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The Basis of the Plio-Pleistocene Boundary in Japan*

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(With 3 Tables and 4 Text-figures)

Foreword

From May 22 to June 4, 1972, the International Colloquium of the Problem "The Boundary between Neogene and Quaternary" was held in Kishinev and Tbilisi of the USSR under auspices of the INQUA Subcommission on the Pliocene-Pleistocene Boundary.

In compliance with the request from Professor K.V. NIKIFOROVA, Geological Institute, Academy of Sciences of the USSR, the Chairman of this Subcommission, the authors have sent to this Colloquium a paper entitled "The basis of the Plio-Pleistocene boundary in Japan". M. ITIHARA and K. SUZUKI attended this Colloquium, and this paper was read by M. ITIHARA.

By kindness of the Organizing Committee this paper was printed in the Volume 2 of the Collection of Papers (ITIHARA, M. *et al.*, 1972), however, it seems better to re-publish it as these offset-printed original volumes of Collection of Papers are supposed to be restricted in distribution. The paper presented here is a facsimile of the original paper but for some minor changes in wording.

Our cordial thanks are to the people, to whom we have owed very much in preparation of the manuscript: the members of the Osaka Group Research Group, the South Kanto Quaternary Research Group, and the Nanaorizaka Research Group. No less sincere thanks are due to advices, discussions and helps from Professor N. IKEBE, Department of Geosciences, Faculty of Science, Osaka City University, Dr. S. IJIRI, the member of the Association for the Geological Collaboration of Japan, Professor M. MINATO, Institute of Geology and Mineralogy, Faculty of Science, Hokkaido University, and Professor K. SOMA, Institute of Biology, Faculty of Science, Tohoku University.

Introduction

The Plio-Pleistocene formations of Japan have been formed by basin-forming movements since Pliocene. These sediments attain about 4,000 m. thick in coastal areas in their full development while in inland areas about 1,000 m. thick in maximum. The coastal successions are represented by marine, fluvial and lacustrine sediments whereas the inland

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successions mainly by fluvial and lacustrine sediments. Volcanics and tephra are also widely developed and many tephra layers intercalated within these sediments have been evaluated as very effective key layers in building up the stratigraphy. However, detailed studies on these Plio-Pleistocene formations have been carried out only in recent years (Fig. 1).

The first discussion meeting on the Plio-Pleistocene boundary in Japan—"The Boundary Problem of Pliocene and Pleistocene in Kanto District"—was held at Tokyo in 1933 (Geol. Soc. Japan, ed., 1933). At that time the Calabrian and Villafranchian were believed to be late Pliocene and the stratigraphy of the Plio-Pleistocene successions in South Kanto was not fully established as yet. The 1948 recommendations from the 18th International Geological Congress (London) were not delivered to the Japanese geologists immediately after the Congress (Pliocene-Pleistocene Boundary Commission, 1950), but after their introduction by IKEBE (1953), YABE (1954) and ASANO (1954) geologists' interest on the boundary problem increased rapidly and some contributions were published about the Plio-Pleistocene sediments in the areas where more detailed stratigraphical studies had been worked out. Most of these studies concern the marine faunas from the Kazusa Group of the Boso Peninsula, where a continuous marine succession is well developed, and also the plant

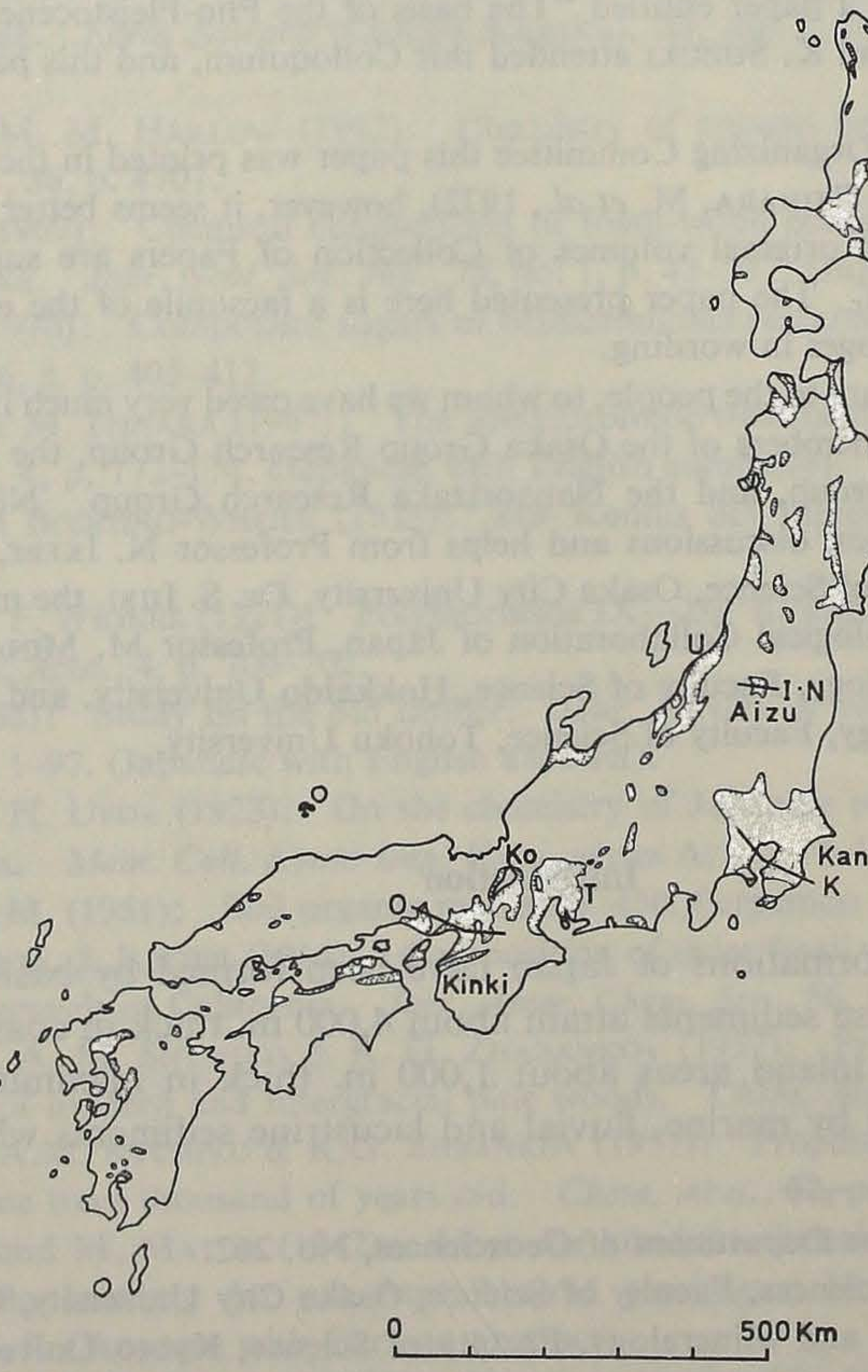

Fig. 1 Distribution of the Plio-Pleistocene sediments in Japan
Bold line shows the location of geological profiles.
O: Osaka Group, K: Kazusa Group, I·N: Izumi and Nanaorizaka Formations, Ko: Kobiwako Group, T: Tokai Group, U: Uonuma Group.

remains and fossil proboscidians from the Osaka Group, which is composed of lacustrine, fluvial and marine sediments.

The post-war progress of Quaternary research in Japan was indebted much to the investigations of the Kanto Loam Formation —the middle and late Pleistocene weathered tephra—which had been initiated by the Kanto Loam Research Group in 1953 (Kanto Loam Research Group, 1965). The versatile activities of this Research Group promoted the subsequent Quaternary research in Japan, which led to establishment of many research groups in various regions of Japan. However, reseach objects of these groups were mainly the middle and late Pleistocene stratigraphy, and as to the Plio-Pleistocene boundary problem only a lesser number of contributions were published. In a large volume entitled "*The Geologic Development of the Japanese Islands*" appeared in 1965 (Minato, Gorai and Hunahashi, ed., 1965) the Osaka and Kazusa Groups were selected as standard Plio-Pleistocene successions in Japan. At present the Pliocene-Pleistocene studies are vigorously carried on by the Quaternary research groups in so many areas such as Hokkaido, Tohoku, Fukushima, Niigata, Kanto, Shinshu, Hokuriku, Tokai, Kinki (Osaka and Kyoto) and San-in Districts etc. The results obtained by these research groups in the years from 1967 to 1970 are summarized in a monograph "*Quaternary System of Japan*" (Research Group on the Quaternary of Japan, ed., 1969) and a special issue of *The Quaternary Research* "Problems of Early Pleistocene" (Japan Association for Quaternary Research, ed., 1970).

In the London recommendations the type area of the Plio-Pleistocene boundary was set in South Italy. So far as the base of Pleistocene should be drawn at the base of Calabrian, the only aim of the present contribution must be discussing what horizon of Japanese Plio-Pleistocene successions can be strictly correlatable to the basal Calabrian. A recent trend of the Plio-Pleistocene boundary research in the world seems focused in palaeomagnetic and absolute chronology and planktonic foraminifer, discoasterid and nannoplankton biostratigraphy. In Japan, beside biostratigraphical studies based on larger plant remains, fossil pollens, proboscidian mammals and foraminifers, studies with help of the aforesaid new methodology are now in progress.

Worth notice is the concept of "Anthropogene" proposed by A.P. Pavlov (1922) for the Quaternary period as a term that means the age of mankind. In the Quaternary studies this line of general thinking should be of prime importance. Ijiri (1969), emphasizing the significance of the Quaternary period as the age of man, concluded that the Plio-Pleistocene boundary must be defined by the appearance of mankind. However to date, unfortunately the Plio-Pleistocene boundary in Japan could not have been decided based on the remains of mankind and its culture due to a very poor occurrence of them.

Nevertheless it is possible at present to mark off the beginning of remarkable climatic deterioration in the Neogene successions in several areas of Japan. In fact there are many reasons that allow us to believe that the said horizon is correlatable almost with the base of type Calabrian. In the present contribution we are willing to give some generalized accounts about several representative Plio-Pleistocene successions, which have been stratigraphically studied in detail by means of tephra and chronologically checked by the data of various faunas and floras, palaeomagnetism and absolute age measurements. The three successions here selected are the Osaka Group in Kinki District (lacustrine, fluvial and marine sediments), the Kazusa Group in South Kanto District (mostly marine but in the western and north-western areas lacustrine and fluvial sediments), and the Izumi and Nanaorizaka Formations in Aizu District, Fukushima Prefecture (lacustrine and fluvial sediments with a lot of tephra layers).

A more fruitful discussion can be made on the Uonuma Group in Niigata District (Fig. 1) about which have been rapidly accumulated the data of plant remains, palaeomagnetism and fission-track ages in recent years. However, the authors should like to find another opportunity of discussing the chronology of this group, one of the most excellent object in considerating the Plio-Pleistocene boundary problem.

The Osaka Group

In Harima, Osaka, Kyoto and Nara Basins of Kinki Districts are developed the Plio-Pleistocene sediments composed of unindurated sand, gravel and clay of lacustrine, fluvial and marine origin with a number of tuff layers. These sediments are named the Osaka Group (Osaka Group Research Group, 1951), which has been considered as a standard Plio-Pleistocene succession in Japan.

As schematically shown in Fig. 2, in Osaka Basin several physiographical units made from various geological formations are discriminated. They are mountainous terrain of the pre-Tertiary basement complex; hills of the Kobe and Nijo Groups (Miocene); hills of the Osaka Group (late Pliocene to early Pleistocene); uplands and terraces of the High, Middle and Low Terrace deposits (middle and late Pleistocene); and lowland (or the Recent* alluvial plain) of the Recent alluvium (latest Pleistocene and Holocene). The Recent alluvium and the Terrace deposits are represented by sediments of 10 to 40 m. or less thick, while the Osaka Group is composed of sediments of 200 to 600 m. or more in thickness, and

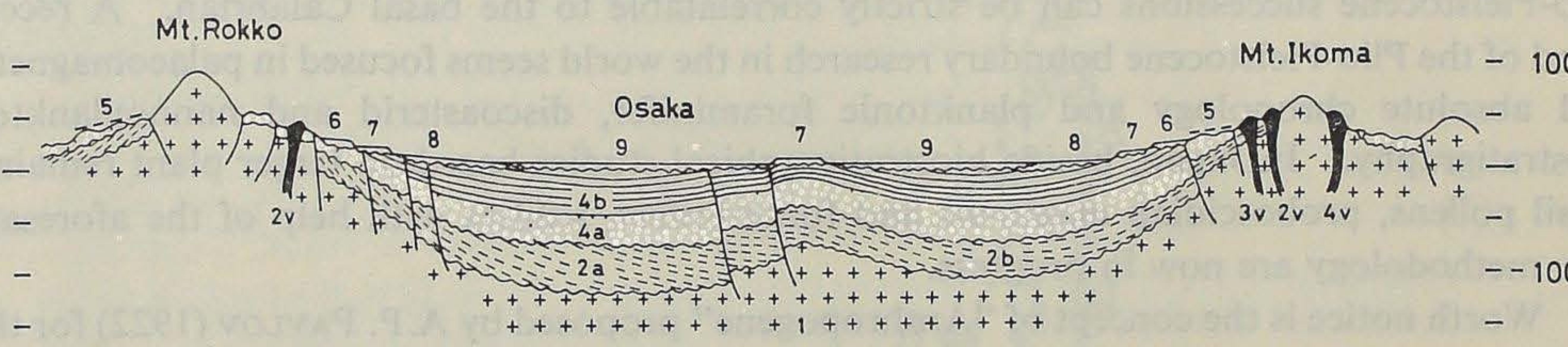

Fig. 2 Geological profile of Osaka Basin (ITIHARA, M., 1966)
1: Basement complex (pre-Tertiary), 2a: Kobe Group (Miocene), 2b: Nijo Group (Miocene), 2v: Middle to late Miocene volcanics, 3v: Latest Miocene to early Pliocene volcanics, 4a: Lowermost to lower part of Osaka Group (late Pliocene to earliest Pleistocene), 4b: Upper part of Osaka Group (early Pleistocene), 4v: Plio-Pleistocene volcanics, 5: Setouchi surface (post-Osaka Group~pre-Terrace deposits), 6: High Terrace deposits (middle Pleistocene), 7: Middle Terrace deposits (middle Pleistocene), 8: Low Terrace deposits (late Pleistocene), 9: Recent alluvial deposits (late Pleistocene to Holocene)

the Kobe and Nijo Groups attain more than 200 m. thick. Each of these geological units are unconformably underlain by the subjacent units. The hills in Osaka Basin are characterized by an accordance of crest levels and the surface restored by connecting these crests has been defined as a probable erosion plain under the name of the Setouchi surface. The geological age of this surface can be assigned to the time interval between the Osaka Group and the Terrace deposits.

The Osaka Group are folded and displaced by faults—the throw is estimated as 200 to

* Recent means latest Pleistocene to Holocene in this paper.

300 m. in maximum—, no remnants of deposition surface being found in the Osaka Group terrain, while in the terrace and lowland areas deposition surfaces are very distinct, the faults, if present, being minor in scale with a throw of less than 10 m. or so. The crustal movements since the age of the Osaka Group up to the present is called the Rokko movements (IKEBE and HUZITA, 1966) with its supposed climax in the time interval between the top of the Osaka Group and the Higher High Terrace deposits.

The Osaka Group can be subdivided by means of tracing of tuff layers and marine clay beds (ITIHARA, M., 1960; ITIHARA *et al.*, 1966). Among these key horizons with regional significance the most remarkable ones are (in ascending order): Shinden, Yellow, Pink, Azuki, Sakura Tuff Layers (maximum thickness 3 to 4 m.), and Ma0 to Ma9 Marine Clay Beds (maximum thickness 10 m. or so in the hill areas) (Table 1). Heavy mineral composition and properties of volcanic glass of these tuff layers (YOKOYAMA and KUSUKI, 1969) serve as diagnostic criteria for correlation of the Osaka Group and its allies in the neighbouring areas (the Kobiwako* Group in Lake Biwa District and the Tokai Group in Nagoya District). The marine clay of the Osaka Group was deposited under reductive, oxygen-poor environments of inner bay, and when weathered under oxidizing conditions, is fractured conchoidally, segregating sulphur and gypsum on the weathered surface (ITIHARA, Y., 1960), which faciliate to distinguish the marine and freshwater clays in the field.

A number of fossil plants and animals are yielded from the Osaka Group, among which the most important are larger plant remains and proboscidians found from various horizons of this group.

Larger plant remains were taxonomically studied in detail first by MIKI (1941a, 1941b, 1948), and then stratigraphically checked by HUZITA (1954). Later, by establishing a detailed stratigraphy and reexamining the horizon of the plant-bearing beds, ITIHARA came to a conclusion: "The age of the lowermost Osaka Group is a warm climate age which can be characterized as the age of *Metasequoia* flora flourish, but in accordance with the climatic deterioration the *Metasequoia* flora entered into the age of extinction··· and at last this flora disappeared before a cold time just below Azuki Tuff Layer, then the climatic amerioration recurred··· In the Osaka Group, the beginning of the age of extinction of *Metasequoia* flora, i.e. the beginning of climatic deterioration, should be inferred as the Plio-Pleistocene boundary". (ITIHARA, M., 1960).

Later, he (ITIHARA, M., 1966; ITIHARA, M. and KAMEI, 1970) lowered the lower limit of his age of *Metasequoia* flora flourish downwards to the base of the Tokai Group, namely to the base of *Pinus trifolia* Bed** (MIKI, 1941a, 1948). The *Metasequoia* flora is a Tertiary-type flora composed of *Metasequoia*, *Glyptostrobus*, *Sequoia*, *Picea koribai*, *Juglans megacinerea*, *Liquidambar*, *Ginkgo*, *Pseudolarix*, *Keteleeria*, *Pinus fujii*, *Nyssa*, *Carya*, *Hemitrapa*, *Pinus trifolia* and other elements. As shown in Table 1 the *Metasequoia* flora from the lowermost Osaka Group has yet maintained the essential characters as Tertiary flora despite that *Nyssa*, *Carya*, *Hemitrapa*, *Pinus trifolia* are lacking. Therefore it can be considered that the climatic fluctuation was feeble during the time when the basal Tokai Group and the lowermost Osaka Group were being deposited.

The entry of climatic deterioration in the Osaka Group is evidenced by the appearance

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* Kobiwako means the Palaeo-Biwa Lake.

** KOKAWA (1964) called the flora from the *Pinus trifolia* Bed the *Pinus trifolia* flora, that from the lowermost Osaka Group the transitional flora, and that from the lower Osaka Group the *Metasequoia* flora.

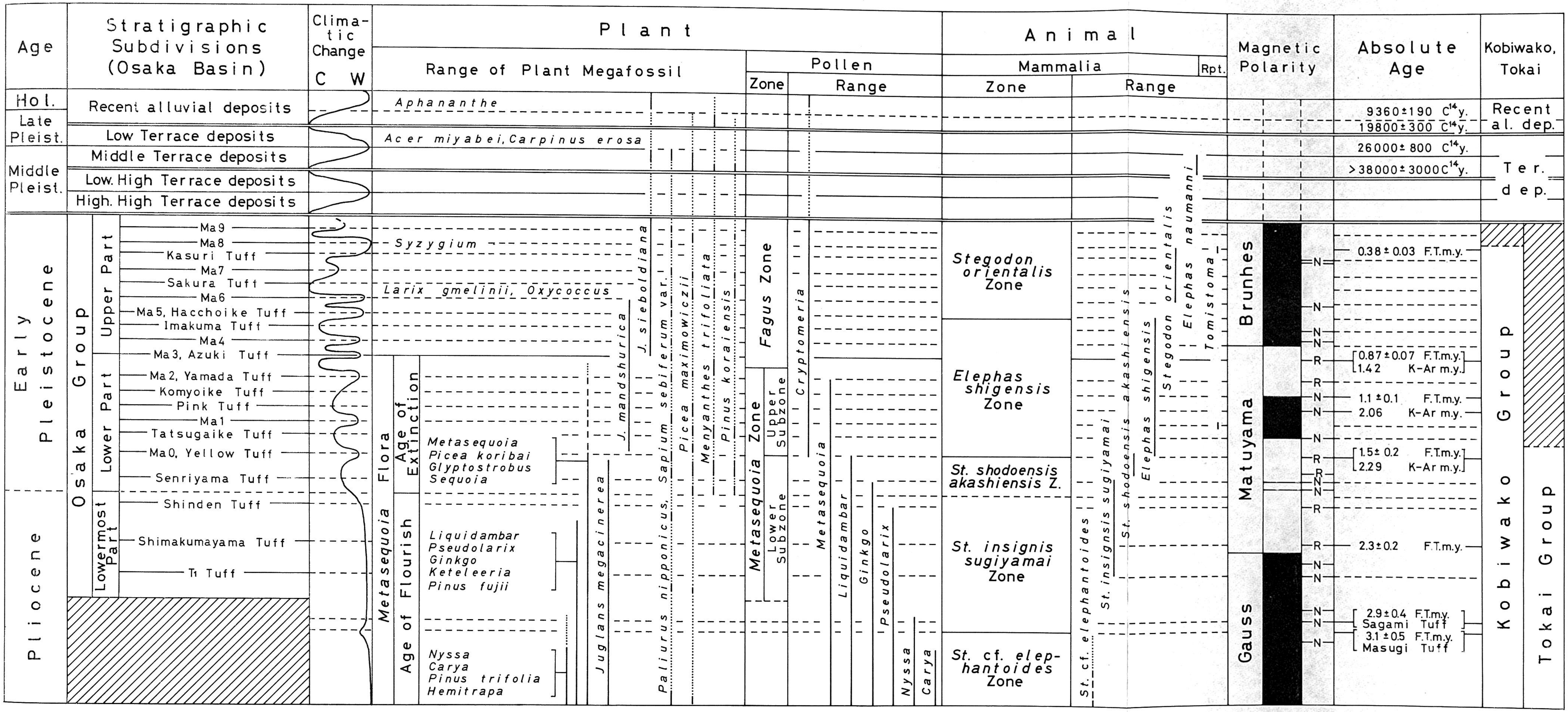
of *Menyanthes* and subalpine species such as *Pinus koraiensis*, *Picea maximowiczii* in combination with the extinction of *Metasequoia* flora. The successive appearance of *Menyanthes*, *Pinus koraiensis* and *Picea maximowiczii* as larger remains is ascertained in the interval spanning between Shinden Tuff Layer and a horizon somewhat below Ma0 Bed (Ibaragi Research Group, 1966), thus the first indication of this remarkable floral change being restricted to the interval between Shinden and Senriyama Tuff Layers. The last-named interval can be defined as the lower limit of the age of *Metasequoia* flora extinction. The last relics of *Metasequoia* flora such as *Metasequoia* and *Picea koribai* disappeared before the entry of a colder spell detected from just below Azuki Tuff Layer. Following the extinction of *Metasequoia* flora a new type flora appeared. For example, *Juglans mandshurica*, and then *Juglans sieboldiana* entered in as alternatives of *Juglans megacinerea* (NIREI, 1970).

The climatic fluctuation became intense after the disappearance of *Metasequoia* flora, namely in the time of the upper Osaka Group. This fact implies the entry of glacial age which was associated with more or less evident climatic fluctuation as proved by the successive and alternating occurrence of plant fossils characteristic of colder and warmer climates. The occurrence of *Larix gmelinii*, *Pinus koraiensis* and *Oxycoccus palustris* from the interval between Ma6 and Ma7 Beds (cold), *Syzygium buxifolium* and *Podocarpus nagi* from Ma8 Bed (warm), and *Pinus koraiensis* and *Picea maximowiczii* from the interval between Ma8 and Ma9 Beds (cold) (Komyoike Research Group, 1971) are believed to be good indications for the said climatic fluctuations.

In the last decade many important informations were brought also from palynological studies of the Osaka Group and its allies. TAI (1966, 1970) subdivided the Osaka Group into the *Metasequoia* and *Fagus* zones by drawing a boundary at the base of Ma3 Bed (Table 1). According to TAI, the entry of climatic deterioration can be detected at a horizon a little above Ma0 Bed, namely within her *Metasequoia* zone, and she divided the last-named zone into the lower and upper *Metasequoia* subzones by taking the aforesaid horizon as the boundary. Interesting is that the lower and upper suzones nearly correspond respectively to the ages of flourish and extinction of ITIHARA's *Metasequoia* flora. No less noticeable is the result obtained from pollen analysis of the Kobiwako Group by NASU (1971). He reported that the basal part of this group is rich in *Carya* and *Nyssa*, however *Carya* became extinct just before a cooler spell of Masugi Tuff Layer while *Nyssa* also disappeared soon after this cooler time. The floral succession revealed from these palynological analyses well coincides with that of the *Metasequoia* flora which have been induced on the basis of larger plant remain studies.

The Osaka Group has been noted long because of the occurrence of rich mammalian faunas, on which stratigraphical studies have been made by IKEBE *et al.* (1966) and KAMEI and SETOGUCHI (1970). KAMEI found that the Osaka Group and its allies (the Kobiwako and Tokai Groups) could be subdivided into the following mammalian zones (in ascending order): Zone 1 of *Stegodon* cf. *elephantoides*, Zone 2 of *Stegodon insignis sugiyamai*, Zone 3 of *Stegodon shodoensis akashiensis*, Zone 4 of *Elephas shigensis*, and Zone 5 of *Stegodon orientalis*. He correlated Zone 1 to the lower Villafranchian, Zone 2 to the middle Villafranchian, Zones 3 and 4 to the upper Villafranchian, and Zone 5 to the post-Villafranchian. According to KAMEI the most characteristic forms of each zone are: Zone 1—the temperate-forest elements of the Indo-Malayan faunal complex widely distributed in Southeast Asia and its environs in late Pliocene; Zones 2 and 3—the remnants of the Indo-Malayan faunal complex and the temperate-forest to grassland elements of the Nihowan fauna of the earliest

Table 1. Pliocene-Pleistocene chronology of the Osaka Group (ITIHARA, M. and KAMEI)



Pleistocene in North China (a mixed faunal complex); Zone 4—the elements of the Nihowan fauna and/or the temperate-forest to grassland elements of the early Pleistocene Choukoutien fauna; and Zone 5—the temperate elements of the middle Pleistocene Wanhsien fauna vigorously developed in South China. *Tomistoma machikanense* from just below Ma8 Bed belongs to the Zone 5 faunal assemblage.

Taking account of the Pliocene-Pleistocene faunal gap (at the boundary between the Zones 1 and 2), the intra-Villafranchian faunal turnover (during the interval from the Zones 1 to 4), and the Villafranchian-post-Villafranchian faunal gap (at the boundary between the Zones 4 and 5), KAMEI pointed out that this process of faunal change could be paralleled to the floral succession since the beginning of the age of *Metasequoia* flora flourish through the age of its extinction then to the following age which was characterized by alternating appearance of new elements of colder and warmer floras (KAMEI and SETOGUCHI, 1970). According to his conclusion the horizon of the aforesaid Pliocene-Pleistocene faunal gap can be placed at least lower than the beginning of the age of *Metasequoia* flora extinction, namely lower than Shinden Tuff Layer. However, more detailed study on the mammalian faunas from the Zones 2 and 3 seems necessary before any more reliable conclusion will be made. It appears very probable that the Plio-Pleistocene boundaries estimated independently from the successions of the mammalian faunas and floras would well coincide to each other in the future.

Passingly to say, occurrence of a left pelvic bone of primitive man was reported from the Byobugaura Clay Bed (a Ma0 equivalent) at the coast of Akashi in Harima by HASEBE (1953) and TAKAI (1953). This bone was named *Nipponanthropus akashiensis* but its exact horizon remains unknown.

Among the results of palaeomagnetism studies must be first referred that of KAWAI (1951) which offered evidences proving that Azuki Tuff Layer was reversely magnetized. The result of a recent palaeomagnetism study on the pyroclastic markers intercalated within the Osaka Group and its allies (ISHIDA *et al.*, 1967) is shown in Table 1. The data suggest that the Osaka Group ranges from the late half of GAUSS normal epoch to the early half of BRUNHES normal epoch of COX's magnetic chronology (COX and DALRYMPLE, 1967; COX, 1969). As previously noted, in the Osaka Oroup the Plio-Pleistocene boundary estimated from the study of plant fossils, namely the lower limit of the age of *Metasequoia* flora ex-inction, falls in the interval between Shinden and Senriyama Tuff Layers. Worth notice is that ISHIDA *et al.* (1967) correlated this interval to the Olduvai normal event based on their palaeomagnetism study.

As to the tuff layers of the Osaka Group absolute age measurements by means of fission-track and K-Ar methods were applied (NISHIMURA *et al.*, 1970; KANEOKA *et al.*, 1970). As shown in Table 1 the absolute ages secured by these two methods disagree with each other, the K-Ar dates surpassing the fission-track dates. Seemingly more reliable is the latter, which shows a more good correspondence to COX's chronological scale. Then it may be said that the absolute age of the Osaka Group probably ranges from 3.0 to 0.3×10^6 years and that the beginning of the age of *Metasequoia* flora extinction is dated about 2.0×10^6 years.

A bit of words may be added on some recent researches of the Osaka Group made on lines of approach different from the aforesaid basic or current methods. One is the study on amino acid content of muddy sediments from the Osaka Group (ITIHARA, Y. and M., 1968). The amino acid identified from the Osaka Group are enumerated 19 showing a similar proportion throughout all the horizons of the Osaka Group. The total amount of amino acid ranges 0.052 to 0.006% in the upper part, 0.006 to 0.001% in the lower part, and 0.002 to 0.001% in the lowermost part. Thus the amino acid content decreases exponentially from the top of this group downwards to the lower part then attaining an almost constant level in the lowermost part. As the amino acid content of the Holocene muddy deposits in Osaka District is measured 0.14% on an average, the amino acid content reduces to 1/70 to 1/140 at near the Plio-Pleistocene boundary in the Osaka Group.

Another type of study is on the main chemical components of fossil wood from the late Cenozoic sediments in the environs of Osaka by means of acetylbromide extraction (ITIHARA, Y. *et al.*, 1966; KAGEMORI and M. ITIHARA, 1967). Acetylbromide dissolves away cellulose, hemicellulose and lignin out of fossil wood, but no humic substance which had altered from the aforesaid original components of living wood. The percentage of acetylbromide-soluble substance of fossil wood is estimated 100 to 89.3 in the Holocene materials but decreases downwards to 86.8 to 67.8 in the Terrace deposits, 62.7 to 49.3 in the upper Osaka Group, 44.8 to 28.4 in the lower and lowermost Osaka Group attaining 0 in the Miocene Nijo Group. Therefore the content of residual soluble components can be estimated $35 \pm 10\%$ at around the Plio-Pleistocene boundary.

The foregoing is a brief summary of recent results of chronological studies of the Osaka Group, which could be made only on the basis of its detailed stratigraphy firmly established in the field. In the present status it must be emphasized that there remain some problems unsolved in the stratigraphy of the lowermost part of this group. Nevertheless it can be safely said that on the basis of the succession of *Metasequoia* flora, the Plio-Pleistocene boundary in the Osaka Group can be placed at the basal horizon of opening of climatic deterioration which coincides with the beginning of the age of *Metasequoia* flora extinction. It can be noted that a fairly well coincidence can be seen between the successions of the mammalian faunas and the *Metasequoia* flora. Synthetic approaches to the study of the Osaka Group must be enforced further in the future and this will raise far more than to date the standing of the Osaka Group as a standard Plio-Pleistocene succession in Japan.

The Kazusa Group

The Kazusa Group is the Plio-Pleistocene sediments widely developed in South Kanto District (Fig. 1). The Kazusa Group, in particular in the Boso Peninsula area, has long been investigated as one of the most representative marine deposits of this age in Japan.

A new stage of the geological researches of the Boso Peninsula was reached at about the mid-1950s. The monumental works that mark the opening of this new epoch are KOIKE's comprehensive study on the tectonic development of the Peninsula as an essential part of South Kanto tectonic province (KOIKE, 1957) and the establishment of a detailed stratigraphy of the Kazusa Group by means of pyroclastic marker tracing by MITSUNASHI and YAZAKI (1958). Since then most of investigations have been carried out on the basis of the stratigraphy established by MITSUNASHI and others.

The importance of the Kazusa Group as the research object of the Plio-Pleistocene boundary problem in Japan is due to that this group is composed of successive and conformable thick marine sediments interbedded with many excellent pyroclastic markers as well as that not only various marine fossils and microfossils but also a variety of terrestrial fossil mammals and pollens are abundantly found from this group. The discussions by ASANO and others on the boundary problem on the basis of planktonic foraminifers (Boso

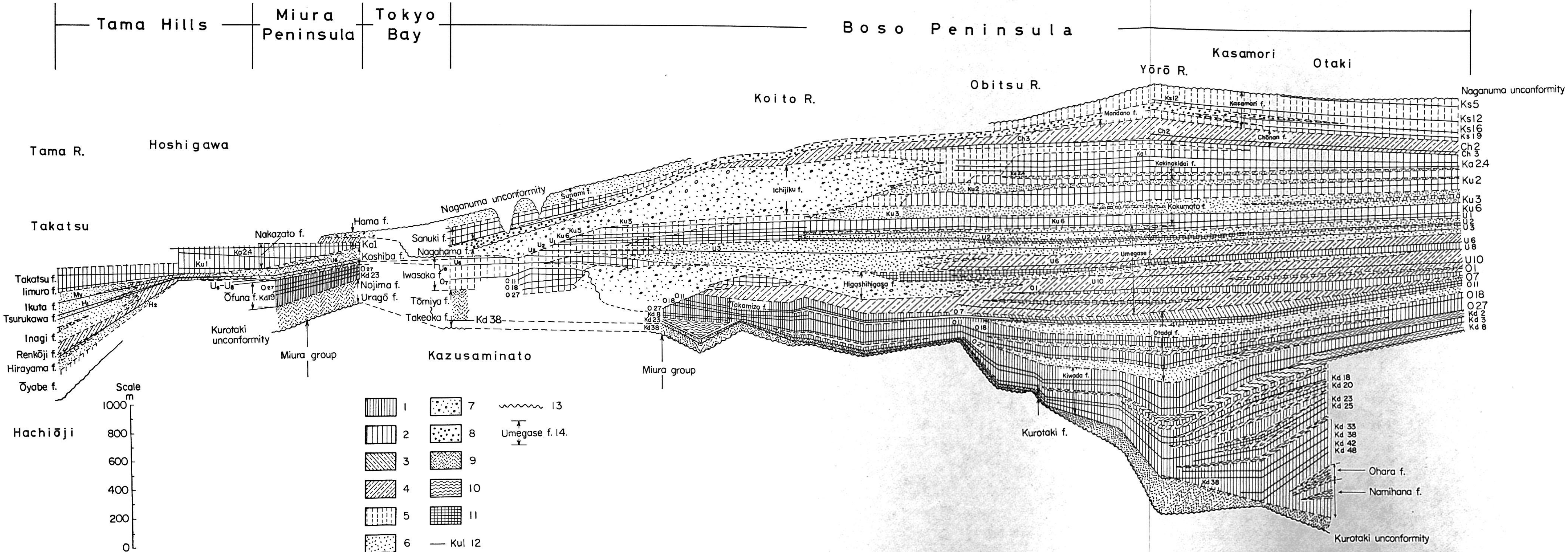


Fig. 3 Stratigraphical profile of the Kazusa Group (MITSUNASHI, 1968)
1: Mudstone, 2: Sandy mudstone, 3: Alternation of sand and mud (mud dominant), 4: Alternation of sand and mud (sand dominant), 5: Muddy sand, 6: Fine to medium sand, 7: Coarse sand (with gravel), 8: Gravel, 9: Tuffaceous sand, 10: Intraformational convolution (deep-seated-type submarine slide), 11: Intraformational convolution (surface-type submarine slide), 12: Pyroclastic key layer, 13: Unconformity, 14: Type locality of formation

Research Group, 1957; Boso and Miura Research Group, 1958) were the forerunner which led the modern chronological studies in the 1960s, and this is due largely to that the Kazusa Group of this peninsula is represented mostly by marine sediments of deeper water facies in which possibilities of international correlation are supposedly concealed.

Meanwhile the tephra found in the Boso area have been traced towards east, northwest and west as shown in Fig. 3, which made possible a regional correlation of this group between the Tama Hills, the Boso and Miura Peninsulas. The Kazusa Group laterally changes its facies from marine to terrestrial in the northwestern areas where larger plant remains are yielded though not so rich in number. This implies a future possibility of correlating the marine and terrestrial successions of the geological age in concern.

In the following lines the authors are willing to outline the results of studies worked out mainly in the 1960s and to discuss in short the Plio-Pleistocene boundary problem in the Kazusa Group.

Studying the planktonic foraminifers from the Kazusa Group ASANO and others pointed out that at near the middle part of Umegase Formation a cold water species *Globigerina pachyderma* rapidly increased in number in parallel with a remarkable decline of warm water species (Boso Research Group, 1957; Boso and Miura Research Group, 1958). Taking into account that this faunal change marks the first remarkable decrease of water temperature in the Kazusa Group they proposed the Plio-Pleistocene boundary to be placed at a horizon near U_6 Tuff Layer. However, AOKI (1964), based on the change in composition of planktonic foraminifer assemblages as related to water temperature fluctuation, concluded that the faunal change at the middle Umegase Formation was not so evident as ASANO and others had emphasized. According to AOKI, variations in assemblage composition are minor throughout the Kazusa Group, and only a few horizons of obvious warm or cold waters can be discriminated. The sediments which have been supposedly deposited under influence of cold current are in the following four horizons: the interval from the upper Otadai to the lower Umegase Formations, and those of the uppermost Umegase, the Chonan, and the upper Kasamori Formations. These colder horizons are traceable widely in the Boso area (AOKI, 1964). The results obtained by AOKI are re-interpreted here and shown in terms of relative temperature fluctuation in Table 2 (Temp. Planktonic Forams) with a slight modification and generalization. As shown in this scheme warm water periods are prevailing in the horizons lower than the lower Otadai Formation (lower than O_{27} Tuff Layer and around) while in the horizons higher than this tuff layer cold water environments rather dominate being associated with minor fluctuations not so less in number. It can be noticed that such minor fluctuations are apparently focused in the interval ranging from the lower Umegase to the lower Kakinokidai Formations. Simply based on this scheme the Plio-Pleistocene boundary might be secured at the middle Otadai Formation (just above O_{27} Tuff Layer) and the overlying lower and middle Umegase Formation can be designated as a transitional interval in which water temperature fluctuation became prominent and frequent gradually upwards.

Recently a few attempts of microbiostratigraphical zonation based on the so-called *Globorotalia tosaensis—truncatulinoides* lineage (BANNER and BLOW, 1965) were made on the Kazusa Group. But the results obtained by AOKI (1969) and NIITSUMA (1970) are quite divergent as shown in Table 2. It must be said that biostratigraphical studies of planktonic foraminifers are yet far from the solution of boundary problem.

AOKI (1963, 1968) attempted to subdivide the Kazusa Group by means of benthonic foraminifer assemblages and proposed 12 or more zones in the eastern part of the Boso

Peninsula where deeper water facies was prevailing (Table 2). Fluctuation of relative water temperature estimated from the composition of assemblages for each zones is shown also in the same Table (Temp. Benthonic Forams). The cold water zones are found in the following four intervals: the uppermost Otadai (*Bolivina spissa* Zone), the upper Umegase (*Uvigerina akitaensis* zone), the Chonan and the lower Kasamori (*Elphidium clavatum* zone), and the upper Kasamori Formations (*Nonionella stella* zone). It must be remarked that the lower half of the Kazusa Group is characterized by assemblages of relatively warm water but in the uppermost Otadai (just above O_7 Tuff Layer) a minor temperature lowering occurred, then in the upper Umegase appeared first a distinct cold water assemblage which was characterized by subarctic species. AOKI (1963) concluded that the Plio-Pleistocene boundary could not be higher than the base of the Chonan Formation because that the assemblages from the Chonan Formation must be interpreted to be the most remarkable cold water ones which might correspond to one of the Pleistocene glacial ages or stadials, but he reserved his conclusion on the probable horizon of the Plio-Pleistocene boundary as a problem for future studies. However, this may be an underestimation by reason that the temperature fluctuation estimated from the composition of benthonic foraminifer assemblages seems to correspond very well to that estimated from the pollen assemblage succession which will be shown below.

Water depth of the sedimentary basin of the Kazusa Group is supposed to have gradually decreased upwards as shown in Table 2 (Biofacies Benthonic Forams), which lead us to a conclusion that the higher the horizon the more prominent the effect of water and air temperatures on the benthonic foraminifer faunas. Then the appearance of *Uvigerina akitaensis* assemblage in the upper Umegase Formation might be interpreted as an indication of cold water period no less cold than the period of the Chonan Formation. Thus on the basis of the first remarkable climatic deterioration in the Kazusa Group the Plio-Pleistocene boundary can be drawn at just above U_6 Tuff Layer.

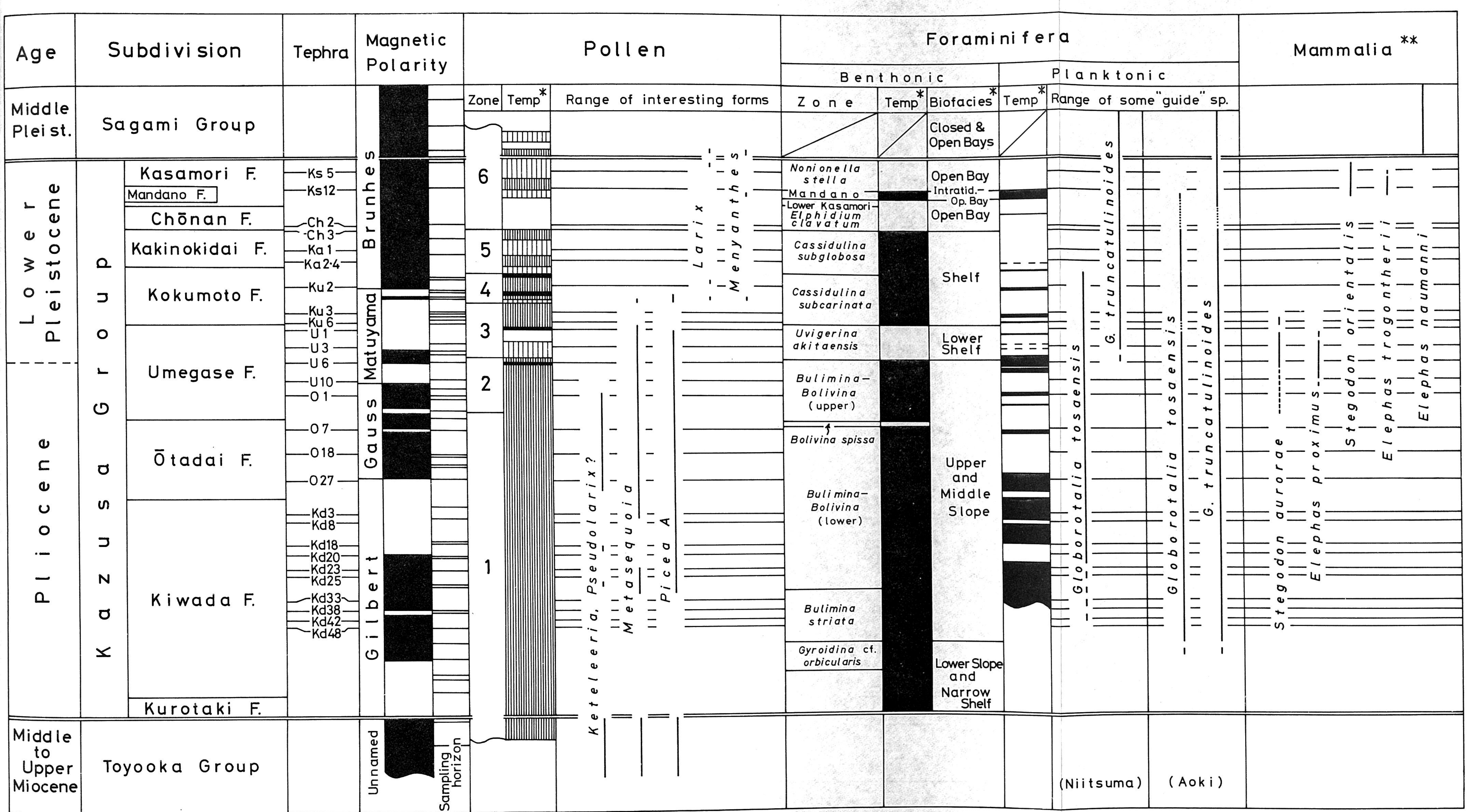
Among the fossil mammals from the Kazusa Group the proboscidians have been noticed as the most important index forms. Ranges of some representative proboscidian species are shown in Table 2: *Stegodon aurorae** ranges from the middle Umegase to the lowermost Kokumoto Formations ($\sim U_6$ to Ku_6) and *Elephas proximus** is apparently restricted within the Umegase Formation (U_{10} to U_1), while *Elephas trogontherii** and *Stegodon orientalis* are found from the Kasamori (the Mandano) Formation.

KAMEI attributed *Stegodon aurorae* to the Indo-Malayan faunal complex, *Elephas proximus* to the Nihowan fauna, and *Stegodon orientalis* to the Wanhsien fauna. Provided that the early Pleistocene should be defined as the age of replacement of the Indo-Malayan faunal complex by the Nihowan fauna, as emphasized by KAMEI and SETOGUCHI (1970) on the basis of the zonation of the Osaka Group and its allies by fossil mammals, the Plio-Pleistocene boundary in the Kazusa Group must be found in a horizon at least a little lower than U_{10} Tuff Layer of the lower Umegase Formation.

ONISHI (1969) subdivided the Kazusa Group of the Boso area into six pollen zones and correlated these zones to the pollen zones of the Osaka Group. The criteria of his correlation are thriving and declining of *Keteleeria*, *Pseudolarix*, *Liquidambar*, *Metasequoia* and *Picea*

* According to KAMEI, *Stegodon aurorae*, *Elephas proximus* and *Elephas trogontherii* are very closely related respectively to *Stegodon shodoensis akashiensis*, *Elephas shigensis* (early type) and *Elephas shigensis* (late type).

Table 2. Pliocene-Pleistocene chronology of the Kazusa Group (MITSUNASHI and KUWANO)



* Compiled by KUWANO, ** Compiled by MITSUNASHI

A* which are characteristic of the *Metasequoia* flora (the Tertiary-type flora), and the mode of occurrence of colder elements such as *Larix* and *Menyanthes*. ONISHI correlated his zone 2, zone 3, and zones 4 to 6 respectively to the lower *Metasequoia* subzone, the upper *Metasequoia* subzone, and the *Fagus* zone of the Osaka Group discriminated by TAI (1966). This means that ONISHI's zones 1 and 2 are equivalent to the age of *Metasequoia* flora flourish while zone 3 to the *Metasequoia* flora extinction. On the basis that in the Osaka Group the Plio-Pleistocene boundary nearly coincides with the horizon of *Pseudolarix* and *Keteleeria* extinction ONISHI proposed the boundary in the Kazusa Group to place at the horizon of *Pseudolarix* and *Keteleeria* extinction, namely in the middle Umegase Formation within the interval between U_{10} and U_6.

The climatic fluctuation estimated by re-interpretation of ONISHI's pollen diagram is shown schematically in Table 2 (Temp. Pollen). The climatic sequence in the Kazusa Group period can be characterized as follows. Through the lower and the middle parts of the Kazusa Group the climate was temperate in general and accompanied only by slow and gentle minor variations. But in the uppermost Otadai (at about O_7 Tuff Layer) appeared an indication of increase in fluctuation first in this group, then in the middle Umegase the climatic fluctuation became distinct, and in the upper Umegase (at a horizon between U_1 and U_3) the first distinct colder spell entered. In the upper half of this group the fluctuations were more evident and rhythmic than its lower half and the cold and warm climates appeared alternately. Thus on the basis of variations in pollen assemblage composition the Plio-Pleistocene boundary can be fixed at the U_6 or the U_3 horizons in the Umegase Formation.

Palaeomagnetism studies have been recently undertaken on the Kazusa Group of the Boso area. According to NAKAGAWA *et al.* (1969) the Kazusa Group ranges from the early GILBERT to the early BRUNHES epochs with two normal events in the MATUYAMA reversed epoch (Table 2). By correlating the last-named two events, namely the upper one in the middle Kokumoto and the lower one in the middle Umegase, respectively to the Jaramillo and the Olduvai events, they reached to a conclusion that the Plio-Pleistocene boundary must be drawn in the middle Umegase Formation (at around U_6 Tuff Layer). Later NAKAGAWA (1971) changed his opinion by reason that in the Le Castella area, South Italy the Gilsa event was detected at a horizon a little lower than the base of Calabrian (NAKAGAWA and NIITSUMA, 1970). His new proposal to place the Plio-Pleistocene boundary in the upper Umegase Formation rests on a re-interpretation of the age of a normal event, which he had previously correlated to the Olduvai, to be an equivalent of the Gilsa event. However, this change appears not so well evidenced but rather arbitrary hence it must be said that the Plio-Pleistocene boundary setting by palaeomagnetic synchronization is left open for future examination.

The Plio-Pleistocene boundary problem is not finally solved yet in the Kazusa Group. But it seems certain that the first indication of climatic deterioration can be detected in the horizon of Otadai Formation and climatic fluctuation became more distinct upwards until an eminent colder spell entered in the middle to upper Umegase Formation. On the basis of variation of foraminifer assemblages, appearance of the elements of the Nihowan fauna, the lower limit of the age of *Metasequoia* flora extinction, and variation of pollen assemblages, the Plio-Pleistocene boundary in the Kazusa Group may be placed at a horizon in the interval ranging from U_{10} to just above U_6 horizons.

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* This form can be compared with *Picea koribai* (TAI, 1963).

The Izumi and Nanaorizaka Formations

—The Plio-Pleistocene succession in the environs of Aizu Basin—

In the environs of Aizu Basin the marine Miocene Yamasato Group is widely developed. This group is conformably overlain by the mainly terrestrial Yamato Group (latest Miocene to early Pleistocene) usually in the central area of the Yamasato Group terrain, but unconformably in the marginal area. In subsurface sections of Aizu Basin the Yamato Group is more or less deep-seated being covered by the middle Pleistocene to Holocene sediments. The Yamasato and Yamato Groups are both folded and faulted, and near the western and eastern margins of the basin they are steeply inclined towards the center of basin to form flexure-like structures (Fig. 4; SUZUKI, 1964).

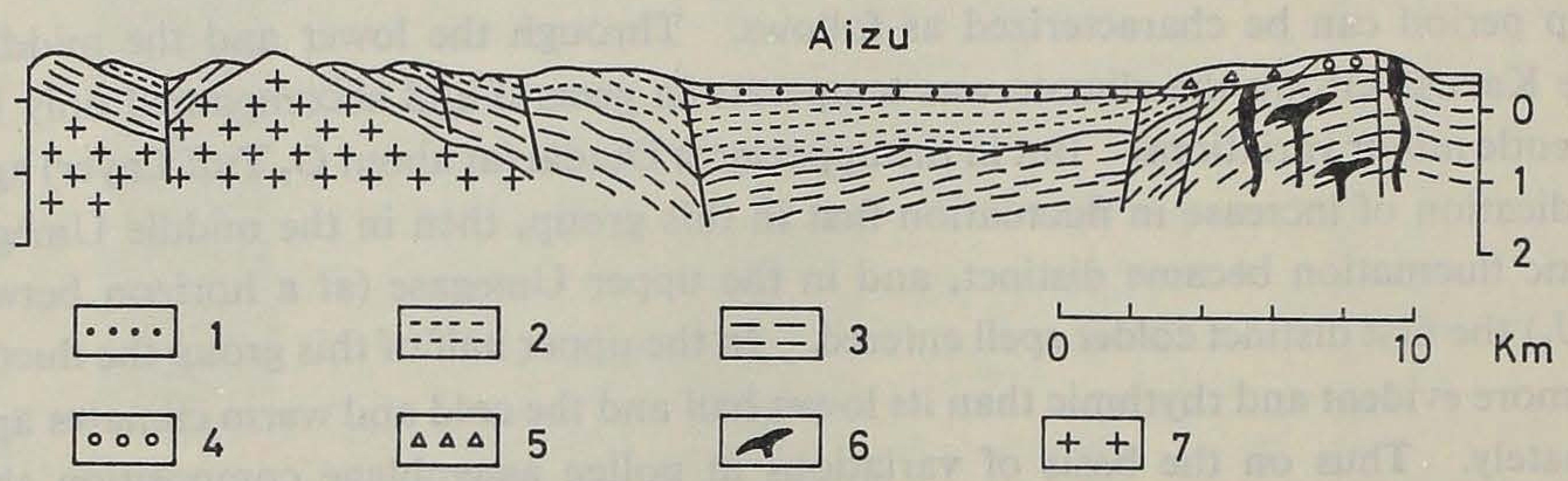


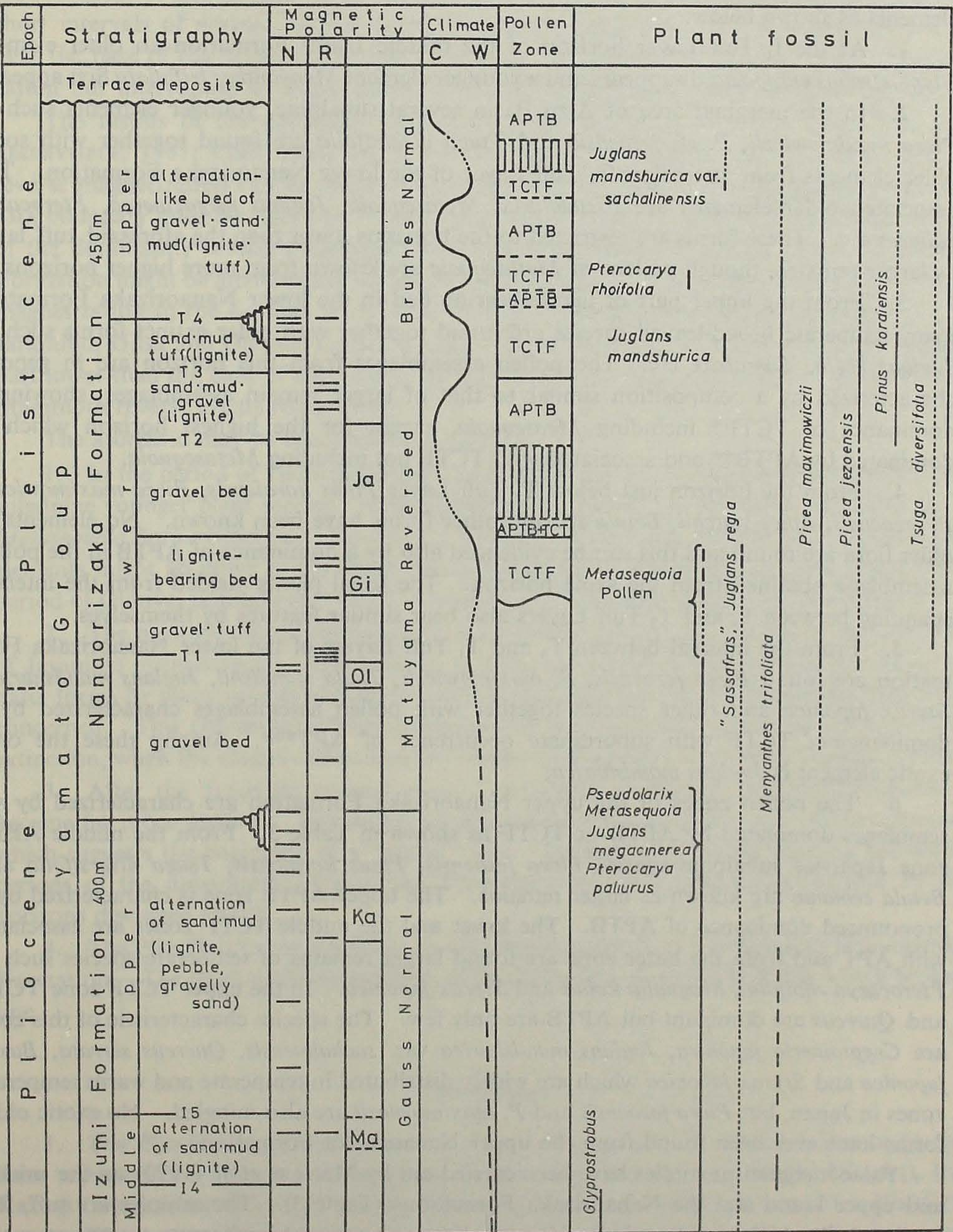
Fig. 4 Geological profile of Aizu Basin and its environs (SUZUKI)
1: Middle to late Pleistocene formations and Recent alluvial deposits, 2: Yamato Group (latest Miocene to early Pleistocene), 3: Yamasato Group (Miocene), 4: Pleistocene volcanics, 5: Welded tuff (Pliocene to early Pleistocene), 6: Dyke and lava (Miocene to Pliocene), 7: Basement complex (pre-Tertiary)

The Yamato Group is subdivided into the Fujitoge, Izumi and Nanaorizaka Formations in ascending order. From the Fujitoge Formation marine molluscs are known while the Izumi Formation is very rich in freshwater molluscs. The fossils most characteristic of these three formations are plant remains by which the geological age of these sediments has been estimated as follows: the Fujitoge Formation is latest Miocene, the Izumi Formation is Pliocene, and the Nanaorizaka Formation is Pliocene and early Pleistocene (SUZUKI *et al.*, 1968; MANABE *et al.*, 1970). The stratigraphy and lithology of the upper Izumi and Nanaorizaka Formations are shown in Table 3.

The Izumi Formation: This formation is about 400 m. in thickness and subdivided into the upper, middle and lower parts, being, as a whole, represented by alternations of sand and mud associated with frequently intercalated medium- to fine-grained gravel layers and a number of lignite seams. Five well marked tuff layers of this formation are named I_1 to I_5 in ascending order.

The Nanaorizaka Formation: This formation is about 450 m. thick, being subdivided into the upper and lower parts. The lower Nanaorizaka Formation is dominated by gravel and tuff layers, being associated with four distinctive tuff layers (dacitic and pumiceous) which are discriminated under the names of T_1 to T_4 in ascending order. In this succession are developed at many horizons alternation-like sedimentary bodies composed of discontinuous sand, mud and tuff, and also lignite seams. The upper Nanaorizaka Formation is also composed of alternation-like beds of gravel, sand and tuff, being associated with a number of peat layers.

Table 3. Pliocene-Pleistocene chronology of the Izumi and Nanaorizaka Formations of Aizu Basin (SUZUKI)



Vertical lines show undivided zones.
TCTF: Taxaceae, Cupressaceae, Taxodiaceae and *Fagus*
APTB: *Abies*, *Picea*, *Tsuga* and *Betula*

To date have been studied in detail larger plant remains from the middle to upper Izumi and the Nanaorizaka Formations and pollen assemblages from the Nanaorizaka Formation. The results (Table 3) suggest that there are several stages in turnover of older and younger elements as shown below.

1. At the I_4 Tuff Layer horizon of the middle Izumi Formation an older element *Glyptostrobus europaeus* disappears and a younger element *Menyanthes trifoliata* first appears.

2. In the marginal area of Aizu Basin several subalpine, younger elements such as *Picea maximowiczii*, *P.* cf. *jezoensis* and *Tsuga diversifolia* are found together with some older elements from just below T_1 Tuff Layer of the lower Nanaorizaka Formation. The associated older elements are *Pseudolarix*, *Metasequoia*, *Juglans megacinerea*, *Pterocarya paliurus* etc. These forms are restricted to the horizons lower than the aforesaid tuff layer as larger remains, though pollens of *Metasequoia* are known from more higher horizons.

3. From the upper part of lignite-bearing bed in the lower Nanaorizaka Formation many temperate broad-leaved species are found together with older extinct forms such as *Juglans regia*, *Sassafras* etc. The pollen assemblages from this horizon are in general characterized by a composition similar to that of larger remain assemblages, showing a dominance of TCTF* including *Measequoia*, except for the highest horizon which is dominated by APTB** and associated with TCTF not including *Metasequoia*.

4. From the horizon just below T_2 Tuff Layer *Pinus koraiensis*, *Picea maximowiczii*, *P. jezoensis*, *Abies veitchii*, *Betula* sp. and other forms have been known. No elements of older flora are found and this can be evidenced also by a dominance of APTB in the pollen assemblage obtained from the same horizon. The fossil plants yielded from the interval spanning between T_2 and T_3 Tuff Layers also bear similar features by themselves.

5. From the interval between T_3 and T_4 Tuff Layers of the lower Nanaorizaka Formation are found *Picea jezoensis*, *P. maximowiczii*, *Thuja standishii*, *Juglans mandshurica*, *Styrax japonica* and other species together with pollen assemblages characterized by a dominance of TCTF with subordinate occurrence of APT***. Among these the only exotic element is *Juglans mandshurica*.

6. The pollen zones of the upper Nanaorizaka Formation are characterized by assemblages dominated by APTB or TCTF as shown in Table 3. From the middle APTB zone Japanese subalpine species *Picea jezoensis*, *Pinus koraiensis*, *Tsuga diversifolia* and *Betula ermanni* are known as larger remains. The upper APTB zone is characterized by a pronounced dominance of APTB. The lower and the middle TCTF zones are associated with APT and from the latter zone are found larger remains of temperate species such as *Pterocarya rhoifolia*, *Magnolia kobus* and *Styrax japonica*. In the upper TCTF zone TCTF and *Quercus* are dominant but APTB are only few. The species characteristic of this zone are *Cryptomeria japonica*, *Juglans mandshurica* var. *sachalinensis*, *Quercus serrata*, *Buxus japonica* and *Styrax japonica* which are widely distributed in temperate and warm temperate zones in Japan, but *Picea jezoensis* and *P. maximowiczii* are also mingled. No exotic older forms have ever been found from the upper Nanaorizaka Formation.

Palaeomagnetism studies have been carried out by MANABE *et al.* (1970) on the middle and upper Izumi and the Nanaorizaka Formations (Table 3). The samples are tuff, fine sand and silt which were tested after demagnetization treatment in alternate current magnetic

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* TCTF: Taxaceae, Cupressaceae, Taxodiaceae and *Fagus*

** APTB: *Abies*, *Picea*, *Tsuga* and *Betula*

*** APT: *Abies*, *Picea* and *Tsuga*

field (100 to 200 Oe). At the horizons higher than T_3 Tuff Layer all the samples are normally magnetized except for one sample from T_4 Tuff Layer*. In the lower Nanaorizaka Formation most of the samples from lower than T_3 Tuff Layer are reversely magnetized but short intervals of normal magnetization can be discriminated. The horizons lower than near the base of the Nanaorizaka Formation are characterized mostly by normal magnetization but interrupted by some subordinate short intervals of reverse magnetization.

The results of chronological interpretation on the basis of Cox's scale (Cox and DALRYMPLE, 1967; Cox, 1969) are shown in Table 3. Because that the upper limit of reverse magnetization can be found at the horizon of T_3 Tuff Layer, the BRUNHES/MATUYAMA boundary must be placed at or just above this tuff layer. Provided that the lower limit of the dominantly reverse-magnetized zone detected at near the base of the Nanaorizaka Formation might be attributed to the MATUYAMA/GAUSS boundary, short intervals of normal magnetization in the horizon lower than T_3 Tuff Layer are supposedly correlatable to the Jaramillo, Gilsa and Olduvai normal events, while those of reverse magnetization from the part lower than the base of the Nanaorizaka Formation can be paralleled to the Kaena and Mammoth reverse events respectively.

The aforesaid may be summarized as follows.

1. In the period of Olduvai normal event in the margin of Aizu Basin appeared some subalpine younger plant species. This change probably reflects the beginning of the age of *Metasequoia* flora extinction. However, a possibility is left that the first entry of these new elements might go down to the upper Izumi Formation. The climatic deterioration in the period of Olduvai normal event is not so remarkable in its scale or extent in Aizu Basin.

2. The most significant change of floral composition took place at about the beginning of Jaramillo normal event. This change, being characterized by the replacement of exotic older forms by many new subalpine elements, is traceable throughout the sedimentary basin concerned. This change probably corresponds to the end of the age of *Metasequoia* flora extinction, when the climatic deterioration became more intense than the preceding periods.

3. After the Jaramillo normal event a periodical oscillation of floral composition became far more distinct. This means an alternating entry of colder and warmer climates which suggests the beginning of a "glacial" age. Worth notice is that the cold and warm periods of the uppermost Nanaorizaka Formation are most distinct throughout all the horizons discussed above.

4. The Plio-Pleistocene boundary in Aizu Basin can be drawn in the lower Nanaorizaka Formation. The most probable position of this boundary is shown in Table 3 by a broken line.

Conclusion

1. The Plio-Pleistocene boundary problem is discussed with special reference to the three representative successions in Japan, namely the Osaka Group (Kinki District), the Kazusa Group (Kanto District) and the Izumi and Nanaorizaka Formations (Aizu District).

2. The stratigraphy of these successions is not only well established by tephrochronologically but also studied in detail in view of biostratigraphy and palaeomagnetic chronology.

* As this reverse magnetization is only local, this phenomenon must be assigned to the magnetization mechanism itself of this layer.

3. As evidenced from these successions the process of the *Metasequoia* flora's succession is believed to be of prime importance as a basis of finding the Plio-Pleistocene boundary in the temperate zone of Japan. During the age of flourish, though some characteristic forms were lost, the *Metasequoia* flora existed maintaining a number of elements of essential to this Tertiary-type flora. However, with the beginning of climatic deterioration, which was reflected in the appearance of subalpine younger new-to-Japan species, the *Metasequoia* flora entered into the age of extinction, and then rapidly losing its components declined towards its extinction and was replaced finally by new-type floras. In view of floral succession the Plio-Pleistocene boundary should be drawn along the boundary between the ages of flourish and extinction of the *Metasequoia* flora.

4. On the basis of succession of mammalian faunas, in particular that of proboscidians, the Osaka Group with its allies and the Kazusa Group can be subdivided into several successive stages, which are represented by the elements of the Indo-Malayan faunal complex, the Nihowan fauna, the Choukoutien fauna, and the Wanhsien fauna in ascending order. Especially noticeable is that the mammalian succession from the Indo-Malayan complex to the Nihowan fauna is almost time-parallel with the *Matasequoia* flora succession. In view of mammalian fossils the Plio-Pleistocene boundary can be marked by the appearance of the Nihowan elements and the beginning of extinction of the Indo-Malayan elements.

5. In the Kazusa Group no decisive conclusion has been reached about the Plio-Pleistocene boundary in the field of planktonic foraminifer studies though some attempts have been made to date with reference to the mass appearance of a cold water species *Globigerina pachyderma* or to the biostratigraphy based on the so-called *Globorotalia tosaensis—truncatulinoides* lineage. Meanwhile the changes in composition of benthonic foraminifer assemblages well correspond to the *Metasequoia* flora succession estimated from pollen analysis, hence it might be said that the Plio-Pleistocene boundary could be placed at the base of *Uvigerina akitaensis* zone which was discriminated by benthonic foraminifer studies.

6. The results of palaeomagnetism studies undertaken on the Osaka Group with its allies, the Kazusa Group, and the Izumi and Nanaorizaka Formations suggest that there are found the probable equivalent of Olduvai event in all of these successions. But more informations seem necessary before a more decisive conclusion will be obtained.

7. There are some discrepancy in the results of absolute age measurement on the tuff layers intercalated within the Osaka Group and its allies by means of fission-track and K-Ar methods. Generally speaking the K-Ar ages surpass the fission-track ages, the latter showing a fairly good correspondence to the palaeomagnetic time-scale established by Cox and others. The age of the Plio-Pleistocene boundary can be estimated as about 2×10^6 years by means of fission-track method.

8. As to the absolute age measurements and palaeomagnetism studies it should be said that the accumulation of more exact data is necessary. This situation appears to be common with the planktonic foraminifer studies, in which further checking of taxonomic criteria, nature of morphological transformation, technique of sample preparation and other subjects would be major points of examination.

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