Palaeenvironment of the Holocene Epoch in Japan

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Abstract

The palaeoenvironmental significance of the Holocene epoch in the Japanese Islands was made on the basis of the geomorphology, topography of the sea bottom, basal topography below the Postglacial deposits as buried valleys and buried river terraces, and stratigraphy and inferred sedimentary environment based on lithofacies and fossil assemblages. The Holocene deposits of the Japanese Islands were formed through the remarkable transgression during the last 10,000 years. The transgression is correlated with the late stage of the Flandrian Transgression, and separated by one minor regression, which may be correlated with the Younger Dryas-the Preboreal. The Postglacial deposits which have been sedimented during the last 18,000 years are divided chronostratigraphically into two members, the Upper and Lower members separated by the Middle sand layer (MS), and into five layers including the gravel layer (BG) on the Lowest buried valley floor. The Lower member, which is composed of brackish to marine deposits of complicated lithofacies (LS and LC), accumulated in narrow drowned valleys during the early stage of the Flandrian Transgression. The Middle sand layer is the foreset bed of deltas, which was formed during a slight regression between about 9,000 and 11,000 years ago. The Upper member, which consists mainly of widespread homogeneous marine clay (UC) and deltaic sand (US), was accumulated in a wide bay or lagoon and their embayments during the late stage of the Flandrian Transgression and the following stage with relatively stable sea-level.

On the basis of the palaeobotanical studies, the change of the palaeovegetation and palaeoclimate during the Holocene epoch is summarized as follows:

1) Cold stage: about 10,000 - 12,000 years B. P.; including the E, F, and G phases- the G phase is characterized by *Fagus-Abies-Pinus haploxylone*-type-*Larix*· the F phase by *Carpinus-Fagus-Alnus*; the E phase by *Fagus-Abies*.

2) Increasing warm stage: about 8,000-10,000 years B. P. ; corresponding to the D phase; the dominating pollen grains deciduous *Quercus (Lepidobalanus)-Fagus-Pinus-Alnus* climatically transitional stage from the Late Glacial to the Postglacial climatic optimum.

3) Postglacial warmest stage: about 4,000-8,000 years B. P. ; corresponding to the C phase and the Atlantic-the early Subboreal; characterized by evergreen *Quercus (Cyclobalanopsis)*-deciduous *Quercus (Lepidobalanus)-Alnus*; being about 2°-3° C higher than the present-day.

4) Cool stage: about 1,500-4,000 years B. P. ; corresponded to the B phase and to the stage of the minor falling of the sea-level; characterized by *Cryptomeria*-evergreen *Quercus (Cyclobalanopsis)*-deciduous *Quercus-Fagus-Pinus*; being about 2°C lower than the present-day.

5) Mild climatic stage: the last about 1,500 years.

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General remarks

The Holocene deposits of the Japanese Islands occupy an areal extent of some 46,500 km^2, which is about 15 % of the total land area, and are distributed mainly along the coastal area and in the lower reaches of rivers. That is, the Holocene deposits comprise fluvial, deltaic, and littoral deposits including such local deposits as coastal sand dunes, deposits of swamps, lakes and lagoons. These deposits form the depositional plains on which rice-cultivation has been conducted since about 2,000 years ago, and there are cities on the plains.

The most precise geological studies on the Holocene deposits have been on the coastal alluvial plains such as around Tokyo Bay, Nagoya Bay, and other coastal low lands, etc. These plains have now been investigated by drilling and other methods of prospecting for the purpose of developing modern industries, and of constructing highways, subways, etc. Especially, in Tokyo, after the great Kwanto Earthquake of 1923, more than 800 boreholes were drilled as part of a subsurface exploration programe for reconstruction of the metropolitan area (Otuka, 1934). The many subsurface geologic investigations have been undertaken to assist in the construction of highways, subways, etc., and to assess the land subsidence in the area. For the reason mentioned above, the latest Quaternary geology below the Holocene alluvial plains has been defined recently.

However, we cannot distinguish generally the Holocene deposits from the latest Pleistocene deposits in the Japanese Islands except for special areas in where an absolute year was dated. Therefore, in this article, the writer states firstly on the topography and stratigraphy of the Postglacial deposits including the Holocene deposits, and secondary on the Holocene-Pleistocene boundary and palaeoenvironmental change of the Holocene epoch.

The sedimentary facies of the Postglacial deposits in the Japanese Islands are usually controlled by the following factors:

(1) changes of sea-level,

(2) the physiographical and hydrological conditions in the drainage basins concerned, and

(3) the sedimentary environment of the deposits.

The Postglacial deposits are defined in this paper as comprising the latest Pleistocene to Holocene strata formed after the lowest stand of sea-level between about 18,000 and 20,000 years B. P. In the early Jomonian cultural age, when the Flandrian Transgression was as its maximal phase, about 8,000 to 5,000 years ago, the shore lines of the Japanese Islands were entirely of the Ria type. The form of the shore lines after the Flandrian Transgression was due to the kind of lithofacies constituting the shore lands.

The local thickness of the Postglacial deposits in coastal areas is closely related to the distance from the edge of the continental shelf off that area (Iseki, 1971). It attains some 50 to 100 m in the lower reaches of large rivers.

In the case of the Kaga-Echizen coastal areas of the Hokuriku district facing the Japan Sea, and of the northern coast of Tokyo Bay, the continental shelf edge are as far as 50 km, and 60 to 70 km from the present strand line respectively. The thickness is about 50 m at the mouth of the Sai River in Kanazawa, and about 90 m at the mouth of the Sagami River, southwest of Tokyo (Kaizuka *et al.*, 1977).

Most of the Postglacial deposits are composed predominantly of coarse-grained materials, which may have been caused by topographical features such as the steep gradient of rivers. For this reason, the littoral and deltaic deposits consist of coarse-grained materials. The broad alluvial plains in the Holocene consist mainly of the deltaic deposits of big rivers, which accumulated during the Jomonian cultural age, about 8,000 to 3,000 years ago. The former valleys were cut into the bed rocks throughout the Wurmian regression. The former valley system is buried under the present alluvial plains.

In this paper, the present writer summarizes the palaeoenvironment during the Holocene epoch in the Japanese Islands from the view of points of the geomorphology, stratigraphy, and the changes of sea-level, palaeovegetation, and palaeoclimate on the basis of palynological study.

Geomorphology

(1) *Topography of the surfaces*

The present outline of the Japanese Islands has resulted from earth movements since the late Pleistocene.

Four principal geomorphic surfaces of the Holocene can be recognized in the Islands. Inasmuch as there are distributed typically in the Kwanto district, especially around the Tokyo Bay, these have been called by names of the local surfaces in this district as the Shimosueyoshi, Musashino, and Tachikawa from older to younger. Each surface can be further subdivided. These surfaces form terraces and uplands.

The Shimosueyoshi surface was formed by a remarkable transgression at about 150,000 to 130, 000 years ago correlated with the Sangamon or Riss-Würm interglacial stage. This terrace is most extensively distributed 20 to 30 m high throughout the Islands.

The Musashino surface was formed at about 50,000 years ago in the middle Wurmian stage.

The Tachikawa surface, either on land or buried beneath the present alluvial plains in the Japanese Islands, is entirely composed of fluvial deposits. This surface was formed at about 30,000 to 15,000 years in the late-last Wurmian stage. Therefore, sea-level must have stood below the present sea-level during the Tachikawa period.

The Holocene alluvial plain was formed mainly since about 8, 000 years ago. The surfaces are composed mainly of the Upper Pleistocene deposits, underlain by the Upper Pliocene to lower Pleistocene deposits, and by the Middle to Upper Pleistocene one.

The deposits, surfaces and radiometric ages of these terraces and plains in and around Tokyo Bay have been geologically studied, and the dates were determined by radiocarbon measurements to 30,000 years ago, and by the fission-track method before that time.

Most of these surfaces are thickly covered with tephra layers in almost areas over the Japanese Islands except parts of areas facing the Japan Sea. Using these tephra layers as stratigraphic key bed, the chronostratigraphic succession of the surfaces as well as of certain buried terrace features below the Postglacial deposits has been established.

(2) *Basal topography below the Postglacial deposits*

The basal topography buried below the Postglacial deposits has been analysed in some coastal alluvial plains, with especially around Tokyo Bay, Nagoya Harbor, and Osaka Bay, etc. with reference to the following sources:

1: geologic descriptions of drilled wells and geologic observation of core samples from wells,

2: results of radiocarbon dating,

3: palaeoenvironmental investigation based on microfossils as pollen grains, foraminifers and diatoms, and molluscan fossils, and

4: pedological investigation.

The basal topography below the Postglacial deposits analysed by these sources is classified into a few geomorphic units as follows:

buried abrasion platforms,
buried valleys, and
buried river terraces.

(a) Buried abrasion platforms

These are subclassified into a lower abrasion platform (about - 20 to - 40 m high), and an upper abrasion platform.

The former platform is distributed at height between - 20 to - 40 m, typically in the northeastern part of Tokyo Bay, and separated into two subplatforms, -20 to -30 and to -40 m high (Kaizuka *et al*., 1977). The latter platform is distributed at height of 0 to -10 m and slopes seaward gently, and is separated into two subplatforms, 0 to - 5 m and - 5 to -10 m high (Matsuda, 1974).

(b) Buried valleys

The buried valleys have been found around Tokyo Bay, Nagoya Bay, Osaka Bay, and in Kanazawa alluvial plain, etc. According to Kaizuka *et al*. (1977), in Tokyo Bay, these pass into the present subserial valleys upstream, and the larger the subserial valley, the broader is the continuing buried valley and the gentler the gradient of the valley floor. The largest buried valley is in Tokyo Bay and is named the Tokyo Valley. It was made by the Palaeo-Tokyo River, and extends to a depth of about 70 m below the present sea-level. Some buried valleys are not distributed only in the southern area of Tokyo Bay, but also occur widely in the western area of the bay.

(c) Buried river terraces

Wherever the already mentioned buried valleys are distributed, the buried river terraces occur generally along the buried valleys. In Tokyo Bay, these terraces are composed of fluvial deposits as gravel and coarse-grained sand, which are covered mostly by the Tachikawa Loam layer. According to Matsuda's investigation (1974), these buried river terrace surfaces are separated into three levels. On the basis of the projected profiles along the buried ancient rivers such as the Palaeo-Tokyo River, and subaerial terraces, buried terraces and buried valley floors, assuming the extent of vertical earth movements in Tokyo Bay after the time of the Tcl surface has not been large, the sea-level in the time of the formation of the Tcl surface is inferred to have been about -40 m high.

The correlation between subaerial river terraces and the lowest sea-level in the Tachikawa period, perhaps in the late-last Wurmian glacial stage, has been examined in various districts of the Japanese Islands by geologists and morphologists. According to the results of their studies, it is concluded that the subaerial river terraces were the river terrace correlative with the sea-level, and the radiocarbon age of these terraces was estimated approximately as about 17,000 to 15,000 years ago (Machida *et al.*, 1971; Fuji, 1979). Therefore, it can be said that the age of the lowest stand of sea-level during the latest Pleistocene epoch may be between about 20,000 and 15,000 years ago.

The sequence of the above-mentioned buried landforms is, from older to younger, as follows:

the Upper buried terrace surface (Tcl),
the Lower buried terrace surface (Tc2),
the Buried valley floor (between Tc2 and Tc3),
the Lower buried abrasion platform (AbL), and
the Upper buried abrasion platform (AbU).

Sea-level in the Tcl age (ca. 30,000 years ago) is estimated to have stood at a height of about -40 m, and during Tc2 age (ca. 20,000 years ago) it fell still more; it attained its lowest stand (about -80～135 m) by Tc3 age (ca. 15,000 years ago).

(3) *Topography of the sea bottom*

The bottom of some bays in the Japanese Islands, where several deltas are situated, is generally shallower than -40 m, and a remarkable flat bottom extends from -10 to -40 m. Topset flats, foreset slopes, and bottomset flats of the deltas are well developed at depths of 0 to -5 m, -5 m to -10 m, and below -10 m respectively. The grain size of the deposits is generally related to the topography of bottom; that is, muddy deposits occur at depths deeper than -10 m, and sandy ones at depths less than -10 m. The bottom topography as in the southern part of Tokyo Bay is somewhat rugged, including a small bank which is thought to represent a submerged terrace of the late Pleistocene. In Tokyo Bay, submarine channels as the Kannon-zaki Submarine Channel are developed at depth of -40 to -90 m. According to Kaizuka *et al* (1977), this may represent a semiburied river valley, as already mentioned the Paleo-Tokyo River formed during the Tachikawa age (the latest Pleistocene). The channels usually terminate on the bottom deeper than -100 m in the Japanese Islands as reported by Shepard *et al.*, (1964). On the canyon in the Uraga Strait, submarine terraces are found at the edge of the continental shelf (-90 to -110 m), and are inferred to be one of the late Pleistocene abrasion platforms (Kaizuka, 1955; Kaizuka *et al.*, 1977).

(4) *Holocene terraces*

The Holocene terraces underlain by marine sediment and with an elevation of several to some dozen meters are sometimes recognized along the coastal lines of the Japanese Islands. As terrace surfaces of this kind were formed in the Jomonian cultural age, they are often called the Jomonian beach or the raised beach by the Japanese geologists and geomorphologists. Former strand lines indicated by these Holocene terraces vary in height at each locality, and the fact simply implies that local vertical fluctuation of terraces since the formation of the terraces has occurred in the Japanese Islands, and that its value may be generally several meters within the last about 6,000 years.

In the Hokuriku district facing the Japan Sea, there are coastal sand dunes, which are separated into three belts by the distribution and age of these formations. Judging from the results on the change of the sea-level and the formation of the coastal sand dunes, the present writer (Fuji, 1965; 1975) concluded that the relative lowering of sea-level is estimated to be about 6 m during the late half of the Holocene epoch, the last about 6,000 years, since the time of the highst Holocene sea-level.

The southern coastal areas of Shikoku and Kwanto districts are famous for localities of the best developed Holocene terraces and of remarkable upheaval. In the Numa area of the Kwanto district, the Holocene terrace is composed mainly of sediments with which coral-reefs and shells are found on the abrasion platform of the basement rocks. Among these coral-reefs, there are some species living in warm water conditions. An age of a fragment of the coral-reefs has been dated at 6, 160±120 ^{14}C years B. P. Most species of these shells do not live in the pressent sea around Numa area, but live in the southern sea of the Japanese Islands.

Judging from the above results, in the early Jomonian cultural age, about 6,000 years ago, the sea is presumed to have been warmer than at the present-day. This inference is supported by a palynological investigation of some sediments of similar age. This warm age is clearly correlated with the climatic optimum and occured within the Flandrian Transgression (Fuji, 1965).

Stratigraphy and sedimentary environment

There are the remarkable differences among various features of the Postglacial deposits occupying respectively the coastal, inland, and offshore areas.

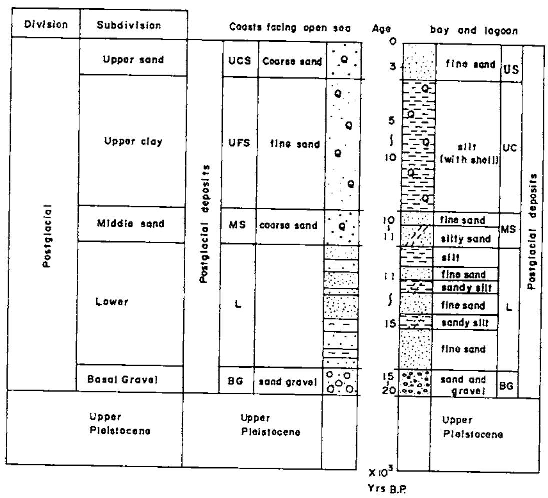
(1) *Coastal areas*

The Postglacial deposits of the coastal areas usually indicate a similar stratigraphic succession. A fluviatile gravel is recognized under the Postglacial deposits.

For discrimination of the Postglacial deposits from the basement rocks, colours, other lithological features of sediments, molluscan, diatom and pollen assemblages, and N-valus of the standard penetration resistance are useful. However, when the remarkable gravel layer is absent and the underlying formations are composed of the Pleistocent deposits, it is difficult to separate the Postglacial deposits from the Pleistocene deposits by examination of well drillings.

Two cycles of sedimentation, upper and lower can be distinguished throughout the geologic column of the Postglacial deposits in the coastal areas, and separated by a remarkable and continuous sandy intercalation at a height of -20 to -40 m. According to the results analysed in the Kwanto, Nagoya and Osaka districts, the stratigraphic succession in the coastal areas can be summarized as follows:

Table 1 Schematical chronostratigraphical division in the coasts facing open sea and in bay and lagoon areas of the Japanese Islands.



Upper member	(U):	alluvial deposits (UA) sand (US) clay (UC)	Holocene epoch
Middle member	(M):	sand (MS)	
Lower member	(L):	alternation of clay (LC) and sand (LS)	the latest Pleistocene epoch
Lowest member	(B):	basal gravel (BG)	

The Upper member (U) may be identical to the Holocene deposits, and the Lower member (L) fits closely the latest Pleistocene deposits.

(a) **Basal Gravel (BG)**

A gravel layer is distributed only on the buried valley floors of the ancient rivers such as the Palaeo-Tokyo River in the latest Wurmian glacial stage. The layer is absent from the floors of the ancient rivers in the same stage of the inland areas. This layer is less than 15 m thick, and the N-value of a standard penetration test more than 5.

(b) **Lower Clay (LC) and Lower Sand (LS)**

These layers are generally seen in the buried valley deeper than -20 to -30 m, and thought to represent fluvial or marine deposits filling in previous river valleys. The lithofacise of the Lower member (L) is variable, being locally composed of clayey sediments, and sometimes of clay with sandy intercalations.

Although marine shells are rare in these layers, humic layers resembling backswamp deposits occur at the basal horizon. The Lower member is locally overlain by the Middle sand or Upper clay layers unconformable and less than 30 m thick. The N-value is generally less than 20 in LC and less than 50 in LS. The unconfined compressive strength of LC is heavier than 12 t/m^2.

(c) **Middle Sand (MS)**

This bed is composed of well-sorted fine to silty sand and locally contains marine shells or humus. It is intercalated at -25 to -40 m in the geologic column, and directly covers the lower buried abrasion platform (AbL). It is thinner than 15 m thick, and the N-value is 15 to 30 in the sandy layers and 5 to 15 in the silty layers respectively. The Middle sand member is presumed to represent the foreset bed of former deltas (Kaizuka *et al*.. 1977) accumulated when there was a halt of sea-level in the process of the Flandrian Transgression. The age of this short stillstand of the sea-level might have been 10,000 years ago.

(d) **Upper Clay (UC)**

This layer is composed mainly of soft clay or silt with abundant marine shells, and less than about 40 m thick. The N-value is less than 5 in the sand-poor portions. Its unconfined compressive strength is 2.5 to 9.0 t/m^2. The Upper clay layer constitutes the bottomset bed in deltaic areas, and forms weak ground for construction wherever it is thick. In the big cities of Japan, especially Tokyo, Osaka and Niigata etc., this layer has been associated with remarkable land subsidence of more than 4 m at the maximum since the begining of the 20th-century and this phenomennon is due to the overextract-ion of underground water (Nakano *et al*., 1970).

(e) **Upper Sand (US)**

This layer is composed of well-sorted, medium-to fine-grained sand with abundant marine shells. The US constitutes the foreset bed of deltas, sand spits, offshore bars, beach ridges, and coastal sand dunes in coastal nondeltaic areas, covering the Upper buried abrasion platform (AbU) directly. The foreset bed might have accumulated with the advance of the deltaic front during the last 5,000 years since the sea-level roughly reached its present level. The layer is less than 15 m thick, sometimes 20 m, and the N-value is 5 to 40, and utilized generally as a supporting foundation bed.

(f) **Upper alluvial deposits (UA)**

This layer comprises the alluvial deposits that make up the surface of the present lowlands. The layer consists of humic clay, mud, and sand, being less than 3 m in thickness. The UA layer is regarded either as the topset bed of a delta or as a stream channel and inter-channel flood deposits. The present coastal plains have been built up during the last 6,000 years. The chronologic consideration on this process of desiccation of coastal plain has been made by mens of the shell mounds and remains of the Jomonian cultural age.

(2) *Inland areas*

The Postglacial deposits in the Japanese Islands comprise those that fill basins, valleys and lakes. They consist of clay, silt and gravel, and locally of peat layers. As the base levels of rivers have not been influenced by the eustatic changes in sea-level, unlike the mode of occurrence of the Postglacial deposits in the coastal areas as above-mentioned, they are inland peat, and not the deposits in the drowned valley. It is possible to determine the age of the deposits only by taking advantages of volcanic ashes or pre-historic remains belonging to either the Holocene or Pleistocene epoch. In the inland areas near coasts, the Postglacial deposits are represented mainly by the alluvial fan deposits.

(3) *Offshore areas*

The Postglacial deposits in the offshore areas of bays are composed mainly of soft, clayey sediments corresponded with the LC layer mentioned already and clay corresponing to the UC layer. However, in the areas, there are lack sand corresponded with the US layer.

Changes of sea-level

Radiometric dates of various horizons of the Postglacial deposits have been obtained from humus, erect stumps and shells of these deposits through ^{14}C dating. Based upon these dates, and already mentioned geologic and geomorphologic descriptions, an age-depth diagram and a curve for the sea-level changes are presented in Fig. 1. According to the diagram, the base of the Postglacial deposits is dated as old as or older than 15,000 years. Of course, all depths of samples used do not only indicate the ancient levels of shoreline or sea-level, but the general tendency in which the sea-level rose rapidly through the period from about 15,000 years B. P. to thousands of years ago is recognized. From the facts stated above, the regression which took place before the deposition of the Postglacial deposits is interpreted as ascribable to the eustatic drop of sea-level. The transgression after about 15,000 years ago corresponded with the Flandrian Transgression and is placed roughly at the time of the early Jomonian cultural age. According to the distribution and ages of remains such as shell mounds and of the coastal sand dunes of the Jomonian cultural age, the rise of sea-level caused by this transgression might have reached to the present sea-level or to a little higher (perhaps about 5 m high) than that of the present sea-level during the Jomonian age. The Postglacial deposits in the Japanese Islands are regarded as a stratigraphic unit or a unit of sediments for the purpose of engineering geology, and the opinion that the Pleistocene-Holocene boundary should be placed at the time of the lowest sea-level has been proposed (Iseki, 1971). On the other hand, that is another opinion that the period of rising of sea-level from 18,000 to 5,000 years B. P. should be called the Holocene epoch based on an eustatism, and the last 5,000 years should be called the Recent (Nasu *et al.*. 1962). The last 20,000 years since the beginning of the world-wide uprising of sea-level should be called the "Eustatic Holocene". For that reason, the Postglacial deposits in the Japanese Islands are a stratigraphic unit formed during the Eustatic Holocene.

Microfossils and the sedimentary environments

Microfossil analysis of the Postglacial deposits, especially the Upper sand layer (US) and Upper clay layer (UC), from the offshore and coastal areas has been carried out for pollen grains, foraminifera, diatoms and radiolarians. However, microfossils are very rare in the Lower clay and Lower sand layers. Among these microfossils, the diatom assemblages in the Upper clay and Upper sand layers are dominantly those of coastal water of strong embayment degree and littoral water, accompanied by many brackish and fresh water dwellers. Therefore, these assemblages indicate an environment as embayment. Most of the microfossil assemblages included in the Middle sand layer (MS) are generally marine. However, a fresh water assemblage of diatoms is contained sometimes in that layer. On the other hand, the diatom assemblages in the Lower clay and Lower sand layers consist mainly of the fresh water and brackish water once with a few marine species.

About 50 samples from 80-meter boring core drilled below Lagoon Kahoku-gata near Kanazawa, Central Japan were analyzed from the view point of a diatom assemblage. The samples cover the last 20,000 years.

Table 2 Subdivision of the Holocene epoch and comparison between the Northwestern Europe and Japanese Islands on the basis of the palynological investigations.

Geologic age		Northwestern Europe: Jessen 1938	Nilsson 1964	Königsson 1968	Fuji ·Könlg 1976	Japan: Hokkaido Nakamura	Tohoku Yamanaka	Hokuriku Fuji	Tokai Nakamura	Kyushu Hatanaka	Years B.P.
Holocene	Subatlantic	IX — *Fagus*	SA 2 SA 1	IX		*Quercus* *Abies*	*Pinvs* *Fagus* *Fagus* *Quercus* *Alnus*	A : *Pinus* *Lepido.* B : *Cryptomeria* *Lepido.* *Fagus*	*Pinus* *Cyclobala.* *Quercus*	*Pinus* *Cyclobala.* *Abies* *Tsuga*	1950 0 1000 1000 A.D 0 B.C 2000 1000 3000
	Sub-boreal	VIII *Quercus*	SB 2 SB 1	VIII		*Quercus* *Ulmus* *Juglans*		C : *Cyclobala.* *Alnus*	*Shiia* *Cyclobala.*	*Cyclobala.* *Podocarpus*	2000 4000 3000 5000
	Atlantic	VII *Quercus*	AT 2 AT 1	VII			*Quercus* *Fagus*	*Lepido.*	*Quercus*		4000 6000 5000 7000 6000 8000
	Boreal	VI *Corylus* V *Pinus*	BO 2 BO 1	VI V	8 〜 18	*Betula*		D : *Lepido.* *Pinus* *Fagus*	*Quercus*	*Pinus* *Ulmus*	7000 9000
	Preboreal	IV *Betula*	PB	IV	4 〜 7		*Betula*	E : *Fagus* *Abies*	*Fagus*	*Quercus*	8000 10000
Late Glacial	Yg. Dryas	III *Pinus*	DR III		1 〜 3	*Betula* *Abies* *Picea*	*Betula* *Abies* *Picea*	F : *Carpinus* *Fagus*	*Pinus* *Abies* *Tsuga* *Quercus*	*Pinus* *Picea* *Ulmus* *Fagus*	9000 11000
	Alleröd	II *Betula*	AL								
	Older Dry.	IC (*Pinus · Salix*)	DR II					G : *Fagus* *Abies* *Pinus hap.*			10000 12000
	Böllling	Ib (*Pinus · Salix*)	BÖ								11000 13000
	Oldest Dry	Ia (*Pinus · Salix*)	DR I								12000 14000

The restult of this investigation is as follows:

(1) The deposits during the past 20,000 years in and around the lagoon are chronostratigraphically divied into two groups as the pre-Postglacial and the Postglacial deposits. The Postglacial deposits are classified into the Basal gravel and sand layer, the Lower sand, silt, and peat alternation layer, the Middle sand layer, the Upper clay layer, and the Upper sand layer as shown in Table 1.

(2) Judging from the diatom assemblage, the deposits of the boring core are divided into six diatom zones as follows:

U-diatom zone: 79.25–68.50 m in the present depth; 21,000–18,000 years B. P.; dividing into three subzones.

U-τ subzone: 79.25–76.75 m; 21,000–20,000 years; marine diatom abundant. *U-β subzone:* 76.75–73.00m 20,000–19,000 years B. P. marine diatom very abundant. *U-α subzone*: 73.00 - 68.50 m; 19,000–18,000 years B. P. brackish water diatom very abundant.

V-diatom zone: 68.50-55.50m; 18,000-14,500 years B. P.; fresh water diatom very abundant.

W-diatom zone: 55.50-47.00m; 14,500-12,500 years B. P.; marine diatom very abundant.

X-diatom: 47, 00-37. 50 m; 12, 500-10, 000 years B. P.; fresh water diatom very abundant.

Y-diatom zone: 37.50-17.00m; 10,000-4,500 years B.P.; marine diatom very abundant.

Z-diatom zone: 17.00-0 m; the last 4,500 years; divided into two subzones. *Z-β subzone:* 17.00-4.50m; 4,500-1,200 years B. P.; fresh water diatom very abundant. *Z-α subzone*: 4.50-0 m; the last 1,200 years; marine diatom common.

As above-mentioned, it seems that the change of the kind of water character as marine, and fresh water condation, agrees with the change of the palaeoclimate.

Judging from the palynological investigation of the Holocene deposits distributed in some regions of the Japanese Islands, the change of the palaeovegetation and palaeoclimate during the Holocene epoch can be divided into several phases and summarized as follows:

(a) **Cold stages:** This stage includes the E, F, and G phases, and is dated between about 12,000 and about 9,000 years ago. The G phase is characterized by *Fagus, Abies, Pinus haploxylon*-type, and *Larix*; the F phase by *Carpinus, Fagus,* and *Alnus*; the E phase by *Fagus, Abies,* and *Larix*. The F phase may be correlated with the Alleröd oscillation of the Northwestern Europe.

(b) **Increasing warm stage**: This stage is the D phase in Table 1, and between about 9,000 years and 8,000 years ago. The stage means climatically transitional stage from the Late Glacial to the climatic optimum in the middle Holocene epoch. The dominating pollen grains are deciduous *Quercus (Lepidobalanus), Fagus, Pinus,* and *Alnus* with *Picea* as the subordinate associates.

(c) **Postglacial warmest stage**: This stage is the C phase, and between about 8, 000 years and 4, 000 years ago. The warmest stage corresponds to the Atlantic and the early Subboreal of Europe. The characteristic genera are evergreen *Quercus (Cyclobalanopsis),* deciduous *Quercus (Lepidobalanus),* and *Alnus,* reaching to the higher altitudes; namely, the forest zone was 200 to 300 m higher than the present-day, and the mean annual temperature was 2° or 3° C higher than that of the present-day. This stage is corresponded mostly to the last stage of the Flandrian Transgression.

(d) **Cool stage**: This stage is the B phase, and dated between about 4,000 years and 1,500 years ago. The characteristic species are the mixed flora of evergreen broad-leaved trees and *Fagus crenata* in Hokuriku region of Central Japan. It is about 1° to 2° C lower than the present-day in the mean annual temperature. The dominating pollen grains are *Cryptomeria,* evergreen *Quercus (Cyclobalanopsis),* deciduous *Quercus (Lepidobalanus), Fagus,* and *Pinus*. The decreasing warm stage may almost correspond to the stage of minor falling of the sea-level.

(e) **Present climatic stage**: This stage is the A phase, and dated the last 1, 500 years.

The comparison between the geochronological subdivisions of the Holocene epoch on the basis of the palynological investigation in Sweden and the Japanese Islands is shown in Table 2. Although the Late Glacial age of Sweden has been divided into five subages as the Oldest Dryas, Bölling, Older Dryas, Alleröd, and Younger Dryas, in the Japanese Islands the Late Glacial age has not been divided always in such detail. Although the beginning of the Holocene epoch in the Japanese Islands is generally correlated with that of the Northwestern Europe, this conclusion from the Japanese Islands is not always supported by radiocarbon datings. The early Holocene epoch is divided into the Preboreal and Boreal ages in the Northwestern

Europe. The early Holocene epoch in the Japanese Islands, however, has been divided into such detail except for a few regions.

Although the beginning of the warmest (Atlantic) age in the Japanese Islands has been corresponded to that of Sweden, the end of the warmest age does not correspond, and is inferred to be about 4,000 years ago rather than 5,000 years ago by the means of radiocarbon datings and archaeological remains, and the cool (Subboreal) age had followed until about 1,500 years ago.

As mentioned above, in the regard to the comparison of the climatic change and geochronological division during the Holocene epoch in the Japanese Islands and Sweden, there are two large differences; one is the difference of the beginning time of the Subboreal age, and another is the difference that the early Holecene epoch and the Late Glacial age are not divided in detail in the Japanese Islands as divided in Sweden.

The beginning of the Subboreal age in Sweden, about 5,000 years ago, is corresponded to the time of the highest sea-level in the Islands named the Jomonian Transgression correlated with the late stage of the Flandrian Transgression, in when the climate of the Japanese Islands was not so cool as in Sweden.

In regard to the detailed geochronological division of the early Holocene epoch, the Japanese Islands are located more south than the latitude of Sweden, and were not covered continental ice sheet. The mountains are higher and more complex, so the flora is diverse and the vegetation of some localities was not always definitely influenced by minor changes of climate during the early Holocene epoch and the Late Glacial age. This problem may be unsolvable before many more detailed pollen diagrams and numerous radiocarbon dates are completed throughout the Islands.

Pleistocene-Holocene boundary

For a recognition concerning the international boundary between the Pleistocene and Holocene epochs, two opinions have been approved recently in Japan.

An opinion advocated by the majority proposes that the beginning of the Holocene or Postglacial age should be placed at the time of climatic amelioration after the maximal phase of the Wurmian glacial age based on the pollen assemblages and glacial stratigraphy. According to this opinion, the boundary between the Pleistocene and Holocene epochs should be drawn about 10,000 years ago.

Another opinion concerning the eustatic theory proposes that the beginning of the Holocene should be placed at the maximal phase when sea-level dropped to the lowest. This opinion has been supported by researchers through their studies made in the coastal areas of the Mississippi delta. According to the latter opinion, the beginning of the Holocene is placed either at 25,000 years or at 18,000 years ago.

Efforts at settling these differences in the Japanese Islands have been made, especially to find fossil evidence concerning the boundary with in the process of climatic amelioration after the late glacial age. In Japan, inasmuch as glaciation is smaller in scale and its deposits are more restricted in distribution, only pollen stratigraphy is available for the purpose of steeling this dispute.

Accordingly, if we are to accept the former opinion of placing the boundary on the basis of the climatic change, we should adopt the proposed international Pleistocene-Holocene boundary with the date of about 10,000 years ago.

Judging from the Japanese archaeologists' investigations, the Japanese Pre-ceramic

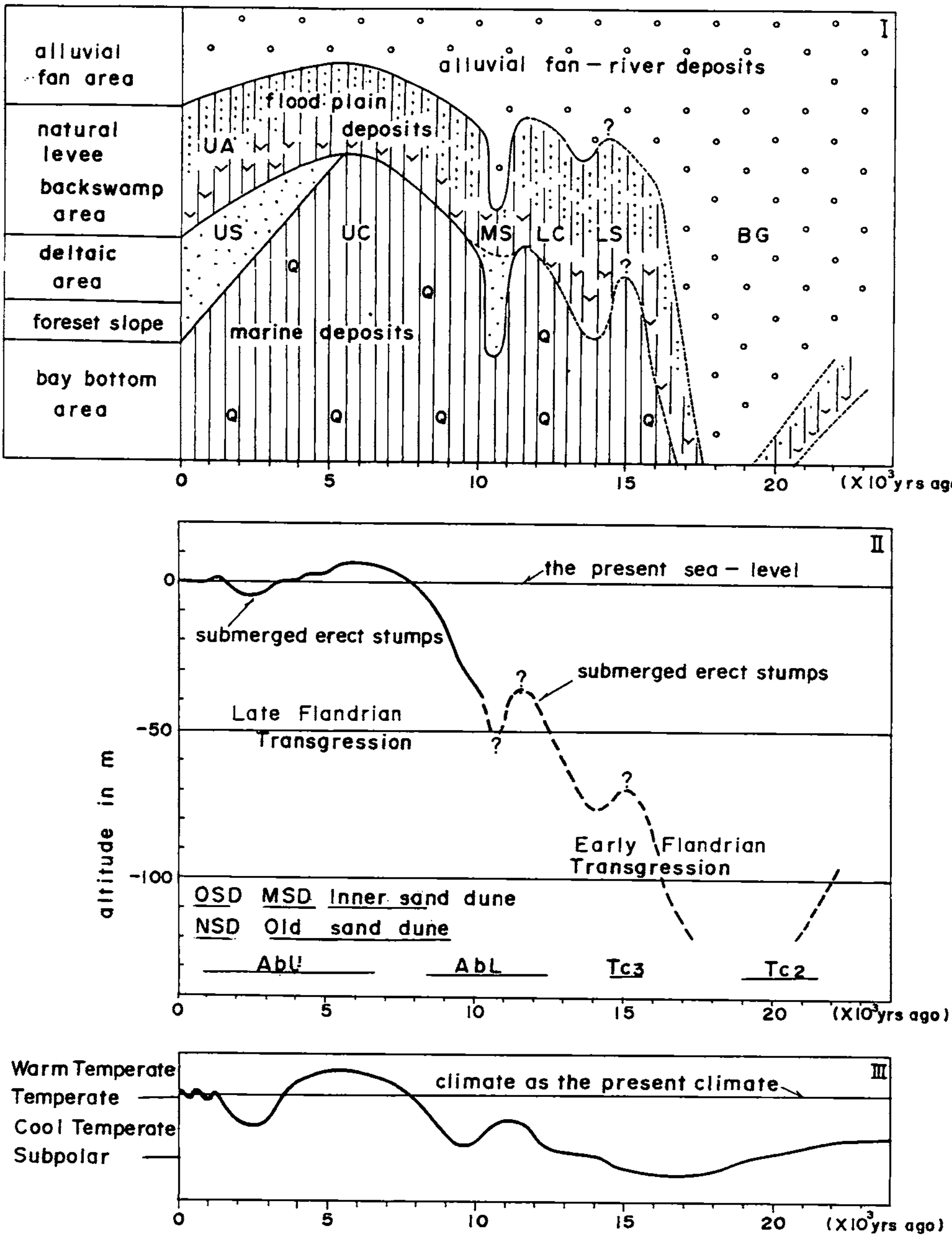


Figure 1 Schematical "depositional environment-time" diagram of the lithofacies of the Postglacial deposits (I), a depth-age"diagram of the dated Postglacial deposits with a probable sea-level change curve, estimated ages of buried landforms and dated coastal sand dunes (II), change of palaeoclimate based on pollen analysis since 24,000 years ago (III), In II, OSD : Outer sand dure, MSD: Middle sand dure, NSD: New sand dure, AbU: Upper buried abrasion platform, AbL: Lower buried abrasion platform, Tc3: the latest Tachikawa surface, Tc2: the lower buried terrace surface in Tachikawa age.

culture changed into the Ceramic culture at about 9,500 years ago. The remains of the Pre-ceramic and Ceramic ages are recognized in a sense as "index fossils" of the Quaternary period.

Apart from this view point, there is another view point namely that the Pleistocene-- - Holocene boundary should be fixed by the examination of the Postglacial deposits in the coastal areas of the Japanese Islands.

Sedimentary history

The age of the lower half of the Postglacial deposits is estimated to range from about 20,000 or 18,000 to 10,000 years B. P., while that of the upper half is younger than about 10,000 years B. P. The Middle sand member (MS) may belong to a period of slight drop in sea-level at some 10, 000 to 11, 000 years B. P. Based on the sea-level curve in Fig. 1and the known changes facies during the Postglacial deposits, a schematic time-space diagram for the sedimentary facies from bays, lagoons, and open sea areas of the Japanese Islands is shown in Fig. 1. As given in the figure, the lithologic boundaries in the Postglacial deposits often intersect obliquely with the time-plane and are diachronous; for example, since the Upper clay layer (UC) was also deposited outside the delta during the deposition of the Upper sand layer (US) (foreset sand), the latter represents a heterotopic facies of the upper part of the Upper clay layer in the offdelta area.

The following six stages are distinguished in the history of the late Pleistocene and Holocene.

(1) *Regression during the late Wurmian stage, ca. 30,000-20,000 years B. P.*

The Tc surfaces were formed during the relatively lowered sea-level in the latter half of the Wurmian glacial age. Judging from the longitudinal profile of the Tcl surface along the rivers, the sea-level then is thought to have been at about the -40 m horizon, so that in Tokyo the sea may have extended into the central prat of Tokyo Bay. The Tc2 surface was formed later at a time of further lowered sea-level.

(2) *The lowest stand of sea-level in the latest Wurmian stage, ca. 20,000-18,000 years B. P.*

Owing to the lowering of sea-level to as much as about 135 m below its present level around Tokyo the whole area to the north of the Uraga strait emerged above sea-level. For the lowering of sea-level at that time, there is another opinion. According to this opinion, the lowest sea-level is inferred have been about 80 m below the present level. The river system beneath the Postglacial deposits was formed. It emptied into the Tokyo Submarine Canyon through the Palaeo-Tokyo River. The depth of the valley floor of the Palaeo-Tokyo River extended to about -70 m in the north of Tokyo Bay and to the present -90 m (about -135 m at that time) at the head of the Tokyo Submarine Canyon. The gravel (the Basal gravel layer), the lowest bed of the Postglacial deposits, accumulated as river floor deposits of the Palaeo-Tokyo, Palaeo-Ara and Palaeo-Tama rivers.

(3) *Early Flandrian Transgression, ca. 18,000-11,000 years B. P.*

The ancient valleys and these tributary valles were dorwned to from long, narrow embayments as the sea-level rose. Continuoust built-up of birdfoot deltas would have ensued in the Tokyo Valley where the supply of clastics was plentiful. The Lower clay and Lower sand layers were sedimented at that time. The highest sea-level horizon reached by the transgression is inferred to have been between -20 and -30 m based on the height of the highest marine horizon of the Lower clay layer and the Lower sand layer. The climate at this stage is presumed to have been a condition as the Cool Temperate zone in the present-day. On land, plants adapted to the Cool Temperate zone and the southern part of the Subpolar zone grew luxuriantly. As shown in the depth-age diagram (Fig. 1), a slight lowering or oscillation of sea-level may have occurred at some 15,000 years B. P. in the course of the early Flandrian Transgression, usually called the early Yûrakucho Transgression, although this problem awaits further studies. The complex lithofacies structure of the Lower clay layer and the Lower sand layer probably arose in the unstable environment of bridfoot deltas and of the oscillating sea-level in the long and narrow embayments.

(4) *Slight regression, ca. 11,000 - 10,000 years B. P.*

The sed-level fell to about -40 m, as known from the depth of the base of the Middle sand layer, leading to partial fluvial and marine erosion of the Lower member (L) of the Postglacial deposits and formation of the Lower member abrasion platform, though the formation of the abrasion platform (AbL) may extend over a long time before and after the lowest stand of sea-level at 11,000-10,000 years B. P. as illustrated in Fig. 1.

This abrasion platform was then overlain by a sand veneer (the Middle sand layer) with recession of the sea cliffs, while the foreset bed (the Middle sand layer) was formed in the deltaic areas in the Japanese Islands. The submergied forests, which had grown on the ancient submergied deltaic area below the present sea-level, have been about -40 m high in the present Toyama Bay.

(5) *Late Flandrian Transgression, ca. 10,000 -5,000 years B. P.*

A rising of the sea-level began rapidly again with widespread marine invasion of the present inland areas along the former valleys (the Yûrakucho Transgression; Matsuda, 1974).

The broad features in the present coastal areas as Tokyo Bay, Nagoya Bay, and Ariake Bay were thus established and marine clay (the Upper clay layer) began to be deposited. Along the coastal areas facing the open sea of the Japan Sea, coastal sand dunes were formed just before and just times of the highest level of about 6,000 years B. P.), and of the slightly high one (5 000 years B. P.) of the late Flandrian Transgression respectively. The dunes are generally called the Inner sand dure.

(6) *Relativery stable sea-level with slight fluctuation, the last 5, 000 years.*

So far as is known in the northern area of Tokyo Bay, where earth movement may have been small since the times of the Shimosueyoshi age correlated with the Riss-Würm interglacial age, the sea-level slowly assumed its present level after attainment of a level at a height of about +5m. Based on the date from the Holocene deposits in several districts, there was a slight fluctuation of sea-level during the last 5,000 years. A slight lowering (about -2m high) of sea-level had been about 2,000-4,000 years ago (Fuji, 1965), and a slight rising of sea-level (the Yayoian Transgression) occurred about 2,000 -1,500 years ago (Fuji, 1965; Iseki, 1964). At this stage, the sea cliffs bordering the Pleistocene uplands retreated through wave erosion leaving wide abrasion platforms (AbU) at their foot. The larger bays such as Osaka, Ariake, Nagoya and Tokyo Bays expanded on the one hand, on the other hand, deltas continued to advance into it as arcuate forms and sand bars formed, closing the mouth of small inlets. Thus the Upper clay layer and the Upper buried abrasion platform (AbU) were both covered with widespread sandy material (the Upper sand layer). During this time, rivers deposited the alluvial deposits (the UA layer) which now extensively cover these deltaic sand areas.

Along the coastal areas of the Japan Sea, at of about 4,000 years ago, a slight rising of the sea-level upto the present sea-level (about 2,000 to 1,500 years ago) occurred, and coastal sand dunes were formed. The older dune is named the Middle sand dunes, and another the Outer sand dune respectively.

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