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771. PALYNOLOGICAL STUDY OF 200-METER CORE SAMPLES FROM LAKE BIWA, CENTRAL JAPAN I: THE PALAEOVEGETATIONAL AND PALAEOCLIMATIC CHANGES DURING THE LAST 600,000 YEARS*

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Abstract. The samples of a 200-meter core obtained from the present bottom in Lake Biwa, Central Japan for the investigations of the palaeoclimatic and palaeovegetational changes in and around the lake during the last 600,000 years can be divided into 19 pollen zones from the view point of palynology. The palaeoclimatic change and the ages of glacial and interglacial stages display similarity to the palaeotemperature curve by oxygen isotope ratio determination from the Caribbean Sea. During the glacial stages or stadials, the typical vegetation thriving today in the Subpolar or Subalpine zone of Japan prevailed at the summit area and/or the montane area around Lake Biwa, and in the lowland around the lake, plants growing today in the Cool Temperate zone were distributed. In the interglacials and interstadials, the palaeovegetation in the higher area was characterized mainly by plants of the Cool Temperate zone and the present Temperate zone, and in the lowland, the palaeovegetation was composed mainly of broadleaved deciduous and evergreen trees growing in the Warm Temperate zone.

Introduction

The existence and character of several Quaternary glaciations are documented by the glacial geology, topography, palaeoclimatology, and palaeopedology in many countries. In Europe, during the cold part of the last glacial age (Dreimanis *et al.*, 1972), some 15,000 to 20,000 years before the present, an inland ice sheet covered the nothern part of the continent, and both mountain and piedmont glaciers covered the Alps. Almost the whole area between the southern border of the inland ice and the Alps was poor of forest; it was covered only with tundra or cold steppe vegetation.

In the Japanese Islands, however, crustal movements, volcanic activity, weathering, and erosion have dominated during this period. The Islands were not affected by an ice sheet or piedmont glaciers; there were only some small glaciers in a few high mountain areas such as the Japan Alps and Hidaka Mountain Chain. It therefore is difficult to depend on glacial geology and topography or palaeopedology to study the history of glaciation in this area. The detailed chronology of stadials and interstadials during the last glacial age is complex. So are correlations with earlier glaciations in

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Europe and North America. Therefore, if we do not want to lose ourselves in a terminology based on inaccurate correlations, it seems necessary to establish a stratigraphic nomenclature which is not primarily based on meager and inaccurate evidences in mountainous regions, but rather on sedimentary sequences in basins outside the glaciated regions. Extensive deposits from glacial and interglacial times can be studied in deep bore holes. Pollen analysis of the stratigraphic sequences in minute details during the last two million years can reveal a continuous record of the change of vegetation and climate in the non-glaciated area.

With this objective in mind, a project was proposed to study 200-m core sediments from Lake Biwa obtained in 1971 (Horie *et al.*, 1974). As a member of a research team the writer has been engaged in an intensive investigation of the palaeolimnological evidence of the subsurface deposits of the lake.

In this paper, a palynological record of the continuous 200-m core sediments, spanning the last about 600,000 years from Lake Biwa is presented, along with the vegetational and climatic interpretations of this record. A more detailed record from the core and the interpretation will be presented in the near future.

Acknowledgments

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Significance of research on deposits from Lake Biwa

Palaeomagnetic stratigraphy has provided a means of correlating continents and oceans over the world. With the advent of deep-sea research by DV Glomar Challenger and other oceanographic vessels, oceanographers and geologists have verified the probable existence of continental drift through work conducted on an international scale and thus established a new field of plate tectonics and neotectonics.

Recent studies of sediments in deep-sea cores (Hays *et al.*, 1969) and of loess deposits from central Europe (Kukla, 1970) indicate successive changes of palaeoclimate during the Quaternary period.

Our understanding of climatic change during the Quaternary period are based primarily on research on terrestrial and submarine deposits. However, the Quaternary system exposed on land is frequently represented by coarse-grained materials such as sand and gravel. This is true of Pleistocene deposits from the Japanese Islands but also in deposits from Europe. The pollen record, unfortunately, is not continuous in northern Europe, because, especially in the late and middle Pleistocene, deposits suitable for pollen preservation, like peat and clay, were principally formed during the interglacials and interstadials. Deposits from glacial times are not preserved even in areas located between the ice sheets. Coarse-grained materials such as sand and gravel are not suitable for pollen analysis. Furthermore, if the change of sea level is explained by glacial-eustatic theory, sea level should have been lower during the cold glacial and stadial times. Therefore, it is difficult to collect continuous samples in the Quaternary period, which is characterized by an alternation of warm and cold climatic times.

On the other hand, although sediments of both the cold and warm periods are complete in the deep-sea cores, we cannot evaluate changes in climate over short periods because of the extremely slow sedimentation rate.

On the basis of the above-mentioned considerations, the following conditions have to be satisfied if climatic changes can be investigated by means of palynological, geochemical and palaeomagnetic analyses:

a: the rate of sedimentation must be large,
b: the sediments must be entirely *fine-grained materials*, such as silt, clay, or gyttja, and
c: the sediments must be *continuous* since the early Pleistocene.

According to a few glacial-geological field works (Minato, 1972; Kobayashi, 1958; and Horie, 1961 etc.), several expansions of glaciers probably occurred in the Japanese Islands during the Wisconsin glacial age, those fluctuations being closely similar to the oscillation of the ice sheets in both Europe and North America. Late-Pleistocene climatic changes were probably synchronous throughout the Northern Hemisphere. In unglaciated areas, the bottom sediments of ancient lakes may cover the whole Pleistocene. Lake Biwa in Central Japan is such a lake (Horie, 1961 & 1962). The exact thickness of bottom deposits in the center of the lake is not known yet, but geological evidence indicates that the lake was formed in the latest Pliocene or earliest Pleistocene and has been in existence continuously. Furthermore, Lake Biwa is the third oldest lake in the world, after Lake Baikal and the Caspian and Aral Seas.

In addition, Lake Biwa is important for the following reasons:

a) A strikingly negative gravity anomaly exists in the northern part of Lake Biwa, amounting to −55 milligal. Isoanomaly lines almost coincide with the outline of coastal line of this lake (Tsuboi *et al.*, 1954; Abe *et al.*, 1974). Such gravity anomaly suggests us the existence of extremely thick (ca. 1,000 m class) lacustrine sediments.

b) A great number of endemic species of animals and plants is known in the lake. They differ markably from the biota of other parts of Japan.

c) Judging from the previous geological studies (Ikebe, 1933; Takaya, 1963; Hayashi, 1974), the Pliocene-Pleistocene and Pleistocene-Holocene boundaries exist in lake sediments that are preserved as the lacustrine terraces. This fact affords us the evidence of an ancient Lake Biwa that appeared in sometime during the Neogene.

A deep boring in such a lake having an extremely long limnetic history must yield valuable samples for palynological research. These samples contain a continuous record of the change in climate since the latest Pliocene or earliest Pleistocene. These results may be correlated with changes in climate during the Quarternary period already worked out in North America (Dreimanis *et al.*, 1972) and Europe. From those viewpoints it may be said that the long core is significant for the promotion of our knowledge in the Quaternary geology not only in the Japanese Islands but also in the other countries of the globe.

Topography

Lake Biwa, the largest lake in the Japanese Islands, is located northeast of Kyoto, Central Japan (approximately 35°13′10″ N. Lat. and 136°1′28″ E. Long.). As shown in the topographic map (Text-fig. 1), a lowland around Lake Biwa is named the Omi Basin. Wakasa and Ise Bays are located respectively in the northwest and southeast of the basin. The lake is situated just on the isthmus that seems to be the distorted portion of two arcs comprising Honshu Island.

The Nosaka Mountains (500—1,000 m) occur on the border between Fukui and Shiga prefectures of the north of this basin, the Ibuki

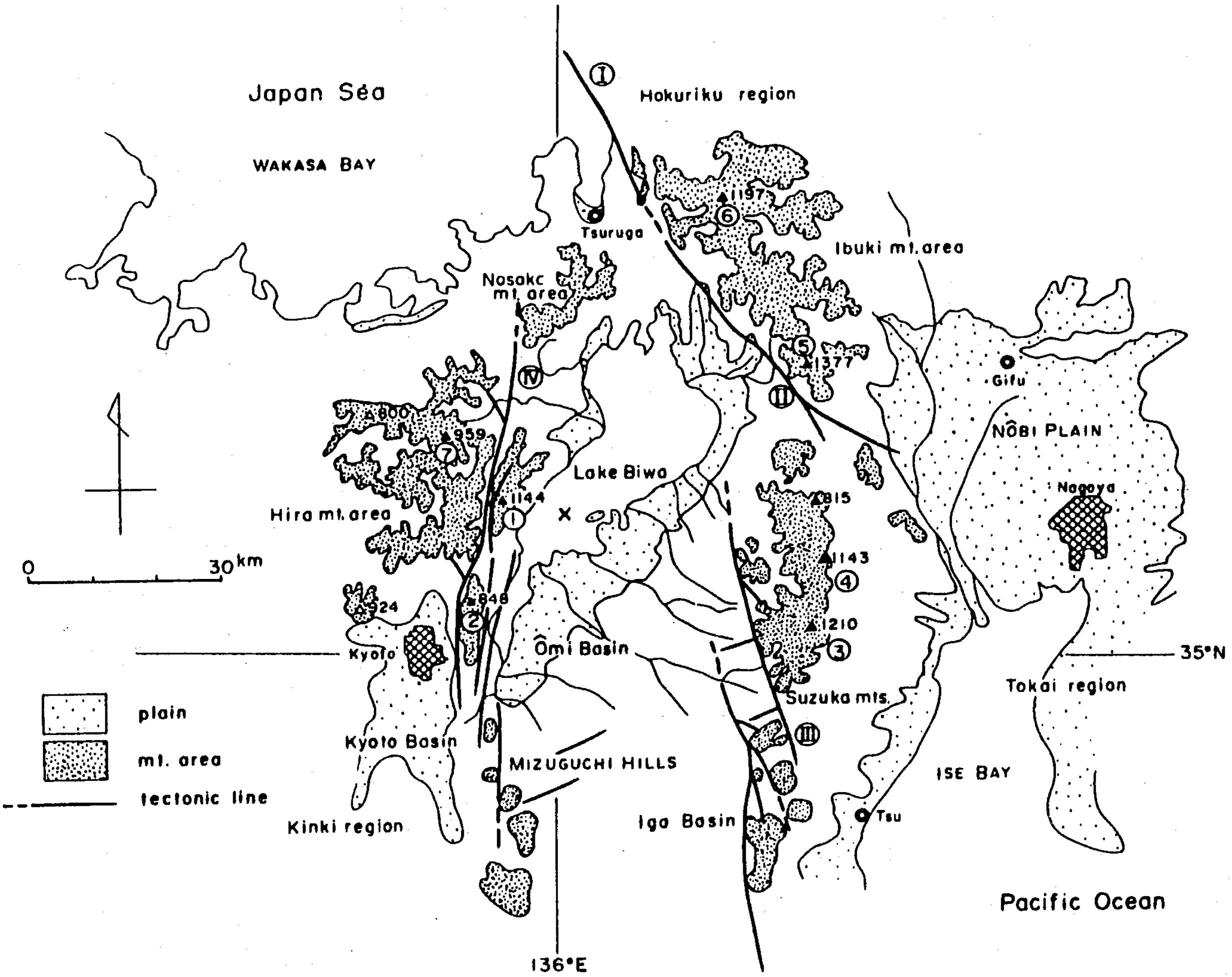
Mountains (500—1,300 m) on the border between Gifu and Shiga prefectures, the Suzuka Mountains (500—1,200 m) on the prefectural borders between Shiga and Mie or Gifu prefectures of the east of the basin, and Hira Mountains (500—1,200 m) and Mizuguchi Hills to the west and south of the lake.

Although the distance between the abovementioned mountain areas and the lake is very short (5—20 km), the difference of height between mountain and the lake is large (500—1,200 m). Rivers flowing into the lake, therefore, generally are fast.

An important topographical character around the lake is an existence of graben structure. In both the eastern and western sides of the lake, there are active faults with north-south trend (the Suzuka trend of Huzita, 1962).

Climate

Most of the Omi region under discussion is the central part of the Temperate zone, and the weather is controlled mainly by topography characterized by the large lake and the north-trending mountains. In general, the weather of the northern half corresponds to that of the Hokuriku region, while the southern part to that of the Kinki region. At Otsu the mean annual temperature is about 14°C.



Text-fig. 1. Topographic map of the Lake Biwa area, Central Japan.
1: Mt. Hira, 2: Mt. Hiei, 3: Mt. Gozaisho, 4: Mt. Fujihara-dake, 5: Mt. Ibuki, 6: Mt. Mikuni-ga-dake, 7: Mt. Mikuni-dake, I: Kaburaki tectonic line, II: Yanagase tectonic line, III: Suzuka tectonic line, IV: Hira tectonic line, x: boring locality.

The weather system in summer is more or less controlled by the Bonin high atmospheric pressure. The mean July temperature of the area increases to about 24°C, and the precipitation decrease to about 150 mm. In spite of little precipitation the Omi basin is relatively humid because of higher evaporation rate from the large lake in its center. During this season a southerly wind prevails.

During the winter the weather is dominated by the Siberian high pressure. The average January temperature is about 2°C, and the precipitation in the same month is about 300 mm. Strong humid northwesterly or westerly winds prevail in the area, and snowfall is abundant in the northern part and mountainous areas.

Frost occurs first in early November. There are 200 non-frost days and 1,900 hours of sunshine per year. The basin is hidden in a mist for about 60 days as the result of much evaporation from the lake.

Vegetation

The vegetation around the lake is complicated, and due partly to the above climatic condition, and partly to the fact that the lake located near Kyoto, which was a capital of Japan for about 1,100 years, for a long time man has exacted a heavy toll on the natural vegetation by clearing forests for farming, by lumbering for ship-building, by cutting wood for charcoal, and by using timber for domestic purposes. The reconstruction of the vegtation around the lake, as in many other areas in the Japanese Islands and in other countries, poses serious difficulties. The original vegetation has been destroyed throughout the surroundings of Lake Biwa.

The vegetation around the lake belongs to the flora of the central part of the Temperate zone and is located near the northern limit of *Citrus* (orange) in the Japanese Islands. The vegetation is divided into two types, namely *Querco-Fagetea crenatae* and *Camellietea japonicae* types (Kobayashi *et al.*, 1974).

1) *Querco-Fagetea crenatae* region

The *Querco-Fagetea crenatae* region occurs around Mt. Hira and in the Ibuki and Suzuka Mountains. The flora of this type is found in areas higher than about 300 m above the sea level in the northern part and higher than 700 m in the southern part of this region.

In the neighborhood of the lake, this type is divided into eight natural communities. They are: *Lindero umbellatae-Fagetum crenatae*, *Querco-Clethretum barbinervis*, *Scrophulario-Aceretum shirasawae*, *Rumohreto-Eupteletum polyandrae*, *Zelkova serrata*, *Enkianthus cernuus forma rubens*, *Fagus crenata-Cryptomeria japonica* and *Hosta montana* communities. Among them, *Lindero umbellatae-Fagetum crenatae* is distributed at about 800 m in the Ibuki Mountains, and *Zelkova serrata* community occurs along a valley, with *Quercus acutissimo serratae* belonging to *Camellietea japonicae* region in the northern part of this region. *Fagus crenata-Cryptomeria japonica* community occurs around the summit area of Mt. Hira. The distribution of the other communities and assemblages is confined to local area in the region. Although *Cryptomeria japonica* does not mix with *Fagus crenata*, the former mixes with *Quercus cripula* or *Castanea crenata*. The *Lindero umbellatae-Fagetum crenatae* is scattered in the *Cryptomeria japonica* forest. *Abies firma-Illicium regiosum* community occurs on a very small scale together with *Larix leptolepis* about 750 m high on Mt. Hiei.

A substitutional vegetation of the *Querco-Fagetea crenatae* region is divided into *Fagus crenata-Quercus mongolica* var. *grosseserrata* community, *Castaneto-Quercetum crispulae*, *Cryptomeria japonica-Chamaecyparis obtusa* plantation, *Sasa* and *Miscanthus sinensis* communities in the Omi region. The *Fagus crenata-Quercus mongolica* var. *grosseserrata* community is substitutional vegetation of *Fagus crenata* forest. Around 700—800 m high in the Nosaka, Hira, Ibuki and Suzuka Mountains, the *Quercus crispula*, *Fagus japonica*, *Acer japonicum*, and *A. rufinerve* are distributed as high trees, *Parabezoin trilobum* of the above-mentioned community grows remarkably as scrub or small tree. *Castaneto-Quercetum cripulae* is distributed wide between *Fagus crenata-Quercus mongolica* var. *grosseserrata* community area and *Quercetum acutissima-serratae* area belonging to *Camellietea japonicae* region. A distributional lower limit of the *Castaneto-Quercetum crispulae* is distributed about 600 m above the sea level at the southern part of this region, and about 300 m at the northern part. *Sasa* or *Miscanthus sinensis* community scatters at the summit areas and ridges reaching to 1,000 m or more in altitude.

2) *Camellietea japonicae* region

The *Camellietea japonicae* region covers a wide area in the Omi basin. However, natural vegetation belonging to this type occupies very small areas. In this region, the natural forest of broadleaved evergreen trees is as follows: *Quercus glauca*, *Quercus myrstona-efolia*, *Bladhio-Shiietum cuspidatae*, *Aucuba japonica* var. *borealis-Quercus stenophylla* communities.

On the other hand, *Alnus japonica* and *Salix scrub* are found on a small scale along the lakeside or riverside in the northern part of this region.

A substitutional vegetation of the *Camellietea japonicae* region is divided into thirteen communities or assemblages as follows: *Quercetum acutissimo-serratae*, *Rhododendron-Pinetum azumanus*, *Rhododendron-Pinetum kinkianum*, *Sasa-bamboo*, *Bamboo* stand, *Miscanthus sinensis*, *Phragmites* communities, *Salix scrub* in riverside, *Thea sinesis* garden, *Mornus* garden, Paddy-field weed communities and *Pinus thunbergii* plantation. Among them, the *Pinus densiflora* forest occupies very wide areas. The forest is divided into *Rhododendron-Pinetum azumanum* and *Rhododendron-Pinetum kinkianum*. The latter assemblage is distributed in the southern part, and the former in the northern part. Roughly speaking, in the northern part of this region the *Quercetum acutissimo-serratae* is distributed wider and higher than the distributional area of the *Pinus densiflora* forest. This assemblage, however, is dotted with the *Pinus* forest in the southern part.

The true natural vegetation is very sparse around Lake Biwa, and most of it is found in the *Querco-Fagetea crenatae* region. The original vegetation is almost never found in the *Camellietea japonicae* region except forests composed of a several broadleaved evergreen trees around some shrines and temples and the *Zelkova serrata* community in the northern part.

In this region, the snow line and forest line are about 4,300 m and 2,300—2,600 m above the present sea level respectively (Minato *et al.*, 1958).

Geology

Palaeolimnology is Pleistocene stratigraphy applied to lakes (Deevey, 1955), that is, it is lacustrine biogeography with a discussion of the problems of such ancient lakes as Lake Biwa. The writer will discuss at first the discontinuous distribution of biota in the lake sediments around the lake.

Judging from many stratigraphic and palaeontologic observations on ancient deposits around the lake (Ikebe, 1933, and Ishida *et al.*, 1969), it is presumed that the lake appeared in the latest Pliocene and has continued its existence ever since.

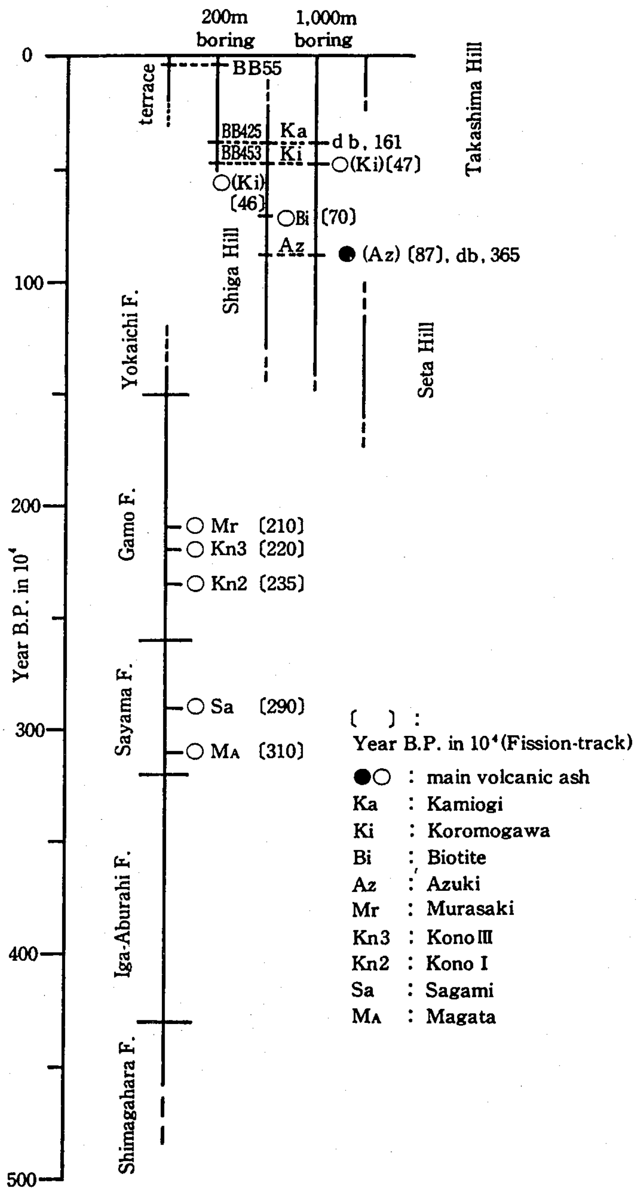
The Quaternary system in and around Lake Biwa has been roughly divided into the following three groups (Yokoyama *et al.*, 1974);

1) Plio-Pleistocene Kobiwako Group

This group occupies the Omi and Iga basins. It is 1,000 to 1,500 m in total thickness and is divided into six formations which are composed of lacustrine and fluvial deposits and yield many lacustrine fossil molluscs similar to those living in the present lake. Some mammal fossils such as *Stegodon orientalis* and *Elephas shigensis* are found in the Pleistocene deposits. The radiometric ages of 3.0 to 0.35 million years from minerals contained in the volcanic ash-layers of this group were obtained by means of the fission-track (Nishimura and Yokoyama, 1975). The absolute age of the basal part of this group is estimated to be 4.5 to 5.0 million years before the present.

2) Middle to Late Pleistocene Terrace Deposits

These deposits consist mainly of a single gravel layer. Fossil remains are scanty except



Text-fig. 2. Chronological correlation among the Quaternary deposits in and around Lake Biwa.

in a few localities. The thickness of these deposits is less than 20 m.

3) Holocene Deposits

These deposits are mostly fan and/or deltaic sediments deposited by the present rivers, and composed of sandy beds mixed with some clay and gravel. The thickness of these deposits is about 10 m.

Geomorphologically the base of the Lake Biwa basin has been regarded as the Neogene (?Miocene) peneplain which was subsided by down-warping accompanied by faulting. The connection between the lake and Japan Sea or Osaka Bay at that time may have been possible, for the peneplain was formed near sea level. The existence of such connection is supported by the occurrence of land-locked marine fishes and molluscs in the lake (Kuroda, 1948). Since then, the lake basin has continuously occupied an environment isolated by the surrounding barriers for more than two million years without any serious geological disturbance.

Tectonic lines stated already show recent activity and indicate that the crustal movement has continued during the Quaternary. The Omi, Iga, Kyoto, and Nara basins near the lake were formed along the Suzuka trend. These tectonic lines are very important in a discussion of the origin and the geological structures in and around the lake.

The center of downwarping of the Lake Biwa basin almost coincides with the center of the gravity anomaly. There is an argument among geophysicists whether such a peculiar gravity anomaly is caused mainly by the special structure of the earth's crust or mainly by thick lacustrine sediments, but if the latter is correct, we can expect the existence of extremely thick sediments, resulting from continuous sinking of the lake basin. This inference is supported by the geological evidence of a few recent long drilled cores in the eastern area of the Omi basin.

Palynological investigation

(a) Location of the Boring

A 200-m core used for the writer's investigation was collected from Lake Biwa in the water depth of 65 m at a location between the Okinoshima Island and Omi-maiko in Shiga Prefecture, during the autumn of 1971.

(b) Description of Core Samples

About one and half months after recovery, the long core was cut at 1 m length, and samples were taken at intervals of about 5 m for primary analyses. The core was then frozen and cut longitudinally. Samples used for geochemical analyses, palaeomagnetic, palaeontologic, mineralogical, granulometric, and radiometric dating analyses were taken always from a half of the core keep under frozen state. The other half of the core was divided for observation of lithofacies and volcanic ashes under the normal state after melting.

The core sediments mainly consist of soft homogeneous clay including at least 30 thin volcanic ash layers. The clay is generally blue in color when it is fresh, though it is grey or black at several horizons. The balck clay contains some plant fragments (Yokoyama *et al.*, 1974, 1975). Almost all grains of sediments are smaller than 44 microns in diameter, except either large plant fragments or volcanic materials.

No sedimentary structure can be observed by the naked eye.

The volcanic materials in the core samples are divided into two types, andesitic and trachytic. The former contains two pyroxenes, hornblende, and abundant volcanic glass. The latter is chiefly composed of orthorhombic pyroxene, hornblende, biotite, quartz, volcanic glass flakes, and small pumice grains and were derived from Quaternary volcanoes such as Dai-sen, Sanbe-yama, Ohe-takayama, etc., which occur 100—350 km west of Lake Biwa (Yokoyama, 1973).

About 50 smaples taken at intervals of about 5 m throughout the core were analyzed for palynological investigation.

The samples taken from the same horizons have been analyzed for chemical components, palaeomagnetism, particle size, clay mineralogy, and microfossils.

(c) Preparation for Pollen Analyses

Pollen grains in the sediments were concentrated with slight modifications (Fuji, 1963, 1965, 1973, 1974, 1975, 1976) of the method described by Faegri and Iversen (1964). Sediments containing coarse organic materials as moss, small leaves, and small shells were strained through a fine screen. As most sediments were predominantly silt and clay, they were left for 2 hours in hydrofluoric acid to remove the siliceous minerals. They were treated by standard acetolysis method. Pollen grains from most samples were stained with safranin, and were mounted in glycerine jelly. Throughout the present investigation one slide (size of covering glass area: 24 x 24 mm) was generally enough to obtain a pollen count of about 500.

(d) Method for Interpretation of Palaeo-vegetation and Climatic History

The writer depends upon pollen analyses for reconstructing a vegetation during a geological age. For the interpretation of pollen spectra obtained from the 200-m core sample the writer used two ways as (1) pollen spectra of the modern samples taken in and around Lake Biwa and from various localities of some climatic zones throughout the Japanese Islands (Wright *et al.*, 1967), and (2) the warmth index (month-degrees) (Fuji, 1965). According to the law of total effective temperature, the distribution of a plant is influenced more with the sum of mean day or month temperature than with the mean annual temperature. The total temperature is given by the formula:

$(e_m - p)$, where

e_m: mean month temperature

p: physiological zero point, which is shown generally to be by 5°C in the Japanese Islands

In the formula, if e_m is smaller than p, $(e_m - p)$ value is omitted from this formula.

The total temperature is generally called the "warmth index" (Kira *et al.*, 1958).

The relationship among the warmth index (month-degrees), major plants growing in the Japanese Islands, latitude, temperature and climatic zones is summarized. On the basis of the distribution of the warmth index of every plant, all of the arboreal genera found from the samples can be grouped into one of the following five groups: the Subpolar or Subalpine zone (warmth index month-degrees: 15°—55°), the Cool Temperate zone (45°—90°): the Cool Temperate zone — Temperate zone (55°—140°); the middle part of the Cool Temperate zone — Warm Temperate zone (70°—140°); and the southern part of the Temperate zone — the Subtropical zone (100°—180°).

(e) Construction of the Diagrams

Shown from the left to the right in pollen diagrams are sediment stratigraphy, lithofacies and depth of the core, spectrum number, C^{14} and fission-track dates, palaeomagnetic stratigraphy, summary diagram, pollen profiles of each taxon and assemblage zone. The pollen sum used on the pollen types concerned, on the local situation, and on the kind of deposit. The main pollen diagram is divided into two parts. The pollen diagram (2) shows all non-arboreal pollen (herbs), aquatic and marsh plants, and ferns, excluded from the pollen sum but calculated as a percentage over the pollen sum. Percentages in both diagrams are shown on two scales; the scale with 10 x exaggeration permits the accurate plotting of minor curves and minor fluctuations. The summary diagram is drawn to facilitate the discussion and interpretation of palaeovegetation and climatic history. This summary diagram is composed of changes of the ratio between total AP and total NAP, and of percentages of the Subpolar plants, Cool Temperate plants, Cool Temperate — Temperate plants, plants of the middle area of the Cool Temperate zone and of the Warm Temperate zone, and plants of the southern area of Temperate zone and of the Subtropical zone, calculated on the basis of the warmth index (month-degrees) as will be described in a later chapter. There follow the curves for boreal conifers.

(f) Remarks on Identification of Pollen Grains

Most of pollen grains from the core samples are found in the present Japanese Islands, and their descriptions can be found in the published references.

Some of the critical genera are discussed below.

1) *Abies*: In the Japanese Islands, six species belong to *Abies*. *A. Mariesii*, *A. Veichii*, *A. sachalinesis*, and *A. sachalinesis* var. *mayriana* grow in the Subpolar or Subalpine zone. *Abies homolepis* and *A. firma* grow in the Cool Temperate and Temperate zones. Pollen grains of latter two species, however, are not distinguished from other species of *Abies* from the view point of the shape of pollen grains.

2) *Picea*: Six species of *Picea* are found in the Islands. Although *Picea* is not classified into species on the basis of pollen morphology, *P. jezoensis* and *P. jezoensis* var. *hondoensis*, *P. glehnii*, *P. bicolor* var. *reflex*, and *P. bicolor* grow in the Subpolar of Subalpine zone, and *Picea polita* is found in the Cool Temperate zone (Yamazaki, 1951).

3) *Pinus*: Genus *Pinus* includes about six spcies. *Pinus pumila* and *P. pentaphylla* are found in the Subpolar or Subalpine zone, *P. koraiensis* grows in the Cool Temperate and Subpolar or Subalpine zones, and *P. densifora*, *P. himekomatsu*, and *P. thunbergii* grow in the Temperate and Warm Temperate zones. *Pinus*, however, is divided easily into two types by the pollen morphology: They are *P. haploxylon*-type and *P. diploxylon*-type. Species with five leaves belong to the former; they grow in the Subpolar or Subalpine zone at the present. The latter includes species with two leaves, such as *P. densiflora*, *P. himekomatsu*, and *P. thunbergii*.

4) Taxodiaceae: For genera belonging to Taxodiaceae, *Cryptomeria* and *Taxodium* grow in the Japanese Islands after the early Pleistocene. However, in the surroundings of Lake Biwa, the Plio-Pleistocene Kobiwako Group is distributed widely and yields pollen grains of *Metasequoia* and *Glyptostrobus*. Accordingly, these pollen grains are found sometimes as secondary (reworked) fossils in younger deposits. Pollen grains of *Metasequoia* and *Cryptomeria* are discriminated from other genera by grain size and shape of papilla. According to the measurement of modern species (Fuji, 1973), *Metasequoia*: 20 x 23 microns in width and length; *Cryptomeria japonica*: 30—33 x 34—38 microns; *Sequoia sempervirens*: 36—42 x 34—38 microns; *Glyptostrobus pensilis*: 26—28 x 30 — 33 microns; *Taxodium distichum*: 22—25 x 25—29 microns. The secondary pollen grains are not shown on the pollen diagram.

5) *Tsuga*: In the present-day Japanese Islands, *Tsuga diversifolia* is found in the Subalpine or Subpolar zone and *T. sieboldii* in the Cool Temperate zone and in the northern part of Temperate zone. They are not differentiated from other species.

6) *Betula*: Species such as *Betula ermani* is found in the Subpolar or Subalpine zone, and *B. platyphylla* in the Cool Temperate zone. Their pollen grains are not differentiated.

7) *Fagus*: In the present-day Japanese Islands, *Fagus* has two species, *F. crenata* and *F. japonica*. According to the wirter's observations: *Fagus crenata* measures 38—40 x 45—48 microns and can thus be distinguished from *F. japonica* which measures 29—32 x 33 microns. *F. crenata* grows in the Cool Temperate zone, and *F. japonica* is found in the middle part of the Cool Temperate and Temperate zones (Fuji, 1976; Fuji *et al.*, 1975).

8) *Quercus*: *Quercus* is divided into two subgenera, *Lepidobalanus* and *Cyclobalanopsis*, by its grain-size and morphology. An evergreen *Quercus* belongs to the latter, and deciduous *Quercus* to the former. Pollen grains of *Cyclobalanopsis* can be distinguished from those of the *Lepidobalanus* by a combination of features (Shimakura, 1973). As shown below, grains of *Cyclobalanopsis* are in general smaller than those of *Lepidobalanus*. The thickness of the pollen grain wall of both subgenera varies from 0.8 to 1.8 microns. The *Lepidobalanus* usually shows a somewhat thicker wall than *Cyclobalanopsis*. The wall in *Cyclobalanopsis*, however, is relatively thicker because of the small size of the grain. The costae in *Cyclobalanopsis* are generally heavier than those of *Lepidobalanus*. The shape of costae and colpi in *Cyclobalanopsis* differs from that of *Lepidobalanus*. The shape of costae and colpi in *Cyclobalanopsis* often shows a poroid area or a constriction (Bottema, 1974).

Cyclobalanopsis (evergreen *Quercus*)

Quercus acuta: 21—23 x 26—27 microns; *Quercus glauca*: 29—20 x 21—23; *Q. phillyraeoides*: 20—22 x 23—26;

Lepidobalanus (deciduous *Quercus*)

Quercus serrata: 22—23 x 24—28 microns; *Q. dentata*: 32—34 x 36—38; *Q. variablilis*: 29—30 x 31—33; *Q. acutissima*: 28—30 x 37—38.

Cyclobalanopsis occurs in the Temperate and Warm Temperate zones, and *Lepidobalanus* in the Cool Temperate zone and in the northern part of the Warm Temperate zone.

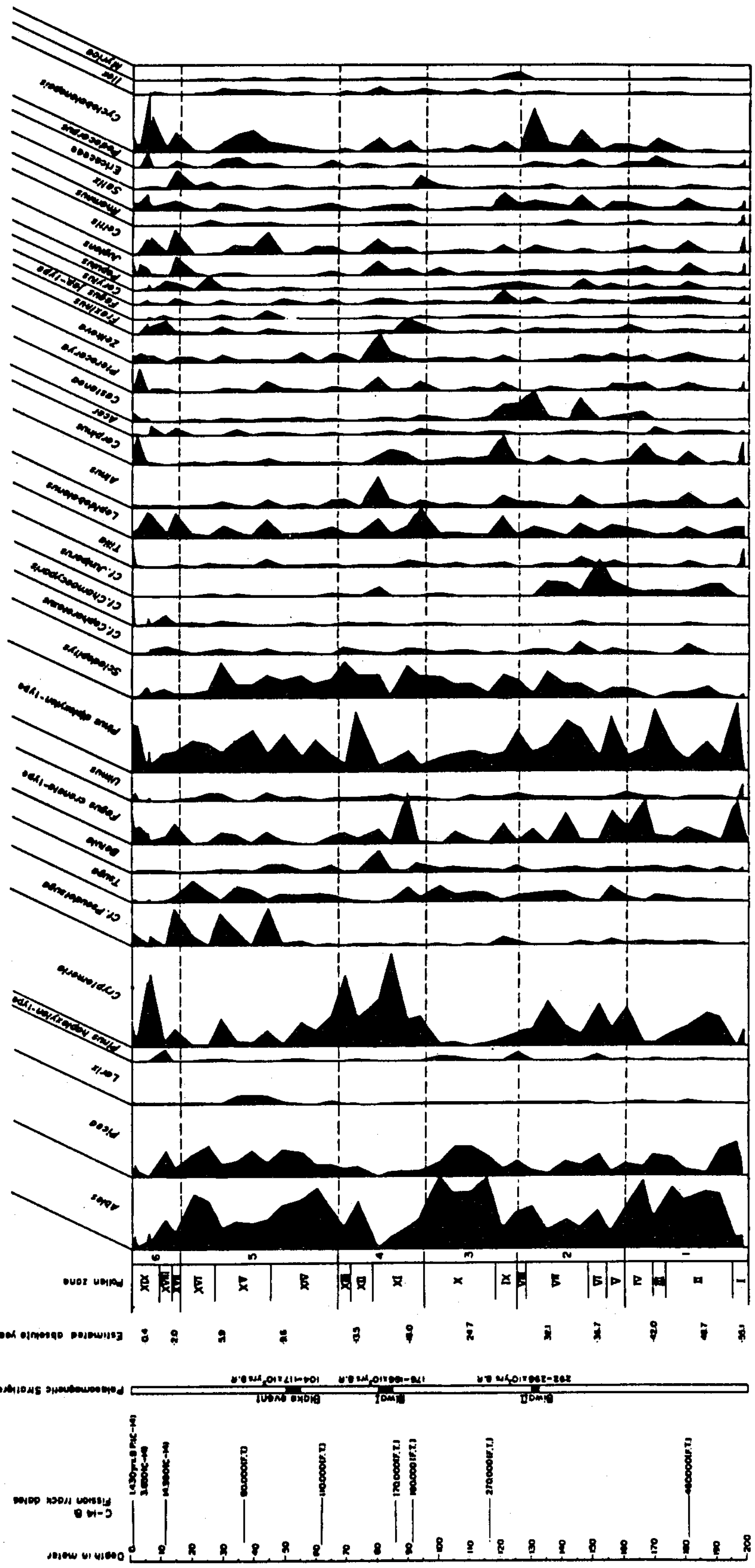
The use of the suffix "-type" after the name of a species or a genus implies that the fossil may belong to the named species or genus or to others of closely similar or identical morphology which have not been distinguished by the writer. Thus, *Pinus haploxylon*-type includes pollen grains of *Pinus* with five leaves such as *Pinus pumila*, *P. pentaphylla*, and *P. koraiensis*. This type is not divided into three above-mentioned species on the basis of pollen morphology. The use of "cf." as in cf. *Cepharotaxus* indicates that most of grains could be referred to this genus.

(g) Zoning of Pollen Assemblages, and Interpretation of Vegetation and Climatic History

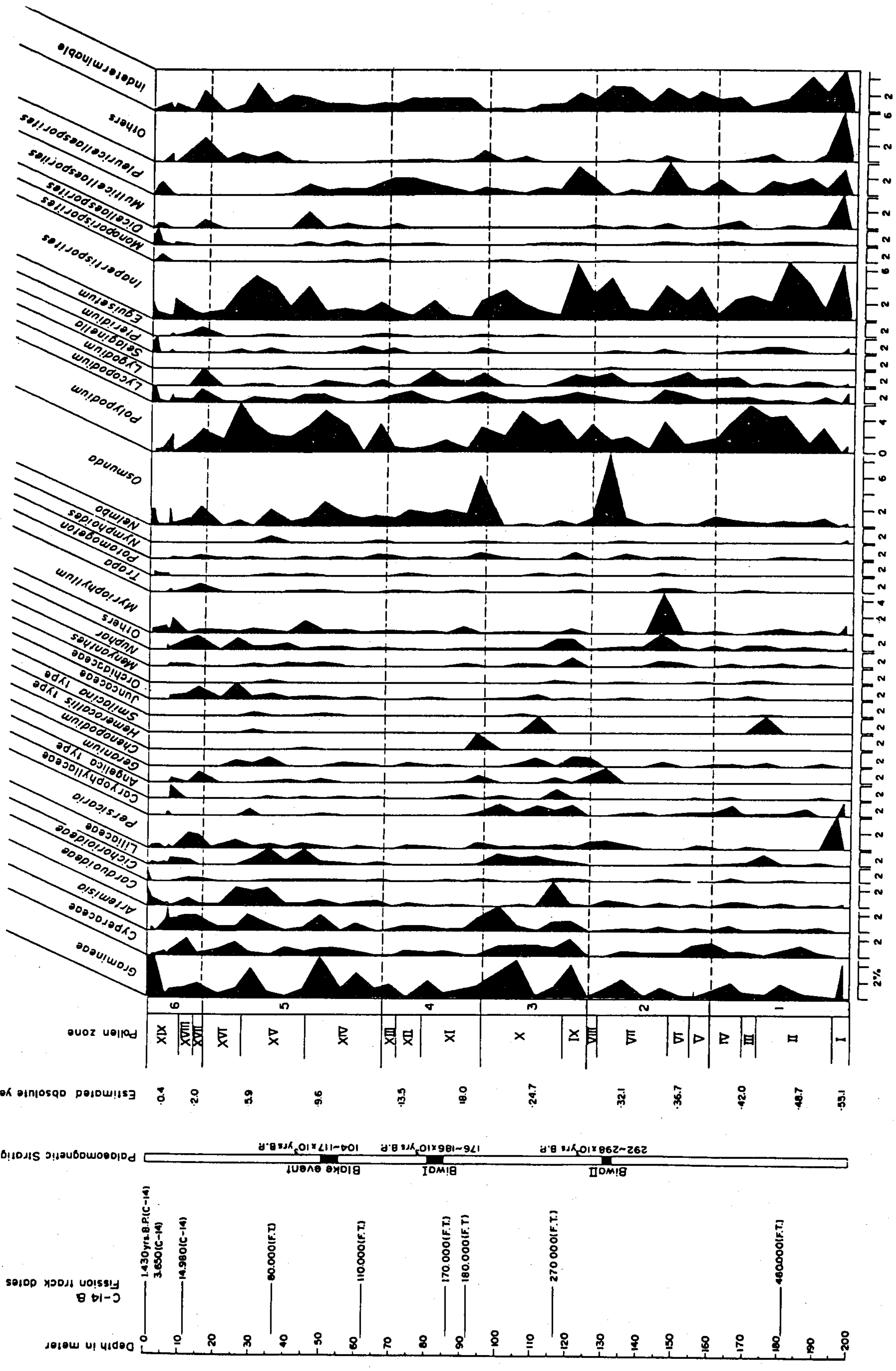
In order to facilitate descriptions and discussions of the pollen assemblages, the pollen diagrams are divided into 19 pollen zones based on distinct changes in pollen percentages (Fuji *et al.*, 1972). Changes in the ratio of Total AP to Total NAP can be established, but changes in the values of one or two pollen types may also lead to the establishment of pollen zones which have similar assemblages of pollen grains and spores. The writer has attempted to indicate them under the same letter code in order to facilitate comparisons.

ZONE I, depth 195—198 m: The pollen assemblage of this zone is defined by *Pinus diploxylon*-type (46%), *Picea* (24%), *Fagus crenata*-type (21%), and *Cryptomeria* (10%), and is characterized by a very high pollen percentage of plants thriving in the middle part of the Cool Temperate — Temperate zone. The mean annual temperature of the summit area and lowland at the time of this zone may have been higher than 5°C and 13°C respectively, and the humidity was probably more or less arid.

ZONE II, depth 173—195 m: This zone is characterized by large amounts of boreal conifers, especially *Abies* and *Picea*, and Cool Temperate — Temperate plants. The climate in the lakeside at that time may be compared with that in the middle part of the Cool Temperate zone. In the lowland areas, *Cryptomeria*, *Pinus diploxylon*-type, *Alnus*, *Fagus crenata*-type, *Carpinus*, *Zelkova*, *Juglands*, and *Lepidobalanus*



Text-fig. 3. Arboreal pollen diagram of samples at 5 meters interval from a 200-meter core.



Text-fig. 4. Non-arboreal pollen diagram of samples at 5-meter interval from a 200-meter core.

grew, and at the mountain sides *Abies*, *Tsuga*, and *Betula* grew. *Pinus pumila* and *Abies* may have prevailed in the summit area during the later part of this period.

ZONE III, depth 168—173 m: Although the pollen percentages of the boreal conifers are almost the same as in Zone II, the pollen values of broadleaved deciduous trees decrease, and plants of the Warm Temperate — Subtropical zones such as broadleaved evergreen trees and *Podocarpus* attain relatively higher values. The climate at that time may have been as warm as that of the present day and relatively arid.

ZONE IV, depth 160—168 m: This zone is characterized by an increase of plants of the Cool Temperate zone and of the Cool Temperate — Temperate zones, and by a decrease in plants of the middle part of the Cool Temperate — Temperate zones and of the southern Temperate — Subtropical zones. Judging from the pollen assemblages, the climate at that time may have been as cool as that in the southern part of the Cool Temperate zone and was probably wet as indicated by the large value of *Cryptomeria*.

ZONE V, depth 154—160 m: This zone is characterized by decreases in the Subpolar or Subalpine plants and in the Cool Temperate — Temperate plants, and by sharp increase in the middle Cool Temperate — Temperate plants. In the mountainous area, broadleaved deciduous trees, *Abies* (perhaps *A. firma*), *Picea* (perhaps *P. polita*), and at the lakeside, *Pinus densiflora* prevailed. There were also scattered *Cryptomeria*, *Zelkova*, *Juglans*, *Salix*, and *Alnus*. The climate may have been similar to that of the present day.

ZONE VI, depth 148—154 m: Relatively high percentages of the Subpolar or Subalpine plants and Cool Temperate — Temperate plants, and decreases in the percentage of the middle Cool Temperate — Temperate plants and the southern Temperate — Subtropical plants are the characteristic features of this zone. The climate of the lowland at the time represented by this zone may have been similar to that of the middle part of the Cool Temperate zone.

ZONE VII, depth 128—148 m: The main elements of this zone are *Pinus diploxylon*-type (28—34%), *Cryptomeria* (12—30%), and *Abies* (13—29%). This zone is characterized by boreal conifers which lasted for a time with only long small fluctuations in abundance. The climatic condition at that time was similar to that of the present day with temporarily cool periods.

ZONE VIII, depth 125—128 m: The pollen assemblage of this zone contains *Pinus diploxylon*-type (28%), *Abies* (25%), *Picea* (11%), and *Cryptomeria* (9%). The zone is notable for drastic increases in the Subpolar of Subalpine plants, and boreal conifers, and for decreases in the Cool Temperate — Temperate and southern Temperate — Subtropical plants. The climate during this time may have been similar to that of the middle part of the Cool Temperate zone, and was probably relative dry with the mean annual temperature of about 10° at the lakeside.

ZONE IX, depth 118—125 m: This zone is similar to zones V and VII. The climatic condition at that time may have been somewhat milder than that in the northern part of the Temperate zone. *Abies* (perhaps *A. homolepis*) and *Picea* prevailed with a little *Betula* (perhaps *B. platyphylla*) and *Fagus crenata*-type in the higher part of mountainous area. In the lowland area, the broadleaved trees, especially *Lepidobalanus*, and *Pinus densiflora* probably prevailed.

ZONE X, depth 95—118 m: This zone is characterized by a high concentration of boreal conifers, especially *Abies* (45%) and *Picea* (18%). The climate in the lowland at that time may have been as cold as that of the northern part of the Cool Temperate zone and dry, with a temporarily cooler interval during the middle of the period. On the other hand, in the mountainous areas, boreal conifers prevailed.

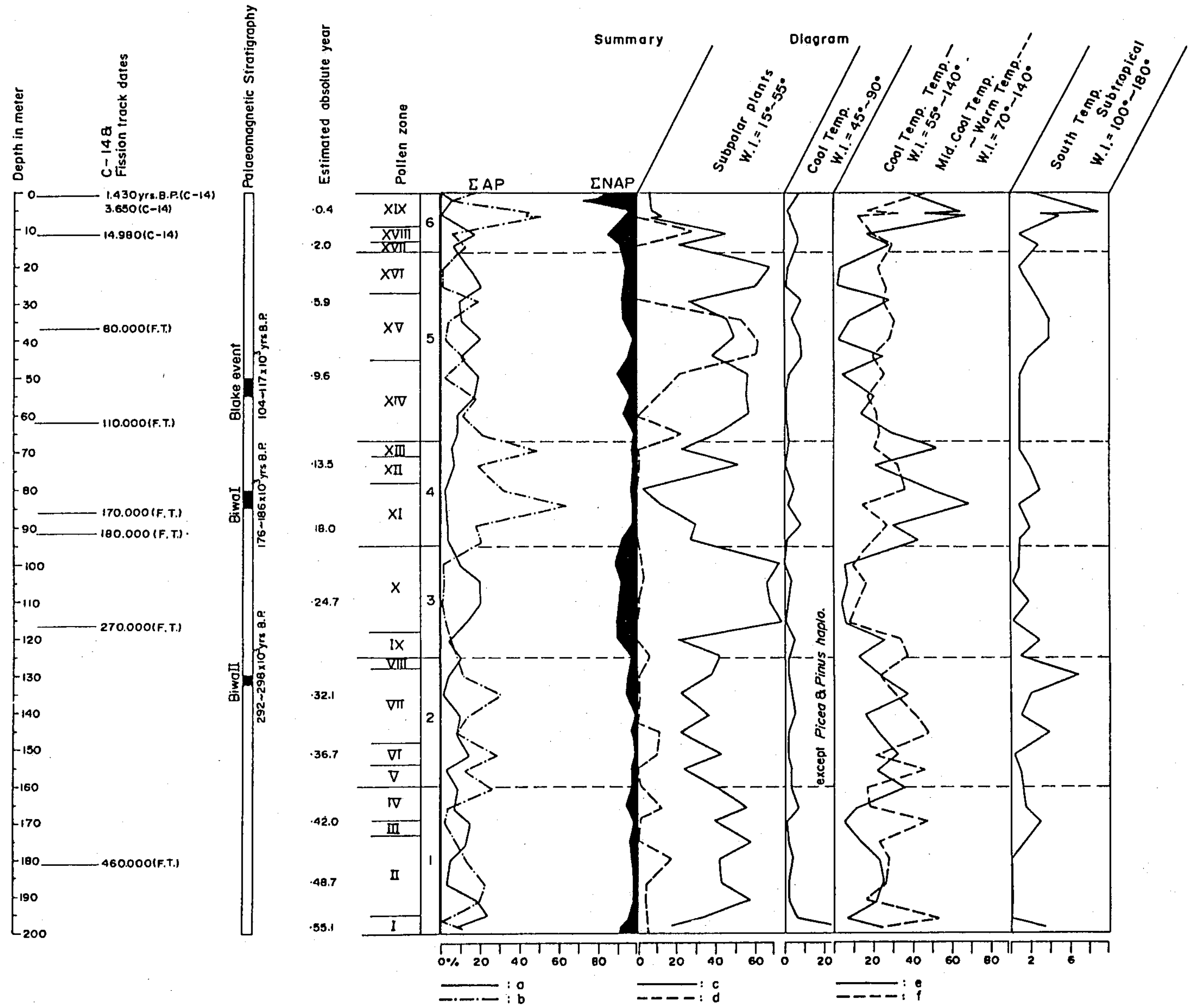
ZONE XI, depth 78—95 m: This zone is characterized by an increase in other plants than boreal conifers. The climate in the lakeside area may have corresponded to that of the northern part of the Temperate zone or of the southern part of the Cool Temperate zone, and wetter condition probably prevailed.

ZONE XII, depth 71—78 m: This zone is characterized by increases in boreal conifers and plants of the middle part of the Cool Temperate — Temperate zones. The climate in the lowland area around Lake Biwa may have been as cool as those of zones VI and VIII, but, on the other hand, *Pinus haploxylon*-type (here perhaps *P. koraiensis*), *Abies* (perhaps *A. homolepis*), and *Picea* (perhaps *P. polita*) presented in the mountainous area.

ZONE XIII, depth 67—71 m: This zone is characterized by a markedly drastic increase in plants growing in the Cool Temperate — Temperate zones, particularly *Cryptomeria*. The climate was probably similar to that of the southern part of the Cool Temperate zone, and was clearly wetter.

ZONE XIV, depth 45—67 m: The main elements of the pollen assemblage of this zone are *Abies* (26—42%), *Pinus diploxylon*-type (21—26%), *Sarix* (24%), *Picea* (17%), and *Cryptomeria* (11—17%). The zone is marked by a drastic decline in plants thriving in the Cool Temperate zone, and by a strong increase in boreal conifers. The climate appeared to have deteriorated slightly during this time from cool condition at the beginning of the period to relatively cold and dry conditions at the middle and at the end of the period.

ZONE XV, depth 27—45 m: The climate



Text-fig. 5. Summary pollen diagram of the palynological analysis of a 200-meter core. a: *Picea*, b: *Cryptomeria*, c: boreal conifers, d: *Pinus haploxylon* + *Larix* (x 10), e: except *Tsuga*, f: except *Abies*.

during the early part of this period may have been similar to that of the northern part of the Temperate zone. In the late period, however, it became cooler and resembled that in the southern part of the Cool Temperate zone.

ZONE XVI, depth 16—27 m: During this period the climate deteriorated and, in the lakeside area, boreal conifers and broadleaved deciduous trees probably prevailed.

ZONE XVII, depth 13—16 m: This zone is characterized by a drastic decline in boreal conifers. Instead of boreal conifers, plants of the Cool Temperate — Temperate zones, particularly *Cryptomeria* (12%), and *Lepidobalanus* (16%) were relatively abundant. The climate at that time may have been correlated to that of the northern part of the Temperate zone or of the southern part of the Cool Temperate zone.

ZONE XVIII, depth 9—13 m: The climate at the time represented by this zone had been the coldest throughout the last 560,000 years, and was almost comparable to that of Zone X. In the summit and mountainous areas, *Pinus pumila*, *Abies* (perhaps *A. mariesii* or *A. veitchii*), and *Picea* prevailed. Boreal conifers such as *Abies homolepis*, *A. firma*, *Picea* (? *P. polita*), *Pinus koraiensis*, *Betula* (perhaps *B. platyphylla*) and other broadleaved trees were distributed in the lowlands around Lake Biwa.

ZONE XIX, depth 0—9 m: During the time represented by this zone, boreal conifers and the Cool Temperate plants decreased in abundance and were replaced by plants growing near the middle part of the Cool Temperate zone and in the southern part of the Temperate — Subtropical zones. At this time, *Lepidobalanus* (perhaps *Quercus crispula* and *Q. serrata*), *Acer*, *Cryptomeria japonica*, and *Chamaecyparis* prevailed in the mountainous area instead of *Abies*, *Larix*, and *Ulmus* as in the period represented by zone XVIII. On the other hand, *Lepidobalanus* as *Quercus acutissima* and *Cyclobalanopsis* as *Quercus glauca* were distributed widely with *Salix* and *Alnus* along the sides of the lake and rivers. The climate of this time may have been 1°—2°C warmer than and more humid than at the present (Fuji, 1976).

Comparison with previous palaeoclimatic analyses

The age determination of the upper part of the core from Lake Biwa has been carried out by the C^{14} method (Horie *et al.*, 1971), and the other by the fission-track method (Nishimura *et al.*, 1975). The age of the lowermost horizon, about 200 m below the present lake bottom, is about 565,500 years, B.P. With the use of the age determination by C^{14} and fission-track methods, and palaeoclimate by the palynology, the writer determined preliminary the ages of the boundaries between glacial and interglacial times, and between stadial and interstadial times.

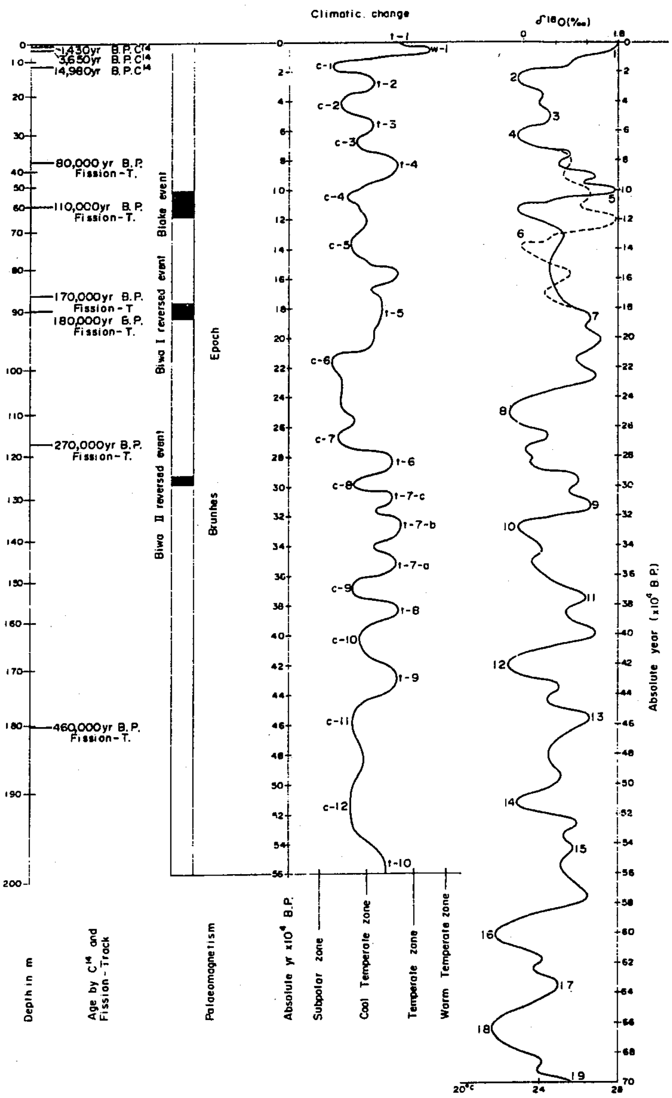
Same samples from the 200-m core analysed for the palynology, geochemistry and other micropalaeontology were studied from the viewpoint of palaeomagnetism (Kawai *et al.*, 1972). All samples are belonged to the Brunhes normal polarity epoch, the past 690,000 years, and the new three short reversed polarity events, called "B", "Biwa I", and "Biwa II" from the lake bottom, have been recognized in the core. Judging from a correlation between the palaeomagnetic results from Lake Biwa (Kawai *et al.*, 1972) and these from some deep-sea cores (Opdyke, 1972; Ninkovich *et al.*, 1966), the "B" reversed polarity event at a depth of 50 to 55 m in the core of Lake Biwa is correlated with the Blake event (Ninkovich *et al.*, 1966; Denham, *et al.*, 1975) which is estimated to have lasted from 117,000 to 104,000 years ago. Then the "Biwa I" event at a depth of 80.5 to 85 m and the "Biwa II" event at a depth of 130.0 to 132.5 m are estimated respectively to be from 176,000 to 186,000 years ago and from 292,000 to 289,000 years ago (Yaskawa, 1974). Accordingly, sedimentation at the 200-m-level must have begun from the early stage of Brunhes normal polarity epoch. Therefore, pollen analysis of this long core stated in this paper has produced a record for most of the Brunhes epoch.

The phases of vegetation development during the time not covered by the radiocarbon and fission-track age determinations need to be dated by the other methods. Geological studies from the surroundings of Lake Biwa unfortunately do not provide much evidence for such dating. So the changes in vegetation and associated climatic changes inferred from the palynological results offer the possibility for further dating. As there are no other palynological studies covering the 565,000 years time span represented by the Lake Biwa core, the writer correlated the pollen diagram from Lake Biwa with Emiliani's palaeotemperature curve (1966 & 1974) based on oxygen isotope analysis. Emiliani's study covers the last 700,000 years and shows fluctuations in more detail than palaeoclimatic curves from other deep-sea cores (for example: Hays *et al.*, 1969).

On the palaeoclimatic curve from Lake Biwa (Text-fig. 6) cold, warm, and temperate climatic periods are named as c-1, c-2, . . . , w-1, and t-1, t-2.

The t-10 period (temperate climatic period) is correlated with period no. 15 in Emiliani's curve, but if estimated age by Kanari *et al.* (1975) is correct, the end of t-10 period was slightly later than period no. 15. A short and relatively mild period separates the c-10 and c-12 periods. This mild period is correlated with a mild period between nos. 13 and 14 of the Emiliani's curve. According to the present writer's curve, the duration of the c-12 period was as long, and the climate was as cold as that of the c-11 period. Although there is a cold period shown by no. 14 in Emiliani's curve correlated with the c-12 period, this cold period was shorter and colder than the c-12 period. A temperate climatic period shown by an abbreviation t-9 may be correlated with period no. 13 in Emiliani's curve. The latter, however, is chronologically older by about 10,000 years than the former. Judging from the present analyses, the duration of the t-9 period is inferred to have been shorter than that of period no. 13. This inconsistancy may result from the long sampling interval (5 m) used in the Lake Biwa core. Shorter sampling intervals should be used in the future.

The t-8 period is clearly correlated with period no. 11 of Emiliani's curve from the



Text-fig. 6. Correlation diagram between the palaeoclimatic change in the Omi Basin and palaeotemperature curve based on oxygen-isotope ratio determination from the Caribbean Sea (Emiliani *et al.*, 1974).

viewpoints of chronology and palaeoclimatology. Lack of exact agreement is again attributed to the long sampling interval in the Lake Biwa core. Climatic fluctuations during the periods from c-9 to c-7 are too indistinct to be correlated with Emiliani's curve. There are so many periods of mild climate that it is difficult for example, to decide which of these should be correlated with the Emiliani's no. 9. However, if it is assumed that the c-8 period is correlated with a cold period between the Emiliani's periods no. 8 and no. 9, the t-7-b subperiod in the present curve may be correlated with the Emiliani's no. 9. A mild climatic period shown by the abbreviation t-6 may be correlated with the cool period just before period no. 8 of Emiliani's curve. Judging from chronological and palaeoclimatic investigations, it is most probable that the cold c-7 and mild t-5 periods are correlated with periods no. 8 and no. 7 of Emiliani's curve respectively. According to the writer's analysis, the climatic condition during the time interval from period c-7 to period c-6 was continuously cold. A marked drastic climate amelioration is recognized in the time, about 210,000 years B.P., between period c-6 and period t-5. A similar climatic amelioration is occurred during the time interval from period no. 8 to period no. 7 of Emiliani's curve but this interval appears to correspond precisely to the time interval from period c-6 to period t-5 in absolute age. The mild t-5 period may be correlated with Emiliani's period no. 7, judging from the climatic fluctuations recorded.

Emiliani and Shackleton (1974) showed two tentative palaeotemperature curves for the period between the mild period no. 7 and cold no. 4. According to the present writer's curve, the climate during this time may have correspond more closely to the trend of the period line in Emiliani's curve, except in the period around about 120,000 years B.P.

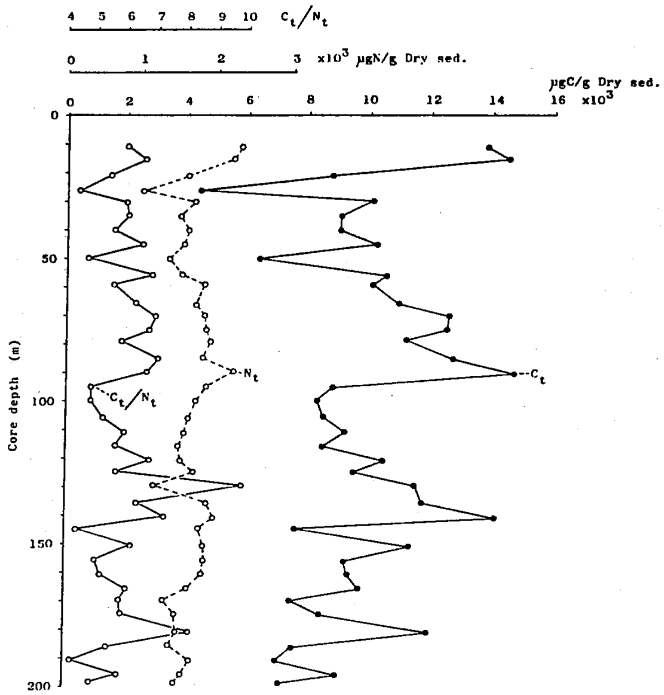
The c-3, t-3, c-1, and t-1 periods may be correlated with periods nos. 4, 3, 2 and 1 of Emiliani's curve, respectively.

In conclusion, judging from this detailed comparison there are a few differences between Emiliani's generalized temperature curve from the Caribbean Sea and the present writer's climatic curve from Lake Biwa, still there seems a general similarity between the curves.

Comparison with chemical, palaeomagnetic, and fossil diatom analyses

The samples examined for the contained microflora were also investigated from palaeomagnetic, chemical, granulometric, mineralogical, and fossil diatoms aspects.

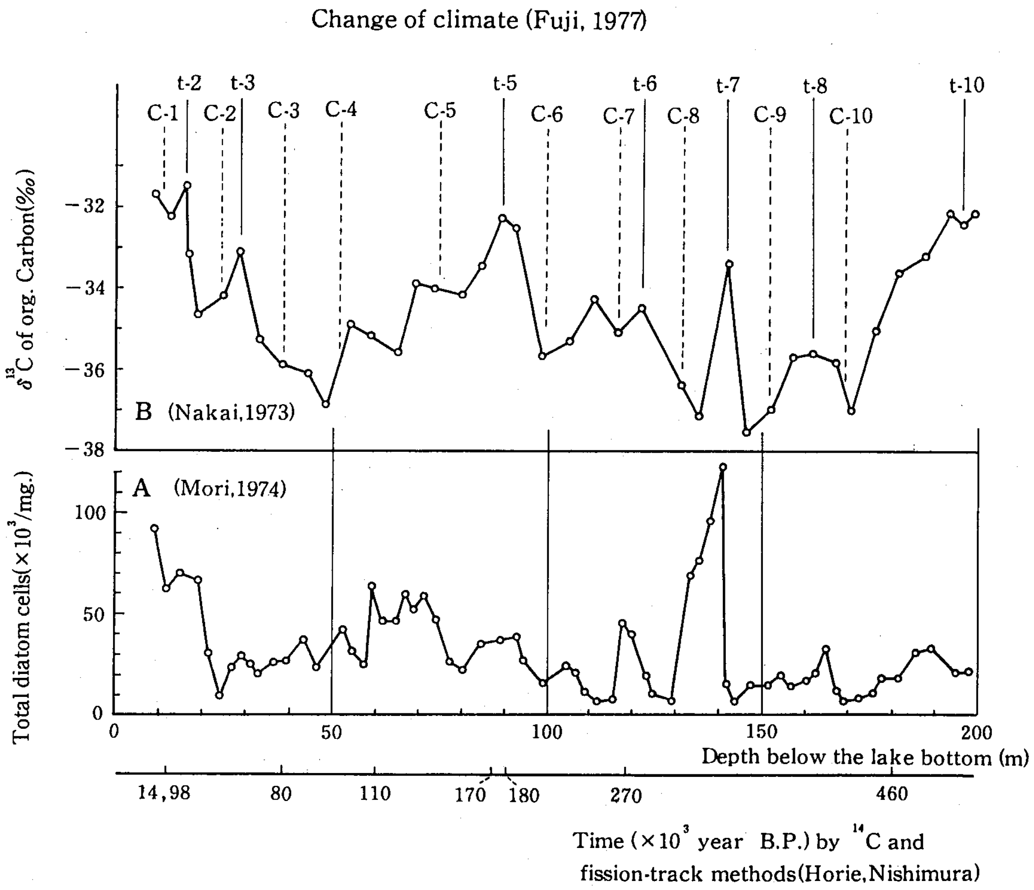
The contents of heavy metal irons in the samples are almost similar to those of soils in unpolluted areas. Ranges of determined values are as follows. As: 9—58 ppm, Cd: 0.24 ppm, Cu: 34—66 ppm, Mn: 620—5300 ppm, Pb: 18—43 ppm, Zn: 98—160 ppm. However, the fact that the highest peakes of Cd and Mn contents are observed at the depth of 130 m suggesting that some environmental change might have taken place at around the age of 300,000 years B.P. The four peaks also correspond to the minimum values of organic carbon/organic nitrogen ratio (Koyama *et al.*, 1973). The content of organic carbon varies similarly to that of the total carbon showing four remarkable peaks at 15 m, 90 m, 140 m warm periods which are recognized from the results of palynological analysis. According to vertical profiles of organic carbon and nitrogen content of the core samples, ranging 4.4—14.7 mgC/g of dry sediment and 1.0—2.3 mgN/g of dry sediment respectively, were found to be almost similar to that of size distribution of the fine-grained clastics. This suggests that the allochthonous materials must



Text-fig. 7. Vertical distribution of total carbon and nitrogen in the core sample from Lake Biwa (Koyama *et al.*, 1973).

contribute to the sedimentary organic materials in certain extent. This fact was supported by the low values of the C_{16} + C_{18}/C_{20} — C_{30} of dicarboxylic acids of the sediments, because C_{20} — C_{30} of the acids are mainly drived from the terrestrial plant wax, whereas C_{16} and C_{18} acids are main constituents of dicarboxylic acids in the autochthonous phytoplankton. The concentration of phaeopigment and carotenoids was determined to vary with intervals of the core depth. Vertical profiles of these plant pigments are almost similar with those of carbohydrate, amino acids and protein and lipid and with that of fossil diatoms. These facts suggest that the productivity of organic materials due to the photosynthetic activities of diatoms in this lake varied with time in the past time. In addition, vertical profiles of these organic materials and fossil diatoms were found to be quite similar with the change in the palaeotemperature around this lake, which was established on the basis of palynological analysis by the present writer.

The positive correlation between the total organic contents and $\delta^{13}C$ values can be found throughout the core samples. The isotopic composition of organic carbon becomes enriched in $\delta^{13}C$ with increase in the organic carbon contents. The isotopic variation in organic carbon in the core samples is undoubtedly controlled with a kinetic isotope effect due to the temperature at which plankton grew. In warmer climate, the production rate of organic materials such as plankton in the lake and their accumulation rate in the sediments are relatively higher, resulting in relatively higher $\delta^{13}C$ enrichment than those in a colder climate. The palaeoclimatic variation estimated by palynological investigation shows an excellent correlation with that by the $\delta^{13}C$ values. From

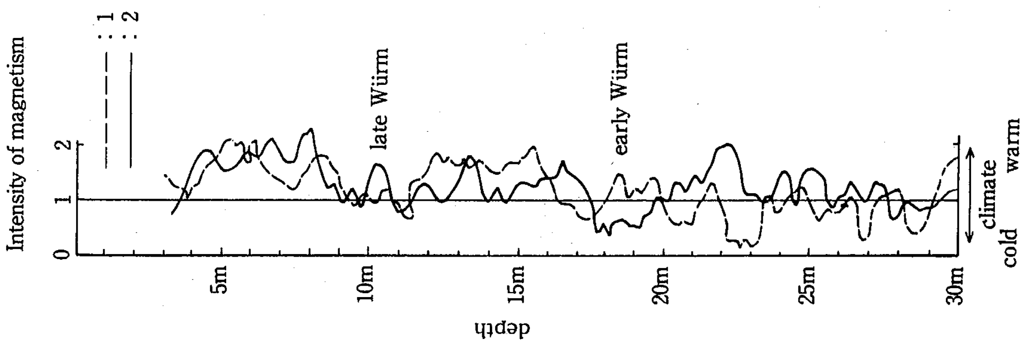


Text-fig. 8. Comparison among the change of climate (Fuji, 1977), $\delta^{13}C$ of organic Carbon and total diatom cells from the samples a 200-meter core in Lake Biwa.

this isotopic study, it can be concluded that three or four glacial and interglacial ages were repeated in the depositional history of Lake Biwa sediments during the past 600,000 years (Nakai, 1973).

On diatom fossils (Mori, 1975) the following are noticed. Two genera of *Melosira* and *Stephanodiscus*, which belong to discoid diatoms and are planktonic habitat, are observed abundantly through the core column. A diatom assemblage consisting mainly of *Melosira solida* and *Stephanodiscus carconensis*, which are observed in the lake at present, is found in a part of 75.0 m in core depth and above. And below that depth diatom assemblages differ remarkably from the viewpoint of a dominant species of diatom. It is possible to recognize five diatom zones in the core column based on the rise and fall in the abundance of *Melosira solida*. There are four periods in the core column when *M. solida* is yielded abundantly. Lake Biwa was under a temperate to warm climate in those peirods.

The palaeomagnetic study of the 200-m core reveals that there are three short reversed polarity events in the Brunhes normal plarity epoch (Kawai *et al.*, 1972). Comparison between the results of the magnetic reversals and of the palaeoclimate estimated by the palynological research is shown in Text-figs. 6 and 9. Viewed from the tentative conclusion on the palaeoclimate during the last 0.6 million years, the cold periods may be chronologically responded to the reversed polarity events. Although the reason remains unknown, when the polarity was reversal, it has not been solved yet in the present why the palaeoclimate was cold or cool (Kawai *et al.*, 1972). In addition, it is a very noticeable fact that some horizons were found in the core at which the variation of fossil diatom abundance and species was correlated with the event of oscillating geomagnetic field. The correlations are shown in the following Table 1. Among the correlations one at the Biwa event II was the most conspicuous. It can be con-



Text-fig. 9. Comparison between the change of palaeoclimate based on the pollen analyses and the intensity of palaeomagnetism in samples of a 200-meter core from Lake Biwa. 1: palaeoclimatic change based on pollen analyses; 2: intensity of palaeomagnetism.

Table 1. Relationship between geomagnetic events and variation of diatom assemblage from a 200-meter core.

Geomagnetic events	Microfloral change of diatom
B (Blake event)	Extinct horizon of *Melosira* cf. *juergensi*
C (Biwa event I)	Decrease horizon of *M.* cf. *juergensi*
C-D (weak magnetism)	Bl diatom subzone
D (Biwa evnet II)	Decrease horizon of *Melosira solida* & *M.* cf. *juergensi*

sidered that an oscillating geomagnetic field had some influence on the diatom fossils existence, though it might be indirect.

The scientific solution of these similarity is due to the detailed measurements and analyses and to the co-operation with the scientists of both geophysics and cosmophysics (Kind, 1969).

Conclusions

(1) Judging from the pollen analyses, the 200-m core samples of Lake Biwa can be divided into 19 pollen zones; Zones I, through XIX.

(2) The climatic curve and ages from Lake Biwa display similarity to the palaeotemperature curve (oxygen-isotope ratio determination) from the Caribbean Sea (Emiliani *et al.*, 1974). In spite of differences in details and in interpretation of curves, general agreement exists in the major trends in the inferred climatic fluctuations of North America, and Europe.

(3) During the glacial stages or stadials, the typical vegetation thriving today in the Subpolar or Subalpine zone of Japan prevailed at the summit area and/or the montane area around Lake Biwa and, in the lowland around the lake, plants growing today in the Cool Temperate zone were distributed. In the interglacials and interstadials, the vegetation in the higher area was characterized mainly by plants of the Cool Temperate zone and the present Temperate zone, and in the lowland, the vegetation was composed mainly of broadleaved deciduous and evergreen trees growing in the Warm Temperate zone.

(4) The remarkable-human influence that is represented by cleaning forest for rice-cultivation and by cutting woods began about 3,000 years B.P. The influence is supported by the archaeological evidence around the lake.

References

Abe, E. and Sasajima, S. (1974): Probable sedimentary thickness in Lake Biwa inferred from the gravity measurement. *IPPCCE Newsletter*, ed. S. Horie, no. 1, p. 2—3.

Bottema, S. (1974): Reconstruction of the late-Quaternary Vegetation of Northwestern Greece. In *Problems of Balkan Flora and Vegetation.* Sofia, p. 58—63.

Deevey, E. S. (1955): Some biogeographic implications of Paleolimnology. *Proc. Internat. Assoc. Theor. Appl. Limnol.*, vol. 12, p. 654—659.

Denham, C. R., Bacon, M. P. and Anderson, R. F. (1975): Status of the Blake Polarity Event. *Science*, 190, p. 62—64.

Dreimanis, A. and Karrow, P. F. (1972): Glacial history of the Great Lakes — St. Lawlence Region, the classification of the Wisconsin Stage, and its correlatives. *Internat. Geol. Congr. 1972, Sec. 12, Quaternary Geol.* ed. J. E. Gill, p. 5—15.

Emiliani, C. (1966): Paleotemperature analysis of the Caribbean Core P 63049 and a generalized temperature curve for the last 425,000 years. *Jour. Geol.* vol. 74, p. 109—126.

—— and Shackleton, N. J. (1974): The Brunhes Epoch: isotopic paleotemperatures and geochronology. *Science*, 181, p. 511—514.

Faegri, K. and Inversen, T. (1964): *Textbook of Pollen Analysis.* 237 pp. Copenhagen, Munksgaab.

Fuji, N. (1963): On the Alluvial Series in the Imizu Plain, Toyama Prefecture, p. 117—219, in *Earth Scientific Studies on Lagoon Hojozugata*, ed. Daiichi-Kowan, Toyama, 219pp.

—— (1965): Palynological Study on the Alluvial peat deposits from the Hokuriku region of Central Japan. *Bull. Fac. Educ. Kanazawa Univ.*, vol. 13, p. 70—173; vol. 14, p. 121—168.

—— (1973): Change of climate during the Wisconsin Stage based on palynological study of 200 meters core sample of Lake Biwa in Japan. *Proc. Japan Acad.*, vol. 49, p. 737—741.

—— (1974): Palynological investigations on 12-meter and 200-meter core samples of Lake Biwa in Central Japan. In *Paleolimnology of Lake Biwa and Japanese Pleistocene*, vol. 2, ed. S. Horie, p. 227—235.

—— (1975): Climatic change of the Wisconsin Stage in the Japanese Islands from the viewpoint of palynological research. *Ibid.*, vol. 3, ed. S. Horie, p. 321—353.

——(1976): Palaeoclimatic and palaeovegetational changes around Lake Biwa, Central Japan, during the past 100,000 years. *Ibid.*, vol. 4, ed. S. Horie, p. 316—356.

—— and Horie, S. (1972): Palynological study on 200-meters core sample of Lake Biwa in Japan. *Proc. Japan Acad.*, vol. 48, p. 500—504.

—— and Horie, S. (1975): Change of climate based on Palynological study of 200-meter core sample in Lake Biwa, Central Japan. *Verh. Internat. Verein. Limnol.* vol. 19, p. 2290—2297.

Hayashi, T. (1974): The Kobiwako Group in the Katata Hills, Shiga Prefecture, Japan. *Jour. Geol. Soc. Japan*, vol. 80, p. 261—276.

Hays, J. P., Saito, T., Opdyke, N. D. and Burckle, L. H. (1969): Pliocene-Pleistocene sediments of Equatorial Pacific; their paleomagnetic, biostratigraphic, and climatic record. *Geol. Soc. Amer., Bull.*, vol. 80, p. 1481—1514.

Horie, S. (1961): Paleolimnological problems of Lake Biwa-ko. *Mem. Coll. Sci., Univ. Kyoto*, Ser. B, vol. 28, p. 53—71.

——(1962): Morphometric features and the classification of all the lakes in Japan. *Ibid.*, Ser. B, vol. 29, p. 191—262.

——, Mitamura, O., Kanari, S., Yamamoto, A. and Fuji, N. (1971): Palaeolimnolgical study on lacustrine sediments of Lake Biwa-ko. *Disaster Prev. Res. Inst. Annuals, Kyoto Univ.*, vol. 14, (B), p. 745—762.

——, Mizuno, A. and Aoki I. (1974): Method and operation of deep coring at Lake Biwa. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 2, ed. S. Horie, p. 47—58.

Huzita, K. (1962): Tectonic development of the median zone (Setouti) of southwest Japan since Miocene. *Jour. Geosci., Osaka City Univ.*, vol. 2, p. 103—104.

Ikebe, N. (1933): Paleo-Biwa Series, A Pleistocene Deposit, to the West of Lake Biwa. *Chikyu*, vol. 20, p. 241—260.

Ikuse, M. (1956): *Pollen Grains of Japan*, Tokyo, Hirokawa Pub. Co., 303pp.

Ishida, S. and Yokoyama, T. (1969): Tephrochronology, Palaeogeography and tectonic development of Plio-Pleistcene in Kinki and Tokai Districts, Japan; *Quaternary Res. (Daiyonki-Kenkyu)*, vol. 8, p. 31—43.

Kanari, S. and Takenoya, Y. (1975): An estimation of the deposition rate of Lake Biwa during the past 560,000 years. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 3, ed. S. Horie, p. 235—240.

Kawai, N., Yaskawa, K., Nakajima, T., Torii, M. Horie, S. (1972): Oscillating geomagnetic field with a recurring reversal discovered from Lake Biwa. *Proc. Japan Acad.*, vol. 48, p. 186—190.

——, ——, ——, —— and Natsuhara, N. (1975): Voice of geomagnetism from Lake Biwa. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 3, ed. S. Horie, p. 143—160.

Kind, N. V. (1969): Problems concerning synchroniety of geological events and cliamatic fluctuations in Anthropogene. In *The Main Problems of Anthropogene Geology in Eurasia*, ed. A. V. Peive, p. 21—35.

Kira, T. and Iida, K. (1958): Ecological system in the mountainous areas. In *Seibutsu to Kankyo*, ed. Tamiya *et al.*, Tokyo, Kyoritsu Shuppan, p. 231—269.

Kobayashi, K. (1958): Quaternary Glaciation of the Japan Alps. *Jour. Shinshu Univ., Fac. Liberal Arts and Sci.*, vol. 8, p. 13—67.

——, Murasawa, N., Kanno, N., Murase, T., Tsuboi, N., Murata, G., Tanimoto, M. and Shinbo, T. (1974): *Shiga-ken no kicho-shizen*, Osaka, Namba Shuppan Co. Ltd., 32 sheets.

Koyama, T., Mizuno, A., Ishiwatari, R., Ogura, K., Handa, N., Terashima, M., Koyama, M., Hori, T., Okuda, J., Fujinaga, T., Takeuchi, T. and Horie, S. (1973): Chemical studies of a 200-meter core sample from Lake Biwa-ko. *Jap. Jour. Limnol.*, vol. 34, p. 75—88.

Kukla, J. (1970): Periglazialzone, Loess und Paleolithikum der Tschechoslowakei. *Geol. foreninges i Stockholm Forh.*, vol. 62, p. 149.

Kuroda, T. (1947): Freshwater Molluscs of Lake Biwa. *Yumehamaguri*, vol. 3, p. 26—51.

——(1948): List of Molluscs of Lake Biwa. *Ibid.*, vol. 22, p. 26—27.

Minato, M. (1972): Late Quaternary geology in Northern Japan. *Internat. Geol. Congr. 1972 (Canada), Quaternary Geol.* ed. J. G. Fyles, p. 63—71.

Minato, M. and Ijiri, S. (1958): *Chikyu no Rekishi*, Tokyo, Iwanami-Shoten, 217pp.

Mori, S. and Horie, S. (1975): Diatom in 197.2-meters Core Samples from Lake Biwa-ko. *Proc. Japan Acad.*, vol. 51, p. 675—679.

Nakai, N. (1973): Carbon Isotopic Composition of Lake Biwa-ko Sediments and the Environmental Change in the Depositional History. *Jap. Jour. Limnol.*, vol. 34, p. 89—96.

Ninkovich, D., Opdyke, N., Heezen, B. C. and Foster, J. H. (1966): Paleomagnetic stratigraphy, rates of deposition and tephrochronology in North Pacific deep-sea sediments. *Earth & Planet. Sci. Lett.*, vol. 1, p. 476.

Nishimura, S. and Yokoyama, T. (1975): Fission-track ages of volcanic ashes of core samples of Lake Biwa and the Kobiwako Group (2). In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 3, ed. S. Horie, p. 138—142.

Opdyke, N. D. (1972): Paleomagnetism of deep-sea cores. *Rev. Geophys. Space Phys.*, vol. 10, p. 213.

Shimakura, M. (1973): *Palynomorphs of Japanese Plants.* Osaka, Osaka Museum of Natural History. 60pp.

Takaya, Y. (1963): Stratigraphy of the Paleo-Biwa Group and the Paleogeography of Lake Biwa with special reference to the origin of the endemic species in Lake Biwa. *Mem. Coll. Sci., Univ. Kyto*, Ser. B, vol. 30, p. 81—119.

Tsuboi, C., Jitsukawa, A. and Tajima, H. (1954): Gravity survey along the lines of precise levels throughout Japan by means of a Worden Gravimeter (V). *Bull. Earthq. Res. Inst., Tokyo Univ., Suppl.*, vol. 4, 198pp.

Yamazaki, T. (1951): Studies on the changes of the forest and the climate in Southern Saghalien and Hokkaido, based on pollen analysis. *Bull, Kyoto Univ. Forest.*, vol. 21, p. 1—77.

Yaskawa, K. (1974): Reversals, excursions and secular variations of the geomagnetic field in the Brunhes normal polarity epoch. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 2, ed. S. Horie, p. 77—88.

Yokoyama, T. (1973): An outline of Quaternary system around Lake Biwa-ko and geologic observations of 200 m core sample obtained from that lake with special reference to mineralogic analysis of volcanic ash layers found in the core sample. *Jap. Jour. Limnol.*, vol. 34, p. 111—118.

——and Horie, S. (1974): Lithofacies on a 200-m core sample from Lake Biwa. In *Paleolimnology of Lake Biwa and the Japanese Pleistocene*, vol. 2, ed. S. Horie, p. 31—37.

——,——, Fuji, N., Handa, N. and Kanari, S. (1975): Comments on columns of the 200 m-long core sediments from Lake Biwa and mutual relations of the samples used for various analyses. *Ibid.*, vol. 3, ed. S. Horie, p. 81—93.

Wright, Jr., H. E., McAndrews, J. H. and van Zeist, W. (1967): Modern pollen rain in western Iran, and its relation to plant geography and Quaternary vegetational history. *Jour. Ecol.*, vol. 55, p. 415—443.

Lake Biwa 琵琶湖, Fujihara-dake 藤原岳, Fukui 福井, Gifu 岐阜, Gozaisho 御在所, Hidaka 日高, Hiei 比叡, Hira 比良, Hokuriku 北陸, Ibuki 伊吹, Iga 伊賀, Ise Bay 伊勢湾, Kaburaki 甲楽城, Kinki 近畿, Kyoto 京都, Mie 三重, Mikuni-ga-dake 三国ケ岳, Mizuguchi 水口, Nara 奈良, Nosaka 野坂, Okinoshima 沖ノ島, Omi 近江, Osaka 大阪, Otsu 大津, Shiga 滋賀, Suzuka 鈴鹿, Wakasa 若狭, Yanagase 柳ケ瀬

琵琶湖底 200 m ボーリング・サンプルの花粉学的研究 I：過去60万年間の古植生と古気候の変遷　日本における第四紀を通じての古植生の変遷とそれに基づく古気候の変化を究明して，世界における第四紀の気候変化の標準の1つにすることを目的として，1971年秋，琵琶湖の水深 65 m の湖底から約 200 m に及ぶボーリングを実施した。そして，殆んど完全に連続するコアを採集することに成功。このコア・サンプルは，研究の第一段階として，5 m 間隔で採集され，花粉分析の視点から研究された。その結果，200 m コアは19の花粉帯に区分され，約60万年間に12回の寒冷期（氷期）と10回の温和期の存在したことが確認された。このような琵琶湖における気候変化の記録をカリブ海からの酸素同位体による古水温変化と比較すると，全般的にみてよく酷似する。なお，琵琶湖底からのサンプルは，有機化学，$\delta^{13}C$，珪藻群集，フィッション・トラック法年代測定，及び古地磁気変の諸視点からも究明され，気候変化とそれらとの比較検討も併せて述べた。　藤　則雄