Impact of Tephra Forming Eruptions on Human Beings and the Environment

Hiroshi MACHIDA

Professor emeritus, Tokyo Metropolitan University
machida@andes.metro-u.ac.jp/QYP04721@nifty.ne.jp

Abstract

This paper firstly addresses that Quaternary tephrochronology should provide basic guidelines for predicting future explosive volcanism, frequency and magnitude. Secondly, application of such studies to archeology and human occupation of volcanic areas is explored using a case study of prehistoric cataclysmic eruptions and their impacts on human beings and the environment. A large volcanic eruption generated significant change in nature and culture in volcanically active area like Japan. The principal mechanism concerned appears to be that of landscape change, which made large-scale adaptation and readjustment necessary. The paper illustrates the wide range of research tools which may be adopted to determine the relationship between an archeological site and the hazards present in the natural environment.

Key words: archeology, AT, cultural discontinuity, dating, environmental change, eruptive history, explosive volcanism, frequency, Japan, Jomon, K-Ah, Late Quaternary, magnitude, microlithic, paleolithic, tephrochronology

1. Introduction

Volcanic ash (tephra) layers not only govern the nature of soil and landforms, but are also important in interpreting past events in highly volcanic areas. Such events include volcanic hazards and environmental changes of the past. This paper firstly emphasizes that Quaternary tephrochronology should provide basic guidelines for predicting future explosive volcanism, because the tephras clearly indicate the size and nature of past explosive events and how frequently they happened. Secondly, application of such studies to archeology and human occupation of volcanic areas is explored using a case study of prehistoric cataclysmic eruptions and their impacts on human beings and the environment. Joint studies between tephrochronology and archeology are significantly useful for such interpretation. The Japan area is selected here because many results have been obtained.

2. Magnitude and Frequency of Very Large Explosive Volcanism in the Late Quaternary in Japan

Simkin *et al*. (1981) and Newhall and Self (1982) proposed a volcanic explosivity index (VEI), which is a general indicator of the explosive character of an eruption on the basis of bulk volume of tephra erupted and the maximum height of the eruption column. Eruptions can be assigned a VEI on a scale of 0 to 8. The larger the VEI value the greater the amount of damage caused by an eruption. Eruptions with VEI of 3 or greater are 'large eruptions' causing severe damage over extensive areas. In Japan explosive activities with VEIs of 4 and 5 have happened several times in historic times, but very large-scale activities with VEIs of 6 or 7 have not taken place for the last 1,000 years. There is much evidence of very explosive activity, however, during prehistoric times. Examples include widespread tephra sheets produced by large caldera volcanoes. Bulk volumes of such tephras are calculated mainly on the basis of isopach maps of fallout tephras and ignimbrite components. All of these eruptions are the products of plinian and ignimbrite-forming activity of VEIs of 6 and 7.

The Late Quaternary eruptive history of Japan is shown in Figs. 1a and 1b on the basis of the tephra catalogue presented "Volcanoes and Tephras in the Japan Area" (See Table 1 on page 23). It is clear that each caldera volcano produced major tephra layers with VEIs of 7 once or twice and VEIs of 6 several times during the last 130,000 years. It is also shown that each large caldera has been formed not by a single eruption but by multiple eruptions that have recurred approximately every 10,000 years.

Volcanoes can be classified in terms of expected maximum magnitude and frequency of eruptions

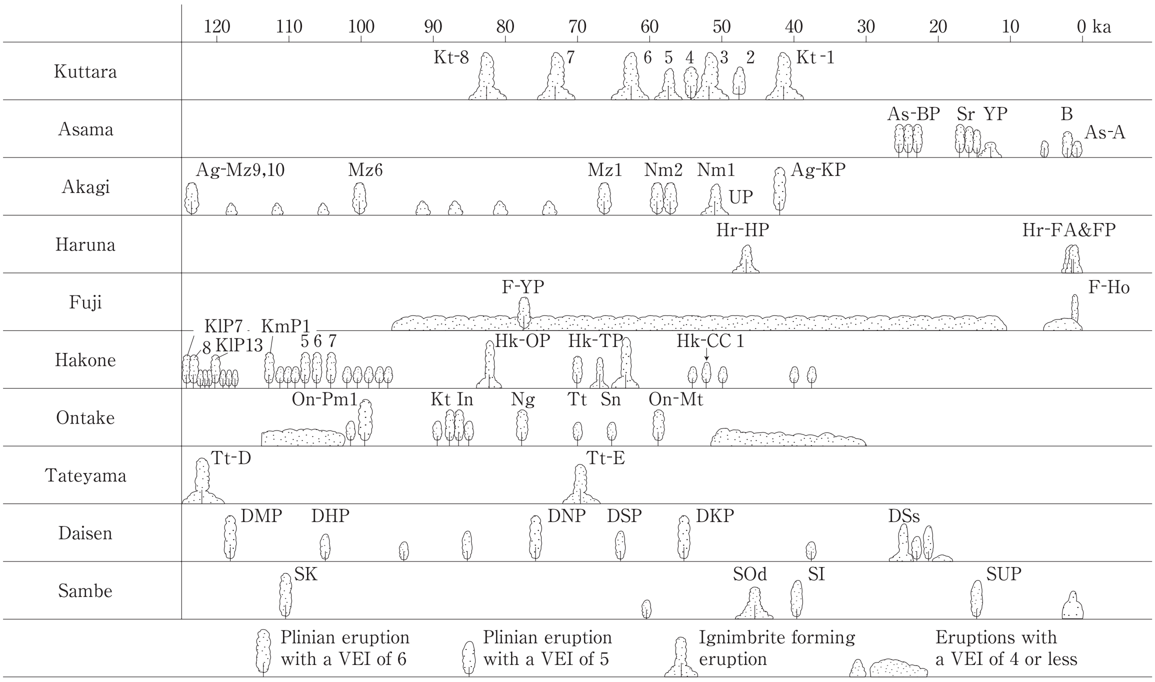

Fig. 1a Late Quaternary large explosive eruptions with a VEI of 5-6 in Japan
Machida and Arai (1992), revised.

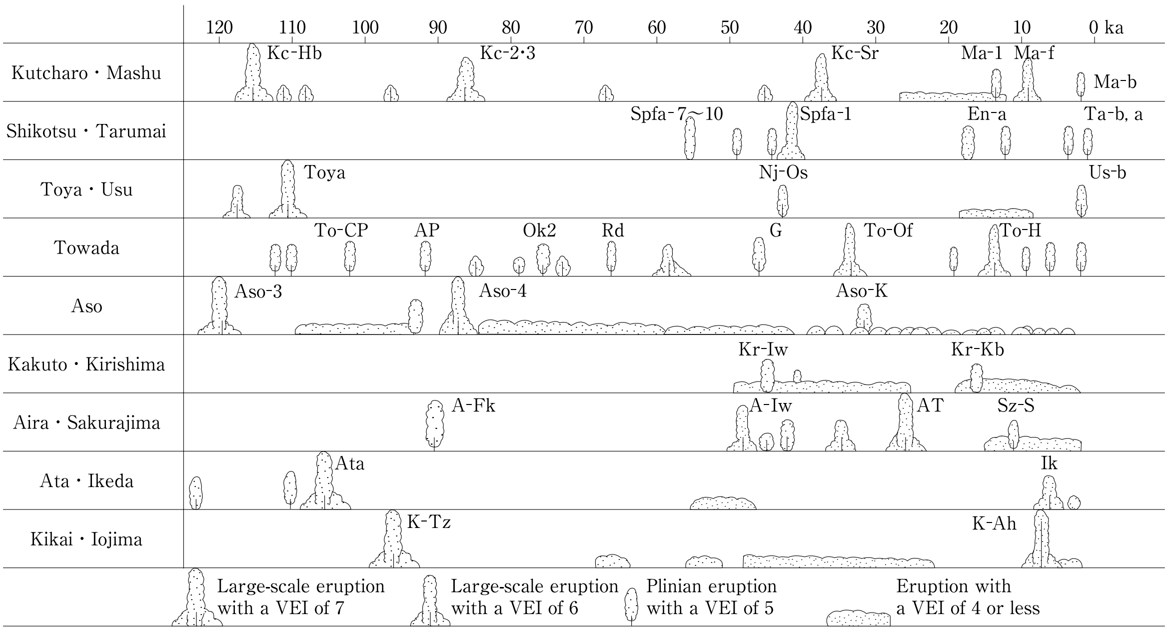

Fig. 1b Late Quaternary large explosive eruptions of caldera volcanoes with a VEI of 6-7 in Japan
Machida and Arai (1992), revised.

based on Quaternary tephrochronology. Figure 2 shows the maximum magnitude of eruption that occurred in the late Quaternary (*ie*., the maximum size of destructive eruption that *has* occurred so that it can therefore be predicted that it *will* occur in the future), the lapse of time since the last major eruption, and the frequency of major eruptions (Machida,1990). It must be remembered that long-quiescent caldera volcanoes, such as Aso, Ata and Toya, with no significant explosive activity (VEI of 7) during these 80,000-110,000 years, are the most hazardous.

The recurrence of such a huge volcanic event would be of catastrophic consequence to the highly populated areas of modern Japan. The impact of large-scale pyroclastic flows and associated ash falls on flora and fauna, as well as human beings, is difficult to predict. Incidentally, the Aso-4 pyroclastic flow deposit of 85,000-90,000 years ago, one of the largest tephra layers in the world, covers a land area of 30,000 km^2, where approximately 10 million people are living now. The effects of such extreme events in the future will almost certainly result in cultural destruction and replacement over a vast area.

Consequently such tephrochronological studies as mentioned here may be significant in the consideration of future eruptions and their effects in highly volcanic areas of the world. It would be instructive to know, therefore, the impact of major past eruptions on prehistoric communities.

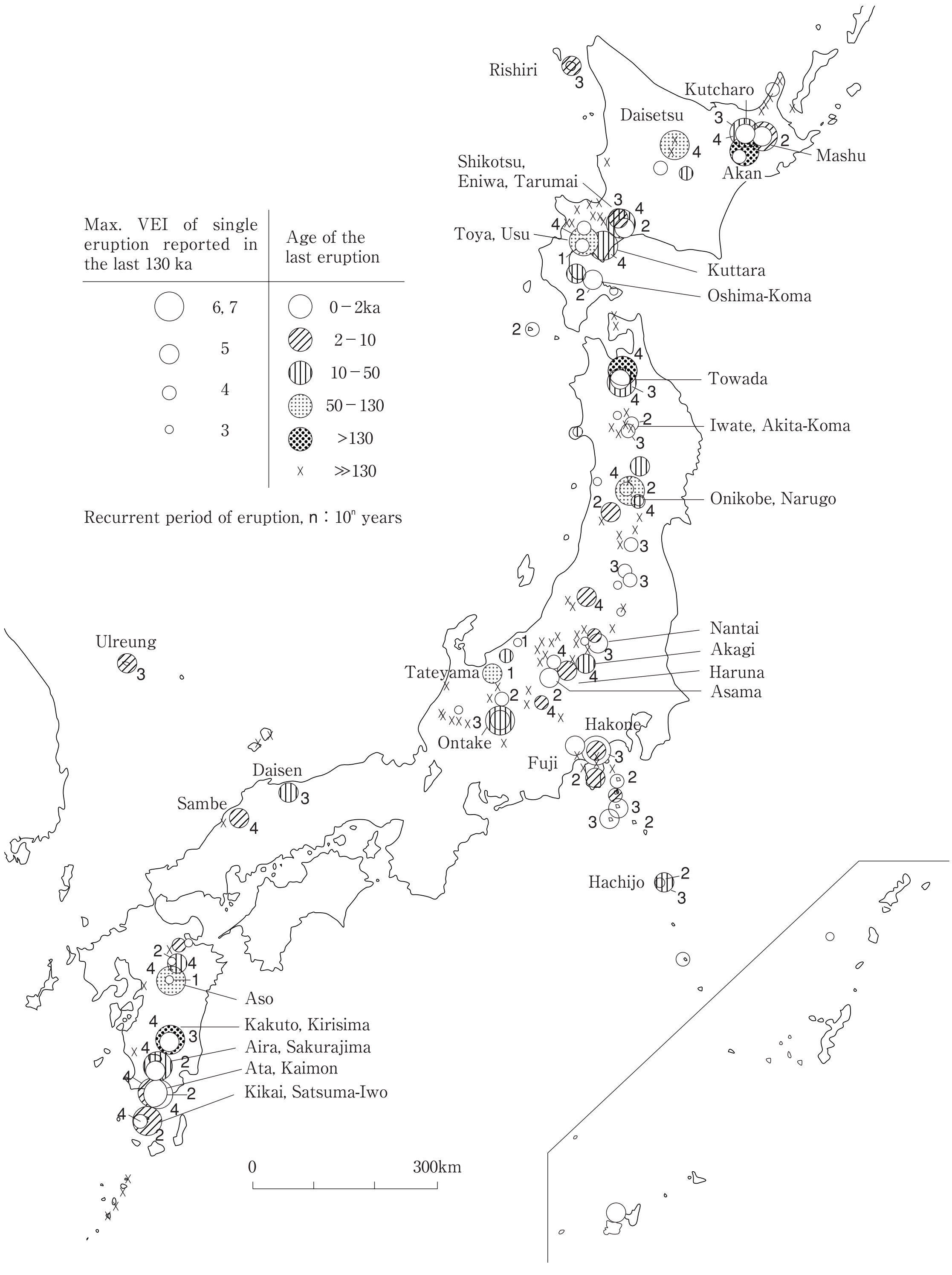

Fig. 2 Japanese volcanoes classified in terms of the maximum eruptive magnitude in the late Quaternary, lapse of time since the last major eruption, and recurrence interval of major eruptive activity.
Machida (1990)

3. The Relationship between Tephra Layers and Archeological Remains

As it is well-known, there are many cases where archeological remains are found sandwiched within the tephra layers. The tephra covers the human beings as they lived and their artifacts, and stores them for a later date. We know of many prehistoric settlements buried by tephra, where the volcanic eruption destroyed the inhabitants' lives directly or indirectly. Dating the tephra can often tell us how old the ancient remains are, while on the other hand archeological research on specific artifacts buried by a tephra layer can often suggest an approximate age of the tephra-forming eruption. Thus, both fields of research have influenced each other.

The common interests of both tephra research and archeology lie in the issues of chronology, disasters and environmental changes caused by the eruptions. Tephrochronology of artifacts in deposits has been carried out actively in Japan. However, little effort has been made towards research on the impacts or effects of volcanic eruptions on human lives and the environment using the archeological evidence found in the tephra. Some of the basic information and topics associated with these issues are discussed below.

3.1 Chronological issues

One of the important points of excavating the archeological sites in the volcanic ash soil is to discover the stratigraphic relationship between certain time-marker tephras and cultural layers. As we have found several widespread late Quaternary marker layers throughout Japan, there should be a level of such tephra virtually everywhere if preservation conditions are good. However, since such tephra consisting mainly of fine-grained glass shards is easily weathered, it can sometimes hardly be identified by the naked eye in the field. Therefore, careful observation and sampling are required for laboratory work on processing and examination.

Basically the archeological remains are not found within the tephra layer but in the soil formed during the dormant period between eruptions. But actually, there are cases in which the stratigraphic relationship between tephra and cultural layers is hard to recognize, because either the artifacts have been moved afterwards by some natural or artificial agents, or the tephra has been reworked. Identification of the cause is an important issue for discussion regarding chronology and paleo-environments.

a) Earlier Paleolithic archeological remains before and after the Aira-Tn tephra eruption (26-29 ka)

Many studies and discussions have been made on the problem of when the earliest human beings appeared in Japan and from where they came. Radiocarbon dating of hominid fossils on Okinawa island has revealed that they are dated at 32,000 to 16,000 yr.^{14}C BP (e.g., Ono *et al.*, 1999). On the other hand earlier paleolithic tools were excavated from volcanic ash soil with a ^{14}C age of about 30,000 yr. BP or younger at several archeological sites in central Japan. Recent studies, however, show a need for revision and refinement of these ages because calibration techniques have progressed from conventional to calendrical ages (Stuiver *et al.*, 1998).

Aira-Tn tephra (AT), the most important time-marker of the Paleolithic age in Japan, was formerly dated at 21,000-22,000 yr.^{14}C BP by conventional radiocarbon methods (Kigoshi *et al.*, 1972; Machida and Arai, 1976), but was redated at ca. 24,500 yr.^{14}C BP by accelerated mass spectrometry radiocarbon methods (e.g., Ikeda *et al.*, 1995). However, it has been further calibrated to a calendrical age of 26,000-29,000 cal yr.BP by combined data between marine oxygen isotope dates and calibration from AMS radiocarbon dates based on high resolution U-series ages.

As the earliest paleolithic tools are found in soil significantly below AT tephra, they are estimated to be dated 35,000 years or older, roughly speaking. Calendrical age determination in this time range is still a subject of further research together with the paleo-environment at that time. We have not yet obtained useful data for calibration older than ca. 30,000 years ago (e.g., Beck *et al.*, 2001). Also, correlation of oxygen isotopic fluctuation with the terrestrial sequences is incomplete in Stage 3.

AT tephra is found on the boundary between the earlier knife-blade culture Phase 1 and the later Phase 2 in Japan (Ono *et al.*, 1999). Although this eruption could have disrupted ecosystems on a fairly large scale, well beyond the direct impact zone, we have as of yet no abundant evidence that any prolonged occupational or cultural hiatus may have occurred. The diversification of stone tools, however, became clear in two major cultural regions, Northeastern Japan and Southwestern Japan. The historical duality in Japanese culture, eastern and western, may have become obvious since then.

b) Some chronological issues from the Latest Paleolithic culture to the Oldest Jomon ceramic culture

Archeological stratigraphy shows that the late Paleolithic cultural phase from ca.18 ka to ca.15 ka is characterized by the spontaneous development of two industries (forms of workmanship). One is characterized by small points, centered in central Honshu. The other is characterized by trapezoids found in Kyushu. These cultures were followed by the microlithic culture, the final stage of the Japanese Paleolithic. It took part in the micro-blade producing trend that spread over eastern Eurasia and North America and was introduced into Japan via Sakhalin and the Korean Peninsula. The microlithic culture was followed by the oldest ceramic Jomon culture, which is characterized by flat based and undecorated pottery (Ono, *et al.*, 1999).

During this period some regional marker tephra layers have been described with a variety of roughly calibrated radiocarbon ages. Kirishima-Kobayashi tephra (Kr-Kb) of ca.16-17 ka in southern Kyushu, Asama-Yellow (Kusatsu) (As-Y) of ca.15-16.5 ka in central Honshu, Eniwa-a (En-a) tephra of ca.19-20 ka in Hokkaido are representative markers immediately before the microlithic industry. Nantai-Imaichi tephra (Nt-I, S) of ca.14-15 ka is one of the markers produced during the microlithic culture phase in northern Kanto. Towada-H tephra (To-H) of ca.15ka is important because it lies just above the microlithic culture. The calendrical age calibration of those tephras has not yet been fully completed and therefore requires urgent study for establishing a high-resolution chronology of the cultural changes during this period.

c) Significance of K-Ah tephra as an important time-marker for the Jomon culture

No widespread tephras have been found for correlating or dating Jomon archeological cultures earlier than K-Ah tephra (7,300 cal. BP), which occurs extensively from southwestern Japan to central Honshu. This is not only an excellent time-marker for the earliest and early Jomon ceramic sequence but also an indicator of significant cultural changes over an extensive area in western Japan. The catastrophic impact of this tephra-forming Kikai eruption is briefly described below. The analysis was carried out via collaborative studies between tephrochronology and archeology.

Machida (1984) discussed the magnitude of this volcanic impact on prehistoric society and the environment. Combined evidence from volcanology and archeology indicate a major cultural discontinuity between the pre-eruption (Earliest Jomon) ceramic culture phase and the post-eruption (Early Jomon) phase. Immediately before the Kikai eruption, Kyushu was occupied by an indigenous ceramic culture represented by the Kyushu-Kaigara-mon style pottery (identified by the use of shell scraping) and by the Oshigata-mon style pottery (distinguished by a roller pattern) as shown in Fig. 3a. These ceramic types are not found in the soil above the K-Ah tephra and therefore may have been terminated as a consequence of the eruption. Archeological research suggests that the post-ash ceramic cultures, the Jokon-mon-style and the Sobata-style, were derived from outside the region (Fig. 3b).

It appears that people of the pre-eruption Jomon culture in southern Kyushu either dispersed to the northwestern part of Kyushu where the volcanic devastation was not so severe, or perished totally in the areas of greatest impact (Fig. 3b). In addition, there is plentiful evidence that the eruption and associated strong earthquakes and tsunamis induced significant landform changes over a vast area following a major decline in natural productivity throughout the region (Machida and Sugiyama, 2002).

d) Chronological issues of the late Jomon and later Period

Many regional and local tephra layers have been useful for correlating and dating archeological sites of the late Jomon and later periods in Japan. This range of periods covers the recent 3,000 years. Much higher resolution age determination is required, with temporal resolution that is at least decadal and ideally, annual or seasonal because we have to reconstruct the detailed history of volcanic activity, environmental change and human history for this recent time span. However, this is not easy work as shown in the following case study on the Baegdusan-Tomakomai tephra that is currently being focused on.

Baegdusan-Tomakomai tephra (B-Tm) occurs in both northern Japan and the northern part of the Korean Peninsula and relates to the youngest eruption of Baegdusan on the border of North Korea and China (Machida *et al.*, 1990; Machida and Arai, 1992). It is one of the largest eruptions during the last 2,000 years in the world. The stratigraphic relationship of this tephra with the immediately underlying Towada-a tephra (possibly the AD 915 eruption of Towada caldera, northern Honshu) and with archeological remains suggests that the Baegdusan eruption occurred in the early half of the 10th century. Microscopic observation of the outermost bark of trees buried in the related ignimbrite suggests that the eruption occurred from autumn to winter (Machida and Mitsutani, 1994). The widespread occurrence of this tephra offers significant potential for reconstructing and correlating historical chronologies in Korea, China and Japan. Also the widespread tephra fallout and flow should have had severe consequences for human beings and the environment in proximal areas. Today we can still observe such traces of the impact on vegetation and land-use around the volcano. Therefore detailed age determinations have been made by various methods, but consensus among authors has not fully been obtained (Table 1).

Generally speaking tephra layers are useful for correlation between archeological sites, for establishment of chronologies, for cross-checking ages determined by various methods and for explaining the relationship between environmental and cultural changes. In particular, we expect to have useful information if we carry out archeological research focusing on the characteristics of tephra as a trigger of environmental changes.

3.2 Influence of tephra eruption on human beings and the environment

We know of some natural catastrophic events that may have caused cultural changes or reformations, or abandonment of areas in historic and prehistoric cultural history. Historians and archeologists are conventionally apt to explain that most of such changes were caused by some human social problems, and have not researched well enough to see whether any natural events induced human changes. Even if there had been some problems within the human society, many of them could be considered to have resulted from complex processes involving both natural events and human history.

A tephra forming eruption is one of the greatest natural events that could cause historical changes. If we focus our research on large explosive volcanism as well as its impact on the ecosystem and human society, we can much better understand past changes.

When we think of a large explosive eruption, the first thing that comes to mind is that the tephra covers

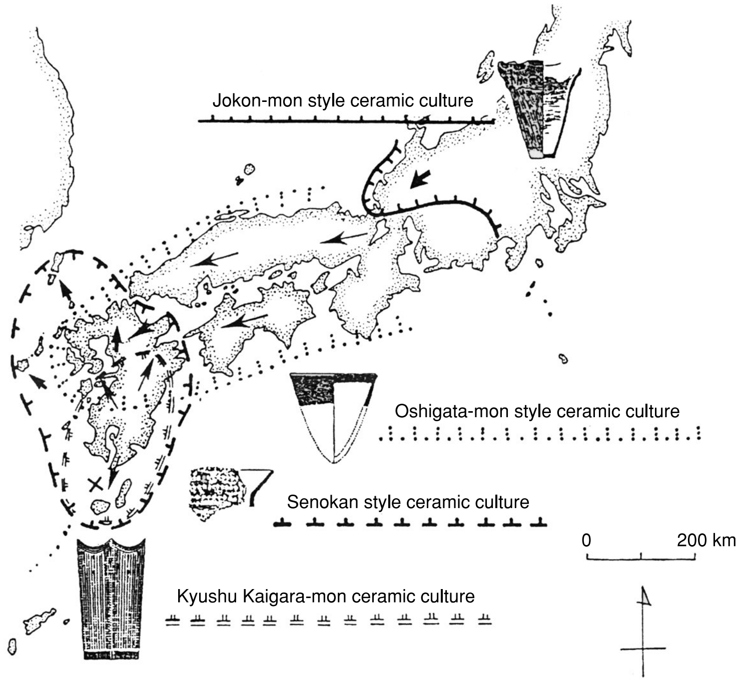

Fig. 3a Geographical extension of the regional phases of the earliest Jomon ceramic culture immediately before the Kikai-Akahoya eruption.
Machida (1984)

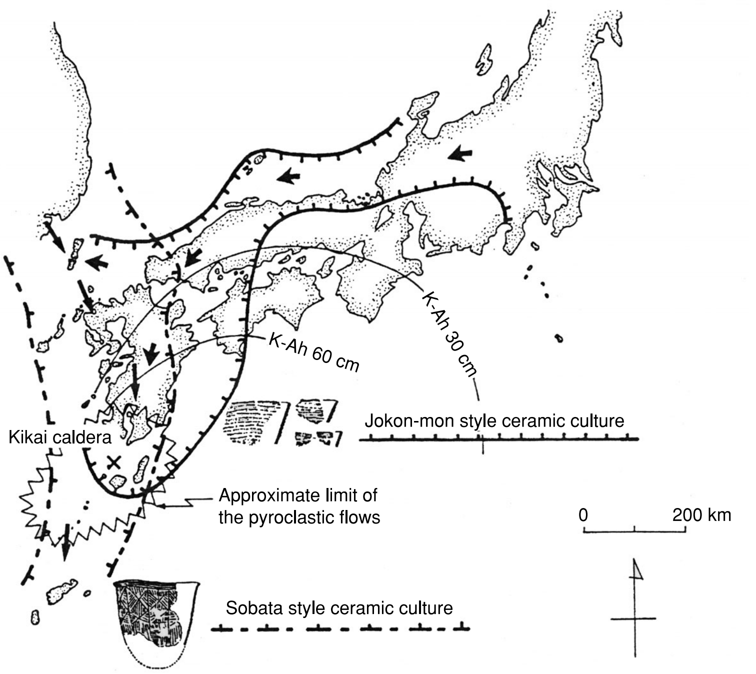

Fig. 3b Geographical extension of the regional phases of the early Jomon ceramic culture after the Kikai-Akahoya eruption.
Machida (1984)

Table 1 Baegdusan-Tm ash ages estimated by various methods.

Estimate age (AD)	Method or evidence	Reference
945 ~ 984 (969 ± 20)	Wiggle-matched ^{14}C dating with an AMS for charred wood buried in the fallout tephra	Horn and Schmincke (2000)
937 ± 8	Wiggle-matched ^{14}C dating with an AMS for charred wood buried in the ignimbrite	Nakamura *et al.* (2002)
916 ~ 936 (1σ) 911 ~ 946 (2σ)	Wiggle-matched ^{14}C dating with an AMS for charred wood buried in the fallout tephra	Machida & Okumura (in press)
937 ~ 938	Lacustrine varve chronology in Lake Ogawara based on the underlying Towada-a tephra age of AD915	Fukusawa *et al.* (1997)
946	Old record of rumbling and ash fall? in the Kinki district	Hayakawa and Koyama (1998)

the ground surface and directly destroy the ecosystem in the surrounding area, but we cannot ignore the fact that it can affect the global climatic system.

Many observations and studies have indicated that explosive eruptions put large amounts of volcanic aerosols into the atmosphere, and the parasol effect decreases the temperature of the lower troposphere for several years (Lamb, 1970). Even relatively small eruptions, such as the Agun eruption of 1963, produce massive amounts of volcanic aerosols such as SO_2 and affect the climate greatly (Palais and Sigurdsson, 1988). Since small-scale eruptions have higher frequencies, they could sum up to have a larger scale influence. There is much research on volcanic eruptions that affected the 'Little ice age' climate (Lamb, 1970). Volume estimation of past volcanic gas by geochemical methods could be an important step for enhancing this research (Sigurdsson *et al.*, 1985).

Joint studies among tephra research, archeology and paleontology, etc. on the 7300 cal. BP Kikai eruption, give a basis for a solution as to what kind of and how much damage this explosive volcanism may have caused to prehistoric human communities and environments as described above. Analysis of recent phenomena would also be instructive. Many events show us that pyroclastic flows and surges result in much more serious consequences than tephra fallout. That is why it is firstly important to identify the process of tephra formation at archeological sites. On the other hand, for fallout tephra, it is important to determine the season of eruption and its original thickness to identify how much damage it caused to the ecosystem. However, there are only a handful of case studies to answer these questions. We need basic research on many individual aspects, such as different climates and vegetations that would affect the situations: what kinds of processes followed after the ecosystem had been destroyed by the volcanic event? Needless to say, it is also important to consider the social organization, that differs from age to age. Large-scale eruptions occur less frequently and research in the historic era is not enough. Therefore, we need to use several different methods of analysis and find out what impacts they had upon human societies as well as ecosystems.

The above descriptions somehow may give a negative impression of the impact of tephra forming eruptions on humans and the natural environment, but over a long-term perspective, we can find positive aspects as well. In fact, tephra provides a parent material for forming soil and increasing the productivity of crops. Pyroclasitc flows change ragged hills and valleys into flat surfaces and plateaus.

Those who live in a volcanic country have to cope with the tephra, use it, and become adapted to it, and many are unaware its benefits. This is true not only regarding eruptions or tephra, but also regarding every natural catastrophe. We have to recognize this paradox where natural ferocity always comes with natural benefits.

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