Field Trip Guide:
Active Faulting along the Median Tectonic Line in the eastern part of Shikoku, southwest Japan

November 11, 2006

Oblique aerial photograph of the Ikeda fault at downtown Ikada, Miyoshi City, Tokushima Prefecture. View is to the west. Photo taken by A.Okada.

Compiled by

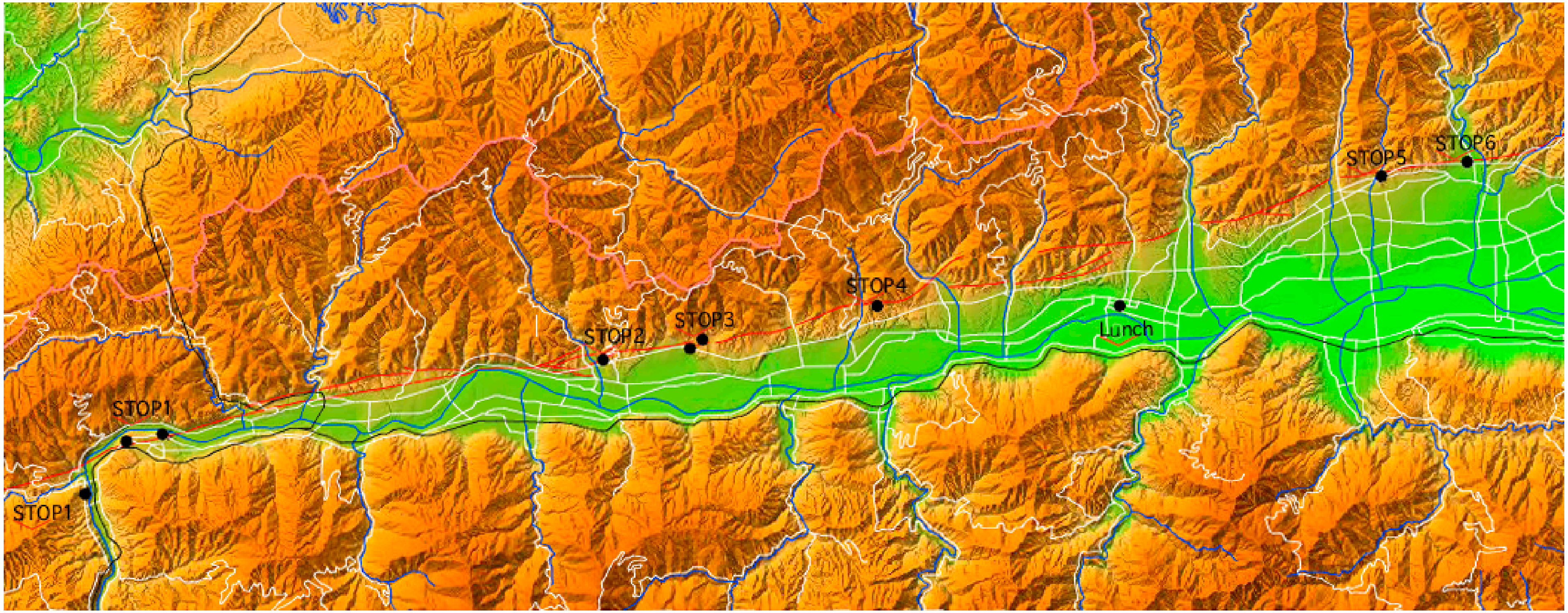
Atsumasa Okada[1] and Shinzou Ooi[2]

1)Research Center for Disaster Mitigation of Urban Heritage,Ritsumeikan University

2)Geographical Survey Institute

6th Joint Meeting of UJNR Panel on Earthquake Research Tokushima, November 8-11, 2006

Guide map for Field Trip Route



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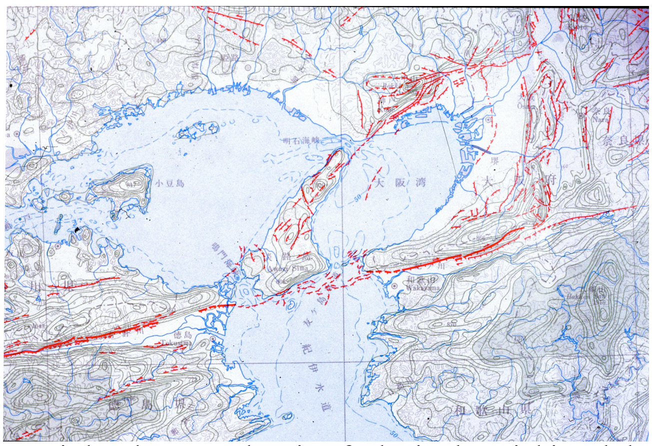


Fig. 0-1 Summit level map and active faults in the Kinki and the NE Shikoku areas. From the Research Group for Active Faults of Japan (1991).

Fig.0-2 Landsat image around Shikoku Island

Fig.0-3 Bird's-eye picture in the eastern part of Sanuki Range, northeast Tokushima Pref. ,along the Median Tectonic Line active fault zone, prepared by A. Okada

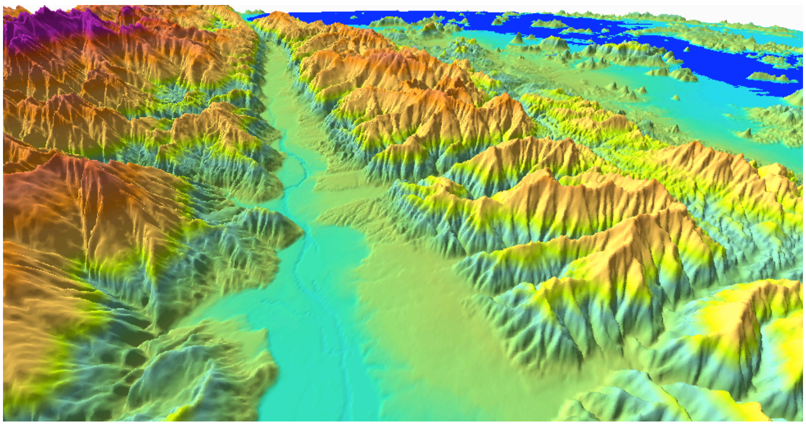


Fig.0-4 Bird's-eye picture in the western part of Sanuki Range, northwest Tokushima Pref. ,along the Median Tectonic Line active fault zone, prepared by A. Okada

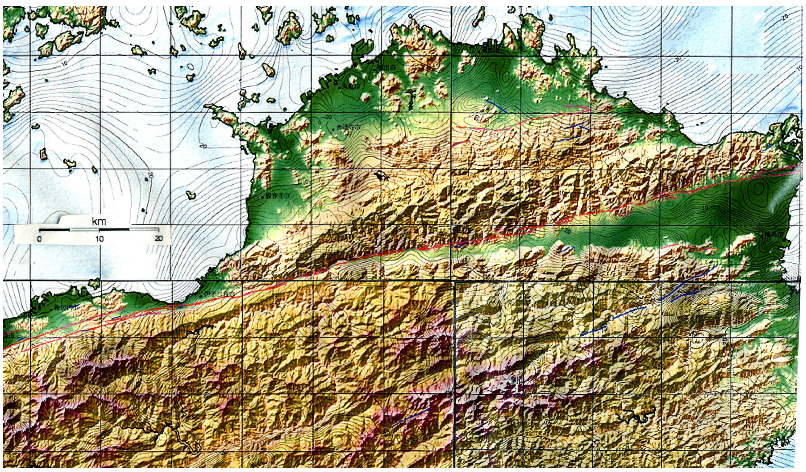


Fig.0-5 Topographic map and Gravity anomaly in the northeastern part of Shikoku (Yamamoto and Shichi, 2004)

Introduction

This field trip provides an opportunity to observe a variety of tectonic geomorphic features and ongoing paleoseismic investigations along the mainly dextral Median Tectonic Line active fault system (MTL), one of the most active faults onshore Japan. The trip begins Tokushima in eastern Shikoku Island and travels to the west Town of Ikeda. We will then head to the east and disperse at Tokushima Tokyu-Inn.

Tectonic Setting of the Median Tectonic Line

The MTL is an arc-parallel, right-lateral strike-slip fault (Fig.0-6) related to oblique subduction of the Philippine Sea plate beneath the Eurasian plate along the Nankai trough (Fitch, 1972). The MTL is the longest continuous active fault in onshore Japan with one of the highest late Quaternary slip rates, 5-10 mm/14C yr on Shikoku (Okada, 1973a, 1980). In addition, the MTL underlies an urban corridor of Kinki and Shikoku and is adjacent to densely populated areas such as the Kyoto-Osaka-Kobe megacities (population more than 10 million), representing one of the largest earthquake risks in the country (Fig.0-6).

The MTL, extending from Chubu westward to Kyushu, is the most pronounced geologic discontinuity in southwest Japan (Fig.0-6). Originating in the late Mesozoic, the MTL separates the low pressure-high temperature Ryoke metamorphic belt to the north and the high pressure-low temperature Sambagawa metamorphic belt to the south for over 1000 km (e.g., Hashimoto and Kanmera, 1991). In Kinki and Shikoku, the Ryoke belt is overlain by the Upper Cretaceous Izumi Group consisting of interbedded sandstone and shale. The eastern end of the MTL is truncated by the NNW-trending Itoigawa-Shizuoka Tectonic Line which was proposed by Nakamura (1983) as a plate boundary between the Eurasian and North American plates (Fig.0-6). Fitch (1972) first proposed that right-lateral strike-slip along the MTL is related to oblique subduction of the Philippine Sea plate beneath the Eurasian plate along the Nankai trough. He suggested that the oblique convergence vector between the plates is partitioned into an arc-normal component (underthrusting along the subduction zone) and an arc-parallel component (right-lateral slip along the MTL). However, this strain partitioning is incomplete: a large portion of the arc-parallel component as well as the arc-normal

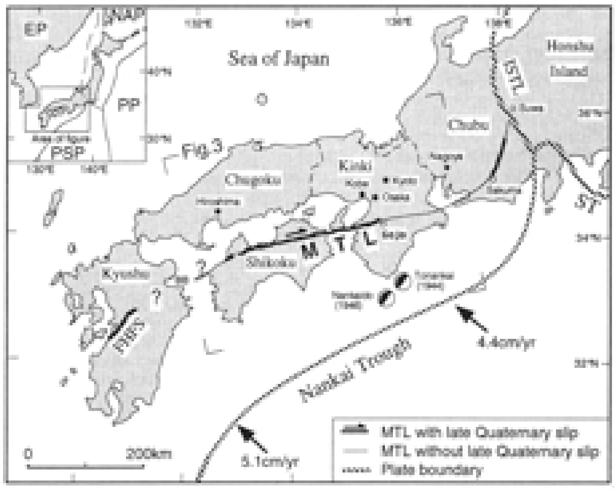


Fig.0-6 Index map showing current plate tectonic regime in southwest Japan. Plate convergence vectors along the Nankai trough are calculated based on work by Seno et al. (1993). Focal mechanisms of Tonankai and Nankaido earthquakes are after Kanamori (1972). Location and late Quaternary activity of the Median Tectonic Line (MTL) are not well defined in Kyushu and offshore between Kyushu and Shikoku. Abbreviations in the inset are EP, Eurasian plate; NAP, North American plate; PP, Pacific plate; PSP, Philippine Sea plate. Abbreviations in the figure are BB, Beppu Bay; FHFS, Futagawa-Hinagu fault system; IP, Izu Peninsula; ISTL, Itoigawa-Shizuoka Tectonic Line; ST, Sagami trough. Chubu, Chugoku, Kinki, Kyushu, and Shikoku represent geographic districts; Kyushu and Shikoku Districts are islands, whereas Chubu, Chugoku, and Kinki Districts (their boundaries are shown) are part of Honshu Island. Location of Fig.0-7 is shown. From Tsutsumi and Okada (1996).

component is accommodated by subduction zone earthquakes along the trough such as the 1944 Tonankai and 1946 Nankaido earthquakes (Fig.0-6). The right-lateral shear is distributed over a wide area of the upper plate (Fig.0-6), and only a fraction of the shear is accommodated by slip on the MTL. The convergence rate between the plates is calculated as 4.4 cm/yr off Kinki and 5.1 cm/yr off Kyushu based on a model by Seno et al. (1993).

Evidence of late Quaternary faulting is recognized along a 300-km-long portion of the MTL in western Kinki and Shikoku (Fig.0-6). Some parts of the MTL in Chubu and Kyushu have also been active in the Quaternary, but the slip rate there is significantly lower than in western Kinki and Shikoku (Okada, 1973a; Research Group for Active Faults of Japan, 1991). The late Quaternary movement along the MTL is predominantly right-lateral strike-slip, with a vertical component of displacement which is generally less than one tenth of the horizontal component (Okada, 1973a, 1980). The active trace of the MTL in western Kinki and Shikoku consists of parallel to subparallel en echelon faults with lengths of several kilometers to several tens of kilometers. Some of the active faults reactivate the terrane boundary between the Sambagawa and Izumi belts, while others are less than a few kilometers to the north of the boundary. These late Quaternary faults are usually referred to as the Median Tectonic Line active fault system, to distinguish them from the MTL as a terrane boundary (Okada, 1973a, 1980). In the remainder of this field trip guide, we call this active fault system "the MTL" and the terrane boundary between the two belts "the terrane boundary of the MTL" for convenience. Based on offset stream channels and terrace risers, the average horizontal slip rate of the MTL in the late Quaternary is estimated as 1-3 mm/14C yr in western Kinki (Okada and Sangawa, 1978) and 5-10 mm/14C yr in Shikoku (Okada, 1970, 1973b). These are among the

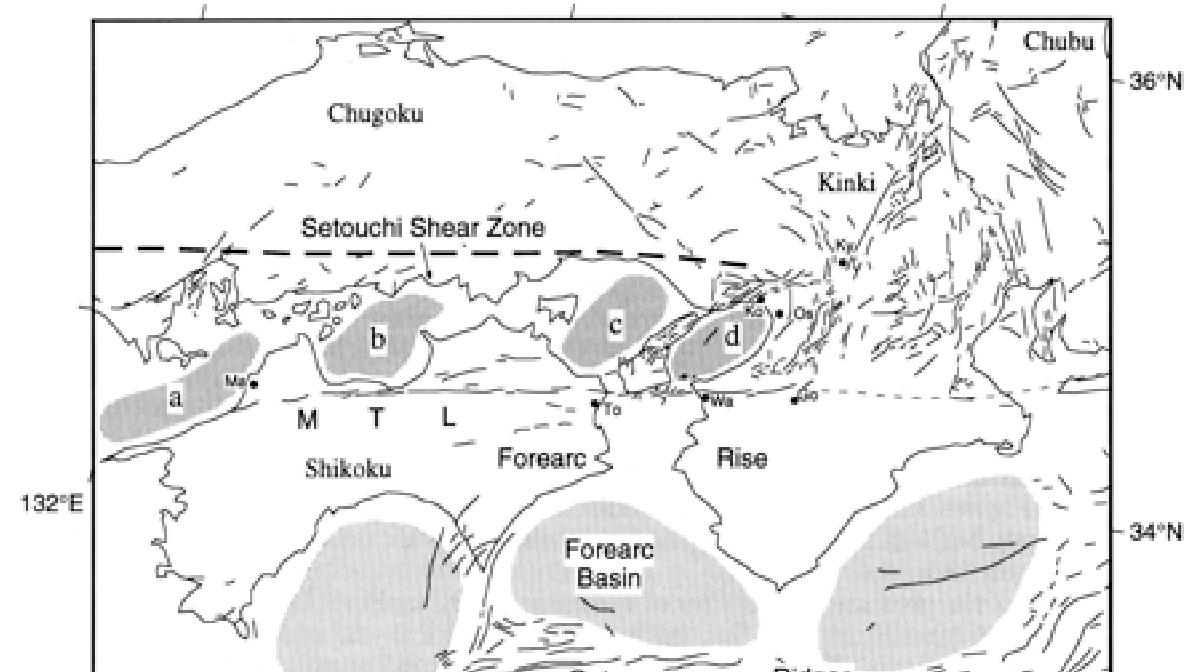


Fig.0-7 Active tectonic map of Chubu, Kinki, Chugoku, and Shikoku Districts showing active faults (solid lines) after Research Group for Active Faults of Japan (1992) and structural zonation after Sugiyama (1994). Region north of the Median Tectonic Line (MTL) has much higher concentration of active faults than region to south. Dashed line east of Gojo (Go) indicates the terrane boundary of the MTL which has not been reactivated in the late Quaternary. Shaded areas indicate basins. The basins in the Setouchi shear zone are a, Sea of Iyo; b, Sea of Hiuchi; c, Sea of Harima; d, Osaka Bay. Abbreviations of cities are Go, Gojo; Ko, Kobe; Ky, Kyoto; Ma, Matsuyama; Os, Osaka; To, Tokushima; Wa, Wakayama. Modified from Tsutsumi and Okada (1996).

highest slip rates for onshore active faults in Japan (Okada, 1973a, 1980; Research Group for Active Faults of Japan, 1991). The MTL in Chubu (Fig.0-6) is characterized by linear valleys with right-laterally deflected stream channels. The average late Quaternary slip rate there is probably less than 1 mm/14C yr (Research Group for Active Faults of Japan, 1991). Between Sakuma in Chubu and Gojo in Kinki, the terrane boundary of the MTL has not been reactivated in the late Quaternary (Okada, 1973a). In Kyushu, the NE-trending Futagawa-Hinagu fault system (Fig.0-6) with a late Quaternary slip rate of 0.8 mm/14C yr is probably the western extension of the MTL (Research Group for Active Faults of Japan, 1991; Chida, 1992). Extensive normal faulting and active volcanism characterize a zone north of the MTL in Kyushu. In this field trip, we visit the MTL in eastern Shikoku where the slip rate is relatively high and where there have been extensive paleoseismological investigations involving detailed geologic mapping and exploratory trench excavations.

There is a remarkable contrast in distribution of active faults from one side of the MTL to the other (Fig.0-7). The area north of the MTL, especially Chubu and Kinki, contains one of the largest concentrations of active faults in Japan with numerous historical destructive earthquakes catalogued by Usami (1987). These faults are interpreted to take up the right-lateral slip on the MTL east of where it becomes inactive near Gojo (Sangawa, 1986). They are classified into NW-trending left-lateral and NE-trending right-lateral strike-slip faults and north-trending reverse faults. Maximum compressional stress direction based on the conjugate sets of strike-slip faults is E-W to WNW-ESE. The Setouchi shear zone (Fig.0-7) is a broad right-lateral shear zone north of the MTL marked by a series of NE-trending anticlines (islands) and synclines (basins) (Tsukuda, 1992; Sugiyama, 1994). In contrast, there are very few active faults onshore south of the MTL (Fig.0-7). This zone between the MTL and forearc basins to the south is considered to behave as a rigid microplate translating to the west in response to oblique plate convergence (Tsukuda, 1992). Historical and instrumental seismicity of the MTL is very low, unlike other large, comparable strike-slip faults worldwide (Ishikawa, 1992). Because of the absence of historical documents of destructive earthquakes along the fault (Usami, 1987), the MTL was previously thought to be unruptured for at least the past 1000 years.

Stop1:Fault scarp at downtown Ikeda, Miyoshi City

The central business district of Town of Ikeda is located on a river terrace of the Yoshino River. The Ikeda fault cuts across the river terrace and forms a south-facing fault scarp which trends N75°E (cover and Fig.1-1; Okada, 1968). The height of the scarp decreases to the east from ~30 m north of Furuike Pond to ~20 m near the Yoshino River. Borehole data suggest that the base of terrace gravels is 40 to 50 m higher on the north side of the fault. Okada (1968) estimated the age of the terrace at ~30 ka based on a radiocarbon age for a wood fragment within the terrace gravels, suggesting that the vertical component of slip rate for the Ikeda fault here is greater than 1 mm/ 14C yr. The NNW-trending erosional scarp west of downtown Ikeda appears to be offset ~200 m right-laterally across the Ikeda fault (Okada, 1968).

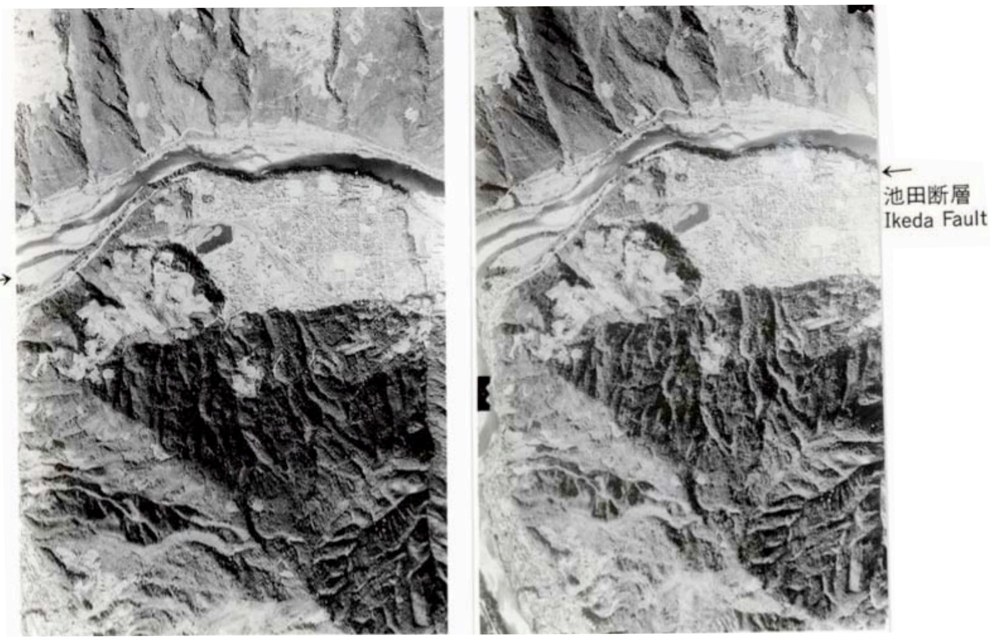


Fig. 1-1 Fault scarplet along the Ikeda fault at downtown Ikeda, Tokushima Prefecture. Aerial photographs by Geographical Survey Institute.

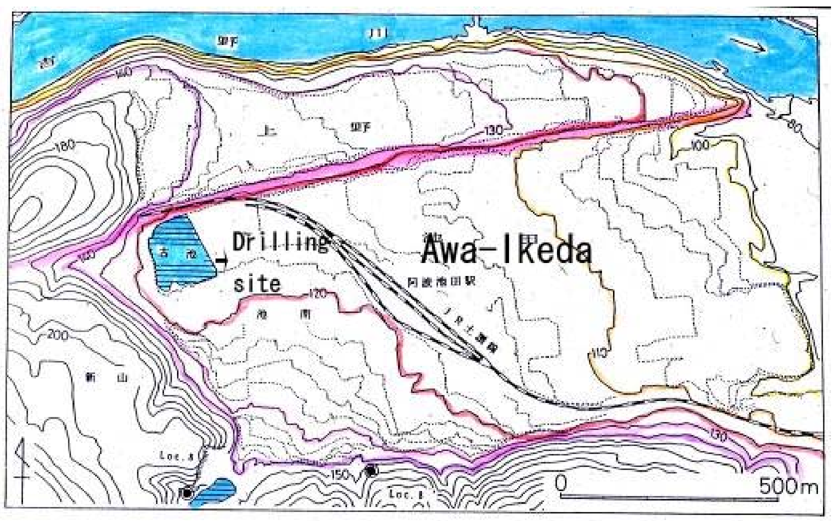


Fig. 1-2 Detailed geomorphic map around downtown Ikeda. Numerals show elevations and contour interval is 2 m.

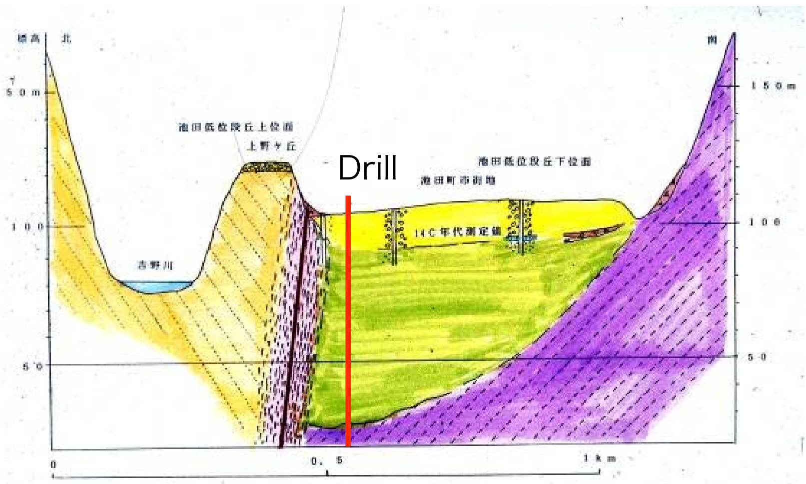


Fig. 1-3 N-S cross-section across the MTL at downtown Ikeda
The Izumi Group (Late Cretaceous) contacts to the Sambagawa crystalline schist at bottom of figure. Although thin gravels cover the Izumi Group at Ikeda upper terrace, Ikeda lower terrace is composed of relatively thick gravel deposits, which overlies the 70m-thick lacustrine sediments and the schist. Based on Okada’s drilling data.

Although the Ikeda fault has reactivated a terrane boundary of the MTL, low-relief hills at Hosono and Shinyama south of the fault are composed of interbedded sandstone and shale of the Izumi Group. The Izumi Group there is extensively fractured and is interpreted as slid blocks from the Sanuki Range to the north (Okada, 1968). Geomorphic features typical of landslides are easily identified on maps and aerial photographs as well as in the field.

Stop2:Outcrop of extensively shattered zone along the MTL in a quary at Shiboo,Town of Mino, Miyoshi City

The Mino fault is accompanied by extensively shattered sandstone and shale of the Izumi Group in a quarry at Shiboo, Mino Town (Fig.2-4). The fault gouge zone, striking about N80°E and dipping 80°N to almost vertical, develops along the southern edge of this outcrop. We can also recognize a few zones of elongated gouge veins composed of the Sambagawa crystalline schist. The terrane boundary of the MTL, known as the Shiboo thrust at this locality, is about 50 m to the south of this outcrop. The Mino fault appears to merge into the terrane boundary of the MTL at depth (Fig.2-4). Wide shattered zones such as the one at this locality generally develop around bending or branching zones along the fault traces.

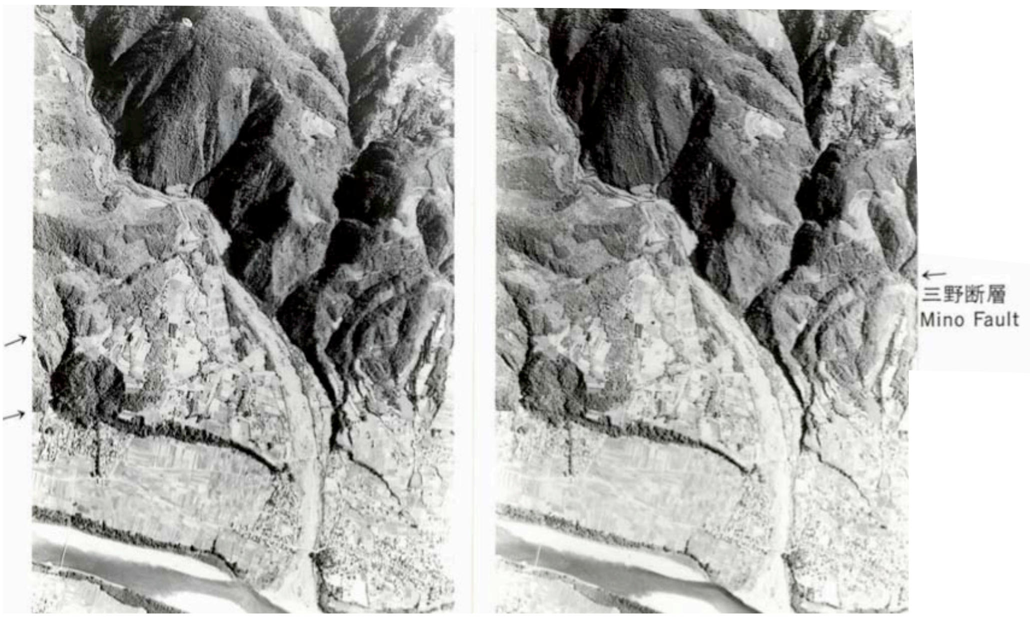
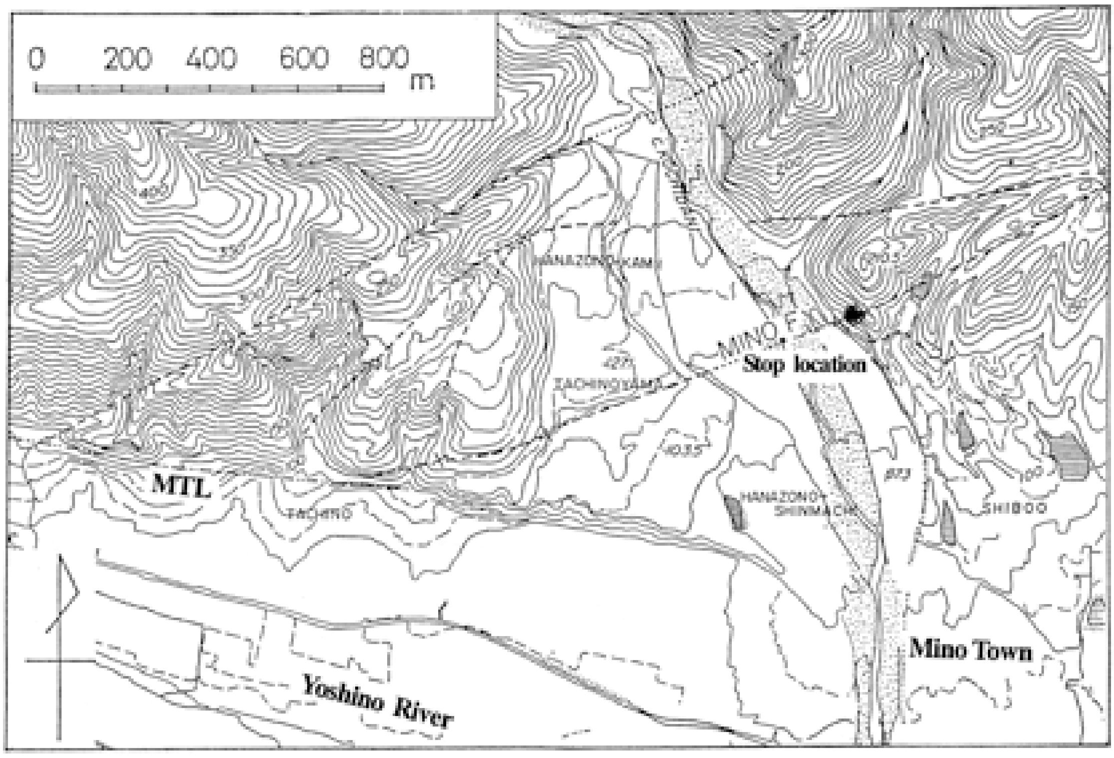


Fig.2-1 Fault topography between Tachino and Shiboo, Mino Town, Miyoshi City, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

Fig.2-2 Oblique aerial photograph of fault scarplet and fault outcrop along the Mino fault at Shiboo, Miyoshi City. View is to the northeast. Photo taken by A.Okada.

Fig.2-3 Photograph of fault outcrop and wide gouge zone along the Mino fault at Shiboo, Miyoshi City. View is to the east. Photo taken by A.Okada.



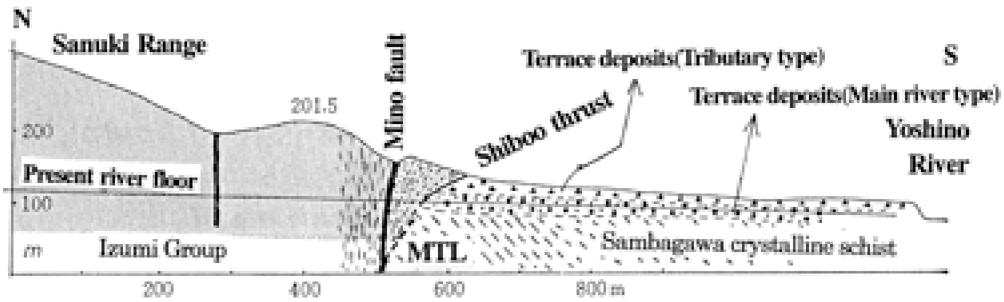


Fig.2-4 Detailed topographic map and geologic cross section of the Mino fault at Shiboo, Mino Town. Upper map shows the traces of the Mino fault (Original scale 1:5,000).

Stop3:Trenchig site at Ueno,Town of Mino,Miyoshi City

A trench was excavated across the Mino fault at Ueno, Town of Mima, 6 km west of Ikenoura on November, 1999. Similarly to Ikenoura, the Mino fault here forms a north-facing fault scarp on middle terrace surface and ponded sediments derived from the north. A fault zone ~2 m wide is exposed on the trench walls. This trench is also being studied as of early January. Log of the trench walls and interpretation of paleoseismic events will be presented on the day of this field trip.

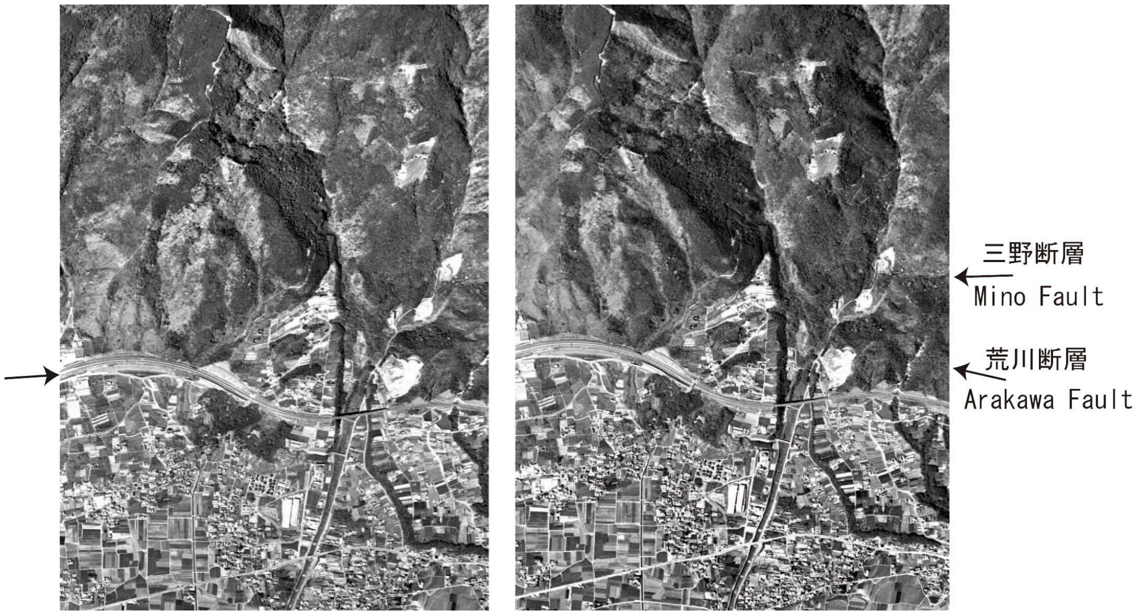


Fig.3-1 Fault topography and deformed terraces along the Mino fault at Ueno, Miyoshi City, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

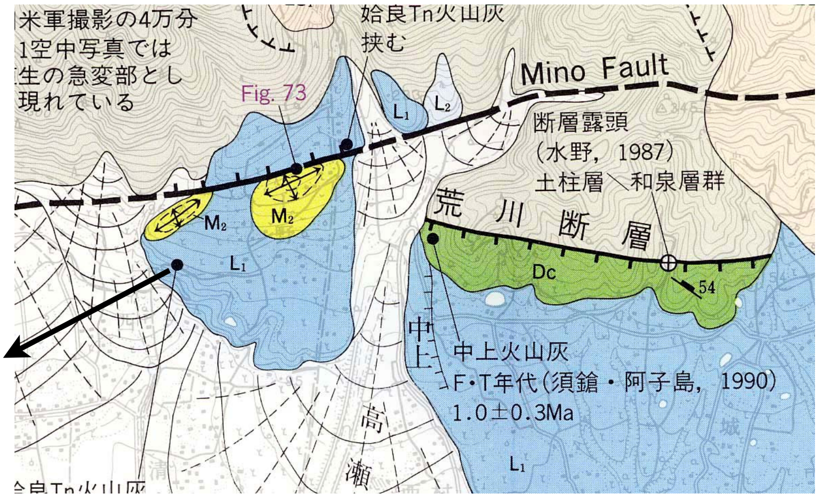


Fig. 3-2 Part of fault strip map (Mizuno and others, 1993), showing the location of trench site at Ueno, Miyoshi City, along the Mino fault.

Photo 3-3 The Aira-Tanzawa air fall ash (AT) micrograph, with an estimated age 26~29 ka (Machida and Arai, 2003)

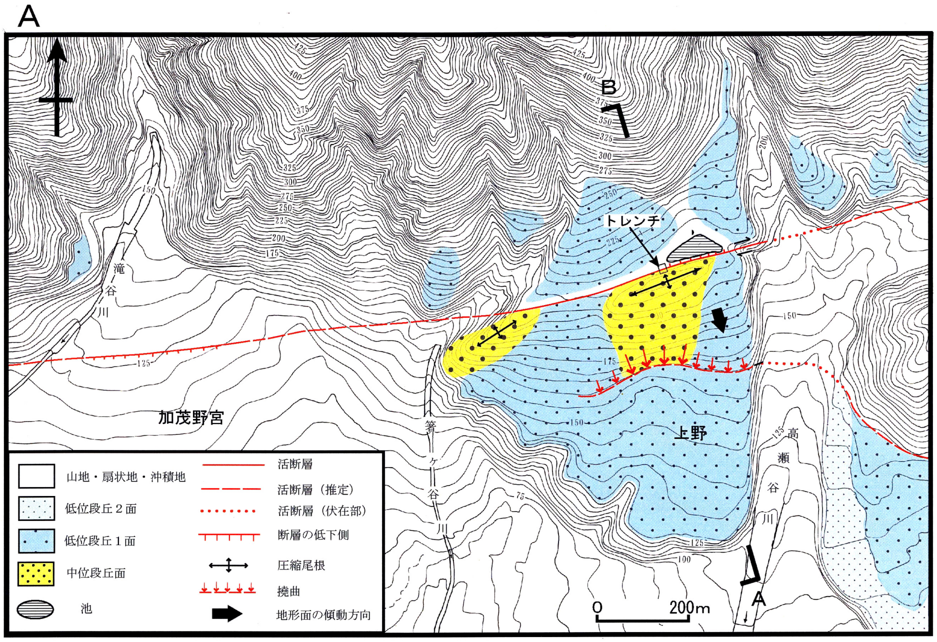


Fig. 3-4 Geomorphic map around the location of trench site at Ueno, Miyoshi City, along the Mino fault (Morino and others,2002).

Photo 3-5 Reverse-facing scarplet and sag pond around the trench site at Ueno, Miyoshi City, along the Mino fault, taken by A.Okada.

Photo 3-6 Trench wall of the west side at Ueno trench, Miyoshi City, along the Mino fault, taken by A.Okada.

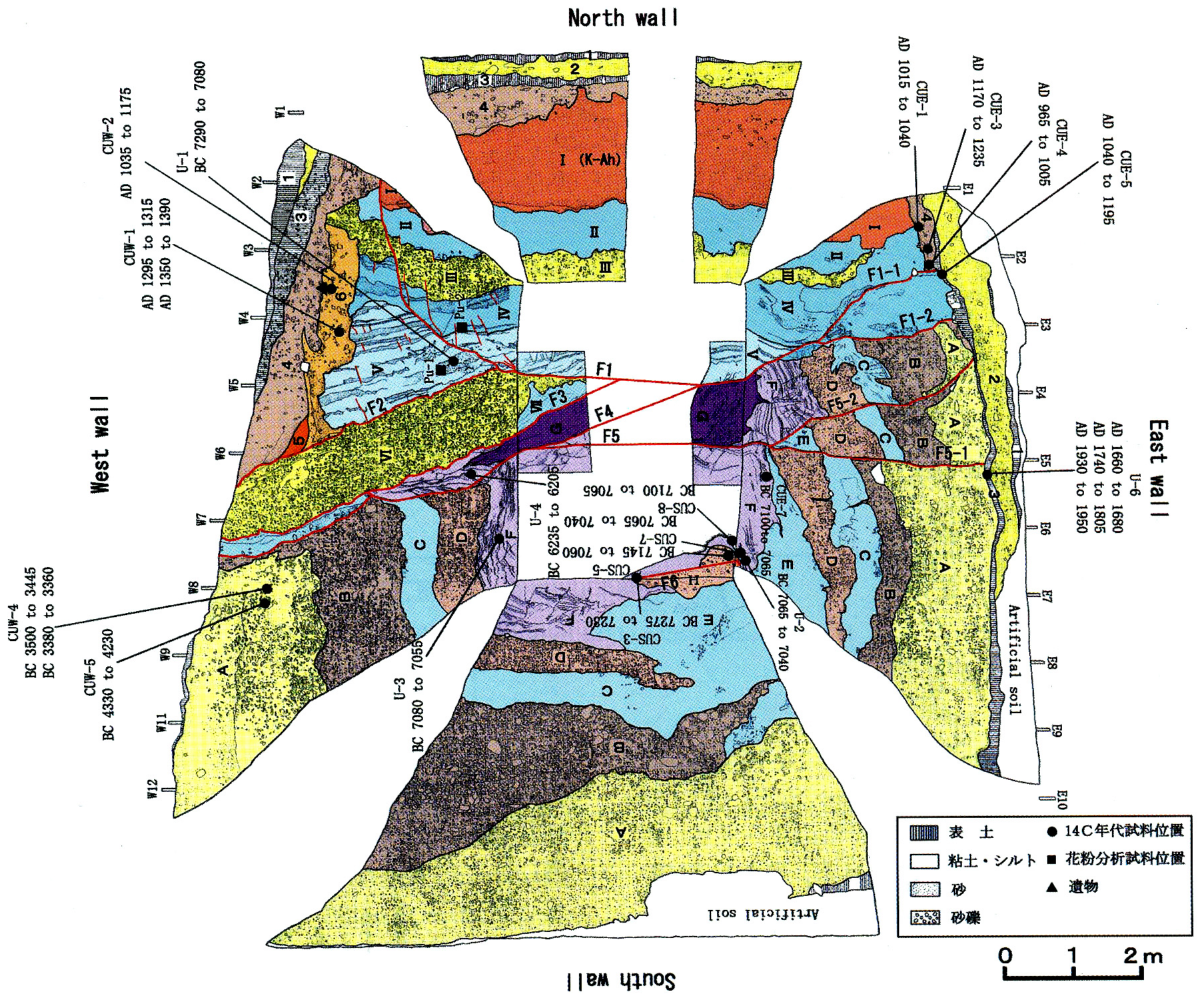


Fig. 3-7 Sketch of exposure of the all sides at Ueno trench, Miyoshi City, along the Mino fault fault (Morino and others,2002).

Stop4:Trenchig site at Ikenoura,Town of Mima, Mima City

The Tokushima Prefectural Government has excavated paleoseismic trenches at two sites (Stops3 and 4) along the MTL in 1999. The eastern trench was excavated across the Mino fault at Ikenoura, Town of Mima (Fig.4-1, Fig.4-2) where stream channels are systematically offset right-laterally across the fault as much as 400 m (Okada, 1970). At Ikenoura, a tectonic depres-

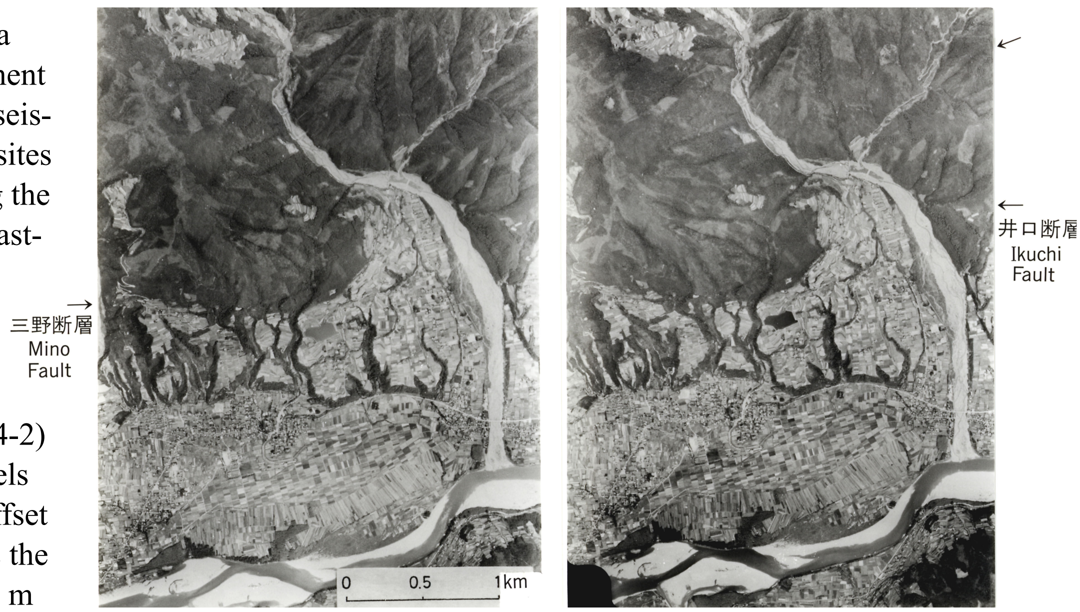


Fig.4-1 Fault topography and deformed terraces along the Mino fault at Ikenoura, Mima City, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

sion 20 to 35 m wide extends for ~250 m with two sag ponds within the depression. The trench was excavated across the southern margin of the depression on December, 1999. A discrete fault zone was exposed immediately beneath the north-facing fault scarp ~1 m high. Log of the trench walls and interpretation of paleoseismic events will be presented on the day of this field trip.

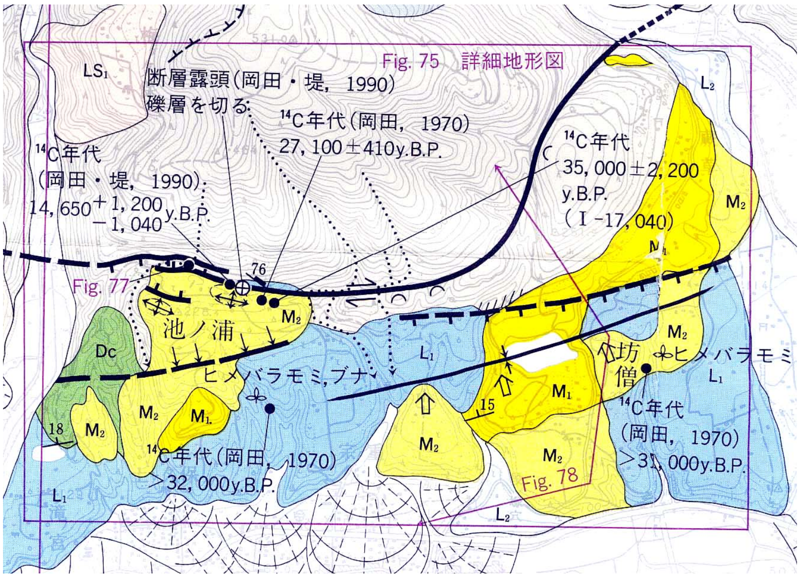


Fig. 4-2 Part of fault strip map (Mizuno and others, 1993), showing the location of trench site at Ikenoura, Mima City, along the Mino fault. Synclinal axis and monoclinal scarp are also described on this map.

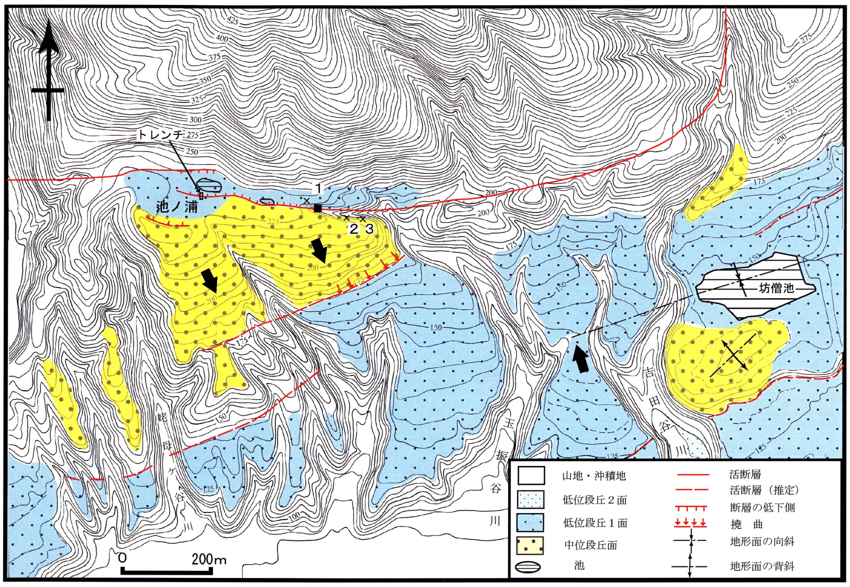


Fig. 4-3 Geomorphic map around the location of trench site at Ikenoura, Mima City, along the Mino fault(Morino and others,2002).

Photo 4-4 Reverse-facing scarplet and sag pond around the trench site at Ikenoura, Mima City, along the Mino fault , taken by A.Okada.

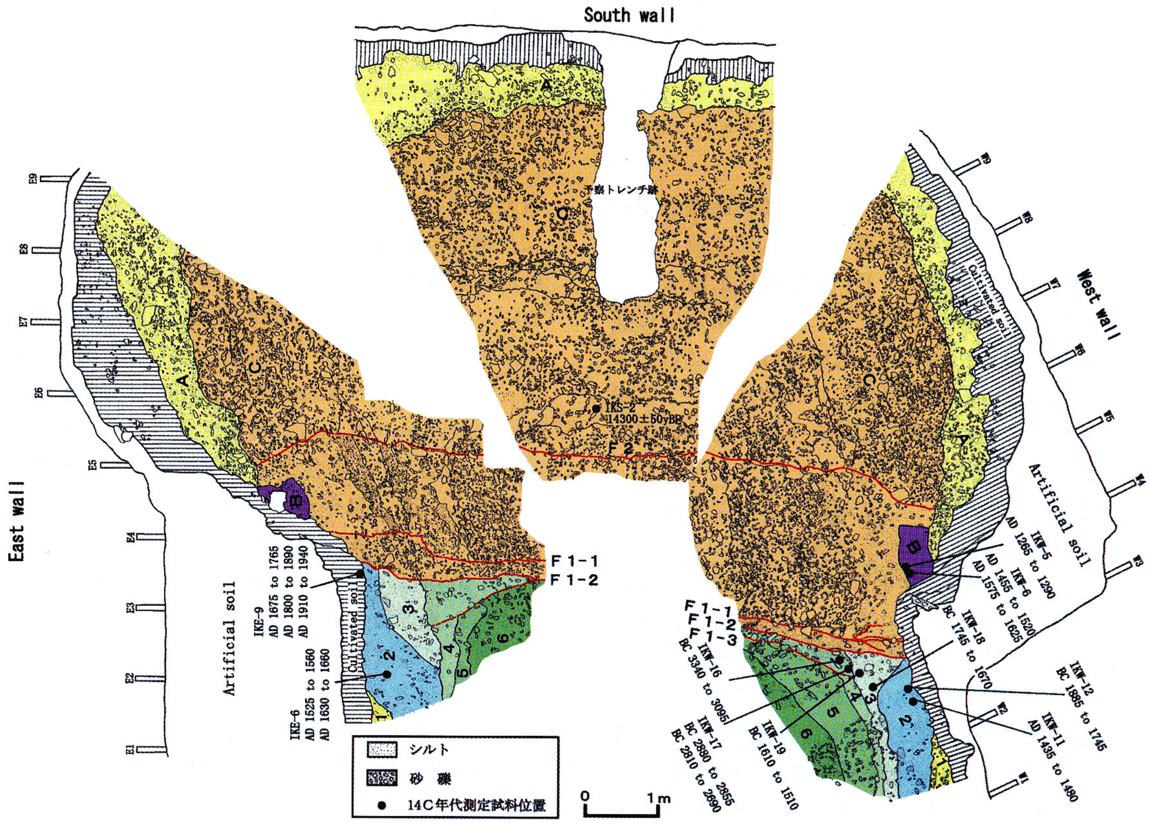


Fig. 4-5 Sketch of exposure of the west, north and east sides at Ikenoura trench, Mima City, along the Mino fault (Morino and others,2002).

Stop5:Fault outcrop at Ideguchi,Town of Awa, Awa City

The fault plane of the Chichio fault is exposed at Ideguchi, Town of Awa (Fig.5-1). The strike and dip of the fault plane are N74°E and 72°N, respectively. Nearly horizontal slickensides are observed on gravels within the fault zone (Mizuno et al., 1993). The strata on both sides of the fault are the Dochu Formation of early Pleistocene age. The white volcanic ash layer within gravels on the south side of the fault was dated at 1.0 ± 0.2 Ma by fission-track method (Akojima and Suyari, 1989).

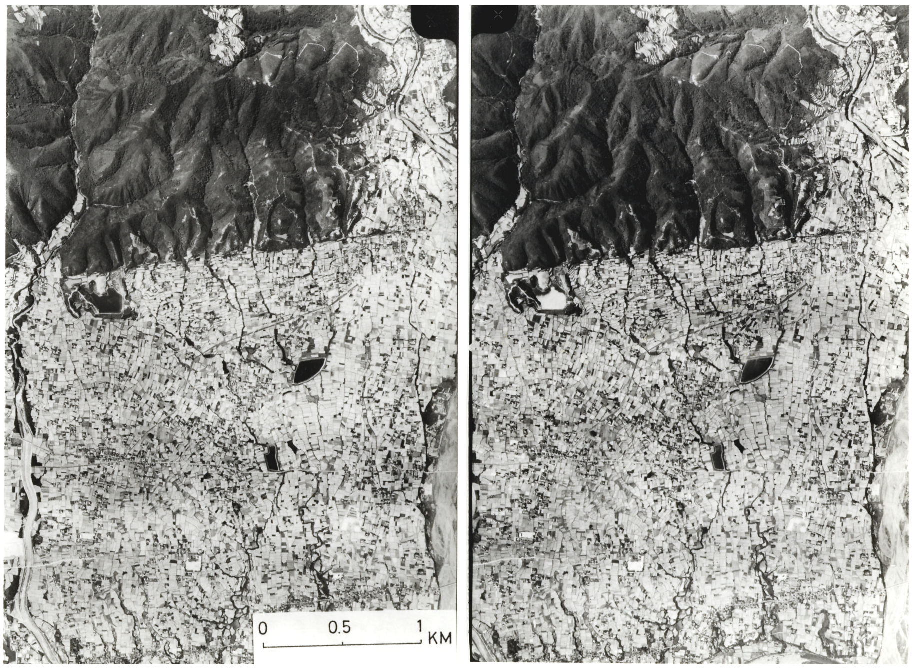


Fig.5-1 Fault topography between Ideguchi and Kamigirai Awa City, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

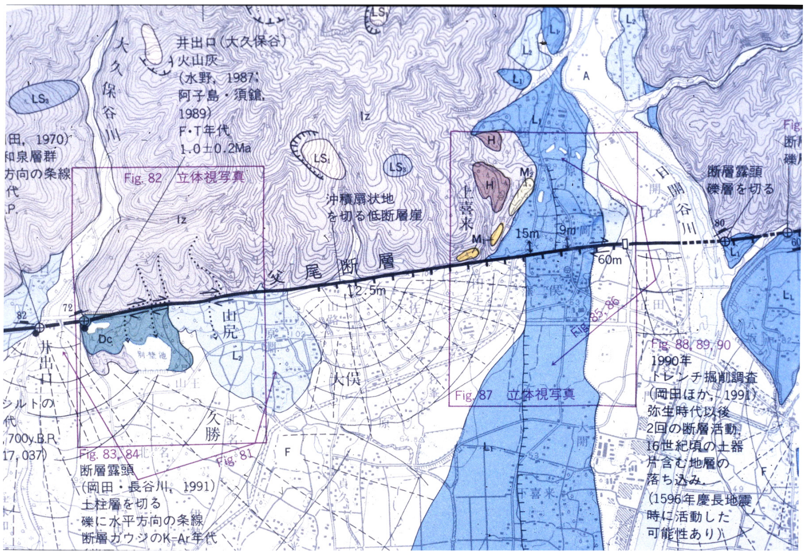


Fig. 5-2 Part of fault strip map (Mizuno and others, 1993), showing the location of Ideguchi to Kamigirai, Ichiba Town, Awa City, along the Chichio fault.

Fig.5-3 Oblique aerial photograph of fault scarp and fault outcrop along the Chichio fault, Awa City. View is to the northeast. Photo taken by A.Okada.

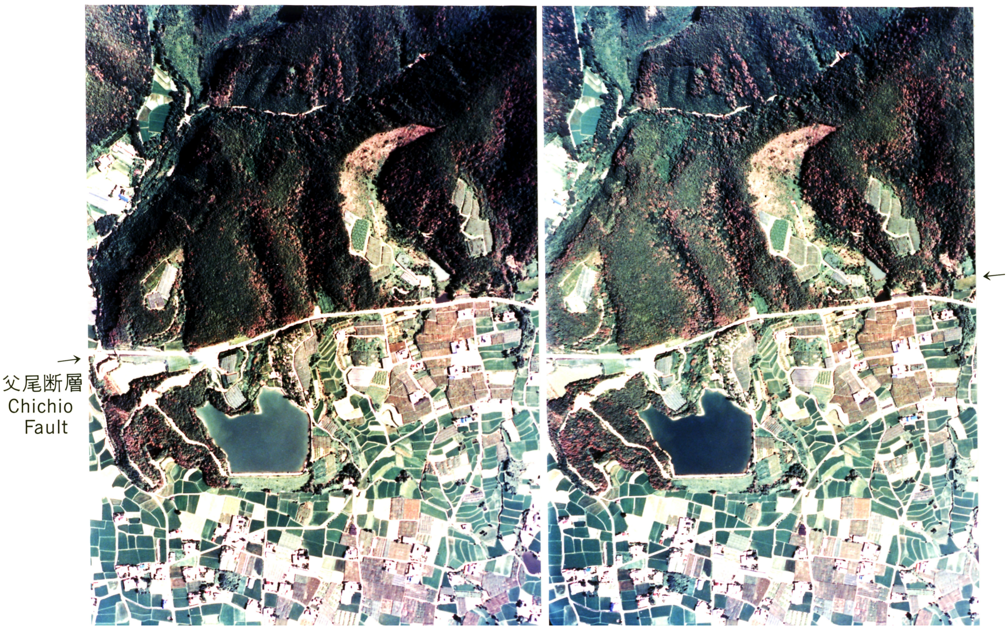


Fig.5-4 Right-laterally offset streams and fault notches at Ideguchi, Awa City, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

Fig.5-5 Fault outcrop at Ideguchi, Awa City, Tokushima Prefecture. Volcanic ash layer (ca. 1 Ma) dated by fission track method is visible on right upper corner. Gravels contain granitic rocks derived by Higaidani stream, about 2km east of this lolality, which indicates at least 2km right lateral cumulative displacement after deposition of this gravels.

Stop6-Fault scarp and offset terrace riser at Kamigirai,Town of Ichiba

Tectonic geomorphic features associated with right-lateral strike-slip faulting along the MTL is well expressed at Kamigirai, Town of Ichiba (Okada, 1970). Here the Chichio fault cuts late Quaternary fluvial terraces of the Higaidani River (Fig.6-1,Fig.6-2). Lower terrace (A and B in Fig.6-2) is offset 5 to 6 m up on the north along the Chichio fault. The age of this terrace is estimated at ~25 ka because the Aira-Tanzawa air fall ash (AT) with an estimated age 26 ~29 ka (Machida and Arai, 2003) is found within the terrace gravels immediately beneath the ground surface 1.5 km southeast of Kamigirai (Mizuno and others, 1993). The north-trending terrace riser between terraces A and C is offset 50 m right-laterally. The formation of this terrace riser is nearly contemporaneous with that of terrace C. Terrace C has not been directly dated but the age is estimated at ~10 ka based on difference in elevation between terraces A and C (5 m) and that between terrace C and the floodplain of the Higaidani River (2 to 3 m). These values give average horizontal

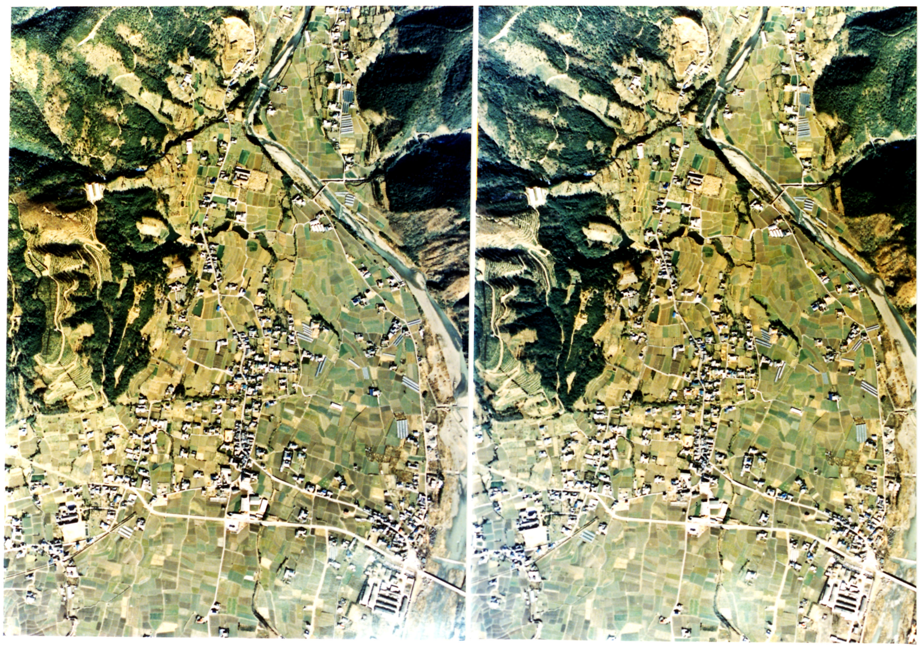


Fig.6-1 Fault scarp and right-laterally offset terrace riser along the Chichio fault at Kamigirai,Town of Ichiba, Tokushima Prefecture. Stereo-pair of aerial photographs by Geographical Survey Institute.

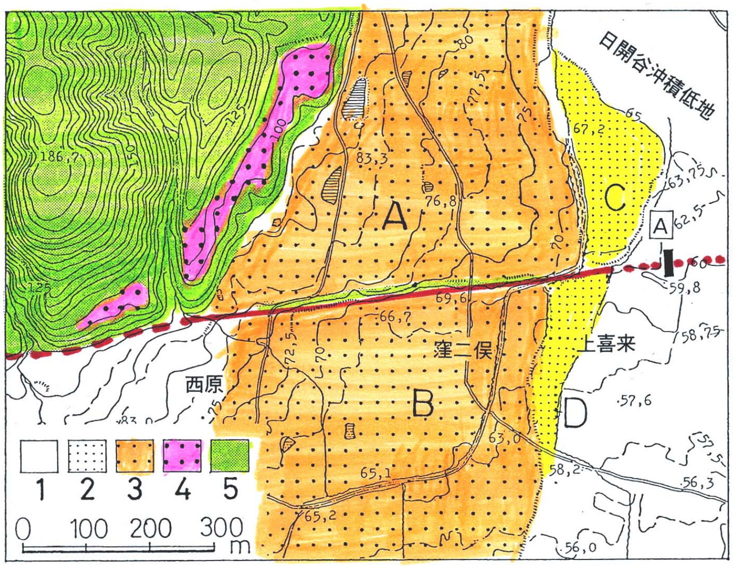


Fig.6-2 Geomorphic map around Kamigirai, Ichiba Town, Awa City. Contour interval is 5m. Black square is the trench site. Right lateral offset (ca 50m) of terrace riser and scarp height (10-20m) disturbing the lower terrace are shown on this map. Modified from A.Okada (1980).
Legend;1:Holocene alluvial plain, 2:lowest terrace, 3:low terrace, 4:middle terrace, 5:Cretaceous.

and vertical slip rates of 6 mm/14C yr and 0.5-0.6 mm/14C yr, respectively, for the Chichio fault (Okada, 1970).

Tsutsumi and Okada (1996) excavated multiple sites along the Chichio fault at Kamigirai to date late Holocene surface-rupturing earthquakes. A 4-m-deep trench excavated into floodplain sediments of the Higaidani River contains stratigraphic evidence for the most recent and penultimate earthquakes on the Chichio fault (Figure.6-2). The fault trace which ruptured during the most recent earthquake offsets all the sediments except for an artificially modified zone immediately below the ground surface. A V-shaped silty deposit near the top of the fault trace is interpreted as cultivated soil for rice farming which filled a coseismic fissure associated with the most recent earthquake. From this deposit, we obtained a pottery fragment which was identified as the mould of a Buddhist artifact used around the 16th century A.D. This age constrains the time of the most recent faulting on the Chichio fault to be during or after the 16th century A.D. This earthquake may be correlated to the 1596 Keicho-Kinki earthquake as was proposed by Ishibashi (1989). However, we cannot preclude the possibility that the Chichio fault ruptured during an earthquake separated from the 1596 event. Another fault trace farther south which does not propagate upsection as high as the fault trace during the most recent event suggests the penultimate earthquake(Fig.6-6). A radiocarbon age and pottery fragments of Yayoi age near the top of the fault trace suggest the time of the penultimate surface-rupturing earthquake at around 2,000 yr B.P.

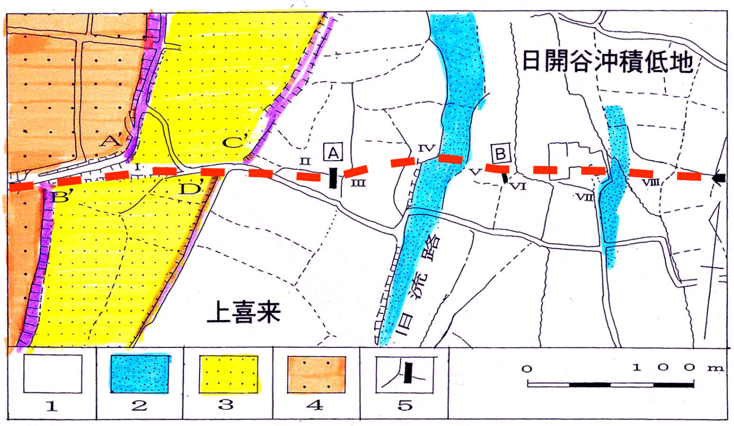


Fig.6-3 Detailed right lateral offset features along the Chichio fault at Kamigirai, Ichiba Town, Awa City. Terrace risers (A'-B',C'-D') and former stream channels are right laterally offset. Black square is the trench site. Modified from Tsutsumi and Okada (1998).
Legend;1:Holocene alluvial plain, 2:abandoned stream channel, 3:lowest terrace, 4:low terrace, 4:middle terrace, 5:trench site.

On the eastern projection of the faults exposed in the trench at Kamigirai, a series of rice paddy dikes are offset right-laterally approximately 7 m (Fig.6-3). A contact between gravels and sands exposed on a plan view during an archeological excavation prior to our trenching was also offset right-laterally approximately 6 m across the fault. These observations suggest that the surface displacement associated with

the most recent earthquake on the Chichio fault was 6-7 m. An empirical relation between surface displacement and magnitude for Japanese intraplate earthquakes (Matsuda, 1977) suggests that the most recent earthquake on the Chichio fault was at least a Mw >7.0 event.

Fig.6-4 Oblique aerial photograph of fault scarplet and right lateral offset of terrace riser along the Chichio fault at Kamigirai, Ichiba Town, Awa City. View is to the northwest. Photo taken by A.Okada.

Fig.6-5 Trench wall at Kamigirai site, Ichiba Town, Awa City. Gravel and sand layers are dislocated by recent movement by the Chichio fault. View is to the southeast. Photo taken by A.Okada.

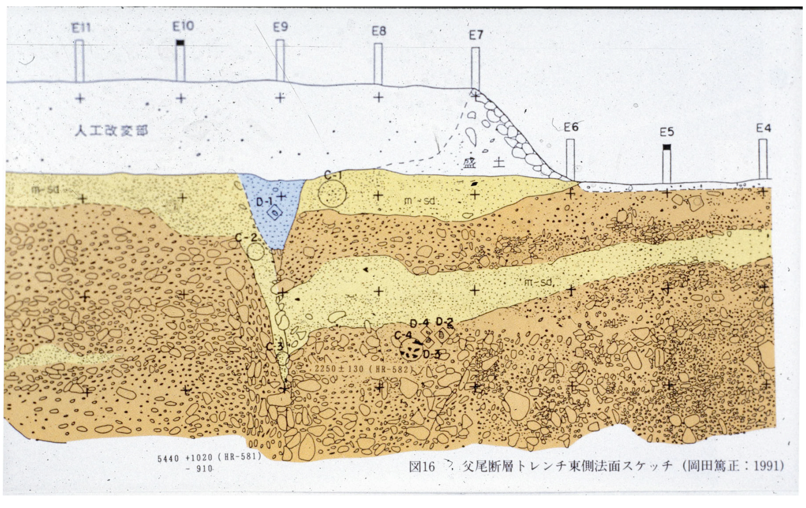


Fig.6-6 Sketch of exposure in the east-side trench wall at Kamigirai site, Ichiba Town, Awa City. Gravel and sand layers are dislocated by recent movement by the Chichio fault. Description is done by Tsutsumi and Okada (1996), Okada and Tsutsumi (1997).

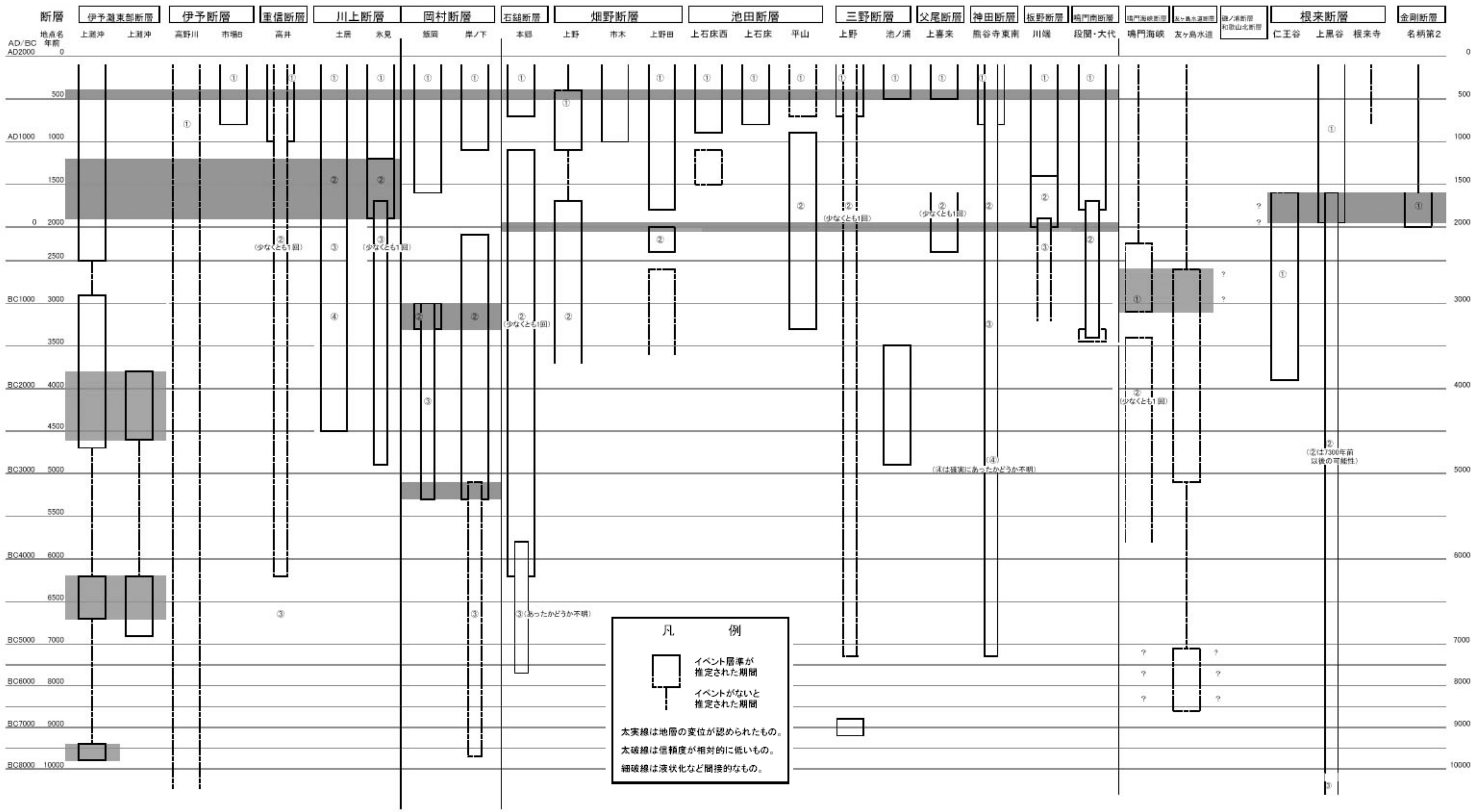


Fig.6-7 Time-space distribution of paleoseismic events estimated from trench excavation surveys, Compiled by Earthquake Research Committee(2004)

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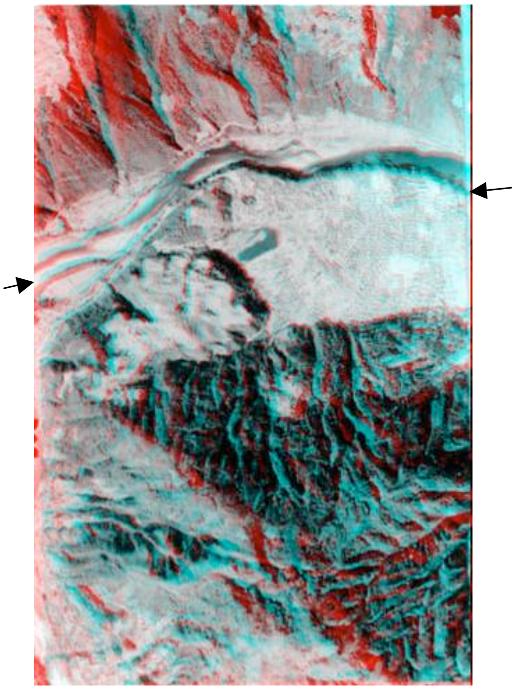
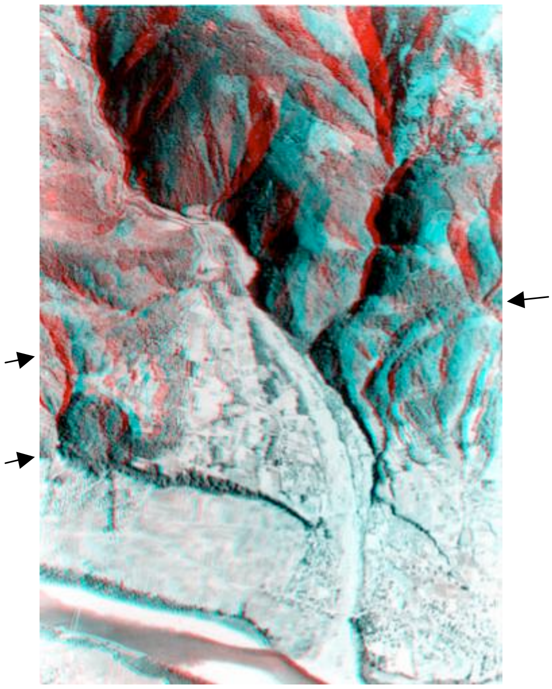
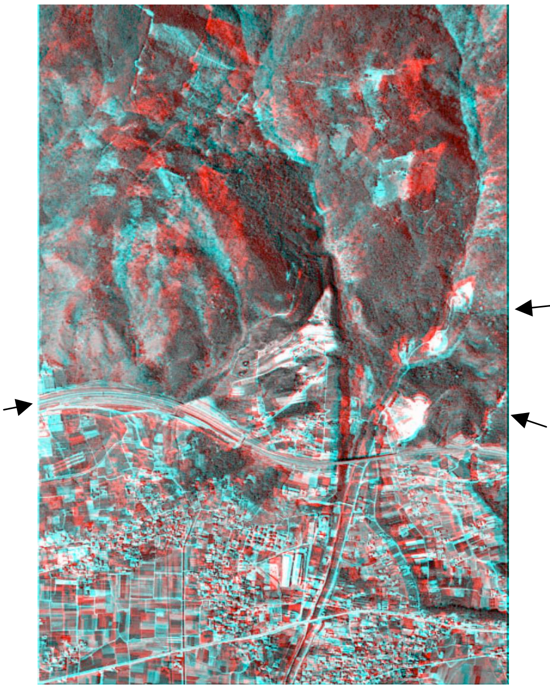
Anagram of Active faut along the Median tectonic Line　1



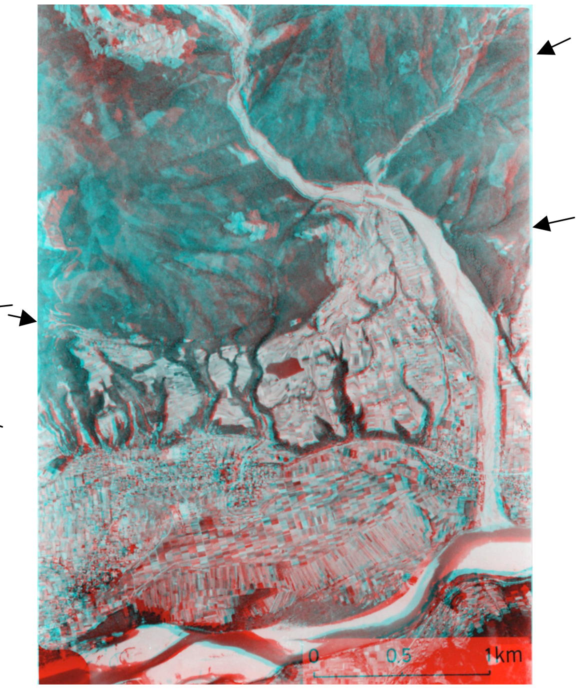
Stop 1　Fig1-1　Ikeda Fault



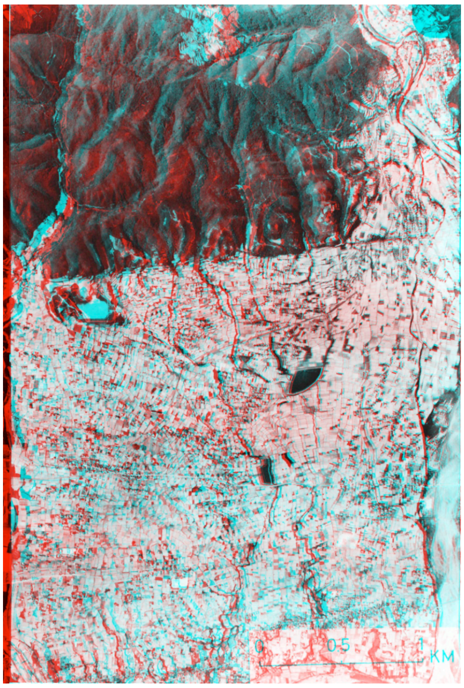
Stop 2　Fig2-1 Mino Fault



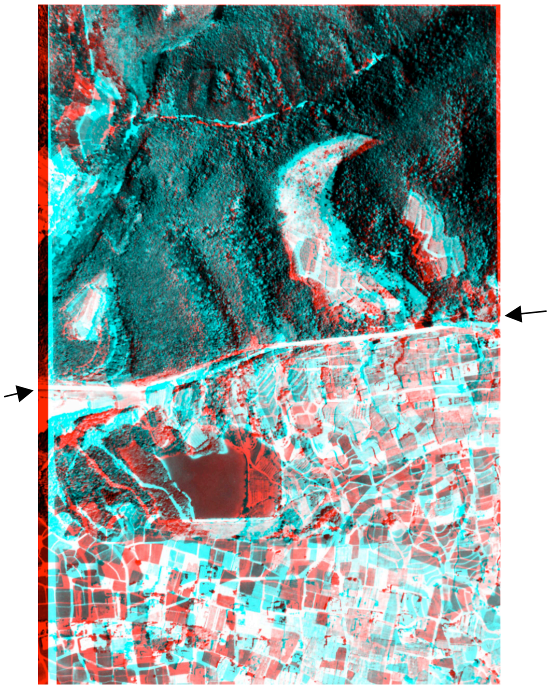
Stop 3　Fig3-1　Mino Fault (Upper)
Arakawa　Fault(Lower)



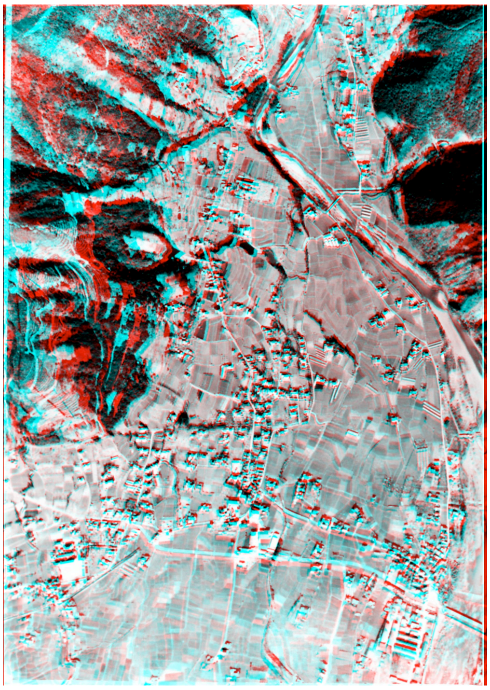
Stop 4　Fig4-1　Mino Fault (Left)
Ikuchi　Fault(Lower-right)



Stop 5 Fig5-1 Chichio Fault



Stop 5 Fig5-5 Chichio Fault



Stop 6 Fig6-1

Fault scap and offset terrace river