FOSSIL POLLEN IN THE NAHARI LIGNITE [1]

By

JUN NAKAMURA

(Botanical Laboratory, Liberal Arts Faculty, Kochi University)

(With Plate I and 1 Text-Figure)

In our country macroscopic plant fossils in Tertiary deposits have been studied by many workers, particulary by Dr. S. MIKI (1937, 1938, 1939, 1941, 1950) and Dr. S. ENDO (1933, 1948) who have thrown light on the tertiary flora in Japan.

But no pollenanalytical study of these deposits has hitherto been done, such a study being limitted to the more recent deposits.

In Europe and America, studies of tertiary pollen and spores have been published by many workers such as WODEHOUSE (1933, 1935), KIRCHHEIMER (1934, 1938), RUDOLPH (1935), WILSON (1946) etc. Their studies of coals and lignites have contributed to the revelation of the climatic changes in the past and the development of mining.

So this paper aims at investigating a tertiary lignite from pollenanalytical point of view.

THE SITE AND STRUCTURE OF THE BEDS

The Nahari lignite beds, believed to correspond with the Toonohama formation in the Lower or Middle Pliocene, are situated at Nahari about 220 km, east of Kochi city, three outcrops (Outcrops A, B and C) appearing near the Nahari mine.

The outcrop A (160 cm thick) is situated on a hill-side (30 m above the sea level), north of the mine. Both the upper and lower parts of this outcrop are bounded by thick gray shales. Beneath the lower shale (60cm thick) there is the outcrop C (20cm thick).

The outcrop B is located at the same hill near the site of a salt works, but 500m to the west of the outcrop A. It is about 45cm thick lying in gray shale.

The stratigraphic relation between A and B cannot be ascertained by a brief field work.

In this stndy, samples were collected at each level from the outcrops A and B.

PREPARATION OF SAMPLES

In a glass tube a 2—3gr. powdered sample was added to 20cc 10% KOH and digested in a boiling water bath for 20 minutes, the sediment being washed once or twice in a centrifuging. Then it was treated with concentrated HF for 2 hours to remove the inorganic matters, and washed several times in centrifuge tubes. Afterwards a small amount of it was mounted in glycerine jelly for microscopic investigation.

DESCRIPTION OF THE MAIN FOSSIL POLLEN

Several systems of pollen and spore nomenclature have been drawn up by palynologists,

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such as WODEHOUSE (1933), POTONIE (1931), KIRCHHEIMER (1931), ERDTMAN (1947). It is desirable that some universal nomenclature should be established by a committee of the international congress.

Some of the species described here appear to be very similar to some of those described by previous investigators and indeed may be the same, but I cannot prove this exactly, and so I have described my species as follows. A fossil grain which matches a living species is called by its generic name followed by "type". Thus a grain which resembles most closely that of the living *Pinus* is named *the Pinus type*.

Tsuga diversifolia type (Pl. I, fig. 8)

Identical with *Ts. diversifolia* MAST. and *Ts. Sieboldii* CARR. described by Dr. T. JIMBO (1933) except for its smaller size, 49 microns in diameter. Such a minute difference in size is not questionable, for, according to BASS (1933), *Ts. diversifolia* ranges from 45 to 80 microns in diameter, and KIRCHHEIMER (1934) also, after comparing with *Ts. diversifolia the Tsuga type* from the lignite in Germany which ranged from 33.6 to 88.2 microns, concluded them to be quite identical.

In our country *Ts. oblonga* MIKI and *Ts. Sieboldii* CARR. are reported, but so far no *Ts. diversifolia* has been found in the Tertiary deposits.

Tsuga canadensis type (Pl. I, fig. 9)

Flattened sphere, with a rudimentary girdle of air sac around the equator. One side of exine thick and heavily wrinkled, the other side not so conspicuous. 51—63 microns in diameter.

Ts. viridifluminipites WODEHOUSE (1933) from the Eocene in north America, which is similar to that of *Ts. canadensis* CARR., and many grains reported by KIRCHHEIMER (1934) from the Lower Tertiary in Germany may be referred to this type. KIRCHHEIMER further pointed out that such a pollen type was abundant in the Lower Tertiary of Germany, whilst it was replaced by *Ts. diversifolia type* in the Upper Tertiary. It is interesting that such a tendency is noticed by the author in the course of this present study.

Pinus type (Pl. I, fig. 6)

Identical with *Pinus densiflora* SIEB. et. ZUCC., *P. pentaphylla* MAYR., *P. Thunbergii* PARL, *P. pumila* REGEL described by Dr. T. JIMBO (1933) in general. But it differs in its minute characters. The air sacs are somewhat halfmoon shaped when seen in dorsal view. In size 45.6—50.0 microns in length including air sacs, 37—45×35—50 microns excluding air sacs. Thus the size is smaller than those of the above mentioned species.

RUDOLPH (1935) divided *Pinus type* pollen from the German brown coal into two subtypes, namely, *Pinus sylvestris type* and *P. haploxylon type*. *The Pinus type* in the present paper exactly matches the latter.

In our conutry *P. Fujii* MIKI and *P. trifolia* MIKI are reported from the Pliocene, and so this fossil may be referred to either *P. Fujii* or *P. trifolia*.

Picea type

identical with *P. jezoensis* CARR., *P. jezoensis* var. *hondoensis* RHED., *P. polita* CARR. described by Dr. T. JIMBO (1933); 100—105 microns in length (including the air sacs), the pollen proper 70—75×70—87 microns.

Taxodium type (Pl. I : fig.14)

Spherical, but split in half. Exine with granular flecks is relatively thin and split in half but the two halves remain jointed at the base. The length of the halves from the tip to the base where they are jointed 28.5—30.0 microns.

This type is apparently identical in all respects with *Taxodium hiatipites* WODEHOUSE (1933) from the tertiary oil shale in America. But such a pollen is seen sometimes in other taxaceous and cupressineous pollen. And so this type may include some taxaceous and cupressineous pollen in this paper. As the remains of *Taxodium* are not yet confirmed from the tertiary deposit in Japan, this fossil requires further study.

Glyptostrobus type (Pl. I. fig.13)

Similar to *Taxodium type*, but differ in the shape of the two halves. Each halves have longitudinal folds under mechanical strain; length of halves 23.5 microns.

This grain matches *G. vacuipites* described by WODEHOUSE (1933) except for its shorter length. In the pliocene flora of Japan *G. pensilis* KOCH is recorded in many districts, consequently it is to be expected that *Glyptostrobus* occurred during the Toonohama epoch. However, as in the case of the fomer type, *Glyptostrobus type* shows no characters which are entirely distinguishable from those of others belonging to this plexus of tribes.

Cunninghamia type (Pl. I. fig.12)

Spherical, but always collapsing irregularly without predetermined folds. Surface granular, without pores. 28—32 microns in diameter.

This fossil matches *C. concedipites* WODEHOUSE (1933) recorded from an American oil shale. According to WODEHOUSE its mode of collapsing without rapture is quite characteristic of the grains of *Cunninghamia* in spite of some hesitation as in the cas of the former type.

Metasequoia type (Pl. I. fig.11)

Spherical; provided with a single pore, surrounding a ligulate projection from the exine. This ligulate projection 5—7 microns and bent to one side. Surface punctate, 19—28.5 microns in diameter.

This grain is similar to that of *Cryptomeria japonica* D. DON described by Dr. T. JIMBO (1933), but differs from it in its smaller diameter and thicker exine. (*Cryptomeria* ranges from 30 to 55 microns in diameter)

The grain of *Sequoia sempervirens* (LAMB.) ENDL. and *S. gigantea* TORR. are also similar to this fossil. According to WODEHOUSE (1935) they are indistinguishable from each other ranging from 23.5 to 41 microns in diameter. Recently STERLING (1949) reported that the grain of *Metasequoia glyptostroboides* HU and CHENG ranged from 19 to 26 microns in diameter and its projection 6—10 microns in length.

In the present paper small grains (mostly 20—25 microns) predominated over large ones (26—28.5 microns). So that most of the fossils of this type fall in dimensions, under *Metasequoia glyptostroboides* and a few may be referred to *Sequoia*.

Many species of *Metasequoia* and *Sequoia* are reported from the tertiary deposits in Japan and so their presence in the Nahari lignite epoch is to be expected. [1)]

Magnolia type (Pl. I. fig.19)

Identical with *M. stellata* MAXIM. and *M. Kobus* DC. described by the author (1943) except for smaller size. 25 microns in diameter.

Juglans type (Pl. I. fig.4)

Identical with *J. Allardiana* var. *acuta* KOIZUMI described by the author (1943) in general. But it differs in its minute characters; pores (about 10) small and not so projected as the above species. 30—35 microns in diameter.

J. cinerea L. is reported from the Pliocene of Japan but it differs from this species in number of pores; the pores of the fossil are more than those of *J. cinerea* (5—8).

Pterocarya type (Pl. I. fig.2)

Identical with *P. rhoifolia* SIEB. et ZUCC. described by the author (1943). 34.2—28.5 microns in diameter.

From the tertiary deposits of Japan *P. multistriata* MIKI and *P. stenoptela* DC. are recorded, but *P. rhoifolia* is not found. So this fossil may be referred to either *P. multistriata* or *P. stenoptera*.

Carya type (Pl. I. fig.3)

Oblately flattened and elliptic, pores 3, confined to the ventral surface. Each pore circular or elliptic, 2.3 microns in diameter. Exine smooth or indistinctly punctate, 31.3 microns in diameter.

A similar grain is described as *Carya* (*Hicoria*) *juxtaporipites* by WODEHOUSE (1933) from the Eocene oil-shale of America, which may be the same species.

From the Pliocene beds of Japan three species of the hickories are reported by Dr. MIKI (1941), but it is, at present, impossible to state which of them this fossil belongs to.

Fagus type (Pl. I. fig.7)

Identical with *F. crenata* BLUME, *F. japonica* MAXIM. described by Dr. T. JIMBO (1933). 30—35 microns in diameter.

Alnus type (Pl. I. fig.17)

Pentagonal, occasionally tetragonal in polar view, elliptic in equatorial view. Pores 5—4; arranged around the eqnator. Each pore protrudes, dichotomous edge of the pore

(1) When I had finished this study, I had a chance to compare the grain of *Sequoia sempervirens* with that of *Metasequoia glyptostroboides* by the courtesy of Dr. T. UENO of Osaka Municipal University. According to this comparison the grains of *Sequoia* are larger in size and thicker in exine and rougher in texture than those of *Metasequoia*. In *Cryptomeria* exine is thinner than that of *Metasequoia*.

in the section indistinct. Exine smooth or slightly rough, conspicuous thickenings of the exine extend in geodetic curves between the pores. 17.5—20 microns in diameter.

These grains are numerous in the lignite. In size they are smaller than the living species described by Dr. T. JIMBO (1933) and *A. specipites* WODEHOUSE (1933) from the American eocene deposit.

Liquidambar type (Pl. I. fig.5)

Identical with *L. formosana* HANCE described by the author (1945). 23.5 microns in diameter.

This frequently occurs in the tertiary deposits in Japan. It is therefore quite possible that this grain belongs to that species.

Tilia type (Pl. I. fig.1)

Identical with *T. japonica* SIMK. described by Dr. T. JIMBO (1933) except for its smaller size. 20.5 microns in diameter.

The pollen of *T. cordata* described by TRELA (1928) and that of *F. americana* by WILSON (1943) are also similler to this fossil in their shape and size. But it is some hesitation that it is assigned to these species.

In our country four species of *Tilia* are reported from the tertiary, so it is to be expected in this deposit.

Nyssa type (Pl. I. fig.20)

Tricolpate, oblately flattened; triangular in outline. Expansion folds closed tightly. Exine thickened at the margin of the expansion fold. Surface punctate. Each pore at the equator rather indistinct. 25—34.2 microns in diameter.

This fossil matches exactly *Nyssa type* described by RUDOLPH (1935) from a German brown coal which KIRCHEHIMER (1930) also described.

Fruits and seeds of *Nyssa sylvatica* MARSH and *N. pachycarpa* MIKI have been found from the Pliocene deposits in Japan by Dr. S. MIKI (1941). So it is to be expected in the Nahari lignite.

Ulmus type (Pl. I. fig.16)

Identical with *U. japonica* SARG. and *U. parvifolia* JACQ. described by Dr. T. JIMBO (1933). 25.6 microns in diameter.

From the tertiary of Japan five species of *Ulmus* including *U. parvifolia* are reported, but it is difficult at present to distinguish them from palynological point of view.

Rhus type

Identical with *R. tricocarpa* MIQUEL described by the author (1943). 20—22.8 microns in diameter.

WODEHOUSE (1933) described this type pollen from an American oil shale as *Rhoipites Bradledyi* and RUDOLPH described that from a German brown coal as *Rhus type*. However, this type is found in many dicotyledonous species, so it is impossible in the fossil condition to identify the species, even if HEIMSCH (1940) succeeded in identifying individual species of this genus.

Gramineous type (Pl. I. fig. 18)

Identical with the grains of *Poaceae* or *Bambusaceae* described by the author (1943). 28.5—48.0 microns in diameter.

This type pollen is unmistakably gramineous, but it is difficult to distinguish its genus. Large grains are especially abundant in all the deposits.

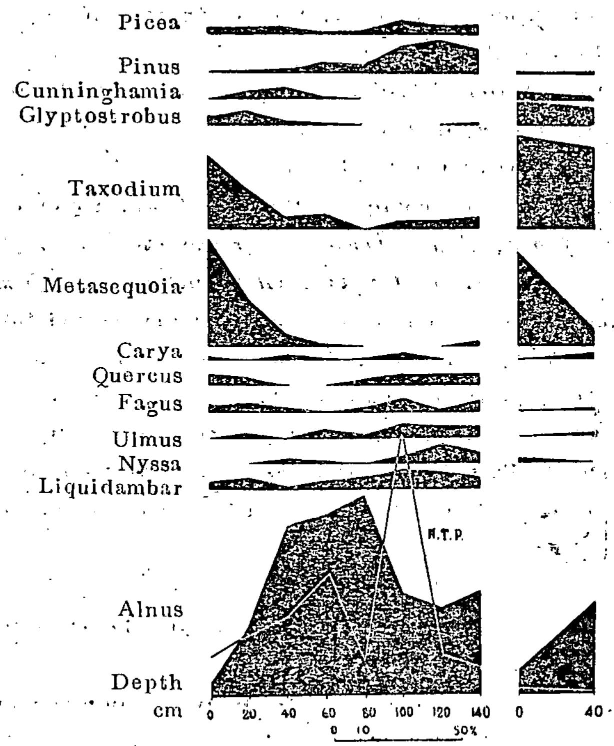
POLLENANALYSES

For the analyses more than 150 grains of tree pollen were counted and the percentages of respective trees registered at each level. These results are shown in the following table and pollendiagram.

Table 1. The results of pollenanlyses from the outcrops A and B

Depth, cm. / Pollen types	Outcrop A								Outcrop B	
	0	20	40	60	80	100	120	140	0	40
Tsuga diversifolia	0.7	0.6	0.9	1.6			0.9			0.7
Ts. canadensis						1.0	2.9			
Pinus	0.7	1.2	1.8	4.0	3.2	10.5	12.8	9.6	0.6	0.7
Picea	2.8	2.5	2.7	0.8	1.6	5.2	3.8	3.4		
Taxodium	28.2	15.5	4.6	5.6		3.3	3.8	4.6	36.2	31.6
Cunninghamia		3.1	4.6	0.8					3.0	1.4
Glyptostrobus	3.5	5.6	1.8	0.8				1.1	9.6	7.2
Metasequoia	41.0	18.2	4.6	0.8				2.3	36.2	6.4
Larix		0.6								
Pterocarya		0.6		0.8				1.1	0.6	0.7
Juglans							0.9			
Carya	0.7		1.8	0.8	0.8	2.1				2.8
Tilia	0.7									
Alnus	5.6	28.0	66.3	70.4	77.4	39.3	34.6	40.6	9.6	36.6
Fagus	2.8	3.7	1.8		1.6	5.2	0.9	4.6		0.7
Quercus	4.2	3.1			2.4	4.2	4.8	4.6		
Magnolia						1.0				
Ulmus		1.8		3.2	1.6	5.2	4.8	4.6		0.7
Carpinus	2.8	0.6	0.9				1.9	1.1	1.2	
Nyssa			1.8	0.8		3.1	7.7	4.6	1.2	
Fraxinus		1.2								0.7
Liquidambar	2.8	3.1	0.9	3.2	4.9	7.3	6.7	4.6		
Rhus	3.5	9.4	5.5	6.4	6.5	12.6	13.5	19.0	0.6	0.7
Ilex		1.2							1.2	9.3
Compositae				0.8						
Gramineae	15.4	24.5	30.3	4.6	18.8	101.5	15.5	5.7	2.4	0.7

Fig. 1. Pollendiagrams of the outcrops A and B



N. T. P. means non-tree/tree pollen ratio.

Outcrop A: It is remarkable that the preponderance of *Alnus*[1] in the lower layers is replaced suddenly by that of *Metasequoia* (including *Sequoia*) and *Taxodium* in the upper layers. The preponderance of *Alnus* may be due to topographic effect. For instance the development of alder wood in sith is noticeable, since its anthers are found sparsely in the deposits, and it is a known fact that this tree flourishes abundantly near wet pleces in general.

Liquidambar, *Nyssa* and *Ulmus* which are relatively abundant in the lower layers decrease toward the upper ones, whilst *Carya* is absent in the lowest layer.

Glyptostrobus and *Cunninghamia* are relatively scarce in amount in the lower layers and tend to increase upward. On the other hand *Pinus* and *Picea* are fairly abundant in the lower ones diminishing upward. *Tsuga diversifolia*, *Pterocarya*, *Fraxinus* and *Carpinus* show no change worth noting in their amount, while *Tsuga canadensis* is found only in the lower layers.

Gramineous pollen is relatively abundant throughout, especially showing abrupt increase at the depth of 100cm.

1) *Alnus* means *Alnus type*; the term "*type*" is omitted throughout the following chapters.

Outcrop B: It is remarkable that the curves of *Alnus*, *Metasequoia* and *Taxodium* are similar to those in the upper of the outcrop A. But many deciduous trees such as *Nyssa*, *Ulmus* and *Fagus* are smaller in amount, and *Liquidambar* and *Quercus* are not seen already. *Pinus* remains consistently while no *Picea* is seen.

These difference between the outcrops A and B show probably that the outcrop B is younger than the outcrop A in the age of deposition.

DISCUSSION

From the above mentioned results it is considered that the dominance of certain hardwoods, namely, *Liquidambar*, *Ulmus*, *Fagus*, *Quercus*, *Carpinus* etc. was replaced at an early stage by conifers such as *Metasequoia*, *Taxodium*, *Glyptostrobus*, *Cunninghamia* etc. Climatically, such a forest sequence denotes an initial warm and dry period followed by a cool and moist climate. Its strongest evidence is the decrease or disappearance of *Liquidambar* in the upper parts of the outcrops A and B.

Then the middle level is marked by a sudden increase of the non-tree/tree pollen ratio followed by the preponderance of *Alnus*, from which it may be inferred that a densely wooded land was destroyed by some geological change such as an earthquake or a land slip.

SUMMARY

Two outcrops of lignite at Nahari, Tosa were investigated palinologically to determine the history of the lignite in that region.

Notes and illustrations of the common pollen type found in the deposits are included in the studies.

Pollenanalytical results indicate that the dominance of deciduous forests mixed with some pine and spruce in the lower part was replaced by coniferous forests in the upper part and that near the middle level an openly wooded land extended.

This indicates a climatic shift; decreasing warmth and increasing wetness from the early stage upwards.

Finally the age of the deposition of the ontcrop A is older than that of the outcrop B.

In conclusion I wish to state my gratefulness to the many friends who have helped with my work, especially the members of the Geological Laboratory of Kochi University; Prof. T. SAWAMURA and Assist. Prof. J. KATTO who have assisted with their advice.

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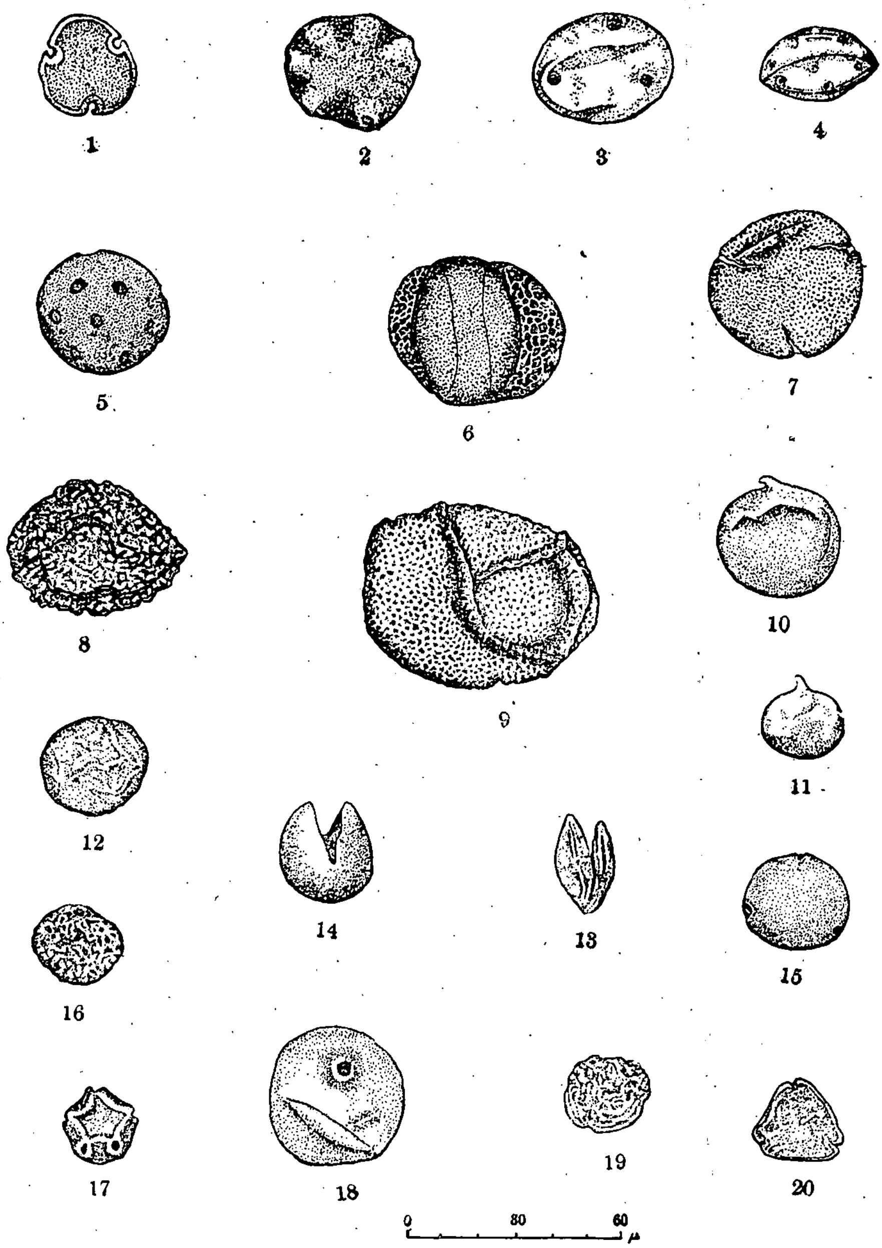
(Pl. I)



EXPLANATION OF PLATE (Pl. I)

Fig. 1. *Tilia type.*
Fig. 2. *Pterocarya type.*
Fig. 3. *Carya type.*
Fig. 4. *Juglans type.*
Fig. 5. *Liquidambar type.*
Fig. 6. *Pinus type.*
Fig. 7. *Fagus type.*
Fig. 8. *Tsuga divesifolia type.*
Fig. 9. *Tsuga canadensis type.*
Fig. 10. *Sequoia type.*
Fig. 11. *Metasequoia type.*
Fig. 12. *Cunninghamia type.*
Fig. 13. *Glyptostrobus type.*
Fig. 14. *Taxodium type.*
Fig. 15. *Carpinus type.*
Fig. 16. *Ulmus type.*
Fig. 17. *Alnus type.*
Fig. 18. *Gramineous type.*
Fig. 19. *Magnolia type.*
Fig. 20. *Nyssa type.*