OFF-FAULT PALEOSEISMOLOGY IN JAPAN: WITH SPECIAL REFERENCE TO THE FUJIKAWA-KAKO FAULT ZONE, CENTRAL JAPAN

Haruo YAMAZAKI, Koichi SHIMOKAWA*, Kiyohide MIZUNO* and Takenobu TANAKA**

Abstract Trench excavation surveys are a most useful and popular method to reconstruct recent fault activity. However, it has gradually become difficult to find suitable sites for trench surveys in Japan due to intensive land use and social restrictions. To solve this problem, a new method called off-fault paleoseismology was recently introduced to active fault research. This tries to uncover the age of past fault events through coseismic geological evidence that are not directly related to seismogenic fault movement. Using this method, we revealed the Holocene history of fault movement of the Fujikawa-kako fault zone (FKZ), which is situated along the onshore plate boundary zone, and which shows the highest vertical slip-rate in Japan. Using chronological data of off-fault geologic features such as scarp failure, emergence of marine terraces, and sudden depression of marshes, it is revealed that the FKZ has repeatedly displaced at ca. 6 ka BP, 4.5 ka BP, 3.0 ka BP and 1.5 ka BP during the Holocene.

Key words: active fault, off-fault paleoseismology, Fujikawa-kako fault zone, trench excavation, fault scarp failure

1. Technical problems of trench excavation for active fault research

Trench excavation surveys, invented by Kerry Sieh (Sieh 1978) in the middle 1970s, has become a most popular and useful geological method to reconstruct the paleoseismicity caused by late Quaternary fault movements. Since the first introduction of this method to Japan in the late 1970s (Okada *et al.* 1981), scientists of the Geological Survey of Japan and universities have carried out a large number of trench surveys for academic purposes. Through these surveys, they have established fundamental techniques suitable for active faults in Japan. In 1995, a reactivated onshore fault caused the Hyogoken-Nanbu earthquake (M7.2) that resulted in major damage to Kobe mega-city. After the earthquake, national concern regarding active faults as a source of future destructive earthquakes rapidly increased.

* Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology

** I.N.A. Co. Inc.

The Japanese Government also started a new active fault research program to reconstruct faulting histories in order to estimate future seismic activity. This program includes research on 98 major active fault zones in Japan and has revealed many recent fault movements through trench surveys. Many kinds of information obtained from the above mentioned researches are utilized for the risk assessment of future earthquakes. However, the numbers of research studies that can provide useful information for risk assessment are small compared with the total number of studies. Many trench excavations conducted in the program failed to expose the fault rupture or resulted in insufficient information to reconstruct paleo-fault activity.

The purpose of trench surveys is not to confirm the buried fault trace but to interpret past fault movements from geological sections exposed in the trench walls in order to assess future activity. Therefore, a trench site has to be selected from places where young sediment recording past fault displacement coincides with the active fault trace. However, it is hard to find even a small open space to make trench excavations on fault traces because of the intensive land use in Japan. This difficulty compels scientists to conduct their research under unfavorable conditions. Another reason why trench excavations in Japan are difficult and inefficient results from the many social restrictions in conducting excavations.

Active faults in and around large plains or basins in Japan often show flexure structures in soft sediments that comprise the upper part of basin fills. Because a flexure does not sharply cut the strata but gently bends it, it is difficult to recognize the precise age of a fault event; a trench survey can identify fault movements using cut-and-cover relationships between faulting and strata. The recent activity of some major faults with flexure structures situated in the vicinity of large cities such as Osaka and Sendai still remains to be revealed.

2. Off-fault paleoseismology

The off-fault paleoseismology of Kinugasa (1998) is a newly adopted method for active fault study to supplement the above-mentioned weak points of trench surveys in Japan. The term "off-fault" has already been defined by McCalpin and Nelson (1996) in their grouping of paleoseismic evidence detected from geomorphic and geologic features. They firstly divided the features into two categories: "primary" that is related to features created by tectonic deformation and "secondary" that is created by seismic shaking. Then they subdivided seismic-related features including each category into "on-fault" and "off-fault". Table 1 shows four types of paleoseismic features yielded by the above-mentioned four categories.

The features of primary and on-fault type have been exclusively utilized as evidence for paleoseismicity and source fault movement in trench excavation research in Japan. The features included in the three other types, which might be of seismic origin, were not utilized to identify specific paleo-earthquakes and their source faults in previous studies.

Off-fault paleoseismology in this paper means studies to identify the ages and source faults of specific paleo-earthquakes using the analysis of geologic and geomorphic features included in the three types on Table 1, except for the primary and on-fault types. Although each of these features, such as landslides, liquefaction and coastal uplift are not directly related to fault movement, a concentration of their occurrence into some specific ages and

Table 1 Hierarchical classification of paleoseismic features (Modified and simplified from McCalpin and Nelson 1996)

	On fault	Off fault
Primary	*Geomorphic features*	
	Fault scarp	Tilted surface
	Fissures	Uplifted shorelines
	Fold	Drowned shorelines
	Moletracks	
	Pressure ridges	
	Stratigraphic features	
	Faulted strata	Tsunami deposits
	Folded (tilted) strata	
	Colluvial wedges	
	Fissure fills	
Secondary	*Geomorphic features*	
	Sand blows (liquefaction)	Sand blows (liquefaction)
	Landslides	Landslides
		Fissures
	Stratigraphic features	
	Sand dykes	Sand dykes
	Rapidly deposited lake or estuarine sediments	Turbidites

areas would provide important clues to identify the precise age and source fault associated with a paleo-earthquake. Therefore, a lot of chronological data is needed using such features as precise ^{14}C dating including the AMS method, and high-resolution tephrochronology. Moreover, in order to identify the source of a paleo-earthquake, we also need to know the tectonic relationship between some features of the primary and off-fault types (Table 1) and the source fault of the paleo-earthquake.

3. Case from the Fujikawa-kako fault zone

Geological outline of the Fujikawa-kako fault zone

The Fujikawa-kako fault zone (FKZ), which has the highest vertical slip-rate among onshore active faults in Japan, is situated at the northern extension of the Suruga Trough where the oceanic Philippine plate is driving beneath the Eurasian plate in central Japan. This fault zone consists of two subparallel fault systems running in a N-S direction. The eastern system, named the Iriyamase-Ohmiya-Agoyama fault system, comprises two echelon- arranged thrust faults and a normal fault connecting the thrust faults (Fig. 1). This system has built a conspicuous fault scarp of more than 100 m in height bounding the subsiding lowland to the east and the uplifting hilly area to the west. The long-term slip-rate of the system is estimated to be 7 mm/year based on vertical offsets of Quaternary sediments. The western faults, called the Iriyama-Shibakawa fault system, with a vertical slip-rate of 1 mm/year, also forms a distinct boundary between the hilly area to the east and the mountains to the west.

Yamazaki (1992) pointed out that active faults constituting the FKZ are imbricate thrusts developed in the accretionary prism associated with the plate subduction. The thick gravels which compose the hilly and mountainous areas were thought to be originally trough fill sediments deposited in Pliocene to middle Pleistocene times. He thought that the reactivation of these thrusts was closely related to the slip of a plate-bounding mega-thrust, which would cause a huge earthquake.

However, we have no obvious historical information on huge earthquakes that have a close relationship to the growing of these imbricate thrusts. The previously accepted idea that the Iriyamase fault, comprising the southern part of the Iriyamase-Ohmiya-Agoyama fault system, could have reactivated during the 1854 Ansei-Tokai earthquake has encountered some objections based on the detailed study of local history. Therefore, the reconstruction of past fault movements of the FKZ provides the most important and useful information for hazard assessment of future destructive earthquakes in the Izu-Tokai region, central Japan.

After the 1995 Hyogo-ken Nanbu earthquake, a trench survey was planned and carried out as well as with other onshore active faults in Japan. However, it failed to reveal the recurrence of fault movement, as the fault scarp was too large to effectively survey using trenches. Therefore, we tried off-fault paleoseismology around the FKZ. We describe the procedures and results of this research method below.

We principally utilize conventional ^{14}C ages rather than calibrated ages. This is because we have to use many age data derived from tephrochronology that are difficult to convert to calibrated ages. Table 2 shows both the conventional and 1 σ calibrated ^{14}C ages of our dated samples.

Trench excavation surveys

In 1996 the Geological Survey of Japan carried out a trench excavation survey at the southeastern end of the Ohmiya fault in Iriyamase, Fujinomiya city (Loc. A in Fig.1: Shimokawa, *et al.* 1996). The trench site was selected at the foot of a fault scarp where a small alluvial plain, formed by the Urui-gawa River, abuts the steep slope of the fault scarp. It was thought that debris caused by the failure of the fault scarp had accumulated and was preserved beneath the plain. They attempted to reveal the recent fault history through stratigraphic and chronological analysis of the deposits. Figure 2 shows a trench log of the southern wall. A normal fault striking sub-parallel to the fault scarp appeared in the lowest part of the trench. The fault cuts a tuffaceous silt layer, age ca.3.2 ka BP, and is underlain by

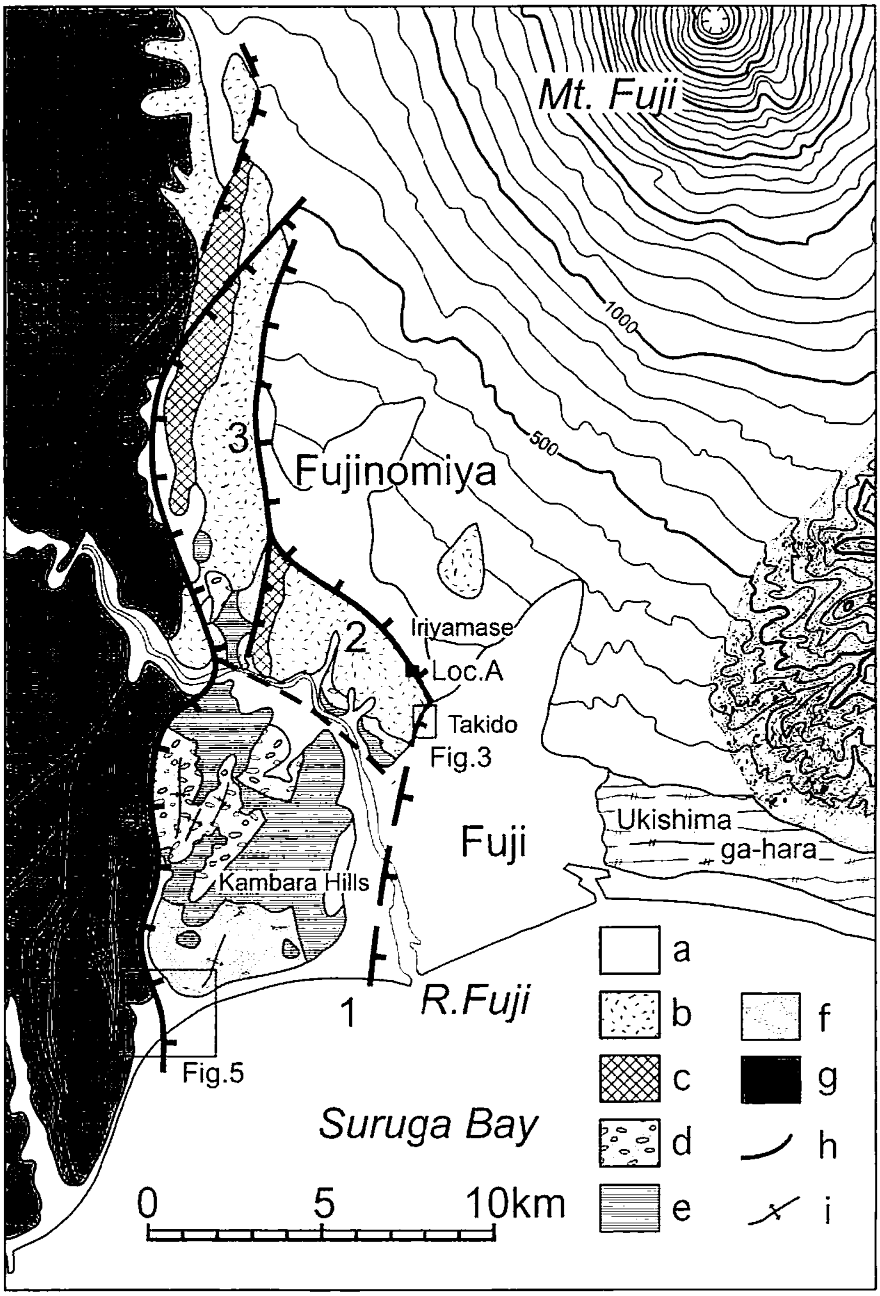

Fig. 1 Map showing the geological structure of the onshore plate boundary zone at the northern extension of the Suruga Trough and the configuration of the Fujikawa-kako fault zone (modified from Yamazaki 1992).

Fault name: 1. Iriyamase fault. 2.Ohmiya fault, 3.Agoyama fault, 4. Iriyama thrust, 5. Shibakawa fault

Legends: a. Alluvium, b. Old Fuji mudflow, c. Fuji Lavas, d. Saginota gravels, e. Iwabuchi andesite, f. Kambara gravels, g. Pre-Quaternary, h. Nonactive fault, i. Fold axis

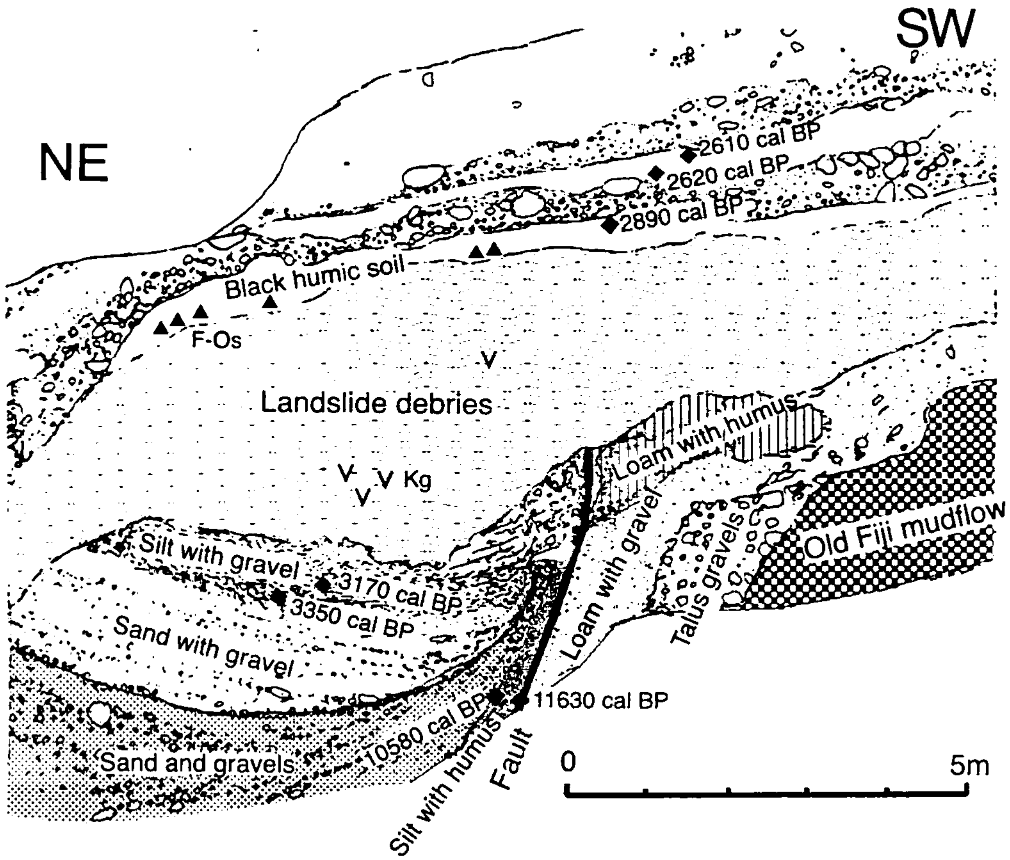

Fig. 2 Trench log of the Ohmiya fault at Iriyamase, Fujinomiya City.

a thick failure block consisting of basaltic debris derived from Old Fuji mudflow deposits of the upper part of the fault scarp. This block contains some fragments of the Kawago-daira pumice layer (Kg) erupted from Amagi volcano in the Izu Peninsula at 3.0 ka BP (3145-3126 cal BP: Okumura *et al.* 1999). Moreover, the debris block is overlain by humic soil containing Osawa scoria (F-Os) erupted from Fuji volcano at ca.2.8 ka BP (Machida and Arai 1992). This means that the failure of the debris block from the fault scarp occurred between ca.3.0 and 2.8 ka BP.

Although slope failure and landslides are originally classified into secondary and off-fault type features where it is difficult to identify the source fault, the proximity in space and time of the failure occurrence and fault movement strongly suggests that the debris failure was caused by the reactivation of the Ohmiya fault at about 3.0-2.8 ka BP.

Concentrated drillings at a foot of fault scarp

As the Iriyamase-Ohmiya-Agoyama fault system shows a conspicuous subsidence of its eastern side, the subsided area looks to have been rapidly buried by alluvial sediments. Therefore some coseismic features such as intermittently accumulated debris falls from the upper part of the fault scarp seem to be preserved in the alluvial sediments at the foot of the scarp.

A steep scarp at the northeastern tip of the Iriyamase fault contacts the alluvial plain at Takido, Fuji city. As the alluvial plain is a swampy area formed at the northern side of a large fluvial fan of the Fuji River, Takido seems to be a very suitable point for a trench excavation survey. However, it is impossible to make a trench across the fault trace because a local highway with much traffic and a watercourse for a power plant run along the foot of the fault scarp. Therefore, a drilling survey was attempted at Takido to obtain some evidence of past fault movements. Three all-core drillings each 40m in depth were arranged at 20m intervals at the foot of the fault scarp as shown in Fig 3. Figure 4 shows the drilling logs, ^{14}C dating ages and their stratigraphical interpretation. Although fine sediments prevail in the core samples, a debris layer with basalt blocks derived from the Old Fuji mudflow are intercalated intermittently in the peaty silt and fine sand sediments. Grain size and thickness of the debris layer gradually fine and thin with distance from the fault scarp. Breccia-rich debris in Boring C, located right under the scarp, indicate that they are failure deposits derived from the fault scarp. In Borings B and A, the breccia facies changes to coarse gravel with sand. That is, debris deposits recognized in the drill cores are scarp-derived colluvial wedges and their secondary sediments. As these colluvial wedges are intercalated in the peaty fine sediments, we ^{14}C dated the peaty layers. Table 2 shows the results of the ^{14}C dating. Although this table shows the calibrated age, we use the conventional age for discussion in this paper to accommodate the pre-existing age data. As a result of ^{14}C dating, five episodes of debris occurrence are recognized from the colluvial wedge horizons dated at 6.0-5.5 ka BP, 4.6-4.3 ka BP, 4.0-3.8 ka BP, ca.3.0 ka BP and ca. 1.5 ka BP. Cyclic facies change and nearly constant intervals of debris age strongly indicate the periodic recurrence of tectonic movement associated with the growing of the fault scarp. However, as scarp failure is a secondary and off-fault feature, it is difficult to prove from debris only that the fault movements caused the slope failure.

Survey of uplifted Holocene terraces

Holocene terraces of marine and fluvial origin are developed along the coastal region of the Kambara Hills that are an uplifted block situated between two fault systems comprising the FKZ. In particular, many Holocene terraces remain at Yui and at Iwabuchi, on the southwestern margin and the eastern edge of the Kambara Hills, respectively. At Yui, as shown in Fig.5, five Holocene terraces (Yu1 to Yu5) are recognized around the mouth of the Yui River. The existence of many young terraces suggests that these terraces formed by coseismic coastal uplift associated with Holocene movements of the Iriyamase-Ohmiya-Agoyama fault system. The lowest Yu5 terrace seems to be of non-tectonic origin associated with artificial changes to the river. Therefore, these uplifted terraces, except for the youngest Yu5 terrace, are primary and off-fault geomorphic features.

To determine the emergence ages of the terraces, we obtained materials for ^{14}C dating through pit excavations on the terraces (Shimokawa *et al.* 1999). As a result, we found a fragment of wood in the thick sediment constituting Yu1 (Loc.1) and dated it to be 7.9 ka BP. As this age indicates that the thick sediments correspond to the postglacial transgression, the emergence of Yu1 is estimated to be ca. 6 ka BP. A fragment of Middle Johmon Period

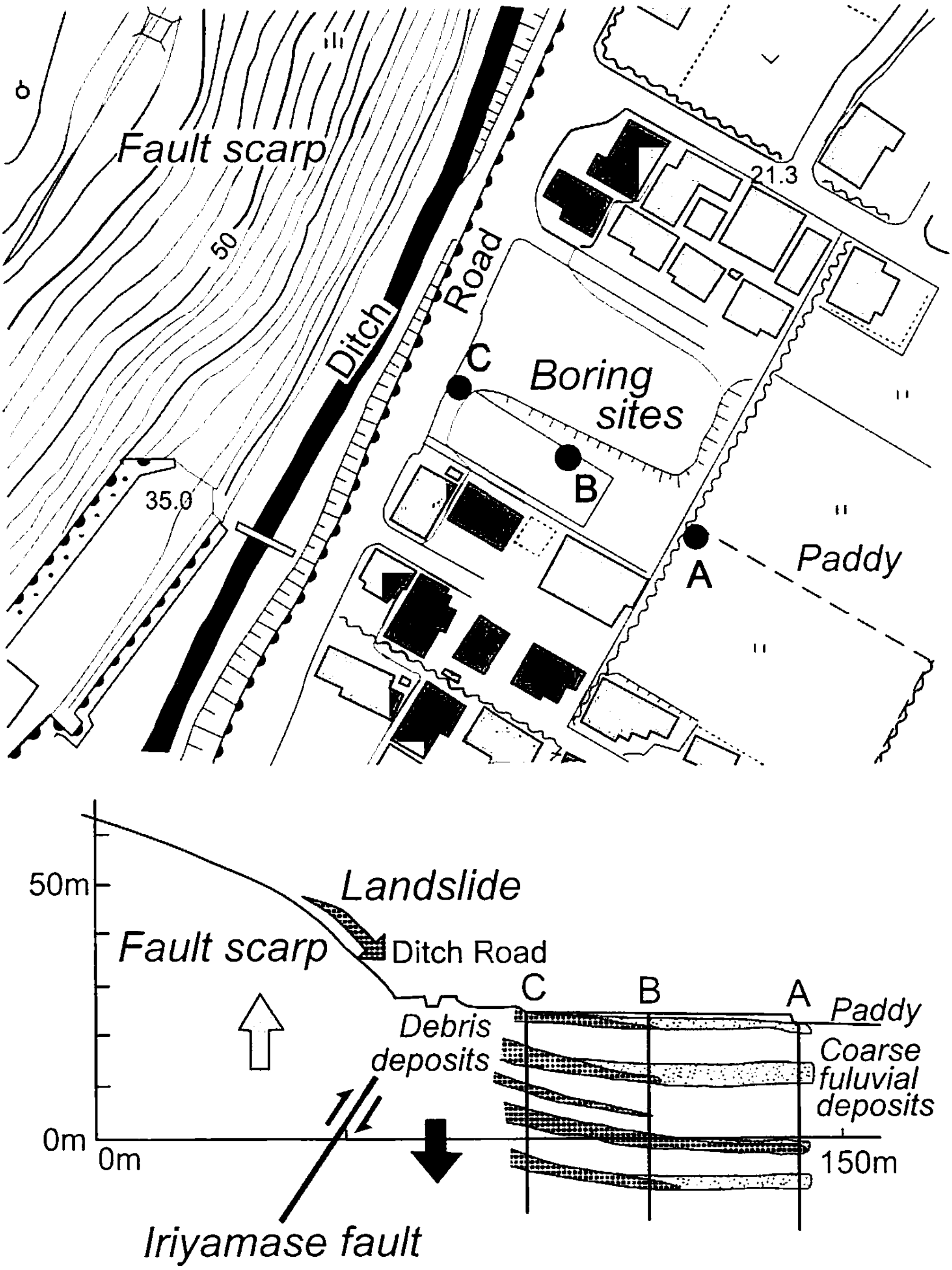

Fig. 3 Upper: Drilling arrangement at the foot of fault scarp in Takido, Fuji City
Lower: Simplified cross section of them.

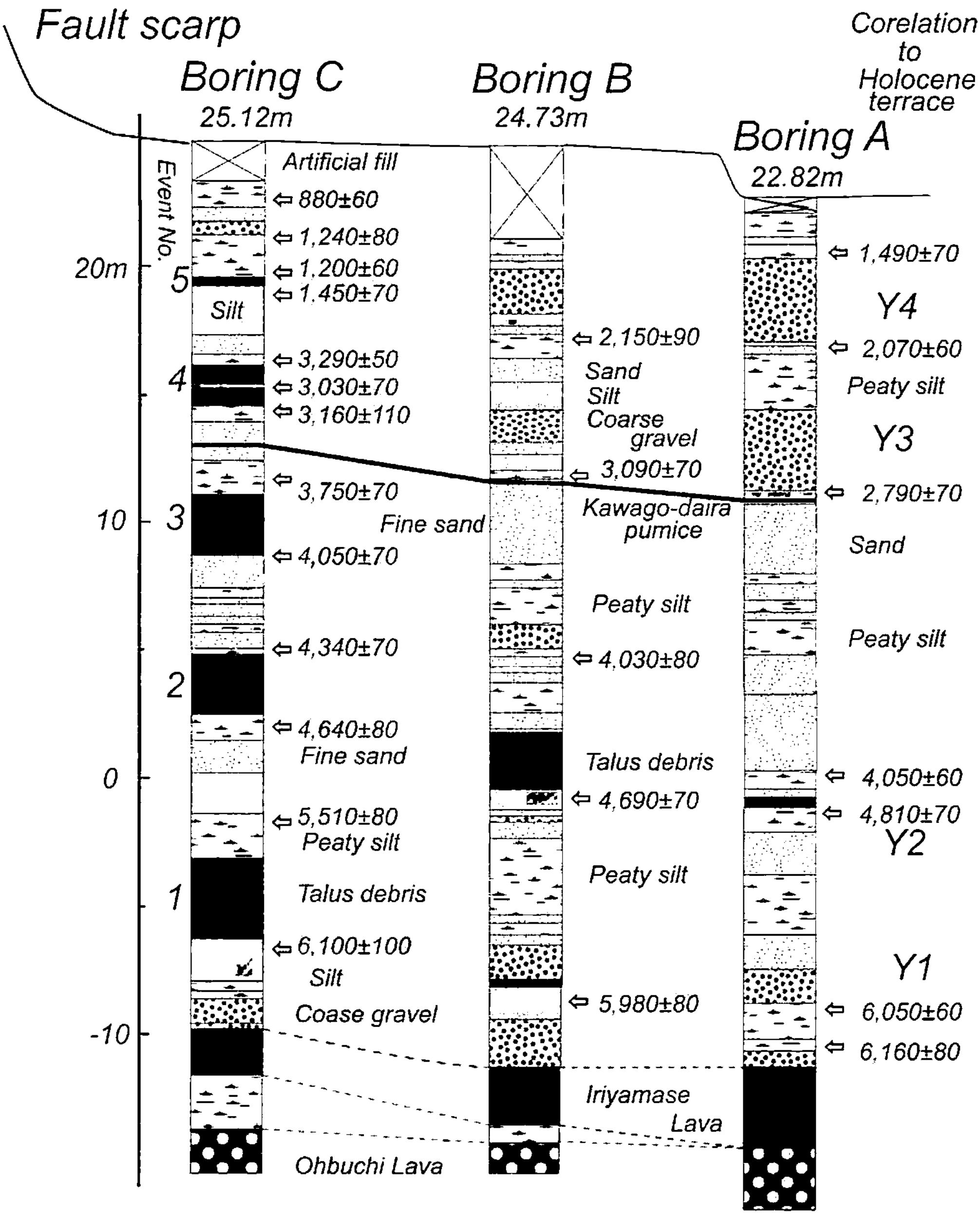

Fig. 4 Drilling logs and their geological interpretation.

(ca.4.5 ka BP) pottery ceramics was found on the top of the Yu2 terrace deposits. Moreover, terrace ages were obtained from the top of the Yu3 terrace (older than 1.7 ka BP) and from the deposits of Yu4 (younger than 2.0 ka BP). From these chronological data, emergence ages of the Yu1 to Yu4 terraces are estimated to be ca.6 ka BP, ca.4.5 ka BP, before 1.7 ka BP, and after 2.0 ka BP, respectively. As there is no record of eustatic sea-level disturbance in the

Table 2 Radiocarbon dates from boring-core samples at Takido, Fuji City

Sample No.	Depth	Code No.	Original dating age	$\delta^{13}C$	Conventional radiocarbon	Calibrated age 1 SIGMA
	m	Beta-	yr BP	‰	yr BP	cal BP
Boring A						
A-2	2.00-2.10	114764	1,450±70	-22.8	1,490±70	1,415 - 1,305
A-5	5.60-5.70	114765	2,030±60	-22.8	2,070±60	2,115 - 1,945
A-11	11.64-11.69	113052	2,740±70	-22.2	2,790±70	2,955 - 2,785
A-22	22.76-22.81	113053	4,110±60	-28.5	4,050±60	4,560 - 4,430
A-23	23.60-23.65	113054	4,810±70	-24.6	4,810±70	5,610 - 5,470
A-31	31.82-31.87	113055	6,040±60	-23.8	6,050±60	6,980 - 6,845
A-32	32.98-33.03	112219	6,190±80	-26.7	6,160±80	7,175 - 6,905
Boring B						
B-4	4.70-4.80	113692	1,450±60	-21.1	1,520±60	1,485 - 1,475
						1,435 - 1,330
B-7	7.30-7.35	113056	2,130±90	-23.6	2,150±90	2,310 - 2,230
						2,200 - 1,995
B-12	12.70-12.75	113057	3,070±70	-24.1	3,090±70	3,370 - 3,215
B-20	20.30-20.35	113058	4,060±80	-26.8	4,030±80	4,560 - 4,410
B-25	25.60-25.65	113059	4,710±70	-26.3	4,690±70	5,565 - 5,530
						5,480 - 5,310
						1,950 - 1,950
B-33	32.98-33.03	113060	5,940±80	-22.7	5,980±80	6,890 - 6,735
Boring C						
C-2	2.20-2.30	114766	870±60	-24.7	880±60	905 - 845
						835 - 3,185
C-4	4.00-4.20	114763	1,210±80	-23	1,240±80	1,265 - 1,065
C-5	5.15-5.25	116199	1,170±60	-23.4	1,200±60	1,390 - 1,290
C-5-1	5.85-5.95	116198	1,420±70	-23.2	1,450±70	1,175 - 1,055
C-8	8.87-8.97	113061	3,290±90	-25	3,290±90	3,620 - 3,390
C-9	9.70-9.80	113062	3,010±70	-24.1	3,030±70	3,340 - 3,095
C-10	10.50-10.55	113063	3,160±110	-24.8	3,160±110	3,470 - 3,245
C-13	13.00-13.05	113064	3,770±70	-26.4	3,750±70	4,220 - 3,980
C-16	16.30-16.35	113065	4,090±70	-27	4,050±70	4,795 - 4,780
						4,570 - 4,425
C-20	20.10-20.15	113066	4,360±70	-26	4,340±70	4,980 - 4,845
C-23	23.46-23.51	113067	4,670±80	-26.9	4,640±80	5,460 - 5,290
C-26	26.93-27.00	113068	5,480±80	-22.7	5,510±80	6,395 - 6,270
C-31	31.40-31.50	113069	6,130±60	-27.1	6,100±60	7,015 - 6,880
C-37	37.80-37.90	113693	10,120±50	-26.2	10,100±50	- -

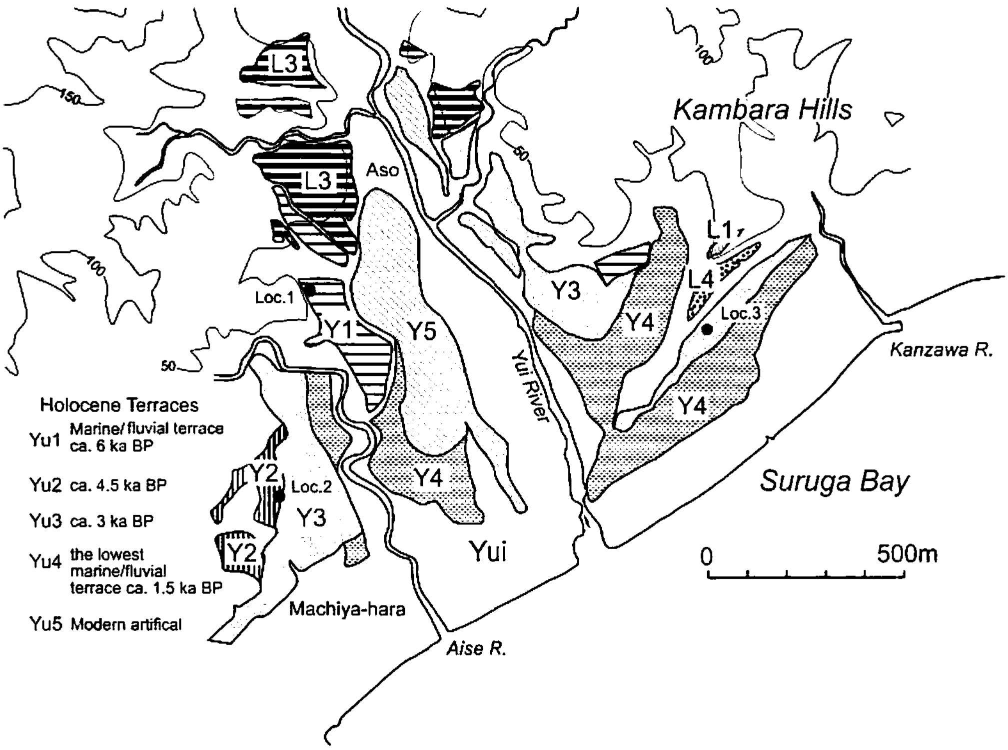

Fig. 5 Holocene terraces at Yui, southwestern edge of the Kambara Hills.

late Holocene, intermittent coseismic uplift associated with the displacement of the FKZ seems to have resulted in the formation of several terraces.

In addition, Holocene terraces occur at Iwabuchi on the eastern edge of the Kambara Hills. The Ib3 terrace emerged at 4.5 to 2.7 ka BP following the thick compilation of peat deposits (Yamazaki 1992) .The formation of Ib3 seems to be related to the sudden tectonic uplift of the Kambara Hills.

Survey of the subsided Ukishima-ga-hara lowland

A large marsh called Ukishima-ga-hara exists along the recesses of Suruga Bay east of the FKZ. Although formation of the marsh was associated with rapid transgression in the Holocene, it seems that tectonic subsidence has also played an important role in marsh development. Yamazaki (1992) estimated a subsidence rate of 3 mm/year based on the depth and age relationship of buried peat and airfall tephras in the marsh-fill sediments. In spite of the rapid subsidence, there is no historical information on coseismic crustal deformation in the area of the northern extension of the Suruga Trough.

In 1988, an archaeological survey was carried out to reveal a buried settlement site from the Yayoi Period (ca. 1.5 ka BP) on the buried barrier in the west of Ukishima-ga-hara. As this site was abandoned at 1.5 ka BP, just after an eruption of Mt. Fuji, which brought the deposition of the Ohbuchi scoria bed (ObS) to the area, Matsubara (1992) considered that the sudden environmental change caused by the volcanic eruption might have compelled the residents to abandon the settlement.

However, through a drilling survey in western Ukishima-ga-hara, Shimokawa et al. (1999) found two horizons of blue silt that directly overlie the airfall Kg and ObS tephras. They thought that the sudden facies change above the two tephra layers indicated instantaneous tectonic subsidence associated with coseismic crustal deformation. From this evidence, it is recognized that coseismic crustal deformation occurred in this region at ca. 3.0 ka BP and ca. 1.5 ka BP, respectively. The age of each of these primary and off-fault features seems to correspond with the age of scarp failures along the Iriyamase-Ohmiya-Agoyama fault system. Based on the tectonic relationship between the fault system and the subsidence region, Shimokawa *et al.* (1999) thought that the above-mentioned subsidence of Ukishima-ga-hara was important evidence showing the recent activity of the FKZ.

4. Conclusions

The ages of coseismic features that are recognized through various geological surveys conducted around the FKZ are shown in Fig. 6. The vertical coordinate axis in Fig. 6 shows the estimated age of each event with error bars and the horizontal axis represents research areas where coseismic features were recognized. Intensive occurrences of coseismic features are recognized around the FKZ at about 6 ka BP, 4.5 ka BP, 3.0 ka BP and 1.5ka BP. Some of the coseismic geological features are classified into primary categories (Table 1). The primary features discussed in this paper are related to subsidence of Ukishima-ga-hara and uplift of the Kambara Hills. These tectonic deformations can be explained by the coseismic fault displacement of the FKZ. Accordingly, the recurrence interval and the last fault event of the FKZ are estimated to be 1.5 ka and 1.5 ka BP, respectively. Coseismic surface break probably reaches more than 10 m because the vertical long-term slip-rate of the FKZ is estimated to be 7 mm per year

Evidence of fault movement is well preserved as failure debris in the alluvial sediments at the foot of fault scarps. As a scarp failure or a landslide is generally classified into the secondary category, it is difficult to identify the source fault without regard to on-fault or off-fault features. However, if some of the secondary features occurred simultaneously with primary and off-fault features, it would be possible to identify the source fault. A conspicuous coseismic failure of a fault scarp was recognized along the Patton Bay fault in Montague Island during the 1964 Alaska earthquake (Plafker 1967). The vertical displacement of the fault reached a maximum of about 10 m. A continuous failure along the fault scarp might be due to a large coseismic displacement of the fault. As the FKZ is also thought to have had a large coseismic vertical slip, it is likely to have accumulated failure debris along the foot of its fault scarp.

Although a debris-fall event occurred at 4.0-3.8 ka BP is recognized at Takido, we cannot find any other features, especially primary features, corresponding to this event around the FKZ. As it is hard to identify past fault displacements from secondary features such as slope failure alone, we think that the event at 4.0-3.8 ka BP was not directly related to movement of the FKZ.

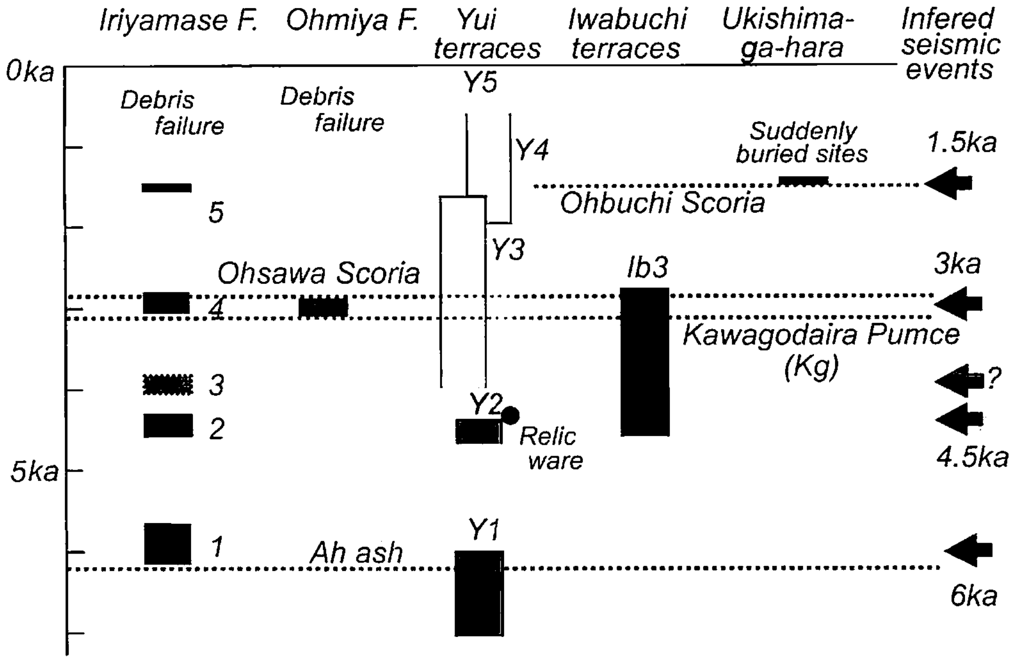

Fig. 6 Age correlation of paleoseismic features around the Fujikawa-kako fault zone.

Acknowledgments

We wish to dedicate this paper to Professor Takao Kikuchi in commemoration of his retirement from Tokyo Metropolitan University.

We wish to express our gratitude for the kind help and encouragement of Professor Takao Kikuchi, Dr. Takehiko Suzuki and Dr. Shuji Yamada of Tokyo Metropolitan University.

We are also greatly indebted to Professor Yoshihiro Kinugasa of Tokyo Institute of Technology, Dr. Yuchi Sugiyama of ASIT, Ms Sayumi Yamashita of former I.N.A. Co. Inc. and Dr. Dennis N. Eden for their kind suggestions and help.

References

Kinugasa, Y. 1998. Off Fault Paleoseismology for Pacific Margin. *Eos Transactions, American Geophysical Union 1998 Western Pacific Geophysics Meeting* **79** (24 suppl.): w81.

MaCalpin, J.P. and Nelson, A.R. 1996. Chapter 1 Introduction to Paleoseismology. In *Paleoseismology*. ed. J.P. MaCalpin, 1-28. San Diego: Academic Press.

Machida, H. and Arai, F. 1992. *Atlas of tephra in and around Japan*. 276p. University of Tokyo Press.*

Matsubara, A. 1992. Environmental change and human activity around Megazuka in the Ukishimagahara lowland, Shizuoka Prefecture. *The Quaternary Research* **31**: 221-227.**

Okada, A., Ando, M. and Tsukuda, T. 1981. Trenches, late Holocene displacement and seismicity of the Shikano fault associated with the 1943 Tottori earthquake. *Annual Report of the Disaster Prevention Research Institute, University of Kyoto* **24**: B-1, 105-126.**

Okumura, K., Suzuki, T. and Shimada, S. 1999. High-precision radiocarbon dating and wiggle matching age estimation of the Kawago-daira pyroclastic flow deposits, central Japan. *Reports for Grant-in Aid for Scientific Research (B)(1) 1997-1998, No. 09680177.* 1-5.*

Plafker, G. 1967. Surface faults on Montague Island associated with the 1964 Alaska earthquake. *U.S.Geological Survey Professional paper* **543-G**: G1-G42.

Shimokawa, K., Yamazaki, H., Mizuno, K. and Imura, R. 1996. Paleoseismology and activity study of the Fujikawa fault system. in 1995 Summary report for the active fault survey. *GSJ Openfile reports* No.259: 73-80.*

Shimokawa, K., Yamazaki, H., and Tanaka, T. 1999. Paleoseismological study of the Fujikawa-kako fault zone. *The Seismological Society of Japan, 1999 Fall meeting, Programme and abstracts* C36.*

Sieh, K. 1978. Prehistoric large earthquakes produced by slip on the San Andreas fault at Pallet Creek, California. *Journal of Geophysical Research* **83**: 3907-3939.

Yamazaki, H. 1992. Tectonics of a plate collision along the northern margin of Izu Peninsula, central Japan. *Bulletin of the Geological Survey of Japan* **43**: 603-657.

(*: in Japanese, **: in Japanese with English abstract)