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TEPHROCHRONOLOGICAL STUDIES IN JAPAN

Diverse Applications,
Especially to the Geomorphology
of the Kantō Plain

By Sōhei Kaizuka

With 9 Figures and 2 Tables

Tephrochronologische Studien in Japan. Ihre Anwendungen besonders für die Geomorphologie der Kantō Ebene

Zusammenfassung: Die japanischen Inseln sahen während des Quartärs so viele vulkanische Eruptionen und wurden so weithin von vulkanischen Aschen überdeckt, daß hier auf dem Gebiete der Geochronologie der tephrochronologischen Methode besondere Bedeutung zukommt.

Die vorliegende Arbeit gibt zunächst einen Überblick über die Ergebnisse tephrochronologischer Studien in Japan im Hinblick auf verschiedene Sachgebiete, wie Vulkanologie, Bodenkunde, Archäologie, Stratigraphie usw.; zum zweiten wird mehr ins einzelne gehend die Anwendungsweise der tephrochronologischen Methode für die Geomorphologie der Kantō Ebene, der größten Ebene Japans, beschrieben.

In der Geomorphologie wird die tephrochronologische Methode für zwei Zwecke verwendet: einerseits für die Aufstellung von Korrelationen zwischen Oberflächen (z. B. Terrassen), andererseits für eine Rekonstruktion des Altreliefs. Ganz gleich, welches Ziel verfolgt wird, der erste Schritt einer tephrochronologischen Untersuchung besteht darin, eine stratigraphische Klassifikation der Ascheschichten aufzustellen, die dann eine Korrelation dieser klassifizierten Ascheschichten über größere Entfernung gestattet. Für eine Korrelation ist es sehr aufschlußreich, die charakteristischen Einschlüsse wie Bimsstein, Schlacke und Bodenteile zu verfolgen und darüber hinaus die Zusammensetzung der vulkanischen Asche im Hinblick auf die Schwerminerale zu analysieren.

Auf der Grundlage dieser tephrochronologischen Arbeitsweisen werden die Reliefoberflächen der Kantō Ebene in fünf Hauptstadien unterteilt und wird schließlich die Entwicklung der Kantō Ebene während des Quartärs aufgezeigt.

1. Introduction

In Japan, as is widely known, there exist a great many volcanoes, of which over 250 were formed during the

Quaternary period. Among these, eruptions have officially been recorded for more than 45 volcanoes so far. As can easily be imagined by this fact, wide areas of the Japanese Islands are covered with volcanic ashes (fig. 1). Southern Kyushu and southern Hokkaido are covered with Holocene volcanic ashes while central Japan, especially the Kantō Plain, is mainly enveloped with Pleistocene volcanic ashes.

Judging from the above fact, "Tephrochronology"¹⁾ should play an important role in the various fields of research in Japan. Although some tephrochronological studies have already been carried out to a certain extent, it was not until the word "Tephrochronology" was proffered by S. Thorarinsson in 1944 that any such Japanese counterpart came into being for use in the scientific fields.

The reason for the vital significance of tephrochronology in Japan can be attributed to the fact that Japan not only is widely covered with volcanic ashes, but also, unlike Europe and some other regions of the world, has almost no ample and suitable geochronological keys, such as palaeolithic implements, glacial morphology, glacial deposits, and loess, all of which are contributive to the chronology of the Quaternary period.

This paper is devoted to the introduction of the tephrochronological studies in various fields in Japan and, at the same time, to the discussion, in a slightly detailed manner, of its application to geomorphology as based on the study of the Kantō Plain, in the central part of which Tokyo is situated.

¹⁾ The term "Tephrochronology" is defined as follows (Thorarinsson, 1944): a geological chronology based on the measuring, interconnecting, and dating of volcanic ash layers in soil profiles. The private communication from Prof. S. Thorarinsson indicated that the soil in the above definition meant all layers above the solid rock and not only the pedological soil.

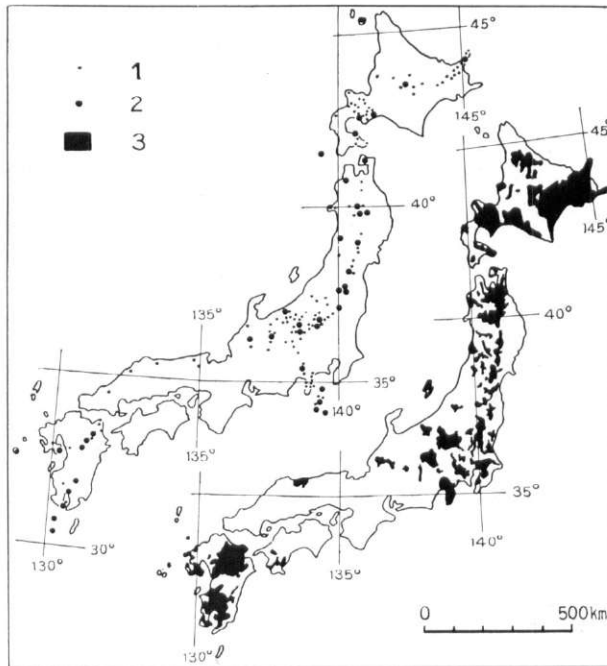


Fig. 1: Distribution of volcanoes and volcanic ash soils in Japan (after S. Yamada, 1940)

- 1 Volcanoes of the Quaternary period, no activity known in historic time (after T. MINAKAMI, 1957).
- 2 Volcanoes active during historic time (after T. MINAKAMI, 1957).
- 3 Areas in which volcanic ash is an important component of surface deposits (after H. KAMOSHITA, 1948).

Acknowledgements

As to the problems on the Kantō Plain, this paper deals with a part of the objectives of the Kantō Loam Research Group; the author wishes to express his sincere gratitude to the members of the Kantō Loam Research Group, of which the author is a member, for their helpful suggestions and untiring cooperation. Thanks are also due to Professor Fumio Tada, Department of Geography, Tokyo University, for his suggestions and criticism, and to Professor Hisashi Kuno, Department of Geology, Tokyo University, for his advice in mineralogical studies. Further the author is deeply indebted to the following scholars who critically read the manuscript: Professor Johannes Maringer, Nanzan University and Director of S. V. D. Archaeological Institute, Dr. John T. Kozakis, U. S. Army Map Service, and Dr. Roy C. Kepperle, U. S. Geological Survey.

II. Tephrochronological Studies in Diverse Fields in Japan

For the convenience of delineation, the author has taken the liberty to classify the tephrochronological studies into five different fields as described below. As they are closely interrelated, at times the studies of some of them have been carried out simultaneously.

1) Volcanology and Dating of Volcanic Ejecta

The eruption of 684 A. D. is said to be the oldest volcanic eruption on record in the litera-

ture. Since then, many volcanic eruptions have been recorded, of which the more violent ones officially number more than 1,000. Since detailed records of the real distribution and characteristics of volcanic ejecta are inadequate, it is not an easy task to determine which eruptions on record have a close connection with certain volcanic ejecta in the field. In other words, it is quite a problem to determine the date of volcanic ejecta in collation with the official literature.

Such being the case, several chronological methods are employed when volcanic ejecta are collated with the literature. For instance, S. Yamada (1940) used the dendrochronological method in determining the date of the volcanic ash layer of Tarumae Volcano situated in southern Hokkaido. More precisely, Yamada, having counted the annual growth-rings of the oldest trees growing in the region covered with a thick layer of volcanic ashes from Tarumae Volcano, was able to obtain the age of 175 years from the trees in question. On the other hand, he found that the trees growing in the region not covered with those ashes were somewhere from 300 to 400 years old. From this, he surmised that the volcanic ashes had fallen some 200 years ago. He then investigated the eruption of Tarumae Volcano and was finally able to ascertain its date to be 1739 A. D.

Yamada also reported an interesting example of tree-ring chronology. In southern Hokkaido, he unearthed some volcanic ash from Mashu Volcano out of the trunk of a tree (fig. 2). The trunk of this tree is believed to have split open at the time of the ash fall and closed after the ashes had settled down in the crevice. Judging from the 250 growth-rings on this tree, Yamada interpreted that the ash fall must have occurred during the last 200 years.

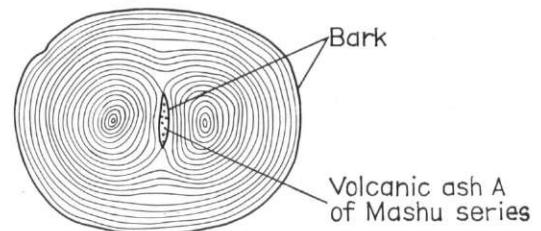


Fig. 2: A trunk section enclosing volcanic ashes in the crevice (after S. YAMADA, 1940)

The following are a few instances of the old and new dates of volcanic eruptions as clarified by the tephrochronological method.

H. Kuno (1950) concluded that the complete formation of Fuji Volcano was younger than that of the central cones of Hakone Volcano, some 30 km southeast of Fuji, on the basis of the blanketing of the central Hakone cones with scoria-

ceous basalt lapilli and volcanic ashes, both volcanic ejecta of Fuji Volcano. Furthermore, he explained that the basaltic ejecta reached as far as the vicinity of Tokyo City, supplying an essential part of the volcanic ash layer, the so-called Kantō Loam, which is believed to be of younger Pleistocene age.

Moreover, *Kuno* (1954) investigated the chronological conditions before and after the eruptions of several minor volcanoes belonging to the Ōmuro-yama Volcano Group, about 30 km south of Hakone, and disclosed the fact that some of them were formed prior to the Fuji volcanic ashes, others during Fuji ash fall, and still others after the ash fall.

In the last part of this section, the author has arranged the general characteristics of volcanic ejecta fall, according to the knowledge of this matter obtained by many researchers, especially *M. Harada* (1943) and *S. Yamada* (1951).

(1) Generally, the distribution of volcanic ejecta takes an elliptical or ovoid shape, with the source volcano being at the terminal of the major axis.

(2) In Japan, the volcanic ejecta that have erupted to a height of more than 1—2 km above the source are transported by westerly winds. Accordingly, the distribution of ejecta fall as a rule is on the east side of the source volcano.

(3) The nearer a position is to the source volcano and the major axis of the distribution, the thicker the ejecta layer and the larger the grain size of ejecta.

(4) In general, the pumice fall is at the earliest stage of a volcanic action and the ash fall follows. Consequently, it is customary that directly under the pumice layers there exist buried soils which indicate the time interval since the foregoing ejecta fall. On the contrary, it is a common matter that the pumice layers are transitionally covered by volcanic ash layers.

2) Pedology

Several regions of Japan, especially southern Hokkaido and southern Kyushu, are extensively covered with volcanic ash layers formed during the Holocene. In these areas, the tephrochronological method has been put to practical use in the soil survey in order to classify the various soil types. In 1940, *Yamada* propounded this practical method in his thesis "Soil Survey of Volcanogenous Soil". According to his definition, a volcanogenous soil is a soil whose nature is affected by volcanic ejecta.

Granting that a certain region is honeycombed with numerous volcanoes and that these volcanoes erupt frequently, emitting much volcanic

ejecta, it is most likely that an overlapping of various phases of soil profiles could be seen on the leeward flanks of these volcanoes. Moreover, should there be any time intervals between the eruptions of volcanic ejecta, it is only natural that buried soils would be formed.

For these reasons, the formation process of the volcanogenous soils is entirely different from that of the ordinary mineral soils. Consequently, it goes without saying that the classification method differs in these two soil types. From this, *Yamada* proffered a criterion for the classification of volcanogenous soils based on his profuse experiences as follows:

(1) First, classify the species of ejecta spread in the area and observe the characteristics of all ejecta.

(2) Based on the observation of the characteristics of each ejectus, study its distribution and variation in thickness, and determine the relation of the stratum between each ejectus.

(3) On the basis of the above investigations, divide the area into soil series according to the differences in the profile of the upper stratum, and finally divide the soil series into soil-types according to the differences in the profile of the substratum deep enough to influence the growth of the crops.

In conformity with the above methods, *Yamada* (1940, 1951), and several others have continued their studies on the volcanogenous soils in Hokkaido up to date, and have made a detailed classification of the volcanic ejecta of the Holocene age (fig. 3). Also in conjunction with their soil surveys, they have employed the technique of tephrochronology in the dating of volcanic ejecta as described above and in the studies of archaeology and sedimentology as set forth below.

3) Archaeology²⁾

In Japan there are many cases in which prehistoric sites have been blanketed with volcanic

²⁾ The prehistoric chronology of Japan is classified in the following table.

Historical age	600 — 700 A.D.		
Kofun age (ancient mound age)	300 — 400 A.D.		
Yayoi age	300 — 200 B.C.		
Jōmon age	<table border="0"> <tr> <td rowspan="4" style="vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">latest</div> <div style="display: inline-block; vertical-align: middle;">late</div> <div style="display: inline-block; vertical-align: middle;">middle</div> <div style="display: inline-block; vertical-align: middle;">early</div> <div style="display: inline-block; vertical-align: middle;">earliest</div> </div> </td> <td>5,000 — 4,000 B.C.</td> </tr> </table>	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">latest</div> <div style="display: inline-block; vertical-align: middle;">late</div> <div style="display: inline-block; vertical-align: middle;">middle</div> <div style="display: inline-block; vertical-align: middle;">early</div> <div style="display: inline-block; vertical-align: middle;">earliest</div> </div>	5,000 — 4,000 B.C.
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	Non-ceramic age (Pre-Jōmon age)		

Irrelevant to the Yayoi and Kofun ages, there were the Zoku-Jōmon and Satsumon ages throughout the greater part of Hokkaido; the Satsumon age continued up to several hundred years ago.

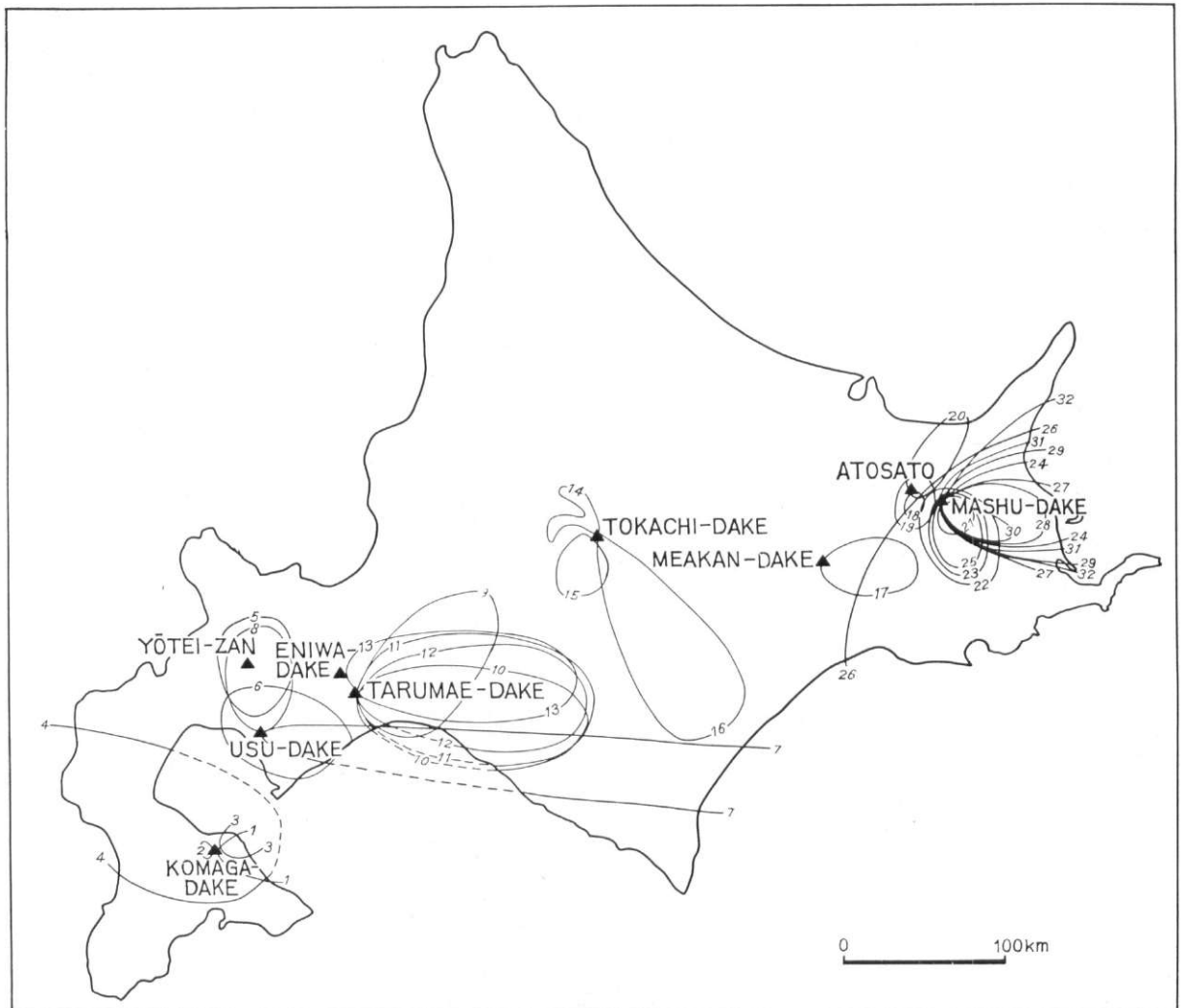


Fig. 3: Distribution of volcanic ash layers in Hokkaido, showing volcanic ash layers more than 10 cm thick (after S. YAMADA, 1951).

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|------|-------------------------|------|--------------------|---------------------|
| 1 A | } of Komaga-dake Series | 17 A | } of Meakan Series | |
| 2 B | | 18 A | | |
| 3 C | | 19 B | | } of Atosato Series |
| 4 D | | 20 C | | |
| 5 A | } of Yotei Series | 21 A | } of Mashu Series | |
| 6 A | | 22 B | | |
| 7 B | | 23 C | | |
| 8 C | } of Usu Series | 24 D | | |
| 9 A | | 25 E | | |
| 10 B | | 26 F | | |
| 11 C | } of Tarumae Series | 27 G | | |
| 12 D | | 28 H | | |
| 13 A | } of Eniwa Series | 29 I | | |
| 14 A | | 30 J | | |
| 15 B | } of Tokachi Series | 31 K | | |
| 16 C | | 32 L | | |

ashes, but, on the other hand, only few cases exist wherein the volcanic ashes are employed in the dating of prehistoric sites or *vice versa*, that is, the prehistoric sites being used for determining the dates of the volcanic ashes.

As previously stated, so extensively are the Holocene volcanic ashes scattered over vast areas of southern Hokkaido that there are many prehistoric sites buried under the volcanic ashes. For instance, *H. Kōno* (1932) made a report on the sites buried by the ashes of Tarumae Volcano. Further, *S. Yamada* (1940) unearthed a site enveloped by the volcanic ash bed 'A of Mashu series' and expounded the fact that the date of the prehistoric site as conceived by archaeologists is not contradictory to that of the Mashu ash fall (last 200 years) estimated through dendrochronology.

In the vicinity of Towada caldera situated in the northern part of Honshu, there are several sites which have been buried by volcanic ashes, among them the Ōyu sites in Akita Prefecture are noted for their stone remains resembling stone circles (The Commission of the Protection of Cultural Properties, 1953). These sites are enveloped with a blanket of pumice layer. Judging from the earthenwares of the sites, the Ōyu stone remains must be of late Jōmon age; there is in the vicinity a ruined site, believed to be of the Nara Era (8th century), which shows no traces of having been enveloped by the pumice layer. Accordingly it may be possible to surmise the age of that pumice layer.

In the central parts of Honshu, volcanic ash layers which are believed to be of Pleistocene age are extensive. Up to recent years, it had been considered that there were no prehistoric vestiges in these volcanic ash layers, but the year 1949 brought the discovery of the so-called Non-ceramic culture or the Pre-Jōmon culture (*Sugihara*, 1956). Since then, many stone implements have been unearthed from these volcanic ash layers in every area concerned (*Serizawa*, 1956).

Parallel with the study of the types of stone implements, the stratigraphical studies of the artifact-bearing volcanic ash layers are being carried out for dating these stone implements. On the other hand, the correlating of volcanic ash layers is more or less executed through the stone implement types so that both studies are pursued together.

The volcanic ashes of the Kantō area are called "Kantō Loam". Several layers of pumice are embedded in the ashes, particularly in the north-western part of it. Moreover, many stone implements have been unearthed from the volcanic

ashes in this region up to the present. Consequently, the chronology of these sites is especially dependent on the horizon of the pumice layers in the volcanic ashes (*Aizawa*, 1957).

4) The Studies of Peat and Sedimentology

The peat lands in Japan are located in the low lands of Hokkaido and northernmost Honshu and in the mountainous regions of central and northern Japan. In these areas, the studies of pollen analysis, and physiographical and ecological studies of peat are being pursued. In connection with these studies, similar to those of *V. Auer* (1933) in Tierra del Fuego, the volcanic ash layers interbedded with the peat are employed as key beds for relevant dating (for instance, The Scientific Researches of the Ozegahara Moor, 1954).

S. Hori (1957) issued a report summarizing his studies of pollen analyses in central Japan. In it, he discussed the results of the pollen analyses of peats over 8 m thick found in the two peat lands of central Japan, the Yashimaga-hara and Oomine-numa bogs, and explained the climatic changes in these regions as follows: Yashimaga-hara and Oomine-numa bogs were supposed to have appeared about 10,000 years ago; first, under cold climatic conditions, then the climate became gradually warmer until about 6,000 years ago. Following this, from 4,000 to 3,000 years ago, the climate was again cold, and thereafter the climate became warmer once more and has so continued up to the present.

In this study, *Hori*, using eruption records in the literature, probed the absolute dates of volcanic ash layers embedded in several peat lands which are situated in central Japan with similar conditions as the preceding two peat lands; and using the dates in question, obtained the accumulation rate of about 1 mm per annum for the peats. In fixing the date to about 10,000 years for the 8 m peat deposits of the Yashimaga-hara and Oomine-numa bogs, he obtained such by basing his calculations on the accumulation rate of peat.

Prior to the study of *Hori*, *S. Yamada* (1940) already calculated the rate of peat deposits in the southeastern part of Hokkaido by employing the volcanic ashes in the peats and invariably obtained the same rate of 1 mm per annum.

The foregoing studies by *Hori* have been focused on the objective to obtain data of the floral and climatic changes, but simultaneously have been an effective application of tephrochronology to sedimentology. In the studies of limnology, there is the application of tephrochronology to sedimentology too.

Although many reports have been made on the excavation of pumice, scoria and volcanic ash layers from the deposits on the bottoms of the innumerable lakes in Japan, there are no other instances except those stated below, wherein studies had been carried out from the tephrochronological standpoint.

Y. Saijō (1956) found volcanic ash layers in the lake deposits in Hokkaido and central Japan. After referring to the records in the literature, the absolute dates of the volcanic ash layers became evident, and from this it was possible to determine the rates of deposition in the lakes as given in table 1.

Table 1 Rate of sedimentation in lakes (after Y. Saijō, 1956)

Lake	Latitude	Height above sea-level (m)	Area (km ²)	Mean depth (m)	Transparency (m)	Total deposit (g/m ² /year)	Carbon (g/m ² /year)	Nitrogen (g/m ² /year)
Oze-numa	36°55'	1.665	1.80	5.8	4—7	35	3.27	0.28
Chuzenzi	36°45'	1.271	11.29	85	8—18	64	4.37	0.33
Akagi-onuma	36°33'	1.345	0.82	10.5	6—7	98	3.55	0.38
Toshima-onuma	42° 0'	130	5.13	6.4	2—3	588	47.4	5.5

5) Stratigraphy and Geomorphology

The stratigraphers frequently employ a characteristic sheet of tuff bed for pertinent correlation. However, in case a zone of cumulative tuff layers differs from the next zone of tuff layers in mineral composition, *Koike* and *Murai* (1950) designated the strata including the given tuff layers a "Tephrozone" as a geohistoric unit, and used it in the correlation of Tertiary strata in southern Kantō.

If the study of tuffs in such strata, used for dating purposes, should also be included in the study of tephrochronology, then there are numerous instances referring to this. Furthermore, there are many instances whereby the study of tephrochronology has been applied to the chronology of terraces and the Quaternary series. Consequently, the author would like to take up only a significant study below and the study of geomorphology of the Kantō Plain in the next paragraph.

Kobayashi and others (1957) unearthed some volcanic ashes from the cirque-bottom deposits of Mt. Kiso-koma in the Central Japan Alps; the stratigraphic sequence of which was as stated below:

Postglacial	}	humic top soil
		talusic deposit
		aeolian volcanic ash (the so-called "loam")
		bluish sand (morainic lake deposits)

Koma-glacial — end moraine (highly oxidized)

This aeolian volcanic ash was correlated with the so-called "loam" that has enveloped the lower terraces in the mountainous land of central Japan, and which have yielded many stone implements, such as blades and points.

The Japanese cirques being hanging cirques, it has been quite a problem to correlate the terraces and glacial deposits geomorphologically. But now, tephrochronological studies have shed a new light on the important problem of the correlation between the Japanese glacial period and the age of terrace morphology. Concerning the worldwide chronological positions of the above events, *Kobayashi* and others estimated that the age of Koma-glacial and the aeolian volcanic ash may be referred respectively to Würm 1—2 and Würm 3 or later.

III. Tephrochronological Study of the Kantō Plain

The Kantō Plain, the largest in Japan, stretches across the vast central region for about 130 km both from east to west and north to south, in the approximate center of which is situated the city of Tokyo. This Kantō Plain is mainly a depositional plain formed by the Quaternary series, being the standard for the Japanese Quaternary series. From the geomorphic standpoint, the Kantō Plain is mainly composed of hills, uplands, terraces and alluvial plains (fig. 4). The hills are the older coastal plains and dissected fans; the uplands are the younger coastal plains, dissected fans and deltas guttered by numerous valleys; and finally the alluvial plains are spread along the coasts and into the valleys. Like the Quaternary series, the geomorphic surfaces act as a standard for Japanese geomorphic surfaces.

The hills, uplands and terraces of the Kantō Plain are completely enveloped with volcanic ashes. These ashes, called the "Kantō Loam" or the "Kantō Volcanic Ash Formation", are derived from the innumerable volcanoes of the north-

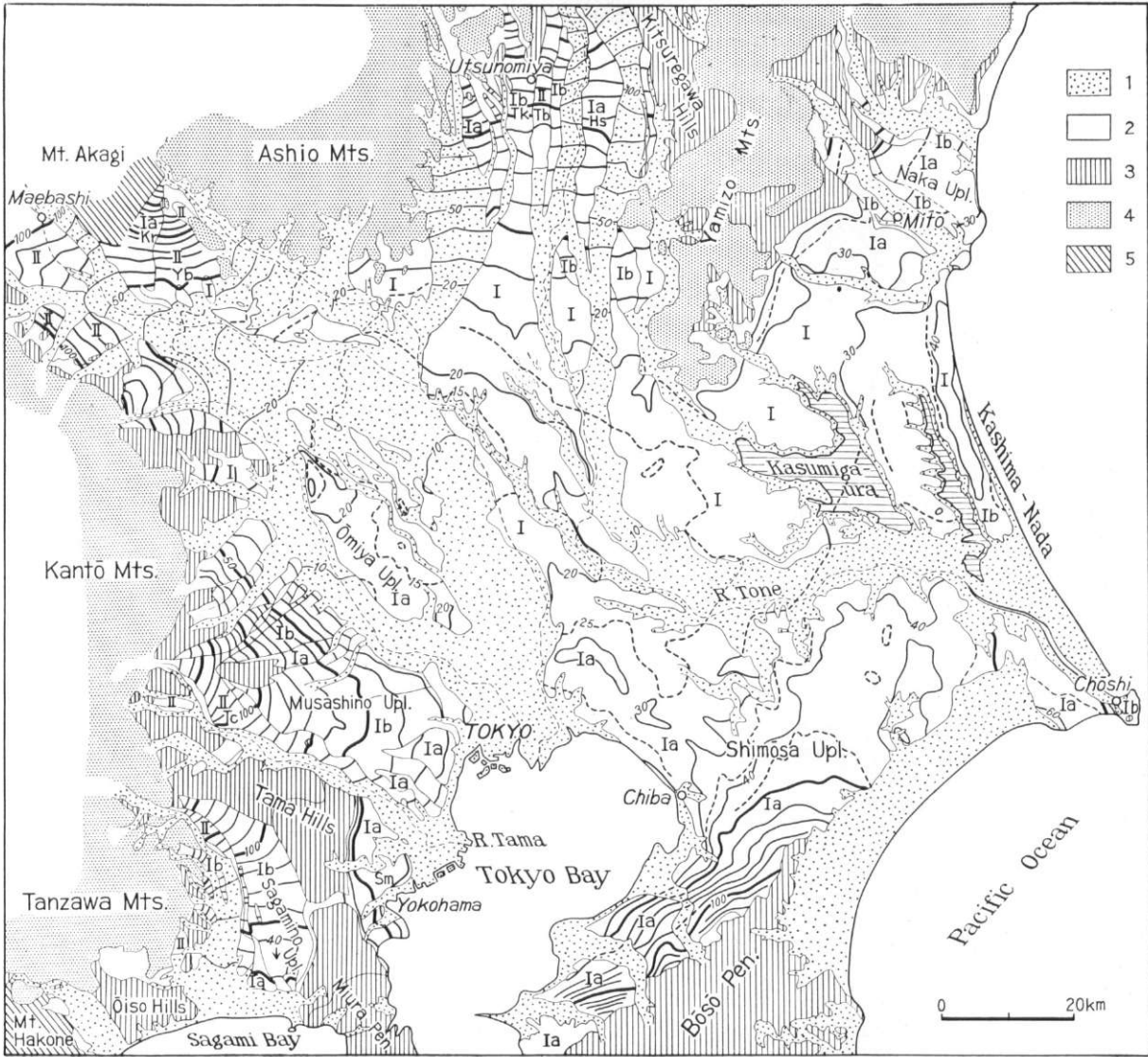


Fig. 4: Morphology of the Kantō Plain

- 1 Alluvial plain (A Surface)
- 2 Upland and terrace (Du Surface);
contour interval: 10 m

- 3 Hilly land (mainly D1 Surface)
- 4 Mountain land
- 5 Volcano

- I Du_I Surface
- Ia Du_{Ia} Surface
- Hs Hōshakuji Terrace
- Kr Kiri-hara Terrace
- Sm Shimosueyoshi Terrace
- Tb Tabara Terrace

- Ib Du_{Ib} Surface
- II Du_{II} Surface
- Tc Tachikawa Terrace
- Tk Takaragi Terrace
- Yb Yabuzuka Terrace

western and southwestern regions of the Kantō Plain, and most of them were deposited in the Pleistocene epoch.

Having a yellowish-brown or auburn tint, the Kantō Loam is a weathered volcanic ash formation. It is mainly a silty loam judging from its grain size, but in the vicinities of the source volcanoes, it is rather coarse. The thickness of the Kantō Loam runs over 40 m at certain places but in the most extensively covered areas it is merely a few meters thick. Its color as well as the vertical cleft makes it resemble loess. However, it differs from loess in that it is not calcareous and is almost sterile of fossils, especially animal fossils. Here and there layers of black scoria and pumices of white, yellow and red tints are sandwiched in the Kantō Loam and, frequently, black bands — identified by *Toya* and *Kaizuka* (1956) to be buried soils — are visible. The use of these volcanic ashes (the Kantō Loam) in the study of the geomorphology of the Kantō Plain is what the author would like to explain in the following pages.

1) Application of Tephrochronology to Geomorphology

Tephrochronology is employed in the study of the geomorphology of the Kantō Plain for two objectives: one is the correlation of geomorphic surfaces, the other is reproduction of palaeo-topography.

*a) Correlation of Geomorphic Surfaces*³⁾. Concerning terrace correlation, there are several methods based on the height of terraces, their degree of dissection, the status of weathering of deposits and the index fossils or archaeological remains in the deposits. Then too, in the regions where the volcanic ash layers have been scattered extensively and repeatedly, tephrochronology becomes of paramount importance for bringing about effective correlation results. It goes without saying, nevertheless, that many other pertinent methods should be employed in coordination with this method.

That the terrace surfaces could be correlated with the volcanic ashes is attributable to the simple principle that the older the terrace surfaces are, the greater the number of volcanic ash layers. This principle, which becomes the basis of correlation, is not only applicable to the volcanic ashes alone, but may also be employed generally in the case of aeolian deposits such as loess, etc.

³⁾ In this paper, a geomorphic or terrace surface means a flat surface, the shape of which is decided by fluvial or marine agencies, exclusive of the eolian volcanic ash layers which cover this surface.

Next, through the actual examples of the Kantō Plain, the author wishes to discuss the problem of terrace correlation with the volcanic ashes.

The volcanic ashes distributed throughout the Kantō Plain were considered, up to around 1945, as a single layer which was formed at the end of the Pleistocene. In 1947, however, *F. Tada* found that the volcanic ash layers of the Musashino Upland in the western suburbs of Tokyo were much thicker than those of the slightly lower Tachikawa Terrace. He expounded that the upper parts of the volcanic ashes on the Musashino Upland were identical to those on the Tachikawa Terrace in that the older the terrace surfaces were, the thicker the accumulation of volcanic ashes. *Tada's* interpretation was then confirmed by *Fukuta* and *Hatori* (1952) in their studies of the mineral compositions of the volcanic ashes in the same region. Also *Kaizuka* and *Toya* (1953) and the Kantō Loam Research Group (1956) brought to light the fact that the relationship between the Kantō Loam and the landform of the southwestern Kantō Plain is in the state as indicated in fig. 5. That is, the Kantō Loam was classified into 4 members, Tama, Shimosueyoshi, Musashino, and Tachikawa Loam in the order of their chronology, and they were identified to have some affiliation with the 4 terrace surfaces respectively. These respective Loam members are considered to have accumulated during a prolonged period rather than suddenly like the accumulation of a sheet of pumice. This can easily be imagined through the existence of buried soils in these members and the thickness of each volcanic ash member (fig. 6).

With the classification of the Kantō Loam as just mentioned, it now becomes possible to carry out the dating of the terrace surfaces and terrace deposits with the help of the tephrochronological method. In utilizing these 4 volcanic ash members, the terrace surfaces may be classified into the following 5 groups.

- (1) The terrace surfaces formed prior to the Tama Loam member.
- (2) The terrace surfaces formed between the Tama and Shimosueyoshi Loam members.
- (3) The terrace surfaces formed between the Shimosueyoshi and Musashino Loam members.
- (4) The terrace surfaces formed between the Musashino and Tachikawa Loam members.
- (5) The terrace surfaces formed after the Tachikawa Loam member.

Moreover, through further intensive surveys, it has become possible to classify the other terraces: those formed during the ash-deposition,

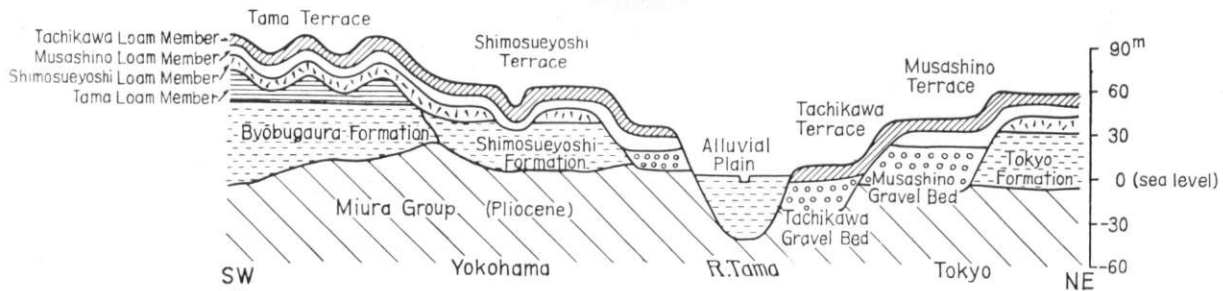


Fig. 5: Diagrammatic section illustrating relationship between volcanic ash layers (Kantō Loam) and geomorphic surfaces in the environs of Tokyo

those formed just prior to the ash-deposition, and finally those formed within some time-interval following the volcanic ash-deposition. For example, when there is some time-interval between the ash fall and terrace surface formation, the terrace deposits weather, the terrace surface is dissected and an unconformable relationship is observed between the terrace deposits and the volcanic ash layer. Or, when both the lower, younger terrace and the higher, older terrace are covered with the same volcanic ashes, the required time intervals should be taken into consideration between the ash fall and the formation of the higher terrace.

In conformity with the above methods, the terrace surfaces have been correlated. Fig. 8 illustrates the chronology of the terrace surfaces and terrace deposits in the Kantō Plain.

b) Reproduction of Palaeo-topography. When the terrace surfaces are correlated in accordance with the preceding methods, the palaeo-geography is reproduced as based on the correlated terrace surfaces. For example, if one of the correlated terrace surfaces is a fluvial terrace and the other a marine terrace, it can be said that the shoreline at that time was situated between the two terraces.

According to the tephrochronological method, however, not only the reproduction of the palaeo-geography becomes possible, but also the palaeo-topography at the time of a certain volcanic ash fall may be reproduced. For example, it can be observed that, as indicated graphically in fig. 5, the Tama Terrace had already been dissected before the deposition of the Shimosueyoshi Loam member. Then too, before the accumulation of the Tachikawa Loam member, it is said that the greater portion of the land, except for the alluvial plain, had the same topographic features as those of the present.

In summary, it goes without saying that through the employment of tephrochronological methods, it becomes apparently possible to corre-

late the terrace surfaces and simultaneously reproduce palaeo-topographic features.

2) Stratigraphic Division and Correlation of Volcanic Ejecta

As can be naturally anticipated in the study of tephrochronology, the stratigraphy of volcanic ejecta is first ascertained, followed by an extensive correlation of volcanic ejecta. Now, the author would like to discuss here the problems of stratigraphic division and correlation of the volcanic ashes (the Kantō Loam) of the Kantō Plain.

a) Stratigraphic Division of the Kantō Loam. The Kantō Loam is extensively distributed over the Kantō Plain. The Kantō Loam of southern Kantō has mainly been derived from the volcanoes of Fuji, Hakone, and others belonging to the so-called Fuji Volcanic Zone in the southwest of the Kantō Plain, while that of northern Kantō is mainly attributable to the volcanoes of Asama, Haruna, Akagi, and others in the chain of the so-called Nasu Volcanic Zone. These facts were practically verified by S. Nakao (1932), M. Harada (1943) and others who had examined the mineral compositions of the volcanic ashes and the distributions of the pumice layers found in the Kantō Loam.

Since there are many discrepancies in the source volcanoes and stratigraphy of the volcanic ashes found in the northern and southern Kantō Plain, the stratigraphic division has been carried out separately in these two areas. In fig. 6 the typical columnar sections of the Kantō Loam of various regions and the main distribution of pumice layers are illustrated.

As for the stratigraphic division of the Kantō Loam, the southern Kantō Loam, as quoted previously, has been classified into 4 members by the Kantō Loam Research Group (1956); and in the western regions of northern Kantō into 3 members, the Upper, the Middle and the Lower Loam member by F. Arai (1956) (fig. 6; No. 9); while in the central regions of northern Kantō, it has been classified by J. Akutsu (1957) into 5 mem-

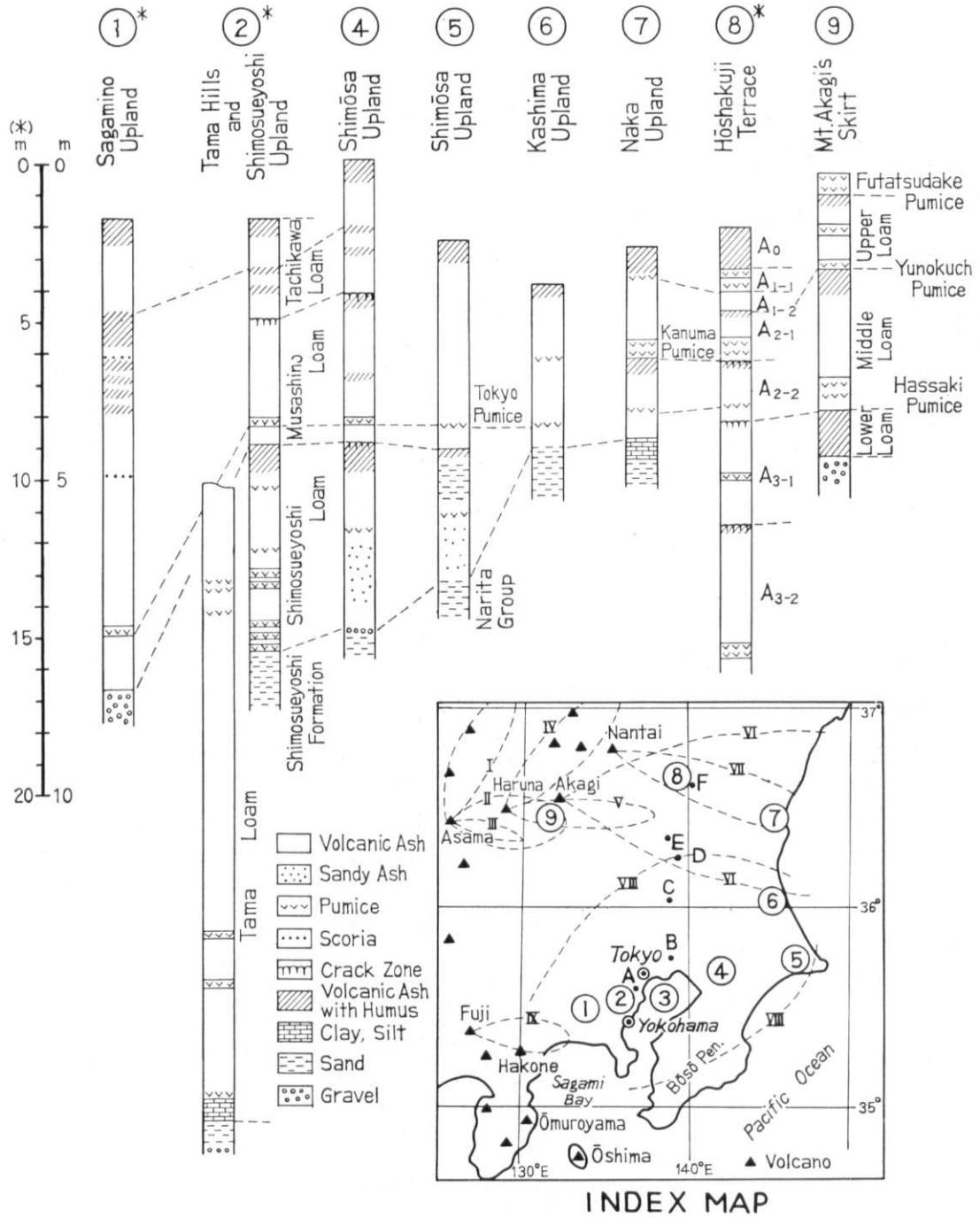


Fig. 6: Typical columnar sections of the Kantō Loam

Asterisk(*)-bearing column is measured with the scale on the left. Roman numerals refer to distribution area of pumice or scoriaceous bed on index map.

- I Kusatsu pumice
- II Yunokuchi pumice
- III Tenmei pumice
- IV Futatsudake pumice
- V Hassaki pumice

- VI Kanuma pumice
- VII Imaichi pumice
- VIII Tokyo pumice
- IX Hōei scoriaceous ejecta

bers, designated in descending order as A_0 , A_1 , A_2 , A_3 and A_4 member all of which are further broken down to A_{1-1} , A_{1-2} , A_{2-1} , A_{2-2} and so on (fig. 6; No. 8). Such stratigraphic division of the Kantō Loam is especially based on the indications of time-intervals observed within the Kantō Loam formation. By indications of time-intervals, the author means the existence of unconformities, the presence of buried soils, the changes of lithofacies and the transformation of mineral compositions within the Kantō Loam formation; all these naturally appear simultaneously.

b) Correlation of Volcanic Ashes in Various Kantō Regions. As aforementioned, after the consummation of the stratigraphic division of the volcanic ashes in every area in question, next comes the mutual correlation; the methods of correlation are as follows:

(1) The tracing of unconformities and buried soils disclosing the pauses during ash falls among the volcanic ash layers.

(2) The correlation through the lithofacies of volcanic ash layers, especially, the tracing of those layers having special external features such as pumice and scoria.

(3) The correlation based on mineral compositions of volcanic ashes.

(4) The correlation based on the relation of volcanic ash layers and terraces.

(5) The correlation based on the relation of volcanic ash layers and archaeological remains.

It is necessary, of course, that the above correlation methods are applied jointly.

In the correlation of the Kantō Loam, it can be said that little difficulty has been encountered in performing the correlation of the east and the west in northern Kantō or of the east and the west in southern Kantō. This is because the volcanic ashes in Japan are generally carried by westerly winds from source volcanoes and are distributed extensively from west to east. On the contrary, however, due to this same reason, it is not an easy task to correlate the volcanic ashes of northern and southern Kantō.

The author now would like to point out the results of the investigations on the correlation of comparatively young volcanic ashes⁴⁾ formed in southern and northern Kantō.

In order to correlate the volcanic ashes of northern Kantō with those of southern Kantō, the author made an investigation on the eastern part of the Kantō Plain (Kaizuka, 1957) and then

⁴⁾ Since the distribution is fragmentary in the older volcanic ashes of the Kantō Plain, such as the Tama Loam, Shimosueyoshi Loam, Lower Loam and A_3 and A_4 members, it would be quite difficult to carry out pertinent correlations through methods (1), (2) and (3).

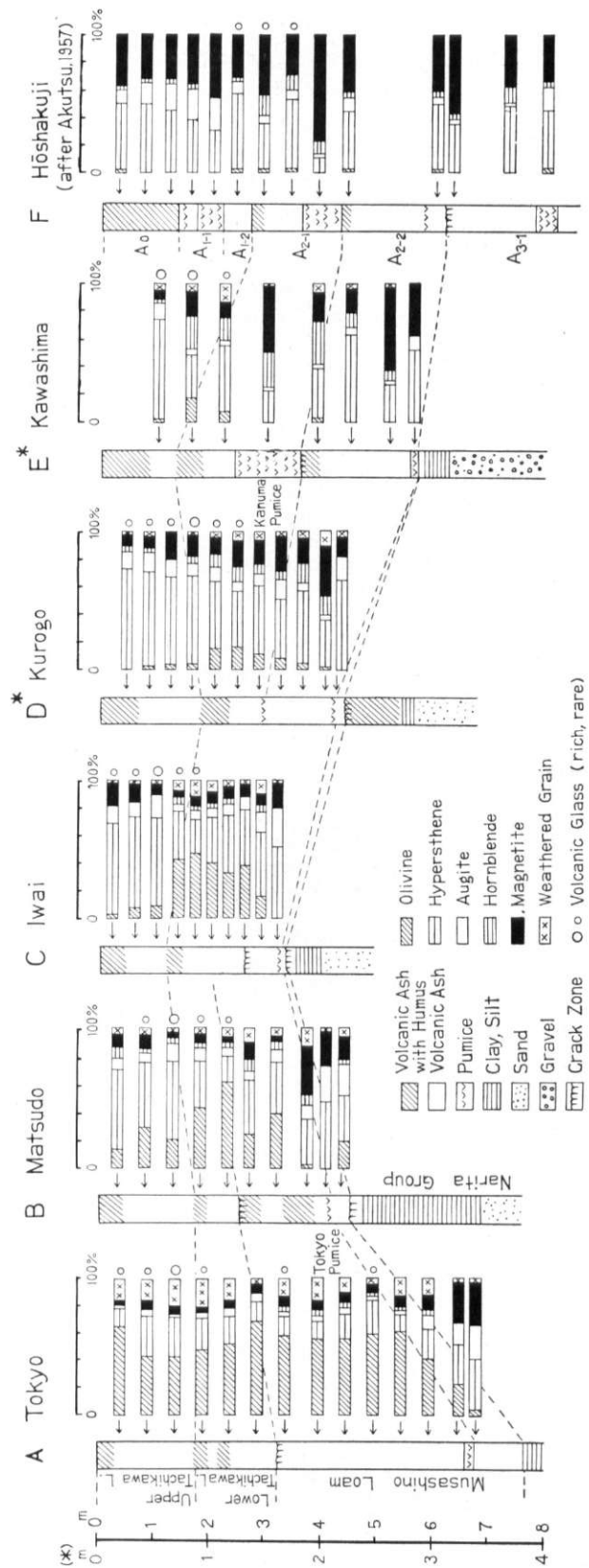


Fig. 7: Columnar sections and heavy mineral composition of the Kantō Loam in the northern, central and southern Kantō Plain. Locations are shown by letter on the index map of fig. 6. Asterisk-bearing column is measured with the scale on the left.

the central part of the plain. There he sought first the mutual relationship of the Kanuma pumice bed, which is inserted in the Middle Loam and A_2 members and is widely distributed over the northern Kantō, and the Tokyo pumice bed, which is inserted in lowest part of the Musashino Loam member and is prevalent over the southern Kantō. And then he discovered that the Kanuma pumice bed overlaps the Tokyo pumice bed. Further, after tracing a buried soil bed in the Tachikawa Loam member and another in the uppermost A_2 member, he ascertained that both buried soil beds actually correlate with each other. Meanwhile, he investigated the mineral composition of the volcanic ashes found in the northern, central and southern Kantō regions. The results are illustrated in fig. 7.

In investigating the mineral composition, samples were taken from exposures, then the mineral grains having $1/4$ — $1/8$ mm diameter of each sample were separated into two parts, heavy and light, by Toulet's liquid (specific gravity: 2.90), and finally 200 grains of the heavy minerals were identified under a microscope.

As indicated in fig. 7 A and B, both the Musashino and Tachikawa Loam members of southern Kantō are rich in olivine, the origin of which is believed to be mainly attributable to Fuji Volcano as disclosed by *Kuno* (1950) previously in this paper. Furthermore, the Tachikawa Loam member is divided into 2 parts, upper and lower, with a buried soil in its central part. The special feature of the upper Tachikawa Loam layer is that it contains at its base plenty of volcanic glass.

Contrarily, however, as seen in fig. 7 E and F the northern Kantō Loam formation has practically no olivine, but has much hornblende; while in the southern Kantō area, no deposit of hornblende could be found except in the Tama Loam member. The A_{1-1} member in the northern Kantō Loam is known to have derived from Nantai Volcano, and the A_{1-2} member is believed to have most likely originated from Asama Volcano. Scarcely any hornblende is found thereabouts, but the A_2 member is characterized by abundant hornblende.

In the central region of the Kantō Plain, as indicated fig. 7 C and D, we are able to find a mixture of olivine and hornblende which are contained in great quantity in the southern and northern Kantō areas respectively. According to minute observation of this figure the following correlations can be discerned.

The upper Tachikawa Loam member \approx The A_{1-2} member
The lower Tachikawa Loam member \approx The A_{2-1} member

The Musashino Loam member \approx The A_{2-2} member

The above results are graphically illustrated in fig. 8. Such correlation of the northern and southern Kantō Loam is supported by the relationship of the Kantō Loam and the type of stone implements as denoted in fig. 8.

3) Chronology of Geomorphic Surfaces based on Volcanic Ejecta

With the correlation of the volcanic ashes in such a manner, the dating of the geomorphic surfaces is also performed in conformity with the methods as explained previously in this paper.

Though numerous other researchers had been engaging in the classification of the geomorphic surfaces of the Kantō Plain (for example, *Aoki* and *Tayama*, 1930; *Makiyama*, 1931), the author, after the model of *Y. Otuka* (1931, 1935) undertook those classifications as indicated on the left side of fig. 8 and in table 2 as A_{II} , A_I , Du_{II} , Du_{Ib} , Du_{Ia} , and Dl_{II} . The distribution of the geomorphic surfaces is denoted in fig. 4⁵⁾.

To correlate the geomorphic surfaces by the tephrochronological method is likewise to date the terrace deposits (the Quaternary layers) from which the geomorphic surfaces are formed. Accordingly, with the collaboration of *Y. Naruse*, the author has tried to delineate in fig. 8 the chronological positions of the Quaternary deposits.

Because of the difficulties involved in not being able to correlate adequately the northern and southern Kantō regions, the Loam members older than the Musashino Loam member were correlated mainly on the bases of altitudes and the degrees of dissection of the geomorphic surfaces covered with the members.

The correlation of the terrace surfaces with the Quaternary deposits of the Kantō Plain entails the possibility of reproducing the palaeo-geomorphology of the Kantō Plain in the Quaternary period.

4) Geomorphic History of the Kantō Plain

In the reproduction of the palaeo-geomorphology based on the dated geomorphic surfaces and Quaternary layers (fig. 9), the author exerted special efforts to delineate the coastlines at the time of the formation of the marine terrace surface. He determined the location of the coastlines of the then Dl_{II} Surface by conjecture based mainly on the distribution of the marine formations, owing to the fact that the coastlines are topographically vague. Nevertheless, the coastlines of the Du_I Surface were comparatively easily determined because of the remaining sea cliff topography.

⁵⁾ For details regarding each geomorphic surface and its relationship to the Kantō Loam, see *S. Kaizuka* (1958).

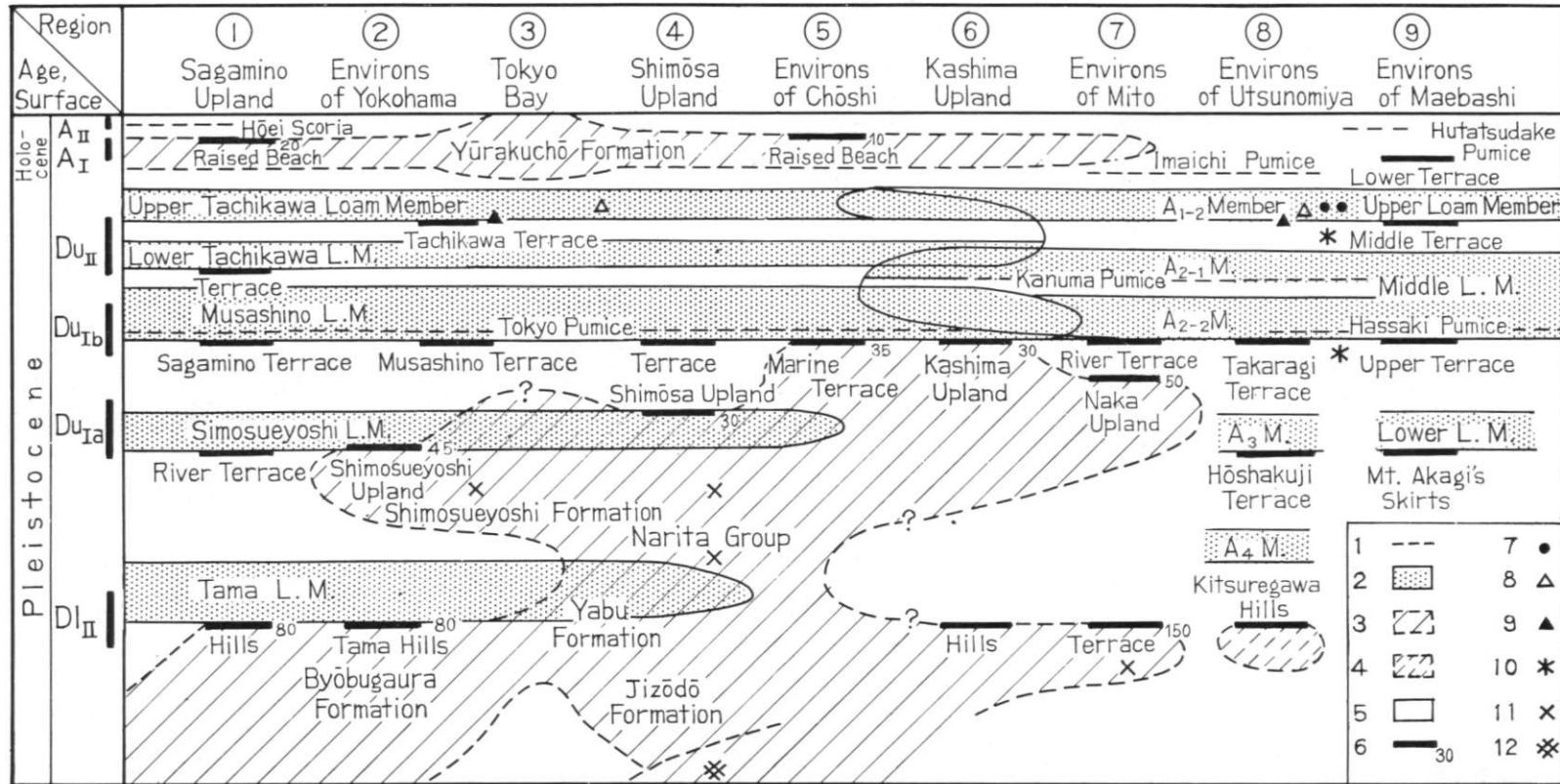


Fig. 8: Chronology of the Kantō Loam, geomorphic surfaces, Quaternary deposits and non-ceramic cultures

Locations are shown by number on the index map of fig. 6.

- | | |
|---|--|
| 1 pumice or scoria bed | 7 point |
| 2 volcanic ash layer (Kantō Loam) | 8 knife-blade |
| 3 marine deposits | 9 blade |
| 4 lacustrine deposits | 10 hand axe |
| 5 subaerial or fluvial area | 11 <i>Palaeoloxodon namadicus naumanni</i> |
| 6 geomorphic surface and its height above/sea-level (m) | 12 <i>Stegodon orientalis</i> |

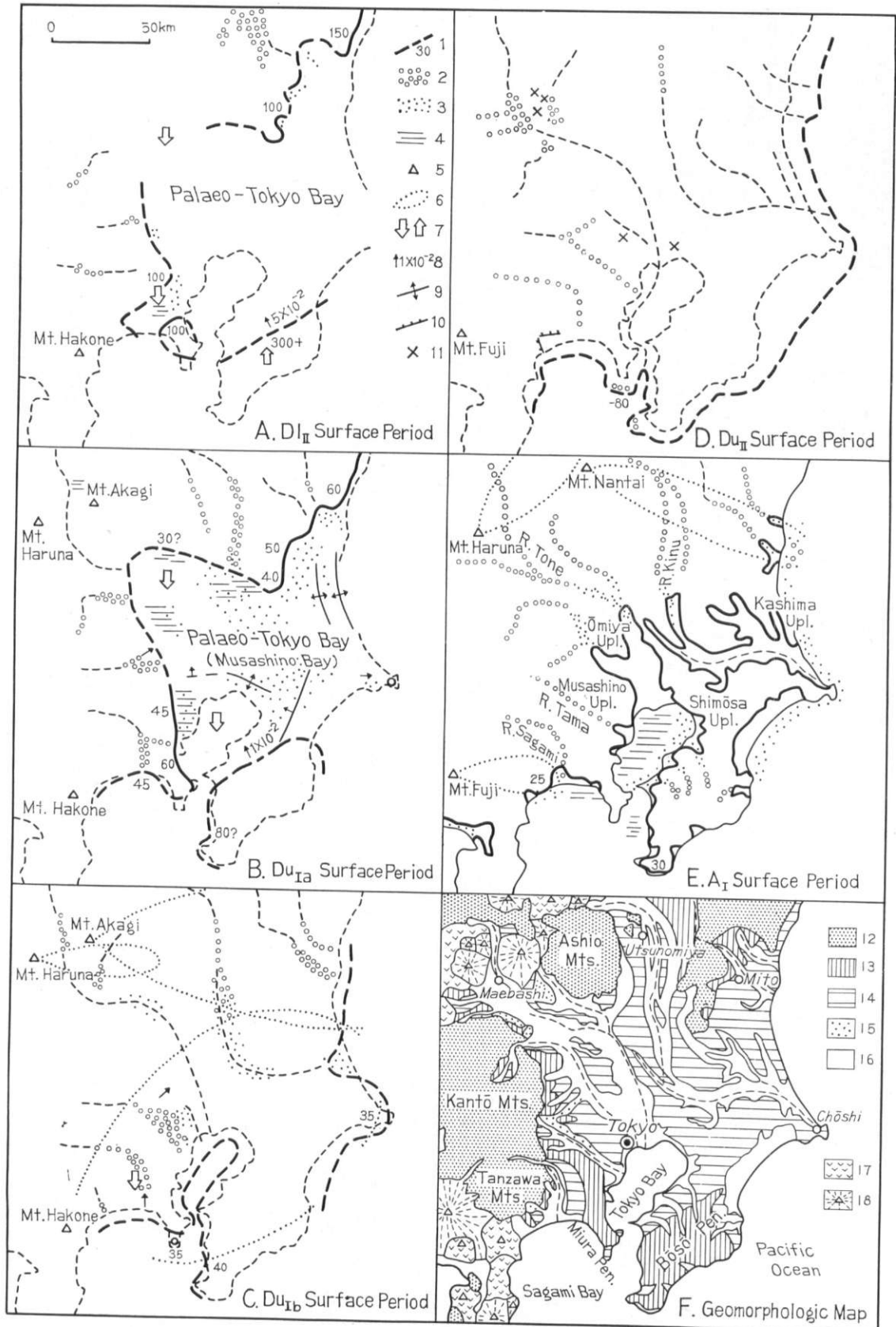


Fig. 9: Palaeogeographic and Geomorphologic Maps of the Kantō Plain

a) *Geomorphic History prior to the D_{II} Surface.* The geomorphic surfaces prior to the D_{II} Surface are unknown topographically and for the present there are no signs of any extensive studies referring to them. Consequently, the author would like to point out briefly the results of the stratigraphic studies by K. Koike (1957) on the period preceding the D_{II} Surface.

In the middle Miocene, the "Tanzawa Orogenic Movement" occurred in the southern Kantō region, followed by a subsequent upheaval stretching from the Tanzawa Mts. over to the Miura and Bōsō Peninsulas. To the northern and southern flanks of the upheaval, there appeared geosynclinal subsidences in the wake of the upheaval. Here the Pliocene layers of the Miura group were deposited and in the late Pliocene the southern flank folded and emerged, while the northern flank continued its subsidence. Although the northern Kantō region had emerged during the Pliocene, it subsided in the early Pleistocene, and thus the Kantō Plain became a single bay, called the "Palaeo-Tokyo Bay" by H. Yabe. In view of the doubtfulness of the accuracy of correlating the Japanese Quaternary period with that of Europe, it is considered that the period of the D_{II} Surface corresponds to the lower or middle Pleistocene.

b) *Period of the D_{II} Surface (fig. 9A).* The D_{II} Surface was formed by a single, violent transgression whereby the Kantō Plain became a unique vast gulf. The marine depositional surfaces of this transgression are presently preserved around the Kantō Plain, the eastern part of the Tama Hills being a striking example of a partial sector of these. The coastlines in the southwestern and northeastern Kantō areas were at that time seemingly about 100–150 m above the present sea-level, and those in the central part of the Bōsō Peninsula were more than 300 m above the present sea-level.

No trace of the D_{II} Surface in the central part of the Kantō Plain. This is because the down-warping thenceforth brought about the subsidence of the surface in question underneath the present alluvial plain. It is worthy of note that the

subsidence of the central portion of the Kantō Plain had been continuing throughout the whole of the Quaternary period, and the Kantō Plain is subsequently called the Kantō Tectonic Basin.

The Tama Loam member was deposited when the marine D_{II} Surface emerged. The newly-formed coastal plain was thickly covered by this Loam.

c) *Period of the D_{Ix} Surface.* A regression stage followed the D_{II} Surface period. Consequently, extended rivers dissected the D_{II} Surface; the valley bottoms of the rivers are called the D_{Ix} Surface. Since these valley bottoms are buried below the deposits that form the subsequent D_{Ia} Surface and alluvial plains, it is rather difficult to ascertain where the coastlines at that time were situated.

d) *Period of the D_{Ia} Surface (fig. 9B).* This was a transgression stage, at which time the Palaeo-Tokyo Bay expanded once again. The marine deposits that accumulated in this bay belong to the upper section of the Narita group and its depositional surface presently covers the extensive area of the Kantō Plain known as younger coastal plain.

Topographically the former coastlines are well preserved, their altitudes being about 50 m above the present sea-level. However, in the central part of the Kantō Plain, the surfaces of this coastal plain are about 20 or less meters above the present sea-level (fig. 4), indicating the influence of the basin forming movement.

It was during the acme of this transgression that the Shimosueyoshi Loam member was deposited. With regard to the appearance of topography of the D_{II} Surface in the period the Shimosueyoshi Loam member was deposited, the investigations carried out by the Kantō Loam Research Group in 1957 showed that the D_{II} Surface, covered with thick layers of the Tama Loam member, had been dissected considerably. This could be observed because the Shimosueyoshi Loam member had practically been washed away except for a part remaining along the slopes of the valleys that dissect the Tama Hills.

e) *Period of the D_{Ib} Surface (fig. 9C).* Regression began and the coastal plain of the D_{Ia} Surface was incised by extended rivers. In this period, a giant fan "Musashino" was formed in the western section of Tokyo. Then, the embryo of the present Tokyo Bay seems to have been formed; and the Palaeo-Tokyo Bay of the D_{Ia} Surface period gradually retreated simultaneously southward towards the present Tokyo Bay and eastward towards Kashima-Nada. This can be surmised from the distribution of the marine deposits of that time. During the same period,

the present	
1 coastline and its height above/sea-level (m)	9 axis of up-warping
2 gravelly deposits	10 faulting
3 sandy deposits	11 site of non-ceramic culture
4 clayey deposits	12 mountain region
5 volcanic activity	13 hills (D_I Surface)
6 distribution of pumice or scoria bed	14 upland (D_{II} Surface)
7 up- and down-warping	15 terrace (D_{II} Surface)
8 tilting and its magnitude (tangent)	16 alluvial plain (A Surface)
	17 older volcano
	18 younger volcano

a gentle up-warping occurred in the eastern part of the Kantō Plain, forming the approximate upland surface features of the present Kantō Plain. After the Du_{Ib} Surface was slightly dissected, the Musashino Loam member was deposited in the southern Kantō region, while in northern Kantō, the A₂ member was deposited.

f) *Period of the Du_{II} Surface (fig. 9 D).* Subsequent to the period of the Du_{Ib} Surface, the regression continued; and the rivers seeking the depressed sea-level continued to dissect the land, forming the Tachikawa Terrace and many others.

Today, we cannot find any marine deposits of this period on the land. Through the investigations of alluvial deposits in the vicinities of Tokyo and Yokohama, it has been revealed that the lowest among the geomorphic surfaces of this period are buried below the alluvial deposits more than 60 m in thickness (for example, *Ōtuka*, 1934), while on the southern submarine shelf of the Kantō area, lies a flat surface 80–110 m below the sea-level (*Kaizuka*, 1955). Because this flat surface is considered to be the then marine abraded platform, the coastlines at that time have been delineated by a 80 m isobathic line as illustrated in fig. 9 D.

Formed in this regression period were the Tachikawa Loam, the Upper Loam, and the A₁₋₂ members. From these volcanic ash layers, stone implements of blade, knife-blade and point types have been unearthed since 1949. The relationship

of this stone culture to the Palaeolithic Culture of the Asian Continent or Europe is as yet unknown, but it is probable that the stone culture in question is of upper Pleistocene age (*Serizawa*, 1956). In this connection, and in view of the late Quaternary history of all Japan (*Iseki*, 1957), the regression of this period is considered to be mainly caused by the sea-level drop through the glacial eustasy of the Würm Glacial Age.

g) *Period of the A Surface (fig. 9 E).* This is mainly the Japanese Neolithic age and the transgression stage of the Jōmon age. That in the early Jōmon age the sea had covered the land most extensively can be verified by the study of shell mounds. The coastlines as illustrated in fig. 9 E are taken from the study of shell mounds by *R. Tōki* (1926). The geomorphic surface formed at the acme of the transgression stage are called the A_I Surface. Thenceforth came a slight regression (*Sugimura* and *Naruse*, 1954) and the present coastlines were established. The present flood plain surface is distinguished from the A_I Surface as the A_{II} Surface. Even after the beginning of the Holocene age, volcanic ejecta fell every now and then, the salient falls among them are the Futatsu-dake pumice bed of Haruna Volcano (about 1,300 years ago), the Hōei scoriaceous bed of Fuji Volcano (1703 A.D.) as investigated by *H. Tsuya* (1955), and the Tenmei pumice bed of Asama Volcano (1783) as probed by *T. Minakami* (1942). Only a brief summary of the history of

Geologic age	Kantō Loam (volcanic ash)		Geomorphic surface		Geomorphic events	Culture and mammal fossil	Relative change of sea-level (Southwestern Kantō)	Local crustal movement (basin forming down-warping)	
	Southern Kantō	Northern Kantō	Symbol	Type surface					
Pleistocene	lower upper Tachikawa Loam member Musashino Loam m. Shimosueyoshi Loam m. Tama Loam member	A ₁₋₁	A ₁₋₁	A _{II}	Alluvial plain	A little regression, formation of the present flood plain		Basin of Tokyo Bay Sagami sedimentary basin Kantō tectonic basin	
		A ₁₋₂	A ₁₋₂	A _I	Numa Terrace	Transgression, formation of embayments			Historical age Yayoi culture
		A ₂₋₁	A ₂₋₁	Du _{II}	Tachikawa Terrace	Regression, deepening of valleys, formation of submarine terrace of 80-100 m below the present sea-level			Jōmon culture
		A ₂₋₂	A ₂₋₂	b	Musashino Terrace	A little regression, emergence of younger coastal plain, erosion by extended rivers			Non-ceramic culture microlith point knife-blade handaxe
		A ₃	A ₃	Du _I	Shimo-sueyoshi Terrace	Transgression, sedimentation of younger coastal plain deposits (Shimosueyoshi formation etc.) in Musashino Bay			?
		A ₄	A ₄	DI _x	Valley bottom under Shimo-sueyoshi formation	Regression, emergence of older coastal plain, deepening of extended rivers			<i>Palaeoloxodon namadicus naumanni</i>
		DI _{II}	DI _{II}	DI _{II}	Tama Hills	Transgression, sedimentation of older coastal plain deposits (Byōbugaura formation, etc.) in a stage of Palaeo-Tokyo Bay			

Table 2: Chronology of physiographic events and cultures in the Kantō Plain

the Holocene age has been cited here, since more extensive studies of this subject may be found in the following references: *Tada, Nakano and Iseki* (1952), and *T. Nakano* (1954).

IV. Conclusion

The author has explained the tephrochronological studies undertaken in the diversified fields up to this time in Japan. He has particularly delineated the methods of correlation of geomorphic surfaces and the reproduction of palaeotopographies based on volcanic ash layers. Through these methods of tephrochronology, he classified the geomorphic surfaces of the Kantō Plain, and interpreted the palaeo-geography of each classified surface period; lastly he explained the geomorphic history of the Kantō Plain. This is summarized in table 2.

As can be seen in the palaeo-geographic maps (fig. 9) and chronological table (table 2) of the Kantō Plain during the Quaternary period, transgression and regression alternated in the Kantō Plain. The geomorphic history of the Kantō Plain was, therefore, mainly caused by these transgressions and regressions, but the distribution and the shape of the geomorphic surfaces were greatly controlled by local crustal movements in this region.

In Iceland, tephrochronological methods have been employed in the studies of archaeological sites, volcanoes, glacial morphology, etc. during the postglacial age (*S. Thorarinsson*, 1944, 1949, 1951), while in Germany, Patagonia, north-western regions of North America, etc., they have been particularly used in parallel with pollen analyses and absolute datings by radio carbon methods (*H. Straka*, 1956).

Unfortunately, here in Japan the calculation of absolute dating is as yet not deeply connected with tephrochronological studies at present. Nevertheless, now, in the field of geomorphology and Quaternary geology as well as volcanology, archaeology, pedology, sedimentology, etc., it has been recognized that the tephrochronology is of great significance.

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ZUR GEOMORPHOLOGISCHEN HOHENSTUFUNG DER SIERRA NEVADA SPANIENS

Ein Beitrag zur klimamorphologischen Zonierung der Erde

Ludwig Hempel

Mit 1 Abbildung und 6 Bildern

Geomorphological Altitudinal Limits in the Spanish Sierra Nevada

Summary: The following values of geomorphological altitudinal limits for the northern flank of the Sierra Nevada have been calculated. Whilst the climatic snow line is now at above 3,500 m., during the late glacial period its highest position was 3,200 m. and its lowest 2,850 m. During the Würm glacial period it lay at 2,400—2,500 m., during earlier glacial periods at 2,000—2,200 m. The present lower limit of solifluction is at 2,100 m., its upper limit above 3,500 m.; during the Pleistocene its maximum altitude was at 800—1,000 m., its upper limit is not ascertainable. These findings agree with other observations in the Mediterranean region, such as those of Büdel in southern Italy and Sicily and Poser in Crete. On the other hand they do not fit into the conjectured profiles of these limits from Europe to Africa which have been given so far. That illustrates the supposition that in the Mediterranean region, as elsewhere, the climate-morphological limits of the Holocene as well as the Pleistocene do not rise regularly.

Vorbemerkung

Dieser Studie liegen Beobachtungen zu Grunde, die ursprünglich nur dazu gedacht waren, einen Beitrag zum Problem der Zertalungsformen im mediterranen Spanien zu liefern. Bei Durchsicht des Beobachtungsmaterials aus der Sierra Nevada stellte sich aber heraus, daß darüber hinaus auch einige Aussagen über die geomorphologische Höhengliederung dieses Gebirges gemacht werden können. Allerdings schienen mir die Ergebnisse über die Höhen-

lage der einzelnen Formenstufen während des Pleistozäns so unwahrscheinlich, daß ich zunächst mit einer Veröffentlichung zögerte und eine erneute Prüfung der Befunde mit Hilfe des Buntfilmmaterials vornahm. Inzwischen hat Poser (1957) eine ebenso auffallende Höhengliederung von Kreta unter 35°N beschrieben und interpretiert. So schien es mir zweckmäßig, die Beobachtungen aus dem westlichen Mittelmeergebiet zum Vergleich danebenzustellen. Da ich nur den Nordteil der Sierra Nevada kennengelernt habe, können meine Bemerkungen und Erklärungen nicht repräsentativ für das ganze Hochgebirge sein. Es ist durchaus möglich, daß bei einer Bearbeitung der ganzen Sierra Nevada auch Stellung und Bedeutung des Gebirges im Rahmen einer klimamorphologischen Zonierung der Erde sowohl für die Jetztzeit als auch für das Pleistozän ein etwas anderes Gewicht bekommen können.

Die Befunde

Die Forschungsgeschichte der Sierra Nevada ist schon sehr alt. Die umfassendste Arbeit, in der alle Teilgebiete der Geographie abgehandelt werden, ist die von Rein (1899). In ihr sind die Ergebnisse der Forschungen des 19. Jahrhunderts verarbeitet. Von den vielen Ergänzungen im Anfang des 20. Jahrhunderts verdient die von Quelle (1908) besondere Beachtung. Er präzierte zum ersten Mal die wichtigsten Fragen, auf die sich die geographische Forschung in der Sierra Nevada konzentrierte und beantwortete auch