The Importance of Stratigraphic Investigations on Anciet Lake Biwa

The Importance of Stratigraphic Investigations on Ancient Lake Biwa[1)]

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Abstract

Lake Biwa is the third oldest lake on the globe. In 1971 and 1982-1983, respectively, the Palaeolimnological Investigation Group for Lake Biwa succeded in the drilling of the two marvelous and attractive long sediment cores, 200 and 1,400meters in length, from beneath the lake bottom in a water depth of 65 meters. This work has attracted the attention of limnologists and geoscientists throughout the world because of its importance in the investigation of palaeoclimatic change. That is, the record of the palaeoclimatic change obtained from two long cores of the lake covers all the Quaternary period, the past 2.5 million years. Because the Quaternary is also the age of human activities, it is particularly important for us to understand the changes in environmental conditions during this period. The emphasis of this article is to explain the importance of investigations on ancient Lake Biwa to understanding global palaeoclimates.

Introduction

Lake Biwa is located in the central part of the Honshu Island, Japan (Figs. 1,2). Although this lake is remarkable as the largest lake in the Japanese Islands, its antiquity is of more interest to the present writer's investigation of palaeoenvironmental change on the lake. The absolute dating by the fission-track method of sediments obtained from the lake indicates that Lake Biwa is about five million years old. This is the third oldest lake on the globe (Horie ed., 1984).

Scientific investigation on Lake Biwa poese many important and attractive problems, including not only limnology and hydrobiology of the modern lake, but also geologic and biologic history, including stratigraphy, of human impacts, palaeoclimatic changes, crustal movements, as well as speciation and migration of species during geologic history. The investigations on Lake Biwa are, therefore, interdisciplinary.

Investigations on Lake Biwa as one of the ancient lakes on the globe are especially important from the viewpoint of stratigraphy.

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Special Problems is Quaternary Stratigraphy

The Quaternary possessess rather special features that make it unique in the geologic record. But the subdivision of even this most recent part of the stratigraphic record should

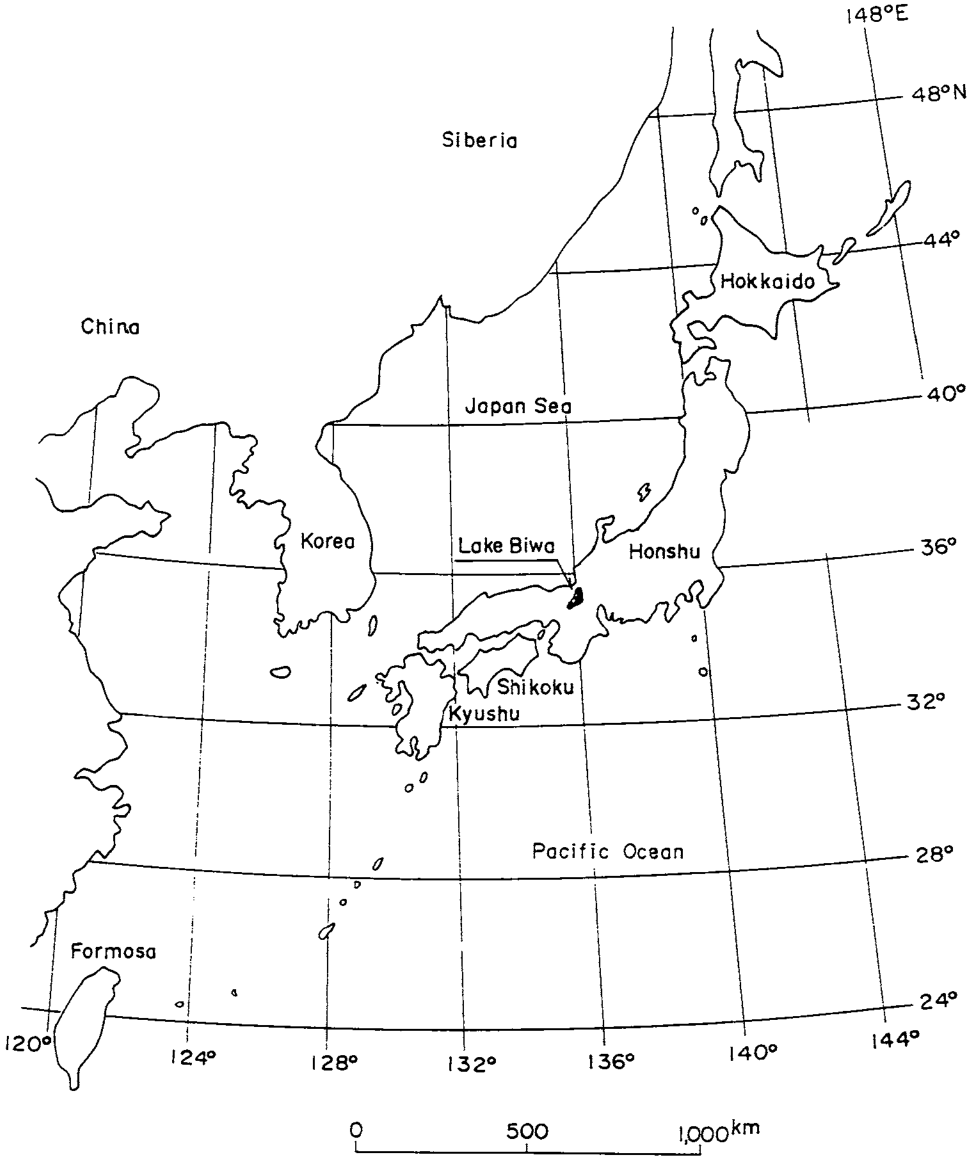

Fig. 1. Locality map showing the studied area.

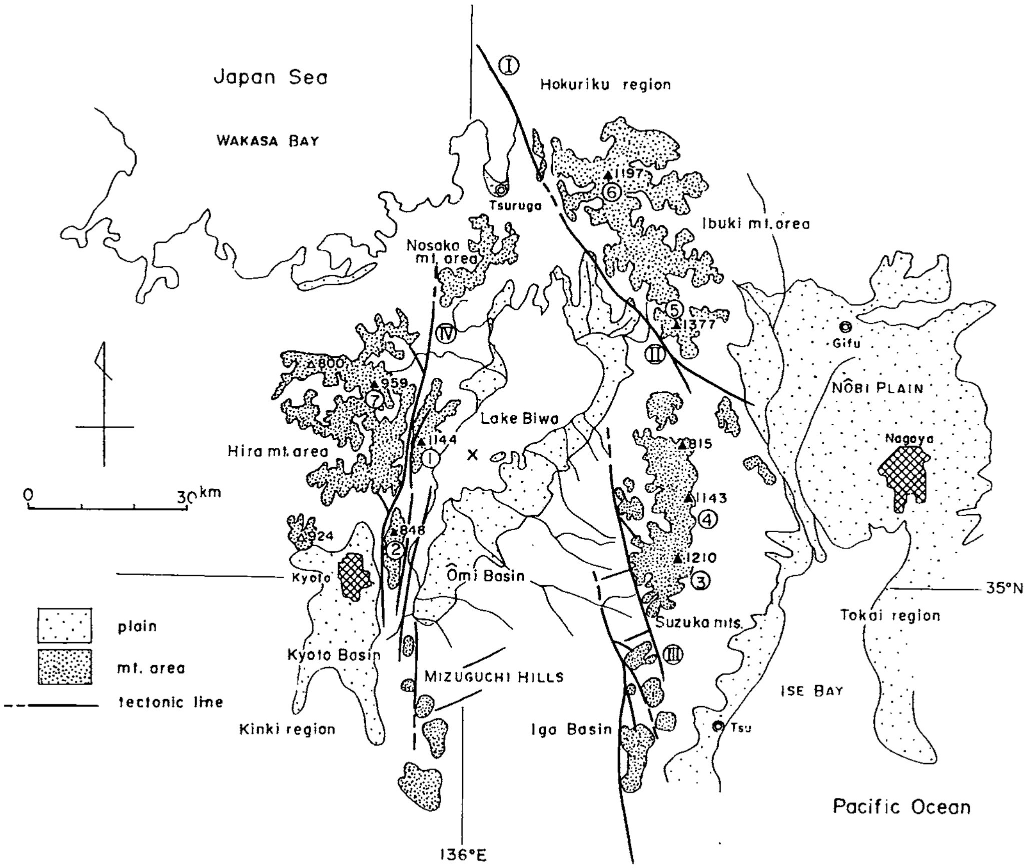

Fig. 2. Topographic map of the Lake Biwa area, central Japan. 1 : Mt. Hira, 2 : Mt. Hiei, 3 : Mt. Gozaisho, 4 : Mt. Fujihara-dake, 5 : Mt. Ibuki, 6 : Mt. Mikuni-ga-dake, 7 : Mt. Mikuni-dake,
I : Kaburaki tectonic line, II : Yanagase tectonic line, III : Suzuka tectonic line, IV : Hira tectonic line,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

follow geologic procedures. For example, in terrestrial successions, lithostratigraphy and biostratigraphy constitute the basic units of classification at the local scale, and these can be clearly defined on the basis of observable criteria.

The international Subcommission on Stratigraphic Classification (ISSC), which was set up by the International Union of Geological Sciences (Hedberg, 1976), recognises three principal categories of stratigraphic subdivision for use throught the geologic column. These are "lithostratigraphy", "biostratigraphy", and "chronostratigraphy", which is also termed "time-stratigraphy". In Quaternary stratigraphy, two further categories have been employed. These are "morphostratigraphy", which is the classification of landforms accrding to their relative order of age, and "geologic-climatic untits", which are the allotment of stratigraphic units to positions within a sequence of inferred climatic episods. The latter classification is generally referred as "climatostratigraphy".

A widely-employed basis for the subdivision of the Quaternary is climatic change, for in many instances the characteristics of the stratigraphic record can be related directly to former climatic conditions. In recognition of this fact, the American Commission on Stratigraphic Nomenclature (1961) established a new stratigraphic subdivision termed a "geologic-climatic unit". In areas affected by Quaternary glaciation, glacials and interglacials constitute the principal geologic-climatic units, while stadials and interstadials or units of lesser rank. In areas not affected by glacialice, it was anticipated that other geologic-climatic units, such as pluvials and interpluvials, would be established.

Geologic-climatic units are undoubtedly useful concepts, insofar as the Quaternary at mid- and high-latitudes tends to the subdivided into glacials and interglacials. They from the basis for stratigraphic subdivision at the continental and regional scales. However, as climatic change is time-transgressive, the boundaries of geologic-climatic units are diachronous. It, therefore, is neither appropriate to use geologic-climatic terms such as glacial or interglacial nor correct to use chronostratigraphic therms such as stage or substage.

In most areas formerly occupied by glacialice, deposits may be laid down only at a late stage in glaciation. Therefore, the actual time interval represented in the stratigraphic record by a till (geologic-climatic unit) reflects only a pary of the pariod of the glacial stage. Geologic-climatic units are in some ways similar to chronostratigraphic units, in that they are both inferential.

The fundamental problem is that it is not climate that is recorded in the stratigraphic record. Climatic reconstructions are, therefore, two steps removed from the observable date, and at each stage in the analysis, interpretation is required. For example in pollen analysis, if pollen assemblage zones are being used as the basis for geologic-climatic units, the first step is to infer vegetational communities and patterns of vegetational change from the pollen record, and the second is to use these reconstructions to infer climatic changes. Some complications that arise in the correlation of Quaternary successions are not only found in the pollen assemblage zones, but also in other fossil zones. However, clearly at the regional and continental scale, lithostratigraphy, biostratography, and climatostratigraphy are not sufficiently sensitive tools with to effect meaningful time-stratigraphic correlations.

Favourable Oxygen Isotopic Records from the Deep-seas

It has already been known that, in the deep-seas of the world, long sequences of relatively undisturbed sediments are preserved that frequently extend back beyond the beginning of the Quaternary. Within these deposits the microfauna and flora contain a record of changing oxygen isotope ratios that not only provide evidence for former glacial and interglacial oscillations, but also form the basis for stratigraphic subdivision and long-distance correlation.

Deep-sea deposits hold a number of abvantages over terrestrial sequences from the point of view of stratigraphic subdivision and correlation. First, the records are more commonly continuous and appear relatively undisturbed. Secondly, a common technique such as oxygen isotope analysis can be used to compare profiles from widely scattered localities on the deep

-sea floors. Thirdly, the pronounced terminations can be used as reference points in inter-core correlation. Fourthly, although the isotopic changes are a consequence of climatic changes, and are therefore time-transgressive, this to a very large extent is masked by the slow rate of sediment accumulation. As a consequence, isotopic stage boundaries and terminations can be interpreted as essentially time-parallel horizons. Fifthly, the sedimentary records can be dated and correlated by the independent method of palaeomagnetic stratigraphy. Although some difficulties, such as continuity of deposition, have yet to be satisfactorily resolved, there is no doubt that the isotopic trace in the ocean sediments provides an unique record of Quaternary climatic change, and it is now widely accepted that the ocean record, rather than terrestrial sequences, provides the basic framwork for a global scheme of Quaternary correlation. Bacause the isotopic stages are essentially a reflection of climatic change, they are, in effect, geologic-climatic units should have correlatives in the terrestrial record. If meaningful global correlations are to be effcted, however, a basis for correlation between the deep-sea record and more discontinuous terrestrial succession is required, and it is to the ways whereby this may be achieved that attention is finally directed.

Ultimately, stratigraphic boundaries are time-transgressive, and should ideally be underpinned by radiometric dates for the aim of correlation. Geologic-climatic units can be established and, despite the problems associated with this form of stratigraphic subdivision, these are likely to continue as the basis for correlation at the continental and regional scale. They are an essential basis for correlation between the marine and terrestrial successions. The oxygen isotope stratigraphy of the deep-sea deposits constitutes a reference standard for global correlation. Emiliani (1955) divided the oxygene isotopic curves from Atlantic and Pacific cores into sixteen stages for stratigraphic purpose. The stratigraphic subdivision of the oxygen isotope record ws subsequently extended by Shackleton and Opdyke's (1973) analysis of deposits in Core V28-238 obtained from a depth of 3,120m at 01° 01' N, 160° 29' E on the Solomon Plateau in the Western Pacific. Within this core, twenty-three isotopic stages younger than Jaramillo Geomagnetic Event were recognised, and the record was interpreted as reflecting more or less continuous deposition since about 870,000 yr. B.P.

The isotopic stages were also recognised in the upper part of Core V28-239.

In addition, in these oxygene isotopic records from deep-sea cores, a characteristic feature is that the transition from glacial to interglacial extremes occurs drastic. These rapid changes have been referred to as "terminations" by Broecker and Donk (1970). These "terminations" are shown in Fig. 3, together with the isotopic stages from Atlantic and Pacific cores.

Essential Criteria for the Use of Terrestrial Sequences in Correlation

If correlations are to be established with the oceanic successions, terrestrial sequences must possess certain characteristic features. They are mainly as the follows: (1) a lengthy stratigraphic record; (2) within terrestrial sequences, evidence of climatic change must be clear and unequivocal so that geologic-climatic units can be inferred for comparison with those based on oxygen isotope profiles; (3) the record of sedimentation must be continuous, with no hiatus or interval of non-sedimentation to pose a potential problem ; and (4) if the succession can be dated by palaeomagnetic method, palaeomagnetic stratigraphy provides a mean of direct comparison between the marine and terrestrial records.

Our understanding of climate change during the Quaternary period is 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 analysis, 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 covered by 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 on land continuous samples from 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 terms have to be satisfied if climatic changes can be investigated by means of palynological, geochemical and palaeomagnetic analyses :

The most impressive and important example of the potential of lake sediment sequences as a basis for world-wide correlation of terrestrial deposits is the record from Lake Biwa, Japan (Fuji, 1983, 1984).

There, over a thousand meters of sediment have been obtained from the lake, and these are believed to span the past 5 million years. The lake deposits contain fossil pollen grains suggesting a record of climatic change that not only provides evidence for former glacial and interglacial oscillations, but also forms the basis for stratigraphic subdivision and long-distance correlation. The deposits cotain a number of distinctive volcanic ash layers, which can be dated by the fission-track method, and further time-stratigraphic control throughout the whole sequence can be obtained from palaeomagnetic analysis.

Then, as mentioned previously, palaeomagnetic stratigraphy and climatostratigraphy have provided a mean of correlating between continents and oceans over the world, especially climatostratigraphy during the Quaternary period. Recent investigations of loess deposits from Central Europe (Kukla, 1975), and of sedimentary cycles and relative sea level changes from Mediterranean (Butzer, 1962, 1963, 1975) indicate successive changes of palaeoclimate during the Quaternary period.

One of standards for correlation in the Quaternary has been provided by aeolian depositional sequences from Central Europe.

Many soil layers are intercalated in the loess sequences, and the complete succession

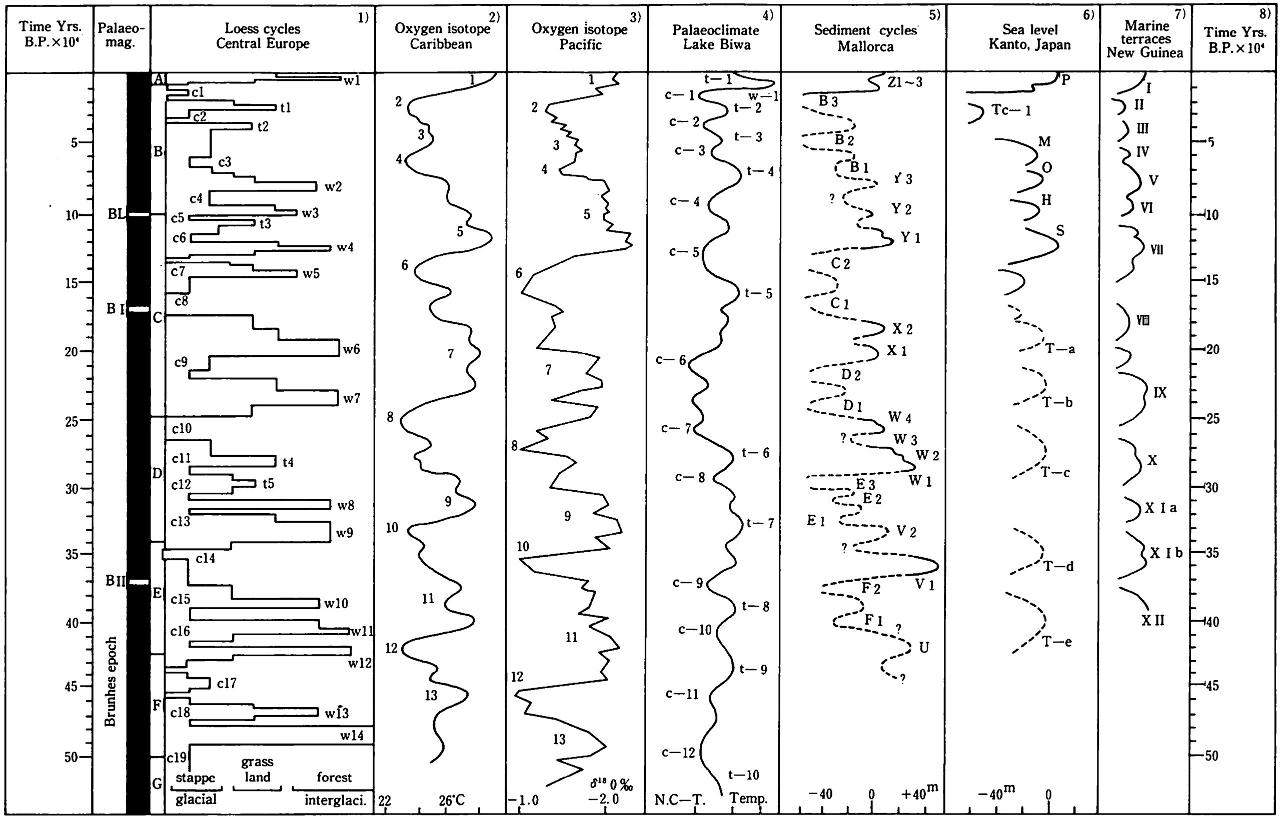

Fig.3 : Tentative comparison of the palaeoclimate from Lake Biwa, oxygen isotope records from deep-seas, sedimentary cycles from Mallorca, sea level changes from Japan and New Guinea, and Loess cycles from Central Europe.

1) : Loess cycles and climate (after Kukla, 1970, 1975) ;
2) : Isotop curve from the Caribbean Sea (after Emiliani *et al.*, 1974) ;
3) : Isotope curve from Equatorial Pacific (Shackleton *et al.*, 1973) ;
4) : Palaeoclimatic change curve from Lake Biwa (Fuji., 1983) ;
5) : Sedimentary cycles from Mallorca, Western Mediterranean (Butzer, 1975) ;
6) : Sea level changes from South Kanto, Japan (Machida, 1975) ;
7) : Marine terraces in New Guinea (Chappell, 1974).

In palaeomagnetic data, BL : Blake event, B I : Biwa I event, B II : Biwa II event ; and in Loess cycles, wl to w14, tl to t5, and cl to c19 are termed expediently for correlation by Fuji.

appears to contain a record of glacial and interglacial conditions (Kukla, 1970, 1975; Fink *et al.*, 1977). In the succession, the loess layers are interpreted as representing full glacial conditions, and on the other hand, the interbedded paiaeosols are considered to be indicative of interglacial and/or interstadial conditions. These records indicate that within the last 1.6 million years, seventeen major glacial and interglacial cycles have affected Central Europe (Fig. 3).

Since changes of eustatic sea levels are partly related to climatic changes, there should be some broad correlation between dated sea level changes in regions not affected by glacio-isostasy and the glacial/interglacial cycles recorded in the deep-sea cores. There should be some correspondence between ages of lowered sea level and cold coñdition, although climatic change and sea level change may be slightly out of phase since time is required for the melting of the ice sheets following climatic improvement.

Two problems remaining to be solved in combining the sea level change with the climatic change are: (a) Eustatic sea level changes from various regions throughout the world are affected by both the voluminal change of ocean water and tectonic movement; and (b) the correlation between the quantity of ice sheets and the global climate has not been well established.

A work on the Pleistocene sedimentary records of Mallorca in the Western Mediterranean is a typical example for comparison between deep-sea and terrestrial records. Parts of the Mallorcan littoral with arid climate and characterized by well-developed and widespread calcareous dunes (Butzer, 1962). According to Butzer (1963), these aeolian sediments accumulated through deflation of freshly-exposed marine deposits during glacio-marine regressions, and each regression can be correlated with each glacial period in areas affected by glaciers. Interglacial high sea levels are recorded by marine terraces and beach deposits. The shoreline stratigraphy in Mallorca is divided into six terrestrial and six marine hemicycles, which have been deted partly on the basis of biostratigraphy and radiometric dating of marine shells (Butzer, 1975). These sequence can be correlated with the loess sequence in Central Europe, and with the oxygen isotope records from the deep-sea floors. It is this type of record combining evidence of both terrestrial and deep-sea changes that offers one of the attractive means of correlation between the marine and terrestrial successions.

Significance of Research on Deposits from Lake Biwa

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, some 15,000 to 20,000 years before the present, an ice sheet covered the northern 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 devoid 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.

According to a few glacial-geological field works (Minato, 1972; Kobayashi, 1958; and Horie, 1961, 1984), several expansions of glaciers probably occurred in the Japanese Islands during the Wichselian 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.

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, as are correlations with earlier glaciations in Europe and North America. Therefore, if we do not want to lose ourselves in a terminology based on inaccurate correlations, it seems necesary to establish a stratigraphic nomenolature 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. For example, 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 areas.

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; 1984). 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 See.

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

a) A strikingly negative gravity anomaly exists in the northern part of the lake, 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. 1,000m class> lacustrine sediments.

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

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

A deep boring in such a lake having an. extremely long limnetic history must yield valuable samples for palynological research. These samples contain continuous record of the change in climate since the latest Pliocene or earliest Pleistocene. These results may be correlated with changes of climate during the Quaternary period already worked out in various localities of lands and deep-oceans. From those view points it may be said that the long core is significant for the promotion of our knowledge on the Quaternary geology not only in the Japanese Islands but also in the other countries of the world.

With this objective in mind, a project was proposed to study 200-metar and 1,400-meter sediment cores obtained from Lake Biwa in 1971 and 1982 to 1983 (Horie, 1984). As a member of the research term, the present writer has been engaged in an intensive investigation of the palaeolimnological evidance of the subsurface deposits of the lake.

A detailed record from the cores and the interpretation correlated with the records from the deep-sea and from loess deposits in Central Europe will be presented in the near future.

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