also in control of the water-movement during deposition of the non-marine sediments.

GEOLOGICAL STRUCTURE

The geological structures and sedimentary structures observed in the present area consist of unconformity, conformity, fault, current structures, contamination structures and minor sedimentary structures. These are mentioned briefly in the following lines.

1. Unconformity. The unconformities observed in the present area are between the Yushima and Kazawa, Mataki and Takizawa, Mataki and Yushima, Mataki and Permian, Takizawa and Permian, and between the mentioned formations and terrace deposits. Although most of these are erosion surfaces, the ones between the Permian and younger deposits are all clino-unconformities. Where the erosion unconformities are observed, in general, the uppermost parts of the subjacent formations are eroded to various grades according to locality and local differences in uplift.

Concerning the unconformity between the Yushima Formation and the Kazawa Formation, it is evident that former is marine in origin whereas that of the latter is terrestrial, and this abrupt change is considered evidence for an unconformity; secondly, the conglomerate at the base of the Kazawa Formation lies upon the sandstone of the upper part of the Yushima Formation at Sengarida, and upon the siltstone of the Yushima at the south of Higashizawa and in the vicinity of Daimon, and it also lies upon the alternation of sandstone and siltstone of the Yushima Formation at the north of Daimon and at Iikura. In detail the alternation just mentioned lies upon the siltstone aforementioned, whereas the sandstone lies below the siltstone. Thus from the stratigraphic sequence it is evident that the Kazawa Formation lies upon different horizons of the Yushima Formation, and therefore, the unconformity is angular but of low dips.

The unconformity between the Mataki and Takizawa formations can be observed at various places, and a typical exposure is at Nakayashiki, where upon the eroded surface of silty tuff of the Mataki Formation the conglomerate at the base of the Takizawa Formation is superposed. The erosion surface between the formations indicates an unconformity, but the time and magnitude of this unconformity remains unknown because of the lack of paleontologic evidence. The same relationship can be observed at Dorohata, Takizawa and at Ichinosawa. The base of the Takizawa Formation is everywhere of conglomerate whereas the topmost part of the Mataki Formation consists of different facies, such as of silty tuff, sandy tuff, sandstone and of tuff, thus it appears as if the Takizawa lies upon different horizons of the Mataki Formation, although actually most of the said facies are lateral changes.

2. Conformity. In the cases where the two formations are in conformable relation with one another there is always found a gradual upwards change in lithofacies from the subjacent to the superjacent. And when conglomerate is found at the basal part of the superjacent formation, the gravels are found to be partly embedded or at least sunken into the stratum at the uppermost part of the subjacent formation.

3. Fault. Faults of major magnitude are not recognized in the present area. The only ones recognized are of very slight throw of only about up to several meters, and all are normal ones, of short distance (traced) and do not affect the geological structure.

Of the two faults observed in the Takizawa Formation at Nakayashiki and Takizawa, it is interesting to notice that both of them cut the Takizawa Formation but not the underlying Mataki Formation, thus proving that they are intraformational or penecontemporaneous developed faults. The throw of these two penecontemporaneous faults are from 20 cm to about 2.5 m, and neither can be traced in the field. The fault observed in the Mataki Formation at the north of Karyusawa is a normal one, almost vertical, and also penecontemporaneous because it cuts neither subjacent nor superjacent formations. These faults can be neglected in the geological map because they do not affect the distribution of the

strata they cut and also because they have so little throw and can be traced only for a very short distance.

4. Current structures. Current structures are represented by small cross-bedding structures and some current marks. The cross-bedding and cross-lamination structures are of small scale, not traceable for any noteworthy distance, developed only very locally and do not affect the lateral change in lithofacies of the formations in which they occur. Thus they are merely mentioned at this place. Other kinds of current structures may be in the form of incipient flute casts and striations at the basal part of the Kazawa and Mataka formations and also in part within the Yushima Formation, but not in the Takizawa Formation.

5. Contamination structures. The contamination structures here referred to is the mixing of sediments comprising the lateral extensions of lithofacies characterizing the formation such as the lateral extension of the Mataka Formation, which in central part of the field, is a mixed facies of both eastern and western lateral extensions of the formation proper.

6. Minor sedimentary structures. The minor sedimentary structures mentioned here consist of such as load cast, minor upward injections resembling incipient clastic dikes and incipient to vague sole marks. Also streaks, thinning out and minor lenticular structures are noticed in the lignitic parts of the beds.

GEOLOGICAL AGE AND CORRELATION OF THE PLIOCENE FORMATIONS

The geological age of the Yushima Formation, the Early Pliocene is based upon the fossil marine molluscs. The more important marine molluscan fossils from the Yushima Formation are, *Fortipecten takahashii* (Yokoyama), *Anadara tatsunokutiensis* (Nomura and Hatai), *Pitar sendaica* Nomura, *Pitar sendaica monstrosa* Nomura and *Polinices kiritaniana* Yokoyama, var., all of which are characteristic in the Tatsunokuchi Formation of the Sendai area. The Tatsunokuchi Formation and its correlatives are well known for the occurrence of the fossils mentioned above in addition to the occurrence of *Trilophodon sendaicus* Matsumoto, an elephant of Pliocene age. Also occurring from the Tatsunokuchi Formation are whales, dolphins, crabs, sharks, plant leaves, drift-woods, abundant marine molluscs besides fishes. The age of the Tatsunokuchi Formation from its abundant fossils of many different kinds has been referred to the Pliocene (Matsumoto, 1927; Nomura and Hatai, 1936; Endo, 1938; Yabe and Hatai, 1940, 1941; Okutsu, 1955; and others — see bibliography), and the age has been accepted in general. Thus, for the reasons just stated the Yushima Formation, from its yield of characteristic marine molluscs that are restricted to Tatsunokuchi time, is inferred to be Pliocene in age, and from stratigraphic position in the geological column in the Sendai area, to represent the Early Pliocene.

The Early Pliocene age of the Yushima Formation is as stated above, but concerning the Kazawa and Mataka formations that are superjacent to the Yushima, some remarks seem to be necessary.

The Kazawa Formation overlies the Yushima Formation with unconformity, and has yielded some plant fossils, such as, *Sassa* sp., *Phragmites* sp., *Glyptostrobus* sp., *Fagus* sp., *Acer* sp. and *Trapa* sp. Although these plant fossils have not been determined to specific level, it is known that the genus *Glyptostrobus* ranges in age from the Miocene to Pliocene and is not known from the Pleistocene, and also, the specimens referred to the genus *Fagus* show resemblance with *Fagus crenata* Blume a characteristic species in the Pliocene Sendai Group of the Sendai area where *Sassa* is also a characteristic member. From the chronostratigraphic range of the genus *Glyptostrobus* and the stratigraphic posi-

tion of the Kazawa Formation in the geological column of the present area, it is without doubt, that the Kazawa is Pliocene age.

The Kazawa Formation is overlain by the Mataka Formation with conformity. The Mataka has yielded plant fossils of the genera *Sequoia*, *Castanea*, *Fagus*, *Quercus*, *Zelkova*, *Acer* and *Trapa* besides woods belonging to the genera *Cedroxylon* (*Abies*), *Cupressinoxylon*, *Gleditschia* and *Taxodioxylon sequoianum* Gothan. Among these plant fossils, *Sequoia*, *Fagus*, and *Quercus* are well known genera of the Sendai Group, and have not been recorded from the Pleistocene formations distributed in the area of Northeast Honshu. *Taxodioxylon sequoianum* Gothan is a species ranging in time from the Miocene to the Pliocene and has not been recorded from the Pleistocene deposits. Thus from the plant fossils and the stratigraphic position of the Mataka Formation which is superjacent to the Kazawa and subjacent to the Takizawa formations, the geological age should also be considered to be Pliocene.

The youngest stratigraphic unit in the area studied is the Takizawa Formation, a unit which lies with distinct unconformity upon the Mataka Formation and also upon the Toyoma Formation (Permian). The Takizawa Formation has yielded *Picea maximowiczii* Regel besides other abundant pollen grains. The just mentioned plant fossil is common in the Pleistocene, but not in the Pliocene or older deposits in the vicinity of the present area. Pollen grains of the genera *Sequoia*, *Metasequoia*, *Glyptostrobus*, *Liquidambar*, *Nyssa* and *Symplocos* besides others disappear at or before reaching the boundary between the Mataka and Takizawa formations, and this is thought to be good evidence that the Mataka is palynologically distinctly older than the Takizawa which does not contain such genera. Further, the genus *Cryptomeria* is common in the Takizawa, but does not appear in the Mataka or older formations, *Cornus* is another genus analogous in range to that of the one just mentioned. This kind of range shown by the genera just mentioned is also thought to support the chronological distinction of the Takizawa from the Mataka, and so far as Northeast Honshu is concerned, to be helpful criteria for separation of the Pleistocene from the Pliocene. Thus the Pleistocene age is ascribed to the Takizawa Formation upon the data mentioned above. Thus from stratigraphic position, relation with the older formations and the yield of Pleistocene plant fossils, the Takizawa Formation is here considered to be Pleistocene age.

From the stratigraphic sequence of the formations developed and distributed in the area studied and their paleontological relationship with the formations of the Sendai Group and younger formations of the Sendai area, correlation between the two is judged to be as shown in Table 2.

With regard to the geological age of the formations older than the Pliocene Yushima Formation, it can be said that the age of the Toyoma Formation is Permian from the occurrence of the two fusulinid genera *Yabeina* and *Neoschwagerina* besides the molluscan fossils reported by Murata (1969). The Toyoma Formation occupies the uppermost part of the geological column of the Paleozoic rocks of the southern part of the Kitakami Mountainland.

The ages of the formations distributed between the Permian Toyoma Formation and the Early Pliocene Ariga Formation are all of Miocene age from the following mentioned paleontological evidence, as well as stratigraphic position in the geological column of the area adjacent to that treated in the present work.

The Shimokurosawa Formation, the earliest of the marine sedimentary units of the Neogene rocks distributed in the area adjacent to the present one has yielded from its upper part the well known marine mammal called *Desmostylus* and from its lower part marine molluscs of the genera *Chlamys*, *Gloripallium*, many other bivalves and univalves which

Table 2. Correlation of the Pliocene and Younger Formations of the Ichinoseki and Sendai Areas

	Present area		Sendai area	
Pleistocene	Terrace Deposits		Terrace Deposits	
	Takizawa Formation		Aobayama Formation	
Pliocene	Kitakamigawa Group	Mataki Formation	Sendai Group	Dainenji Formation
		Kazawa Formation		Yagiyama Formation
		Yushima Formation		Hirosegawa Tuff
		Ariga Formation		Kitayama Formation
				Tatsunokuchi Formation
		Kameoka Formation		

are characteristic of the Miocene deposits of northeastern Honshu, such as, *Chlamys kotorana* Otuka, *Placopecten akihoensis* (Matsumoto), *Gloripallium crassivenius* (Yokoyama), *Mizuhopecten kimurai* (Yokoyama), *Nanaochlamys* sp., *Venericardia siogamensis* Nomura, *Trachycardium shiobarensis* (Yokoyama), *Dosinia kaneharai* Yokoyama, *Dosinia akaisiana* Nomura, *Mactra kurikoma* Nomura, *Macoma aomoriensis* Nomura, *Soletellina minoensis* Yokoyama, *Cultellus izumoensis* Yokoyama, *Panomya simotomensis* Otuka, *Turritella shataii* Nomura, *Neptunea koromogawana* Nomura, the shark teeth *Isurus hastalis* (Agassiz) and *Carcharodon megalodon* (Charlesworth), the sponge *Aphrocallistes* sp., plant remains as *Populus balsamoides* Göppert and *Fagus antipofi* Heer besides others. Among the fossils mentioned, *Desmostylus* is known only from stratigraphic levels restricted to the Early to early Middle Miocene, the scallops to the Early Miocene but some range up to the Middle Miocene, and the other fossils are all restricted to Miocene in range and none are known from the Upper Miocene. The plant fossils, shark teeth and sponge are all characteristic in the Miocene deposits. From the evidence just mentioned it is believed that the Shimokurosawa Formation ranges in age from the latter part of the Early Miocene to Middle Miocene.

From the stratigraphic position of the Genbi Formation, which is characterized by its acidic rocks, that is to say, superposed with unconformity upon the Shimokurosawa Formation and subjacent with distinct unconformity with the Ariga and younger formations of Pliocene age, the Genbi could be allocated to the Late Miocene age.

It may also be said that during the Late Miocene time in Northeastern Honshu there was an intense volcanic activity of acidic rocks, particularly of Dacite, and this particular volcanism marks the Late Miocene where sedimentary rocks are lacking.

From the stratigraphic position of the formations aforementioned, their stratigraphic relations with younger and older formations, paleozoological and paleobotanical evidences, it is judged that the Miocene and Pliocene formations of the present area can be correlated with the Miocene and Pliocene formations distributed in the Sendai area.

GEOLOGICAL HISTORY

After a long period of subaerial denudation the southern area adjacent to the area studied was flooded by warm, shallow, tranquil seas which brought into the area such fossils

as *Placopecten akihoensis* (Matsumoto), *Mizuhopecten kimurai* (Yokoyama), *Nanaochlamys* sp., many cockles, gastropods, sponges, shark teeth and other fossils. The inundation of the seas accompanied with gradual subsidence of the then existing land area resulted in sedimentation of the Shimokurosawa Formation during which latter part the sea mammal called *Desmostylus* invaded the area. The *Desmostylus* is a northern circum-pacific aquatic mammal thriving in shallow inner neritic areas and feeding mainly on burrowing molluscs and sea-weeds. The marine invasion was widespread and covered the larger part of the then existing Japanese Islands, extending to the southeastern part of Korea, over a large part of Hokkaido, Northeast Japan as well as other parts of the Japanese Islands.

Following sedimentation of the Shimokurosawa Formation and nearing its completion, gradual uplift accompanied with regression of the seas was the time of invasion of the *Desmostylus*, after which complete uplift occurred. The uplift and regression of the tranquil seas resulted in a rather long period of erosion during which the land surface was peneplaned. Thereafter there occurred rather intense volcanic activity of acidic rocks, particularly of dacite, that was spread widely over the northern part of Japan. This dacite eruption was concentrated largely to the present area of the backbone ranges and its eastern and western borderlands. By this dacite eruption associated with partial marine invasions and deposition of fossiliferous sedimentary rocks, the Genbi Formation and its correlative was developed. The age of this period is generally accepted as equivalent to the Upper Miocene, whereas that of the subjacent Shimokurosawa Formation to late Early Miocene to Middle Miocene.

During the deposition and development of the Shimokurosawa and Genbi formations the crustal stability was rather uniform and no noteworthy events occurred in the area studied.

After deposition of the Shimokurosawa Formation and development of the next younger Genbi Formation there occurred in the present area uplift followed by subaerial denudation that resulted in lowering of the land surface. This destructional history is well displayed in the conglomerate of the next younger Pliocene Ariga Formation, the lowest of the Pliocene deposits in the present area. The Ariga Formation distributed in the present area is a lacustrine deposit composed of sandstone and siltstone with conglomerate at the basal part. The Ariga was succeeded by a gradual subsidence of the land and the first marine transgression of the Pliocene age in northeastern Honshu, Japan. The first stage of the Yushima Formation, the earliest of the marine formations in northeastern Japan, commenced with lignitic material at places, thus showing that the first stage was a shallow lagoonal condition. However, under the condition of continued subsidence and flooding of the area by shallow marine water, there was brought into the present area typical shallow water marine shells as *Clinocardium californiense* (Deshayes), *Lucinoma acutilineatum* (Conrad), *Macoma tokyoensis* Makiyama, *Macoma incongrua* (v. Martens), *Ostrea gigas* Thumberg, *Fortipecten takahashii* (Yokoyama), *Panopaea japonica* (A. Adams), *Anadara tatsunokutiensis* (Nomura and Hatai), *Pitar sendaica* Nomura, all of which are infaunal species except *Fortipecten* and *Ostrea*. The only epifaunal species are *Fortipecten* and *Ostrea* including *Polinices kiritaniana* (Yokoyama). These marine shells are quite characteristics of the Pliocene, especially the *Fortipecten*, *Pitar*, *Anadara* and gastropod, and widely distributed in the Tatsunokuchi sea of northeastern Japan. The Tatsunokuchi sea was a rather shallow, cold water and more or less stable, at least during the larger part of its development. However, nearing the end of Yushima time, there occurred gradual uplift of the area and regression of the sea.

By the marine regression and subsequent erosion of the land, there again occurred gradual subsidence in association with the uplift of the eastern and western sides of the

area, the latter probably related with the anticlinal axis of the Yushima Formation and the former by the rising hinterland of Paleozoic rocks. In this gradually depressing area or sedimentary basin, the Kazawa Formation was deposited. During deposition of the Kazawa Formation the western area of the sedimentary basin was favored with the development of a low-land forest from where such pollen as the following were brought into the present area, namely, of Taxodiaceae (mainly of the genera *Sequoia*, *Glyptostrobus* and *Metasequoia*) associated with *Alnus*, *Fagus* and *Quercus* in the lower part of the formation or during the early phase of deposition. During the later phase such genera as *Fagus*, *Quercus*, *Alnus*, *Ulmus*, *Carpinus* and *Pinus* were brought into the present area. However, because the strata corresponding to the Kazawa Formation are not distributed along the eastern border of the sedimentary basin, there is no evidence for interpretation of the conditions of the pollen flora of that time. But, it may be possible that the Kazawa is covered by the Mataka and buried deeply below the ground surface, but since there is no direct evidence, further explanations must be reserved.

In the western part of the basin where the Kazawa Formation is well developed and distributed in north to south direction and also part of the southwestern part of the basin, the following can be stated from the evidence of the pollen grains. That is to say, it is interesting to notice that the frequency of the pollen grains from west to east directions showed a decline and this clearly points to the transportation by running water and wind. The larger and heavier pollen grains deposited earlier than the smaller and lighter ones. And, this change in frequency in pollen grains from west to east is in good accordance with the change in lithofacies and distribution of the formation.

Continued subsidence resulted of lacustrine to terrestrial facies in the deposition of the Mataka Formation. In the western part of the basin such pollen grains as *Sequoia*, *Glyptostrobus*, *Fagus*, *Quercus*, *Alnus*, *Nyssa*, *Carpinus*, *Corylus* and *Ulmus* were buried, and in the central part of the basin the pollen grains comprised *Alnus*, *Fagus*, *Abies*, *Pinus* in the main whereas in the eastern part of the basin such pollen as *Abies*, *Picea*, *Pinus*, *Fagus*, *Quercus*, *Carpinus* and *Pterocarya* were found (Figs. 5, 6). The frequency in occurrence of the pollen genera seems to be good agreement with the distance from their sources and of the transporting ability of the streams and wind from their original places of growth. In the central part of the basin some contamination of pollen grains is found as in the case of the sediments.

Subsequent to the deposition of the Mataka Formation, gradual uplift occurred and the entire sedimentary basin become subjected to subaerial denudation by which the land surface was lowered. Following this stage the basin again commenced subsidence by which the Pleistocene Takizawa Formation was deposited. It is in this basin that the pollen grains of the western and eastern parts are quite different, indicating that their hinterlands were different. The pollen grains derived from the western side of the Takizawa sedimentary basin consists of the genera *Alnus*, *Quercus*, *Ulmus*, *Pterocarya*, *Juglans*, *Betula* and others whereas at the eastern part of the basin the genera are characterized by *Pinus*, *Abies*, *Picea*, *Fagus*, *Alnus* and *Quercus*. This difference in generic composition is noteworthy as it indicates or at least suggests the different conditions of the sedimentary basin, from the viewpoint of hinterlands at the eastern and western sides, different kinds of flora growing at those places and may also be indicative of the different heights of the back-grounds at the western and eastern sides of the basin.

Since the Takizawa basin commenced gradual uplift after deposition of its sediments the entire basin was uplifted differentially, the southern side being most uplifted compared with the western and eastern sides and on the contrary the northern side seems to have been stable or subsided to some degree.

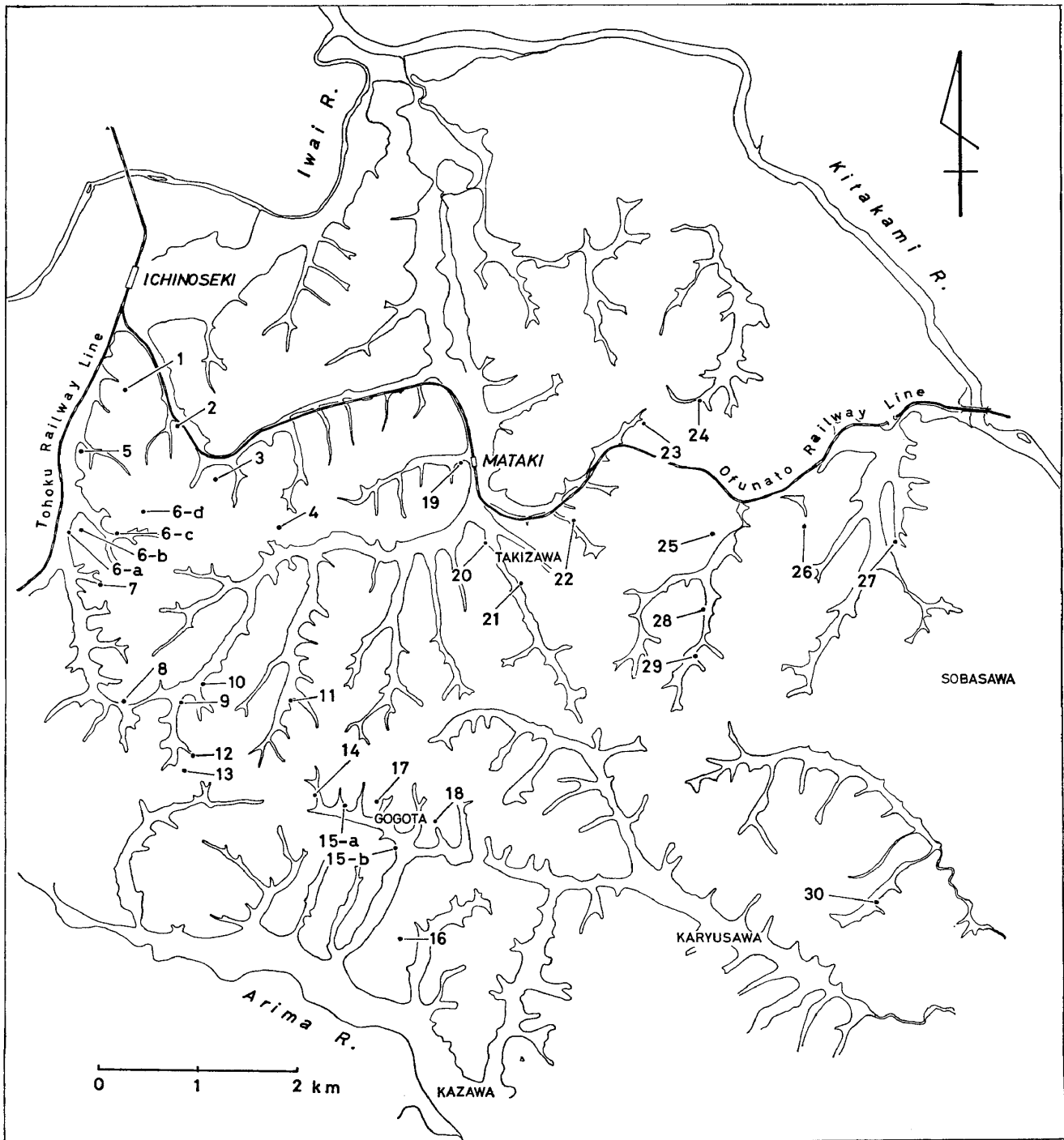


Fig. 3 Map showing the sampling localities in the hilly area southeast of Ichinoseki City.

During the deposition of the respective formations within the sedimentary basin it is evident from their distributions, thickness and directions of lithological facies changes that the movements were not the same throughout the development of the formations. During the first stage or that of the Ariga and Yushima formations the subsidence was greater at the western and southern sides whereas at the eastern side the conditions seem to have been rather stable. However, after deposition of the Yushima Formation and during uplift of the formation, the eastern and western sides as well as part of the southern

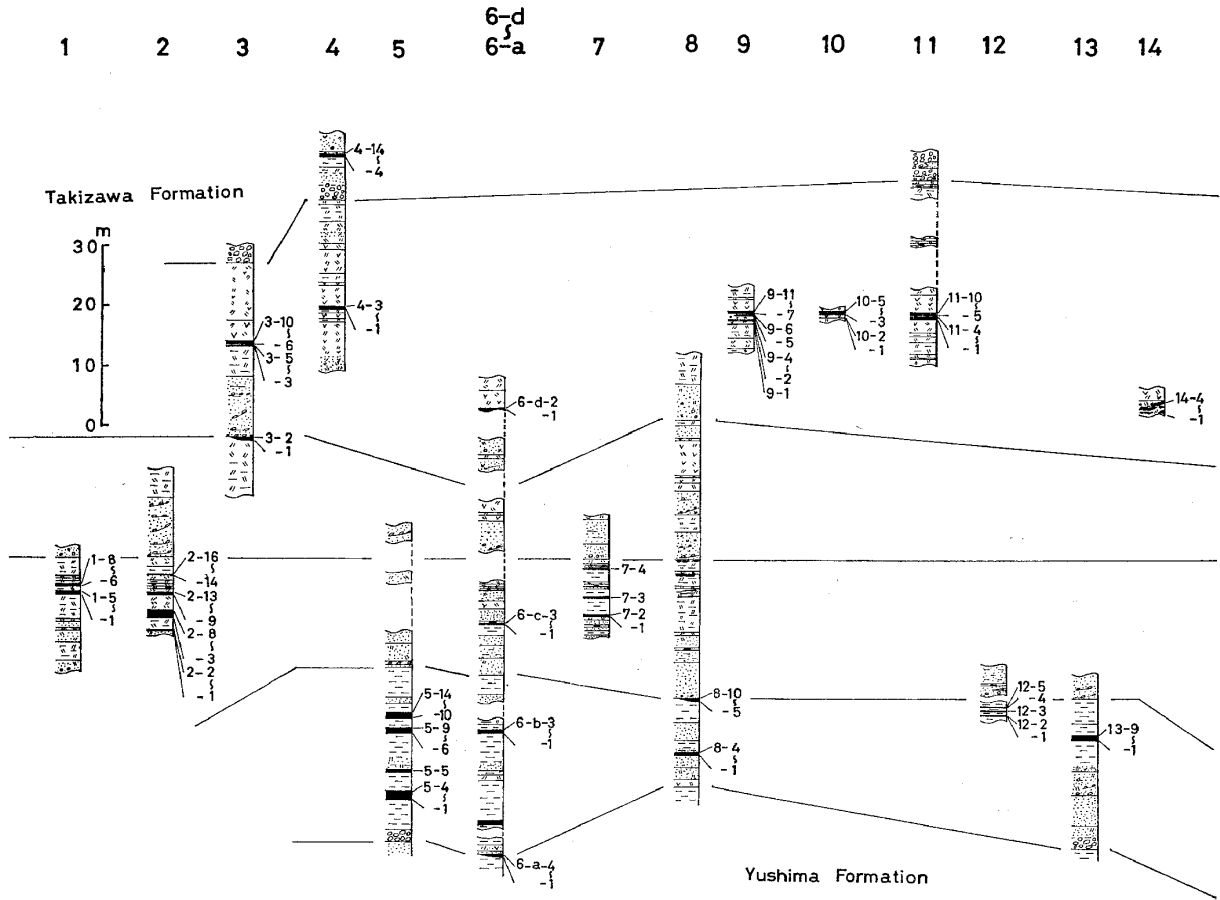


Fig. 4 Columnar sections showing the stratigraphic positions of the samples

side were more uplifted than the central part which was subjected to gradual subsidence leading to the development of the sedimentary basin in which the terrestrial sediments were deposited. During deposition of the Kazawa Formation there was uplift of its western, southern and northwestern sides contemporaneously with the deposition of the Mataki Formation. The lower part of the Mataki although the dips are a little different from that of the Kazawa Formation, is continuous and conformable with the Kazawa. This difference might be mainly due to the gradual uplift of the western side of the basin where the lower part of the Kazawa Formation is developed, and contemporaneous subsidence of the central part of same basin where occupied by upper part of the formation during the deposition of the Kazawa and Mataki formations.

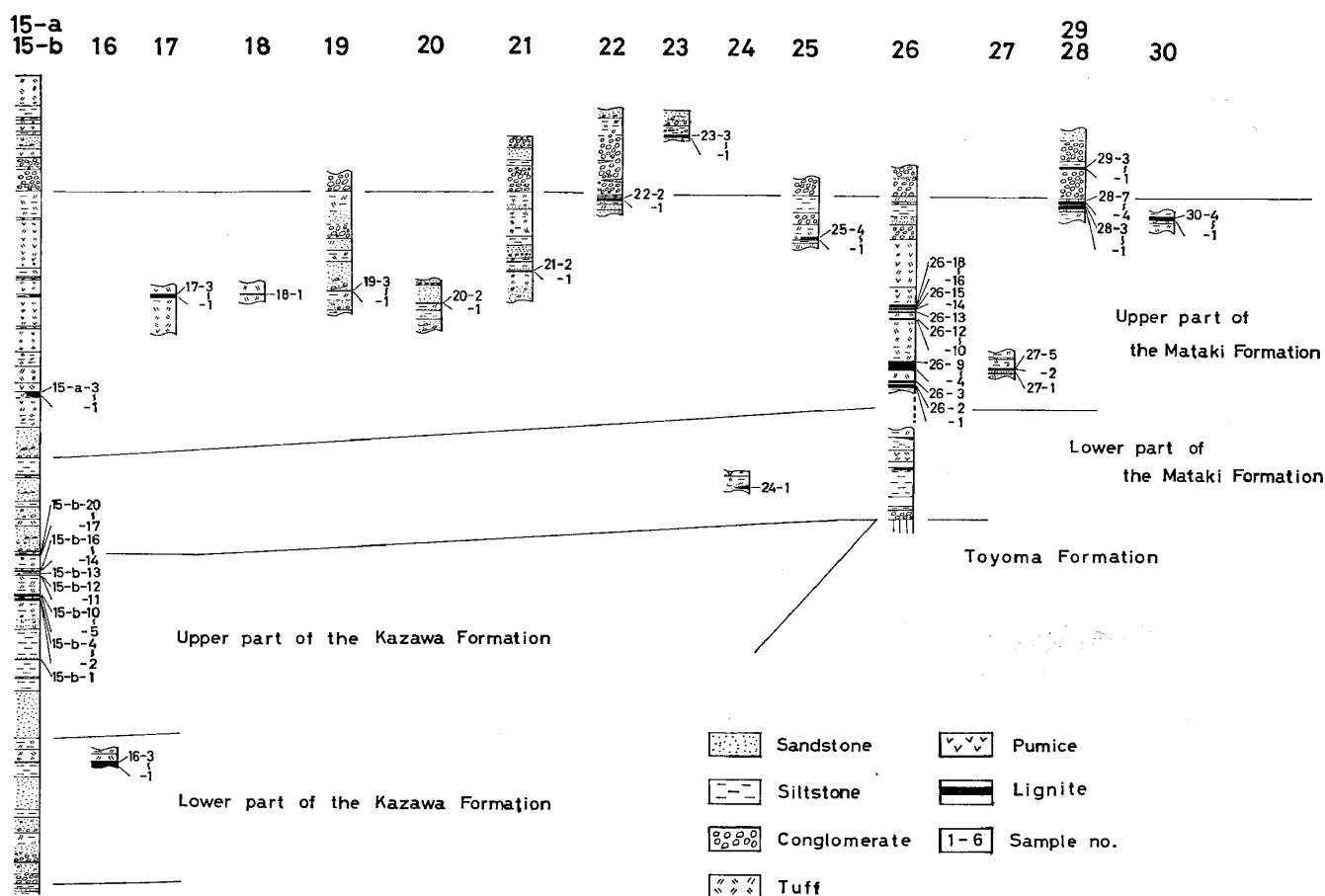
Thus in the present basin, although faults or shear zones of noteworthy scale have not been observed, it is evident that the trace of crustal movement existed.

PALYNOLOGY OF THE HILLY AREA SOUTHEAST OF ICHINOSEKI CITY

A. Method of Study and Palynological Analyses of the Samples

a. Localities and Geological Horizons of the Materials

The materials used in the present study for analyses of the pollen grains and spores were collected at more than 30 localities by the writer mainly from the Kazawa, Mataki, and Takizawa formations and a few from the Yushima Formation. The collections were



studied. Localities are shown in Fig. 3.

made from lignite seams or coaly siltstones as well as from immediately above and below, and the vertical interval between the sampling horizons was generally 10 to 20 cm for the sake of convenience and especially where the lithology was homogeneous. Where the vertical change in the lithology was significant, sampling was done at closer intervals in order that details of change in environment as related to facies could be analysed or interpreted.

The localities and horizons of the samples as well as the name of the stratigraphic unit of occurrence are stated below (Figs. 3, 4). The precise stratigraphic horizon in the geological column of each locality is shown in the columnar sections given in Fig. 4.

- Locality no. 1: About 500 m south of Hataoriyama, Ichinoseki City. Eight samples, from the three lignite seams of the upper part of the Kazawa Formation.
- Locality no. 2: West of Sawa, Ichinoseki City. Sixteen samples, from the four lignite and coaly siltstone layers of the upper part of the Kazawa Formation.
- Locality no. 3: About 700 m southeast of Locality no. 2, Hosoda, Ichinoseki City. Two samples, from the tuffaceous coaly siltstone of the lower part of the Mataki Formation, and eight samples from the two lignite seams of the upper part of the same formation.
- Locality no. 4: Nakayashiki, Ichinoseki City. Three samples, from the lignite seam of the upper part of the Mataki Formation, and ten from the peaty layer of the Takizawa Formation.
- Locality no. 5: Southwest of the Ichinoseki Chugakuko, Sengarida, Ichinoseki City. Fourteen samples, from the four lignite seams of the lower part of the Kazawa Formation.
- Locality no. 6-a: Sengarida, Ichinoseki City. Four samples, from the lignite seam of the Yushima

- Formation.
- Locality no. 6-b: Sengarida, Ichinoseki City. Three samples, from the lignite seam of the lower part of the Kazawa Formation.
- Locality no. 6-c: About 350 m east of Locality no. 6-b, Sengarida, Ichinoseki City. Three samples, from the coaly siltstone layer of the lower part of the Kazawa Formation.
- Locality no. 6-d: About 350 m northeast of Locality no. 6-c, Sengarida, Ichinoseki City. Two samples, from the two lignite seams of the upper part of the Mataki Formation.
- Locality no. 7: North of Higashizawa, Ichinoseki City. Four samples, from the three lignite and coaly layers of the upper part of the Kazawa Formation.
- Locality no. 8: South of Higashizawa, Ichinoseki City. Ten samples, from the two lignite seams of the lower part of the Kazawa Formation.
- Locality no. 9: Hanukidachi, Ichinoseki City. Eleven samples, from the four lignite and coaly siltstone layers of the upper part of the Mataki Formation.
- Locality no. 10: Hanukidachi, Ichinoseki City. Five samples, from the two lignite seams of the upper part of the Mataki Formation.
- Locality no. 11: South of Maesawa, Ichinoseki City. Ten samples, from the two lignite seams of the upper part of the Mataki Formation.
- Locality no. 12: South of Hanukidachi, Ichinoseki City. Five samples, from the three lignite seams of the lower part of the Kazawa Formation.
- Locality no. 13: South of Hanukidachi, the boundary between Ichinoseki City and Hanaizumi Town. Nine samples, from the lignite seam of the lower part of the Kazawa Formation.
- Locality no. 14: West of Gogota, Hanaizumi Town, Nishiiwai-gun. Four samples, from the tuffaceous coaly siltstone of the upper part of the Mataki Formation.
- Locality no. 15-a: About 300 m east of Locality no. 14, Gogota, Hanaizumi Town. Three samples, from the tuffaceous coaly siltstone of the upper part of the Mataki Formation.
- Locality no. 15-b: North of Hinata, Hanaizumi Town. Twenty samples, from the seven lignite and coaly siltstone layers of the upper part of the Kazawa Formation.
- Locality no. 16: The ridge north of Iikura, Hanaizumi Town. Three samples, from the lignite seam of the lower part of the Kazawa Formation.
- Locality no. 17: About 350 m east of Locality no. 15-a, Gogota, Hanaizumi Town. Three samples, from the lignite seam of the upper part of the Mataki Formation.
- Locality no. 18: About 600 m east of Locality no. 17, Gogota, Hanaizumi Town. One sample, from the lignite seam of the upper part of the Mataki Formation.
- Locality no. 19: About 130 m west of the Mataki Station along the Ofunato Railway Line, Tate-shita, Ichinoseki City. Three samples, from the lignite seam of the upper part of the Mataki Formation.
- Locality no. 20: Ogurasawa, Ichinoseki City. Two samples, from the coaly siltstone layer of the upper part of the Mataki Formation.
- Locality no. 21: About 600 m southeast of Locality no. 20, Takizawa, Ichinoseki City. Two samples, from the coaly siltstone layer of the upper part of the Mataki Formation.
- Locality no. 22: About 850 m northeast of Locality no. 21, Takizawa, Ichinoseki City. Two samples, from the coaly siltstone layer of the upper part of the Mataki Formation.
- Locality no. 23: Northeast of Kinokawa, Ichinoseki City. Three samples, from the peaty layer of the Takizawa Formation.
- Locality no. 24: About 600 m northeast of Locality no. 23, Kamifuji, Ichinoseki City. One sample, from the tuffaceous coaly sandstone of the lower part of the Mataki Formation.
- Locality no. 25: Fuji, Ichinoseki City. Four samples, from the coaly siltstone of the upper part of the Mataki Formation.
- Locality no. 26: About 950 m east of Locality no. 25, Fuji, Ichinoseki City. Eighteen samples, from the eight lignite seams of the upper part of the Mataki Formation.
- Locality no. 27: About 900 m east of Locality no. 26, South of Hirasawa in Yasakae, Ichinoseki City. Six samples, from the coaly siltstone layers of the Mataki Formation.
- Locality no. 28: About 850 m south of Locality no. 25, north of Ichinosawa, Ichinoseki City. Seven samples, from the two lignite and coaly siltstone layers of the upper part of the Mataki Formation.
- Locality no. 29: About 500 m south of Locality no. 28, Ichinosawa, Ichinoseki City. Three samples,

from the peaty layer of the Takizawa Formation.

Locality no. 30: About 1000 m south of Haseba, Ichinoseki City, Four samples, from the two lignite seams of the upper part of the Mataki Formation.

b. Preparation of the Material for Study

For the sample obtained from the sampling localities mentioned above the following analytical procedure was undertaken.

b-1. Mechanical treatment:

- (1) The sample is dried in a paper sack, then crushed to about 3 mm in diameter by beating without grinding.
- (2) The sample is split by repeating the "Quatering Method", and about 20 grams of it are transferred to a 500 cc beaker.

b-2. Chemical treatment:

- (1) About 50 cc of 10 percent potassium hydroxide is added to the beaker, and the sample is left to set for 24 hours.
- (2) The upper part of the water in the beaker is removed and renewed every 12 hours. This procedure was continued for about 5 days.
- (3) A certain quantity of the sample with water is put in the polyethylene tube to centrifuge and thereafter the water is excepted by the centrifuge.
- (4) A small quantity of hydrofluoric acid is added to the sample, which is then immersed in boiling water for about 5 minutes.
- (5) A few drops of concentrated hydrochloric acid is added again to this material. After a few minutes, the liquid is separated from the sample by centrifuging.
- (6) The sample is washed with water several times, and then transferred to the glass tube of the centrifuge.
- (7) A small quantity of glacial acetic acid is added to the sample. After about 30 seconds, the acid is separated from the sample by centrifuging.
- (8) A small quantity of the mixed liquid of acetic acid anhydride and sulfuric acid (9:1 in volume) is added to the sample, which is then immersed in boiling water for about 5 minutes.
- (9) This liquid is separated from the sample by centrifuging.
- (10) A small quantity of glacial acetic acid is added to the sample. After about 30 seconds, this acid is separated from the sample by centrifuging.
- (11) The sample is washed with water several times.
- (12) A small quantity of the sample is retained with a small quantity of water in the glass tube of the centrifuge.

b-3. Preparation of slides:

- (1) A small quantity of glycerine jelly is dropped on the slide glass which is heated on the plate glass by steam.
- (2) A small quantity of the sample is put on the glycerine jelly, then mixed and left to set for a while.
- (3) The cover glass is gently put on the slide glass.
- (4) After cooling, the cover glass is sealed.

c. Method of Study

The counting of the pollen grains and spores was made along the zones chosen with use of a mechanical stage. All of the specimens which appeared in those zones were observed and counted. The counting was continued until more than 200 specimens of arboreal pollen were identified and counted. When the specimens of arboreal pollen

counted from one slide were less than 200, the counting was continued on the other slides which were prepared from the same sample in order that the total count would exceed 200.

The frequency of each genus obtained by the count of more than 200 specimens of arboreal pollen from the samples were recorded on the distribution chart and the values were then arranged in stratigraphic order. All the strewn slides were generally examined under the same magnification of microscope, 600 times in counting, and under the magnification of 1000 times when necessary.

d. Repository of Slides

The slides containing the registered specimens are deposited in the collection of the Institute of Geology and Paleontology, Tohoku University.

The slides observed for this study included; four slides from four samples of one locality from the Yushima Formation, 115 slides from 95 samples of 11 localities from the Kazawa Formation, 102 slides from 100 samples of 21 localities from the Mataka Formation, and 20 slides from 16 samples of 3 localities from the Takizawa Formation.

Thus, the writer examined 241 slides from 215 samples collected from the hilly area southeast of Ichinoseki City.

e. Results of Palynological Analysis

The data of the present analysis of pollen grains and spores are given in the distribution charts of Tables 3, 4 and 5. In the tables, the sample numbers are shown by the numbers corresponding to those in Fig. 4. The tables include 215 samples for the present study. In the tables, the percentage of the arboreal taxa represents their ratios to the total amounts of the arboreal pollen, and the percentage of the non-arboreal taxa is the ratios to the total amounts of pollen grains and spores.

In the results, the writer describes the pollen frequency as follows: dominant indicates more than 50%, common 5-50%, rare less than 5% and very rare 1~2% or less.

1. Yushima Formation

Only four samples were collected from only one locality of the Yushima Formation.

Sample nos. 6-a-1~4 (Locality no. 6-a): The distribution of the pollen grains and spores found in the samples is shown in Table 3. From the samples, 26 genera and 1 family of arboreal pollen were identified. Among them, the pollen grains of Taxodiaceae such as *Sequoia* and *Glyptostrobus* are dominant, and *Fagus*, *Abies* and *Alnus* are common. A small quantity of *Quercus*, *Pinus* and *Liquidambar* pollen grains were found. A steep rise of the Taxodiaceae curve with the ascent of the lignite seam is recognized.

2. Kazawa Formation

A total of 95 samples from 11 localities of the Kazawa Formation were examined. Among them 47 samples are from the lower part of the formation at seven localities and 48 samples from the upper part of the formation at four localities. In the Kazawa Formation, 50 taxa of pollen and spores were found, among which 33 arboreal taxa and 17 non-arboreal ones were discriminated. The results are shown in Table 3.

(1) Lower part of the Kazawa Formation

Sample nos. 5-1~14 (Locality no. 5): The analysed samples contained 31 genera and one family of arboreal pollen. A high value for the pollen grains of Taxodiaceae, *Fagus* and *Alnus* are recognized. A small amount of *Pinus* and *Quercus* pollen grains occurred and *Liquidambar* was found in some quantity. The other tree pollen such as *Nyssa*, *Carpinus*, *Ulmus* and *Pterocarya* are rare in occurrence.

Sample nos. 6-b-1~3, 6-c-1~3 (Locality nos. 6-b, 6-c): The samples yielded 26

genera of arboreal pollen. The frequencies of each genera are similar to that of the sample from the Locality no. 5. The pollen grains of Taxodiaceae, *Fagus* and *Alnus* are abundant, and *Quercus*, *Pinus*, *Liquidambar* and *Ulmus* are common. The other genera are rare in frequency.

Sample nos. 8-1~10 (Locality no. 8): At the Locality no. 8, two lignite seams are recognized, and of them the upper one dies out in lenticular form. The samples yielded 31 genera of arboreal pollen. In the sample nos. 8-1~4 (lower lignite seam), Taxodiaceae, *Fagus*, *Quercus* and *Alnus* pollen grains are abundant. The grains of *Nyssa* were recognized in some quantity, but only a few of *Liquidambar* were found. In the Sample nos. 8-5~10 (upper lignite seam), the grains of *Alnus* shows high percentage, and it is accompanied with Taxodiaceae, *Fagus* and *Quercus*.

Sample nos. 12-1~5 (Locality no. 12): The samples yielded 27 genera of arboreal pollen grains. *Alnus* and Taxodiaceae pollen grains are dominant, and *Fagus* is common. A few pollen grains of *Quercus*, *Pinus*, *Liquidambar* and *Nyssa* were found.

Sample nos. 13-1~9 (Locality no. 13): The samples produced 28 genera and one family of arboreal pollen. The tendency of the frequency of the genera is similar to that of the Sample nos. 8-5~10. *Alnus* pollen grains are dominant but Taxodiaceae and *Fagus* are substantial in amount. A few pollen grains of *Nyssa* and *Liquidambar* were found.

Sample nos. 16-1~3 (Locality no. 16): The samples yielded 22 genera and one family of arboreal pollen. Among them, a considerably high value for the Taxodiaceae prevailed, and *Fagus* and *Alnus* are common. The majority of the other genera are rare (less than 4 percent).

(2) Upper part of the Kazawa Formation

Sample nos. 1-1~8 (Locality no. 1): From the samples 25 genera and one family of arboreal pollen were identified. Among them, the pollen grains of *Alnus* showed the highest frequency, and it is accompanied with *Fagus*, Taxodiaceae and *Pinus*. The grains of *Quercus* and *Picea* are found in small quantity.

Sample nos. 2-1~16 (Locality no. 2): From the samples 30 genera and one family of arboreal pollen are identified. The tendency of the frequency of the genera is similar to that of the Sample nos. 1-1~8. The pollen grains of *Alnus* are dominant. The grains of *Quercus* and Taxodiaceae show a frequency slightly higher than at the Locality no. 1, on the contrary, *Pinus* and *Picea* show a frequency less than at the Locality no. 1.

Sample nos. 7-1~4 (Locality no. 7): The samples yielded 24 genera of arboreal pollen grains. The frequency of each genera are similar to the samples of the Locality no. 1 mentioned above. The pollen grains of *Alnus* are dominant, and Taxodiaceae and *Fagus* are common. It is noteworthy that coniferous pollen grains such as *Pinus*, *Picea*, *Abies* and *Tsuga* are very rare or absent.

Sample nos. 15-b-1~20 (Locality no. 15-b): The samples yielded 29 genera and one family of arboreal pollen. Roughly speaking, the pollen grains of *Alnus* are dominant, and it is accompanied with *Fagus* and Taxodiaceae. But a change of them can be recognized from the lower part upwards of the pollen assemblage. In the Sample nos. 15-b-1~3, the grains of *Alnus* are high in value, and *Fagus* and Taxodiaceae are found in small quantity. In the Sample nos. 15-b-4~10, the grains of *Alnus* decrease, but *Fagus*, *Pinus* and *Picea* increase conspicuously. *Quercus* and Taxodiaceae pollen grains are found in small quantity. In the Sample nos. 15-b-11~16, the grains of *Alnus* are dominant again, and *Fagus* and Taxodiaceae are common. *Pinus* and *Picea* pollen grains show low frequencies. In the Sample nos. 15-b-17~20, the frequencies of each genera are almost similar to the Sample nos. 15-b-1~3.

3. Mataka Formation

from the Yushima and Kazawa Formations

Flax	Fraxinus	Symplocos	Viburnum	Lonicera	Elaeagnus	Ericaceae	Gramineae	Cyperaceae	Nymphaeaceae	Potamogetonaceae	Caryophyllaceae	Chenopodiaceae	Umbelliferae	Compositae	Artemisia	Sanguisorba	Myriophyllum	Persicaria	Typha	Polypodiaceae	Osmundaceae	Lycopodiaceae	Sphagnum	Unknown	MAP/TP
1.0	0.5	1.0				1.0		1.0			1.0									12.0	3.0	0.7		9.0	33.1
0.6	0.4	0.4				1.0		0.4			1.0									14.4	15.2	0.4		1.5	25.9
0.4	0.4	0.4				1.0		0.4			1.0									16.1	16.1	0.4		1.3	36.9
0.4	0.4	0.4				1.0		0.4			1.0									16.0	16.0	0.4		2.9	27.3
0.4	0.4	0.4				1.0		0.4			1.0									4.2	4.2	0.2		0.7	16.5
0.4	0.4	0.4				1.0		0.4			1.0									15.3	15.3	0.2		0.4	29.1
0.4	0.4	0.4				1.0		0.4			1.0									3.9	3.9	0.2		0.6	30.6
0.4	0.4	0.4				1.0		0.4			1.0									10.9	10.9	0.2		0.7	27.7
0.4	0.4	0.4				1.0		0.4			1.0									4.4	4.4	0.2		0.9	16.9
0.4	0.4	0.4				1.0		0.4			1.0									0.9	0.9	0.2		0.4	31.6
0.4	0.4	0.4				1.0		0.4			1.0									0.7	0.7	0.2		0.4	11.2
0.4	0.4	0.4				1.0		0.4			1.0									0.8	0.8	0.2		0.1	13.2
0.4	0.4	0.4				1.0		0.4			1.0									0.7	0.7	0.2		1.0	23.2
0.4	0.4	0.4				1.0		0.4			1.0									0.5	0.5	0.2		1.1	31.5
0.4	0.4	0.4				1.0		0.4			1.0									0.9	0.9	0.2		1.3	24.5
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.3	41.6
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.5	0.5	0.2		1.2	31.6
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0									0.3	0.3	0.2		1.2	40.9
0.4	0.4	0.4				1.0		0.4			1.0														

Table 5. Distribution of the Pollen Grains and

Sample number	T-C-T	Pinus	Picea	Abies	Taxus	Sciadopitys	Alnus	Fagus	Quercus	Betula	Carpinus	Corylus	Castanea	Salix	Ulmus	Zelkova	Juglans	Pterocarya	Acer
4-14	1.4	0	0.4	0.2	-	-	78.6	0	10.4	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-13	1.8	0	0.4	0.2	-	-	51.4	0	17.4	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-12	1.6	0	0.4	0.4	-	-	56.4	0	16.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-11	1.2	0	0.4	0.4	-	-	79.0	0	10.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-10	1.0	0	0.4	0.4	-	-	59.6	0	12.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-9	0.4	0	0.4	0.2	-	-	55.6	0	12.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-8	0.6	0	0.4	0.2	-	-	73.8	0	14.8	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-7	3.2	0	0.4	0.4	-	0.4	80.0	0	4.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-6	0.6	0	0.4	0.4	-	-	73.8	0	6.2	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-5	1.0	0	0.4	0.4	-	-	53.8	0	4.0	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
-4	0.2	0	0.4	0.4	-	-	80.0	0	1.4	2.0	0.4	0.0	0.0	0.6	0.0	-	1.0	0.0	0.2
23-3	19.1	20.0	2.7	11.8	-	1.8	12.718	0	0.4	0.0	0.0	0.0	0.0	0.3	0.0	-	0.6	0.0	0.2
-2	14.5	53.5	4.0	11.0	-	-	4.0	4.0	3.0	0.5	0.5	0.5	0.5	0.5	0.5	-	0.5	0.5	0.5
-1	13.0	43.0	4.5	11.0	-	-	10.5	4.0	4.5	0.5	0.5	0.5	0.5	0.5	0.5	-	0.5	0.5	0.5
29-3	20.0	29.5	10.0	19.0	-	-	13.5	3.0	-	-	-	-	-	-	-	-	-	-	-
-2	19.5	28.0	14.0	22.5	-	-	6.5	3.0	-	-	-	-	-	-	-	-	-	-	-
-1	20.0	28.0	20.5	10.0	-	-	13.0	1.5	1.0	1.0	0.5	-	-	-	-	-	-	-	-

From the Mataki Formation 100 samples from 21 localities were examined for the present study. Among them, 3 samples were obtained from the lower part of the formation at 2 localities and 97 samples were obtained from the upper part of the formation at 19 localities. In the Mataki Formation, 50 taxa of pollen and spores were found, among which 33 arboreal taxa and 17 non-arboreal ones were discriminated. The results are shown in Table 4.

(1) Lower part of the Mataki Formation

Sample nos. 3-1~2 (Locality no. 3): The samples yielded 21 genera of arboreal pollen. The pollen grains of Taxodiaceae, *Quercus* and *Fagus* are dominant. The grains of *Ulmus*, *Carpinus* and *Pinus* were found in some quantity together with *Alnus*. *Nyssa* and *Liquidambar* pollen grains are absent.

Sample no. 24-1 (Locality no. 24): From the sample, 12 genera of arboreal pollen were identified. *Abies*, *Picea* and *Pinus* pollen grains are dominant, and the other tree pollen grains are very rare.

(2) Upper part of the Mataki Formation

Sample nos. 3-3~10 (Locality no. 3): The samples yielded 26 genera of arboreal pollen. Conspicuously high value of Taxodiaceae pollen grains are recognized. The pollen grains of *Alnus* and *Fagus* are common, and *Quercus* and *Nyssa* are rare. The value for the grains of *Alnus* is much higher in the basal than in the upper part of the lignite seams. On the contrary, an almost reversed tendency is recognized in the occurrence of the grains of *Fagus*, *Quercus* and *Nyssa*.

Sample nos. 4-1~3 (Locality no. 4): The samples yielded 27 genera and one family of arboreal pollen. The pollen grains of Taxodiaceae are dominant, and *Alnus*, *Fagus*, *Quercus*, and *Nyssa* are common. The value for the Taxodiaceae is much higher in the basal than in the upper part of the lignite seam. On the contrary, an almost reversed tendency is recognized in the occurrence of the grains of *Fagus*, *Quercus*, and *Nyssa*.

Sample nos. 6-d-1~2 (Locality no. 6-d): The samples yielded 22 genera and one family of arboreal pollen. The grains of *Fagus*, *Quercus* and *Alnus* are dominant, and they are accompanied with *Nyssa* and Taxodiaceae.

The samples of three localities, Sample nos. 9-1~11 (Locality no. 9), Sample nos. 10-1~5 (Locality no. 10) and Sample nos. 11-1~10 (Locality no. 11), yielded 28 genera and one family of arboreal pollen. The pollen assemblages are similar to each other. The pollen grains of Taxodiaceae, *Alnus* and *Fagus* are dominant, and *Quercus* are common. At the Locality no. 11, the grains of *Nyssa* show a frequency higher than at the other

Spores from the Takizawa Formation

Rhus	Ilex	Fragaria	Viburnum	Cornus	Ericaceae	Gramineae	Cyperaceae	Potamogetonaceae	Caryophyllaceae	Chenopodiaceae	Umbelliferae	Compositae	Artemisia	Sanguisorba	Persicaria	Typha	Polypodiaceae	Osmundaceae	Lycopodiaceae	Unknown	MAP/TP
-	0.8	0.0	-	-	0.2	4.1	3.3	-	-	0.2	-	-	-	-	1.5	0.5	2.6	-	-	2.6	17.8
-	1.0	0.0	-	-	-	3.7	3.3	-	-	-	-	-	-	-	1.5	0.5	3.3	-	-	4.0	15.3
0.2	5.0	3.3	-	-	-	4.4	4.4	-	-	-	-	0.2	-	-	0.2	0.5	3.3	-	-	4.0	23.3
-	3.3	3.3	-	-	-	3.3	3.3	-	-	-	-	0.3	-	-	0.2	0.5	3.3	-	-	4.0	34.3
-	1.0	0.0	-	-	-	1.9	1.1	-	-	-	-	0.6	-	-	0.2	0.5	3.3	-	-	4.0	17.8
-	4.0	0.0	-	-	-	2.2	1.1	-	-	0.2	-	0.6	-	-	0.2	0.5	3.3	-	-	4.0	14.4
-	1.2	0.0	-	-	-	0.6	0.3	-	-	-	-	0.4	-	-	0.2	0.5	3.3	-	-	4.0	6.4
-	-	0.5	-	0.5	0.5	4.4	2.2	-	-	1.1	0.6	0.7	-	-	0.2	0.5	3.3	-	-	4.0	33.3
-	-	-	-	-	0.5	11.6	10.5	-	-	0.6	0.7	1.1	-	-	0.2	0.5	3.3	-	-	4.0	55.3
-	-	-	-	-	0.5	9.5	18.9	-	-	0.6	0.7	1.1	-	-	0.2	0.5	3.3	-	-	4.0	54.3
0.5	-	-	-	-	9.4	14.4	-	-	-	-	0.6	0.7	-	-	0.2	0.5	3.3	-	-	4.0	56.3
-	-	-	-	-	-	-	-	-	-	-	0.6	0.7	-	-	0.2	0.5	3.3	-	-	4.0	44.3

two localities.

Sample nos. 14-1 ~4 (Locality no. 14) and Sample nos. 15-a-1 ~3 (Locality no. 15-a): The results of pollen analysis of the samples of two localities are the similar to each other, though the former yielded 22 genera of arboreal pollen, and the latter 26 genera and one family. The samples are characterized by the excess of *Alnus* pollen grains. The other pollen grains such as *Fagus*, *Quercus* and Taxodiaceae are common.

Sample nos. 17-1 ~3 (Locality no. 17) and Sample no. 18-1 (Locality no. 18): The results of analysis of these samples are also the similar to each other. Taxodiaceae, *Alnus* and *Fagus* pollen grains are dominant, and *Quercus* are rare. In Sample no. 18-1, a comparatively high value for the pollen grains of *Nyssa* were recognized.

Sample nos. 19-1 ~3 (Locality no. 19): The samples yielded 19 genera of arboreal pollen. Among them, the pollen grains of Taxodiaceae and *Alnus* are dominant, and *Fagus*, *Carpinus* and *Ulmus* are common.

Sample nos. 20-1 ~2 (Locality no. 20): The samples yielded 15 genera of arboreal pollen grains. Among them, *Alnus* grains are very abundant, and a small amount of *Fagus*, *Quercus*, Taxodiaceae, *Abies* and *Pinus* occurred. *Nyssa* and *Liquidambar* pollen grains were not found.

Sample nos. 21-1 ~2 (Locality no. 21): The samples yielded 15 genera of arboreal pollen. The samples are characterized by the excess of *Alnus* pollen grains, accompanied with a small amount of *Abies*. The other pollen grains are very rare in quantity and kinds.

Sample nos. 22-1 ~2 (Locality no. 22): From the samples 18 genera of arboreal pollen were identified. The pollen grains of *Alnus* are dominant, and *Fagus*, Taxodiaceae, *Quercus*, *Pterocarya*, *Ulmus* and *Abies* are common.

Sample nos. 25-1 ~4 (Locality no. 25): The samples yielded 18 genera of arboreal pollen. *Fagus* and *Alnus* pollen grains are dominant, and *Quercus*, *Abies*, *Pinus* and Taxodiaceae are found in some quantity. The other tree pollen grains are rare.

Sample nos. 26-1 ~18 (Locality no. 26): The samples yielded 24 genera of arboreal pollen. Among them, the pollen grains of *Alnus* are very abundant, and accompanied with the grains of *Abies*, *Fagus*, Taxodiaceae and *Quercus*.

Sample nos. 27-1 ~5 (Locality no. 27): The samples yielded 23 genera of arboreal pollen. *Abies*, *Pinus* and *Fagus* pollen grains are dominant, and Taxodiaceae, *Picea* and *Quercus* are common. A small quantity of *Carpinus* and *Pterocarya* pollen grains are found.

Sample nos. 28-1 ~7 (Locality no. 28): From the samples 26 genera of arboreal pollen were identified. Taxodiaceae and *Alnus* pollen grains are dominant, and *Fagus* are substantial in amount. The pollen grains of *Quercus* and *Carpinus* were recognized in small quantity.

Sample nos. 30-1 ~4 (Locality no. 30): The samples yielded 24 genera of arboreal pollen. *Fagus*, *Quercus* and Taxodiaceae pollen grains are dominant, and *Ulmus*, *Pterocarya* and *Alnus* are common. The coniferous pollen grains such as *Pinus*, *Picea* and *Abies* are rare.

4. Takizawa Formation

From the Takizawa Formation, 16 samples from 3 localities were collected, and 39 taxa of pollen and spores were found, among which 25 arboreal taxa and 14 non-arboreal ones were discriminated. The results are shown in Table 5.

Sample nos. 4-4 ~14 (Locality no. 4): The samples yielded 22 genera and one family of arboreal pollen. The pollen grains of *Alnus* are dominant, and *Quercus*, *Ulmus*, *Pterocarya* and *Juglans* are common. The pollen grains of *Pinus*, *Picea*, *Cryptomeria*, *Betula*, *Carpinus*, *Corylus*, *Ilex* and *Fraxinus* were found in low frequencies.

Sample nos. 23-1 ~3 (Locality no. 23): The samples yielded 21 genera and one family of arboreal pollen. Among them, the pollen grains of *Pinus* are dominant, and *Abies*, *Picea*, *Cryptomeria*, *Alnus*, *Fagus* and *Quercus* are substantial in amount.

Sample nos. 29-1 ~3 (Locality no. 29): The samples yielded 14 genera of arboreal pollen. Among them, the pollen grains of *Pinus*, *Abies*, *Picea* and *Alnus* are dominant, and *Cryptomeria*, *Tsuga* and *Fagus* are found in some quantity.

B. Paleoecological Implication

a. Pollen Assemblage

Analysis of the pollen of the genera *Alnus*, *Fagus*, *Quercus*, *Abies*, *Picea*, *Pinus*, *Nyssa*, *Liquidambar*, and Taxodiaceae, along the west-east cross-section of the upper part of the Mataki Formation, from the percentages of occurrence of the different genera, resulted in the following (Figs. 5, 6). The genus *Alnus* was found to be most dominant in the central part of the distribution of the Mataki Formation. The genus *Alnus* is known to flourish in damp lowland areas, and is most easily carried by wind and drainage. The pollen of the other genera mentioned above are all very few in the central area where *Alnus* predominate. The pollen of the genera *Sequoia* and *Glyptostrobus* are most abundant in the western part of the distribution of the Mataki Formation, almost absent in the central area and not common at the eastern part of the Mataki basin. These two genera are common lowland plants of rather damp places, and indicate a mild climate. The three genera mentioned were all, at least assumed, to have been transported from the western side of the Mataki sedimentary basin. The genera *Nyssa* and *Liquidambar* are found only on the western side of the basin; only a few were found in the eastern side, and these were probably driven from the western side of the basin. The genera *Abies* and *Picea* are common or rather abundant on the eastern side of the basin and gradually become fewer westwards, though not common in the central part of the basin. This shows that they were derived from the eastern side of the basin. Those two genera are inhabitants of the subalpine forest zone, and from the paleogeography, it is assumed that the hinterland on the eastern side of the sedimentary basin was rather high, topographically. In all cases it is noteworthy that the central area shows a mixed assemblage of the pollen grains, though none are to be considered common or abundant. The genera *Fagus* and Taxodiaceae such as *Sequoia* and *Glyptostrobus* show a reversed relation, that is to say, where *Fagus* is com-

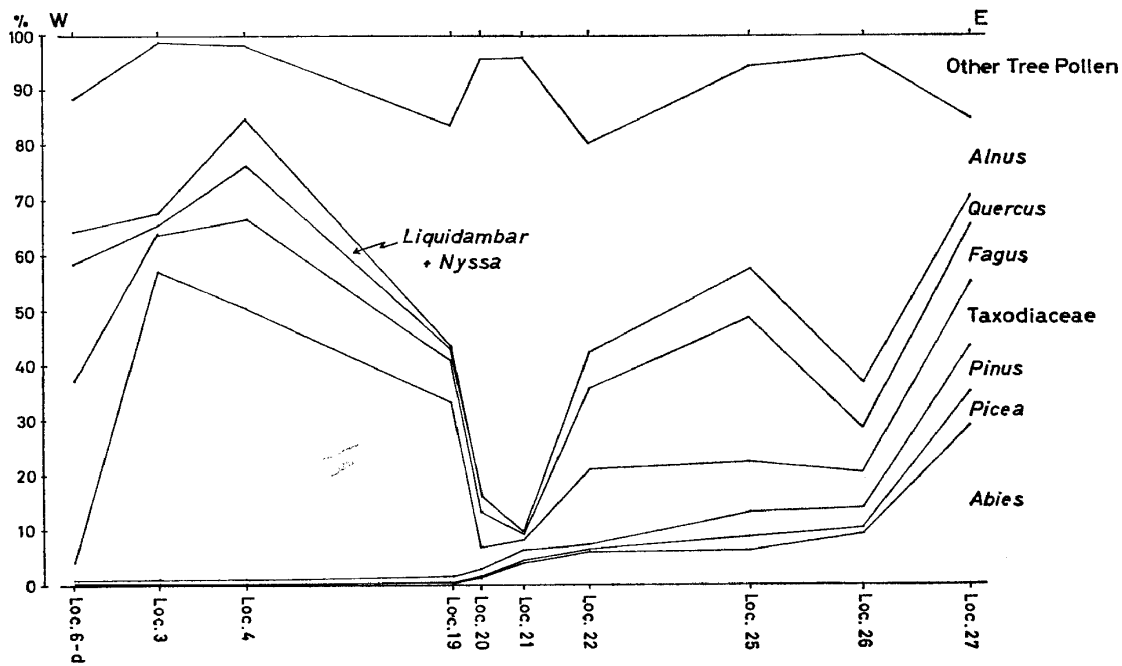


Fig. 5 Frequency variation of pollen genera of the upper part of the Mataki Formation in West-East direction (1).

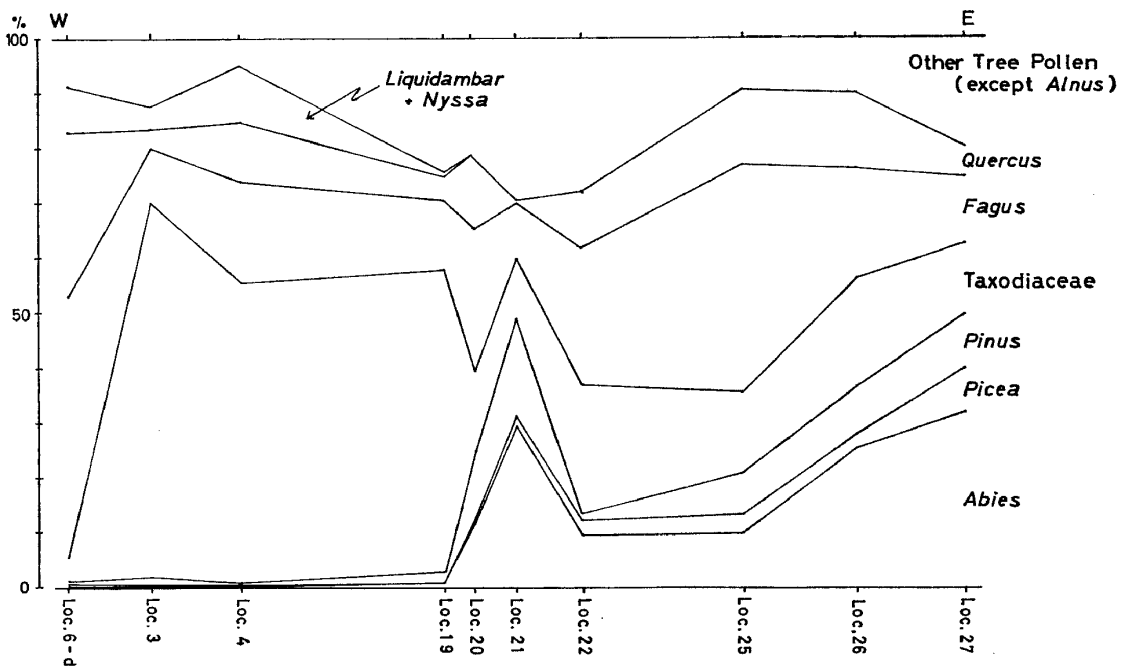


Fig. 6 Frequency variation of pollen genera of the upper part of the Mataki Formation in West-East direction (2). (except *Alnus* Pollen).

mon the Taxodiaceae are rare, and where the latter are common the former are rare. This reversed relation is important in interpreting the implication of the pollen grain. The genus *Fagus* although showing one peak on the western side of the basin is most common and abundant on the eastern side. This frequency in pollen grains seems to be closely related with the paleotopography of the area bordering the sedimentary basin. The

Table 6. Pollen Assemblage within Area studied

Assemblage Unit \ Area	Western side	Central part	Eastern side
Takizawa F.	<i>Quercus-Ulmus</i> - <i>Pterocarya</i> with <i>Alnus, Cryptomeria</i>	<i>Alnus-Fagus</i> - <i>Quercus</i>	<i>Abies-Pinus-Picea</i> with <i>Fagus, Alnus</i>
Upper part of the Mataki F.	<i>Sequoia-Fagus</i> - <i>Nyssa</i>	<i>Alnus</i> accompanied with <i>Abies, Fagus, Sequoia</i>	<i>Abies-Pinus-Fagus</i>
Lower part of the Mataki F.	<i>Sequoia-Quercus</i> - <i>Fagus</i>	absent	<i>Abies-Picea-Pinus</i>
Upper part of the Kazawa F.	<i>Alnus-Fagus</i> - <i>Pinus</i>	absent	absent
Lower part of the Kazawa F.	<i>Sequoia-Fagus</i> - <i>Liquidambar</i>	absent	absent
Upper part of the Yushima F.	<i>Fagus-Sequoia</i> - <i>Abies</i>	absent	absent

Western side : lowland flora

Central part : mixed flora of lowland and highland

Eastern side : highland flora with some lowland elements

Taxodiaceae are most common and abundant on the western side of the basin where lowlands existed, and thus their abundancy seems to be related with the paleotopography of the area bordering the sedimentary basin. In the central part of the basin the pollen grains of *Fagus* and Taxodiaceae show almost the same amount, thus this may indicate their mode of derivation or transportation from the bordering area of the basin.

From the above results of pollen analysis along the west to east section of the Mataki sedimentary basin, it is evident that the frequency of the grains is suggestive of the paleogeography or paleotopography of the areas bordering the basin and also indicate the then existing aqueous and aeolian agencies of transportation.

Also the frequency of the pollen grains can be considered to have direct relation with the climate prevailing during their time of flourishing, and with regard to the climatic conditions another section will be devoted.

As already described in a previous section on the method of sampling and also of the lithology of the different formations distributed in the present area, it is clear that the pollen grains analysed in the present work are from many different horizons and lithology. From the lateral and vertical distributions of the pollen grains collected horizon by horizon, it became possible to make a chart indicating their frequency distributions.

From the distribution charts of the pollen grains identified, it is evident that considerable differences can be seen in the assemblage or pollen-types in vertical succession, and the lateral arrangement according to position along the cross-section of the basin also reveals difference (Table 6). Such differences can be correlated with the distance from their respective source areas as well as also from their ages. However, within the distributions of the pollen grains whether vertical or lateral, it is also evident that contamination or their mixing occurs in certain parts of the basin, particularly in the central part of the basin such phenomenon is noteworthy. This shows that derivation from their sources area of western and eastern sides of the basin where the topographic features were different from the time of Yushima transgression to the final stage represented by the Takizawa

Formation.

Taking the different pollen identified from the different horizons of the formations ranging from the Yushima up to and including the Takizawa, it is evident that the characteristics are as shown in Fig. 7 and 8. From these figures it must be mentioned that, the Taxodiaceae shows remarkable differences such as being particularly abundant during the uppermost part of Yushima time, decreasing gradually to the basal part of the Kazawa Formation, and from the lower part the pollen again increases and becomes abundant at the uppermost part of the lower part of the Kazawa Formation, therefrom again decreasing to the uppermost part of the Kazawa Formation. Here is another increase of the same group of pollen from the lower to upper parts of the Mataki Formation, after which the group becomes extinct in the present area. This increase and decrease of the pollen of the Taxodiaceae group vertically along the western margin of the basin, clearly shows that considerable differences in the paleoenvironment occurred during from Yushima up to the end of Mataki times.

The change just mentioned is difficult to correlate throughout the field because the Yushima and Kazawa formations are not developed along the eastern side of the basin. But, comparing the pollen frequency of the same group of the central and eastern sides of the basin with that of the western side, it is noticed that the pollen group is much less in the central part, but increases at the eastern side, although those of the central and eastern sides are much less than that of the western side. This points to that the conditions within the same basin as indicated by the same group of pollen is quite different, probably the central part in being remote from both marginal areas had but few pollen, whereas that of the eastern side was not so favorable for thriving of the said group of pollen.

At the southern area of the basin where the Kazawa and Mataki formations are developed, it is noticed that when the same group is considered, the tendency is the same as seen at the western side although the frequency of the pollen grains is less (Fig. 9).

The said pollen group does not occur in the Takizawa Formation, therefore it can be said that the group became extinct before Takizawa time and also this time of extinction may be good evidence for drawing the boundary between the Pliocene and Pleistocene ages in the present area.

The pollen of the genus *Fagus* shows a frequency reverse to that of the Taxodiaceae (*Sequoia*, *Glyptostrobus* etc.), being few during Yushima time, abundant at the lower part of the Kazawa Formation, few at the upper part of the formation, and thereon upwards the *Fagus*-pollen although present but not abundant up to the end of Mataki time. The pollen of *Fagus* are present during Takizawa time but much less than during the time of Kazawa and Mataki. This difference of the *Fagus* pollen also points to the changing environmental conditions during deposition of the Kazawa to Takizawa formations in the basin.

The pollen of the genera *Nyssa* and *Liquidambar* are also interesting in being few during Yushima time, but increasing in the lower part of the Kazawa Formation, but again becoming few during Upper Kazawa to Lower Mataki times, and again increasing to the Upper Mataki but extinct thereafter, and none are known from the Takizawa Formation. This shows that the *Nyssa-Liquidambar* group of pollen becomes extinct in the present area at the end of Mataki time and before Takizawa time.

The characteristics of the other pollen in vertical sequence are shown in Fig. 7 and 9, from which their relation with the formations in which they occur can be inferred. This figure is also important in indicating the biostratigraphical significance of the pollen in addition to the changes in the paleoenvironment during deposition of the different formations in the structural basin.

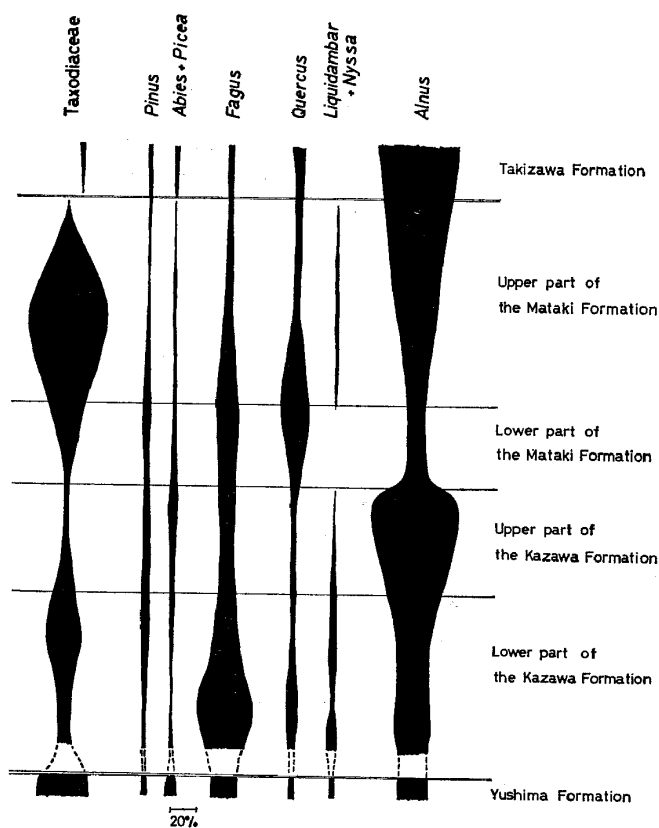


Fig. 7

Fig. 7 Frequency variation of pollen genera from the Yushima Formation up to and including the Takizawa Formation of the western side of the basin (1).

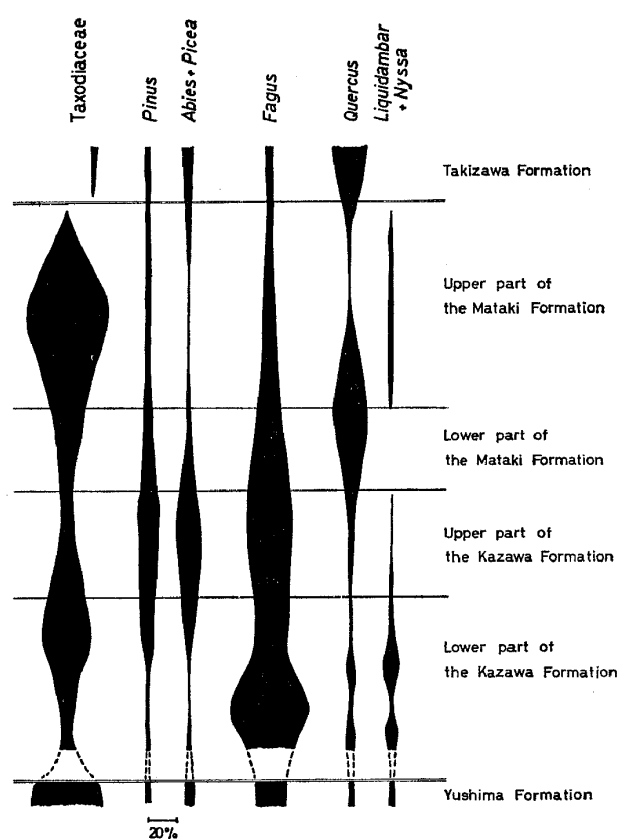


Fig. 8

Fig. 8 Frequency variation of pollen genera from the Yushima Formation up to and including the Takizawa Formation of the western side of the basin (2). (except *Alnus* Pollen)

b. Transportation of the Pollen Grains

Transportation of the pollen grains, their deposition and redeposition, are features important in the interpretation of the assemblages. Transportation may be aeolian or aqueous processes aside from the organic and inorganic means. Organic transportation can be accomplished by birds or four-legged animals, the pollen grains adhering to their feet (birds) or wings or to the food being carried by them, or in the intestines of four-legged animals or attached to their external surface (skin, etc.). Transportation may also be done as the result of streams eroding pre-existing geological formations and redepositing the grains by dropping them in foreign environments. Thus the fossil grains may comprise assemblages of the pollen derived from different geological formations and of different ages, thereby indicating an age and ecological condition quite different from that of the original. Aeolian process in the transportation of the pollen grains is usually by wind agencies, whereby the grains may be carried long distance before deposition.

Various processes are possible for distributing the pollen grains, and various environments may be their final place of burial. However, in the case of the fossil pollen grains dealt with in this article, only several types of transportation have been recognized, as mentioned below.

From the frequencies, generic compositions and assemblages of the fossil pollen

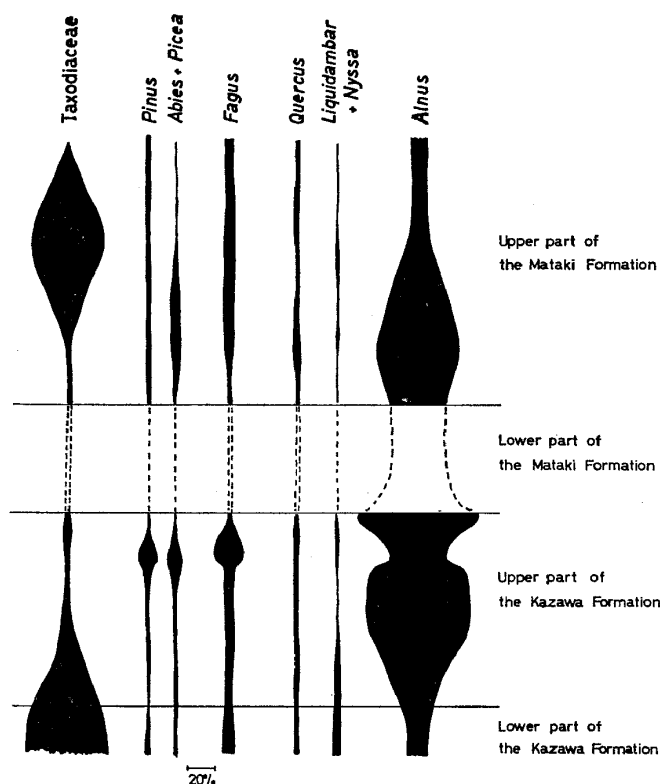


Fig. 9 Frequency variation of pollen genera from the Kazawa Formation up to the Matakai Formation of the southern side of the basin.

grains collected and identified in the present study, it is quite evident that the means of their transportation were chiefly by streams on the one hand and also partly to wind on the other, whereas no direct evidence for organic or inorganic transportation could be recognized. In other words the main inorganic transportation processes were accomplished by streams flowing either from the lowland area (western side of the basin) or from the topographic high hinterland (eastern side of the sedimentary basin).

Thus from the agencies in transportation inferred from the assemblages of the specific and generic categories, redeposited specimens derived from pre-existing geological formations were not recognized. Therefore, the pollen grains collected from each of the different horizons of the geological formations treated in the present article may be taken as worthy for indicating the geological ages, climatic conditions and paleoenvironmental conditions under which the respective formations were deposited.

The sedimentary basin in which the Kazawa to and including the Takizawa formations were deposited is assumed to be as mentioned below.

The basin was developed at the western foot of the topographic high consisting of the Paleozoic terrain (hinterland), and the western side of the basin is inferred to have been a rather undulated lowland and the northern side of the basin an instable area. From the development of the different formations and also from their thickness, subsidence and uplift were the most active movements as may be inferred from the conformity and unconformity situated at different horizons.

The inland sedimentary basin was fed with the drainage of small streams both from the western lowland area and also from the topographic high hinterland on the eastern side. All of the area just mentioned were occupied with rather rich vegetation of *Alnus*,

Fagus, *Quercus*, *Pinus*, etc., and in the inland aqueous part of the basin by waterplants as *Trapa*, *Glyptostrobos* and near shore plants as *Alnus* and others. The pollen of such plants including several others were transported into the sedimentary basin by small streams to be deposited at the different horizons of the Kazawa to Takizawa formations at different times.

The general climatic conditions during survival of the inland basin was varied, especially during the Upper Pliocene and Pleistocene times, as may be noticed from the pollen content of the Kazawa, Mataka and Takizawa formations. During Kazawa time the climatic conditions of the sedimentary basin seem to have been slightly different on both sides, that is to say, the western side was favored with a mild climate whereas the eastern side owing the high topographic relief consisted of plants favoring a more cooler climatic condition. In other words the western lowland side had sufficient sunlight without much shaded areas, whereas the eastern side owing the high topographic condition of the hinterland was much shaded and with less sunlight. For such reason, as seen also during the times of Mataka and Takizawa, the pollen flora was slightly different on both sides of the basin, as would be expected from the difference in the prevailing physical conditions.

Another noteworthy view is that the difference in geological age between the Takizawa and the underlying Mataka and Kazawa formations also had intimate bearing on the climatic conditions prevailing during those ages. The Takizawa Formation of Pleistocene age had a cooler climatic flora than that of the Pliocene Kazawa and Mataka formations judged from the pollen flora indicated in Tables 3, 4, 5 and 6, and Figs. 7 and 8.

c. Paleoenvironment

The paleoenvironment during deposition of the Yushima Formation up to and including the Takizawa Formation based upon the fossil marine fauna of the Yushima and the fossil pollen flora of the Yushima up to and including the Takizawa Formation brings into consideration the topographic features of the area surrounding the sedimentary basin. Although the evidence for such a consideration may not be sufficient, in the following lines is given a brief account of the paleoenvironment.

The Yushima Formation of marine origin also yielded pollen grains from its upper part and molluscan remains from its middle to lower parts. From the marine fauna, as already pointed out by Hatai and Yamamoto (1940), the present area was flooded with a shallow tranquil sea of embayment aspect and of a rather cool temperature as may be judged from the occurrence of thick shelled molluscs, abundant individuals but not species, occurrence of infaunal elements of muddy to sandy-muddy sea bottoms and by the lack of open sea species. On the landward side of this shallow embaymental sea there is thought to have existed at the western side of the basin a low hilly topography as may be seen from the pollen of lowland types, whereas at the eastern side of the basin the topographic features were probably of high relief as may be noticed from the flora, and it is in such a condition that the Yushima Formation was deposited.

However, from the regression of the Yushima sea and uplift of the basin and surrounding areas, the pollen flora showed considerable change as for example, *Tsuga*, *Zelkova*, *Celtis*, *Rhus*, *Tilia*, *Viburnum*, *Lonicera* and *Elaeagnus* which are absent during Yushima time, make their first appearance with Kazawa time, and this shows that a noteworthy change occurred in the climatic conditions probably assisted by the change in the topographic features by the uplift of the area. The climatic conditions showed change from cool to temperate then to moderate or mild up to and including Mataka time, but a cooling with the opening of Takizawa time. This change may be interpreted from the occurrence of warm climatic plants as *Liquidambar* and its absence during the lower part of Mataka

Table 7. Vertical Distribution of the Fossil Pollen in the Area

	Yu-shima F.	Lower part of the Kazawa F.	Upper part of the Kazawa F.	Lower part of the Mataki F.	Upper part of the Mataki F.	Taki-zawa F.
	U	L ↔ U	L ↔ U	L ↔ U	L ↔ U	L
<i>Cryptomeria</i>						×
<i>Sequoia</i>	×	××××	××	×	××	
<i>Metasequoia</i>	×	××××	××	×	××	
<i>Glyptostrobus</i>	×	××××	××	×	××	
<i>Pinus</i>	×	××××	××	×	××	×
<i>Picea</i>	×	××××	××	×	××	×
<i>Abies</i>	×	×××	××	×	××	×
<i>Tsuga polyspinosa</i>	×	×××	××		××	×
<i>Tsuga diversifolia</i>			××		××	×
<i>Sciadopitys</i>	×	×	××	×	××	×
<i>Alnus raris</i>	×	××××	××	×	××	×
<i>Alnus japonica</i>	×	××××	××	×	××	×
<i>Fagus shimakurai</i>	×	××××	××	×	××	×
<i>Fagus silvatica</i>	×	××××	××	×	××	×
<i>Quercus</i>	×	××××	××	×	××	×
<i>Liquidambar</i>	×	××××	×		×	
<i>Nyssa</i>	×	××××	×		×	
<i>Betula</i>	×	××	××	×	×	×
<i>Carpinus</i>	×	××	××	×	××	×
<i>Corylus</i>	×	××	××	×	××	×
<i>Castanea</i>	×	××	×	×	××	×
<i>Salix</i>	×	××××	×		××	×
<i>Ulmus</i>	×	××××	××	×	××	×
<i>Zelkova</i>		×	××	×	×	×
<i>Celtis</i>		×	×		×	
<i>Juglans</i>	×	×	××	×	×	×
<i>Pterocarya</i>	×	××××	××	×	××	×
<i>Acer</i>	×	××	×	×	××	×
<i>Rhus</i>		×	×		×	×
<i>Tilia</i>		×	×		×	
<i>Ilex</i>	×	××	××		××	×
<i>Fraxinus</i>	×	××	××	×	××	×
<i>Symplocos</i>	×	××××	××	×	××	×
<i>Viburnum</i>		×	×		××	×
<i>Weigera</i>					×	
<i>Lonicera</i>		×				
<i>Cornus</i>						×
<i>Elaeagnus</i>		×	×		×	
<i>Ericaceae</i>	×	×	×	×	××	×

U : upper part

L : lower part

× : occurrence of the fossil pollen

time to and including Takizawa time. The absence of the genera *Abies*, *Tsuga* and several others during Mataki time and their re-occurrence in the Takizawa seem to point to that a similar climatic pattern as seen during early Mataki to late Kazawa times was again experienced during the Takizawa stage. However, it must also be pointed out that the pollen flora of the eastern and western sides of the sedimentary basin during Mataki time was not the same because the topographic features were different. However, during Takizawa time the climatic conditions and pollen flora were rather uniform throughout, showing that the topographic features as well as the climatic conditions were also different

from that of the earlier stages.

It may be added that during Takizawa time the climatic conditions were uniformly cool as would be expected for early Pleistocene floral elements, whereas during the earlier stages in the present area the conditions were more temperate and even cool during the Yushima stage. Thus there was a gradual change in climate from cool during Yushima time to temperate in the Kazawa stage then transformation to mild during Mataki time, then a sudden lowering of the temperature with the opening of Takizawa time. During the evolution of climate the changes were somewhat abrupt where breaks in deposition of the strata are recognized yet slight fluctuations accompanied the changes from the Yushima up to and including the Takizawa, the latter is thus judged to be of Pleistocene age from the sudden drop in the temperature in correspondence with that of the Early Pleistocene.

Comparing the pollen flora of the Kitayama, Yagiyama and Dainenji formations of the Sendai area (Jimbo, 1958; Shimada, 1951; Sohma, 1956, 1957, 1958) with those of the Kazawa and Mataki formations of the present area, considerable differences can be recognized. In particular, *Liriodendron* and *Pseudotsuga* occur in the three mentioned formations in the Sendai area but are not known from any of the formations of the present area. On the other hand, *Pinus* is more abundant in the Sendai area than in the present one, whereas, *Abies* is more abundant in the present area than in the Sendai area. The Kitayama Formation is characterized by *Alnus*, *Fagus*, *Sequoia*-type pollen accompanied with *Pinus* and *Picea*. The Yagiyama Formation is characterized by *Alnus*, *Fagus* and *Quercus* in almost the same amount. These are accompanied by *Sequoia*-type pollen, *Pinus*, *Carpinus* and *Pterocarya*. The Dainenji Formation is noted for the occurrence of abundant *Alnus*, and is accompanied with such pollen grains as of the genera *Fagus*, *Quercus*, *Sequoia*-type pollen and *Pinus*. The pollen in the present area shows somewhat different aspect, the lower part of the Kazawa is characterized by the pollen of the genera *Fagus*, *Sequoia*, *Quercus* and *Alnus*, and its upper part is noted for the genera of *Alnus*, *Fagus* and *Pinus*. The lower part of the Mataki Formation is noted for such pollen grains as *Sequoia*, *Fagus*, *Quercus*, and *Alnus* in almost the same amount, whereas its upper part is characterized by *Sequoia* (abundant), accompanied with *Fagus*, *Quercus* and *Alnus*. The pollen just mentioned are those of the western side of the sedimentary basin. At the eastern side of the basin the upper part of the Mataki Formation, the only exposed stratigraphic unit, is characterized by *Abies*, *Picea*, *Pinus* and *Fagus* among which *Abies* is most abundant, the three others occur in almost the same amount. These are accompanied by *Alnus* and *Quercus*.

The differences in the pollen flora of the Sendai area and the present one can be explained by differences in latitude, altitude and surrounding topographic features.

Here it should be mentioned that each stratigraphic horizon in each areas has their own pollen assemblages by which they are characterized. The assemblages although somewhat different according to area and horizon in the geological column of the respective areas point not to different ages or climate, but reveal differences within the limits of each age and stratigraphic position in the geological column of the geological ages considered. For this reason in correlation or comparison it may not always be expected that the same assemblage will occur in the same stratigraphic position of the separated areas because local environmental criteria are not the same everywhere. However, the correlation of one area with another is rendered possible through the succession of the pollen-types, their indicated climatic pattern and assemblages restricted chronostratigraphically, and with the latitudinal criteria subjected to full consideration.

Comparing the flora and formations just mentioned with one another, the correlation may be as shown in Table 2. It should be mentioned that there seems to be no

stratigraphic unit in the Sendai area that can be correlated with the Takizawa Formation.

C. Systematic Descriptions of the Important and Characteristic Pollen Grains

More than 30 genera of fossil pollen and spores were distinguished from the materials at hand. These are shown in Tables 3, 4 and 5. Among the fossil flora, 18 genera are treated systematically because of their importance in the interpretation of the paleoenvironment and also as they are very characteristic in the pollen flora, based upon the specimens collected by the writer during the past ten years. The details of the sampling localities of the fossil pollen grains and spores are given in Fig. 3.

Subdivision Gymnospermae

Order Pinales

Family Pinaceae

Genus *Pinus* Linnaeus

Pinus Linn.; Wodehouse, 1935, p. 256-261, pl. 2, fig. 9, pl. 3, figs. 3, 9-11.

Pinus Linn.; Erdtman, 1954, p. 136-140, pl. 24, figs. 421-428.

Pinus Linn.; Erdtman, 1957, p. 34-36, figs. 57-58.

Pinus Linn.; Erdtman, 1965, p. 56-60, pls. 16-19.

Description: - Grains characterized by the possession of two large, conspicuous, air-filled bladders. The size of the bladder is almost equal to that of the body grain. The body of the grain is round or slightly elliptical in distal or proximal side. The cap is of a well defined granular texture and generally with a conspicuous rim at the point of transition to the distal part of the pollen grains. The sculpture of exine of the bladders is loosely reticulate.

Remarks: - As pointed out by Gerasimov (1930) and described by Rudolph (1935), there are two general types of bladders, namely, the *silvestris*-type and the *haploxylon*-type. In the *silvestris*-type, the bladders are more or less contracted at their base and represent more than half of the sphere. In polar view, the parts of three intersecting circles form the contour of the grain. In the pollen grain of the *haploxylon*-type, the bladders are semicircular, and broadly attached to the body. In polar view, the contour of the entire grain is rather elliptical. According to Erdtman (1954), "*Pinus banksiana*, *Pinus montana*, and *Pinus silvestris* may be used as examples of the former type, and *Pinus cembra*, and *Pinus peuce* may be of the latter type".

On the other hand, it has been treated the genus *Pinus* as composed of two subgenera; Subgen. *Haploxylon* and Subgen. *Diploxylon*. According to Shimakura (1971), the exine of the ventral surface usually shows granular texture in the pollen grain of the former subgenus but such is absent in the latter.

Based upon the morphological characteristics as mentioned under the description and remarks of the genus, several new species of pollen grains are distinguished. These pollen grains are described in the following pages together with those previously known.

Pinus shimakurai Takeuti, n. sp.

Pl. 1, figs. 1, 2.

Pinus Linn.; Shimakura, 1971, pl. 18-103 (Q-26), figs. 2, 3.

Description: - Grains with two air-filled bladders. The bladders are nearly circular, constricted at the base, analogous to the *Pinus silvestris*-type. The body of the grain is round or slightly elliptical in distal or proximal side. Cap of well defined granular texture, well developed marginal ridge. Sculpture of exine bladders loosely reticulate.

Holotype: - IGPS coll. cat. no. 93551 (Slide no. 4-14-151)

Paratype:—IGPS coll. cat. no. 93552-1 (Slide no. 3-9)

Dimensions:—total length of grain with bladders: 55 to 85 μ

length of body: 45 to 80 μ

bladder diameter: 30 to 50 μ

Remarks:—The pollen grains under consideration are identical with the grains of *Pinus* illustrated but not described by Shimakura, 1971 (Op. cit.).

This new species can be distinguished from *Pinus amplivesiculate* Traverse, 1955 (1955 p. 42, fig. 9 (19)) from the Cenozoic deposits of North America, by having a larger bladder in comparison with the size of the body and also by the thinner exine.

The fossil pollen grains under consideration can be distinguished from those of the living *Pinus* of Japan by the details of the relation of the bladder to body size and also by the thickness of the exine.

The specific name is given in honor of Dr. Misaburo Shimakura of the Nara University in Nara City, Nara Prefecture, in recognition of his many contributions to the study of Recent and fossil pollen flora of Japan.

Occurrence:—The present new species is found very rarely in the lignite seams of the Yushima, Kazawa and Mataki formations, whereas it is common in the lignite seams and peaty layers of the upper part of the Mataki Formation and also in the Takizawa Formation. Locality nos. 1-7, 9-11, 14, 15-a, 19-27, 29, 30.

Pinus tenuextima Traverse

Pl. 1, figs. 3, 4.

Pinus tenuextima Traverse, 1955, p. 41, fig. 8 (13-14).

Description:—Grains with two air-filled bladders. Bladders attached broadly to body, forming hemisphere in fashion of *Pinus haploxyylon*-type. Exine of proximal side of body rather thin, displaying no pronounced marginal ridge. Sculpture of exine of bladders loosely reticulate, that of body finely reticulate.

Figured specimens:—IGPS coll. cat. nos. 93553 (Slide no. 15-b-225), 93554 (Slide no. 15-b-8-209)

Dimensions:—total length of grain with bladders: 60 to 100 μ

length of body: 45 to 80 μ

bladder diameter: 30 to 60 μ

Remarks:—The pollen grains identified with the named species can be distinguished from *Pinus baileyana* Traverse (1955, p. 40, fig. 8 (11-12)) from the Cenozoic deposits of North America by the thinner exine of the broader body and also by the details of the surface sculpture.

Occurrence:—This species is commonly found in the lignite seams of the Yushima, Kazawa and lower part of Mataki formations, and is rare in the lignite seams and peaty layers of the upper part of the Mataki Formation and in the Takizawa Formation. Locality nos. 1-30.

Family Pinaceae

Genus *Picea* A. Dietrich

Picea sp.

Pl. 1, fig. 5.

Compare:—

Picea A. Dietr.; Wodehouse, 1935, p. 262-263, pl. 3, figs. 4, 6, 7. *Picea* A. Dietr.; Erdtman, 1954, p. 134-136, pl. 23, figs. 418-420. *Picea* A. Dietr.; Erdtman, 1957, p. 32-33, fig. 53. *Picea* sp.; Tokunaga, 1958, p. 30, pl. 4, fig. 1. *Picea* A. Dietr.; Erdtman, 1965, p. 54-55. *Picea*

A. Dietr.; Shimakura, 1971, pl. 18-103 (Q-26), figs. 5a, 5b.

Description: - Grains with two poorly developed bladders. The body is biconvex with well rounded corners in lateral view, and circular or slightly elliptical in polar view. The bladders are comparatively low, their contours in polar view, extend uniformly into the lateral contours of the body without forming any apparent angles. The exine of the cap has a fine granular texture and passes gradually into the more or less reticular texture of the bladders. There is no real marginal ridge.

Figured specimen: - IGPS coll. cat. no. 93555-1 (Slide no. 13-8)

Dimensions: - total length of grain with bladders: 95 to 135 μ
length of body: 70 to 110 μ
bladder diameter: 68 to 75 μ

Remarks: - The grains of the present specimens are nearly of the same size as those of the genus *Abies*, but they are provided with lower bladders and they show, in lateral view, a smaller re-entrant angle between the proximal root of the bladders and the contour line of the body. The texture of the cap is very fine, finer than in the genera *Abies*, *Cedrus* and *Pinus*, and the thickness of the exine in the proximal surface is thinner than in *Abies*. The fossil pollen grains referred to the genus *Picea* are difficult to be distinguished specifically because of the indistinct fine structure and sculpture. Generally, pollen morphological variation of one species overlaps that of another species in the same genus.

Occurrence: - The genus *Picea* is rarely found from the Yushima and Kazawa formations and commonly from the Matakai and Takizawa formations. Locality nos. 1-17, 20-30.

Family Pinaceae
Genus *Abies* Miller
Abies sp.
Pl. 1, figs. 6-8.

Compare: -

Abies Mill.; Wodehouse, 1935, p. 263-265, pl. 3, figs. 1, 3, 13, 14. *Abies* Mill.; Erdtman, 1954, p. 129-130, pl. 21, fig. 390. *Abies* Mill.; Erdtman, 1957, p. 6-7, fig. 2. *Abies* sp.; Tokunaga, 1958, p. 30, pl. 4, fig. 2. *Abies* Mill.; Erdtman, 1965, p. 13, 14. *Abies* Mill.; Shimakura, 1971, pl. 18-103 (Q-26), fig. 6.

Description: - Grains large, mostly over 100 μ in diameter. Exine of the cap very thick with coarse texture, marginal ridge unknown, boundary between body and bladders usually defined. Exine of the ventral surface usually smooth or slightly warty. The bladders generally small in proportion to the size of the grain, and loosely reticulate.

Figured specimens: - IGPS coll. cat. nos. 93556 (Slide no. 4-14-140), 93557-1 (Slide no. 29-1), 93558 (Slide no. 4-14-150)

Dimensions: - total length of grain with bladders: 115 to 140 μ
length of body: 80 to 110 μ
bladder diameter: 65 to 75 μ

Remarks: - The grains of the present specimens are similar to those of the genus *Pinus*, but differ from it in the size of the grains and bladders. The size of the bladder is generally smaller than other pollen grains with air-sacks in relation to the body size. According to Wodehouse (1935), this genus is easily distinguished from other winged-grained pollen by the large size, the thick and coarse texture of the cap, and the bladders which are generally small and frequently globular, and having the appearance of being stuck on the grain. The species name of the present fossil pollen grains of *Abies* is not determined

because the fine structure and sculpture are not so distinct.

Occurrence:— This genus is rarely found from the Yushima and Kazawa formations and commonly from the Mataka and Takizawa formations. Locality nos. 1–6, 8, 10–30.

Family Pinaceae
Genus *Tsuga* Carriere

Tsuga Carr.; Erdtman, 1954, p. 143–144, pl. 25, fig. 441, pl. 26, figs. 442, 443.

Tsuga Carr.; Erdtman, 1957, p. 43–44, fig. 73.

Tsuga Carr.; Erdtman, 1965, p. 78–80.

Tsuga Carr.; Shimakura, 1971, pl. 18–103 (Q–26), fig. 7.

Description:— Grains circular in polar view, flat or cup-shaped in lateral view, the center of the distal part is frequently somewhat depressed. Grains without a well-marked furrow and without bladders, encircled by a well developed marginal fringe. The fringe is more or less “Puffy” with frequently rather twisted protrusions compactly arranged.

Remarks:— According to Jimbo (1933), the entire surface of the pollen grains of *Tsuga diversifolia* is covered by relatively short and sharp spines. However, in some specimens of that species, the spines are hardly developed whereas on other specimens the spines are well developed but very few in number.

It is noticed that among the pollen grains of the genus *Tsuga* observed in the present study, there are abundant grains with the entire surface covered with short spines as in *Tsuga diversifolia*, but differing therefrom in having an enormously larger number, whereby the fossil grains can be distinguished easily from the ones reported by Jimbo (Op. cit.). The grains with numerous short spines all over the surface is proposed as a new species and described in the following.

Tsuga polyspinosa Takeuti, n. sp.

Pl. 1, fig. 11.

Description:— Grains circular in polar view, flat or cup-shaped in lateral view, center of distal part frequently somewhat depressed. Grains without well-marked furrow and without bladders, encircled by marginal fringe. Entire surface covered with numerous short spines. Exine not very thick but roughly corrugated.

Holotype:— IGPS coll. cat. no. 93559 (Slide no. 15–b–8–227)

Dimensions:— 65 to 110 μ in diameter

Remarks:— Compared with *Tsuga diversifolia*, the present new species has a large number of spines covering the entire surface and the marginal fringe is thinner, and in diameter the former is slightly smaller than the latter.

Occurrence:— The pollen grains of the new species occur from the Yushima Formation up to and including the Takizawa Formation, and is rather few throughout. Locality nos. 1–8, 10–16, 18, 21, 23–27, 29, 30.

Tsuga diversifolia Masters

Pl. 1, fig. 12.

Tsuga diversifolia Mast.; Jimbo, 1933, p. 290, pl. 11, figs. 3a, 3b.

Tsuga diversifolia Mast.; Erdtman, 1954, p. 143–144, pl. 25, fig. 441, pl. 26, figs. 442, 443.

Description:— Grains circular in polar view, flat or cup-shaped in lateral view. Grains encircled by a well developed marginal fringe.

Figured specimen:— IGPS coll. cat. no. 93560 (Slide no. 15–b–8–211)

Dimensions:— 62 to 90 μ in diameter

Remarks:—The present species is characterized by the marginal fringe well developed and in the fossil specimens having no spines on the surface. In other features the present species resembles *Tsuga polyspinosa* Takeuti, a fossil species of the Ichinoseki area, and in size, the present species is slightly smaller than the newly proposed species.

Occurrence:—This species occurs from the upper part of the Kazawa Formation and extends into the Takizawa Formation. The pollen grains of this species are fewer than those of *Tsuga polyspinosa*. Locality nos. 1–4, 14–15b, 23, 26, 27, 29.

Family Taxodiaceae
Genus *Cryptomeria* D. Don
Cryptomeria japonica D. Don
Pl. 1, figs. 13, 14.

Cryptomeria japonica D. Don; Wodehouse, 1935, p. 268–269, pl. 2, figs. 2, 8.

Cryptomeria japonica D. Don; Erdtman, 1954, p. 130, pl. 22, fig. 400.

Cryptomeria D. Don; Erdtman, 1957, p. 12, fig. 15.

Cryptomeria D. Don; Erdtman, 1965, p. 26–28.

Cryptomeria D. Don; Shimakura, 1971, pl. 18–103 (Q–26), fig. 11.

Description:—Grains spheroidal, monoporate, provided with a single germinal pore. Pore consists of a finger-like projection standing straight up from its surface and slightly bent at the top. Exine is thin and flecked, and intine thick.

Figured specimens:—IGPS coll. cat. nos. 93561 (Slide no. 4–14–124), 93557–2 (Slide no. 29–1)

Dimensions:—24 to 35 μ in diameter

Remarks:—There is one species of the genus *Cryptomeria* and it is distributed only in Japan. The genus *Cryptomeria* resembles the genus *Sequoia* but is distinguished by its longer and less bent finger-like germinal papilla and its smaller size. According to Wodehouse (1935), “*Taxodium distichum* consists of a conical papilla similar to but much less prominent than that of *Cryptomeria* and not bent at the tip”.

Occurrence:—The present fossil pollen grains are commonly found in the peat layers of the Takizawa Formation. Locality nos. 4, 23, 29.

Family Taxodiaceae
Genus *Sequoia* Endlicher
Sequoia sp.
Pl. 1, figs. 15–17.

Compare:—

Sequoia Endl.; Wodehouse, 1935, p. 269–271. *Sequoia* Endl.; Erdtman, 1954, p. 142, pl. 25, figs. 435, 436. *Sequoia* Endl.; Erdtman, 1957, p. 41, fig. 66. *Sequoia* Endl.; Erdtman, 1965, p. 73–74.

Description:—Grains approximately spheroidal in shape, monoporate, provided with a single germinal pore, consisting of a conical projection which rises abruptly from the surface and bends sharply to the side. Exine is thin and flecked, and intine is thick.

Figured specimens:—IGPS coll. cat. nos. 93555–2 (Slide no. 13–8), 93562 (Slide no. 4–2–311), 93563–2 (Slide no. 17–3)

Dimensions:—25 to 40 μ in diameter

Remarks:—The genus *Sequoia* is similar to *Cryptomeria*, but it differs from the latter in its slightly larger size and the bent shape of its germinal papilla. According to Wodehouse (1935), “The genus *Sequoia* contains only two living species, *Sequoia sempervirens* Endl. and *Sequoia gigantea* Decne, confined in distribution to the coast of California and

Oregon and the mountains of California; but it is known to have had a distribution with several species over most of the Northern Hemisphere in Cretaceous and Tertiary times".

From the Pliocene formations in the area of Northeast Honshu, Japan, the plant fossils of the species *Sequoia sempervirens* Endl. and *Sequoia affinis* Lesquereux have been recorded. The fossil pollen grains referred to the genus *Sequoia* are characteristic as mentioned above, but specific identification is withheld because the fine structure and sculpture are not clear enough to determine the species.

Occurrence:— This genus occurs from the Yushima, Kazawa and Mataka formations, and is common throughout. Locality nos. 1–22, 24–28, 30.

Family Taxodiaceae
Genus *Glyptostrobus* Endlicher
Glyptostrobus sp.
Pl. 1, fig. 18.

Compare:—

Glyptostrobus Endl.; Erdtman, 1957, p. 21, fig. 33. *Glyptostrobus* sp.; Tokunaga, 1958, p. 32, pl. 4, fig. 11. *Glyptostrobus* Endl.; Erdtman, 1965, p. 42.

Description:— Grains spheroidal, monoporate, provided with a small germinal papilla, which is pointed and curved sharply to one side. Exine is thin and lightly flecked with a few scattered granules.

Figured specimen:— IGPS coll. cat. no. 93564–1 (Slide no. 3–7)

Dimensions:— 25 to 35 μ in diameter.

Remarks:— The pollen grains of the genus *Glyptostrobus* are similar to those of *Cryptomeria* and *Sequoia*, but differ from those of the latter by having a much smaller germinal papilla and rather thicker exine. The fossil pollen grains are frequently torn into two longitudinal parts, and the papilla becomes dipped in the depression.

In the Japanese Islands, there are not known any living species of the genus *Glyptostrobus*, but from the Pliocene formations, the occurrence of plant fossils such as *Glyptostrobus europaeus* Heer, *G. pensilis* Koch and *G.* sp. have been reported. The present fossil grains of *Glyptostrobus* are not named specifically because of the fine structure and sculpture being not distinct enough to determine the species.

Occurrence:— The genus *Glyptostrobus* is commonly found in the lignite seams and coaly siltstone from the Yushima Formation up to the Mataka Formation. Locality nos. 1–22, 24–28, 30.

Subdivision Angiospermae
Class Dicotyledoneae
Family Fagaceae
Genus *Fagus* Linnaeus
Fagus shimakurai Takeuti, n. sp.
Pl. 2, fig. 5.

Fagus Linn.; Shimakura (in part), 1971, pl. 18–104 (Q–27), fig. 10b (figs. a, c seem to belong to a different species, and are of the *F. silvatica*-type of pollen).

Description:— Grains spheroidal, tricolporate, with longitudinal furrows running nearly from pole to pole. The furrows are narrow, long and clean edged, usually spaced around the equator and meridionally arranged. Each furrow has a distinct equatorial germinal pore with prominent margin. Exine thick, heavy and coarsely granulate.

Holotype:— IGPS coll. cat. no. 93564–3 (Slide no. 3–7)

Dimensions:— 32 to 40 μ in diameter

Remarks:— The fossil pollen grains here identified as belonging to the genus *Fagus*, comprise two types, one has the short and dies out furrows, whereas the other type has longer furrows which have narrow yet rounded terminal and thick intine surrounding the pore. The former type is quite identical with *Fagus silvatica* recorded and illustrated by Erdtman (1954, Chapter VIII, pl. 11, figs. 181–183), a Recent species from Ryttern, Sweden and the latter is considered to be identical with an unidentified species of *Fagus* illustrated by Shimakura (1971, pl. 18–104, fig. 10b), a Quaternary *Fagus* from the Katada Formation in Shiga Prefecture. Since Shimakura's illustrated but not described *Fagus* has not been named and is identical with the fossil pollen grains of one type of *Fagus* from the Ichinoseki area, a new specific name becomes necessary in order that it can be used for biostratigraphic application and also for the classification of the fossil pollen. For this reason, the name of *Fagus shimakurai* Takeuti, n. sp. is proposed for Shimakura's figured fossil pollen grains of *Fagus* from the stratigraphic unit mentioned above. The other type of pollen is named *Fagus silvatica* Linnaeus.

The species name is given in honor of Dr. Misaburo Shimakura of the Nara University, Nara Prefecture, in recognition of his contributions to the study of pollen in Japan.

Occurrence:— The present new species is rarely found from the Yushima Formation up to and including the Takizawa Formation, and is especially very rare in the Takizawa Formation. Locality nos. 1–15b, 17–20, 22, 25–28, 30.

Fagus silvatica Linnaeus

Pl. 2, figs. 6, 7.

Fagus silvatica Linn.; Wodehouse, 1935, p. 379.

Fagus silvatica Linn.; Erdtman, 1954, p. 98, pl. 11, figs. 181–183.

Description:— Grains spheroidal, tricolporete, with longitudinal furrows. The furrows are rather short, narrow and tapering. Each furrow has a distinct equatorial germinal pore. Exine somewhat thin and granulate.

Figured specimens:— IGPS coll. cat. nos. 93565. (Slide no. 4–2–305), 93566 (Slide no. 15–b–16–204)

Dimensions:— 35 to 45 μ in diameter

Remarks:— The pollen grains of *Fagus silvatica* Linnaeus, which are known only from the northern part of Europe as Recent, and the present record seems to be the first from Japan or the Far East. The pollen grains, which are indistinguishable from the figures and descriptive remarks of *Fagus silvatica* given by Erdtman (1954), are found among the samples taken from the formations ranging from the Yushima up to and including the Takizawa, thus in time from the Early Pliocene to Pleistocene. It is expected that the grains of this species will be found in other younger Cenozoic formations of the Japanese Islands, and it is thought that many of the pollen grains merely listed as *Fagus* may include this species as well as *Fagus shimakurai* described above.

Occurrence:— The pollen grains of this species are commonly found from the Yushima, Kazawa, Mataka and Takizawa formations. Locality nos. 1–30.

Family Fagaceae

Genus *Quercus* Linnaeus

Quercus sp.

Pl. 2, figs. 8–10.

Compare:—

Quercus Linn.; Wodehouse, 1935, p. 373–379, pl. 7, fig. 6. *Quercus* Linn.; Erdtman, 1952, p. 177.

Quercus Linn.; Erdtman, 1954, p. 100–101, pl. 11, figs. 188–195. *Quercus* sp.; Tokunaga, 1958, p. 33, pl. 5, figs. 11–14, 18–22, 26–28, 31, 34, 35, pl. 6, figs. 4, 7, 9, 13. *Quercus* Linn.; Shimakura, 1971, pl. 18–104 (Q-27), figs. 12a–12c.

Description:—Grains subprolate to spheroidal, tricolpate, with long and very pronounced longitudinal furrows. The furrows meridional in arrangement, tapering to pointed ends. Exine is thin and warty-granulate. Three or occasionally four furrows broadly expanded one to each angle of the grain.

Figured specimens:—IGPS coll. cat. nos. 93552–2 (Slide no. 3–9), 93567 (Slide no. 2–16–6), 93568 (Slide no. 4–14–159)

Dimensions:—25 to 40 μ in diameter

Remarks:—According to Fuji (1965), “As the sculpture is missing, if this pollen grain is determined by the grain size and shape, it must belong to *Helianthus*, *Quercus*, *Castanopsis*, *Tetragonia*, *Citrus*, *Euonymus* or *Pleuropteropyrum*. The difference between *Helianthus*, *Quercus*, *Castanopsis*, *Tetragonia* and the three others is as stated below, the former has many spinules on the perine, but the latter has no spinule but a reticulum. As the sculptures are not preserved in fossil pollen grains, this difference is entirely indistinguishable.”

The present fossil grains compared with the figures given by the author's mentioned above and also with the living materials, show some differences. The differences are in size and sculpture. However, specific naming is withheld because the fine structure and sculpture are not distinct enough to determine the species.

Occurrence:—The grains are commonly found from the Yushima Formation up to the Mataka Formation, and are abundant in the peaty layers of the Takizawa Formation. Locality nos. 1–30.

Family Hamamelidaceae
Genus *Liquidambar* Linnaeus
Liquidambar sp.
Pl. 1, figs. 19–22.

Compare:—

Liquidambar styraciflua Linn.; Wodehouse, 1935, p. 425, pl. 6, fig. 2. *Liquidambar styraciflua* Linn.; Erdtman, 1954, p. 102, pl. 12, fig. 217. *Liquidambar mangelsdorffiana* Traverse, 1955, p. 53, fig. 10 (59). *Liquidambar brandonensis* Traverse, 1955, p. 53, fig. 10 (60, 61).

Description:—Grains spheroidal, poriporate, provided with 12 to 20 large pores which are approximately circular or elliptical. The pore membranes conspicuously flecked. The germ pores are not uniform even on the same grain, 6 to 10 μ in diameter, in arrangement they appear to be irregular. Exine is thickened and deeply pitted with minute round pits.

Figured specimens:—IGPS coll. cat. nos. 93569–1 (Slide no. 13–2), 93569–2 (Slide no. 13–2), 93570–1 (Slide no. 13–3), 93555 (Slide no. 13–8)

Dimensions:—35 to 40 μ in diameter.

Remarks:—The genus *Liquidambar* now living in the Ryukyu Islands and Taiwan, has been frequently reported from the younger Cenozoic deposits in various places in the Japanese Islands. From the present geographical distribution the genus as fossil has been considered an indicator of warm climatic conditions. The present fossil grains of *Liquidambar* are not named specifically because the fine structure and sculpture are not so distinct.

Occurrence:—The genus *Liquidambar* is commonly found from the Yushima and the lower part of the Kazawa formations, and is very rare in the lignite seams of the upper

part of the Kazawa Formation and also so in the upper part of the Mataka Formation. Locality nos. 1-3, 5-13, 15-16.

Family Nyssaceae
Genus *Nyssa* Gronovius
Nyssa sp.
Pl. 2, figs. 1-4.

Compare: -

Nyssa sylvatica Marsh.; Wodehouse, 1935, p. 446, pl. 10, fig. 5. *Nyssa sylvatica* Marsh.; Sohma, 1963, p. 391, pl. 10, figs. e-h. *Nyssa biflora* Walt.; Sohma, 1963, p. 391, pl. 11, figs. a-d. *Nyssa ogeche* Walt.; Sohma, 1963, p. 391, pl. 11, figs. e-h. *Nyssa javanica* Wanger.; Sohma, 1967, p. 527, figs. 1-4. *Nyssa aquatica* Linn.; Sohma, 1967, p. 527-529, figs. 5-8. *Nyssa sinensis* Oliv.; Sohma, 1967, p. 529-530, figs. 9-12.

Description: - Grains tricolporate, suboblate to prolate spheroidal in equatorial view, more or less flattened at the polar areas, and roundly triangular in polar view. The furrows at the angles, long and narrow, expanding slightly at the equator. Very pronounced germ pores at equator, rounded or somewhat elliptical in outline. The demarcation of ectexine and endexine is clear, ectexine decreasing in thickness toward the furrows. The external appearance of the exine more or less uniformly reticulate.

Figured specimens: - IGPS coll. cat. nos. 93564-2 (Slide no. 3-7), 93571 (Slide no. 18-1), 93572 (Slide no. 2-16-12), 93563-1 (Slide no. 17-3)

Dimensions: - 28 to 41 μ in diameter.

Remarks: - The living seven species of *Nyssa* are now distributed in eastern North America, Mexico and Southeastern Asia, but not in the Japanese Islands. However, the plant fossils of *Nyssa* such as *Nyssa sylvatica* Marshall and *Nyssa* sp. have been reported from the Pliocene deposits in many places in the Japanese Islands. The present fossil pollen grains are not named specifically because the fine structure and sculpture are not so distinct.

Occurrence: - The pollen grains of *Nyssa* occur rarely from the Yushima and Kazawa formations and more commonly from the upper part of the Mataka Formation. Locality nos. 2, 4-19, 28.

Family Betulaceae
Genus *Alnus* Miller
Alnus raris Takeuti, n. sp.
Pl. 2, fig. 11.

Description: - Grains flattened, oblata spheroidal to suboblate, with thin bands connecting pores. The pores are mostly five in number. The grain in polar view is pentagonal. The pores are situated in the angles, aspidate, narrowly elliptical. Exine thin, smooth or slightly granulate.

Holotype: - IGPS coll. cat. no. 93573 (Slide no. 2-16-2)

Dimensions: - 22 to 30 μ in diameter

Remarks: - The fossil pollen grains of *Alnus* here under consideration are not comparable with any illustrated pollen grains of the genus published in Japan, but show resemblance with the grains of *Alnus incana* Linnaeus (Wodehouse, 1935, p. 371; Erdtman, 1954, p. 70, pl. 4, figs. 54-58, refer to fig. 54), a Recent species of Sweden. However, the present fossil grains can be distinguished from those of the Swedish species by the equatorial arrangement of the pores and by the less distinct aspidate pores, and by the thinner exine. Based upon the mentioned differences the Ichinoseki fossil pollen grains are given the new

species name of *Alnus raris* Takeuti.

The new species ranges from the Yushima Formation up to and including the Takizawa Formation, or in time from lower Pliocene to Pleistocene. Although having a rather long time range in the present area, the grains are few throughout.

The new species name *raris* is taken from its rare occurrence in the formations extending from Early Pliocene to Pleistocene.

Occurrence:—This new species occurs from the Yushima, Kazawa, Mataki and Takizawa formations, and is rare throughout. Locality nos. 1–23, 25–30.

Alnus japonica Siebold et Zuccarini

Pl. 2, figs. 12–14.

Alnus japonica Sieb. et Zucc.; Ikuse, 1956, p. 61, pl. 52, figs. 64, 65.

Alnus Mill.; Shimakura, 1971, pl. 18–104 (Q–27), fig. 5a.

Description:—Grain flattened, oblate spheroidal to suboblate, with thickened bands connecting pores. The pores are five or sometimes four or six in number. The grain in polar view is square, pentagonal, or hexagonal according to the number of pores. The pores situated in the angles, aspidate, narrowly elliptical or slit-shaped. Exine rather thick, smooth or slightly granulate.

Figured specimens:—IGPS coll. cat. nos. 93569–3 (Slide no. 13–2), 93563–3 (Slide no. 17–3), 93574 (Slide no. 2–16–1)

Dimensions:—20 to 32 μ in diameter

Remarks:—The pollen grains of *Alnus japonica* illustrated by Ikuse (1956) well agree with the present fossil pollen grains, which are identified with that species. The unnamed pollen illustrated by Shimakura (1971, pl. 18–104, fig. 5a) is thought to be identical with the present fossil pollen.

As known at the present time *Alnus japonica* as fossil is known only from the Manchidani Formation in Hyogo Prefecture (Quaternary) and the present record is the second in Japan.

The species *japonica* in the present area ranges in common from the Yushima Formation of Early Pliocene age up to and including the Pleistocene Takizawa Formation.

Occurrence:—The present pollen grains are commonly found from the Yushima, Kazawa, Mataki and Takizawa formations. Locality nos. 1–30.

Family Betulaceae

Genus *Betula* Linnaeus

Betula sp.

Pl. 2, fig. 18.

Compare:—

Betula Linn.; Wodehouse, 1935, p. 366–367, pl. 7, fig. 1. *Betula* Linn.; Erdtman, 1954, p. 72–74, pl. 5, figs. 62–75. *Betula* sp.; Tokunaga, 1958, p. 36, pl. 6, fig. 27. *Betula* Linn.; Shimakura, 1971, pl. 18–104 (Q–27), fig. 8.

Description:—Grains suboblate to spheroidal, less flattened than the grains of the genus *Alnus*. In polar view more or less angular owing to aspidate pores, germinal pores mostly three, rarely four, equatorially arranged and equally spaced. Exine slightly granular or nearly smooth. The pores more or less elliptical.

Figured specimen:—IGPS coll. cat. no. 93575 (Slide no. 4–14–157)

Dimensions:—24 to 27 μ in polar view

Remarks:—The pore pattern is similar to that of the genus *Carpinus*, but the exine

of *Carpinus* surrounding the pore is less thickened, and the size is larger. The species name of *Betula* is not determined because the fine structure and sculpture are not distinct enough to determine the species.

Occurrence:—The genus *Betula* is found very rarely from the Yushima Formation up to and including the Takizawa Formation. Locality nos. 1–16, 19–20, 22, 23, 26–30.

Family Betulaceae
Genus *Carpinus* Linnaeus
Carpinus sp.
Pl. 2, figs. 15–17.

Compare:—

Carpinus Linn.; Wodehouse, 1935, p. 368. *Carpinus* Linn.; Erdtman, 1954, p. 76, pl. 5, figs. 76–81.

Carpinus sp.; Tokunaga, 1958, p. 36, pl. 6, fig. 26. *Carpinus* Linn.; Shimakura, 1971, pl. 18–104 (Q–27), fig. 7.

Description:—Grains similar to those of the genus *Betula* but nearly spheroidal, and the exine is thinner. Pores generally three, sometimes four, rarely five. The exine surrounding the pore is not thickened, and raises distinctly from the general surface of the grain. The pores are circular or broadly elliptical.

Figured specimens:—IGPS coll. cat. nos. 93576 (Slide no. 15–b–8–2307), 93577 (Slide no. 2–16–44), 93578 (Slide no. 15–b–8–229)

Dimensions:—25 to 47 μ in polar view

Remarks:—According to Erdtman (1954), “Grains of about the same morphological type as those of *Betula*. They are, however, more rounded and the exine is thinner. The pore pattern is similar to that in *Betula*, but the ectexine surrounding the pore is not thickened”.

The species name of the present fossil pollen grains of *Carpinus* is not determined owing to that the fine structure and sculpture are not so distinct.

Occurrence:—The present fossil pollen grains are commonly found from the Yushima, Kazawa, Mataka and Takizawa formations. Locality nos. 1–23, 25–30.

Family Betulaceae
Genus *Corylus* Linnaeus
Corylus sp.
Pl. 2, figs. 19, 20.

Compare:—

Corylus Linn.; Wodehouse, 1935, p. 369. *Corylus* Linn.; Erdtman, 1954, p. 76–77, figs. 82–89.

Corylus sp., Tokunaga, 1958, p. 37, pl. 6, fig. 30. *Corylus* Linn.; Shimakura, 1971, pl. 18–104 (Q–27), fig. 6.

Description:—Grains psilate, more or less triangular in polar view. The grain has usually three pores equally spaced on the equator at the angles. The pore apertures slightly elliptical or more or less circular. Exine gradually and only slightly raised above the surface of the grain at the pores.

Figured specimens:—IGPS coll. cat. nos. 93579–1 (Slide no. 15–a–3), 93564–4 (Slide no. 3–7)

Dimensions:—23 to 30 μ in polar view

Remarks:—The pollen grains referred to the genus *Corylus* are readily recognized by their characteristics mentioned above, but the species determination is difficult owing to that the fine structure and sculpture are not so distinct, therefore, the present grains have been left indetermined.

Occurrence:—The present fossil pollen grains are found rarely from the Yushima Formation up to and including the Takizawa Formation. Locality nos. 1–15, 17–28, 30.

Family Ulmaceae
Genus *Ulmus* Linnaeus
Ulmus sp.
Pl. 2, figs. 22, 23.

Compare:—

Ulmus Linn.; Wodehouse, 1935, p. 384–386, pl. 7, fig. 10. *Ulmus* Linn.; Erdtman, 1952, p. 442.
Ulmus Linn.; Erdtman, 1954, p. 124–125, pl. 20, figs. 368–370.

Description:—Grains suboblate, stephanoporate. Germinal pores four to six, generally four, and elliptical or narrowly elongate in shape. Their apertures 4 to 6 μ in length, equatorially arranged. Texture of the exine smooth but marked by slight undulations which are due to internal reticulate thickening.

Figured specimens:—IGPS coll. cat. nos. 93570–2 (Slide no. 13–3), 93580 (Slide no. 4–14–129)

Dimensions:—26 to 42 μ in polar view

Remarks:—The grains of the genus *Ulmus* are very similar to those of the genus *Zelkova*. According to Wodehouse (1935), the former can be distinguished from the latter by the texture of the exine. The fossil grains referred to the genus *Ulmus* are quite characteristic as described above. But specific identification is withheld owing to the indistinct fine structure and sculpture.

Occurrence:—The genus *Ulmus* is rarely found from the Yushima, Kazawa and Mataka formations, and is common in the Takizawa Formation. Locality nos. 1–30.

Family Aceraceae
Genus *Acer* Linnaeus
Acer sp.
Pl. 2, figs. 26, 27.

Compare:—

Acer Linn.; Wodehouse, 1935, p. 438–442, pl. 10, fig. 1. *Acer* Linn.; Erdtman, 1952, p. 33. Aceraceae; Erdtman, 1954, p. 66, pl. 3, figs. 34–41, pl. 4, figs. 42, 43. *Acer* Linn.; Shimakura, 1971, pl. 18–105 (Q–28), fig. 3.

Description:—Grains when moistened become oblatly spheroidal, when unexpanded they are ellipsoidal, and prevailingly tricolpate. The meridional furrow is equally spaced around the equator. When expanded, the grains are often noticeably flattened with the meridional furrows gaping widely open. The general surface of the exine is always conspicuously granulate, the granules are arranged more or less in rows, giving the exine a striate appearance. These striae have a tendency to run parallel to furrows, and form the patterns which resemble thumb-prints. The exine gradually thins towards the margins of the furrows.

Figured specimens:—IGPS coll. cat. nos. 93564–5 (Slide no. 3–7), 93581–1 (Slide no. 8–6)

Dimensions:—28 to 40 μ in diameter

Remarks:—The leaves of the genus *Acer* have been recorded from many Pliocene and Pleistocene formations in the Japanese Islands, but the pollen grains referred to the genus are difficult to distinguish specifically, particularly because the fine structure and sculpture are not so clear.

Occurrence:—The present fossil pollen grains occur from the Yushima Formation up to and including the Takizawa Formation, and is very rare throughout. Locality nos. 1-13, 15-19, 21, 22, 25, 27, 28, 30.

Family Juglandaceae
Genus *Pterocarya* Kunth
Pterocarya sp.
Pl. 2, fig. 25.

Compare:—

Pterocarya Kunth; Wodehouse, 1935, p. 356, 362, pl. 6, fig. 7. *Pterocarya* Kunth; Erdtman, 1954, p. 106, pl. 13, fig. 231. *Pterocarya* sp.; Tokunaga, 1958, p. 37, pl. 7, figs. 6, 11, 12.

Description:—Grains flattened, angular in outline, stephanoporate. Pores generally five to seven, one at each angle of the grain. Their apertures elliptical, 3 to 5 μ long, subexineous thickening of small extent. The pores arranged around the equator are occasionally irregular in arrangement. There is a juglandaceous tendency to have the pores more or less displaced off the equator into one hemisphere. Exine slightly granulate.

Figured specimen:—IGPS coll. cat. no. 93569-4 (Slide no. 13-2)

Dimensions:—30 to 40 μ in diameter

Remarks:—This genus is very similar to the genus *Juglans*. It has been generally said that the former is distinguished from the latter by the smaller size and the difference of the germ pores in arrangement, but it is difficult to distinguish the pollen grains between those two genera. Naming of the species was not done owing to the indistinct fine structure and sculpture.

Occurrence:—The fossil pollen grains of *Pterocarya* are commonly found from the Yushima, Kazawa, Mataka and Takizawa formations. Locality nos. 1-13, 15-24, 26-30.

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Explanation of Plate 1

- Figs. 1, 2. *Pinus shimakurai* Takeuti, n. sp. 1—polar view, Holotype, IGPS coll. cat. no. 93551 (Slide no. 4-14-151), $\times 330$. Loc. no. 4, Takizawa Formation, Early Pleistocene. 2—lateral view, Paratype, IGPS coll. cat. no. 93552-1 (Slide no. 3-9), $\times 330$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Figs. 3, 4. *Pinus tenuextima* Traverse. 3—oblique lateral view, IGPS coll. cat. no. 93553 (Slide no. 15-b-8-225), $\times 330$. 4—polar view, IGPS coll. cat. no. 93554 (Slide no. 15-b-8-209), $\times 330$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Fig. 5. *Picea* sp. oblique lateral view, IGPS coll. cat. no. 93555-1 (Slide no. 13-8), $\times 330$. Loc. no. 13, Kazawa Formation, Late Pliocene.
- Figs. 6-8. *Abies* sp. 6—lateral view, IGPS coll. cat. no. 93556 (Slide no. 4-14-140), $\times 170$. Loc. no. 4. 7—oblique lateral view, IGPS coll. cat. no. 93557-1 (Slide no. 29-1), $\times 170$. Loc. no. 29. 8—polar view, IGPS coll. cat. no. 93558 (Slide no. 4-14-150), $\times 170$. Loc. no. 4. Takizawa Formation, Early Pleistocene.
- Fig. 9. *Sciadopitys* sp. polar view, IGPS coll. cat. no. 93582 (Slide no. 15-b-8-224), $\times 630$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Fig. 10. *Metasequoia* sp. lateral view, IGPS coll. cat. no. 93583 (Slide no. 3-5), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Fig. 11. *Tsuga polyspinosa* Takeuti, n. sp. polar view, Holotype, IGPS coll. cat. no. 93559 (Slide no. 15-b-8-227), $\times 330$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Fig. 12. *Tsuga diversifolia* Masters. polar view, IGPS coll. cat. no. 93560 (Slide no. 15-b-8-211), $\times 330$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Figs. 13, 14. *Cryptomeria japonica* D. Don. 13—polar view, IGPS coll. cat. no. 93561 (Slide no. 4-14-124), $\times 630$. Loc. no. 4. 14—oblique lateral view, IGPS coll. cat. no. 93557-2 (Slide no. 29-1), $\times 630$. Loc. no. 29. Takizawa Formation, Early Pleistocene.
- Figs. 15-17. *Sequoia* sp. 15—oblique lateral view, IGPS coll. cat. no. 93555-2 (Slide no. 13-8), $\times 630$. Loc. no. 13, Kazawa Formation, Late Pliocene. 16—oblique lateral view, IGPS coll. cat. no. 93562 (Slide no. 4-2-311), $\times 630$. Loc. no. 4, Mataki Formation, Late Pliocene. 17—lateral view, IGPS coll. cat. no. 93563-2 (Slide no. 17-3), $\times 630$. Loc. no. 17, Mataki Formation, Late Pliocene.
- Fig. 18. *Glyptostrobus* sp. lateral view, IGPS coll. cat. no. 93564-1 (Slide no. 3-7), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Figs. 19-22. *Liquidambar* sp. polar view, IGPS coll. cat. nos. 93569-1, 93570-1, 93555-3, 93569-2 (Slide nos. 13-2, -3, -8, -2), $\times 630$. Loc. no. 13, Kazawa Formation, Late Pliocene.



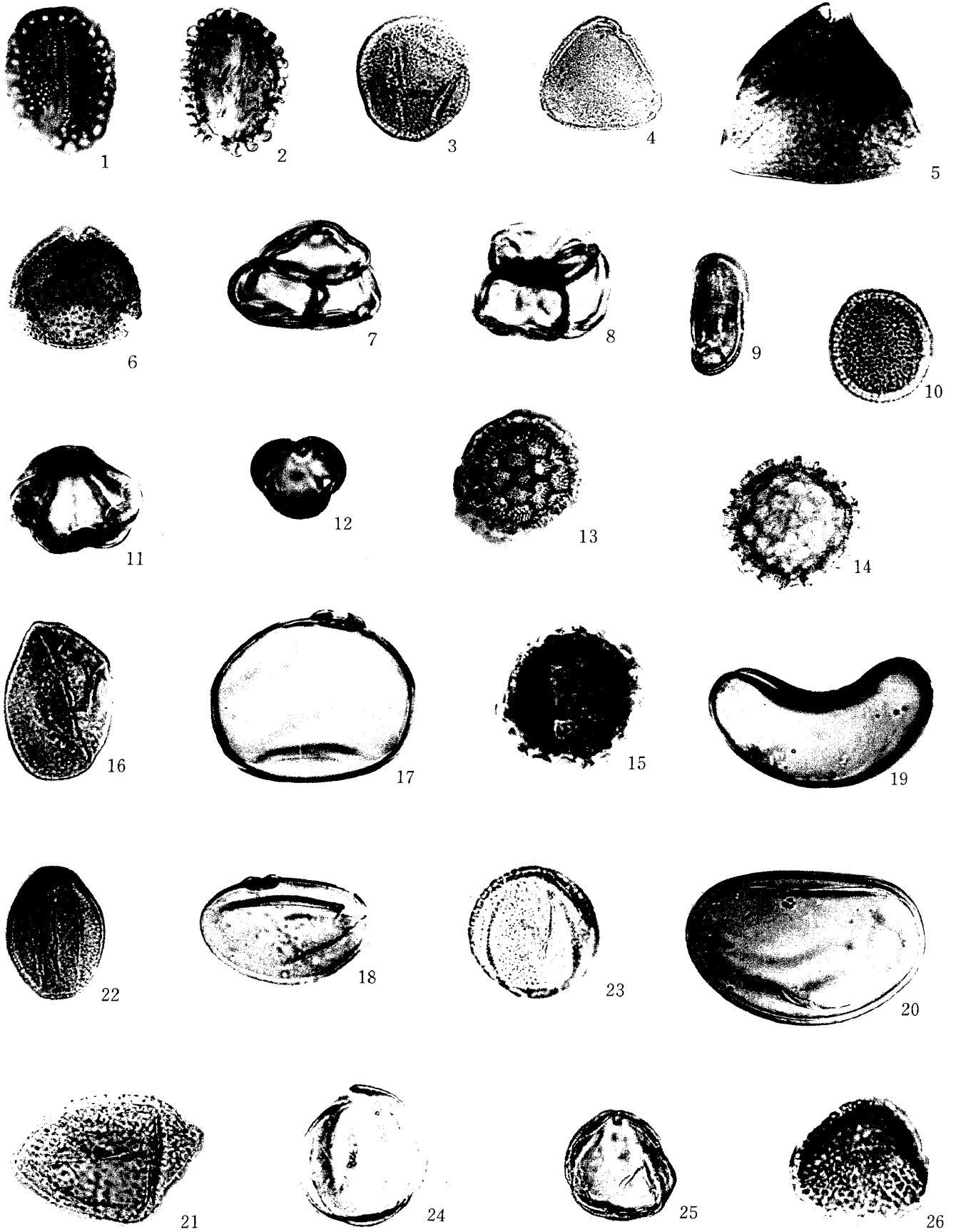


Explanation of Plate 2
(all figures $\times 630$)

- Figs. 1-4. *Nyssa* sp. 1-polar view, IGPS coll. cat. no. 93564-2 (Slide no. 3-7). Loc. no. 3, Mataki Formation, Late Pliocene. 2-oblique polar view, IGPS coll. cat. no. 93571 (Slide no. 18-1). Loc. no. 18, Mataki Formation, Late Pliocene. 3-oblique polar view, IGPS coll. cat. no. 93572 (Slide no. 2-16-12). Loc. no. 2, Kazawa Formation, Late Pliocene. 4-oblique equatorial view, IGPS coll. cat. no. 93563-1 (Slide no. 17-3). Loc. no. 17, Mataki Formation, Late Pliocene.
- Fig. 5. *Fagus shimakurai* Takeuti, n. sp. oblique polar view, Holotype, IGPS coll. cat. no. 93564-3 (Slide no. 3-7). Loc. no. 3, Mataki Formation, Late Pliocene.
- Figs. 6, 7. *Fagus silvatica* Linnaeus. 6-polar view, IGPS coll. cat. no. 93565 (Slide no. 4-2-305). Loc. no. 4, Mataki Formation, Late Pliocene. 7-equatorial view, IGPS coll. cat. no. 93566 (Slide no. 15-b-16-204). Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Figs. 8-10. *Quercus* sp. 8-oblique equatorial view, IGPS coll. cat. no. 93552-2 (Slide no. 3-9). Loc. no. 3, Mataki Formation, Late Pliocene. 9-oblique equatorial view, IGPS coll. cat. no. 93567 (Slide no. 2-16-6). Loc. no. 2, Kazawa Formation, Late Pliocene. 10-equatorial view, IGPS coll. cat. no. 93568 (Slide no. 4-14-159). Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Fig. 11. *Alnus raris* Takeuti, n. sp. polar view, Holotype, IGPS coll. cat. no. 93573 (Slide no. 2-16-2). Loc. no. 2, Kazawa Formation, Late Pliocene.
- Figs. 12-14. *Alnus japonica* Siebold et Zuccarini. 12-polar view, IGPS coll. cat. no. 93569-3 (Slide no. 13-2). Loc. no. 13, Kazawa Formation, Late Pliocene. 13-polar view, IGPS coll. cat. no. 93563-3 (Slide no. 17-3). Loc. no. 17, Mataki Formation, Late Pliocene. 14-polar view, IGPS coll. cat. no. 93574 (Slide no. 2-16-1). Loc. no. 2, Kazawa Formation, Late Pliocene.
- Figs. 15-17. *Carpinus* sp. 15-polar view, IGPS coll. cat. no. 93576 (Slide no. 15-b-8-230). Loc. no. 15-b. 16-oblique polar view, IGPS coll. cat. no. 93577 (Slide no. 2-16-44). Loc. no. 2. 17-oblique polar view, IGPS coll. cat. no. 93578 (Slide no. 15-b-8-229). Loc. no. 15-b. Kazawa Formation, Late Pliocene.
- Fig. 18. *Betula* sp. oblique equatorial view, IGPS coll. cat. no. 93575 (Slide no. 4-14-157). Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Figs. 19, 20. *Corylus* sp. 19-oblique polar view, IGPS coll. cat. no. 93579-1 (Slide no. 15-a-3). Loc. no. 15-a. 20-polar view, IGPS coll. cat. no. 93564-4 (Slide no. 3-7). Loc. no. 3. Mataki Formation, Late Pliocene.
- Fig. 21. *Zelkova* sp. oblique polar view, IGPS coll. cat. no. 93555-4 (Slide no. 13-8). Loc. no. 13, Kazawa Formation, Late Pliocene.
- Figs. 22, 23. *Ulmus* sp. 22-oblique polar view, IGPS coll. cat. no. 93570-2 (Slide no. 13-3). Loc. no. 13, Kazawa Formation, Late Pliocene. 23-oblique polar view, IGPS coll. cat. no. 93580 (Slide no. 4-14-129). Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Fig. 24. *Juglans* sp. oblique polar view, IGPS coll. cat. no. 93584 (Slide no. 4-14-156). Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Fig. 25. *Pterocarya* sp. polar view, IGPS coll. cat. no. 93569-4 (Slide no. 13-2). Loc. no. 13, Kazawa Formation, Late Pliocene.
- Figs. 26, 27. *Acer* sp. 26-oblique equatorial view, IGPS coll. cat. no. 93564-5 (Slide no. 3-7). Loc. no. 3, Mataki Formation, Late Pliocene. 27-oblique polar view, IGPS coll. cat. no. 93581-1 (Slide no. 8-6). Loc. no. 8, Kazawa Formation, Late Pliocene.

Explanation of Plate 3

- Figs. 1, 2. *Ilex* sp. 1-focus high. 2-focus low. equatorial view, IGPS coll. cat. no. 93585 (Slide no. 2-16-32), $\times 630$. Loc. no. 2, Kazawa Formation, Late Pliocene.
- Fig. 3. *Fraxinus* sp. equatorial view, IGPS coll. cat. no. 93570-3 (Slide no. 13-3), $\times 630$. Loc. no. 13, Kazawa Formation, Late Pliocene.
- Fig. 4. *Symplocos* sp. polar view, IGPS coll. cat. no. 93586 (Slide no. 2-16-54), $\times 630$. Loc. no. 2, Kazawa Formation, Late Pliocene.
- Fig. 5. *Elaeagnus* sp. polar view, IGPS coll. cat. no. 93581-2 (Slide no. 8-6), $\times 630$. Loc. no. 8, Kazawa Formation, Late Pliocene.
- Fig. 6. *Lonicera* sp. polar view, IGPS coll. cat. no. 93587 (Slide no. 15-b-8-235), $\times 630$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Figs. 7, 8. Ericaceae gen. et sp. indet. polar view, 7-IGPS coll. cat. no. 93588 (Slide no. 4-2-315), $\times 630$. Loc. no. 4, Mataki Formation, Late Pliocene. 8-IGPS coll. cat. no. 93555-5 (Slide no. 13-8), $\times 630$. Loc. no. 13, Kazawa Formation, Late Pliocene.
- Fig. 9. Umbelliferae gen. et sp. indet. equatorial view, IGPS coll. cat. no. 93589-1 (Slide no. 3-1), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Fig. 10. *Typha* sp. single grain, oblique polar view, IGPS coll. cat. no. 93590 (Slide no. 3-3), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Fig. 11. *Sanguisorba* sp. oblique polar view, IGPS coll. cat. no. 93579-2 (Slide no. 15-a-3), $\times 630$. Loc. no. 15-a, Mataki Formation, Late Pliocene.
- Fig. 12. *Artemisia* sp. oblique polar view, IGPS coll. cat. no. 93557-3 (Slide no. 4-12), $\times 630$. Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Figs. 13, 14. *Persicaria* sp. 13-focus high. 14-focus low. polar view, IGPS coll. cat. no. 93591 (Slide no. 4-14-103), $\times 630$. Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Fig. 15. Compositae gen. et sp. indet. equatorial view, IGPS coll. cat. no. 93557-4 (Slide no. 29-1), $\times 630$. Loc. no. 29, Takizawa Formation, Early Pleistocene.
- Fig. 16. Cyperaceae gen. et sp. indet. polar view, IGPS coll. cat. no. 93589-2 (Slide no. 3-1), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Figs. 17, 18. Gramineae gen. et sp. indet. 17-lateral view, IGPS coll. cat. no. 93579-3 (Slide no. 15-a-3), $\times 630$. Loc. no. 15-a. 18-lateral view, IGPS coll. cat. no. 93552-3 (Slide no. 3-9), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene.
- Figs. 19, 20. Polypodiaceae gen. et sp. indet. 19-lateral view, IGPS coll. cat. no. 93589-3 (Slide no. 3-1), $\times 630$. Loc. no. 3, Mataki Formation, Late Pliocene. 20-lateral view, IGPS coll. cat. no. 93592 (Slide no. 4-14-105), $\times 330$. Loc. no. 4, Takizawa Formation, Early Pleistocene.
- Fig. 21. Osmundaceae gen. et sp. indet. oblique lateral view, IGPS coll. cat. no. 93593 (Slide no. 15-b-8-217), $\times 330$. Loc. no. 15-b, Kazawa Formation, Late Pliocene.
- Figs. 22-26. Unknown pollen grain. 22-IGPS coll. cat. no. 93564-6 (Slide no. 3-7). Loc. no. 3, Mataki Formation, Late Pliocene. 23-IGPS coll. cat. no. 93594 (Slide no. 2-16-7). Loc. no. 2, Kazawa Formation, Late Pliocene. 24-IGPS coll. cat. no. 93595 (Slide no. 2-16-21). Loc. no. 2, Kazawa Formation, Late Pliocene. 25-IGPS coll. cat. no. 93596 (Slide no. 2-16-20). Loc. no. 2, Kazawa Formation, Late Pliocene. 26-IGPS coll. cat. no. 93579-4 (Slide no. 15-a-3). Loc. no. 15-a, Mataki Formation, Late Pliocene, all figures $\times 630$.





Explanation of Plate 4

- Fig. 1. Coaly siltstone layers in the lower part of the Kazawa Formation. The samples for pollen were collected from the coaly part shown in the upper part of the photograph. Locality:-Road cutting south of Hanukidachi situated between Ichinoseki City and Hanaizumi Town, Iwate Prefecture.
- Fig. 2. Alternation of tuff and siltstone in the uppermost part of the Kazawa Formation. Sampling for pollen grains was made from the lower part of the outcrop. Locality:-Railway cutting west of Sawa, Ichinoseki City.
- Fig. 3. Conglomerate at the lower part of the Takizawa Formation. Locality:-Takizawa, Ichinoseki City.

Explanation of Plate 5

- Fig. 1. Lignite seam (middle of photograph) intercalated in tuff of the upper part of the Mataki Formation. Sampling was made from the lignite seam. Locality:-Cliff of the ground of a company under construction, north of Hosoda, Ichinoseki City.
- Fig. 2. Sandy conglomerate at the upper part of the Mataki Formation showing cross-bedding. Locality:-Road cutting at Ogurasawa, Ichinoseki City.
- Fig. 3. Tuff of the upper part of the Mataki Formation, the uppermost part of the photograph is silty tuff and the larger part is of pumiceous tuff. Sampling was made from a coaly siltstone at the lowest part of the photograph. Locality:-Road cliff at Gogota, Hanaizumi Town, Iwate Prefecture.
- Fig. 4. Gravelly sandstone at the lower part of the Mataki Formation exposed in a cliff of a path leading to the ground under construction. Locality:-South of Hosoda, Ichinoseki City.

