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LATE CRETACEOUS POLLEN AND SPORE FLORAS OF NORTHERN JAPAN: COMPOSITION AND INTERPRETATION

by

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(with 12 Text-figures and 5 Tables)

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Abstract

For the establishment of floristic sequences, pollen and spore floras from the Late Cretaceous sediments ranging from Cenomanian to Maestrichtian of northern Japan are studied. Four areas where the Late Cretaceous sediments are typically well developed are selected: the Ishikari coal field (the Campanian-Maestrichtian Hakobuchi Group), Saku area (the Cenomanian-Campanian Middle and Upper Yezo Groups), the Kuji coal field (the early Senonian Kuji Group) and the Joban coal field (the early Senonian Futaba Group). Nine pollen and spore floras two of which had been studied by previous investigators, are discussed. Based on floristic composition and components, the four floras of Cenomanian-Turonian, Early Senonian, Campanian and Maestrichtian ages are distinguishable.

The oldest flora is characterized by diverse pteridophytes, particularly Schizaeaceous spores, and by less diversified angiosperms containing few porate pollen. The second has still the relic of Mesophytic appearance: pteridophytes are more or less superior to angiosperms in taxonomic diversity, containing commonly Schizaeaceous and Gleicheniaceous spores. Of gymnosperm pollen *Cycadopites, Monosulcites, Araucariacites, Rugubivesiculites* and *Classopollis* are common. Angiosperm are composed predominantly of tricolpate pollen, but are represented by few porate pollen. The third is characterized by the predomint angiosperms and also by diverse species of *Aquilapollenites*. Pteridophytes are sparsely represented in Schizaeaceous spores. The youngest flora is composed of a predominant porate pollen, which occupies a majority of angiosperm pollen. This flora is characterized also by diverse pollen of uncertain taxonomic position such as *Aquilapollenites, Wodehouseia* and *Ocellipollis*. These floristic sequences in northern Japan shows that pteridophytes and gymnosperms forming the major constituents during Cenomanian-Turonian times were gradually replaced by angiosperms towards Maestrichtian time. Late Cretaceous floristic changes of northern Japan are very similar to those of Eastern Siberia, especially of the Zeya-Bureya basin.

Introduction

Cretaceous palynology has been considerably advanced during these two decades, and has greatly contributed to paleobotany. A great deal of

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palynological studies on the Cretaceous sediments of the world are revealing the precise evolutionary history of the shift from the Mesophytic to the Cenophytic plant Kingdom. Palynological investigations have revealed important information regarding the origin and early development of angiosperms (Couper, 1964; Muller, 1970; Doyle, 1969). Furthermore, recent studies also have revealed that some phytogeographical provinces are distinguishable especially in Eurasia during Cretaceous time (Zaklinskaya, 1962; Samoilovitch, 1967). Based on the establishment of the floristic sequences, Cretaceous palynology has contributed to the exploration of petroleum fields.

In Japan, paleobotanical studies on the Cretaceous have not been well developed in the fields of macrofossils and microfossils. Late Cretaceous terrestrial sediments bearing plant fossils are poorly distributed in Japan. Based on leaves, cones and woods, several important contributions have been presented: the Upper Yezo and Hakobuchi floras in Hokkaido (Stopes and Fujii, 1909; Endo, 1925; Oishi, 1940), Oarai flora in eastern Honshu (Oyama, 1956–61) and Asuwa and Omichidani floras in central Honshu (Matsuo, 1962, 1970). However, Late Cretaceous floristic sequences have not yet been fully established.

The Late Cretaceous of Japan are composed mostly of marine sediments. Therefore, palynological investigations are expected to establish successive floristic changes in both marine and terrestrial sediments. Sato (1961) published the first contribution to Cretaceous palynology in Japan. He reported on a pollen and spore flora from the Hakobuchi Group in northern Hokkaido with brief discussions and descriptions of some new species. Then Takahashi (1964) made an important contribution to the study of the latest Cretaceous microflora: he revealed a pollen and spore flora from the Hakobuchi Group in its type area, describing about one hundred species of pollen and spores. This pollen and spore flora which represents Campanian to Maestrichtian microflora in Japan is characterized by diverse *Aquilapollenites*. Furthermore, Takahashi (1967, 1970) described some spores and pollen from the uppermost Cretaceous sediments of Hokkaido.

Since 1967, the author has investigated Cretaceous palynology in northern Japan, because the Upper Cretaceous sediments, both of marine and terrestrial origin, are typically well developed there. In 1972 the author described two early Senonian pollen and spore floras from the Kuji and Futaba Groups of northern Honshu (Miki, 1972a, b). Subsequently he reported a Cenomanian to Turonian pollen and spore flora from the upper part of the Middle Yezo Group of northern Hokkaido (Miki, 1973). He has further investigated the early Senonian marine sediments, the Upper Yezo Group, and also reexamined the Hakobuchi Group. Through these investigations from 1967 to 1974, the author could reveal Late Cretaceous pollen and spore floras of northern Japan, which range from Cenomanian to Maestrichtian time. Some important information is added to the evolutionary history of the Late Cretaceous plant kingdom, especially that of early angiosperm development.

In this paper the author describes Late Cretaceous pollen and spore floras, and briefly discusses floristic changes. Taxonomical descriptions and discussions will be treated in the succeeding paper.

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The Upper Cretaceous Sediments in Northern Japan

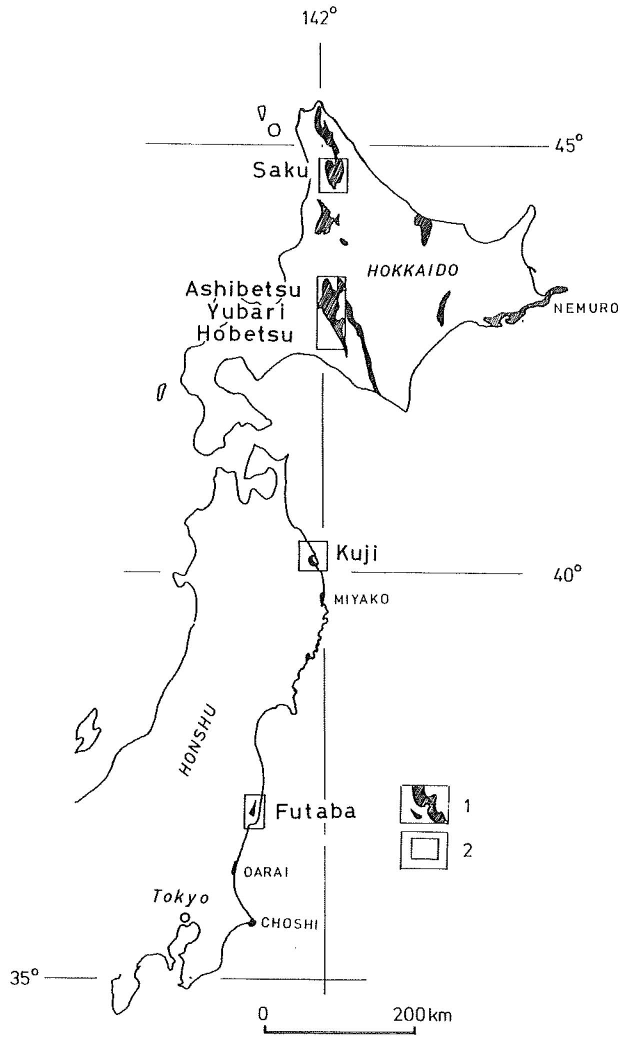
The Upper Cretaceous sediments are well developed in Hokkaido, and are poorly developed in northern Honshu (Text-fig. 1). In Hokkaido, the Upper Cretaceous is distributed along a long, narrow zone in the central area of Hokkaido from Cape Soya in the north to Urakawa in the south. These sediments were formed during the geosynclinal stage of the Hidaka orogenic belt. The Uppermost Cretaceous is also distributed in eastern Hokkaido.

In northern Honshu, the Upper Cretaceous sediments are distributed mainly in some small basins facing the Pacific, on the eastern foot of the Kitakami and Abukuma Mountains. These sediments are called the Kuji Group in the northern Kitakami Mountains, and the Futaba Group in the southern Abukuma Mountains. Small outcropped areas of the Latest Cretaceous sediments are have been discovered at Iwaizumi and Kado in the Kitakami Mountains, and at Oarai in eastern Kwanto, Honshu.

The general stratigraphy and correlation of the Upper Cretaceous sediments in northern Japan are shown in Table 1.

Hokkaido

The upper part of the Middle Yezo, the Upper Yezo and the Hakobuchi Groups represent later stages of sediments formed in the central geosynclinal basin. The Middle Yezo Group which conformably covers the Lower Yezo Group of the late Early Cretaceous is predominated by black shale in the lower part, and is variable in lithology in its upper part. The uppermost part of the Middle Yezo Group, the Saku formation in the northern part of the basin, is



Text-figure 1 Distribution of the Cretaceous sediments in northern Japan. 1. Outcropped area of the Cretaceous sediments. 2. Studied area.

composed of alternating sandstone and siltstone. The Group is 2000 to 3500 meters thick and is dated from the late Albian to Turonian age by ammonites and *Inoceramus*.

The Upper Yezo Group lying conformably on the Middle Yezo Group is 400 to 1500 meters thick, and is of off-shore origin. It is composed of monotonous siltstone except for sandy sediments in the middle. The sandy part in the northern area of the basin is called the Omagari formation. The Group is rich in ammonites and *Inoceramus* ranging mainly from the Coniacian to early

Table 1 Correlation table of the Late Cretaceous sediments in northern Japan (partly arranged after Matsumoto, 1942–43).

Age		Hokkaido: Saku	Hokkaido: Ashibetsu-Yubari-Hobetsu	Hokkaido: Nemuro	Tohoku: Kuji	Tohoku: Futaba	Kanto: Naka-Minato	Age (Domestic)	
TERT.	PALEOCENE								
UPPER CRETACEOUS	MAESTRICHTIAN		Hakobuchi Group*: Hu₅, Hu₄, Hu₃, Hu₂, Hu₁	Nemuro Group			Naka Group	K6β	HETONAIAN
UPPER CRETACEOUS	CAMPANIAN	Yasukawa Fm.; Upper Yezo Group: Osoushinai Fm.	Hakobuchi Group*: Lower Hakobuchi Subgroup	Nemuro Group	Kuji Group: Sawayama Fm.		Naka Group	K6α, K5γ	HETONAIAN
UPPER CRETACEOUS	SANTONIAN	Upper Yezo Group: Osoushinai Fm.	Upper Yezo Group		Kuji Group: Kunitan Fm.	Futaba Gr.: Tamayama Fm.		K5β	URAKAWAN
UPPER CRETACEOUS	CONIACIAN	Upper Yezo Group: Omagari Fm., Nishichirashinai Fm.	Upper Yezo Group: (Tsukimi F.)		Kuji Group: Tamagawa Fm.	Futaba Gr.: Tamayama Fm., Kasamatsu Fm., Ashizawa Fm.		K5α	URAKAWAN
UPPER CRETACEOUS	TURONIAN	Middle Yezo Group: Saku Fm.	Middle Yezo Group: Mikasa Fm.					K4β	GYLIAKIAN
UPPER CRETACEOUS	CENOMANIAN	Middle Yezo Group: Sagugawa Fm., Sakotandake Fm.	Middle Yezo Group: Mikasa Fm., Main Part					K4α, K3γ	GYLIAKIAN, MIYAKOAN
LOWER CRETACEOUS	ALBIAN	Middle Yezo Group: Sakotandake Fm., Shirataki Fm., Moehoro Fm.	Middle Yezo Group: Main Part					K3β	MIYAKOAN

* Hu_1 : Lower Sandyshale Fm. Hu_2 : Fukaushi Conglomerate Fm. Hu_3 : Fukaushi Sandstone Fm. Hu_4 : Upper Sandyshale Fm. Hu_5 : Sanushube Sandstone Fm.

Campanian age.

The Hakobuchi Group conformably covers the upper Yezo Group, and is less than 800 meters thick. It is predominated by coarse-grained sediments including conglomerate deposited in the shallow marine environment. In the central part of the basin the coal bearing terrestrial sediments are developed in the middle part of the Hakobuchi Group. Based on ammonites and *Inoceramus*, the lower part of the Group is assigned to the campanian age and the upper part to the Maestrichtian age. The sediments corresponding to the Maestrichtian is unknown in the Saku area in the northern area of the basin.

Northern Honshu

The Kuji and Futaba Groups are composed of sediments formed by Senonian transgression, and are of neritic to terrestrial origin.

The Kuji Group: The Group unconformably covers pre-Aptian rocks, and is 500 to 600 meters thick. It is dominated by littoral sediments such as sandstone and conglomerate in the lower part, by neritic fine-gained sandstone in the middle and by terrestrial siltstone and tuff in the upper. The Group is assigned to the early Senonian age, based on ammonites and *Inoceramus*.

The Futaba Group: overlying the Paleozoic system and pre-Late Cretaceous granite, the Futaba Group is of shallow marine origin. It is represented by fine-grained sandstone in the lower part. The middle is predominated by cross-laminated fine- to medium-grained sandstone with little siltstone. The upper is predominated by coarse-grained quartzose sandstone. The Group, approximately 300 meters thick, is dated from Coniacian to early Santonian by *Inoceramus.*

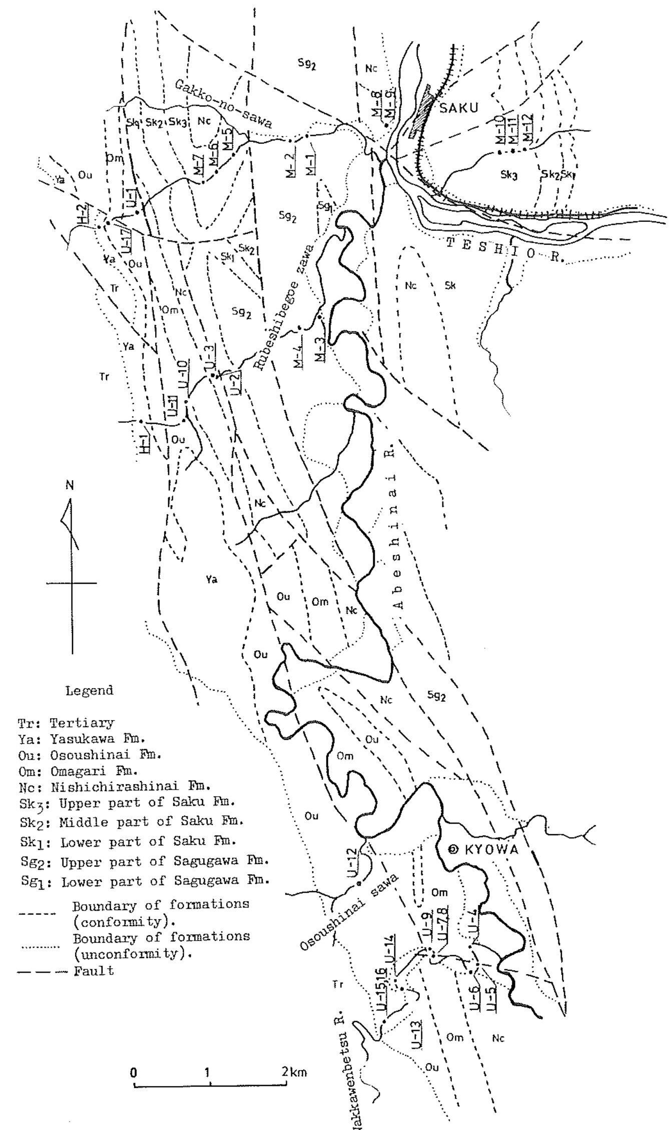
Description of Pollen and Spore Floras

The Late Cretaceous sediments in northern Japan range from the Cenomanian to Maestrichtian ages, as described above. For the establishment of Late Cretaceous floristic sequences and phytogeography, the author has dealt with the following four areas where the sediments are typically well developed: the Ishikari coal field (the Campanian-Maestrichtian Hakobuchi Group), Saku area (the Cenomanian-Turonian Middle Yezo Group and the Coniacian-Campanian Upper Yezo Group), the Kuji coal field (the early Senonian Kuji Group) and the Joban coal field (the early Senonian Futaba Group).

Cenomanian-Turonian Pollen and Spore Flora

Pollen and spore flora, called the Saku microflora, from the upper part of the Middle Yezo Group (Cenomanian-Turonian) in the Saku area was preliminarily reported by the author (Miki, 1973). The Saku area is situated in the central part of Nakagawa town in northern Hokkaido (45°N in latitude, 142°E in longitude). In this area the Cretaceous sediments comprising the Lower Yezo, the Middle Yezo, the Upper Yezo and the Hakobuchi Groups are widely developed. All samples were collected from sediments younger than the upper part of the Middle Yezo Group: only the two upper formations of the Middle Yezo Group, the Sakugawa and Saku, yield pollen and spores, as shown in Text-fig. 2.

The Saku pollen and spore flora is represented by 160 sporomorph species (Table 2): they are composed mainly of pteridophytes and subordinately of gymnosperms and angiosperms. Ninety-three species (58 per cent of the total



Text-figure 2 Outline of geology in the Saku area (after Hashimoto et al., 1967) and locations of samples. Sg_1 : Lower part of the Sagugawa fm. Sg_2 : Upper part of the Sagugawa fm. Sk_1 : Lower part of the Saku fm. Sk_2 : Middle part of the Saku fm. Sk_3 : Upper part of the Saku fm. Nc: Nishichirashinai fm. Om: Omagari-fm. Ou: Osoushinai fm. Ya: Yasukawa fm. Tr: Tertiary.

Table 2 Occurrence and distribution of sporomorphs in the Middle Yezo Group (revised after Miki, 1973). Numbers in brackets are very similar specimens and those with question mark are doubtful specimens. Cross mark shows presence of the species.

Formation / Samples / Sample Designation	MIDDLE YEZO GROUP											
	SAKUGAWA FORMATION				SAKU FORMATION							
Samples	68072703	68072704	68072801	68072802	68072710	68072711	68072712	69100902	69100903	70072601	70072602	70072603
Sample Designation	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10	M-11	M-12
Stereisporites sp.	1?		+		1?							
Lycopodiacidites hamulatis											1	
Lycopodiumsporites subreticulaesporites				+					+			
L. cf. papillaesporites			+						+			
Osmundacidites comaumensis									+			
O. wellmanii							+	+	+	+	+	
Todisporites major		(+)					+	(1)	+	(+)		
T. minor		+						(+)				1
Appendicisporites tricornitatus							+		(+)	1	(+)	+
A. cf. caucasica					(+)					+	+	2
A. cf. silvestris												1
A. undosus	(+)											+
A. spp.			+		1	1			+		+	1
Cicatricosisporites australiensis		+	(1)				+	1	1			+
C. cf. dorogensis								1				
C. minuteaestriatus	+	1	1		+		+	+	+	+	2	2
C. perforatus		+	+					+				+
C. tersus				+				+		+	+	
C. hughesi						(+)			+		+	+
C. subrotundus								+				
C. breavilaesuratus									(+)	(+)		+
C. cf. exilioides								+				
C. cf. pseudotripartitus				+			+			+		
C. tricostatus			+	+			+					
C. spp.			+	+	+		+	5		1		1
Klukisporites variegatus		(+)						2				
K. aff. pseudoreticulatus			1									
Lygodiumsporites subsimplex		+					+		(1)			+
Trilobosporites crassus							+					+
T. marylandensis		+					+					
T. trioreticulosus		+	+					+				
T. sp.		+	+									
Pilosisporites sp.	+											
Schizaeoisporites ? spp.								1				+
Gleicheniidites circinidites	+											
G. delicatus	3	+					1					
G. laetus	1					1			1		+	
G. senonicus	7	1	+	1		1			2		3	
G. sp.	2		1									
Ornamentifera echinata				+								
Hymenophyllumsporites deltoida		+					+					
H. furcosus		+										
Cyathidites australis					+	+	1	+	+			1
C. minor		1	2	1	1		3	1	3	2	1	2
C. punctatus		+			+						+	
Kuylisporites lunaris	+											
Trilites simplex			+		+	+	+	1				
T. tanaii		+	1		1	+	+	1	1	1	+	1
T. sp.		+									+	
Matonisporites cf. iwatensis								1				
Dictyophyllidites tazawaensis											1	+
Laevigatosporites haardti	1	4		1		+		1		5		
L. ovatus	+		2	+	2	2		2			3	2
Acanthotriletes varispinosus								1		+		+
A. sp.					+							
Aequitriradites spinulosus										1		
Apiculatisporis satoii	+	1			+	1	+	1	+	1	3	+
A. sp.										+		
Balmeisporites sp.								+				
Biretisporites ? sp.	+	+										
Cingulatisporites distaverrucosus		1			1		+			+		1
C. sp.	+				+							
Concavisporites sp.							1			+		
Converrucosisporites sp.	3						+					
Deltoidospora cascadensis	(3)		2		+			5	(3)	3	+	
D. halli	(2)	1		(1)		+			+			+
D. microforma			1				2			+	1	+
D. nodaense	3		(+)			(1)	+			(1)	+	
D. psilotoma						+						1

	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10	M-11	M-12
Densoisporites velatus					+		+		+	+		+
Foveosporites delectus							+					
F. cf. canalis			+					+				
F. sp. A					+	+				+		+
F. sp. B		+					+					+
F. sp. D					+			2				+
Granulatisporites variabilis		(1)			+	1	+		+	+	+	+
Jimboisporites simiscalaris	+				1		+		2	+		1
Laevigatosporites hokkaidoensis							+	1	+		+	+
Leptolepidites verrucatus	1											
Lophotriletes spp.	2	+						+			1	
Monoleiotriletes parvus										1	1	
M. samuraihamaensis		1	+			+	1	2	2	+	+	+
M. subcircularis					+					+	+	+
M. sp.			+	1	(3)		2		+	+	+	
Perotrilites sp.a							+	+				
Punctatisporites cf. embetsuensis			1			+						
P. cf. parvigranulatus						1	1	5	4	4	1	+
Rugulatisporites sp.								+				
Stenozonotriletes radiatus					+	+	+	+				
S. cf. exuperans						+	+					
Polycingulatisporites reduncus					+			+	+	+	1	+
Verrucosisporites sp.						+	+					
Uvaesporites margaritatus								+				
Indetermined Spores	1		1	1	1	3	3	2	2	3	1	2
Cycadopites spp.	31	16	30	17	4	26	13		3	5	2	
Monosulcites epakros	24	22	2	43	8	48	10	11	6	5	3	6
M. spp.	10	14	31	11	16	6	13		4	3	1	16
Vitreisporites pallidus	3		1	1	+	2	1	2	1	1	+	+
Araucariacites austra;is				+	4	2	7	4	3	+	7	7
A. limbatus				1		1	5		4	+	1	1
Alisporites spp.	1				1		4	1	3	4	5	6
Abiespollenites sp.	5	1			+	1	3	5	3	4	1	2
Abietineaepollenites + Pityosporites + Piceaepollenites	14	2		3	18	3	24	43	21	23	13	17
Podocarpidites sp. indet.					1				1	+		1
Phyllocladidites transiens	1?			1		1	1			+	1	1
Rugubivesiculites sp. indet.								6			1	
Inaperturopollenites spp. (Taxodiaceae-Cupressaceae Complex)	61	29	39	19	107	54	64	40	77	71	93	91
Inaperturopollenites microrugulatus	+	25	29	30								
Inaperturopollenites ? baculatus	+	10	6	6								
Inaperturopollenites spp.	3	2		2	1	1	2	2	1	1		
Classopollis + Circulina	9	51	37	55	15	12	15	19	20	18	11	18
Magnosporites ? ovalis					1	9	+	6	+	+	7	2
Equisetosporites spp.	1	2		2	1	1	4	1	7	2		2
Retitricolpites delicatus	2	1			+	2	+					
R. lepidus	+	2		+?	+	4	7	5	4	5	5	5
R. cf. geogensis											3	
R. sp. C		1?		2					1			
R. sp.								1				
Psilatricolpites debilis	1	2		1		2			+	+	1	+
P. meinohamensis rotundus							5					1
P. cf. Meinohamensis rodundus									1			
P. cf. parvulus		1	3			2	3		1		3	
P. cf. subasper												1
Fraxinoipollenites hobetsuensis												2
F. minutiretiformis			1	+		+		1?	4	7		
F. microreticulatus										2		
F. cf. clavireticulatus						+						
F. sp. A	+	4	2	1	3	7	1	4	4	8	2	+
F. sp. indet.		3	1		+	1						
Tricolpites minimus			1		1		+	2	5			
T. psilaexinus								1		3	3	1
T. cf. microreticulatus											+	
T. nipponicus					+			+	+		+	
T. anguloluminosus		+							+	+		
T. sp. A							+	+		+		
T. sp. indet.										1		
Tricolporopollenites spp.			1							1		
Triporopollenites minor						2	2			3	3	+
T. spp.					+	+						
Proteacidites striatus						+			+		+	+
P. sp.											+	
Clavatipollenites sp.	1											
Monocolpopollenites pflugii	2				+	1	1	1	1	2		+
M. cf. kyushuensis						+						
Peromonolites reticulatus										1		
Utriculites visus								6	5	3		1
Indetermined Angiospermae			1		1	2	1	2	1		1	
Indetermined Sporomorphs	1		1		5	1					1	
Total Specimens	200	200	200	200	200	200	200	200	200	200	200	200

species) are pteridophytes, 33 species (21 per cent) are gymnosperms, and 33 species (21 per cent) are angiosperms. As already published (Miki, 1973), the Saku Microflora is characterized by diverse species of pteridophytes; they are composed mainly of Schizaeaceous spores, *Cyathidites minor, Gleicheniidites, Trilites. Laevigatosporites* and *Deltoidospora*. In particular, Schizaeaceous spores are represented by more than 35 species, including such genera as *Appendicisporites, Cicatricosisporites, Klukisporites* and *Trilobosporites*. Furthermore, Early Cretaceous spores such as *Trilobosporites* spp., *Pilosisporites* sp. and *Granulatisporites dailyi* are found, though rarely.

Among gymnosperms, Cycadaceae-Ginkgoaceous pollen such as *Cycadopites* spp., and *Monosulcites epakros*, Taxodiaceae-Cupressaceous inaperturate pollen and *Classopollis* are abundant. Mesophytic coniferous pollen are commonly found: there are six genera, *Araucariacites, Alisporites, Rugubivesiculites, Classopollis, Phyllocladidites* and *Podocarpidites*. Though not common, the following Cenophytic coniferous pollen are also found: *Pityosporites, Abietineaepollenites* and others. Most angiosperms, represented by tricolpate pollen, are not very diversified. Porate pollen is found only from the Saku formation.

Early Senonian Pollen and Spore Flora

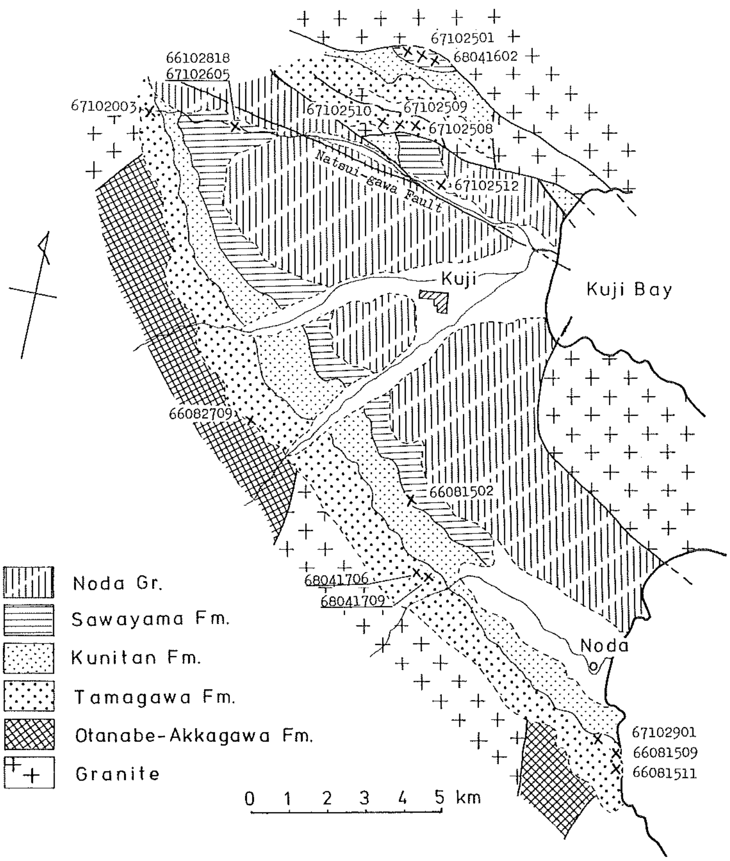
The pollen and spore flora from the Kuji Group, called Kuji microflora, and that from the Futaba Group, called Futaba microflora, were already described by the author (Miki, 1972a, b). These microfloras are very similar to each other in their floristic compositions and components. The pollen and spore flora from the Upper Yezo Group in northern Hokkaido, called Kyowa microflora, to be described later, is also correlated to the above two. All of these three microfloras are from the early Senonian sediments.

Kuji Microflora

The Kuji Group is distributed in the vicinity of Kuji City (40°N in latitude, 142°E in longitude) at northeastern end of the Kitakami Mountains. The group is composed of three formations: the Tamagawa, the Kunitan and the Sawayama in ascending order. Seventeen samples were collected from the Kuji Group as shown in Text-fig. 3, 4. Occurrence and distribution of pollen and spores are shown in Text-fig. 5.

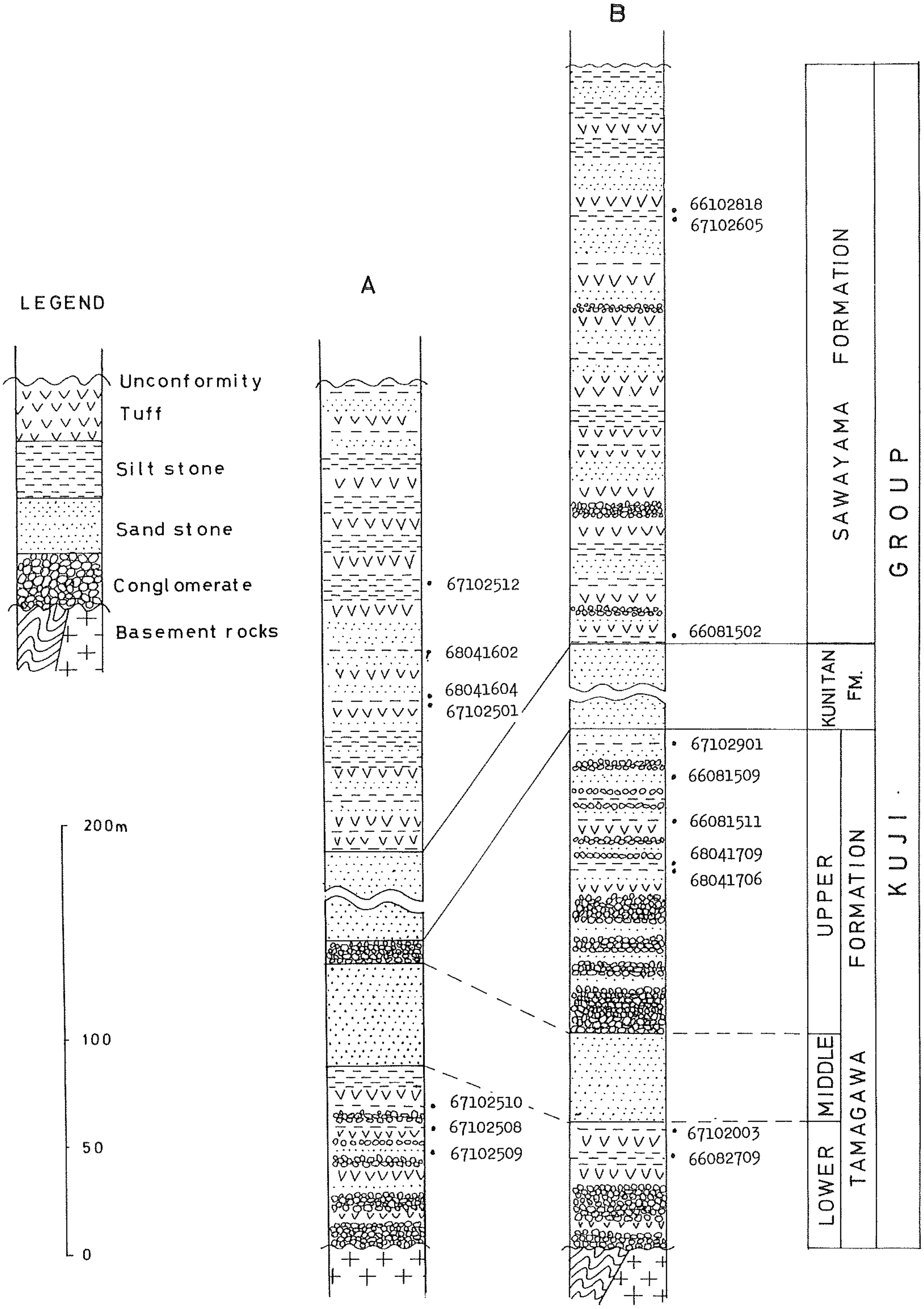
The Kuji microflora is summarized as follows:

1) It is composed mainly of pteridophytes, with subordinate gymnosperms and angiosperms. These three major taxa comprise 56 per cent, 20 per cent and 26 per cent of the total species respectively. 2) Pteridophytes include predominant Schizaeaceous spores, i.e. five species of *Appendicisporites* and four species of *Cicatricosisporites*, and Gleicheniaceous spores. A few Early to Middle Cretaceous elements such as *Appendicisporites* cf. *tricornitatus, A.*

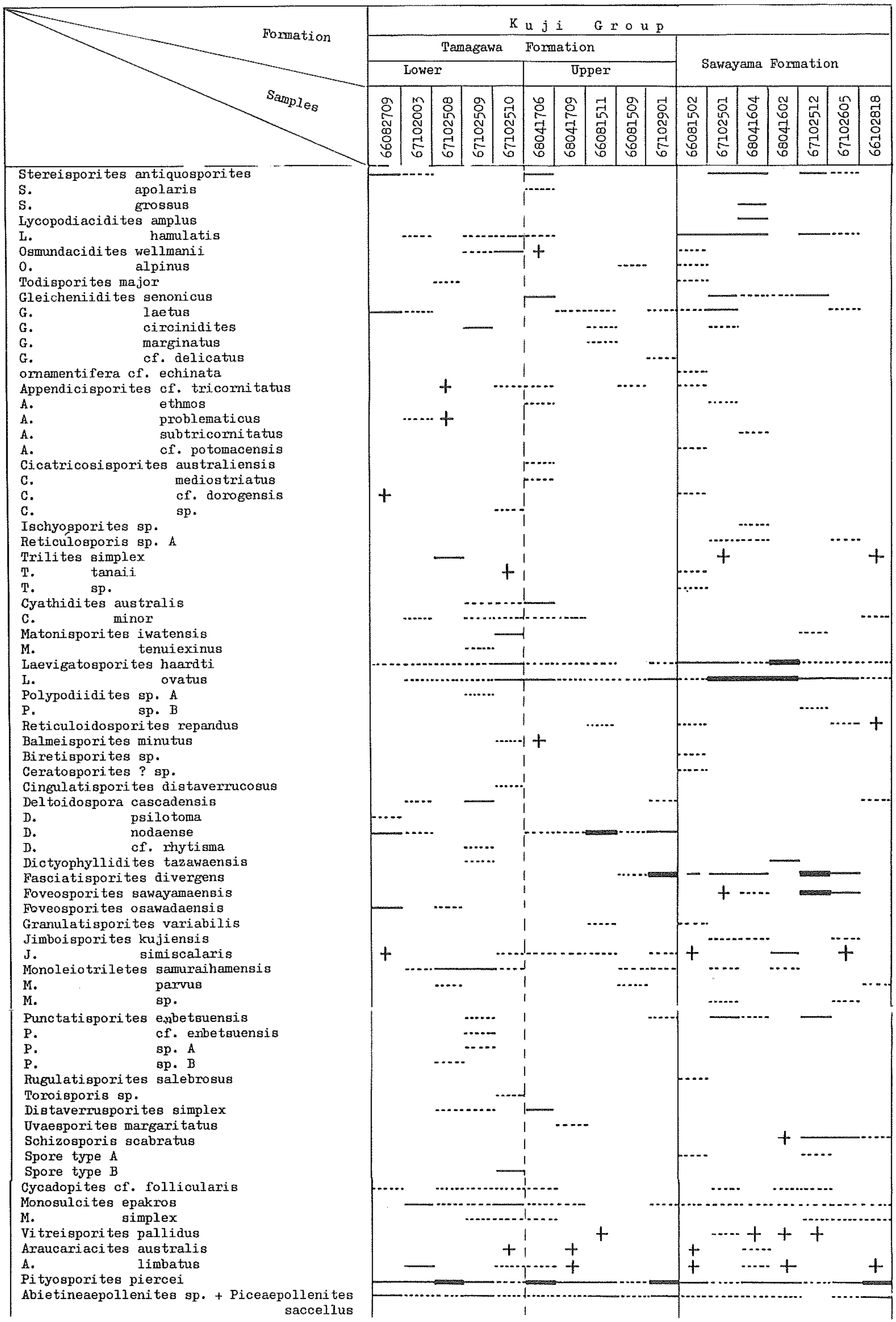


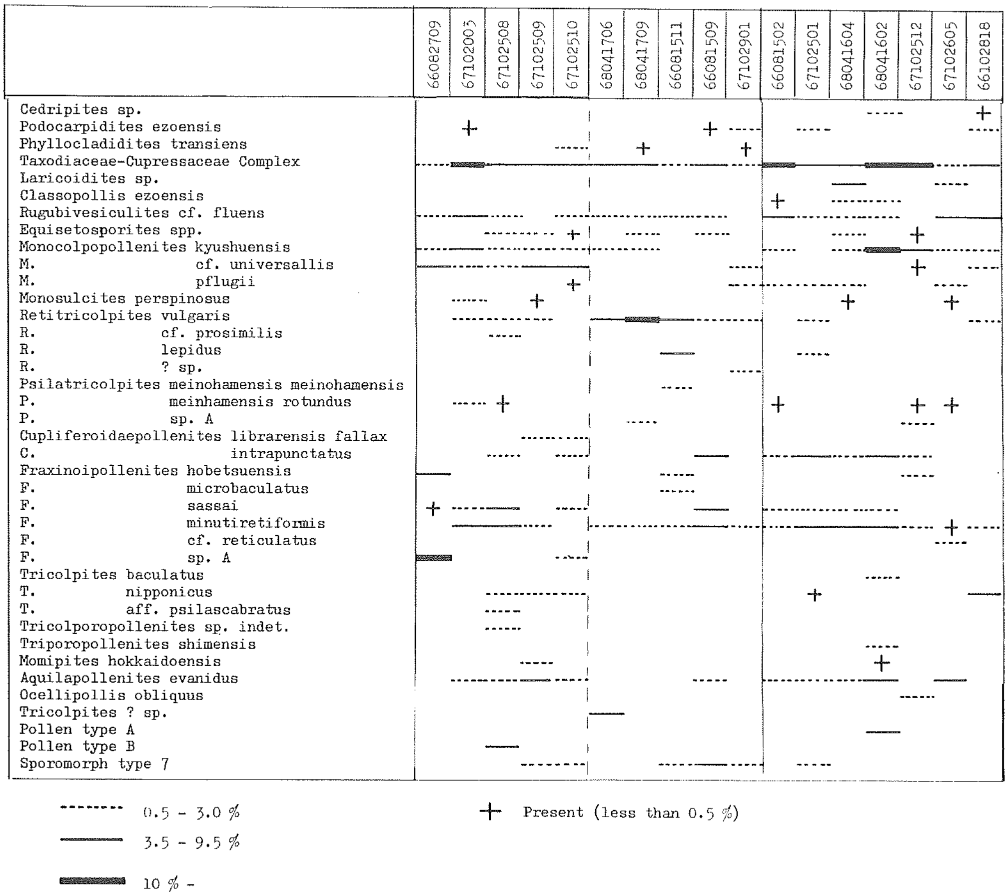
Text-figure 3 Geological map of the Kuji area (after Sawara, 1967) with locations of samples.

ethmos, Cicatricosisporites australiensis, Cyathidites australis, and *Trilites* spp. are found. There are some spores generally found in rather younger sediments, Late Senonian or Earliest Tertiary: they are *Lycopodiacidites hamulatis, Reticulosporis* sp., *Reticuloidosporites repandus, Fasciatisporites divergens, Punctatisporites enbetsuensis* and *Schizosporis scabratus*. 3) Pinaceous winged and Taxodiaceous inaperturate pollen dominate the gymnosperms. *Cycadopites* and *Monosulcites* are also commonly included. Mesophytic coniferous pollen such as *Araucariacites, Phyllocladidites, Podocarpidites, Rugubivesiculites* and *Classopollis* share important roles among conifers. 4) Angiosperm pollen is composed mostly of the tricolpate type; the porate type is represented by only a few specimens of *Triporopollenites*. 5) *Aquilapollenites evanidus* occurs frequently within the *Aquilapollenites* group. *Ocellipollis obliquus* is encountered only in the Sawayama formation, but rarely.



Text-figure 4 Schematic geological columner sections of the Kuji Group (after Sawara, 1967) and horizons of samples. A: at northern part of Natsuigawa fault. B: at southern part of the fault.


Formation
Samples
Kuji Group
Tamagawa Formation
Lower
Upper
Sawayama Formation
66082709
67102003
67102508
67102509
67102510
68041706
68041709
66081511
66081509
67102901
66081502
67102501
68041604
68041602
67102512
67102605
66102818
Stereisporites antiquosporites
S. apolaris
S. grossus
Lycopodiacidites amplus
L. hamulatis
Osmundacidites wellmanii
O. alpinus
Todisporites major
Gleicheniidites senonicus
G. laetus
G. circinidites
G. marginatus
G. cf. delicatus
ornamentifera cf. echinata
Appendicisporites cf. tricornitatus
A. ethmos
A. problematicus
A. subtricornitatus
A. cf. potomacensis
Cicatricosisporites australiensis
C. mediostriatus
C. cf. dorogensis
C. sp.
Ischyosporites sp.
Reticulosporis sp. A
Trilites simplex
T. tanaii
T. sp.
Cyathidites australis
C. minor
Matonisporites iwatensis
M. tenuiexinus
Laevigatosporites haardti
L. ovatus
Polypodiidites sp. A
P. sp. B
Reticuloidosporites repandus
Balmeisporites minutus
Biretisporites sp.
Ceratosporites ? sp.
Cingulatisporites distaverrucosus
Deltoidospora cascadensis
D. psilotoma
D. nodaense
D. cf. rhytisma
Dictyophyllidites tazawaensis
Fasciatisporites divergens
Foveosporites sawayamaensis
Foveosporites osawadaensis
Granulatisporites variabilis
Jimboisporites kujiensis
J. simiscalaris
Monoleiotriletes samuraihamensis
M. parvus
M. sp.
Punctatisporites embetsuensis
P. cf. embetsuensis
P. sp. A
P. sp. B
Rugulatisporites salebrosus
Toroisporis sp.
Distaverrusporites simplex
Uvaesporites margaritatus
Schizosporis scabratus
Spore type A
Spore type B
Cycadopites cf. follicularis
Monosulcites epakros
M. simplex
Vitreisporites pallidus
Araucariacites australis
A. limbatus
Pityosporites piercei
Abietineaepollenites sp. + Piceaepollenites saccellus



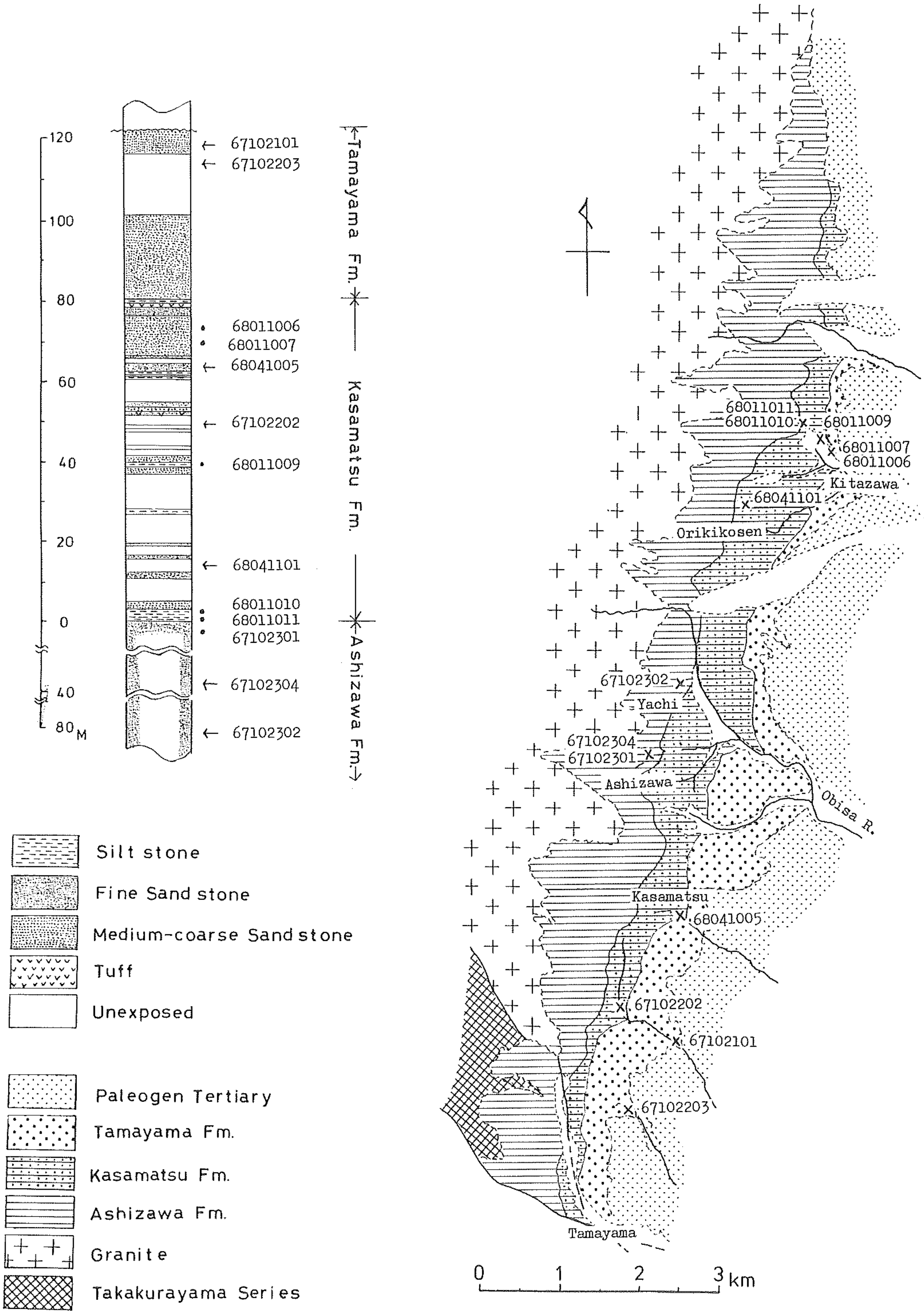
Text-figure 5. Occurrence and distribution of sporomorphs in the Kuji Group (partly revised after Miki, 1972a).

Futaba microflora

Futaba area is situated on the eastern foothills of the Abukuma Mountains in Fukushima Prefecture (approximately 37°N in latitude and 141°E in longitude). The Futaba Group is composed of three formations: the Ashizawa, the Kasamatsu and the Tamayama formations in ascending order. Thirteen samples were collected as shown in Text-fig. 6.

Futaba microflora was preliminarily discussed by the author (Miki, 1972b), and its floristic composition is summarized as follows:

1) Microflora is composed mainly of pteridophytes with subordianate gymnosperms and angiosperms (Table 3). Of 120 sporomorphs identified, 57 species (48 per cent of the total) are pteridophytes, 26 species (22 per cent) are gymnosperms and 37 species (30 per cent) are angiosperms. 2) Pteridophytes



Text-figure 6 Geological map of the Futaba area (after Iwao and Matsui, 1961) with locations of samples and columner section at Kitazawa with horizons of samples.

Table 3 Percentage distribution of sporomorphs in the Futaba Group (revised after Miki, 1972b). Question mark shows doubtful specimens. Cross mark shows presence of the species.

Formation / Samples	FUTABA GROUP												
	Ashizawa Fm.			Kasamatsu Fm.								Tamayama Fm.	
	67102302	67102304	67102301	68011011	68011010	68041101	68011009	67102202	68041005	68011007	68011006	67102203	67102101
Stereisporites ? sp. indet.			0.5										
Lycopodiacidites hamulatis							+				1.0		
Lycopodiacidites sp. A,B									16.5				
Camarozonosporites rudis							10.						
Lycopodiumsporites subreticulaesporites				2.5			0.5?						
Osmundacidites ? sp.				2.0			1.0						
Todisporites minor			1.0										
T. cf. minor				1.5	1.0								
Appendicisporites cf. tricornitatus	+	0.5			0.5	+	3.5				1.5		
Cicatricosisporites australiensis					+		+			1.0			
C. cf. australiensis						0.5	0.5						
C. hughesi				2.5	+		1.0			+			
C. minutaestriatus						1.5	0.5			+			
Cicatricosisporites sp. indet.				0.5	1.0	1.5	+		0.5	1.0			
Reticulosporis sp. B						0.5	1.0						
Gleicheniidites laetus	0.5	1.0	0.5						3.0				
G. cf. delicatus							2.0						
Aff. Gleicheniidites sp.		2.0			0.5								
Cyathidites australis				+	+		+		?				
C. minor	0.5	1.0		2.0	11.5	1.0	0.5			0.5		1.0	
Trilites simplex			5.0				1.0						
T. tanaii	0.5	1.0	+		+		1.0	+	0.5		2.5		
Matonisporites iwatensis						0.5		0.5	2.5	+	3.5		
Matonisporites ? sp.						0.5	0.5						
Laevigatosporites ovatus	1.0	1.0	2.5	7.0	1.5	2.0	1.5	8.0	5.5	18.0	6.0		2.0
L. haardti			1.0	2.0	1.0	0.5	3.0		3.0	8.5			2.0
Aequitriradites spinulosus				+		+			+				
Apiculatisporis sp.									0.5				
Balmeisporites holodictyus				+	+								
B. minutus					0.5								
Baculatisporites ? sp.									1.0				
Ceratosporites sp.						1.5	3.0		1.0				
Cingulatisporites distaverrucosus							0.5			1.0			
Cryberosporites sp.					1.5								
Deltoidospora nodaense		3.5								1.0			
D. cf. nodaense						0.5							
D. cascadensis					9.5					1.5			
D. halli					3.0								
D. aff. halli		0.5					1.5						
Deltoidospora sp.		1.5						1.0					1.0
Densoisporites ? sp.											+		
Distaverrusporites simplex							+				+		
Foveosporites intrabaculatiformis				+	2.0								
Foveosporites sp.					+	+							
Jimboisporites simiscalaris					+	+		1.0	0.5	+			
Lygodioisporites sp.									6.0	0.5			
Monoleiotriletes samuraihamensis						0.5	1.5	3.0	1.5	1.5			
M. cf. samuraihamensis							3.5						
M. purvus					1.0								
M. cf. purvus						1.0						3.5	
M. subcircularis		+					1.0		+				
Microleticulatisporites sp. indet.											0.5		
Perotrilites spp.		0.5			0.5								
Punctatisporites adriennis		0.5											
Punctatisporites sp.				+	0.5		0.5						
Toroisporis sp.								1.0					
Uvaesporites margaritatus							1.5			0.5			
Verrucosisporites sp. indet.							0.5						
Spore type B												0.5	1.0
Spore gen. et sp. indet.	0.5	0.5	3.0	2.0	1.5	4.0	2.0		1.5		0.5	2.5	1.0
Cycadopites cf. follicularis	0.5				0.5				1.0				
C. giganteus		0.5				0.5	7.0				0.5		
C. parvus								0.5	1.0			1.0	
Cycadopites sp.			2.5			1.0							
Monosulcites epakros	2.0	9.5	13.0		7.5	2.5	3.5					16.5	5.0
M. longus								1.0					
	1	2	3	4	5	6	7	8	9	10	11	12	13

Sporomorphs	1	2	3	4	5	6	7	8	9	10	11	12	13
Monosulcites spp.		1.0	0.5	10.0	0.5	0.5	1.0	0.5	2.5	2.0			1.0
Vitreisporites pallidus		0.5				0.5							
Araucariacites australis	1.0		1.0		+			1.5			+	(0.5)	
A. limbatus	4.5			7.0	1.0	3.0		3.5		4.0	1.5	0.5	3.0
Abiespollenites sp.		0.5											
Abietineaepollenites sp.		2.5					1.5						
Piceaepollenites saccellus	2.0	2.0	1.0			2.5	1.5	0.5			4.5		3.0
Pityosporites aliformis			4.0		6.0	5.0							
P. piercei	+	4.0	2.5		11.5	11.5	7.5	3.5			21.0		
Pityosporites spp.		0.5			2.0	2.5	1.0						
Pityosporites + Abietineaepollenites	2.5		4.0	1.5	6.5				1.5				27.0
Bivesiculate Pinaceae gen. et sp. indet.	17.5	2.5	4.5	5.0		4.0	6.0	20.5	2.5	1.0	20.5	1.0	1.0
Tsugaepollenites sp.						0.5	+						
Laricoidites sp.										3.5			
Podocarpidites ezoensis			0.5		+								
Podocarpidites sp.						0.5	0.5	1.0		+			2.0
Phyllocladidites transiens								1.5		+	+		
Rugubivesiculites fluens	6.0	1.0	1.0	0.5	1.5	10.5	5.5	6.0	0.5	4.0	13.5		3.0
Inaperturopollenites laevigatus	46.0	29.0	16.5	14.5	7.5	8.0	2.0	14.5	6.0	8.0	1.0	25.5	4.0
I. pseudodubius	1.0			1.5				0.5		2.0	1.5		
Classopollis ezoensis	5.0	6.0	7.5	26.5	1.5	2.0	21.0	18.0	31.0		6.5		
Equisetosporites spp.	1.0	2.0	0.5		1.0	1.5	2.0	3.5	0.5	3.5	1.0	1.5	
Retitricolpites delicatus		0.5											
R. lepidus		2.5	1.0		1.0	1.0	1.0		0.5				
R. vulgaris	+	1.0	2.0		0.5	0.5		1.5	1.0	1.0		0.5	11.0
Retitricolpites spp.			0.5			0.5			0.5	22.5		0.5	1.0
Psilatricolpites debilis			0.5			1.0		0.5		0.5	2.0	1.0	3.0
P. cf. ditis				0.5		0.5						0.5	
P. meinohamensis rotundus			1.0			1.0							
P. minutissimus		0.5				0.5							
P. cf. parvulus												1.0	
P. simplicissimus					0.5								
Psilatricolpites sp. A							0.5						
Cupliferoidaepollenites intrapunctatus			2.0						0.5	4.0			
C. librarensis fallax			1.0										
Fraxinoipollenites sp. A	1.5		0.5	2.0				1.0	1.5	4.0			
F. hobetsuensis		1.0							+				
F. cf. minutus		2.0	0.5			1.5							
F. minutiretiformis	1.5	1.0	+	0.5	0.5		1.0				0.5		
F. rudis						0.5							
F. tamayamaensis												2.5	
Fraxinoipollenites sp. indet.		0.5	1.5	2.0	+	0.5			0.5		0.5	0.5	
Clavatricolpites cf. prolatus			1.5										
Tricolpites minimus						9.0		1.5		1.5	+	1.0	2.0
T. psilascabratus			0.5			0.5	1.0					0.5	
T. hironoensis											2.0		
T. nipponicus		1.0			1.5			2.5	1.0		7.0		
Tricolpites ? sp.	2.0	1.0	3.5			7.5	1.0			1.5	+	0.5	
Tricolporopollenites sp. indet.		1.0	0.5			0.5	0.5			+	0.5		1.0
Alnipollenites eminens									0.5				1.0
Triporopollenites shimensis	0.5	1.0							1.0				
Triporopollenites sp. indet.		0.5									+		
Caryapollenites chikuhoensis									2.0				
Cf. Liliacidites dividuus													3.0
Spinizonocolpites echinatus	0.5					0.5					0.5		
Monocolpopollenites kyushuensis		1.5	5.0	4.5	8.5				1.0	1.0		34.0	6.0
M. pflugii	0.5		2.5			0.5						1.5	3.0
Monocolpopollenites sp. indet.		1.5	1.0	1.5	0.5	0.5	1.0	1.0					5.0
Peromonolites cf. reticulatus	0.5					0.5						0.5	2.0
Ericaceoipollenites sp.					1.0								1.0
Angiosperm gen. et sp. indet.			1.0		0.5							0.5	1.0
Sporomorph type 7		5.0	1.0									1.5	3.0
Indetermined sporomorphs		3.5		0.5									
Total specimens	200	200	200	200	200	200	200	200	200	200	200	200	99

are characterized by diverse Schizaeaceous spores, including three *Appendicisporites* species and five *Cicatricosisporites* species. It is also noteworthy that they contain several species generally identified in the Early to Middle Cretaceous, i.e. *Cicatricosiporites hughesi, Cyathidites australis, Aequitriradites spinulosus* and *Densoisporites velatus*. 3) Gymnosperms are characterized by the predominance of Cycadaceae-Ginkgoaceous pollen, Pinaceous bivesiculate pollen, Taxodiaceae-Cupressaceous pollen and *Classopollis*. Gymnosperms are composed of eight genera of Mesophytic pollen and six genera of Cenophytic. 4) Angiosperms are characterized by being sparsely represented in porate type species by only a few grains of *Caryapollenites, Alnipollenites* and *Triporopollenites.*

Kyowa microflora

Kyowa microflora was obtained from the Upper Yezo Group in the Saku area, which is composed of the following three formations, the Nishichirashinai, the Omagari and the Osoushinai. Seventeen samples were collected as shown in Text-fig. 2.

Kyowa microflora is named after the sampling location, Kyowa village. Microflora is dominant in both pteridophytes and angiosperms with nearly equal frequency, but is less dominant in gymnosperms. Of the 146 sporomorphs identified (Table 4), 56 species (38 per cent) are pteridophytes, 36 species (25 per cent) are gymnosperms, and 54 species (37 per cent) are angiosperms.

The characteristic features of Kyowa microflora are summarized as follows:

1) Pteridophytes are represented mainly by Gleicheniaceous spores of the *Gleicheniidites* group and *Deltoidospora nodaense*, and Cyatheaceous spores of *Cyathidites minor*. Schizaeaceous spores are sparsely represented. 2) Gymnosperms commonly contain Ginkgoaceous pollen of the *Monosulcites* group, Taxodiaceae-Cupressaceous pollen such as *Inaperturopollenites laevigatus*, and Pinaceous bisaccate pollen. Gymnosperms are composed of eight Mesophytic genera and seven Cenophytic ones. 3) Angiosperms are markedly characterized by very diversified tricolpate and less diversified porate pollen. The appearance of some new types of tricolpate pollen with strioreticulate and foveolate exine for the first time is noteworthy. 4) Several species of *Aquilapollenites* are present.

The early Senonian pollen and spore flora is generally characterized by remaining Mesophytic appearances. Pteridophytes are more or less superior to gymnosperms and angiosperms in number of species. Late Mesophytic pteridophytes, the Schizaeaceae and the Gleicheniaceae may characterize the early Senonian flora. Both Cycadaceae-Ginkgoaceous and Mesophytic coniferous pollen, including *Araucariacites, Classopollis, Phyllocladidites* and *Rugubivesiculites*, share important roles in gymnosperms. The tricolpate type is predominant in angiosperm pollen, while the porate type is less developed. On the other hand, latest Cretaceous to earliest Tertiary elements such as *Aquilapollenites* are even less diversified, with only several species.

Campanian Pollen and Spore Flora

Pollen and spore flora from the Lower Hakobuchi subgroup was called the Lower Hakobuchi pollen flora by Takahashi (1964). The author reexamined it,

Table 4 Occurrence and distribution of sporomorphs in the Upper Yezo Group. Numbers in brackets are closely similar specimens and those with question mark are doubtful specimens. Cross mark shows presence of the species.

Formation	UPPER YEZO GROUP																
	NISHICHIRASINAI FM.						OMAGARI FM.			OSOUSHINAI FM.							
Sample	68072717	68072804	68072805	68072904	68072905	68072907	68072908	68072909	70072702	68072813	68072810	70072716	68072910	68072914	68072918	68072919	70072804
Sample Designation	U-1	U-2	U-3	U-4	U-5	U-6	U-7	U-8	U-9	U-10	U-11	U-12	U-13	U-14	U-15	U-16	U-17
Stereisporites antiquosporites																	1
S. aporalis												1					
Lycopodiumsporites subreticulaesporites		+	+						+								
L. reticulumsporites												1					
Baculatisporites comaumensis																+	
B. vallidus												+					
Osmundacidites wellmanii				1	1		+				+		1?				3
Todisporites major			+							2	+						
T. minor			+				?										
Appendicisporites cf. tricornitatus		+														+	
A. subtricornitatus						+									1		
A. sp. indet.	1			1					+								1
Cicatricosisporites australiensis			+													+	
C. hughesi	1																
C. perforatus												+					
C. sp. indet.						+	+		+	1		2					2
Gleicheniidites senonicus		+	1	6		2	+	+	3	1		1	+	1		4	
G. laetus	2	+			1		+	1						2	2	1	+
G. circinidites							1										
G. cf. delicatus				1	+												1
Ornamentifera echinata		1	1		+	+							+			+	
Deltoidospora nodaense		1		(1)	2		1		1			1		1			2
Cyathidites australis			+	(2)		+	+				+	+				?	
C. minor		1	2	2	1	+	3	3		1	+	6	1	1	2	1	5
Trilites simplex					+								+			+	+
T. tanaii							+	+			+	2			+	+	
T. cf. simplex											1						
Matonisporites iwatensis															2		
M. magnus																	1
Laevigatosporites haardti	6	2	3	6	3	4	1	7	1	8		7	1		1	3	4
L. ovatus		3	5	6	2	2				5	2		1				2
Reticuloidosporites repandus			+													+	
Leptolepidites cf. tenuis		1										1					
Apiculatisporites satoi	1	1	+	1	1				+						1	+	+
Balmeisporites minutus											+						
Cingulatisporites distaverrucosus			+														
Deltoidospora cascadensis			+	?	+	1	1	+	2	1							
D. halli																1	
D. sp.													1	1		2	
Densoisporites velatus				+													
Dictyophyllidites tazawaensis							+										
D. sp.	1																2
Distaverrusporites simplex																	1
Foveosporites intrabaculatiformis							+										
F. sp.							+									+	
Granulatisporites valiabilis													1				
Jimboisporites simiscalaris	1?			+												+	
Monoleiotriletes parvus						1		1									
M. subcircularis					+												
M. samuraihamensis	+						+	?			+	+			+	+	4
Nevesisporites sp.											+						
Perotrilites sp. indet.							+									+	
Punctatisporites embetsuensis						(+)						1	+				
P. cf. parvigranulosus			+														
Triporoletes sp.	+			+					+	1			+		+		1
Rugulatisporites salebrosus																+	
Styx sp.														+		+	
Polycingulatisporites reduncus		+	+	1	+						+	+	+	1	+	+	2
Spore gen. et sp. indet.		2						2	2			2					1
Cycadopites cf. fragilis	1	1	2						1		1						
C. cf. giganteus												1			+		
C. cf. scabratus		+						1									
C. spp.				2			+	1?			1					+	
Monosulcites epakros	40	24	33	3	35	47	23	37	21	19	37	7	22	19	14	7	14
M. fusiformis	2	5	3	2	6	1	1	16	2	4		1	4	4	4		2
M. longus											+		+				
M. praeacutus		+									+		1	1		1	
M. simplex		+		+	+			1	4					2	2	1	
M. spp.	2	3	10	2	1		2	1?	1		2	2				2	
Vitreisporites pallidus	4	5	2	2	5	5	4	6	9	+	2	3	+	4	1	4	4
Araucariacites australis	+	1	+	+		1	+				+	+	+	1	1		(+)
A. limbatus		1														+	
A. ? sp.				1			2		3	1			1				
Abiespollenites sp.		+		1			1		3	1	+	4		+			2
Abietineaepollenites sp. A							2				4		+			5	
A. sp. B			2		3					3						4	6
A. sp. C					1	1	1		2			6		5	1		
A. sp. indet.	4	4	5	6			4		1		2						
Piceaepollenites saccellus			1	+					2			3					8
P. sp. indet.		1			1		1			2						1	
Pityosporites piercei		+	3	8	1	2	3	2	4	1	9	26		7	3	6	1
P. aliformis		1						1		(1)							
P. sp. C																+	
P. sp. indet.	2	4		1									5				
Bivesiculate Pinaceae gen. et sp. indet.	3	3	7	11	3	6	8	5	9	2	2	6	6	7	2	4	3
Laricoidites sp. indet.			1	4	+		1			1			2				
Inaperturopollenites laevigatus	92	81	80	44	77	89	87	71	91	102	80	74	98	93	116	111	62
I. pseudodubius				2	3							+		1	1	1	3

	U-1	U-2	U-3	U-4	U-5	U-6	U-7	U-8	U-9	U-10	U-11	U-12	U-13	U-14	U-15	U-16	U-17
Sequoiapollenites parvipapillosus							+									+	
Podocarpidites ezoensis			+	+	+	+					1						+
P. sp. indet.	+								1				1		+		
Phyllocladidites transiens	1	12	2	11	2	1	2	1	2	2	2	2	4	6		+	14
Phyllocladidites parvus	2	+	1	2	1	+	1	+ ,	+	2	1	+	+		2		1
Rugubivesiculites cf. fluens		+	+		+	+	3	1	+	+	4	2	4	1	3	+	
Inaperturopollenites sp. indet,		1	1		3								1				2
Classopollis ezoensis	15	1	3	32	2	15	14	13	6	2	7	13	23	20	6	1	12
C. sp.											2						
Equisetosporites multicostatus							+										
E. sp. B				4	2	+				+		1	1	2		1	2
E. sp. C							+										
E. sp. D			+	1			+				+		2		+		
E. sp. indet.	1	+	+	4	1		+	1	1				1				1
Monosulcites perspinosus							1									+	
Palmaepollenites sp.		1					+										
Liliacidites cf. peroreticulatus															1	1	
L. sp. A										+							
L. sp. B	1	+						1	4								
L. ? sp.													1				
Monocolpopollenites kyushuensis	1	4		3	2	3									1		
M. pflugii		+		1	1		2		1	2				1		1	1
M. shuparoensis											+						
M. sp. indet.		1?	2	2			1	1	1		+	1					
Retimonocolpites ? sp. indet,		1?		1									1?				
Alnipollenites eminens								1									
Momipites constatus	1				+									+			
M. hokkaidoensis		4	1	2	+	+	+		+	3		3	1	+	1	1	2
M. sp.													1?				
Retitricolpites delicatus	2	+		1			1	1	3	6	6	2	1		1		2
R. cf. georgensis						+											
R. lepidus	2	1	2	3	+	1	4	5	2	5	1	2	3	2	5	5	1
R. vulgaris			+				2		1	+		2			+	2	1
R. spp.		1				(3)			3							1	1
Clavatricolpites prolatus				+			+	+		+							1
Psilatricolpites debilis	1					4	7	3					1	1			
P. meinohamensis meinohamensis									1?								
P. meinohamensis rotundus	1	2						4				1		1		2	3
P. minutissimus	1																
P. cf. parvulus		3	1		3	1		1		2							
P. subasper														+			
P. subpunctulatus		2						1						1	2		
P. sp. A		+	3	2	1		1				5	1	1			2	
Cupliferoidaepollenites librarensis fallax	1																
C. intrapunctatus																	1
Fraxinoipollenites hobetsuensis		+	1	1			+	+			10	1			4		2
F. microbaculatus	1		1	3	1			1	3		2	4		+	1		2
F. microclavatus										1							
F. microreticulatus				2		+									1	(1)	
F. minutiretiformis						2			1	1		+			3	+	+
F. microfoveoreticulatus						+						+					
F. reticulatus		(1)		1						+		+			1		
F. sassai				2			2		1			1			2	16	1
F. tsukimiensis												+					
F. sp. A	3	8	8		7	3	4	1		8	1		5	3	6		
F. sp. indet.	1	2	5		2	1		1	1		2	1	1	3	1		2
Tricolpites minimus		1									1						
T. psilaexinus		2		+				2									
T. psilascabratus			1						+	4	+		1	4			1
T. nipponicus									+	+	1		+				
T. strioreticulatus						2	+				+	+		1			1
T. cf. microreticulatus			+														
T. sp. A					+		2		2	+		2				1	1
T. sp. indet.																	2
Ericaceoipollenites ? sp.							1?										
Aquilapollenites hakobuchiensis																+	
A. rigidus			+		1			1	1		+				1	1	2
A. cf. rigidus										1							
A. evanidus		2	+	+	+	+	1?	+	1	+	+	+	+	+	+	4	+
A. sp. B		+					+										
A. sp. indet.												1					
Periporate type pollen					1						1						
Monoporate ? pollen							1?										
Angiosperm gen. et sp. indet.									2	1							
Utliculites visus															1		
Angiosperm ? pollen		1		3			1		1								
Sporomorph type 7	1	2					2		2	1	1					1	
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

based on samples from three localities in central Hokkaido. An assemblage from the Yasukawa formation, contemporaneous with the Lower Hakobuchi subgroup in Enbetsu, was reported by Sato (1961). The author also investigated an assemblage from the same formation in Saku. These assemblages are very similar to that of Lower Hakobuchi pollen flora in composition and components.

The pollen and spore assemblages from the Yasukawa formation in the Saku area

The Yasukawa formation locally distributed in the Saku area is similar in lithology to the Hakobuchi Group. This formation is inferred to be of Campanian age, based on ammonites and *Inoceramus*. Only two samples were collected from the Yasukawa formation. Occurrence and distribution of sporomorphs from them are shown in Table 5. The sporomorph assemblage is predominated by angiosperm pollen, and is inferior in pteridophytes and gymnosperms. Pteridophytes contain *Laevigatosporites haardti, L. ovatus* and *Gleicheniidites senonicus. Monosulcites* group, *M. epakros* and others, and *Phyllocladidites transiens* are the main elements among the gymnosperms. Among angiosperms the tricolpate type is superior to the porate type. The assemblage is markedly characterized by the diverse and abundant pollen of the *Aquilapollenites* group with 12 species and 42 per cent of the total angiosperm pollen grains.

The assemblage investigated by Sato (1961) was from carbonaceous rocks collected a few kilometers west of the locality mentioned above. It contains very abundant monolete Polypodiaceous spores and *Fasciatisporites divergens*, commonly *Punctatisporites enbetsuensis*, and rarely *Cyathidites minor* and *Appendicisporites subtricornitatus*. It also contains abundant pollen of the Taxodiaceae and *Quercus* sp., and commonly contains *Betulaepollenites. Phyllocladidites transiens, Podocarpidites ezoensis, Alnipollenites, Aquilapollenites hakobuchiensis* and *A. cretaceus* are found, though rarely.

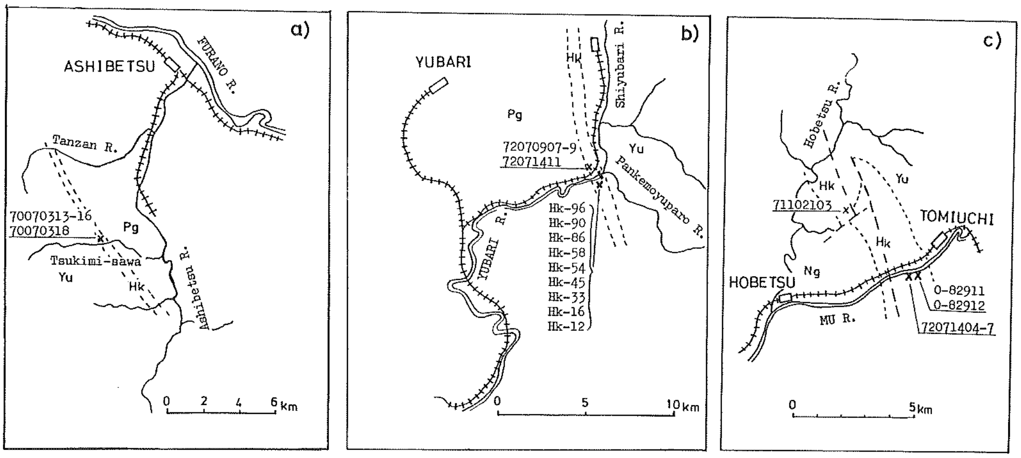
Lower Hakobuchi microflora

The Upper Cretaceous sediments ranging from the Lower Yezo Group to the Hakobuchi Group are developed in the Ishikari coal field and its southern extension.

Three well-developed sections of the Hakobuchi Group were selected for the investigation: Ashibetsu, Yubari and Hobetsu areas. The Group is divided into two subgroups, the lower Hakobuchi and the Upper Hakobuchi. Twenty samples were collected from the Lower Hakobuchi subgroup: five of them were from Ashibetsu, nine from Yubari and the rest from Hobetsu. Their localities and stratigraphic positions are shown in Text-fig. 7, 8.

Of 169 sporomorphs identified (Tabale 5), 56 species (33 per cent) are pteridophytes, 36 species (21 per cent) gymnosperms, and 77 species (46 per cent) angiosperms. The Lower Hakobuchi microflora are summarized as follows:

1) This microflora is characterized by predominance of angiosperm pollen. They occupy about half of the total sporomorphs in terms of number of species and specimens. 2) Except for *Gleicheniidites senonicus* and *Cyathidites minor* which appear with low frequency, Schizaeaceous spores are quite scarce. On the other hand, Osmundaceous spores are comparatively dominant. Some pteridophyte spores such as *Fasciatisporites divergence, Monoleiotriletes*



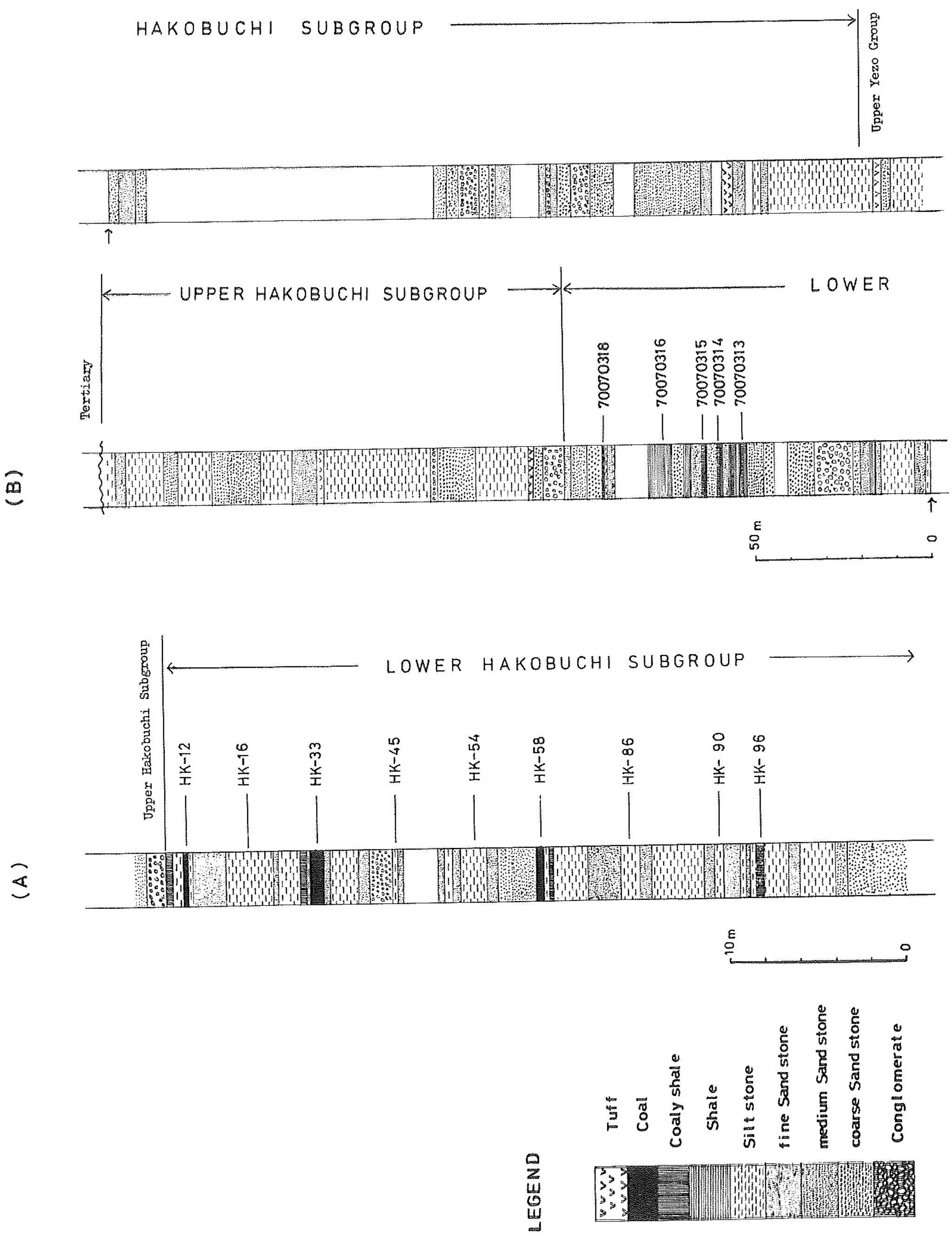
Text-figure 7 Locations of samples from the Hakobuchi Group at a) Ashibetsu, b) Yubari and c) Hobetsu. Yu: the Upper Yezo Group, Hk: the Hakobuchi Group. Pg: the Paleogene Tertiary. Ng: the Neogene Tertiary.

samuraihamensis and *Punctatisporites enbetsuensis* are found through all the samples. It is noteworthy that there are *Lycopodiacidites amples* and *L. hamulatis* though rare: these two are commonly found from the Maestrichtian to the Eocene of North America and Europe. *Inundatisporites tomiuchiensis* is restricted to the Lower Hakobuchi subgroup. 3) Among gymnosperms, Cycadaceous pollen such as *Cycadopites*, is encountered occasionally, while Ginkgoaceous pollen such as various species of *Monosulcites* frequently occur. Five genera of Late Mesophytic coniferous pollen, *Phyllocladidites, Podocarpidites, Araucariacites, Rugubivesiculites* and *Classopollis*, are found, though their occurrences are quite few except for the first. On the other hand, six genera of Cenophytic coniferous pollen are present; *Pityosporites* and *Inaperturopollenites* are particularly abundant. 4) Angiosperm pollen is characterized by diverse tricolpate type with high frequency. Juglandaceous and Btulaceae-Myricaceous porate pollen show medial to low frequency. Tricolpate pollen is far more dominant than porate. 5) Diverse species of *Aquilapollenites, Orbiculapollis, Ocellipollis* and *Cranwellia*, especially 13 species of *Aquilapollenites*, are characteristic.

The above-noted distinctive features of Lower Hakobuchi microflora are commonly observed in all the Campanian pollen and spore floras of northern Japan.

Maestrichtian Pollen and Spore Flora

Pollen and spore flora from the Upper Hakobuchi subgroup, called Upper Hakobuchi microflora, was reported by Takahashi (1964). A pollen and spore



Text-figure 8 Columner sections of the Hakobuchi Group at (A) Hakobuchi valley in Yubari area and (B) Tsukimi-sawa in Ashibetsu area, and horizons of samples.

Table 5 Occurrence and distribution of sporomorphs in the Yasukawa formation and the Hakobuchi Group. Numbers in brackets are closely similar specimens and those with question mark are doubtful specimens. Cross mark shows presence of the species.

Formation / Area sampled / Sample / Sample Designation	H-1	H-2	A-1	A-2	A-3	A-4	A-5	Y-1	Y-2	Y-3	Y-4	Y-5	Y-6	Y-7	Y-8	Y-9	Hb-1	Hb-2	Hb-3	Hb-4	Hb-5	Hb-6	Y-10	Y-11	Y-12	Hb-7	Y-13
Formation	Yasukawa Formation		Lower Hakobuchi Subgroup																				Upper Hakobuchi Subgroup: Fukaushi Sst. Fm.				Upper Hakobuchi Subgroup: U. S.
Area sampled	Saku		Ashibetsu			Yubari											Hobetsu						Yubari			Hob.	Yub.
Sample	68072806	70072806	70070313	70070314	70070315	70070316	70070318	HK-96	HK-90	HK-86	HK-58	HK-54	HK-45	HK-33	HK-16	HK-12	O-82911	O-82912	72071404	72071405	72071406	72071407	72070907	72070908	72070909	71102103	72071411
Stereisporites antiquosporites			+		+			1		10	1			38		3		38			14	15	1				
S. aporalis			14	2	+	+				6	+		+			3		+			3	1					
S. limbatus					+		+						+	21		5		+			10	4			1		
S. pseudostereoides			+		1					+	+		+	40		1	4				+	15	3				
S. cf. regium																					2						
Lycopodiumsporites subreticulaesporites																							+				
Lycopodiacidites amplus													+	5											1		
L. hamulatis										+			+	3		+	+	9									
Apiculatisporis inouei										1	7	1	1			9	1										
Baculatisporites comaumensis											1	1	+		+	9											1
B. vallidus		+	+	1							+		+			2						1					
Osmundacidites wellmanii		+	2	2	+	+								+		4					4	+	1				
Todisporites major						1																	1			(+)	
T. minor															+												+
Appendicisporites cf. tricornitatus				+	1												+										
A. subtricornitatus			+		+					2							1	+				+					
A. sp. indet.								+		1				+								+					
Cicatricosisporites hakobuchiensis																4											
C. sp. indet.			+	+																							
Reticulosporis sp. A														1			+				1	+					
Gleicheniidites senonicus	1	+		+		1	+		3	2			1	+			17	1	2	+	24	2	3			1	
G. laetus							+																			12	
G. circinidites			+																								
G. marginatus			6	+				+		6				21		+					6						
G. cf. delicatus																					1						
Clavifera ? sp.																	2										
Deltoidospora nodaense																2						+					
Cyathidites australis												1			+												
C. minor	1		+	6	1	1	+		+		+		+		1	+	8	9		+	+	+	+		1		
Trilites simplex									3		+																
T. cf. simplex											1					+											
T. tanaii		+	+																								
Matonisporites magnus			1						2			+		+													
Laevigatosporites haarditi	5	2	28	2	19	7	2	8	5	26	15	15	11	2	3	10	14	5	17	5	5	4	30	9	15	10	5
L. ovatus		2	40	1	18	6	+	14	4	4	30	1	2			9	4	17	4	3	6			1	4	5	3
Reticuloidosporites repandus					1		+				5		2	+	+	5		1	4	+	18	34	1				1
Leptolepidites cf. tenueis						1?			+			+				+											
Acantosporites ? sp.																							1				
Cingulatisporites sp.																							3				
Concavisporites sp. indet.															1												
Deltoidospora cascadensis			3					1							+		7?					+				17	
D. halli	2			6?	(6)						+										(3)		(+)				
D. sp.		1	1			1	5	1						+			1				1						
Densoisporites velatus									+																		
Dictyophyllidites tazawaensis			+															1									
D. sp.					4					+																	
Fasciatisporites divergens			1		2	1		1		2	+	1	1			3	5	31		1	18						
Foveosporites sawayamaensis		+			2												1?										
Glanulatisporites valiabilis									+								1										
Inundatisporites tomiuchiensis			2	+	+					2			1			+					+						
Jimboisporites kujiensis																		+				+					
J. simiscalaris			1	+	1	+							+				3	1				+					
Laevigatisporites hokkaidoensis				(1)					2																		
Monoleiotriletes parvus			1								1												1				
M. samuraihamensis		+	+	1	3	+	+	2			2	+					3	9							2		
M. subcircularis	+										+							3									
Punctatisporites embetsuensis			8	1	11					3				15		13	19	1		1	2	43					
P. sp.																1?		1?					1?				
Radialisporites radiatus														1	+							+	+				
Triporoletes sp.																										2	
Rugulatisporites salebrosus			9		1	+				1								1		+							
Styx sp.				+											2												
Verrucosisporites sp. indet.																							1?				
Schizosporis scabratus		+		+													+					+	+			5	
Spore gen. et sp. indet.	2				5	+		1	1									1	1			1	3			1	
Cycadopites cf. follicularis							1	1	1							1									1		
C. cf. fragilis			2	+	+			3	1	2		6		1													
C. cf. scabratus			+																								
C. cf. giganteus						+													+	+							
C. spp.			2	22	1			2					2					2									1?
Monosulcites epakros	39	6		5	6	4	2	2		2			5	1		12		14	10		10	10					
Monosulcites fusiformis	1		1		2	3	5	1	1							12					7	3	1			3	
M. simplex		1		1	3				1	12	6	11	6	5	16		17		2	3			7	4	5	4	3
M. sp. B				1	1	1			2	2		+	2	2		+			3	1					1	1	
M. longus												1															
M. praeacutus									1	2																	
M. spp.		2	5	3	2		1	4	1		2	3	16	1			3	2				1?	2		3		
Vitreisporites pallidus	3	1			+				1								2	+									
Araucariacites australis	1	2	1			+	+													+							1
A. ? sp.																							1			1	
Abiespollenites sp.		2							1													+				+	
Abietineaepollenites sp. A	3		1								2												1				
A. sp. B	4								4	2			1		1	+						+					1
A. sp. C		(3)																									
A. sp. indet.				1				3				1										1			2	1	
Piceaepollenites saccellus	1		+			+		2						1					1	+			1	3	1	2	
P. sp.			+		2						2					+				1							
P. sp. indet.								1																			
Pityosporites piercei							+					+			1								1	2	2	+	
P. aliformis			6	12	3	1			1		(2)	+			1		9									5	
P. sp. B			2	10	9			6				+			+			2	1				1		1		1
P. sp. C												2	1										2			9	
P. sp. indet.		5								1										4			1		3	4	
Cedripites sp. indet.																										+	
Bivesiculate Pinaceae gen. et sp. indet.	1	2	1		2	2		2		1	2					1			1							7	
Inaperturopollenites laevigatus	105		8		14	35	70	36	19	4	32	49	58	12	40	47	41	35	14	19	8	9	6	3	14	5	9
I. pseudodubius					1																		9				
Sequoiapollenites parvipapillosus						+	2						2	+	+	+											
Podocarpidites ezoensis			+	+		2						?				+	+			+							
P. sp. indet.								+	+					+													
Phyllocladidites transiens	4	4	1	+	1	2	+	2	2				1	1	+	+	+					+				3	
P. parvus	1	+				+																					
Rugubivesiculites cf. fluens			2	+	+																					+	

	H-1	H-2	A-1	A-2	A-3	A-4	A-5	Y-1	Y-2	Y-3	Y-4	Y-5	Y-6	Y-7	Y-8	Y-9	Hb-1	Hb-2	Hb-3	Hb-4	Hb-5	Hb-6	Y-10	Y-11	Y-12	Hb-7	Y-13
Inaperturopollenites sp. indet.														2										1			
Classopollis ezoensis	6			+	+									+			+			+	1	+	2		1		
Equisetosporites sp. B							+							1		1				+		+			1		+
E. sp. C												1															
E. sp. D							2																				
E. sp. indet.				+				1			1										2						
Gnetaceaepollenites sp.																							1		3		
Monosulcites perspinosus			+	1	+	+																					
Clavatipollenites sp.		1?																									
Liliacidites sp. A		+							+	6						+											
L. sp. B		+																								2	
Monocolpopollenites kyushuensis				1	+			1	3			3		4						6						7	
M. pflugii	1		7	+		3				1	1	3	2	+	1	3	4		8	+		+	1	2	3	2	3
M. shuparoensis		+														1							1				
M. foveolatus															+?				4	3							
M. sp. indet.		2		1	2	1																		2	1	1	1
Weylandipollis retiformis		1	2	5		7	4	9	2?	+	29	1	4		+	+			7	4		+				1	2
Pterocaryapollenites sp.																			1		3	1			4?	+	
Polyporopollenites sp.		5					1						1						1	+	+	17		+	1	+	
Alnipollenites eminens			1		1	+			1	+	+	1		+		1			3	1	+	1	1	5	1	(2)	3
Betulaepollenites normalis			1	3	3	13	39	6	+		+			+		1	1		+	2	2	3				3	
B. minutulus																								(2)	4		1
Momipites constatus	1	(+)					10	3		4	2	+		3		1					1	+	3		10		
M. hokkaidoensis		+	4	4	11	2			+	1						+		1	+	+			2	1	1	1	
Triporopollenites festatus							(7)																				
T. kasuyaensis																			+				(7)	(3)			
T. shimensis		6	2	3	1	34			1		+	1				+			1	+	1	+	10	12	4	+	2
Ulmoideipites punctatus																							25	77	37		25
Anacolosidites ? sp.																											3
Ericaceoipollenites sp.			2	+	1														2	+	3	+	1				
Retitricolpites delicatus			(1)	1+(2)				(1)																			
R. lepidus	3			16	5'	1			1		+	1		+	2	1	1			1	6						1
R. vulgaris			1										+		2										(1)		
R. validus									1						11				2								
R. sp.				+	1		+																				
Psilatricolpites debilis						3										(2)					1						
P. ditis													+				3?										
P. meinohamensis meinohamensis																			+								
P. meinohamensis rotundus	1	1	6	9	6		3			1	1		3			1	1	1	1		3	3	4	7	3	1	
P. subpunctulatus						+	9					8		2					1						1		
P. sp. A	1			3		+			1			1							1	1	2						
Cupliferoideaepollenites librarensis fallax						(8)				1	1		1		(1)				2				1	1	2		
C. intrapunctatus		4						7	14	18		2	13		7				6			1		1	1	13	
Fraxinoipollenites sp. A	6			1																							
F. hobetsuensis		1	1			1		11	1			10	3	2	2	22	1		4	1	8	+	1		(1)	16	
F. microbaculatus			+			23		52	12	24	27	43	6	9	30	3			7	2	1		2			7	
F. sassai		9	+	1		3	1		1		21	7	13	1	14	+			10	10	17	18	1	4		6	
F. minutiretiformis		17							1	1	4	4	8							1	1	(2)				4	10
F. microreticulatus				1	(1)				2						(1)												
F. reticulatus			+																								
F. tsukimiensis			2			2	1		3									3				+					
F. sp. indet.		2		1	1		1	3	3	1	1	3		+		2	5		1	2	2		10	2		2	
Foveotricolpites microfoveoreticulatus			3		1											1		+				+					
Striatopollis psilastriatus														1									2	2	2		+
S. sp.																				1		6	3				
Tricolpites minimus		(1)		1												1							1	1	4?		
T. psilaexinus																								5	1		
T. aff. psilascabratus																					2				3		+
T. nipponicus		+					+					+															
T. strioreticulatus																	9										
T. parvistriatus																								(2)	2		+
T. sp. A					+														+			+					
T. sp. indet.					1												1	4	1				1				
Longaevipollis siviricus																							2	6	2		+
Tricolporopollenites brevicolpus		+																	5	18			1		1		
T. spp.		4				+			1	1	1	+	+	1									1	1	1		1
Triporopollenites sp. A		1																									
T. sp. B																			1								+
T. sp. C		1																									
T. sp. indet.		2						1				1										1	4		2		6
Aquilapollenites hakobuchiensis		+							33		13	15	12	1	27				48	73		2					
A. attenuatus																										6	
A. cf. turbidus		1				24	32																				
A. asper																											5
A. rectus		22							+														1			(3)	
A. rigidus		1																								2	
A. cf. rigidus								2		45				+	+												
A. quadrinus																							6	6			11
A. evanidus		+				+				+			3				8										
A. sakuensis		6																									
A. aff. rombicus				40	4																						
A. borealis		5	12	16	27				16			3	1		3	+	1		7	17		+	+	+			4
A. reticulatus		+											1										+				1
A. cretaceus		+				+		+		+	+	1	2		1	+			3	+		+				+	(1)
A. striatus		1											1		+	+			6	8	1	1				2	
A. conatus nipponicus																							+	1	(1)+1		
A. sp. C																							4	2	6		
A. sp. D																								3			2
A. sp. E																							2				
A. sp. F		+																									
A. sp. G			2	+	5																						+
A. sp. H																							1		7		+
A. sp. indet.																	4						+		+		
Cranwellia rumseyensis																			5	8			2	6		2	9
Kurtzipites ezoensis									20										1	2			1	2+1?	2	9	44
Orbiculapollis cf. lucidus		3							28				3		2				1	+							
Ocellipollis munitus		3																									
O. obliquus																	+	4					5	8	4	+	31
Tricolpites striatus																							2	6	2		1
Wodehouseia spinata																											2
W. parvus																							3	2	12		8
Pollen type I											3?																
Sporomorph type 7																											6
Monoporate ? pollen																	2						1		4	3	1
Angiosperm gen. sp. indet.		1																									
Total	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

assemblage equivalent to the Upper Hakobuchi was reported from the Nemuro Group of eastern Hokkaido (Takahashi, 1965, 1970). The author investigated the assemblages from the Upper Hakobuchi subgroup in the Yubari and Hobetsu areas. These assemblages are almost identical in all essential characteristics with Upper Hakobuchi microflora. They have more numerous constituents represented by well-preserved specimens, and they clearly show the characteristic features of Maestrichtian pollen and spore floras.

Upper Hakobuchi microflora

The Upper Hakobuchi subgroup is composed of Lower sandy shale, Fukaushi sandstone, Fukaushi conglomerate, Upper sandy shale and Sanushupe sandstone formations. Five samples were collected: four from the Fukaushi sandstone formation at Yubari and Hobetsu, and the rest from the Upper sandy shale formation at Yubari.

The author identified 113 species of sporomorphs from the Upper Hakobuchi subgroup (Table 5). Of them, 26 (23 per cent) are pteridophytes, 24 (21 per cent) are gymnosperms and 63 (56 per cent) are angiosperms. We can recognize that these three taxa also show similar relationships in relative frequency, based on 200 counted grains in each sample. Angiosperms represent 54 to 88 per cent, gymnosperms 8 to 22 per cent and pteridophytes 5 to 25 per cent. Thus, angiosperms are the main components of the flora, and pteridophytes and gymnosperms are subordinate.

Pteridophytes are represented mainly by Polypodiaceous spores such as *Laevigatosporites* and Gleichniaceous spores. Among the gymnosperm, Ginkgoaceous pollen, Pinaceous bivesiculate pollen and Taxodiaceous inaperturate pollen are predominant. A few specimens of *Cycadopites, Araucariacites, Abietineaepollenites, Cedripites, Phyllocladidites, Classopollis, Rugubivesiculites, Equisetosporites* and *Gnetaceaepollenites* are found. Angiosperms are mainly represented by the tricolpate pollen, porate pollen and various pollen of uncertain taxomic position, such as *Aquilapollenites, Wodehouseia* and *Orbiculapollis*.

Porate pollen occupies 19 per cent of the total angiosperm species, but is more common in number of specimens. Among the porate type, Ulmaceous pollen is most abundant, and its sudden appearance with high frequency becomes a distinct marker of Upper Hakobuchi microflora. Juglandaceous pollen is encountered occasionally, while Betulaceae-Myricaceous pollen shows even distribution with low frequency through most of the samples. Tricolpate pollen with various complicated exine patterns occupies 27 per cent of the total.

Angiosperm pollen of uncertain taxonomic position occupies one third of total angiosperm species, and always constitute more than ten per cent of the

200 grains counted in each sample. *Aquilapollenites* includes 15 species, consisting of the *"Aquilapollenites"*, *"Integricorpus"*, *"Mancicorpus"* and *"Triprojectus"* types. *Wodehouseia* includes 2 species. It is noteworthy to include *Elytranthe*-like pollen such as *Cranwellia* cf. *rumseyensis* and *Tricolpites striatellus*. These two species are restricted to the Maestrichtian sediments of Siberia and western North America.

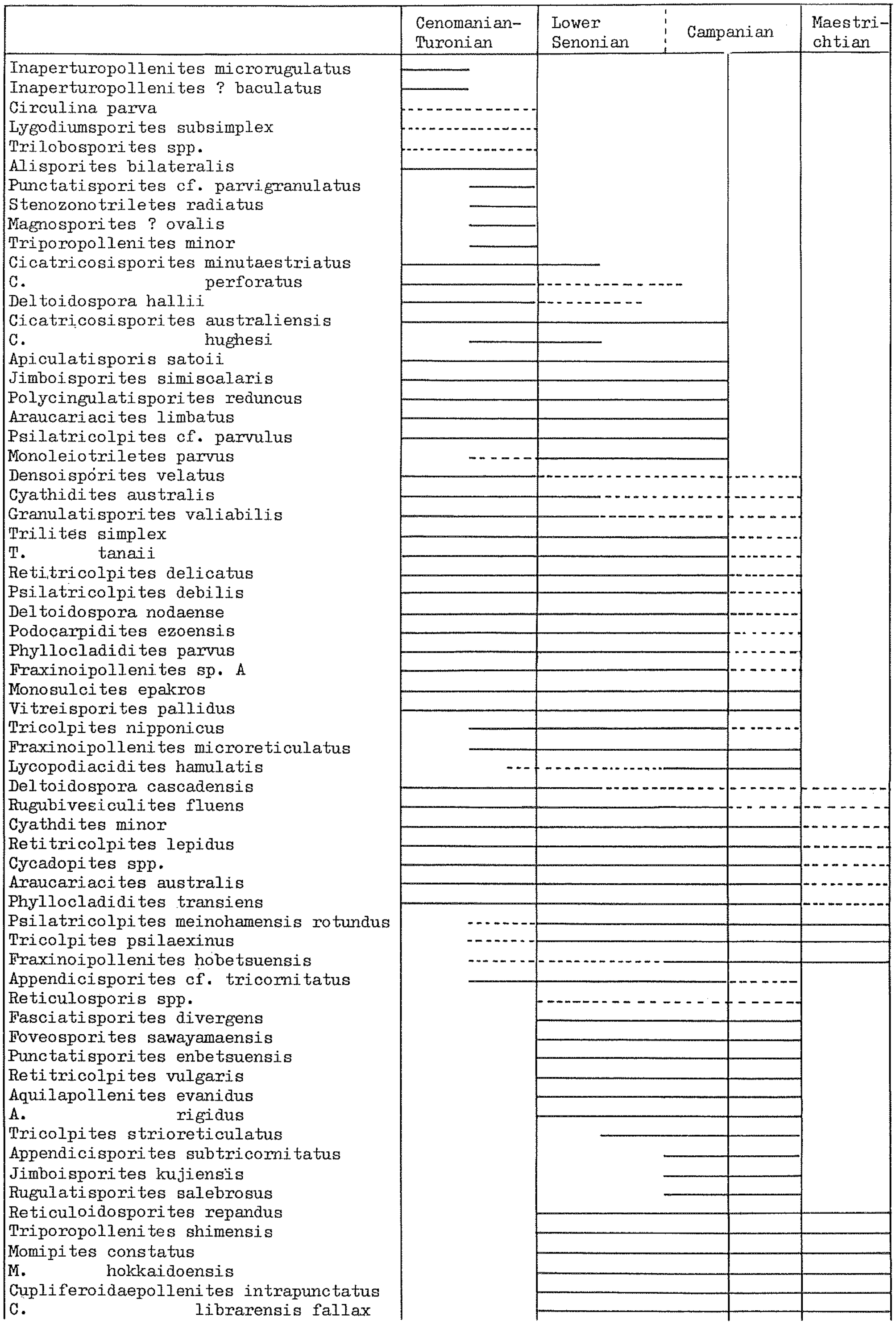
The pollen and spore flora from the Nemuro Group in eastern Hokkaido

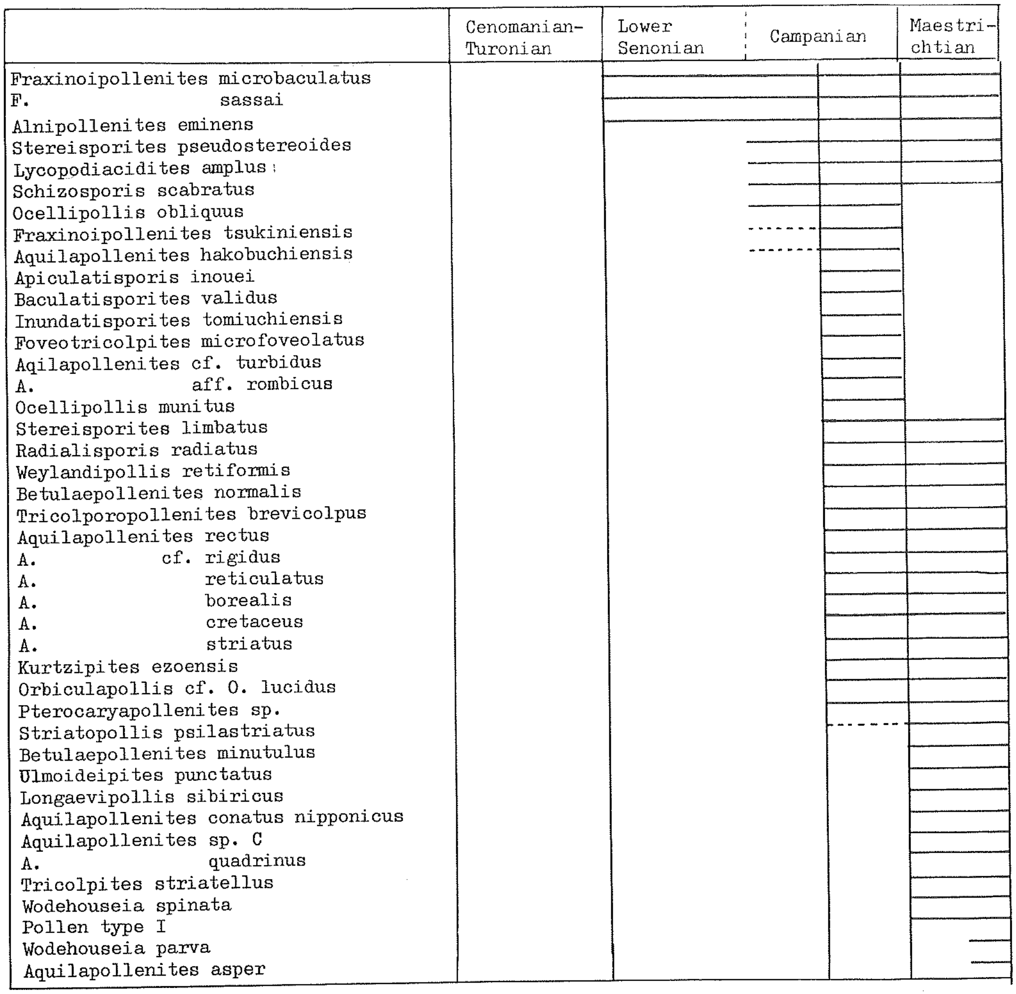
Takahashi (1965) reported a microflora from the bore-hole samples (Sk-1) of the latest Cretaceous sediments, the Nemuro Group, drilled in Nishibetsu, Bekkai-mura, eastern Hokkaido. According to Takahashi Nishibetsu microflora contains some common species with the Upper Hakobuchi; of them, *Betulaepollenites minutulus* has been restricted to the Upper Hakobuchi subgroup. There are several latest Cretaceous elements: *Cranwellia striata, C.* cf. *rumseyensis, Proteacidites thalmani*, which have been found only from the Maestrichtian and the Tertiary, and three species belonging to the *Aquilapollenites* group, *A. parvus, A.* cf. *mirabilis, Mancicorpus* sp. Takahashi suggested that the Nishibetsu microflora might be equivalent to the Upper Hakobuchi. The author fully agrees with him.

The characteristics of Maestrichtian pollen and spore flora are summarized as follows: 1) Angiosperms are main components of the flora, occupying the majority of the sporomorphs. 2) Among pteridophytes and gymnosperms Late Mesophytic elements are scarcely found. 3) The porate type is predominant among angiosperm pollen; it is represented largely by Ulmaceous pollen. 4) Japanese Maestrichtian microflora is characterized by the diverse pollen of uncertain taxonomic position such as *Aquilapollenites, Wodehouseia* and *Ocellipollis*. Among the *Aquilapollenites* group, *"Triprojectus"* type appears in this microflora first, while *"Fibulapollis"* type probably disappears before Maestrichtian time.

Late Cretaceous Pollen and Spore Floristic Sequences in Northern Japan

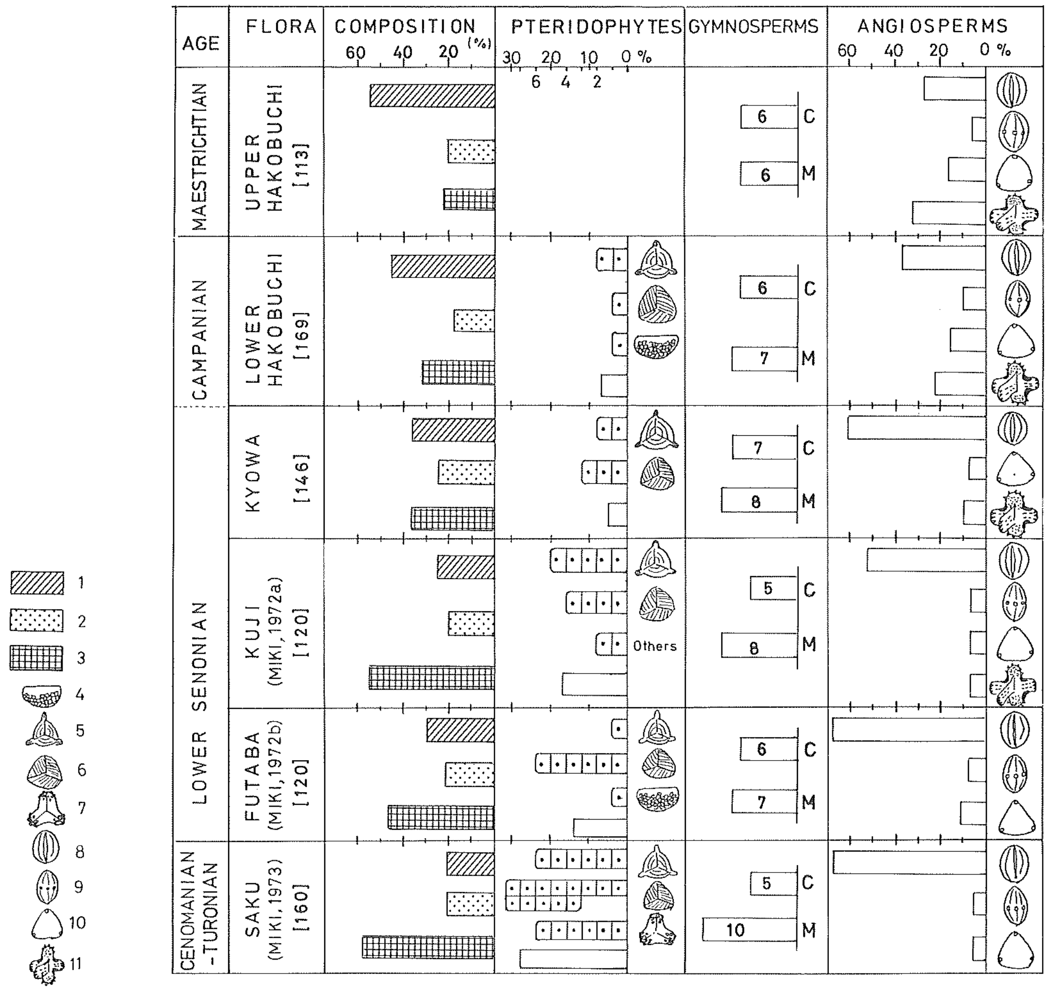
In the preceding chapter nine Late Cretaceous microfloras were discussed; they were grouped into four floras, based on their floristic composition and the vicissitudes of stratigraphically restricted sporomorphs (Text-fig. 9). These four represent the Cenomanian-Turonian, Early Senonian, Campanian and Maestrichtian floras respectively. The differences among the four in the composition were summarized in Text-fig. 10. Pteridophytes predominant in Cenomanian-Turonian flora were gradually replaced by angiosperms toward Campanian-Maestrichtian flora. Such compositional changes may represent the gradual development of early angiosperms during Late Cretaceous time. Such an evolutionary trend is clearly shown by the relative frequency of angiosperm


Cenomanian-Turonian
Lower Senonian
Campanian
Maestrichtian
Inaperturopollenites microrugulatus
Inaperturopollenites ? baculatus
Circulina parva
Lygodiumsporites subsimplex
Trilobosporites spp.
Alisporites bilateralis
Punctatisporites cf. parvigranulatus
Stenozonotriletes radiatus
Magnosporites ? ovalis
Triporopollenites minor
Cicatricosisporites minutaestriatus
C. perforatus
Deltoidospora hallii
Cicatricosisporites australiensis
C. hughesi
Apiculatisporis satoii
Jimboisporites simiscalaris
Polycingulatisporites reduncus
Araucariacites limbatus
Psilatricolpites cf. parvulus
Monoleiotriletes parvus
Densoisporites velatus
Cyathidites australis
Granulatisporites valiabilis
Trilites simplex
T. tanaii
Retitricolpites delicatus
Psilatricolpites debilis
Deltoidospora nodaense
Podocarpidites ezoensis
Phyllocladidites parvus
Fraxinoipollenites sp. A
Monosulcites epakros
Vitreisporites pallidus
Tricolpites nipponicus
Fraxinoipollenites microreticulatus
Lycopodiacidites hamulatis
Deltoidospora cascadensis
Rugubivesiculites fluens
Cyathdites minor
Retitricolpites lepidus
Cycadopites spp.
Araucariacites australis
Phyllocladidites transiens
Psilatricolpites meinohamensis rotundus
Tricolpites psilaexinus
Fraxinoipollenites hobetsuensis
Appendicisporites cf. tricornitatus
Reticulosporis spp.
Fasciatisporites divergens
Foveosporites sawayamaensis
Punctatisporites enbetsuensis
Retitricolpites vulgaris
Aquilapollenites evanidus
A. rigidus
Tricolpites strioreticulatus
Appendicisporites subtricornitatus
Jimboisporites kujiensis
Rugulatisporites salebrosus
Reticuloidosporites repandus
Triporopollenites shimensis
Momipites constatus
M. hokkaidoensis
Cupliferoidaepollenites intrapunctatus
C. librarensis fallax

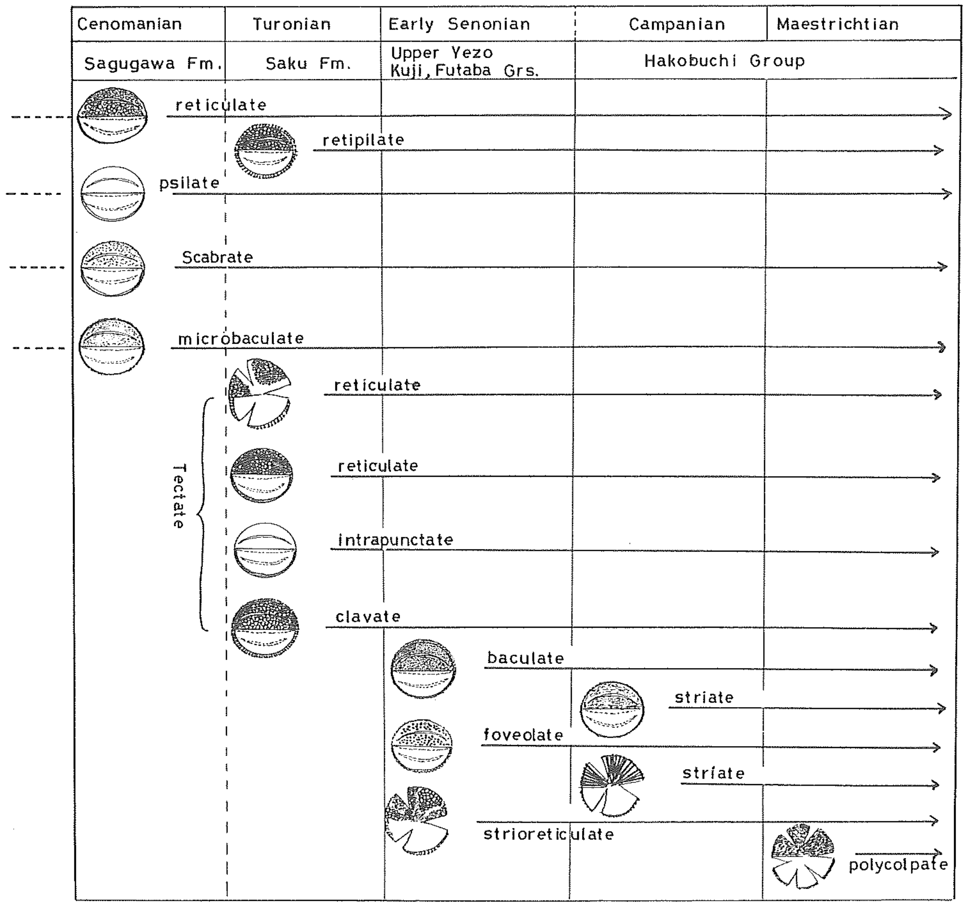


Text-figure 9 Time range of selected sporomorphs from the Late Cretaceous of northern Japan.

species against pteridophytes and gymnosperms: angiosperms increase from 21 per cent in the earliest flora to 56 per cent in the youngest. Furthermore, this development is accentuated by the morphological changes of pollen. Earlier angiosperm pollen are represented largely by the tricolpate type but a few are the porate type: these tricolpate pollen are mostly single-layered, non-or-simply sculptured but few are tectate in exine; triporate pollen provide a simple pore structure without a pore chamber. On the other hand, younger angiosperm pollen are mainly represented by both types: tricolpate pollen are commonly tectate and sometimes striate or foveolate in exine as shown in Text-fig. 11; the porate pollen have complex and or multi pore.



Text-figure 10 Outline of Late Cretaceous pollen and spore flora in northern Japan. In the second column, numbers in squre bracketes are the total numbers of.species constituting each flora. In the fourth column the ratio of Schizaeaceous spores to total numbers of spore species and the numbers of Schizaeaceous species in some genera are given. In the fifth column, the numbers of genera of Meso (M)- and Ceno (C)- phytic elements are given. In the sixth column the ratios of four pollen groups to the total numbers of angiosperm species are given. 1. Angiosperms. 2. Gymnosperms. 3. Bryophytes and Pteridophytes. 4. *Reticulosporis.* 5. *Appendicisporites.* 6. *cicatricosisporites.* 7. *Klukisporites* and *Trilobosporites.* 8. Tricolpate type pollen. 9. Tricolporate type pollen. 10. Porate type pollen. 11. *Aquilapollenites-Wodehouseia-Orbiculapollis-Ocellipollis-Kurztipites-Tricolpites striattellus* complex.



Text-figure 11 Morphological variation of tricolpate pollen and their first appearances in northern Japan.

Porate pollen are, in general, considered to be rather more advanced than tricolpate pollen. The porate type which appeared in the Turonian Saku formation rapidly increased both in taxonomic diversity and in total number of specimens during Campanian time, and became one of the representative angiosperm pollen during the Maestrichtian.

It is a conspicuous fact that angiosperm pollen of uncertain taxonomic position such as *Aquilapollenites, Wodehouseia* increased drastically in numbers of specimens and species during the Campanian and Maestrichtian, as is also found in Siberia and western North America. The *Aquilapollenites* group first appeared in the Coniacian age (the Kuji and Kyowa microfloras). The earlier pollen of this group is represented by the *"Aquilapollenites"* and *"Fibula-pollis"* types. The first appearance of the *"Integricorpus"* and *"Mancicorpus"* types was during late Campanian (the Lower Hakobuchi microflora). The *"Triprojectus"* type first appeared during Maestrichtian (Upper Hakobuchi microflora). *Ocellipollis, Orbiculapollis* and *Kurtzipites* appeared in Lower Hakobuchi microflora, and *Wodehouseia* appeared in the Maestrichtian time.

Pteridophyte spores and gymnosperm pollen gradually decreased in numbers of species and specimens. It is noteworthy that Mesophytic elements such as Schizaeaceous spores gradually diminished toward the Campanian. Schizaeaceae is known as one of the representatives of Late Mesophytic peteridophytes. Cenomanian-Turonian microfloras comprise a large number of Schizaeaceous spore species such as *Appendicisporites, Cicatricosisporites, Klukisporites* and *Trilobosporites*, but younger microfloras comprise only a small amount of them. Moreover, Schizaeaceous spores are almost completely absent in the Maestrichtian microflora. Among the gymnosperms, Cycadaceous pollen, such as *Cycadopites*, decreased in number of grains during the Maestrichtian age. Late Mesophytic coniferous pollen such as *Araucariacites, Podocarpidites, Phyllocladidites, Rugubivesiculites* and *Classopollis* gradually decreased and was replaced by Cenophytic. *Alisporites* and *Circulina* are encountered occasionally and only in the earliest microflora.

The plant world on land had dramatically changed its composition during Cretaceous time by the rapid development of angiosperms which first appeared approximately in earliest Cretaceous time and by the decline of pteridophytes and gymnosperms Floristic changes through four pollen and spore floras in northern Japan revealed that angiosperms developed step by step with increasing numbers and taxonomic diversity and that they became gradually superior to pteridophytes and gymnosperms. Such floristic changes confirmed by Cretaceous palynology in northern Japan are consistent with the evolutionary development of the Cretaceous plant kingdom on land in the Northern Hemisphere.

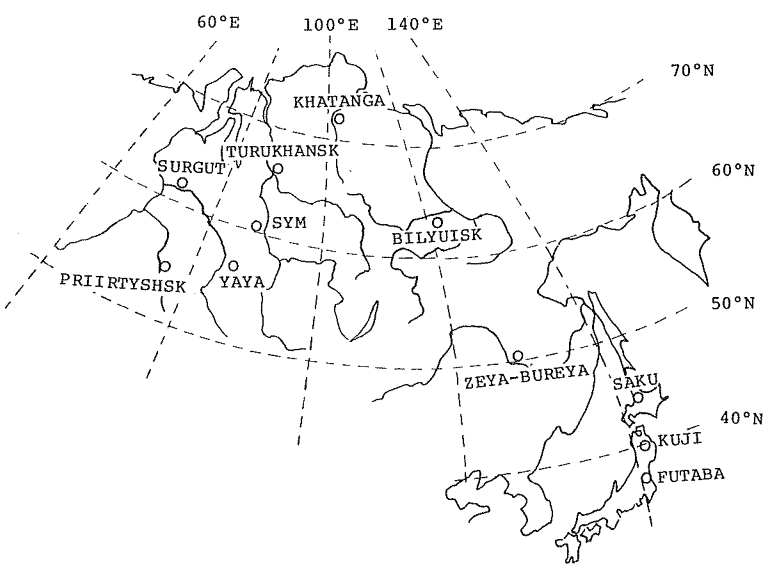
Comparison of Japanese Pollen and Spore Floras with those in Siberia

Comparing Late Cretaceous microfloristic sequences in Japan revealed in the preceding chapter with those of the East Asian continent is important for cretaceous phytogeography. Before proceeding to the comparison, the author would like to refer briefly to a few problems about regional or latitudianal differences in floristic composition during Cretaceous time.

Many paleobotanical contributions during the last twenty years suggest that some phytogeographical provinces or latitudinal differences in floristic composition might have existed during the Mesozoic Era (Markova, 1962; Zaklinskaya, 1962; Vakhrameev, 1964; Pokrovskaya, 1966; Samoilovich, 1967; Takahashi, 1970; Vakhrameev, et al., 1970). An inference that the two major phytogeographical provinces, the Siberian and the Indo-European, existed in Eurasia during Cretaceous time is well accepted by many investigators. A view that the Siberian province may have contained western North America is widely accepted. Samoilovich (1967), based on Palynological study, proposed that the Siberian province during the Late Senonian to Danian ages was divided into two regions, the northern Khatanga-Lena and the southern Enisey-Amur. It has been suggested by some authors (Bolkhovitina, 1959; Markova, 1962; Pokrovskaya, 1966) that the appearance of angiosperms was somewhat different in age in various areas of Siberia. On the whole, the appearance and radiation of angiosperms in northeastern Siberia took place at a latter stage than in southern Siberia. The author has successfully compared the Kuji, Futaba and Saku microfloras with Siberian microfloras by taking the phytogeography and the regional or latitudinal differences of the angiosperm development during Cretaceous time into account.

The Pollen and Spore Floras in the Zeya-Bureya Basin

Cretaceous terrestrial sediments are developed in the Zeya-Bureya basin in the Far East Soviet Union, which is included in Enisey-Amur floristic province. Chlonova (1969) and Bratzeva (1969) described Late Cretaceous pollen and spore floras of this region.



Text-figure 12 Index map of the locations of Late Cretaceous microfloras in northern Asia.

According to Bratzeva, who established the floristic sequences, the Cenomanian-Turonian pollen and spore flora have the following characteristics similar to Saku microflora: 1) Pteridophytes constitute approximately more than half of the total species. Schizaeaceous spores occupy about 40 per cent of the total pteridophyte species. 2) Angiosperms occupy nearly 10 per cent of the total: they are represented largely by the tricolpate type, and with a few of the porate type. Early Senonian pollen and spore flora are dominated by gymnosperms and pteridophytes, and are not common in angiosperms. Pinaceous and Taxodiaceous pollen are abundant among gymnosperms, and both tricolpate and *Aquilapollenites* pollen are abundant among angiosperms. *Aquilapollenites* is represented by the *"Aquilapollenites"* and *"Fibulapollis"* types. These floristic characteristics are closely similar to those of the Kyowa microfloras. Maestrichtian pollen and spore flora are similar to the Upper Hakobuchi microflora and are characterized by diverse and abundant angiosperms which occupy more than half of the total species. Angiosperm pollen are composed mainly of diversified *Proteacidites*, the porate type such as Ulmaceous and Betulaceae-Myricaceous pollen, and various pollen of taxonomically uncertain position. *Aquilapollenites* has 19 species. Pteridophytes rarely have Schizaeaceous spores, and gymnosperms include small amounts of Cycado-Ginkgoaceous pollen.

But, Late Cretaceous microfloras in Japan slightly differ from those of Zeya-Bureya: Japanese microfloras contain no *Cedrus*-like pollen and rarely contain Proteaceous pollen. However, *Cedrus*-like pollen are commonly found through Late Cretaceous time in Zeya-Bureya, while Proteaceous pollen are only found in Maestrichtian microflora.

It can be concluded that Late Cretaceous microfloristic changes in the Zeya-Bureya basin show no essential differences from that of northern Japan: the development of Cenophytic land plants progressed with similar features.

The Pollen and Spore Floras in the Bilyui Basin

From the Cretaceous terrestrial sediments in the Bilyui basin in the Central Yakut Lowland, Late Cretaceous pollen and spore floras have been reported by Bolkhovitina (1959) and Samoilovich (1964).

According to Bolkhovitina (1959), Cenomanian to Turonian pollen and spore flora is composed largely of pteridophytes and gymnosperms, and poor in angiosperms. Angiosperms constitute approximately 10 per cent of the total species, and have few porate types. Schizaeaceous spores constitute 20 per cent of the total spore species. Gymnosperms include Late Mesophytic coniferous pollen such as *Araucaria, Protopicea* and *Podocarpus*.

The Santonian pollen and spore flora is generally similar in floristic composition to those of the previous age, but contains somewhat more angiosperm pollen. Of angiosperms, the porate type increased, but *Aquilapollenites* pollen was absent. Though gymnosperms are dominated by Pinaceous pollen and Taxodiaceae-Cupressaceous pollen, *Araucaria, Psophosphera* and *Podozamites* spp. are present.

According to Samoilovich (1964) the pollen and spore flora from the Maestrichtian?-Danian is characterized by abundant angiosperms which are superior to the two other taxa, and diverse species of the *Aquilapollenites* group. The porate type represented largely by Myricaceous pollen is superior to the tricolpate type. Gymnosperms consist mainly of Pinaceous and Taxodiaceous pollen.

Comparing the Late Cretaceous pollen and spore floras in the Bilyui basin with those of Japan, Cenomanian-Turonian pollen and spore flora in the Bilyui basin resembles the Kuji and Futaba microfloras in general outline, though it is slightly lower in angiosperm representation. "Maestrichtian?-Danian" pollen and spore flora in Bilyui is more similar to the Danian-Paleocene pollen and spore flora of the Zeya-Bureya basin and the Paleocene pollen and spore flora of western North America than to the Upper Hakobuchi microflora for the following reasons: 1) it is lower in representation of angiosperms but much higher in gymnosperms than the Maestrichtian; 2) and it is abundant in Myricaceous pollen and lacking in Ulmaceous pollen. Floristic changes from Cenomanian to Santonian times in the Bilyui basin are generally similar to those of Japan, excepting a somewhat slower development of angiosperms.

To speak conclusively, Late Cretaceous floristic changes in northern Japan are very similar to those of eastern Siberia, especially to those of the Zeya-Bureya basin. Northern Japan appears to have belonged to the Enisey-Amur province including the Zeya-Bureya basin and to have been distinguished from the Khatanga-Lena province.

Conclusion

Late Cretaceous pollen and spore floras of northern Japan are divided into four according to floristic composition and components, as summarized in Text-fig. 10: they represent Cenomanian-Turonian, Early Senonian, Campanian and Maestrichtian floras respectively.

The characteristic feature in these floristic sequences is the fact that pteridophytes and gymnosperms forming major constituents during Cenomanian-Turonian time were gradually replaced by angiosperms toward Maestrichtian time. Such an evolutionary change is distinctly shown in the relative frequencies of the three major taxa during each age in northern Japan: Angiosperms constitute approximately 20 per cent of the total species in the Cenomanian-Turonian, 25–40 per cent in the early Senonian, 46 per cent in the Campanian, and 56 per cent in the Maestrichtian. The development of angiosperms did not occur abruptly during a short interval, but gradually progressed with the diversification of angiosperms themselves. The porate type is few in the Turonian, compared with the rather common tricolpate type, and gradually increased with diversity towards the Maestrichtian. The tricolpate type also diversified with complicated exine sculptures, as already show in Text-fig. 11.

The formation of the Cenophytic plant world was accelerated by the decline of pteridophytes and gymnosperms; gradulal changes of these two earlier major taxa are clearly shown by decreasing Schizaeaceous spores in pteridophytes and decreasing Mesophytic genera in gymnosperms.

Late Cretaceous floristic changes of northern Japan are very similar to those of Eastern Siberia, especially the Zeya-Bureya basin. The development toward the Cenophytic plant kingdom in East Asia progressed gradually during Late Cretaceous time.

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