A study of paleoearthquakes at archeological sites

— A new interdisciplinary area between paleoseismology and archeology —

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Traces of paleoearthquakes have been found at many archeological sites in Japan. However, most of them have been neglected to date and not considered to be a subject relevant to archeological research. The author has studied these traces since 1988, naming this new study field “Earthquake Archaeology”. The field has become popular both in archeology and paleoseismology and many important and useful results have been gradually obtained. These developments will lead to a deeper understanding of the natural and cultural history of the earthquake-prone country, Japan. Most paleoearthquake phenomena present at archeological sites manifest as liquefaction, lateral spreading and landslides. Detailed geological observations may also contribute to a reduction in damage caused by big earthquakes.

Keywords : Earthquake archeology, archeological sites, trace of earthquake, active fault, liquefaction, Nankai Trough, Fushimi earthquake, Great Hanshin-Awaji earthquake

1 Introduction

The Japanese Archipelago was shaped into its thin, long form as the plates covering the surface of the earth pushed against each other and caused earthquakes. The residents of the Japanese Archipelago have experienced the devastation of earthquakes, and continue to be exposed to their threat. Recently, the Iwate Miyagi Inland Earthquake occurred on June 14, 2008, and the Great Hanshin Awaji Earthquake (official name designated by the Japan Meteorological Agency is “1995 Southern Hyogo Prefecture Earthquake”) on January 17, 1995 claimed the lives of 6,434 people.

In the near future, epicenetral earthquake is expected to hit the Tokyo area, and mega-earthquakes such as the Tokai, Tonankai, and Nankai earthquakes are expected to occur during this century in the Pacific region from Kanto to Kyushu.

In Japan, which is one of the most earthquake-prone countries in the world, measures against earthquakes are mandatory, and researches on predictions of place, magnitude, and time of earthquakes, as well as projections of damages and measures to minimize damages are conducted from various perspectives. On the other hand, diffusion of knowledge of earthquakes to the general public is an important issue, since the knowledge of earthquake studies can contribute to the minimization of earthquake damages only when the results are fed back to society.

I have engaged in research to contribute to society by reducing earthquake damages. My area of specialty is the study of active faults that are distributed throughout Japan, and since 1986, I have engaged in research in collaboration with the archaeological discipline that was unrelated to seismology. Specifically, I focused on the traces of earthquakes found during the archaeological excavations. In this paper, I shall describe the process of research and outline the results.

2 History of research of active faults

In Japan, research on active faults as cause of inland earthquakes started in the 1960s. I started studying active faults using geomorphological and geological methods from the early 1970s, mainly in the Kansai region. At the time, few active faults were known, and it was an “age of reconnaissance and discovery of active faults” where new faults were identified and their basic attributes were surveyed.

In 1976, about 30 active fault researchers organized the Research Group for Active Faults. The objective of this group was to create a general catalog by investigating the characteristics of active faults that are distributed throughout Japan, using a uniform standard. As a member of the research group, I engaged in the survey of faults in Kinki, Chugoku, and Shikoku regions. Using the 1:40,000 aerial photographs, the positions of the faults were estimated from geomorphological viewpoint, and the presence of faults was checked through geological survey. The result was published in 1980[1].

I joined the Geological Survey of Japan, Agency of Industrial Science and Technology, Ministry of International Trade and Industry in 1979, when the compilation of the “1:500,000 Neotectonic Maps” started. Japan was divided into 15 regions on 1:500,000 scale maps to which geological information and major faults were added. As part of the neotectonic map series, compiled maps of the 15 regions were published from 1982 to 1987[2].

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Through this process, we could now see the overall picture of the active faults in Japan. The researchers were now encouraged to move to the next step from diverse perspectives, such as research on the "mechanism of earthquake occurrence at active faults," "detailed investigation of the characters of individual active faults," and "consideration of fault activities and history of geomorphology."

3 New research developments

When the compilation of the 1:500,0000 Neotectonic Maps was almost complete, I started to pay attention to archaeological sites. This happened coincidentally.

I visited a town history library of the Imazu Town Hall, Takashima-gun (currently Takashima City) in spring of 1986 to collect historical materials on Lake Biwa. The excavation of Kitoge Nishikaido Site was being conducted by the Imazu-cho Education Board, and I had an opportunity to talk to the archaeologist who conducted the excavations. He found a strange crack filled with sand at the excavation site, and asked me whether it may be related to past earthquakes.

The Kitoge Nishikaido Site was identified as the cemetery of the Jomon to Yayoi periods. I immediately visited the site, and observed a crack of about 1 m width, running straight and filled with sand. By digging the ground and looking at the cross section of the geological layers, it was found that the sand emerged from the underlying sand layer that rose and filled the crack. This was a trace left when the area was hit by a strong seismic tremor, the underground sand layer liquefied, the layers covering it were ripped apart, and a sand boil erupted onto the ground surface.

As shown in Fig. 1, the old graves from the Jomon Period were ripped apart while the new graves were dug into the sand boils. The ripped graves were built before the earthquake, while graves on top of the sand boil were built after the earthquake. There were two kinds of graves found at the site: *dokoubo* (hole grave) where bodies were buried in holes dug into the ground, and *dokikanbo* (earthenware coffin grave) where the bodies were placed in coffin jars and buried. The graves were dated using the earthenware buried with the body and the coffin jars. Based on these informations, the earthquake occurred in the Late Jomon Period or Shigasato "a" Period according to archaeological sequencing, or about 3,000 years ago[3].

I found great interest in the fact that the traces of earthquake was found in an archaeological excavation and that I was able to identify an earthquake occurrence that was not recorded in writing, and decided to look for earthquake traces in other archaeological sites. When I made an inquiry to the Kyoto Prefecture Research Center for Archaeological Properties, I obtained information that similar formations were found at the Kizugawa Riverbed Site in Yawata City, Kyoto, where excavations were being carried out at the time.

Large-scale liquefaction had occurred at the Kizugawa Riverbed Site, and cracks (sand vein) of about 1 m width crisscrossed the ground surface (Fig. 2). The sand boil that erupted from the cracks tore the layers of Nanbokucho and Muromachi periods, but was covered by the Edo Period layer. Therefore, these were traces of an earthquake that occurred at the end of the 16th Century.

In fact, there are many written records of Keicho Fushimi Earthquake that occurred on September 5, 1596 (5th year of Bunroku, leap month July 13 of 1st year of Keicho) and caused great damages to Kyoto. It is written that the houses were leveled in the villages of Yawata where the Kizugawa Riverbed Site is located. Hence, I was able to find physical evidence of a recorded earthquake at the Kizugawa Riverbed Site[4].

Japan was enjoying steady economic growth in 1986, and transportation network and residences were constructed actively. The cultural properties buried underground would be destroyed due to these developments, and many archaeological surveys were conducted prior to construction. In the course of this process, archaeological materials were accumulated, sequencing of artifacts such as pottery progressed, and it

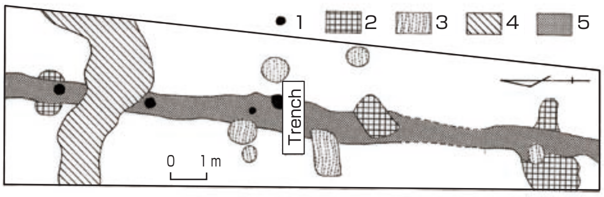

Fig. 1 Traces of earthquake found at the Kitoge Nishikaido Site (information added to Reference[3]).

1. Modern stake marks. 2. *Dokoubo* (hole-shaped grave). 3. *Dokikanbo* (coffin jar grave). 4. Remains from the Yayoi Period. 5. Sand vein.
The area marked "trench" was excavated to reveal that this was a trace of liquefaction.

Fig. 2 Traces of liquefaction at the Kizugawa Riverbed Site.

The white line that stretches diagonally is the sand vein (excavation of Kyoto Prefecture Research Center for Archaeological Properties, photography by Sangawa).

became possible to identify the dates of individual artifacts fairly accurately.

Hardly any attention was paid to the “traces of earthquakes” that must have been found in the process of the archaeological excavations. Even if the earthquake traces showed up, most were neglected as items unrelated to archaeology, without knowledge that they were products of earthquakes. Even if the archaeologist noticed that they might be related to earthquakes, the survey methods were unaltered and the traces remained untouched, except in very few cases.

In July, 1987, I moved from the Tsukuba Science City to the Geological Survey Osaka that was located in the government building of Chuo-ku, Osaka. Many archaeological excavations were conducted in the Kansai area, since this was the seat of central government in ancient and medieval periods, and public interest in archaeology was high. I frequently visited the archaeological sites where the earthquake traces were found and participated in the excavation. I learned the survey methods and dates of artifacts from the archaeologists in charge of the excavation, and in exchange, taught them the basic knowledge of earthquakes.

In November, 1987, I presented the case studies and the basic survey methods of earthquake traces in a lecture of the Kodaigaku (Ancient Study) Research Group, Osaka[5]. Many participants enthusiastically reported that they had come across earthquake traces in past excavations. Immediately after, with advice from an archaeologist, I named this study “earthquake archaeology,” and officially declared its establishment at the Japanese Society for Scientific Studies on Cultural Property and the Japan Archaeological Association in spring of 1988[6][7]. In the following year, I presented the basic survey methods for earthquake archaeology in the journal of the Society of Archaeological Studies[8].

By using the name “earthquake archaeology,” people involved in the archaeological excavations became aware that earthquake traces were subjects of archaeology. There increased the number of cases where the dates were narrowed down and the effects of earthquakes on the people were investigated when earthquake traces were found in the course of an archaeological excavation. It became routine to include a detailed description of earthquake traces in the archaeological site reports[9].

At the Nara National Research Institute for Cultural Properties (currently part of the National Institutes for Cultural Heritage), there is a system of training new research methods for archaeologists in charge of excavations from local governments and research centers for buried cultural properties throughout Japan. From 1989, I started lecturing on the survey methods for earthquake traces.

4 Characteristic of the study

Areas with rich traces of people’s existence buried underground and buildings (such as *kofun* or mound tomb) valuable as cultural heritages are designated “archaeological or historical sites” based on the Law for the Protection of Cultural Properties established in 1950. An archaeological site contains abundant remains such as residences and structures as well as artifacts such as plates, bowls, burial goods, and agricultural tools. When a site is to be destroyed by development, archaeological excavation is conducted prior to the construction.

In Japanese archaeology, date sequencing for remains and artifacts has been studied thoroughly so that when an earthquake trace is found in an archaeological excavation, the date of the earthquake that left the trace can be narrowed down by looking at the sequential relationship of the remains and artifacts for which the dates have been confirmed. Particularly, archaeological sequencing through remains and artifacts as well as absolute dating are well-established for the 2,000 years after the Late Yayoi Period, and narrowed-down dates of the earthquake traces can be obtained.

Since the Japanese Archipelago is subject to severe tectonic activities, the submerging areas are covered by sediments carried by rivers and ocean, and plains and basins are formed. Our ancestors set up residence in flat places close to the water, and majority of the archaeological sites are concentrated in plains and basins. Older remains and artifacts are buried in the lower layers.

When a major earthquake strikes, the area with weak foundation suffers most, and traces of liquefaction are seen in Kitoge Nishikaido and Kizugawa Riverbed sites. Liquefaction drew attention when a modern city suffered great damages in the Niigata Earthquake that occurred in 1964, and severe damages occurred to lifelines in the Great Hanshin Awaji Earthquake of 1995. When sand is carried up to the surface with underground water due to liquefaction, sand boils are formed.

In the soft sand layer deposited underground, there are spaces between the sand grains, and with strong tremors, the sand grains juggle around to reduce the space, which in turn compacts the sand layer. The underground water in the space is compressed, resulting in increased water pressure, and water spews out onto the surface along with sand as they tear the layers above. Figure 3 is a schematic diagram of a trace of sand boiling, and the layer torn by the sand boil was deposited before the earthquake while the layer covering the sand boil was deposited after the earthquake. The dates of the two layers are determined by the remains and artifacts in each layer. As in this figure, assuming that the topmost layer torn by the sand boil (before the earthquake) is dated to the

7th century and the lowest layer covering the sand boil (after the earthquake) is of the 8th century, it can be known that this sand boil is a trace of a major earthquake that occurred from the 7th to 8th centuries.

In Japan, there are written records for the past thousand or more years, and there are many references to damages by earthquakes. After the Noubi Earthquake of 1891, the Imperial Earthquake Investigation Committee was created, and the collection of earthquake records was started as one of its activities. This work continues to the present[10]-[12], and interdisciplinary research on historical earthquake materials are done by the Society of Historical Earthquake Studies. Since many of the disaster records include the time and date of the earthquakes, the time at which the earthquake traces were left can be obtained by comparing the written records against the traces at the sites.

When the earthquake traces are confirmed, the records of temples and shrines and the diaries of aristocrats which mention the earthquakes are also confirmed. In the periods before the Edo Period when there is markedly less number of written records, great earthquakes may not have been documented, but the gaps in history can be filled through earthquake traces at the archaeological sites. Also, before the Kofun Period where there is no written record, the earthquake traces lead to discovery of earthquakes.

By comparing the records of historical earthquakes, the accuracy of dates of earthquake traces is increased. In turn, presence of earthquake traces raise the reliability of historical earthquakes in written records, and the history of earthquakes can be traced to periods without written records.

5 Outline of research results

Majority of the archaeological excavation in Japan are conducted due to development, and therefore, where and what kind of earthquake traces are found is dominated by chance. Progress of research depends on the discovered traces. I shall describe some of the results obtained so far[13]-[16].

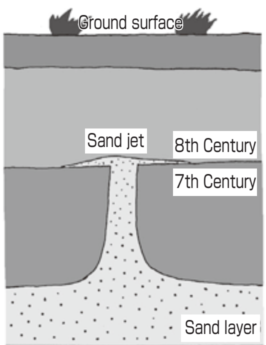

Fig. 3 Schematic diagram of liquefaction trace.
The yellow part in the diagram is the sand.

5.1 Earthquakes in periods without written records

As an example where an earthquake in periods without written records was found, I shall describe the region around Lake Biwa. As mentioned before, earthquake traces of the Jomon Period was found at the Kitoge Nishikaido Site. After this find, the Shiga Prefecture Cultural Properties Protection Association conducted an excavation of the Hariehama Site, which is a lake-bottom site, 250 m off the coast of Shinasahi-cho, Takashima-gun, located in the northwestern area of Lake Biwa. When the lake bottom was dug for about 1 m, the ground on which the people of Middle Yayoi Period lived was revealed, and remains of furrows, agricultural tools, and fallen willow trees were found. This ground was covered by a sand boil that poured out from the underground sand layer. It is thought that the land on the lakeshore submerged due to an earthquake, and liquefaction occurred due to severe seismic tremors. In the alluvial lowlands around Lake Biwa, traces of liquefaction thought to have occurred in the same period were found at several sites (Fig. 4), and it is highly likely that a great earthquake during the middle of the Yayoi Period caused part of the lakeshore to submerge as the area around Lake Biwa was shaken severely.

5.2 Earthquakes described in the Nihonshoki

The word "*jishin* (earthquake)" appears for the first time in the *Nihonshoki* (Chronicles of Japan). In the "7th Year of the Reign of Emperor Tenmu (679 AD)," there is a specific description of the damages caused by the Tsukushi Earthquake: "The earth was torn and the width of the rift was about 2 *jo* (about 6 m) and the length more than 3,000 *jo* (about 10 km), and many houses fell in all villages." However, the *Nihonshoki* contains several alterations of historical facts and imitations of Chinese history, and verification was necessary for the reference to the Tsukushi Earthquake.

Since the birth of earthquake archaeology in 1988, traces of

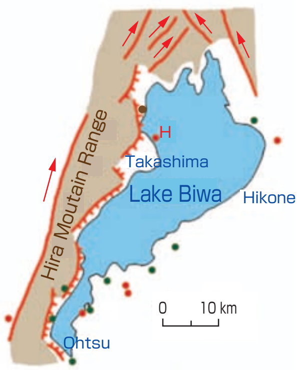

Fig. 4 Traces of earthquakes around Lake Biwa.
The red lines represent active faults (the hatching sides are relatively submerged, while the arrows show the direction of lateral shift). Green dots represent the sites from which medieval to modern (Edo period) earthquake traces were found. Red are sites from which earthquake traces of Yayoi Period were found. Brown is the Kitoge Nishikaido Site where the Jomon Period earthquake trace was found. H is Hariehama Site.

earthquakes were reported in the sites around Kurume City, Fukuoka Prefecture, including the archaeological site of the ancient Tsukushi Capital. Their dates were limited to the late 7th century, and this corresponded with the Tsukushi Earthquake described in the *Nihonshoki*. In 1992, a trace of fault activity during this period was found in the survey of Maekawa Maeda Site located right on top of the Minou Fault Zone that runs east-west along the east of Kurume City. Thus, it was verified that a great earthquake occurred due to the activities of Minou Fault Zone in 679, and this event was recorded in the *Nihonshoki*.

Also, in the *Nihonshoki*, the earthquake of 684 (13th Year of the Reign of Emperor Tenmu) is described in details: "Great earthquake occurred at around 10 o'clock at night, and men and women throughout the country screamed and ran. Mountains collapsed and rivers flooded. Government buildings, people's houses, warehouses, temples, and shrines in the provinces were damaged, and many people and cattle were injured or died. The hot springs of Dogo Spa of Iyo stopped. In the province of Tosa (Kochi Prefecture), about 500,000 *shiro* or 1,000 *choho* (about 10 km^2) of farmland submerged and became ocean. Waves rushed to the shores and ships for carrying tributes were swept away."

Severe tremors in a wide area including Kinai, stopping of the hot springs of the Dogo Spa, submersion of Kochi Plain, and tsunami along the Pacific coast are characteristics of the Nankai earthquake that occurs at the "Nankai Trough" which is on the plate boundary of the Pacific Ocean bottom. Therefore, it can be seen that a Nankai earthquake occurred in 684.

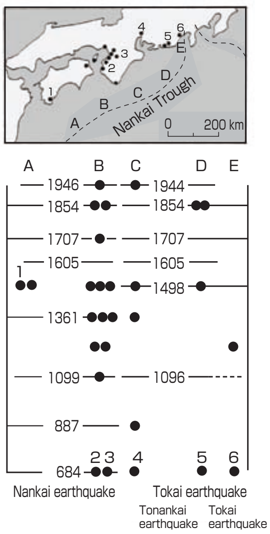

Fig. 5 Timetable for great earthquakes of the Nankai Trough (additions to Reference[13]).

The years shown in Western calendar years are occurrences of earthquakes known from written record. ● represent sites from which earthquake traces were found.

1. Azono Site. 2. Kawanabe Site. 3. Sakafuneishi Site. 4. Tadokoro Site. 5. Sakajiri Site. 6. Kawai Site.

5.3 Great earthquakes in the Nankai Trough

Figure 5 shows the timetable of mega-earthquakes in the Nankai Trough. The Trough is divided into 5 segments, A~E. A to B cause the Nankai earthquake, and C to E cause the Tokai earthquake. After the Showa Period, the latter is divided into C and D for Tonankai earthquake and E for postulated Tokai earthquake. In Fig. 5, the western calendar years are dates of occurrences that can be determined from written records such as the Nankai earthquake of 684.

After the Edo Period where there are abundant historical materials, most major earthquakes were recorded in writing. In contrast, the absolute quantity of historical materials decreases significantly before the Edo Period, and records may not exist for earthquake occurrences. This is the reason the number of earthquakes after the Edo Period increases in the western calendar timetable in Fig. 5.

In the survey of Sakajiri Site in Fukuroi City located east of Lake Hamana, Shizuoka Prefecture, the residential remains from the mid 7th century were torn by many sand boils. Since government buildings were built in early 8th century on top of the sand boil, it could be seen that the Tokai region was severely shaken in the late 7th century. Moreover, traces of liquefaction in the same period were discovered in the Kawai Site in Shizuoka City and the Tadokoro Site of Aichi Prefecture. Therefore, there is high possibility that a Tokai earthquake occurred at the same time as the Nankai earthquake of 684 described in the *Nihonshoki*. For the Nankai earthquake of 684, corresponding earthquake traces

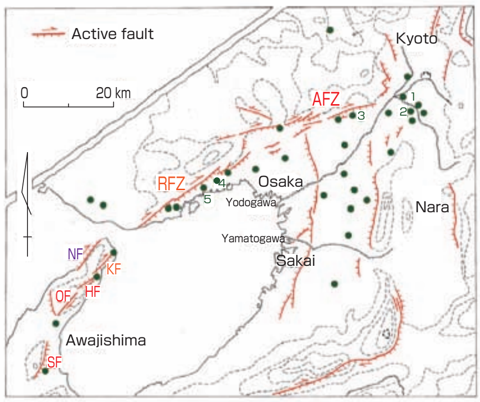

Fig. 6 Traces of earthquake that are thought to be left by the Fushimi Earthquake (additions to Reference[16]).

● represent the sites from which traces of the Fushimi Earthquake were found.

1. Kizugawa Riverbed Site. 2. Uchisato Haccho Site. 3. Imashirozuka Tomb. 4. Sumiyoshi Miyamachi Site. 5. Nishimotomezuka Tomb.

The fault that was active in the Great Hanshin Awaji Earthquake of 1995: NF Nojima Fault.

Ones that were active in the Fushimi Earthquake of 1596: AFZ Arima-Takatsuki Fault Zone, HF Higashiura Fault, OF Nodao Fault, and SF Senzan Fault.

Ones that are speculated to have been active in the Fushimi Earthquake: RFS Rokko Fault Zone and KF Kusumoto Fault.

were found at the Kawanabe Site in Wakayama City and the Sakafuneishi Site of Nara Prefecture.

On the other hand, there are some records of the Tokai earthquake in 1498, but no historical record of the Nankai earthquake exists. However, after 1989, the traces of liquefaction attributed to about the 15th century were found one after the other at the Azono Site, Shimanto City, Kochi Prefecture of Shikoku as well as at sites in Itano-cho, Tokushima Prefecture[9][17], and it can be seen that there was a Nankai earthquake that rocked the entire island of Shikoku.

When the earthquake traces of both earthquakes are entered into the timetable along with the dates of earthquakes known from written records, it can be seen that the great earthquakes of the Nankai Trough occur at fairly regular intervals at the same time or in sequence.

5.4 Investigating the total picture of the Keicho Fushimi Earthquake

On the other hand, many traces of inland earthquakes were found around the Osaka Plain. Because the majority of the traces show that the medieval layers were torn but were covered by layers of the Edo period, they are suspected to be due to the Keicho Fushimi Earthquake of 1596, as in the Kizugawa Riverbed Site (Fig. 6). There are several types of earthquake traces. Traces of large-scale liquefaction can be seen in the alluvial lowlands with high groundwater level in southern Kyoto Basin, as in Kizugawa Riverbed Site and Uchisato Haccho Site (Fig. 7). Also, at Sumiyoshi Miyamachi Site in the southern foot of the Rokko Mountain Range, traces of lateral flow in which the ground slid sideways due to liquefaction were found. In the Imashirozuka Tomb of Takatsuki City and the Nishimotomezuka Tomb of Kobe City, although the mounds were deformed due to landslides, from the date of the layer covered by the soil from the collapsed mound, it was known that the trace was of the Keicho Fushimi Earthquake.

For this earthquake, the chronicles of temples and shrines and aristocrats' diaries describe that the tower of the Fushimi Castle collapsed in Kyoto, the temples Toji, Daikakuji, Tenryuji, and Nisonin were destroyed, houses of Osaka and Sakai were damaged, and the fires consumed the fallen buildings in Hyogo (current Kobe). As will be described later, from the trench excavation of active faults, it was found that this earthquake was caused by the Arima-Takatsuki Fault Zone and the active faults of Awajishima.

In the case of the Keicho Fushimi Earthquake, the active fault was identified and the damages to castles, temples, and houses were determined from written records. Adding the ground disaster that could be learned from earthquake traces at the archaeological sites, the overall picture of the earthquake can be seen from three perspectives.

5.5 New findings on liquefaction

Since the Niigata Earthquake of 1964, liquefaction came into the spotlight, as sand boils that pour out on to the surface can be observed by anyone immediately after the earthquake. However, there was lack of knowledge about the original sand layer that supplied the sand boils, as well as for the mechanism of sand boil rising to the ground. Knowledge was limited to speculations based on results of underground boring. However, when liquefaction traces were found at archaeological sites, observation of the cross section of layers could be made by excavating the ground, and the following basic facts that were unknown before were clarified.

For example, the depth of the sand layer that supplied sand to the sand boil when liquefaction occurred was only tens of cm to 2 m deep, and it was shallower than originally thought. Also, liquefaction was thought to occur in the sand layer, but many cases were found where the gravel layer containing large proportions of gravel liquefied and rose through the sand vein. Figure 8 shows the trace of liquefaction observed at the Hariehama Site at the bottom of Lake Biwa. Liquefaction occurs in the sand layer containing plenty of

Fig. 7 Traces of liquefaction of the Uchisato Haccho Site (excavation of Yawata City Education Board, photography by Sangawa).

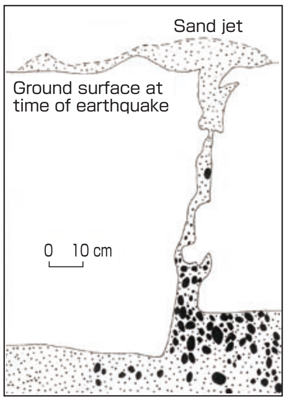

Fig. 8 Traces of liquefaction at the Hariehama Site.
The liquefaction occurred in the gravel layer, but large gravels did not reach the ground surface.

gravel, but large pebbles are left behind when sand and gravel rise with the underground water. In this case, looking only at the surface, it seems that liquefaction occurred in the sand layer without gravel, but that is not the actual case. Basic knowledge can be obtained by sequential observation of the flow in the layer when liquefaction occurs up to the arrival of the sand boil to the surface.

6 The Great Hanshin Awaji Earthquake

The Hanshin Awaji Earthquake of January 17, 1995 was caused by the activity of the Nojima Fault shown in the “Akashi” section of 1:50,000 Geological Map published in 1990 by the Geological Survey of Japan[18]. The position and the movement of this fault was correctly described in the map manual, but at the time of its writing, the information was not at the level that allowed predictions of the scale of earthquake damages to be caused by future activities of the faults.

After the Hanshin Awaji Earthquake, the importance of active faults was recognized, and the Headquarter for Earthquake Studies Promotion was established in the Agency for Science and Technology (current Ministry of Education, Culture, Sports, Science and Technology). The national project was started to study the accurate positions and activities of major active faults throughout Japan, to predict statistically the future fault activities by investigating the history of their activities, and to project the scale and spread of the seismic movement caused by their activities. The survey was conducted as joint efforts of the Geological Survey of Japan, Agency of Science and Technology, as well as the local governments and universities throughout Japan.

Many active faults stretch from the southwestern area of the Kyoto Basin, passing by the north rim of the Osaka Plain, and traveling all the way to Awajishima. The Hanshin Awaji Earthquake was caused mainly by the movement of the Nojima Fault (labeled NF in Fig. 6). Immediately after the earthquake, there was worry that a larger earthquake may occur in the near future in connection with this earthquake if there were other faults that were inactive for long periods and their energy was being accumulated. Many people living in the northern part of Osaka Plain became worried.

However, traces of the Keicho Fushimi Earthquake in 1596 were found from many archaeological sites in the Keihanshin and Awaji regions (Fig. 6), and based on these evidences, the active faults in question were active in the earthquake 399 years ago. Moreover, in the trench survey of active faults conducted by the Geological Survey in 1995, it was found that many faults in the north rim of the Osaka Plain to the east coast of Awajishima, such as Arima-Takatsuki Fault Zone (labeled AFZ in Fig. 6) were active in the Keicho Fushimi Earthquake[19]. Together with the result of the trench survey that the activity of the Arima-Takatsuki Fault Zone prior to this occurred about 3,000 years ago[19], people were relieved of their worry that “a giant earthquake capable of annihilating the Keihanshin region will follow the Hanshin Awaji Earthquake.”

On the other hand, many cultural properties such as Buddhist sculptures were damaged when the temples and shrines collapsed, as well as the archaeological artifacts that were on display during the Hanshin Awaji Earthquake. Demands were raised for measures against earthquakes for cultural properties and for support activities after the earthquake in the fields of history and archaeology.

Although swift recovery measures were needed in the Hanshin and Awaji regions that were hardest hit by the disaster, the construction work for recovery destroyed buried cultural properties, and the number of excavation surveys of archaeological sites increased sharply. As emergency measures, many archaeologists of the local governments throughout Japan were dispatched to the Hyogo Prefecture to support the excavations, and joined the survey with local archaeologists[20].

The archaeologists dispatched from around Japan had first-hand observation of the earthquake damages, and learned the basic knowledge of earthquakes. Moreover, in the process of excavating the sites of the Hanshin Awaji regions, many traces of the Keicho Fushimi Earthquake were discovered[21], and people who were unfamiliar with earthquake traces were able to learn the basic survey methods.

With the increased interests in earthquake traces, the archaeologists of Japan took part to edit and publish the *Excavated Traces of Earthquake*, a catalog of earthquake traces[22]. The journal *Kodaigaku Kenkyu* started a section for collecting earthquake traces in each issue, and this continues to the present[17][23].

In the aforementioned 1:500,000 Neotectonic Map series, the “Kyoto” region which became the center of attention in the Hanshin Awaji Earthquake was revised totally, and the second edition was published. In the “Paleoearthquake Data Map,” the traces of Keicho Fushimi Earthquake and the mega-earthquakes from the Nankai Trough are shown in different colors to indicate the corresponding earthquakes[24].

7 In preparation for the earthquakes in the 21st century

Immediately after the Hanshin Awaji Earthquake, I spoke with many people of the disaster regions, and was shocked to find that most people had believed, “There will be no earthquake in the Kansai area.” In reality, there are many active faults in this area, and great disaster befell in the Keicho Fushimi Earthquake about 400 years ago. At the same time, I felt strongly that if the knowledge of earthquakes known to researchers were widely known to the general public, perhaps the damages might have been decreased.

According to the timetable (Fig. 5) compiled from the written records and earthquake trace materials for the great earthquakes from the Nankai Trough, it is almost inevitable that a Nankai and Tokai (Tonankai) earthquakes will occur in the middle of the 21st century. Moreover, it is highly likely that these great earthquakes will occur simultaneously or sequentially. In addition, there is a period of increased earthquakes (active period) several decades prior to the Nankai earthquake, and it is believed that the active period started after the Hanshin Awaji Earthquake[25].

In the new century, measures against earthquakes are becoming important, and both research institutes and governments are working on them. I think it is particularly effective to utilize the earthquake traces in archaeological sites to diffuse the knowledge to the general public.

As an example, I shall mention the Takamatsuzuka Tomb in Asuka, south of Nara. In 1972, the colorful wall paintings of the beauties of Asuka Period were found in the stone chamber of this tomb, and public interest in archaeology increased. In the recent survey, many fissures were found in the mound of the Takamatsuzuka Tomb, and some fissures reached the stone chamber[26]. These were caused by the great earthquakes that occurred repeatedly at the Nankai Trough. In 2006, the stone chamber was disassembled to prevent the deterioration of the wall paintings, and the results of the excavation done at the time were covered widely by the newspapers and television. In addition, traces of the earthquake that damaged the Takamatsuzuka Tomb was reported, and many people learned that " great earthquakes of the Nankai Trough is approaching, and a broad area including Asuka will be shaken."

The general public holds the impression that the mechanism of earthquakes is difficult to understand. However, by looking at the earthquake traces at the archaeological site, they can easily understand that in the past, a great earthquake struck the area they reside and left markings. When an archaeological excavation is done, public viewings are held, and in some cases tens of thousands of people visit the site. Since the establishment of earthquake archaeology, earthquake traces have also become subjects of viewing and are reported each time by the media. Their effectiveness as educational tools is great.

I have several opportunities to talk about earthquakes to the general public at lectures and events. On such occasions, referring to archaeological sites and history eases diffusion of knowledge to people who are not particularly interested in earthquakes. Recently, there are increased opportunities for earthquake education to elementary school students, and using earthquake traces of well-known archaeological sites improves educational value.

About 20 years have passed since I started this study, and the awareness to take up earthquake traces found at archaeological surveys as subjects of research has diffused widely among archaeologists, along with basic survey methods. In this sense, my initial objective has been achieved. I have written books for the general public on this subject. Particularly, in the book published in 1992[13], I described the research results and survey methods of the earthquake traces in archaeological sites, and many readers adopted interest in earthquake archaeology. I also introduced the history of earthquakes in Japan since the Jomon Period[16].

The consciousness that archaeological sites, which may seem unrelated, may become subjects of research has spread to researchers of various earthquake-related fields such as geology and engineering, and research from new perspectives are being started.

I worked as visiting professor at the Institute of Industrial Sciences, the University of Tokyo, as well as at the Disaster Prevention Research Institute, Kyoto University, and am conducting research in collaboration with researchers of earthquake engineering and geotechnical engineering.

As one example, as in the aforementioned Hariehama Site, at the Motojima Site of Shizuoka Prefecture, traces where only sand rose out from the gravel layer in liquefaction were observed[27]. Various other findings on liquefaction obtained from the sites are becoming widely known among engineering researchers[28].

Also, in the Imashirozuka Tomb where the sliding and moving of the soil of the mound in a landslide could be observed sequentially, joint research including mathematical analysis was conducted[29]. Also, traces of landslide and fissures are being studied with engineers at the Nishimotomezuka Tomb and Takamatsuzuka Tomb[30]-[32].

In the future, I hope studies using archaeological sites will progress further, and I shall continue to work on the diffusion of this knowledge.

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Discussion with Reviewers

1 Activities to diffuse “earthquake archaeology”

Question and Comments (Eikichi Tsukuda, Research Coordinator, AIST)

The research of Dr. Sangawa is widely known throughout society, has received the attention of the mass media, and I think much contribution was made in reducing earthquake disasters. Earthquake study is rapidly advancing in recent years, but for the results to be returned to society as *Full Research*, and to actually reduce earthquake damages, increased understanding of the general public about earthquakes is necessary, and it must result in both long-term activities (earthquake resistant residences) and short-term activities (immediately after an occurrence of an earthquake). I think Dr. Sangawa’s research, as a *Full Research*, is an extremely important contribution in the field of earthquake disaster reduction. Can you please provide comments about the diffusion activity through your experience in collaboration with the mass media?

Answer (Akira Sangawa)

As you indicated, I think diffusion through the mass media is important. Although lectures and writings by researchers can transmit specialized knowledge to the general public, there is an enormous difference in the capacity to reach many people through newspapers, TV, and radio. In that sense, the mass media plays the role as a bridge between the researchers and the general public, and is important in widely publicizing the research results. When there is coverage, I try to provide sufficient explanation so my intent is communicated accurately, and specialized knowledge is explained where needed to make the contents of coverage as high quality as possible. I think the people of AIST, particularly of the Geological Survey, who are involved in earthquake research, respond very carefully to news interviews.

As long as we live in Japan, there is a chance that our lives may be lost due to an earthquake, and it is necessary for all Japanese citizens to have at least some knowledge of earthquakes. However, not too many people seek this knowledge actively. I think it is important to engage in diffusion to people who think earthquakes are too difficult for them to understand. As one method, I talk in terms of subjects that the general public find interesting. It is more effective if earthquakes are coupled with cultural properties such as tombs and famous historical events.

2 Synthetic process of “earthquake archaeology”

Question and comment (Akira Ono, Vice President, AIST)

I think this is an excellent research where archaeology and seismology were fused to successfully create a new discipline. Can you please explain, using diagrams if possible, how a new fused discipline was created from two different disciplines?

Answer (Akira Sangawa)

I created Fig. a. Although it is a fusion of archaeology and seismology, seismology mainly utilizes geologic methodology, so I added “geology” in small type under seismology in the figure on the left.

In the survey of archaeological sites, excavation is done from the ground surface downward to dig up the remains and artifacts, dates are figured out using archaeological methods, and comparisons made with ancient records and writings. As a result, new findings can be added to the history of the region.

In seismology, the fields involved and methodologies are diverse, so I listed the research subjects in Fig. a. The subjects are: places where the earthquake occurs like plate boundaries and active faults; also, events that occur due to an earthquake such as liquefaction and landslides. Advancements of both researches are necessary for earthquake prediction and damage reduction.

Earthquake archaeology begins when a trace of an earthquake is found at an archaeological site. The date of the earthquake trace is obtained using the dates of remains and artifacts, and such materials are accumulated to build a history of earthquakes. Recently, the study of the history of active faults has progressed, and we find many earthquake traces that correspond to fault activities. Each earthquake history of plate boundaries and active faults becomes basic material for predicting future occurrences. On the other hand, observation of sand flow and movement brings new findings about liquefaction. The traces of landslide in structures whose original shape are known, as in a tomb, help clarifying the mechanism of landslides.

In archaeology, earthquake traces used to be meaningless, mysterious things. Some of the mysteries of archaeology, such as the disappearance or the decline of a village after the date earthquake traces were left, the discovery of remains that show evidences of residences from lake bottoms, and the presence of strangely shaped tombs can now be solved by introducing the concept of earthquakes. In the case where there are abundant earthquake traces and the overall picture of earthquakes can be readily seen, as in the Tsukushi Earthquake of 679 and the Keicho Fushimi Earthquake of 1596, the earthquake traces provide exact dates and help refine archaeological dating.

3 Traces of earthquakes other than liquefaction

Question and comment (Akira Ono)

In this paper, liquefaction is mainly described as a trace of great earthquakes on archaeological sites, but are there other kinds of traces?

Answer (Akira Sangawa)

In archaeological surveys, many traces of liquefaction in particular are found readily. Liquefaction occurs in the soft sand layer with abundant underground water. Our ancestors lived mainly in the plain with abundant water supply, so the traces of liquefaction can be found in the residences. Also, the traces of sand boils that poured out onto the surface by liquefaction allow dating the earthquake. Other than this, tombs that were built on slightly higher grounds show traces of landslides and fissures due to seismic movements. In the Tsukushi Earthquake of 679, excavations were done right on top of the active fault that caused the earthquake, and we were able to observe direct evidence of the fault activities.

4 Estimation of magnitude of earthquakes

Question and comment (Akira Ono)

Figure 5 shows the past great earthquakes of the Nankai Trough, but what was the magnitude of the earthquakes that could be estimated by the earthquake archaeology methods?

Answer (Akira Sangawa)

When earthquake traces are found in some archaeological sites, I can estimate the scale of the tremor at that place. When the earthquake traces of the same earthquake are found in multiple points in a widespread area, I can see the range of the region that was hit by a severe tremor, and can estimate the magnitude of the earthquake. In case of the great earthquake in the Nankai Trough, there are plenty of written records of damages, and I can estimate the magnitude based on such materials. Recently, there are advances in the studies of traces of tsunami, and the history of the occurrence of great earthquakes can be seen from tsunami traces. I think it is good to observe from both aspects of tremors and tsunamis.

5 Application to foreign earthquakes

Question and comment (Akira Ono)

Do you think it is possible to apply earthquake archaeology to earthquakes that occurred abroad? What are the points that differ from Japan?

Answer (Akira Sangawa)

In Japan, a great number of excavations have been done, and archaeological sequencing is very refined. The population density was high, and the life cycle of artifacts used were short because houses were made of wood and people used easily breakable earthenware and pottery, and this enables fine sequencing. Also, there are written records for the past thousand or more years, and the accuracy of archaeological sequencing is increased through comparison with written records. Of course, Japan is one of the most earthquake-prone countries in the world, and people lived in the plains with abundant water supply, so there are many traces of liquefaction. Therefore, it is a land most suited for studying the history of earthquakes in conjunction with archaeology. Although it may not be the same as Japan, any country can adopt the perspective of studying earthquakes through archaeological sites, and I think it is possible to devise methods that suit the situation of the country.

6 Fusion of fields of sciences and humanities

Question and comment (Akira Ono)

Earthquake archaeology is a fused discipline that handles the fields of humanities and sciences that are quite a distance apart. Wasn’t reading ancient documents a difficult factor for a scientific researcher? Please comment on other points in fusing humanities and sciences.

Answer (Akira Sangawa)

I think reading ancient writings and records can be a very difficult process for scientific researchers. However, in Japan, collection of old records on earthquakes has been done actively after the Meiji Era, and the documents are available in modern type, so one can read them fairly easily. I like archaeology as well as Japanese literature and Japanese history, so reading old writings and records is quite enjoyable. However, I am handicapped because I am not specially trained, but I feel my understanding has deepened as I read more. At any rate, for fusion of science and humanities, the essential condition is that you fall in love with the other discipline.

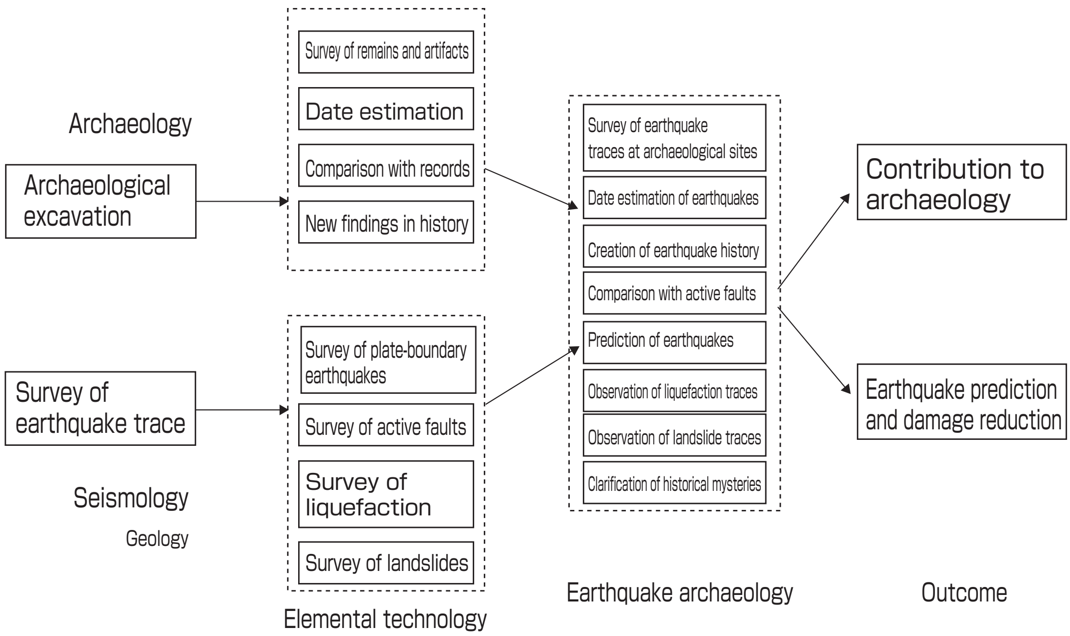

Fig a. Process of synthesis in earthquake archaeology