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Tectonics of a Plate Collision along the Northern Margin of Izu Peninsula, Central Japan

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Abstract: The northern tip of the oceanic Philippine Sea plate (PHS) is generally thought to have been colliding with the continental Eurasian plate (EUR) at the northern margin of Izu Peninsula (Izu Borderland), central Japan. Intense Quaternary crustal movement, such as active faulting with high slip-rate and rapid uplifting or subsiding, occurs along this inland plate boundary. Although this crustal movement seems to have close relationship with the convergence of the plates, the regional diversity of the tectonics along the boundary has not yet been studied so well as to reveal their characteristics in the framework of plate tectonics.

To clarify the significance of these regional Quaternary tectonics, the author described the faulting and related geological history in the following three subdivisions of the Izu Borderland: 1) the area to the north of Suruga Bay, 2) the area along the southern margin of Tanzawa Mts. and 3) Ashigara Plain-Oiso Hills areas. With respect to evaluating of the tectonics in each area, much attention was paid not only to the relative slip-rate of each active fault used in the previous works, but also to the absolute movement of each block divided by active faults.

Many features associated with Quaternary tectonics in and around the Izu Borderland were revealed. The Quaternary system in the studied area is classified into basin-fill type deposits (1a and 1b) and non-basin-fill type (2a and 2 b) according to their thickness, lithofacies and tectonic features. The study of the tectonic evolution in the Izu Borderland revealed two common features, i.e. 1) subsiding basins gradually turned into uplifting areas, 2) active faulting and subsiding migrated systematically towards Izu Peninsula through the Quaternary period. A circular evolution of the tectonics in the Izu Borderland was concluded from these geological and tectonic features. The process of this tectonic evolution is very similar to the growth of accretionary prism which is formed along the trench axis at the foot of continental slope associated with the plate subduction.

The Quaternary tectonics in most part of the Izu Borderland has been controlled not by a uniform plate collision but by buoyant subduction of the PHS under the EUR resulting in the development of the accretionary prism on land. On the other hand, intense regional uplift occurred along the southwestern margin of Tanzawa Mts. since the Middle Pleistocene with no conspicuous

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migration of faults and subsiding area. This feature is interpreted as a transformation of the formerly existing subduction to present-day collision. Many active faults with short length and high slip-rate around the Izu Borderland are interpreted as imbricated thrusts in the accretionary prism. Hence, the active faults in the plate boundary zone cannot be placed on the same level with the active faults in other inland regions.

1. INTRODUCTION

1.1 Problem settings and purposes of this study

The oceanic Philippine Sea plate (PHS) is underthrusting northwestward beneath the Eurasian plate (EUR) along Nankai trough off Southwest Japan. The direction of this plate boundary turns toward north on the west of Izu Peninsula and extends from Suruga trough through the subaerial region on the northern border of Izu Peninsula (Izu Borderland) to Sagami trough (Sugimura, 1972; Fig. 1). These areas constitute a part of the major tectonic province called the South Fossa Magna that comprises thick accumulation of Neogene sediments and volcanics. These rocks are strongly shortened and a northward curving fold zone is formed along the northern margin of Izu Peninsula (Matsuda, 1962). This structure has been caused by repeated subduction of the buoyant Izu-Ogasawara arc including Izu Peninsula, the volcanic arc in the eastern margin of the PHS, beneath the EUR (Sugimura, 1972; Matsuda, 1978).

On the other hand, many active faults with high slip-rate occur in the Izu Borderland as a result of strong shortening (Yamazaki, 1979). The term active fault denotes a fault having evidences of repeated fault movements in the present tectonic stress field and liable to be activated in the future. The author thinks that the active faults constitute a major basic element of the Quaternary tectonics in Japan, and configurations of active faults, their activity and history of faulting represent the actual condition and evolution of tectonic setting in this region. The intense activity and the strikes of these faults suggest that the fault movements have close relation to the plate convergence between the PHS and the EUR plates (Yamazaki, 1984). However, nothing is definite on the implication and role of each active fault in the setting of plate tectonics. Therefore, this paper first describes the history of faulting and of related crustal movement in the following three areas along the subaerial plate convergence boundary: 1) the area to the north of Suruga Bay including the southwestern foot of Mt. Fuji, 2) the southern end of the Tanzawa Mts., 3) Oiso Hills and Ashigara Plain area. As Izu block is migrating to the northwest, each area seems to show the various tectonic histories to correspond to the direction of convergence boundary. Then, based on these data, the author discusses the relationship between each active faults and plate tectonics through the comparison of the local tectonic evolution. Figure 2 is the index map of locality name used in this paper.

1.2 Significance and feature of this study

The study areas include the inferred hypocentral region of Suruga Bay for the future great Tokai earthquake (Ishibashi, 1981), and Sagami Bay for the west Kanagawa earthquake (Ishibashi, 1988 a,b). Study on the implication of active fault in the setting of plate tectonics will contribute to the progress of the effective earthquake prediction that was proposed by Ishibashi (1978).

The investigated area has a unique tectonic feature: the convergence boundary at the northern margin of the PHS crosses an island arc system continuing from Northeast Japan arc to Izu-Ogasawara arc, and the intersec-

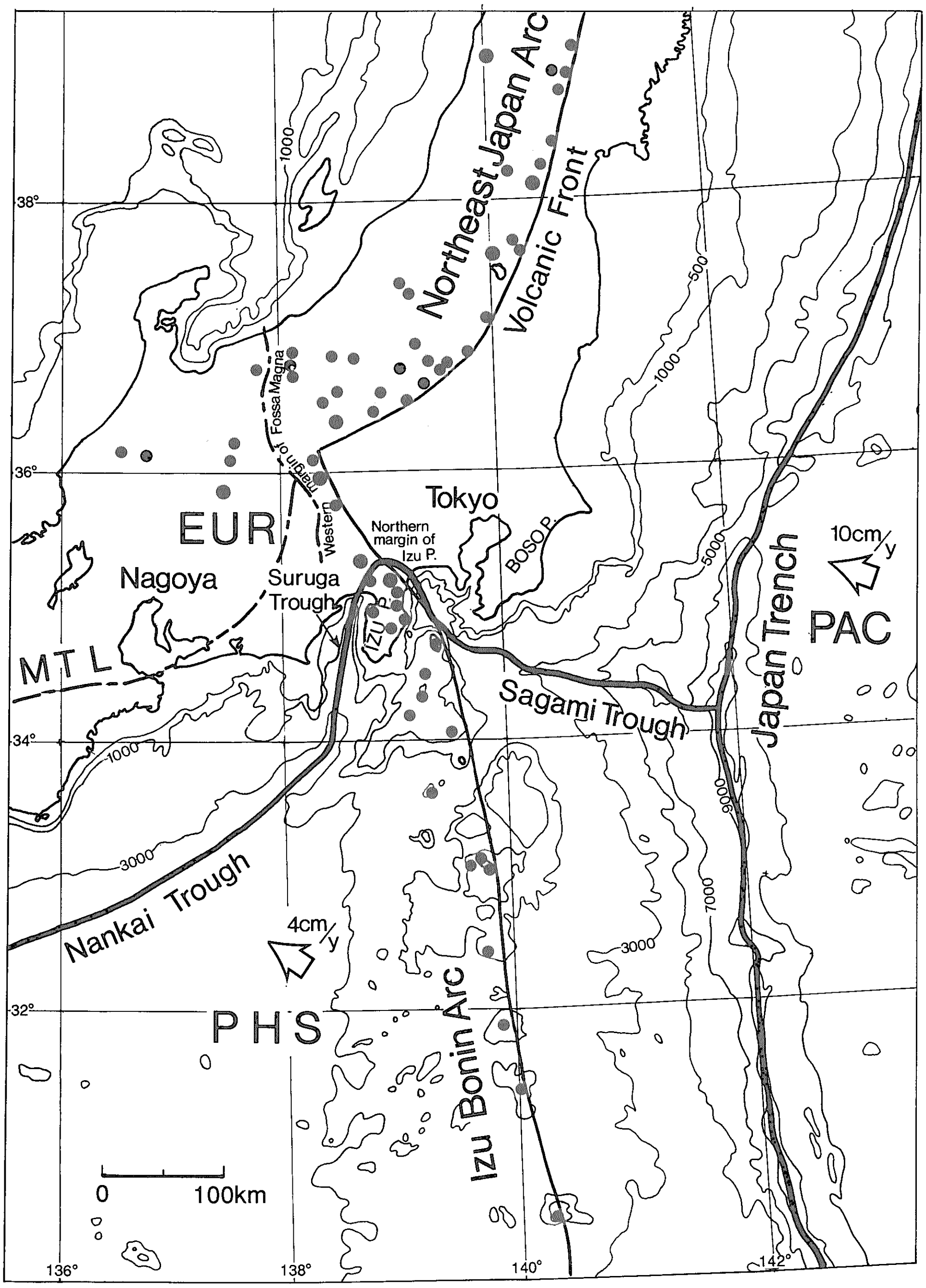


Fig. 1 Plate tectonic setting around Izu Peninsula, central Japan. Arrows show the direction of motion of the Pacific and Philippine Sea plate relative to the Eurasian plate. Filled circles indicate the Quaternary volcanoes. Bold lines represent the plate convergence boundary.

PAC: Pacific plate, PHS: Philippine Sea plate, EVR: Eurasian plate, MTL: Median Tectonic Line.

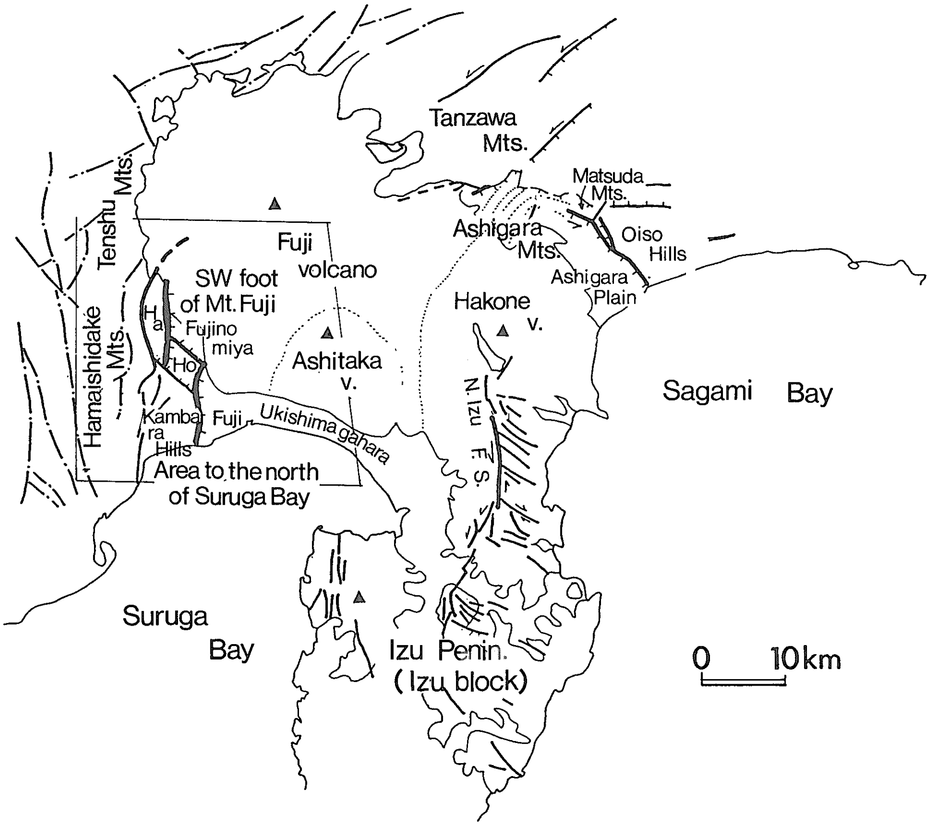


Fig. 2 Index map showing the geographical names in and around the study area. Bold-solid, bold-broken and fine-solid lines show the active faults, major geological faults and outline of the Quaternary volcanoes. Ha: Habuna Hills, Ho: Hoshiyama Hills.

tion part emerges in the subaerial area to the north of Izu Peninsula. As most of the convergence boundaries exist in the deep sea bottom such as trenches or troughs, the geological information is less reliable than that of in the subaerial area. Therefore the detailed data on geological history and tectonics of study area will provide the world's best analogue for the tectonic evolution of the submarine plate boundary.

In order to obtain the detailed information on the Quaternary geology and faulting in the study area, this paper introduces the following new idea. Previous studies on active faults have used the long-term slip-rate to evaluate their activity. This rate means the average rate of the relative slip of two blocks bounded by fault and indicates the

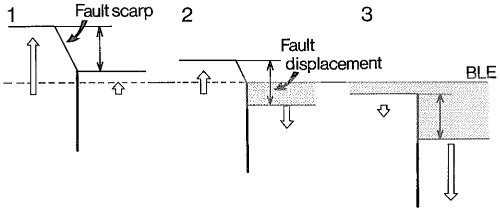


Fig. 3 Relationship between the formation of the fault scarp or tectonic landform and absolute crustal movement of each block divided by a fault. Arrows indicate the direction and rate of tectonic block. Dotted parts represent the fill sediments.
BLE: Base level of erosion

rate of crustal strain accumulated around the fault. The author, however, argues that the long-term slip-rate is not always adequate to interpret the evolution of tectonic landforms. For instance, as shown in Fig. 3, the tectonic landform caused by dip-slip faulting greatly varies with the motion of individual block bounded by fault toward the base level of erosion. If a faulting occurs in the subsiding area, most of the fault topography would soon be buried by basin fill sediments. The absolute rate of uplifting or subsiding on each faulted block seems to be a more important factor in the formation of tectonic landforms than the long-term slip-rate of the fault. Furthermore, the absolute crustal movement is fundamentally significant for the study of tectonic evolution in the plate convergence region where the behavior of crust changes from subsiding to uplifting in a short period. Therefore, to recoustruct the fault evolution, the author examines not only the relative displacement of fault, but also the absolute crustal movement deduced from the elevation of faulted surfaces, the thickness of the Quaternary sediments, their ages and paleoenvironment and so on.

2. PREVIOUS WORKS

2.1 Study on active faults in and around Izu Peninsula

In 1920's and 1930's, several investigations carried out in South Kanto and Izu Peninsula on crustal deformations associated with the great Kanto earthquake of 1923 and the Kita-Izu earthquake of 1930. These surveys depicted the outline of major active faults in these regions such as the Kozu-Matsuda fault and the Kita-Izu fault system. Yamasaki (1926) and Otuka (1929, 1930) estimated the existence of Kozu-Matsuda fault from a prominent straight scarp between the Oiso Hills and Ashigara Plain, and discussed the Quaternary tectonics in these areas. Although existence of the Tanna fault, a part of northern portion of the Kita-Izu faults system, had been known by the geological survey for a tunnel construction before 1930, investigations to trace the earthquake faults of 1930 by Ihara & Ishii (1932), Otuka (1933) and others revealed the cumulative tectonic features along the fault system. Particularly, Kuno (1936) pointed out that the Tanna fault had 1 km of total left-lateral displacement based on the length of valley offset and the distance of separated same lava flow.

In the late 1930's to early 1940's, the tectonic histories of the Iriyama thrust, the faults in southwestern foot of Mt. Fuji and the Kannawa fault at southern margine of the Tanzawa Mts. were described by Otuka (1984), Tsuya (1940) and Tsuya (1942) respectively based on the progress of stratigraphical and chronological studies on the Quaternary formation.

In the late 1960's, the active fault study has been introduced in the program of earthquake prediction as one of the national projects. By the end of 1970's, most of the major active faults in Japan have been discovered through fault survey using aerial photo-interpretation. In the study areas, the quantitative information on active faults, such as long-term slip-rate, vertical and lateral displacements of the fault, was accumulated by means of progress of tephrochronology and radiometric dating method. Machida & Moriyama (1968) reported geomorphic history around the Kozu-Matsuda fault. Matsushima & Imanaga (1968), Machida *et al.* (1975) and Kano *et al.* (1979) revealed the fault movement on the Kannawa fault in the middle to late Quaternary. Yamazaki (1979) revealed the fault behavior and the tectonic significance on the active faults in southwestern foot of Mt. Fuji. All these data obtained by 1980 were compiled in "Active faults in Japan" which is an inventory book on active faults in Japan by Research Group for Active Fault Japan (R.G.A.F.J.) (1980).

Since then, the active fault study in Japan branched off into two fields. One is the study on the detailed history of each fault movement during Holocene time. Many trenches were excavated across various faults to know the age of recent faulting and the recurrence interval that provide us useful information about the long-term earthquake prediction. Archaeological records and ancient manuscripts were also used to specify the age and locality of faulting that caused historical earthquakes. Another study is on the clarification of the implication of each active fault in the regional tectonics. With increase of the information on plate collision at Izu Borderland, Yamazaki (1984) and Ito *et al.* (1989) discussed the meaning of active faults in the framework of plate tectonics. This paper lies on the field of the latter.

2.2 Relationship between active faults and plate boundary

Sugimura (1972) first delineated that the plate boundary in the South Fossa Magna region extended from Suruga trough through the inland area to Sagami trough. He also thought that the buoyant Izu block on the PHS collided with the EUR at the northern margin of Izu Peninsula and northward migration of Izu block bent the plate boundary in an arc. The Kozu-Matsuda and Kannawa faults to the north of Izu Peninsula were thought to be the plate-boundary faults where the PHS directly contacted with the EUR.

However, as these faults had extraordinarily smaller slip-rate than the relative plate motion between the PHS and the EUR, it was unnatural to think that these faults represent directly the plate boundary. Ishibashi (1976) thought that the commencement of new subduction zone off the east coast of Izu Peninsula diminished the inter-plate convergence rate in Izu Borderland. According to this thought, some transform faults across Izu Peninsula are needed to connect Suruga trough with a new subduction zone. Therefore, he argued that the numerous NW-SE trending faults in the peninsula acted as the transform fault connecting the both subduction zones, and named the group of these faults as Izu transform belt. Ishibashi (1977) further suggested the possibility that the active fault along the new subduction zone caused periodically large earthquakes and moved coseismically at the event of 1923 great Kanto earthquake.

Contrary to this hypothesis, Somerville (1978) discussed that the crustal strain caused by plate collision was accommodated by the slip of intraplate faulting in Izu block. He argued that the subduction zone off the east coast of Izu Peninsula was not needed for the explanation of the decrease of interplate convergence rate at Izu Borderland.

Although the above mentioned hypothesis postulated that the active faulting in Izu Borderland directly represented the plate motion along the convergence boundary, Nakamura *et al.*(1984) proposed a new idea to classify the plate boundary into mechanical boundary zone and material boundary. They showed that the inland plate boundary in Izu Borderland, pointed out by Sugimura (1972), was the material boundary, and the mechanical boundary zone corresponded to the active faults zone to the north of material boundary.

Yamazaki (1984) investigated the history of fault movement and its tectonic feature along the mechanical boundary zone. He showed that the crustal evolution of this region was caused by the formation of accretionary prism associated with the plate subduction. He also pointed out that the active faults in this region corresponded to the imbricated thrusts in the accretionary prism.

Recently, Ishibashi (1988 a,b) reconstructed his original hypothesis and showed that the west Sagami bay fault was not a interplate fault at the subduction boundary but a kind of intraplate hinge fault bounding the buoyant inner arc from the subducting outer arc in the Izu-Ogasawara arc. He renamed the fracture zone as the west Sagami fracture zone (WSF). He warned the reactivation of WSF in the near future based on the fact that the periodical movement of the WSF had repeatedly damaged Odawara area every 70 years through the historical time.

2.3 Relative motion of the PHS toward the EUR

Many earth scientists in Japan supported the NW direction for the relative motion of the PHS toward the EUR along Nankai trough. However, two estimations: 1) N to NNW direction and 2) NW to WNW direction, were proposed for the motion of the PHS in Izu Borderland (Ishibashi, 1984). The former was derived from the studies on the geological history and landform evolution in the South Fossa Magna region (Kaizuka, 1975; Matsuda, 1978). The later was obtained from the plate motion model on the basis of the focal mechanism of great earthquakes along the plate boundary (Seno, 1977; Minster & Jordan, 1978, 1979). To solve this inconsistency, Nakamura & Shimazaki (1981) concluded that the PHS had moved toward north before 1 Ma, and then changed its direction to the northwest. Kaizuka (1984) showed many geological data to support this idea.

Seno (1985) tried to interpret the above mentioned inconsistency using the new hypothesis proposed by Nakamura (1983) and Kobayashi (1983) that northern Honshu is a portion of the North American plate (NAM) and migrating to the west. He considered that the migrating direction of the PHS changed from NNW to WNW at about 1.5 Ma, and then at 0.5 Ma the boundary between the EUR and NAM which originally run through the central Hokkaido, jumped to the eastern margin of Japan Sea and the central Japan. He thought that this jumping of plate boundary caused the westward migration of Northeast Japan as a portion of NAM. On the other hand, Ishibashi (1984) who shared the view point that Northeast Japan was a independent microplate, concluded that many phenomena on the tectonic evolution in late Neogene Japan, such as the different convergence direction between Nankai and Sagami trough, are interpreted consistently with the idea that the Southwest Japan commenced its eastward migration at about 1 to 2 Ma. Although this controversy remains inconclusive, recently Yamazaki (1988) and Maritime Safety Agency (1988) proposed a doubt for the existence of this new plate boundary along the eastern margin of Japan sea on which the both hypothesis are based.

Consequently, the author thinks that the interpretation of tectonic evolution in the Izu Borderland is indispensable to solve the problem of different direction of plate convergence between Nankai and Sagami troughs.

3. OUTLINE OF GEOLOGY

3.1 Setting in the plate tectonics

From the viewpoint of island arc system, Izu Borderland is a intersection between the East Japan island arc system (Sugimura & Uyeda, 1973) extending from Kuril Islands through Northeast Japan to Izu-Ogasawara islands and the plate convergence zone at the northern end of the PHS (Kaizuka, 1975). Izu-Ogasawara arc is divided into the non-volcanic outer arc and the volcanic inner arc by the volcanic front.

In and around Izu Peninsula, the N-S trending volcanic front runs in Sagami Bay. Izu-Ogasawara inner arc to the west of the volcanic front contains Mt. Fuji, Hakone, Amagi and some other Quaternary volcanoes in Izu Peninsula and Izu Borderland (Fig. 1). Because of this inner arc is made of relatively low density volcanic rocks, the crust is thicker than that of non-volcanic outer arc. Consequently, the subduction of the inner arc beneath the EUR becomes difficult and the convergence boundary is pushed northward. Therefore, Izu Borderland is a place subject to extreme crustal deformation.

3.2 Topographical and geological structure of the South Fossa Magna

The Izu Borderland constitutes a part of the Fossa Magna which is a huge depressed zone dividing the Japanese Islands into Southwest Japan and Northeast Japan. The Fossa Magna region is estimated to initiate its deformation in the middle Early Miocene to early Middle Miocene (Kato,1992). The thick accumulation of Neogene Tertiary and Quaternary volcanics fill the depression of the pre-Neogene rocks. The Fossa Magna is divided into two sedimentary basins, i.e. the North and South Fossa Magna, by the rise of the Central Upheaval Zone in the central part. Izu Peninsula and Izu Borderland constitute some portion of the South Fossa Magna. In and around Izu Peninsula, the South Fossa Magna is divided mainly into two tectonic provinces; 1) the stable Izu Peninsula (Izu block) consisting of the Tertiary and Quaternary volcanics and 2) the extra peninsula folded belt (the South Fossa Magna folded belt) consisting of sedimentary rocks and volcanics since the Miocene time (Matsuda, 1962).

The Izu block consists mainly of the Yugashima Group (Lower to Middle Miocene) and the Shirahama Group (Upper Miocene to Lower Pliocene) underlying Quaternary volcanics. Shirahama Group (11 to 8 Ma in age) yielded the Foraminiferum *Lepidocyclina* (*Nephrolepidina*) *japonica* of which has not been found in the contemporaneous Tertiary rocks of Japanese islands except for Izu Peninsula (Saito, 1963). *Lepidocyclina* has lived in tropical shallow waters indicating that the Izu block comprised a number of volcanic islands situated to the south of Japanese Islands at the late Miocene (Ibaraki, 1981). The Miocene sediments in this Peninsula do not show any large scale deformations caused by faulting, folding or uplifting. The topographic relief exceeding 1,000 m in Izu Peninsula has made by the growth of Quaternary volcanoes.

On the other hand, many steep mountains such as the Misaka, Tenshu and Tanzawa Mts. lie on the South Fossa Magna folded belt in consequence of vigorous uplifting. This folded zone consists of the Tanzawa, Koma and Nishi-Yatsushiro Groups of the lower to middle Miocene and the Fujigawa, Nishi-Katsura, Aikawa and Ashigara Groups of the upper Miocene to Pleistocene (Matsuda, 1958). The former is mainly marine deposits interbedded with volcanic materials and their thickness exceeds 1,000 m. The latter is sedimentary rocks composed of thick mudstones and conglomerates. Their sedimentary facies and structure indicate that some of them were the subsiding trough fill sediments (Ito, 1985; Amano *et al.*, 1986). These rocks experienced the most extreme shortening of more than 20 km in Tertiary formations of the Japanese Islands (Matsuda, 1962, 1984). The folded structure extends around the Izu block with a strong convexity towards the north. In the folded belt, the lower to middle Miocene crops out in the portion of anticlinal axis and the upper Miocene to Pliocene fills the synclinal portion (Matsuda, 1962).

These geological structure indicates that the South Fossa Magna folded belt is the locus of collision and accretion of the buoyant crust, such as Izu block, towards the EUR. The formation of subductive trough between the PHS and the EUR plates has been repeated through the Neogene period (Matsuda, 1978; Amano *et al.*, 1986). The active faults in this region extend along the southern margin of the South Fossa Magna folded belt to surround the northern margin of Izu Peninsula.

4. ACTIVE FAULTS AND CRUSTAL DEFORMATIONS IN THE AREA TO THE NORTH OF SURUGA BAY

4.1 Outline

The geological and topographical structure in the area to the north of Suruga Bay is characterized by a N-S trending zonal structure as shown in Fig. 4. Two N-S trending fault systems with W-upthrow divide the region into three blocks. The east fault system is composed of the Iriyamase, Omiya and Agoyama faults. They consist the geological and topographical boundary between alluvial lowlands of Fuji and Fujinomiya in the east, and the Kambara, Habuna and Hoshiyama Hills in the west. The west one consists of the N-S trending Iriyama and Shibakawa thrusts and divides the area into

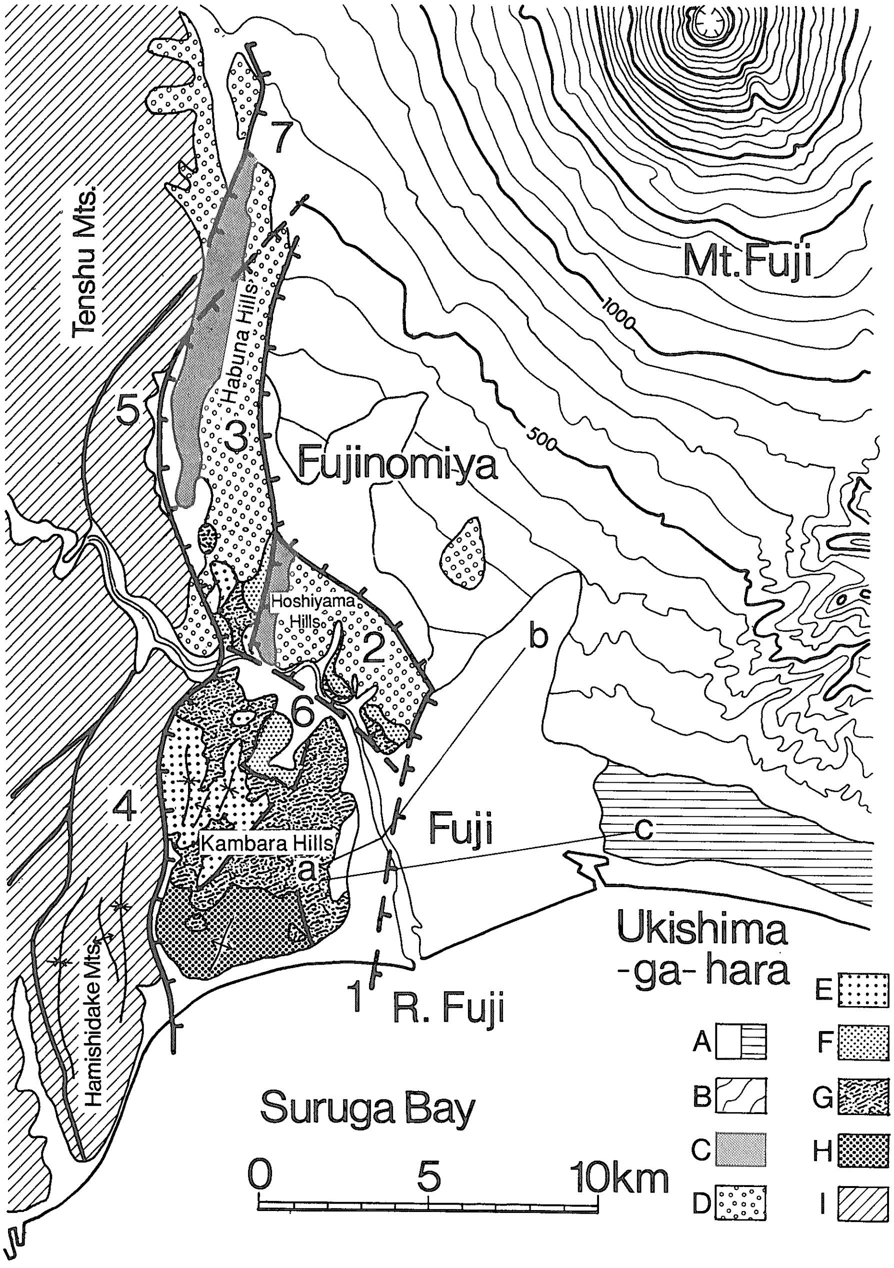


Fig. 4 Geologic sketch map of the inland area to the north of Suruga Bay. Geological sections are shown in Fig. 8. Bold and bold-broken lines indicate the active faults. Fault name: 1.Iriyamase fault, 2.Omiya fault, 3.Agoyama fault, 4.Iriyama fault, 5. Shibakawa fault, 6.Matsuno fault, 7.Noshita fault. Legend: A. Alluvial fan and backmarsh (parallel lines). B. Volcanic slope of Mt. Fuji. C. Lava flows from Mt. Fuji. D. Older Fuji mudflow deposits. E. Saginota gravels in the Middle Pleistocene. F. Bessho gravels in the lower Pleistocene. G. Iwabuchi andesite. H. Kambara conglomerate in the early Pleistocene. I. Tertiary rocks.

hills to the east and Hamaishi-dake and Tenshu Mts. to the west.

4.2 Tectonic evolution of each faulted block

(1) Hamaishi-dake and Tenshu Mountains

The Hamaishi-dake and Tenshu Mts. situated on the western margin of study area are steep and dissected mountains ranging in altitude from 500 to 1,300 meters. These two mountains are composed of the upper Fujigawa Group of the Pliocene, which consists mainly of conglomerate and sandstone with a maximum thickness of more than 4,000 m. Fujigawa Group is the thick fill deposits of the ancient trough located at the Pliocene plate boundary to the south of the Kanto and Misaka Mts. This subsided trough has changed to uplifting area since the beginning of the Pleistocene (Matsuda,1984).

(2) Kambara, Habuna and Hoshiyama Hills

The Kambara, Habuna and Hoshiyama Hills, located to the east of the mountains, are bounded on west and east by the Iriyama-Shibakawa thrust system and the Iriyamase-Omiya-Agoyama fault system respectively.

a. Kambara Hills: The Kambara Hills, located in the southwestern side of River Fuji, is a dissected hilly area 400-500 meters in altitude without flat surfaces on it. The geology of these hills consists mostly of the lower Pleistocene Kambara conglomerate, Iwabuchi andesite and middle Pleistocene Saginota gravels which uncomfortably rest on the former two formations (Table 1, Fig. 4). These Quaternary units have been vertically displaced by the reverse faulting at both margins of the hills and also have undergone small scale deformation caused by faulting and folding in the hills (Sugiyama & Shimokawa, 1982). Due to the recent uplift, a narrow Holocene terrace has been formed on the eastern margin of the hills.

The Kambara conglomerate (Konno & Otuka, 1933), extensively distributed in the southern Kambara Hills, consists mostly of 600 m thick pebbly gravels with sand-enriched matrix. The relatively monotonous facies despite the large thickness of this formation indicates that the Kambara conglomerate is fluvial and shallow water deposits originally accumulated in the subsiding depression such as the place on the northern border of present Suruga trough.

The Iwabuchi andesite (Otuka, 1938), remains of the early Pleistocene volcano, is composed mainly of tuff breccia and lavas and encloses a series of sedimentary beds correlated with the Bessho gravels in the

Table 1 Quaternary stratigraphy of the area to the north of Suruga bay.

Geological Age		Kambara Hills (Sugiyama & Shimokawa,1982)	Habuna-Hoshiyama Hills
Holocene		Alluvium	Alluvium
		Iwabuchi terrace deposit	
Pleistocene	Late	Fuji lava flows	Younger Fuji lava flows
			Older Fuji mudflows
	Middle	Saginota gravels	Saginota gravels
	Early	Iwabuchi andesite	Iwabuchi andesite
		Sediments	Bessho gravels
			Iwabuchi andesite
		Kambara conglomerate	
Pliocene		Fujikawa Group	Fujikawa Group

——— Conformity
– – – – Unconformity

Habuna and Hoshiyama Hills. This formation overlies the Kambara conglomerate conformably and underlies the middle Pleistocene Saginota gravels unconformably. The age of this volcano is estimated to be the Matuyama reversed magnetic epoch in the early Pleistocene from the reversed magnetization of lava blocks obtained from the upper part of the formation.

The Saginota gravels (Konno & Otuka, 1933) are fluvial fan deposits of 200 m in thickness distributed in the western half of Kambara Hills and in the southern Habuna Hills. The age is estimated to be 0.4 to 0.5 Ma on the basis of yielding of *Stegodon Orientalis* and the occurrence of widespread vitric ash which is potentially correlated to Ks-10 ash in the middle Pleistocene Kazusa Group, Boso Peninsula (Machida *et al.*, 1980).

The Iwabuchi terrace of 30 to 40 m in altitude, on the eastern margin of Kambara Hills, is an uplifted Holocene terrace composed of coarse fluvial and fine brackish water sediments. Akahoya ash (Ah) erupted in Southern Kyushu at 6,300 years ago was found in the brackish water sediment at 13.7 m in height (Yamazaki *et al.*, 1981). These facts indicate that 1) Iwabuchi terrace is a filltop terrace created by the postglacial transgression, and 2) assuming the paleo-sea level of 6,000 years ago was about 2 m above the present one, the eastern margin of Kambara Hills was uplifted 11.7 m at a rate of 1.9 m/10^3 years since after the fall of Ah ash.

The following geological evolution of the Kambara Hills is obtained from the above mentioned stratigraphical data.

In the early Pleistocene, the Kambara conglomerate accumulated thickly in the subsided depression similar to present bottom of Suruga trough. The activity of Iwabuchi volcano has also occurred in the depression following the deposition of Kambara conglomerate and a thick series of andesitic lavas and agglomerate has consequently accumulated. In the early Middle Pleistocene, the Saginota gravels overspread the present Kambara Hills and its adjacent area as fluvial deposits. Then, subsiding of these areas gradually changed into uplifting. As a result of the change, the Saginota gravels emerged and the erosional process began in the Kambara Hills area.

b. Habuna-Hoshiyama Hills : The Habuna and Hoshiyama Hills ranging in altitude from 100 to 300 m, in the northeast bank of River Fuji, are bounded by the Iriyamase, Omiya, Agoyama and Shibakawa faults. The gentle inclination of depositional surfaces preserved well on both hills indicate that the Habuna and Hoshiyama Hills were tilted to the west and to the north, respectively. The geology of these hills consists of Iwabuchi andesite intercalating with the thick Bessho gravels, the late Pleistocene Older Fuji mudflow units and several sheets of Younger Fuji lavas in the late Pleistocene to Holocene.

Hitherto, the Bessho gravels extensively distributed in both hills were assumed to be equivalent to the Saginota gravels in the Kambara Hills because the Bessho gravels seemed to overlie the agglomerate of Iwabuchi andesite unconformably at several outcrops along the River Fuji (Tsuya, 1940; Otuka, 1938). But this study has confirmed that the Bessho gravels can be classified into two formations; upper formation which is relative to the Saginota gravels in the Kambara Hills and lower one enclosed in Iwabuchi andesite.

The former, gravels of 200 m in thickness, occupies the southern Habuna Hills with N-S or NE-SW strike and E dip. The mud layer bearing abundant plant fossils at the base of upper formation intercalates with a thin glassy marker tephra identical with the ash layer in Saginota gravels. The Saginota gravels in the Habuna Hills have undergone more intense deformation than those in the Kambara Hills. This fact implies the existence of a fault (the Matsuno fault) running through between two hills along the River Fuji.

The latter formation (Bessho gravels)

extensively distributed in the Habuna and Hoshiyama Hills is composed of totally more than 1000m thick and well stratified cobble-pebble-sized layers intercalated with thin sand beds. The extremely large thickness and monotonous facies of this formation suggest that the Bessho gravels are resulted by the accumulation of coarse sediments in a continuous depression. They were transpoted from Misaka Mts. by the Paleo-River Fuji. The geological structure of the Bessho gravels is different largely between that of the Habuna Hills with NW-SE strike, SW dip of 40 to 60 degrees and of the Hoshiyama Hills with NW-SE strike, NE dip of 30 to 50 degrees. This fact also indicates that the Agoyama fault has commenced its activity after the accumulation of Bessho gravels traversing its sedimentary basin, and consequently the blocks on either side of the fault have developed different tilting from each other. As there has not been observed any erosional surface on the contact between the Iwabuchi andesite and the underlying mud layer top of Kambara conglomerate (Sugiyama & Shimokawa, 1982), the Bessho gravels and the Kambara conglomerate are assumed to have accumulated in a series of subsiding basin. The thickness of Bessho gravels is increasing toward the north indicating that the center of subsidence has migrated to the north during early Pleistocene.

The Older Fuji mudflows in the late Pleistocene (Tsuya, 1968 ; Agglomeratic mudflows of Tsuya, 1940) are composed mainly of original mudflow deposits derived from Older Fuji volcano, their secondary deposits and alluvial fan gravels at volcanic foot. As the depositional surfaces of these mudflows are well preserved on both hills, they can subdivide into several units through the

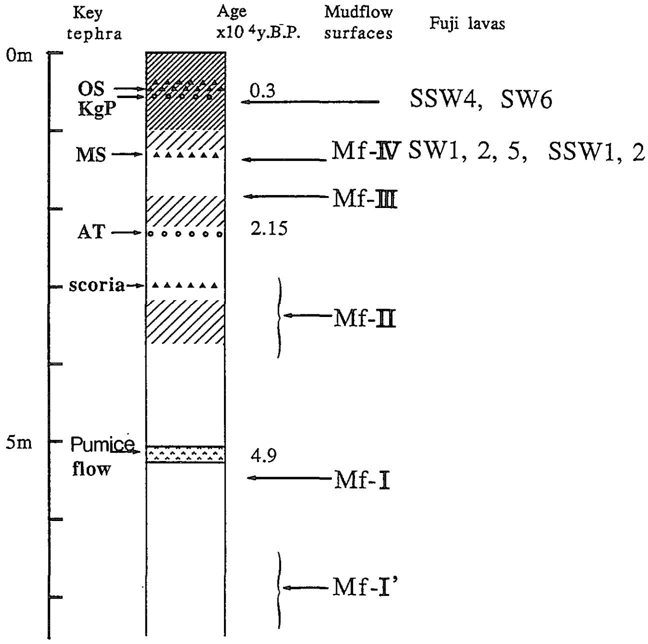


Fig. 5 Tephrochronology of lava and mudflow deposits in the area of southern foot of Mt. Fuji. OS : Osawa scoria, KgP : Kawagodaira pumice, MS : Murayama scoria, AT : Aira-Tn ash, Pumice flow : Hakone younger pyroclastic flow, Mf-I' to Mf-IV represent the depositional surfaces of the Older Fuji mudflow. Filled triangles, open circles and oblique lines in the columnar section indicate the scoria layer, pumice or vitric ash layer and humic soil respectively.

chronological survey of the surfaces. Machida (1977) divides the mudflows into older and younger units on the basis of thickness of the covering tephra. Yamazaki (1979) and Yamazaki *et al.*, (1981) also studied the stratigraphy of tephra and distinguished five surfaces on the mudflow deposits (Figs.5, 6). These surfaces contain several depositional surfaces of original mudflows from the older Fuji volcano and fluvial surfaces of tributary flow of the River Fuji.

These numerous surfaces have been form-

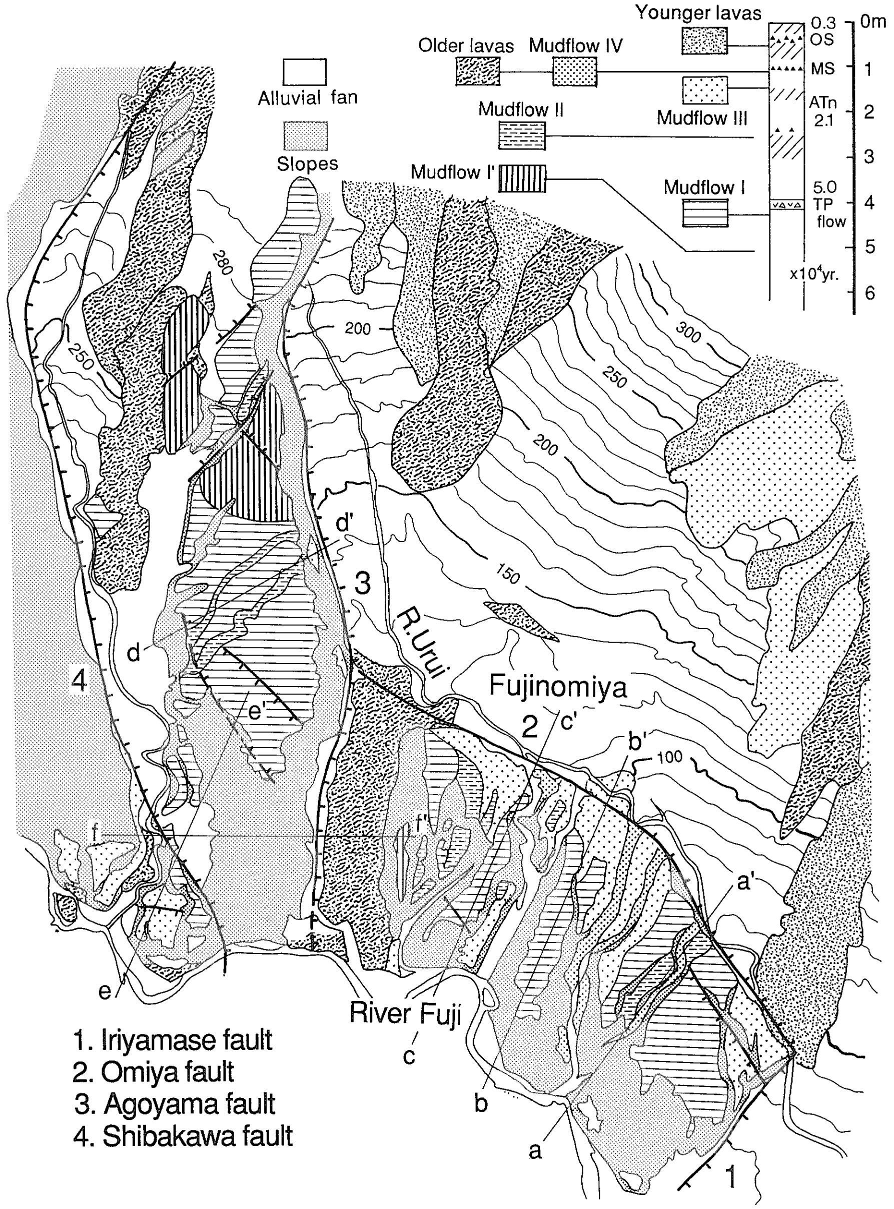


Fig. 6 Geomorphological map of Hoshiyama and Habuna Hills. Older Fuji mudflow deposits can be divided into five units based on the tephrochronology. Columnar section corresponds to that in Fig. 5

ed by the intermittent uplifting of two hills, caused by faulting along the eastern margin of the hills system. But the distribution pattern of mudflow surfaces shows the regional characteristics, that is, the surfaces older than 50,000 years ago (Mf-I and I') develop well on the Habuna Hills, while younger surfaces, especially the surface of 20,000 years ago (Mf-III) extend over the Hoshiyama Hills. This contrast is due to a relatively higher uplifting rate and earlier emergence of the Habuna Hills than those of the Hoshiyama Hills. Each of surfaces on the Hoshiyama Hills extends from north to south in direction with narrow width. The younger Fuji lavas (SSW 2, SW5) erupted about 10,000 years ago flew over the hills and reached River Fuji. Although Tsuya (1940) assumed that these lavas have not been displaced by Omiya fault at the eastern margin of the hills, the large gap of lava height, exceeding 50 m, between Fujinomiya Basin and Hoshiyama Hills indicates that the Omiya fault has vertically displaced these lavas.

Above data lead to the following conclusion on geological evolution of the Habuna and Hoshiyama Hills. The Habuna and Hoshiyama Hills were a place intensely subsiding where the thick Bessho gravels had accumulated during early Pleistocene time. In the Middle Pleistocene, this area was still subsiding contemporaneously with the accumulation of Saginota gravels. But around 80,000 years ago when older Fuji volcano commenced its activity, the crustal movement in this area had gradually changed from subsidence into uplift. Since 50,000 yr B.P., though both hills have undergone the same significant uplifting, the difference of distribution pattern of mudflow surfaces became prominent between two hills due to the difference of tilting direction.

(3) Fuji-Fujinomiya lowland

Fuji-Fujinomiya lowland, located in the northern extension of axis of Suruga trough and extending over the east side of Habuna and Hoshiyama Hills, is composed of the Fujigawa alluvial fan, Ukishimagahara swamp on the southern flank of Mt. Ashitaka and Fujinomiya basin.

a. Fujigawa alluvial fan: Thick fluvial gravels transported from the Misaka and Akaishi Mts. by the River Fuji are the constituent material of this fan. These gravels intercalate the SSW 1 lava of Fuji volcano with the radiocarbon age of 14,000 yr B.P. (Yamazaki, *et al.*, 1981). The maximum depth of this lava reaches up to -140 m at the mouth of River Fuji (Murashita, 1977).

b. Ukishimagahara: Ukishimagahara is a lagoon formed by the continual subduction and the formation of barrier along the southern flank of Mt. Ashitaka. The marker tephra of KgP (2,900 yr B.P.) and K-Ah ash (6,300 yr B.P.) were found in this lagoon sediments at depth of -6 m and -17.8 m respectively (Yamazaki *et al.*, 1981). The depth of these tephras approximately indicates the subsidence of Ukishimagahara since after the deposition of these tephras because the sea level has been relatively stable during last 6,000 years. The mean subsiding rate is estimated to be 2 m/10^3 years since the KgP age and to be 3 m/10^3 years since the Ah ash age. Figure 7 shows the relationship between the altitude of sampled peats in the lagoon sediments and their radiocarbon age.

c. Fujinomiya basin: This basin is a fault angle depression formed on the southwestern foot of Fuji volcano. A 300 m drilling revealed that this basin was composed of thick Holocene Fuji lavas and Older Fuji mudflows younger than 80,000 years ago. The bottom of drilled core did not reach the Bessho gravels underlying Older Fuji mudflows (Yamazaki *et al.*, 1981). This fact indicates that Fujinomiya basin has undergone intense subsiding at a rate of 2 to 3 m/10^3 years since the late Pleistocene.

4.3 Movement of active faults

(1) Iriyamase-Omiya-Agoyama fault system

This fault system divides the region into subsiding lowland to the east and uplifting

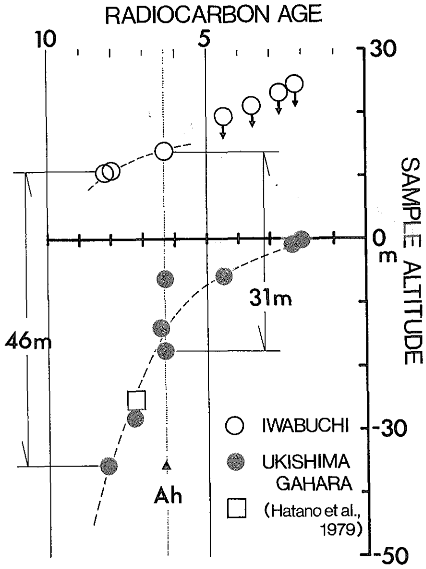


Fig. 7 Comparison of the sample heights and their ages between two drillings on the both sides of the Iriyamase fault.

hilly land to the west. This system extends from the mouth of River Fuji to the north and disappears into the younger lava field. The Iriyamase and Agoyama faults in this system are reverse faults showing a sinistral en echelon configuration. The Omiya fault is a normal fault connecting the Iriyamase and Agoyama faults (Fig. 4).

a. Iriyamase fault (Tsuya, 1940): This fault, bounding the eastern margin of Kambara and Hoshiyama Hills, is a thrust having the W part upthrown, and extends from the mouth of River Fuji to the north. Southern extension of the fault is also assumed to continue to the submarine active fault along the base of western slope of Suruga trough.

Although no tectonic landform is found on the surface of Fujikawa alluvial fan, the late Pleistocene to Holocene sediments beneath the fan are vertically displaced by faulting. Comparing the displacement reference horizons (DRH) on both sides of the fault, less than 100 m, 46 m and 31.5 m of the west-side upthrown are recognized for SSW 1 lava of 14,000 years ago, peaty layers of 8,000 years ago and Ah ash fall respectively (Fig. 8). The long-term slip-rate of the fault derived from these data is estimated to be constant with a value of 7 to 5 m/10^3 years during Holocene time. This is the largest value of vertical slip rate of the active faults in the land of Japan.

At the event of the Ansei-Tokai earthquake that occurred in Suruga trough in 1854, a small mound called "Jishinyama" (earthquake mound) appeared on the flood plain near the mouth of River Fuji (Omori, 1919). Judging from the fact that a vast area of cultivated land was developed to the west of the mound after the earthquake, it is concluded that the formation of "Jishinyama" is not a small local event but a tectonic landform accompanied with extensive uplifting of the western side of the Iriyamase fault. This means that the southern segment of Iriyamase fault has moved at the Ansei-Tokai earthquake of 1854.

SSW 1 lava of 14,000 yr B.P. outcrops to the west of the Iriyamase fault. This lava seems to have deposited on the river floor because it rests directly on the flood loam. Assuming that the sea level of 14,000 yr B.P. was 50 to 60 m lower than present level and the height of the outcrop above sea level at that time was the same as the present value (+15m), the original altitude of this lava might be −35 to −45 m. Consequently, the western block of the Iriyamase fault has been uplifted 50 to 60 m at a rate of 3.5 to 4.4 m/10^3 years since the deposition of SSW 1 lava, and the eastern block has subsided 55 to 45 m with the rate of 3.3 to 3.9 m/10^3 years.

Table. 2 shows the relative slip rate of the faults and the absolute rates of block movement which were obtained from the heights of several DRH and the heights of sea level when DRH were deposited.

b. Omiya fault (Tsuya, 1940; Yamazaki, 1979): Tsuya (1940) inferred the existence of an arcuate fault along the eastern margin of Habuna and Hoshiyama Hills and named it the Omiya fault. Suzuki (1968) estimated that the Omiya fault was a part of normal ring fault surrounding Mt. Fuji, caused by the

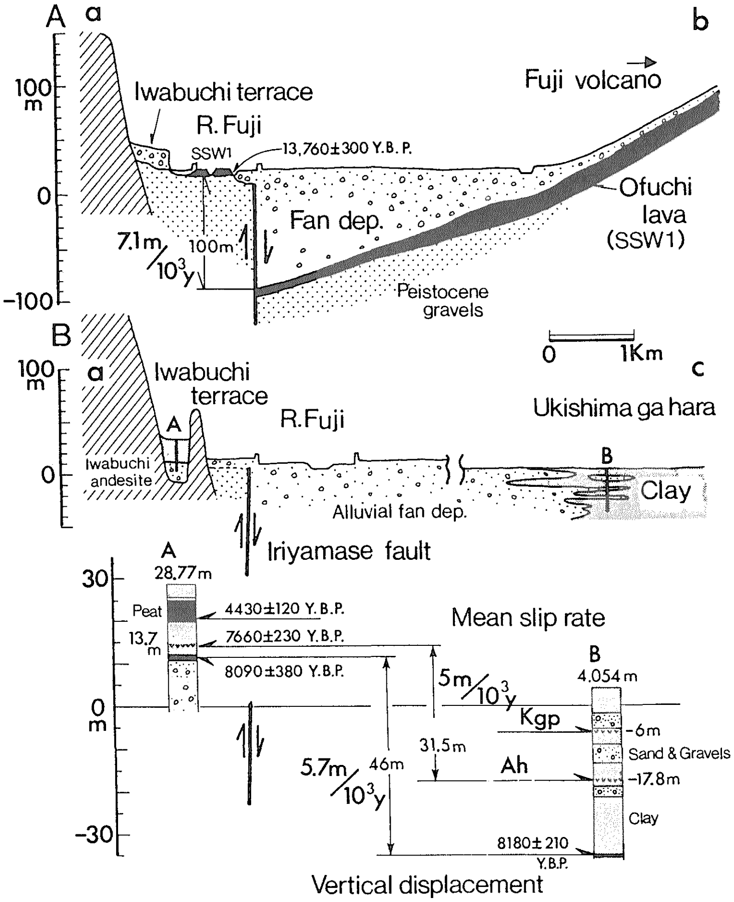


Fig. 8 Displacement of the Holocene sediment and the Fuji lava by the Iriyamase fault in the lower part of River Fuji.
A: Displacement of Ofuchi lava (SSW1). B : Displacement of the Holocene transgression sediment. Section lines correspond to those in Fig. 4

Table 2 Block movement on the each side of the Iriyamase and Kozu-Matsuda faults (after Yamazaki, 1984).

Fault name	Reference	Age	Sea level	Upthrown side			Downthrown side			Fault displace-ment	long-term slip-rate
				Height	Uplift	Uplift rate	Height	Subsidence	Subsidence rate		
		(Ka)	(m)	(m)	(m)	(m/10³y)	(m)	(m)	(m/10³y)	(m)	(m/10³y)
Kozu-Matsuda fault	Ah ash	6.3	2	20.5	18.5	2.9	1.8～2.3	3.8～4.3	0.6～0.7	21～23	3.3
	M_2 surface	60	-15	90	105	1.8	-43.5	30.3	0.5	135	2.3
	OS_2	250	-	-	-	-	-500	500	2	-	-
Iriyamase-Agoyama fault	KgP	2.9	0	-	-	-	-6	6	2	-	-
	Ah ash	6.3	2	13.7	11.7	1.9	-17.8	19.8	3.2	31.5	5.0
	Holocene peat	8.0	-10～-15	11.0	21～26	2.6～3.1	-35	20～25	2.5～3.1	46	5.8
	SSW-1 lava	13.7	-50	15	65	4.7	-90	40	2.9	105	7.6
	OF mudflow	80	-3～-9	250	260	3.2	-160	150	1.9	410	5.1

differential settlement accompanied with the growth of volcanic cone.

On the other hand, Yamazaki (1979) thought that the northeastern margin of Hoshiyama Hills was a trace of normal fault to connect the Iriyamase and Agoyama reverse faults having a sinistral en echelon configuration. He redefined this normal fault as the Omiya fault. The height of the fault scarp of the Omiya fault decreases from southeast to northwest. This fault dislocates the Mf-III surface of 20,000 yr B.P. and has a scarp 80 m high in the southwestern portion of the fault trace. Whereas in the northwestern part, the steep scarp turns into gentle flexure scarp 40 to 50 m high (Fig. 9). The long-term slip-rate along the Omiya fault is estimated to be 4 to 2 m/10^3 years during the last 20,000 years.

In the Hoshiyama Hills, the younger mudflow surfaces dip toward the River Fuji (to SSW) but on the contrary, the older surfaces dip to the opposite direction (to NNE). Iwabuchi andesite and the Bessho gravels appear on the southwestern margin of the hills also have a NE-SW strike and NE dip concordant with the tilting of older mudflow surfaces. From the straight trace of the fault and northeastward accumulative tilting of the hills, the Omiya fault seems to be a normal fault with steeply-dipping fault plane.

c. Agoyama fault (Tsuya, 1940; Yamazaki, 1979): The Agoyama fault is a reverse fault bounding the eastern margin of Habuna Hills with high vertical slip-rate. Remarkable features along this fault are the existence of steep fault scarp of 160 m in height and the large westward tilting of the hills. The geomorphic surface on the Habuna Hills consists mainly of mudflow deposits older than Mf-I surface of 50,000 yr B.P. These surfaces are steeper than those of the alluvial fan at the southwestern foot of Mt. Fuji. The deformation of Bessho gravels underlying the mudflow deposits is also concordant with the tilting of mudflow surfaces.

From the accumulative tilting of upthrown side of the fault, the Agoyama fault is estimated to be a thrust fault with a relatively low-angle fault plane. Figure 10 illustrates the geological cross section (d-d') traversing the Habuna Hills and Fujinomiya lowland in the E-W direction. The Agoyama fault displaces the base of mudflow deposit more than

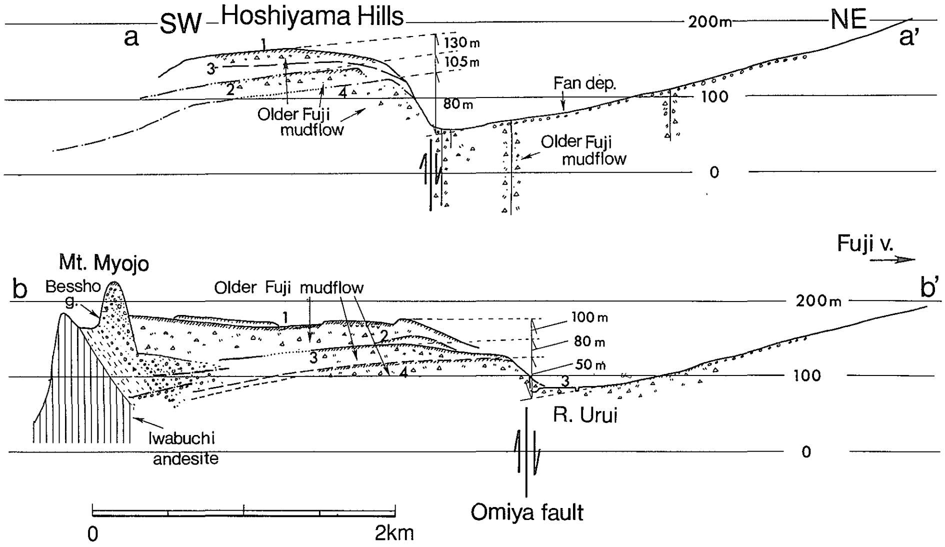


Fig. 9 Geologic sections across the Omiya and Agoyama faults (part 1). Section-lines of a-a' and b-b' correspond to those in Fig. 6

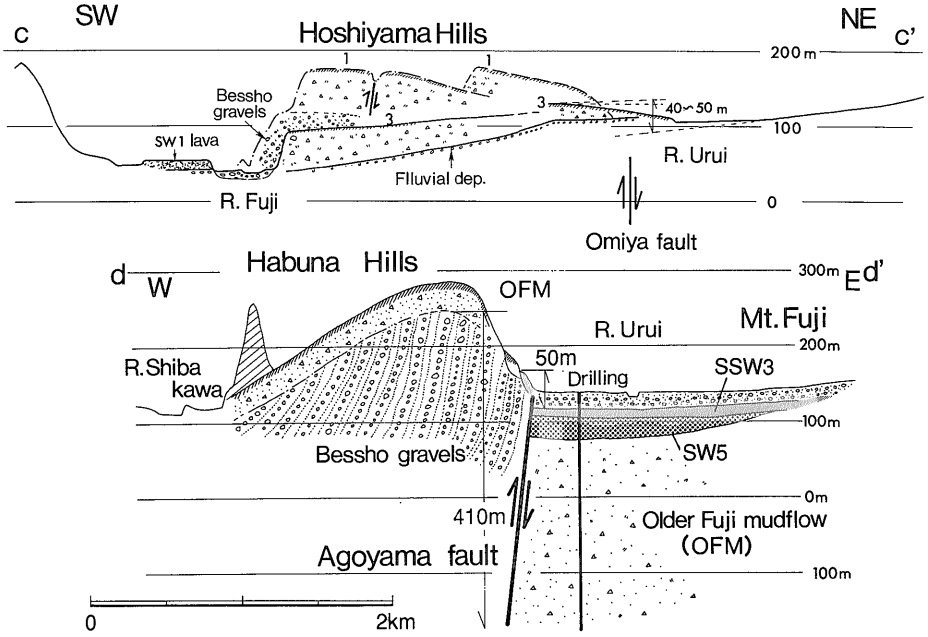


Fig. 10 Geologic sections across the Omiya and Agoyama faults (part 2). Section-line of c-c' and d-d' correspond to those in Fig. 6

410 m between the hills and lowland. Assuming that the base of mudflows was formed after the initiation of the activity of older Fuji volcano 80,000 years ago (Machida *et al.*, 1975), the minimum mean slip-rate of the Agoyama fault is estimated to be 5.1 m/10^3 years. On the other hand, the Agoyama fault vertically dislocates the top surface of the SSW 3 lava flow (ca. 10,000 years ago) about 50 m as shown in Fig. 10. The mean vertical slip-rate of the SSW 3 is calculated to be 1 m/10^3 years. The same slip rates of the two different DRH indicate that the Agoyama fault has constantly repeated the movement during the late Quaternary time.

(2) Iriyama-Shibakawa fault system

The Iriyama-Shibakawa fault system with N-S strike extends from the coast of Suruga Bay to the western foot of Mt. Fuji approximately 25 km long. This system is composed of two thrusts dividing the mountain area on the west from the hilly land on the east. The segment to the south of the River Fuji is called the Iriyama thrust and the Shibakawa thrust to the north of the river.

a. Iriyama thrust (Konno & Otuka, 1933) : Along 10 km of the Iriyama thrust, Pliocene Fujigawa Group to the west overthrusts up on the Quaternary group to the east. A wide fracture zone can be observed along the boundary between the Hamaishi-dake Mts. and Kambara Hills. Although the Iriyama thrust displaces the Quaternary deposits in the Kambara Hills and marks their western boundary, no significant fault scarp or tectonic landforms are recognized along the fault trace. From these characteristics, Yamazaki (1979) considered that the Iriyama thrust had ceased its recent activity. But some evidences of the recent faulting were found later on several man-made outcrops in the Kambara Hills. Sugiyama & Shimokawa (1982) estimated that the Iriyama thrust has continued its movement at a vertical slip-rate of 0.25 m/10^3 years during late Pleistocene and Holocene.

Although the recent fault slip-rate of the Iriyama trust is less vigorous than that of the

Iriyamase and Agoyama faults, the wide fracture zone along the thrust and large deformation of the early Quaternary suggest that the Iriyama thrust had a long history of faulting and there was a more active period than the present one. Presumably, the Iriyama thrust had moved vigorously as a boundary between the uplifting Hamaishi-dake and subsiding Kambara Hills during the depositional period of the early Pleistocene Kambara conglomerate and Iwabuchi andesite.

b. Shibakawa thrust (Yamazaki, 1979) : The name of the Shibakawa thrust is assigned to the 15 km long segment of the Iriyama-Shibakawa fault system to the north of River Fuji. The west side of the fault is upthrown. In the northern extreme of this thrust, the strike turns from N-S to NE and the fault trace seems to plunge into the younger Fuji lava field (Fig. 4). The DRH which records the recent activity of the Shibakawa thrust is the older Fuji mudflow of 50,000 yr B.P. (Mf-I) and the younger Fuji lava about 10,000 yr B.P. (SW-1 and SW-3). Figure 11 illustrates the west-upthrown vertical displacement of 50 m for the Mf-I surface and of 20 m for the SW-1 lava surfaces. Then mean slip-rate using every DRH is estimated to be 1 m/10^3 years. These data indicate that the Shibakawa thrust has repeated its movement more vigorous than the Iriyama thrust during the late Quaternary time. In the northern half of the Shibakawa thrust, SW-3 lava serves only a DRH for the recent movement. This is subject to 30 to 40 m vertical displacement of W-upthrow. Assuming that SW-3 lava flowed out 10,000 years ago, mean slip-rate is estimated to be 3 to 4 m/10^3 years. These facts indicate that the activity of the Shibakawa thrust gradually increases toward

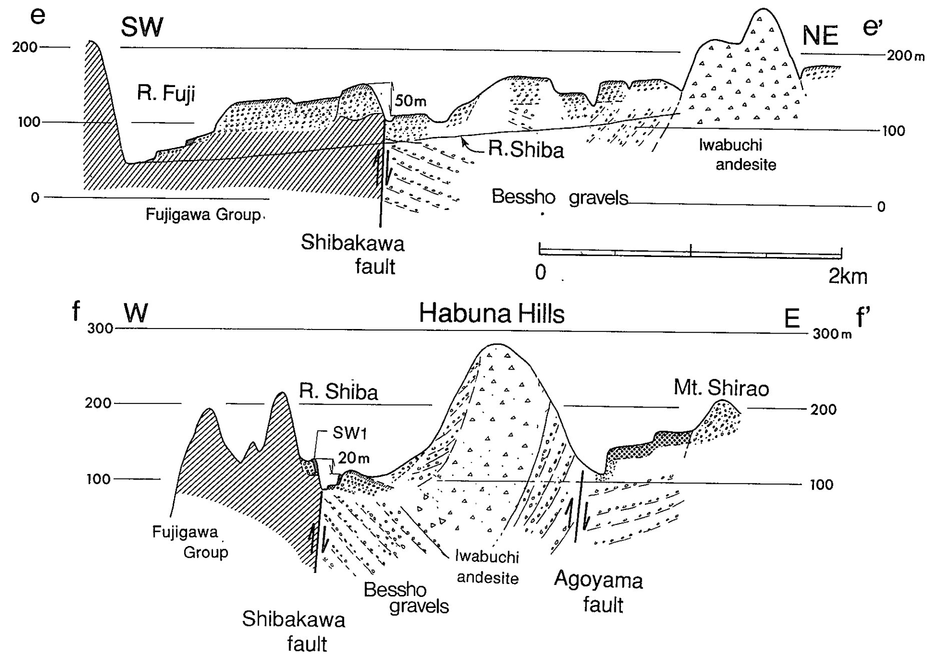


Fig. 11 Geologic sections across the Shibakawa fault.
e-e' section: The 50 m of fault displacement on Mf-I surface of 50,000 yr B.P. is observed across the Shibakawa fault.
f-f' section: The 20 m of fault displacement on SW1 lava flow is observed between the two sides of Shibakawa valley.
Section-lines of e-e' and f-f' correspond to those in Fig. 6

the north. This characteristics can be interpreted as that the Shibakawa fault gradually inherits the vigorous activity of the Agoyama fault when they come to each other to the north of Fujinomiya city.

(3) Other faults

a. Matsuno fault: The NW trending and SW upthrown Matsuno fault is inferred along the River Fuji from the structural difference of Saginota gravels between the Kambara and Habuna Hills. This fault is interpreted to be a normal fault which have been formed to connect the two en echelon arranged reverse faults, i.e. the Iriyamase and Shibakawa faults, during the Middle Pleistocene time. But this fault has no evidence of recent activity.

b. Noshita thrust and its northern extension: A conspicuous scarp, whose height exceeds 50 m, is recognized at the eastern margin of the older Fuji mudflow deposit (Mf-III) distributed along the eastern flank of the Tenshu Mts. This scarp seems to extend southwestward to the Noshita thrust dividing the Miocene Nishi-Yatsushiro Group and the Pliocene Fujigawa Group in the Tenshu Mts. area. As the Noshita thrust shows a sinistral en echelon configuration to the Shibakawa thrust, the activity of the Shibakawa thrust seems to transfer to the northern extension of the Noshita thrust.

4.4 Geological history and fault movement

In Pliocene time, the area of the Hamaishidake and Tenshu Mts. was a part of ancient subsiding Suruga trough where Fujigawa Group, consisting of thick coarse clastics derived from northern mountains, has been deposited.

During the early Pleistocene, the west-upthrown Iriyama and Shibakawa thrusts have commenced their motion to divide the sedimentary basin of the Fujigawa Group. The west side of the thrust, i.e. the Hamaishidake and Tenshu Mts., was uplifted gradually and the axis of subsidence has shifted to the east of the thrust. The Kambara conglomerate has accumulated in this new subsiding basin and was soon after covered by the Iwabuchi andesite. During the active stage of this volcano, the subsidence in the present Kambara Hills area has gradually decreased and the subsiding center has moved northward resulting in the accumulation of the Bessho gravels in the area of Habuna and Hoshiyama Hills. This migration is considered to correspond with the development of the Iriyamase fault.

In the middle Pleistocene, the subsidence in the Habuna and Hoshiyama Hills area became less intense, and subsequently the area has gradually changed into the uplifting area. Then, the Agoyama, Omiya and Matsuno faults commenced their activity, resulting in the eastward migration of the subsiding center toward the Fuji-Fujinomiya lowland. About 0.5 to 0.4 Ma, the alluvial fan of the River Fuji spread over the Kambara and Habuna Hills area to deposit the Saginota gravels. The subsequent uplifting of Kambara Hills has left the Saginota gravels on the hills as terrace deposits. As the Saginota gravels in the Habuna Hills have not undergone strong uplift, it seems that the uplift of Habuna and Hoshiyama Hills commenced late, compared to that of Kambara Hills. The tectonic inversion in Kambara Hills from subsidence to uplift has turned the character of Iriyama thrust from a major fault between the uplifting and subsiding blocks to a fault representing the relative slip between the both uplifting blocks. As a result of this change, the Iriyama thrust has decreased its activity.

During the late Middle Pleistocene to the early Late Pleistocene, the Iriyamase, Omiya and Agoyama faults have acted as the boundary faults between the uplifting hilly land and subsiding lowland. Consequently, the Kambara Hills has become a dissected hilly land due to uplifting and erosion.

On the other hand, the accumulation and erosion of the upper Quaternary have been repeated in the Habuna and Hoshiyama Hills where uplifting has been delayed as compared with the Kambara Hills. At this time, the Matsuno fault had already ceased its activity.

Although the Southern Shibakawa fault has decreased its slip rate due to the development of the Agoyama fault, the northern Shibakawa fault has maintained relatively high slip-rate because no active fault has appeared to the east of the Shibakawa fault.

The older Fuji volcano started its activity ca. 80,000 years ago. Since then mudflow deposits from this volcano have filled the subsiding area to the east of the Iriyamase, Omiya and Agoyama faults, and frequently overflowed into the Habuna and Hoshiyama Hills where the strong uplift had already started.

About 50,000 years ago, the Habuna Hills completely emerged and the broad Mf-I surface was formed on the hills. In and around the Hoshiyama Hills, the River Fuji intensely incised its channel associated with the uplifting and northward tilting of the hills. Head-erosions from the valley of River Fuji developed some tributaries northward in the hills. Before long, these tributaries extended to Fujinomiya lowland, traversing the Hoshiyama Hills. Consequently the tributaries captured the upper reaches of the river which had flown to the southeast in southwestern foot of the older Fuji volcano. Then mudflows and lavas from the volcano filled the narrow valleys in the hills again.

When the hills uplifted by the recurrent fault movement, these valley floors remained as flat surfaces in the hills. Subsequent head erosions from the River Fuji extended to Fujinomiya and caused stream piracy once more. As a result of these processes, i.e. uplifting, head erosion, stream capture, valley fill and uplifting, a flight of terraces developed on the Hoshiyama Hills during late Pleistocene time.

Thus, geological and geomorphological studies in the region to the north of Suruga Bay reveal that the N-S trending tectonic landform has been formed by the eastward migration of faulting and subsiding since the Pliocene.

5. ACTIVE FAULTS IN THE SOUTHERN MARGIN OF THE TANZAWA MOUNTAINS

The area of the southern margin of the Tanzawa Mts. is divided into two portions, i. e., western part and eastern part, due to the difference of topographical configuration.

In the western part, as shown in Fig. 12, the steep Tanzawa Mts. ranging in altitude from 1,500 m to 800 m contact directly with the Ashigara Mts. (less than 1,000 m high) and Hakone volcano. No obvious depression develops between two mountains except the western extreme of the area where a small dissected hilly land is situated. While, in the eastern part, the Tanzawa Mts. bounds on Ashigara plain with steep slope facing south. This topographical distinction between the west and east part seems to reflect the characteristic of tectonic evolution.

5.1 Geology and crustal movement along the western part of the southern margin of the Tanzawa Mts.

(1) Outline of geology and topography

a. Tanzawa Mountains: The Tanzawa Mts. consist mainly of volcanic rocks of the Miocene Tanzawa Group (Mikami, 1958) which is bounded on the south by the N-E trending Kannawa fault system (Matsushima & Imanaga, 1968). Recent studies (Amano, 1986; Ishibashi, 1986 a, etc.) indicate that the Tanzawa Group was originated as a mass of volcanics constituting a ridge on Izu-Ogasawara arc far south, which approached the Japanese Islands following the northward migration of the PHS plate and finally collided with Honshu at about 5 to 6 Ma (early Pliocene). In late Pliocene, a new subduction zone occurred along the southern margin of the Tanzawa area due to the northward shift of Izu block which also belonged to an offshore volcanic ridge on the Izu-Ogasawara arc. Consequently, the uplifting of the Tanzawa Mts. was initiated and the Ashigara Group accumulated in the subsiding depression (trough) between the Tanzawa Mts. and

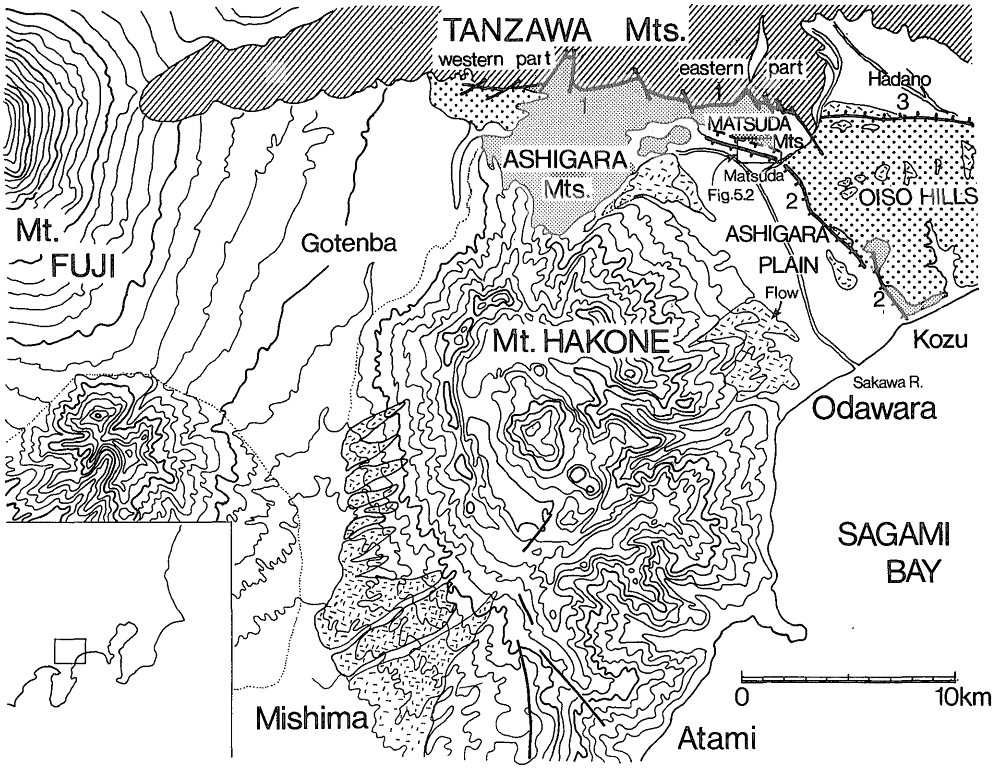


Fig. 12 Geological sketch and locality index map of the southern margin of the Tanzawa Mts. and the Ashigara Plain-Oiso Hills area.
The oblique stripes, fine dots and coarse dots indicate the area of the Neogene Tertiary, the Plio-Pleistocene Ashigara group and late Quaternary sediments respectively. Fault: 1. Kannawa fault system, 2.Kozu-Matsuda fault, 3.Shibusawa fault.

Izu block.

In the early Pleistocene, the upheaval of Tanzawa Mts. was accelerated by the collision and subsequent accretion of Izu block toward Honshu. The exposure of the Neogene metamorphic rocks in the central part of the Tanzawa Mts. indicates that the this range has been subjected to intense uplifting and denuding during Quaternary (Matsuda, 1978). The uplifting rate is estimated to be 3 to 4 $m/10^3$ years by Kaizuka (1987). Thus, the Tanzawa Mts. has experienced continuous upheaval due to the collision-accretion tectonics at the northern extreme of the PHS plate during the late Pliocene to Quaternary.

b. The Ashigara Mts. and its adjacent area: The topography to the south of the Kannawa fault system consists of the Ashigara Mts., Hakone volcano and the hilly land in the northwestern extreme of the area. The Ashigara Mts. are composed of the Plio-Pleistocene Ashigara Group. The deep gorges and steep slopes in the mountains indicate that this area has experienced intense uplift and denudation process together with that of the Tanzawa Mts. due to continuous upheaval during the middle to late Quaternary.

The Ashigara Group is composed of coarse and thick clastics from the Tanzawa Mts., having accumulated in a paleo-trough located between Honshu and Izu block associated with the plate subduction. The total thickness amounts to 1,000 m.

Since the 1980's, many much attention has been paid to the stratigraphy, structure and evolutionary process of the Ashigara Group, because this group has recorded the bulk of evidence on the collision of Izu block and the subsequent upheaval of the Tanzawa Mts. (Amano *et al.*, 1986; Huchon & Kitazato, 1984, etc). Consequently, the Ashigara Group was divided into four formations and their sedimentary ages were estimated to range from the late Pliocene to the early Middle Pleistocene based on the yields of *Parastegodon aurorae,* assemblage of molluscan shells, foraminiferal biostratigraphy and paleomagnetic stratigraphy.

The Ashigara Group shows a dome-like structure dipping to NW and NE. Moreover, this group has been subjected to large deformation by faulting. For instance, the dips gradually increase toward the northwest by the drag deformation associated with the thrusting of Kannawa fault system (Amano *et al.*, 1986).

The hilly land to the northwest of the Ashigara Mts., where the geology is composed of the Suruga gravels in late Pleistocene and overlying late Pleistocene tephras, is also well dissected. The accumulation (as much as 100 m in thickness of cobble-rich facies) of the Suruga gravels indicate that this formation was originally fluvial sediments derived from the Tanzawa Mts. and filled a relative depression between the Tanzawa and Ashigara Mts.

Referring to the origin of the accumulation of the Suruga gravels, Machida *et al.* (1975) inferred that the gravels have been deposited in a relative depression formed by the growth of volcanic cone of Older Fuji volcano. Kano *et al.* (1984) suggested that some of the lateral slip faults, obliquely cut the Kannawa thrust, have also participated in the development of that depression. The dissected Suruga gravels indicate that the area has undergone intense uplift during Late Quaternary time.

Thus, the Pliocene to early Pleistocene sedimentary basin of the Ashigara Group along the western part of the southern margin of the Tanzawa Mts. gradually turned into an upheaval area since after the beginning of the Middle Pleistocene (0.7 Ma). Consequently, the upheaval of this area has promoted extensive denudation to form the steep mountains and the hilly land.

(2) Activity of the Kannawa fault system

The Kannawa fault system dividing the Tanzawa Group and the Ashigara Group runs along the southern margin of the Tanzawa Mts. Hitherto, this system was thought to be a north-dipping thrust (Kannawa fault) because the northern block is upthrown and the trace is winding (Matsushima & Imanaga, 1968). But recently, it is presumed that the Kannawa fault is a fault system compounded by E-W trending thrusts and NW and NE trending strike-slip faults (Kano *et al.*, 1979). After this, the author calls the E-W trending thrust as the Kannawa thrust, and names the composite fault system including the thrust and lateral slip faults as the Kannawa fault system. Machida *et al.* (1975) recognized that the Kannawa thrust has continued its thrust movement at a rate of 1 m/10^3 years since beginning of the Late Quaternary based on the vertical displacement of Suruga gravels as much as 100 m by two reverse faults (Ks and Kn faults) branched from the Kannawa thrust.

On the other hand, Kano *et al.* (1979) pointed out that the Ks fault was not a thrust but a NE trending strike-slip fault offsetting the Kannawa thrust. Furthermore, they suggested that the E-W trending Kannawa thrust of the Kannawa fault system has completely ceased its activity in the late Quaternary (Ito *et al.*, 1986). But the author does not agree with the above opinions because there are several south facing steep slopes as much as 100 m high, which are likely to be the fault scarp representing the recent activity along the Kannawa thrust.

The above mentioned data derive the following history on the movement of the Kannawa fault system. During the sedimentation of the Ashigara Group in Pliocene to early Pleistocene time, the Kannawa thrust was vigorous as a boundary fault between the uplifting Tanzawa Mts. and subsiding sedimentary basin. But the Kannawa thrust gradually diminished its activity because the sedimentary basin of Ashigara Group turned into an uplifting area due to the progress of the Izu collision in the middle Pleistocene. Ito *et al*. (1986) pointed out that the NE and NW trending strike-slip faults offsetting the Kannawa thrust initiated its activity at that age. The reason for the commencement of the strike-slip faulting oblique to the thrust is ascribed to the decrease of fault mobility on the Kannawa thrust, which is caused by the intensification of crustal shortening of the Ashigara Group and steepening of the fault plane associated with the Izu collision.

Ito *et al*. (1987) concluded that the activity of the Kannawa fault system has also weakened since the early Late Pleistocene based on an outcrop data of the NE trending Hirayama fault (Amano *et al*., 1984). However, the author disagrees with this thought because the faulting data from an outcrop cannot represent the whole tectonic movement on the Kannawa fault system.

5.2 Geology and crustal movement along the eastern half of the southern margin of the Tanzawa Mts.

Along the southeastern margin of the Tanzawa Mts., there is a strip of the Matsuda Mts. which is a fault-bounded and flat-topped block consists of the Ashigara Group and Quaternary sediments. The mountains are in fault contact with the subsiding Ashigara Plain on the south and the uplifting Tanzawa Mts. on the north. As illustrated in Fig 12, the two faults bounding both rims of the Matsuda Mts. correspond to the northwestern extension of the Kozu-Matsuda fault and the eastern part of the Kannawa fault system respectively. The southern margin of the Matsuda Mts. is fringed with an area 500 m to 1 km wide of dissected foothills 100 to 300 m high. This narrow foothills comprises mainly middle to late Quaternary sediments. The geological history of this foothills will describe the intense crustal deformation along the active faults during the late Pleistocene and Holocene.

(1) Stratigraphy and geological structure of the foothills

The geology of the narrow hills on the southern foot of the Matsuda Mts. consists of the middle to upper Pleistocene clastics unconformably overlying the Pliocene Ashigara Group. The stratigraphy of the foot hills is as follows.

a. Ashigara Group: The Pliocene Neishi Formation of Ashigara Group unconformably underlying the Pleistocene sediments consists mainly of alternating beds of sandstone and siltstone, andesitic lava and volcano-clastics. This formation strikes nearly NW-SE and dips, 40 to 50 northeast. Consequently, the younger and gravel rich formations of Ashigara Group appear in the Matsuda Mts. to the north. These formations were main source of the coarse talus deposits in the hills.

b. Middle to Late Pleistocene deposits: These Pleistocene deposits are composed of the fluvial sediments of the River Sakawa, mudflow deposits from Hakone volcano, talus deposits from Matsuda Mts. and some pile of tephra layers from Hakone and Fuji volcano (Fig. 13). Table 3 summarizes the stratigraphy of this area and the facies of each layer.

The Kananzawa gravels (Yamazaki & Machida, 1981) consist of pyroclastic flows, air-fall tephras, mudflow layers from Hakone volcano and the fluvial sediments of the River Sakawa in the late Middle Pleistocene. As shown in Fig. 13, the Pleistocene sediments in the hills has undergone the strong shortening to form a fold structure with NW trending axial plane.

Kananzawa loam (Yamazaki & Machida, 1981), overlying the Kananzawa gravels, is a pile of tephra layers including some pumice falls from Hakone volcano in the early Late Pleistocene (0.12 Ma). This loam is overlain unconformably by the Matsuda gravels.

The Matsuda gravels (Yamazaki & Machida, 1981) are a sequence of coarse talus

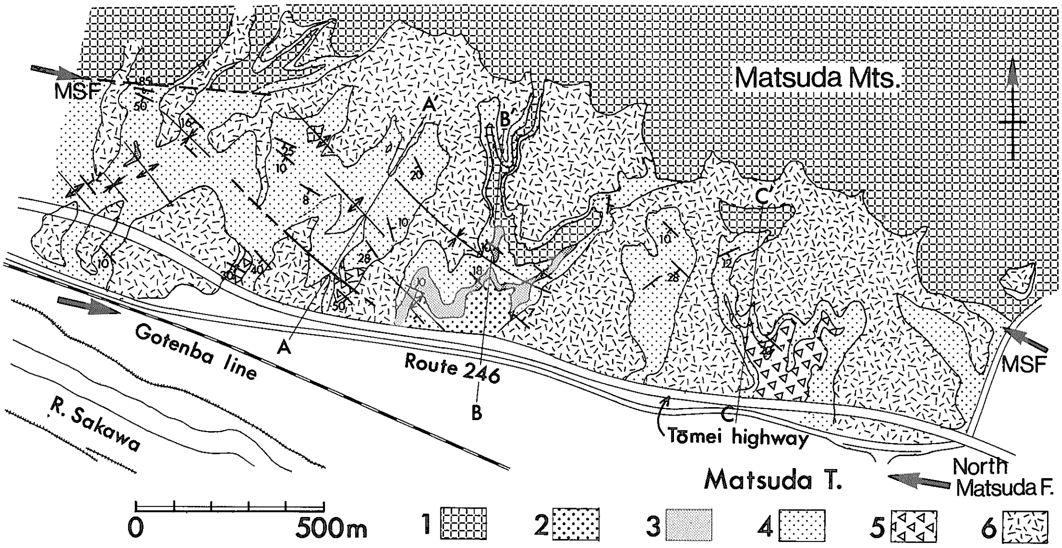


Fig. 13 Detailed geologic map of the hilly area in the southern foot of the Matsuda Mts. Locality is shown in Fig. 12
Legend 1 : Ashigara group, 2 : Kananzawa gravels, 3 : Kananzawa loam, 4 : Matsuda gravels, 5 : Pyroclastic flow deposit, 6 : Fuji tephra layers
Black arrows show the direction of the North Matsuda fault and the Matsuda-sanroku fault (MSF). Section lines A-A' to C-C' correspond to those in Fig. 14

Table 3 Stratigraphy of the hilly area in the southern foot of the Matsuda Mts. (after Yamazaki *et al.*, 1982).

			Facies	Features	Age
Holocene		Fuji Tephras	Scoria ash fall	Stratified fall	After 30,000 yr ago
Late Pleistocene	late	Upper Matsuda gravel	Talus deposits	Breccia derived from Ashigara group in the Matsuda Mts. Cross-bedded AW type tephras are intercalated	30,000 - 50,000 yrB.P.
	middle	Hakone younger pyroclastic flow (TP flow)	Black-gray colored Pumice flow	TP fall (1 m in thickness) underlies the flow	ca. 50,000 yrB.P.
		Lower Matsuda gravels	Talus deposits (Breccia and loam)	Breccia derived from Ashigara group in the Matsuda Mts.	ca. 50,000 - 80,000 yrB.P.
	early	Kananzawa loam	Air-fall tephra	Pumice falls (Klp 6-14) mainly from Hakone Volcano are intercalated	ca. 120,000 yrB.P. Last inter-glacial period
Middle Pleistocene		Kananzawa gravels	Fluvial sediments Mudflow deposits Pumice flow, ash in Middle Pleistocene	Boulder-rich gravels of the Sakawa River, Andesitic mudflow and Pumice flow from Hakone Volcano	ca. 130,000 - 200,000 yrB.P.

deposits derived from the conglomerate of Ashigara Group in the Matsuda Mts. The gravels contain several intercalated key tephras such as Pm-I pumice of 0.08 Ma from central Japan and the Younger Pyroclastic Flow of Hakone volcano (TP flow) of 0.05 Ma, and underlie the scoria ash from Fuji volcano. The age of the gravels is estimated to be middle to late Late Pleistocene time.

(2) Fault movement along the southern foot of Matsuda Mts.

The sedimentary sequence of the southern foothills of Matsuda Mts. shows two major turning points on the tectonics in this area. One is the beginning of the accumulation of Matsuda gravels in the early Late Pleistocene. This rapid increase of the sedimentary supply implies the accelerated upheaval of the Matsuda Mts., associated with the activation of the fault (Matsuda-sanroku fault: Yamazaki & Machida, 1981) along the southern margin of the Matsuda Mts.

The other is the end of the accumulation of the Matsuda gravels. Since then, the southern flank of the Matsuda Mts. has been terraced to form the foothills. This also suggests a weakening of the activity of the Matsuda-sanroku fault and the onset of the new faulting (North Matsuda fault: Yamazaki & Machida, 1981) along the present margin of the foothills. Accordingly, the fault scarp rapidly developed during the late Late Pleistocene to Holocene at the southern margin of the foothills. The eastern extension of this fault scarp seems to continue to the northern trace of the Kozu-Matsuda fault mentioned later.

Figures 13 and 14 illustrate that the foothills area has undergone a short wave-length folding with NW axis associated with the activity of the North Matsuda fault. This folding accompanies several reverse faults with same strike to the fold axis. The arrangement of these structures suggests that

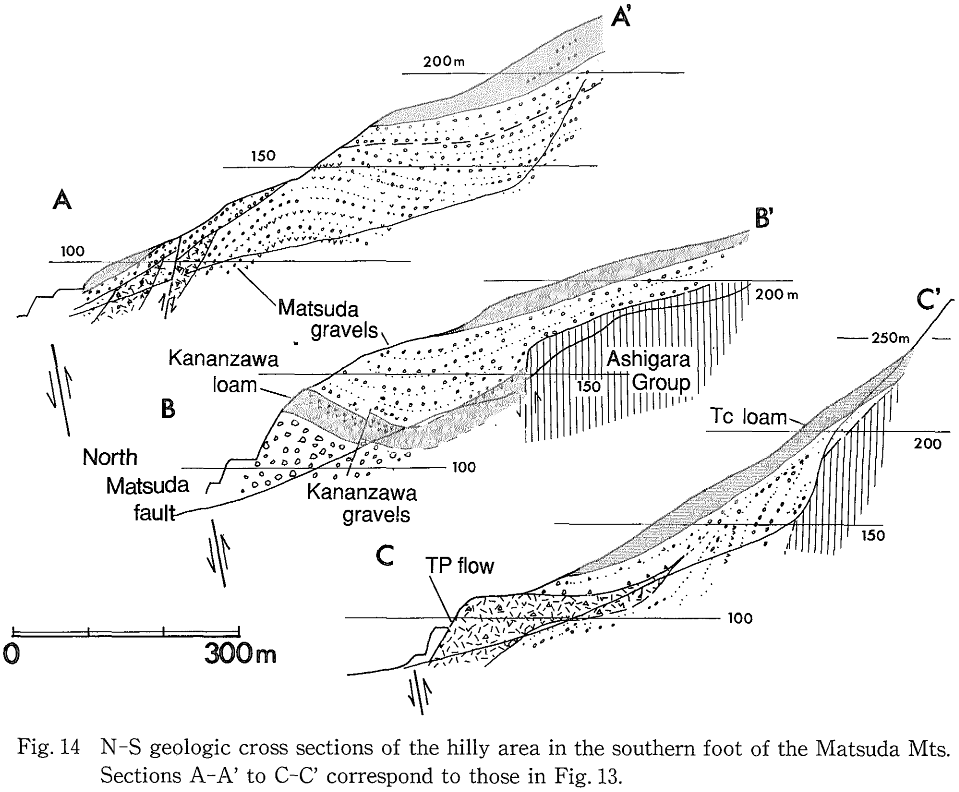


Fig. 14 N-S geologic cross sections of the hilly area in the southern foot of the Matsuda Mts. Sections A-A' to C-C' correspond to those in Fig. 13.

the North Matsuda fault has a left lateral slip component as well as N upthrown. From this sense of the fault movement and E-W strike of the fault, the stress field in this area is estimated to be NE compression during Late Pleistocene to Holocene time. Northeast compression is also pointed out from the micro structures developed in the Ashigara Group. That is, Huchon & Kitazato (1983) inferred that the stress field in the Matsuda Mts. area shifted from a NW compression to a NNE at about 0.3 Ma, based on the minor faults analysis of the Ashigara Group.

However, the orientation of stress field derived from the geological evidence discords with the expected NW compression from the plate motion of the PHS. This fact suggests that the complicated local crustal movement including the rotation of large block has occurred along the plate convergence boundary during the late Quaternary.

5.3 Characteristics of the crustal movement along the southern margin of the Tanzawa Mts.

Along the southern margin of the persistently uplifting Tanzawa Mts., the style of crustal movement shows a spatial difference between the eastern and western parts. In the western part, the sedimentary basin of the Ashigara Group has been extensively uplifted since the Middle Pleistocene. No subsidence has occurred except on the western extreme where the fluvial deposits accumulated in the small basin formed by local tectonics or environmental change.

During the Middle Pleistocene, the activity of the E-W trending Kannawa thrust diminished, and NE and NW trending faults concurrently initiated the strike-slip movement. The indistinctness of the topographical boundary between the Tanzawa and Ashigara Mts. is ascribed to this diminishing vertical movement since the Middle Pleistocene.

On the other hand, the E-W trending fault has created a salient topographical boundary between the Tanzawa Mts. and the Ashigara Plain in the eastern part. The characteristics of faulting in this area is the migration of fault movement toward the south with time and the associated uplift in the backward area of the active fault. These characteristics are very similar to the ones in the southwestern foot of Mt. Fuji described in chapter 4, though the time scale and magnitude of the movement in this area are a much lesser degree than in Fuji area.

The spatial (east-west) difference of the tectonic features along the southern margin of Tanzawa Mts. might be ascribed to the difference of relative distances from the northern tip of Izu block where the PHS collides with the EUR. That is, the western part of the Tanzawa margin, located on the north to northwest of Izu Peninsula, is thought to be the plate collision area. The extensive upheaval of the Tanzawa and the Ashigara Mts. might be caused by the intensive crustal shortening and uplift, like a pressure ridge, due to the collision of Izu block which cannot subduct under Honshu.

In the eastern part, there are some tectonic features such as the salient topographical boundary between the Tanzawa Mts. and Ashigara Plain, and the migration of fault movement. The existence of a subsiding depression, the Ashigara Plain, perhaps indicates that the crustal shortening of the eastern part is less advanced than that of the western part due to the endurance of plate subduction despite the approach of Izu block.

Although the migration of fault movement shows a similar pattern to that of the southwestern foot area of Mt. Fuji, there are conspicuous differences between two areas for the occurrence interval of migration events. As previously mentioned, the Tanzawa and Ashigara Mts. areas are thought to be the plate collision zone during the Quaternary period.

Therefore, the shorter interval for the fault migration in the eastern Tanzawa area as compared to that of Mt. Fuji area suggests that the interval relates to the rate of crustal shortening and the convergent style between two plates.

6. ACTIVE FAULTS AND TECTONICS IN THE ASHIGARA PLAIN - OISO HILLS AREAS

6.1 Outline

In the northern extension of Sagami trough, which is generally believed to be the plate convergence boundary between the PHS and EUR, there are several topographical provinces such as the Oiso Hills, the Ashigara Plain, Hakone volcano and the Tanzawa Mts. in northern extreme (Figs. 2 and 12). The Oiso Hills, an uplifted block surrounded by several active faults, is located in the northwestern extension of Okinoyama banks, which extended along the northeastern side of Sagami trough, and is thought to be a part of a tectonic zone caused by the vigorous crustal movement associated with the plate convergence (Kaneko, 1971). At the northwestern extension of trough axis, there is the subsiding Ashigara Plain (Ashigara depression) on the west of the Oiso Hills, which is thought to have been the extension of Sagami trough filled with the thick deposits derived from the Tanzawa Mts. The NW tending Kozu-Matsuda fault runs between the Oiso Hills and the Ashigara Plain forming the distinct fault scarp of 300 m high.

6.2 Geology and crustal movement in Oiso Hills and Ashigara Plain

(1) Oiso Hills

The geology of the Oiso Hills consists of marine and fluvial sediments and air fall tephras, which were deposited since the beginning of Middle Pleistocene underlain by the Neogene-Tertiary. The geological structure of the hills is characterized by a basin structure with an anticlinal axis along the western margin of the hills and a depression at the central part (Uesugi, 1986). With reference to the tectonic evolution of the hills, the Association of Kanto Quaternary Research (A.K.Q.R.) (1980) pointed out that the tectonic movement changed from subsidence to upheaval during Middle Pleistocene time.

a. Pre-Quaternary rocks : The pre-Quaternary rocks whose outcrops are bounded by faults are distributed in several parts, especially in the northwestern part of the hills (Fig. 15). These rocks consist of alternating Miocene volcanics, mudstone and Pliocene conglomerate (Otuka, 1929 ; Ota *et al.*, 1982 ; Ito, 1985).

b. Quaternary sediments : The Quaternary sediments in the Oiso Hills consist mainly of the middle Pleistocene Ninomiya Formation, middle Pleistocene to Holocene marine and fluvial sediments and an overlying thick tephra sequence from several volcanoes to the west. With reference to these tephras, Machida *et al.* (1974) established the chronology of tephra, marine and fluvial sediments since the Middle Pleistocene (Table 4).

The underlying Ninomiya Formation which outcrops in the southern part of the hills consists mainly of sand and mud layers, total thickness of which amounts to 200 m. The age of this group is estimated to be the early Middle Pleistocene because the Matuyama-Brunhes magnetic boundary (0.7 Ma) is found at the lowest part of the Ninomiya Formation (Koyama *et al.*, 1986 ; Honma *et al.*, 1985). On the basis of benthonic foraminifera, Yano (1986) estimated a shallow sea (less than a few hundred meters in depth) was the sedimentary environment of the Ninomiya Formation. The relatively small thickness of the Ninomiya Group indicates that this group is a non-basin fill sediment accumulated in the exteriors of the subsiding area.

The Quaternary sediments in the Oiso Hills contain 8 units of marine and fluvial terrace sequence, namely the T-f, T-e, T-d, T-c, T-b, T-a, K and H formation in order of decreasing age (Table 4), and basin fill sediments of the Sogayama formation in the Middle Pleistocene. The age of each terrace deposit is estimated to be 0.5 Ma, 0.4 Ma, 0.35 Ma, 0.28 Ma, 0.23 Ma, 0.18 Ma, 0.13 Ma and 0.06 Ma respectively based on the stratigraphic

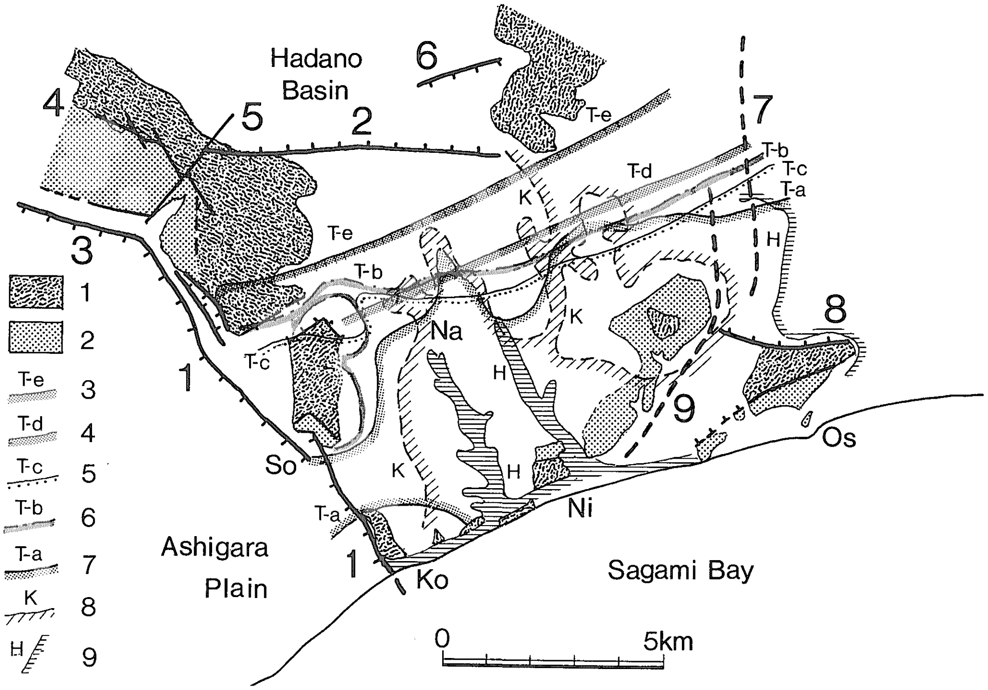


Fig. 15 Map showing the distribution of pre-Quaternary rocks, faults and marine terrace strandlines in and around the Oiso Hills (after A.K.Q.R., 1987).
Legend : 1.Miocene Tanzawa Group, 2.Plio-Pleistocene Ashigara Group, 3-9.Strandlines of the T-e to H marine terraces.
Fault number : 1.Kozu-Matsuda fault, 2.Shibusawa fault, 3.North Matsuda fault, 4.Kannawa fault system, 5.Kawaotagawa fault, 6.Hadano fault, 7.Isehara fault, 8.Komukai fault, 9. Ikusawa tectonic line.

relation with the dated tephras (Machida *et al.*,1974, Machida, 1975, A.K.Q.R.,1987).

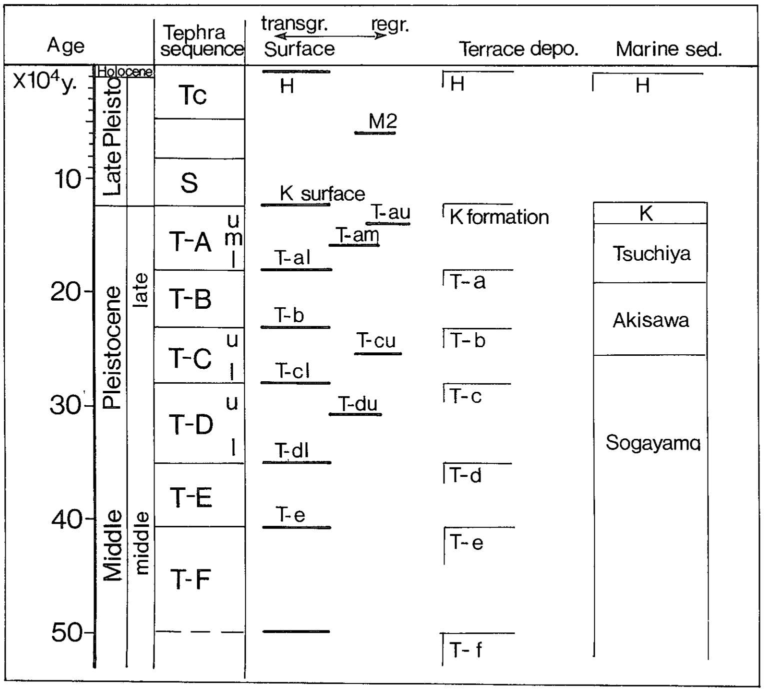
The Oiso Hills can be divided into the following four areas, due to the inequality of crustal movement in the Oiso Hills.

In the northern area of the Oiso Hills, the T-f to K formations of terrace deposits, composed of sand beds and gravels less than a few tens of meters in thickness, show accumulative tilting toward the east. Accordingly, the older formations are well exposed in the west part of the area. Most of the formations are intercalated with the air fall tephras toward the east. The alternated sedimentary and eolian deposits in this area indicate that the eastward tilting occurred since after the accumulation of T-D tephra formation (0.4 Ma).

The western area of the Oiso Hills is underlain by the middle Pleistocene Ninomiya and Sogayama Formations and terrace deposits younger than T-c formation. The Sogayama Formation which constitutes the Sogayama upheaval block, occurs along the western and southwestern margin of the Oiso Hills. This formation consists of mud layers in the lowermost part and pebble to cobble size unconsolidated gravels about 500 m in thickness. Hitherto, the correlation of the Sogayama formation in the stratigraphic sequence were not confirmed because of various opinions on its age (Kojima, 1954 ; Kikuchi & A.K.Q.R., 1977; Yano, 1986).

Recently, a glassy ash layer which can presumably be correlated to the Handa tuff in the upper most Osaka Group, in south west Japan was discovered at the lower part of the Sogayama formation (Mizuno & Kikkawa,

Table 4 Chrono-stratigraphy of tephras in the Oiso Hills and its relationship to the geomorphological surfaces and the terrace deposits. After Machida *et al.* (1974) and A.K.Q. R.(1987).



1991). As the Handa tuff has already been recognized in the middle part of the T-D tephra formation of the Oiso Hills (Uesugi, *et al.*, 1985), the age of Sogayama Formation is estimated to be the age of T-E to T-D tephra formation.

The similarity of lithofacies and thickness of the Sogayama Formation to that of the Bessho gravels in the southwestern foot of Mt. Fuji indicates that this formation was a submarine basin fill sediment accumulated in the subsided trough close to the coast. The deposition of Sogayama Formation implies the occurrence of the NW trending subsided trough in the western part of present Oiso Hills during middle Middle Pleistocene time. As the deformed Sogayama Formation is unconformably covered by the less deformed T-c terrace deposits, the subsiding movement in this area is estimated to have turned into upheaval before the accumulation of T-c formation (about 0.3 Ma).

The Quaternary geology of the southern area contains the Kuzukawa (Harukawa *et al.*, 1977), Akisawa, Tsuchiya (Kikuchi & A. K.Q.R., 1977), K and H formations overlying the Ninomiya Formation. The first three formations correspond to the Sogayama, T-c to T-b, and T-a formations respectively. Each of these formations consists of marine sand and mud layers intercalating with thin gravel strata. The thickness of each formation is less than 100 m. The K (Kissawa) formation is the transgressive sediments of the last inter-glacial (0.13 Ma). The H formation is the marine terrace sediments formed by the post glacial transgression. The depositional surface of this formation is called the Nakamurahara surface (Yonekura *et al.*, 1968), emerged 6,300 years ago. The top of marine sediments is at an altitude of about 20 m along the southern coast of the Oiso Hills. The mean uplift rate in the southern area of the Oiso Hills is calculated to be about 3 m/10^3 years.

Therefore the gentle subsidence continued through the Middle Pleistocene age and this area was frequently inundated with sea water at high sea-level stages. The change from subsidence to upheaval might have occurred since after the last interglacial period in the southern area. Machida & Moriyama (1968) pointed out that the upheaval of the Oiso Hills became active in the recent geological time, based on the elevation ratio of K to H terraces. The recent increase of uplifting is in good agreement with the above estimation.

In the eastern area, the last interglacial K formation composed of sand and pebble layers extensively distributed to fringe the protruding Pre-Quaternary rocks. As most of Quaternary sediments underlie the K formation (Oka *et al.*, 1979), it seems that the subsiding in this area had exceed before the accumulation of the K formation. This fact also suggests that the tectonic inversion occurred from subsidence to upheaval in the beginning of Late Pleistocene.

The following tectonic evolution of the Oiso Hills is deduced from the geological data mentioned above.

The Oiso Hills was subjected to slight subsidence during the early Middle Pleistocene (0.7 to 0.5 Ma). About 0.5 Ma, the NE trending depression occurred in the northern and western areas of the hills to deposit the thick Sogayama Formation. But the stable tectonic condition was still continuing in the southern and eastern areas. The Sogayama Formation accumulated mainly in the western area of the hills. The crustal movement of the northern area, where subsidence was originally not intense, gradually changed into upheaval and caused the eastward tilting.

About 0.3 Ma, the crustal movement in the western area converted from the intense subsidence to upheaval and consequently the Oiso Hills tilted toward east. Although the slight subsidence in the southern and eastern areas still continued after 0.3 Ma, the whole Oiso Hills changed into active uplifting area after the Last Interglacial Stage (about 0.13 Ma).

(2) Ashigara Plain

The Ashigara Plain, located in the northwestern extension of Sagami trough, is composed of extensive alluvial fan developing in the lower reach of the River Sakawa and the Holocene terrace with small relative height. This plain, bounded on the eastern and northern margin by the active faults, is a kind of fault angle depression developed in the eastern foot of Hakone volcano. As shown in Fig. 16, the geomorphic features of the Ashigara Plain are characterized by extensive development of the Holocene Kamonomiya terrace and a lack of the last interglacial terrace (K terrace). The Kamonomiya terrace is the depositional surface of the Gotemba mudflow (GMF: Machida, 1964) from Fuji volcano at 2,300 years ago.

The gravity map of South Kanto and Tokai district (Komazawa,1982) shows the continuous low anomaly zone which stretches from the Ashigara Plain to the Ashigara Mts. This anomaly pattern suggests that the thick accumulation of the Plio-Pleistocene Ashigara Group fills the depression basin beneath the Ashigara Plain. After this the author calls this subsiding depression the "Ashigara depression".

According to the drilling data (Yamazaki *et al.*, 1982, Fig. 17), the Holocene sediments in this plain are composed of the alluvial fan gravels distributed in the northern part and along the river course, and marine fine sediments of the Kamonomiya terrace. The Kamonomiya terrace deposit is intercalated with several key beds such as peat layers, volcanic ash, and GMF etc., which are possible to yield the age of the layers. Figure 18 shows the relationship between the ages of these layers and their depth.

The younger Hakone pyroclastic flow deposits (TP flow: 50,000 years old) and the M_2 terrace deposits (60,000 years old) underlie the alluvium of the Ashigara Plain (Yamazaki *et al.*, 1982). These deposits are under-

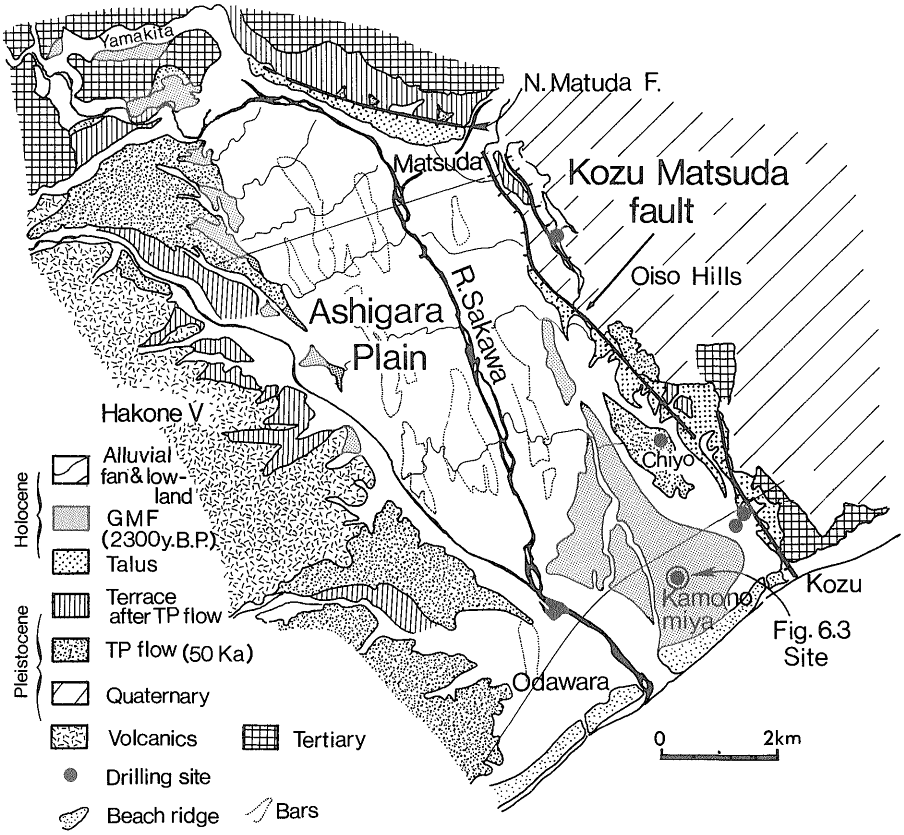


Fig. 16 Geomorphological map of the Ashigara plain, southwest Kanto.

lain by the thick gravels including cobbles derived from the lava of Old Somma stage 2 (OS 2) (Kuno, 1950, 1951) of Hakone volcano up to 500 m in depth.

As the beginning of the OS 2 stage proned to be about 0.3 Ma by tephrochronology (Machida *et al*, 1974), the age of the sediments filling the depression is assumed to be younger than 0.3 Ma. Therefor, the calculated long-term subsidence rate of the Ashigara depression is more than 1.7 m/10^3 years. While, the mean subsidence rate of the younger sediments has a smaller value than that of the older ones. For instance, the M_2 terrace deposit, which appears at -45.3 m in depth beneath the eastern Ashigara Plain, shows 39 m of subsidence at most if the altitude of the original sea-level of 60,000 years ago is assumed to be lower than -6 m (Machida, 1975). Accordingly, mean subsidence rate of the M_2 terrace deposit is estimated to be 0.65 m/10^3 years. Further, the Ah ash, deposited in the brackish water environment near the coast, appears at -1.8 to -2.3 m in depth (Matsushima, 1982). This depth indicates 4 m of subsidence and 0.6 m/10^3 years of mean subsidence rate during last 6,300 years if the original sea-level is assumed to be 2 m above present.

The difference of the mean subsidence rate between the older and younger markers indicates that the subsidence movement in the Ashigara depression gradually became weak through the Late Pleistocene. The depth of Ah ash below the present sea-level means that the subsidence of the Ashigara depression has still continued in the Holocene, though the rate has decreased. On the other

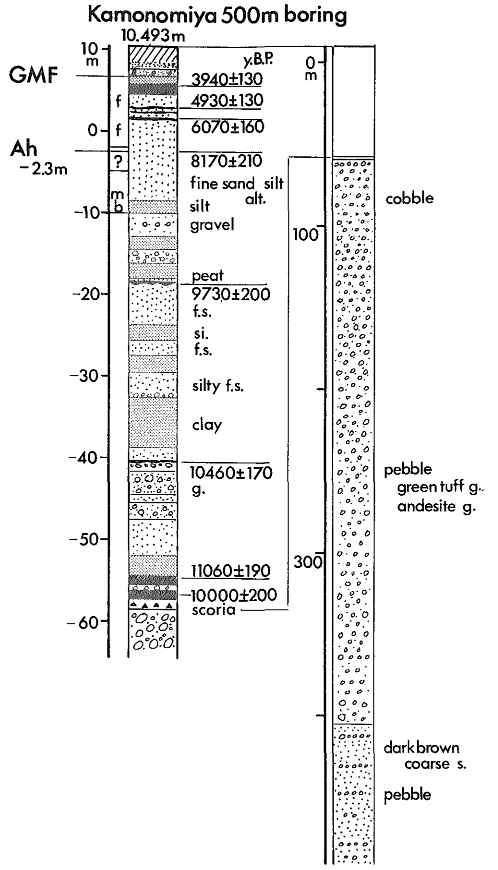


Fig. 17 Geological logs of the 500 m drilling carried out by GSJ at Kamonomiya in the Ashigara plain.
GMF : Gotemba mudflow deposit of 2,300 yr B.P. from Mt. Fuji. Ah : Akahoya glassy ash layer of 6,300 yr B.P. from south Kyushu.

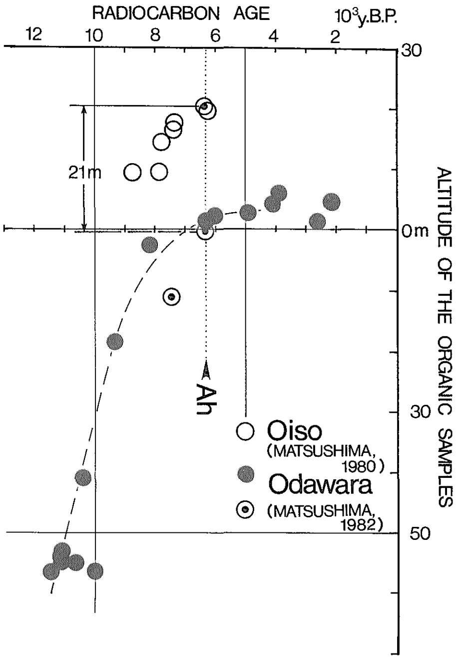


Fig. 18 Comparison of the sample heights and their ages of the Holocene sediments between the both sides of the Kozu-Matsuda fault. The dated samples of Odawara were obtained from the Kamonomiya 500 m drilling. Ah shows the Akahoya ash layer.

hand, the Ashigara Plain, together with the Oiso Hills, were uplifted 1.8 to 1.2 m by the co-seismic crustal movement associated with the 1923 Great Kanto Earthquake (Omura, 1925).

Furthermore, the Kamonomiya terrace which is a part of the uplifted flood plain of 2,300 years ago has 3 to 4 m relative height from the present flood plain. These facts suggest that the formation of the Kamonomiya terrace was closely related with the co-seismic crustal movement of the great earthquakes caused by the plate subduction along the Sagami trough. After this author calls this type of earthquake the "Kanto-type earthquake". The relationship between the long term accumulative subsidence of the Ashigara depression and the recent uplift associated with the Kanto-type earthquake will be discussed in Chapter 8.

6.3 Kozu-Matsuda fault

In the western Oiso Hills area where the Sogayama Formation thickly accumulated during T-D tephra stage, the subsidence weakened and partly changed into a slight upheaval in the T-C tephra stage (ca. 0.3 to 0.25 Ma). Then, the Sogayama block has emerged to form the hilly land. This tectonic change was presumably caused by the activation of the vertical slip on the Kozu-Matsuda fault with east side upthrow. Consequently, the origination of the Kozu-Matsuda fault is inferred to be at the T-D tephra stage (0.3 to 0.4 Ma).

In the later half of Middle Pleistocene (0.25 to 0.13 Ma), the T-a marine terrace of 0.15 Ma locally extend over the southern part of the Kozu-Matsuda fault. This means that despite the vigorous activity of the Kozu-Matsuda, the fault scarp did not have such a large relative height at that time compared with present. Accordingly, the scarp height of the present Kozu-Matsuda fault is thought to have mostly grown during the late Pleistocene to Holocene.

With reference to the vertical displacement of the Kozu-Matsuda fault, no precise estimation can be derived from the DRH formed before 60,000 years ago because of the lack of detailed stratigraphical information in the Ashigara depression. But if the author broadly estimates the long term slip rate of the Kozu-Matsuda fault, it can be said to have a value of more than 2 m/10^3 years since 0.3 Ma. That is, the sediment beneath the Ashigara Plain at 500 m in depth is possibly correlated with the T-c to T-a (0.3 to 0.15 Ma) terrace deposits which lie in the Oiso Hills above 100 m in altitude. Accordingly, the displacement of the T-c terrace deposit by the Kozu-Matsuda fault is estimated to be more than 600 m and the mean slip-rate is calculated to be more than 2 m/10^3 years.

As mentioned in the previous section, the M_2 marine terrace deposits in the Ashigara Plain and Oiso Hills appears -45.3 m and +90 m in altitude respectively. Mean slip-rate for the last 60,000 years is calculated to be 2.3 m/10^3 years. With reference to the Holocene sediment, Matsushima (1982) showed 22 m of vertical fault offset during last 6,300 years and calculated at 3.5 m/10^3 years of slip-rate.

Thus the mean slip-rate on the Kozu-Matsuda fault, which is obtained from the various fault DRH, indicates that this fault has recurred to the movement at the slip-rate of 2 to 3.5 m/10^3 years since the middle Middle Pleistocene. But, as previously mentioned, the appearance of fault scarp on the Kozu-Matsuda fault fell behind the initiation of fault movement for a few hundred thousand years. This delay suggests that the mean-slip rate which represents the relative movement of the two blocks divided by the fault is not always adequate to reconstruct the fault evolution and related geological history in detail. The author thinks the most important factor to indicate the degree of fault evolution and to affect the growth of the fault scarp is not the mean slip-rate of the fault but the absolute movement of each faulted block.

Table 2 shows the absolute displacement and displacement-rate of each faulted block based on the present altitude and original height of the M_2 terrace and Holocene sediments. The data on the table reveal that the displacement of the Kozu-Matsuda fault during middle Pleistocene time was mostly compensated by the subsidence of the Ashigara depression and the upheaval of the Oiso Hills was relatively small. This means that the faulting of the Kozu-Matsuda fault hardly contributed to the growth of the fault scarp in the middle Pleistocene. While during late Pleistocene to Holocene, although the faulting on the Kozu-Matsuda fault continued at a constant relative slip rate, the absolute movement of each block varied widely. That is, the subsidence rate of the Ashigara depression decreased with time and, on the contrary, the uplift rate of the Oiso Hills increased to form the conspicuous fault scarp.

In spite of the recent activation of the movement that formed the fault scarp, no fault scarplet displaying the recent faulting is found along the major scarp. The lack of a fault scarplet can presumably be interpreted as a result of flexure appearing as the surface expression of the reverse faulting; this may be due to the distribution of thick unconsolidated deposits along the Kozu-Matsuda fault.

Along the northern trace of the Kozu-Matsuda fault, the obvious fault scarp with 50 m of relative height appears at the western margin of the fluvial M_3 terrace of 50,000 years ago. This M_3 terrace is also bounded to the east by a graben younger than the M_3 terrace. These facts indicate that the westward migration of faulting has occurred in the northern part of the Kozu-Matsuda fault during the later half of Late Pleistocene to Holocene. This feature (the recent migration of the fault movement) is well similar to that of the North Matsuda fault in the southern margin of the Matsuda Mts., located to the northwest of the Kozu-Matsuda fault. This tectonic similarity between two faults indicates that the northern part of the Kozu-Matsuda fault and the North Matsuda fault have behaved as a single fault in the recent geological time.

Nakamura *et al.* (1984) supposed that the WNW moving PHS caused the eduction along the western part of Sagami trough and consequently the Kozu-Matsuda fault was formed as a normal one. But, the development of numerous thrusts with NW-SE strike and the anticlinal structure with N-S axis in the western Oiso Hills area do not support the above hypothesis and, to the contrary, it indicates that the Kozu-Matsuda fault is a thrust fault with some left lateral slip component.

6.4 Tectonic evolution

The crustal movement took place toward the middle Middle Pleistocene in this area. The lithofacies and sedimentary structure of the Ninomiya formation which is the lowest Middle Pleistocene underlying the terrace deposits of the Oiso Hills do not contain any evidence of the vigorous tectonic movement during the accumulation of this formation. As the plate boundary connecting southern Tanzawa region and the Japan Trench ought to have existed in the early stage of the middle Pleistocene, the calm crustal movement at that age indicates that the style of the tectonic movement along the plate boundary was possibly not plate subduction but transform faulting or eduction without vertical displacement.

Although the reason is uncertain, the subsiding depression formed on the western Oiso Hills area about 0.5 Ma where the thick Sogayama formation accumulated. One plausible reason for this tectonic change is the transition of the convergent style of plate boundary from transform faulting to subduction along the Sagami trough.

Circa 0.4 to 0.3 Ma, in the middle Middle Pleistocene, the Kozu-Matsuda fault commenced its activity in this subsiding depression or western margin of it. The western side of this fault subsided at a rate of more than 2 $m/10^3$ years to form the Ashigara depression. In spite of the vigorous activity of the Kozu-Matsuda fault, the fault scarp dividing the Oiso Hills and the Ashigara Plain was not overt because of the upheaval of the hills was still small at that time.

In the late Middle Pleistocene (0.2 to 0.15 Ma), the upheaval rate of the Oiso Hills gradually increased and the Sogayama block composed of the Sogayama Formation in the western Oiso Hills area emerged. On the other hand, the subsidence of the Ashigara depression slowly weakened. Since after the last interglacial period (0.12 Ma), the uplift of the Oiso Hills accelerated according as subsidence in the Ashigara Plain has decreased. As a result of this tectonic change, the scarp of the Kozu-Matsuda fault has rapidly developed, though the relative slip rate of the fault remained unchanged.

7. SUMMARY OF THE QUATERNARY SYSTEM AND THE ACTIVE STRUCTURES ALONG THE IZU BORDERLAND

7.1 Quaternary systems

The Quaternary chrono-stratigraphy and the evolution of fault systems shown in Fig. 19 reveal that the Quaternary system of the Izu borderland is classified into two categories: the basin-fill type and the non-basin-fill type. The former was deposited in subsiding tectonic basins and accumulated to more than several hundred meters in thickness. The latter was deposited outside the

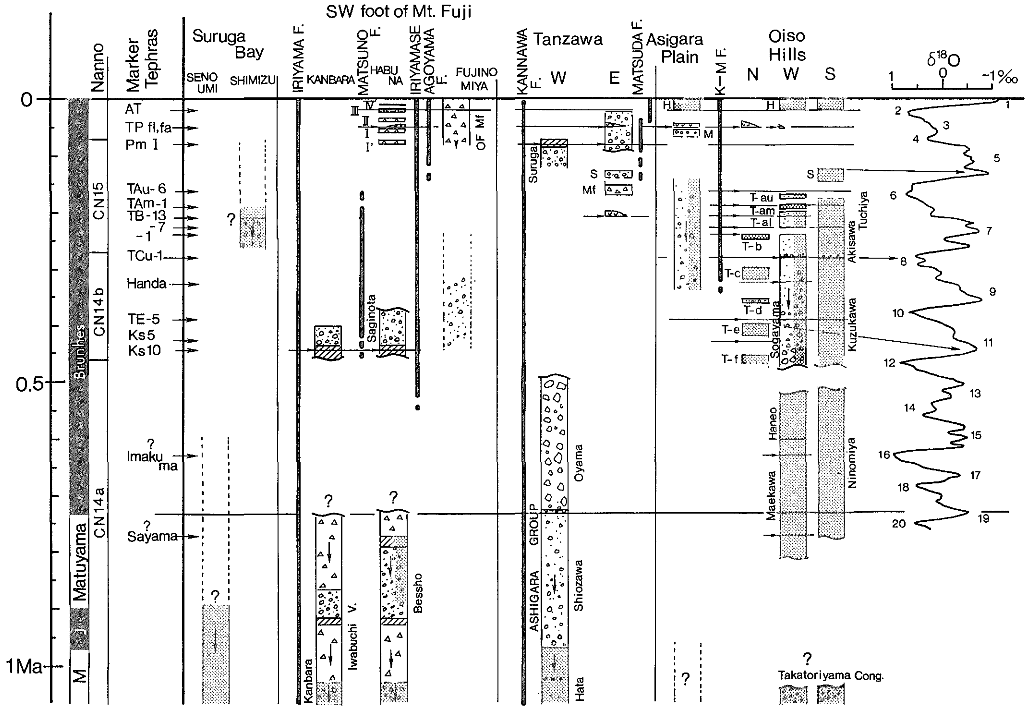


Fig. 19 Quaternary stratigraphy of the plate convergence region in the northern margin of Izu Peninsula. Bold line under fault names indicates the duration of the fault movements. Screened and hatched parts indicate the marine and lacustrine deposits respectively.

subsiding areas. The distribution of each deposit is shown in Fig. 20

The regional evolution of crustal movement brought about two groups of sedimentary basins. One is under continuous subsidence up to present including the fill deposits in Fuji-Fujinomiya lowlands and Ashigara plain. Thus the deposits in the basins of this group, namely 1 a type , are found along the continuation of trough axes on land. The crustal movement in the other group (1 b type basin) was converted from subsidence to uplift, and consequently the sediments in these basins are now exposed and eroded. The Kambara conglomerate, Iwabuchi andesite and Bessho gravels in the Kambara, Habuna, and Hoshiyama Hills, the Ashigara Group in the southern margin of Tanzawa Mts. and the Sogayama Formation in the Oiso Hills are deposits of the 1 b type basins. The deposits of the 1 a and 1 b type, except for volcanic rocks, are mostly composed of monotonous conglomerate intercalating with thin sand or mud beds. The sedimentary environment of such sediments is considered to be a rapidly subsiding area around a mouth of river which has transported a large amount of coarse materials.

On the other hand, the non-basin-fill type deposits are subdivided into two groups according to their thickness and duration of deposition. The thicker deposits of the 2 a type, 200 to 300 m in thickness, have been accumulated continuously for a long time at a low sedimentary rate, without affecting the intense subsidence. The thinner deposits (2 b type), less than 100 m thick are terrace deposits, that covered the 1 b type deposits unconformably during the uplifting period. The Ninomiya Formation, the Akisawa-Tsuchiya Formations in the Oiso Hills belong to the 2 a type, and the Saginota gravels in the

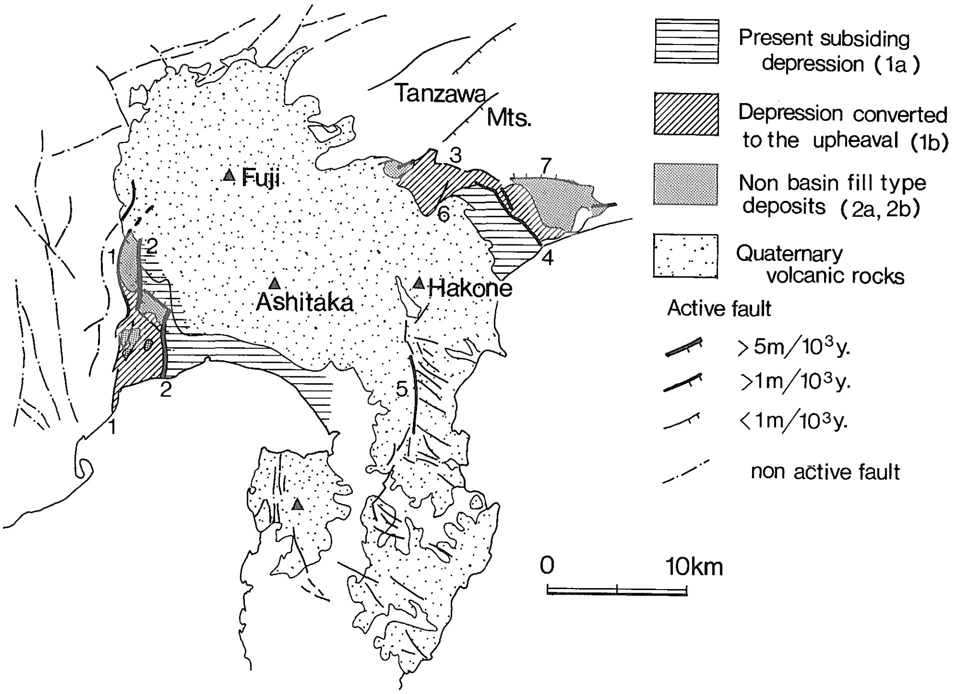


Fig. 20 Distribution of the Quaternary sediments and of active faults in the plate convergence region of the northern margin of Izu Peninsula.
Fault name: 1. Iriyama-Shibakawa thrust, 2. Iriyamase-Omiya-Agoyama fault (system), 3. Kannawa fault system, 4. Kozu-Matsuda fault, 5. Kita-Izu fault system, 6. Hirayama fault, 7. Shibusawa fault.

Kambara Hills, Older Fuji mudflow deposits in the Hoshiyama and Habuna Hills, Suruga gravels in the southern margin of Tanzawa Mts. and from the T-e to H formations in the Oiso Hills belong to the 2 b type.

7.2 Characteristics of Active Faults

The main active faults in the studied area are compiled in Table 5. Figure 20 shows the distribution of major active faults in the South Fossa Magna around Izu Peninsula. The thickness of each fault line in the figure indicates the long term slip-rate of the fault. The vertical components of slip rate of the faults in Table 5 are so large as to be classified as the most active faults in Japan. Their net slip will be larger if strike-slip component is taken into account. Notwithstanding their high activity, the length of each fault is extraordinarily short in comparison with other major active faults in Japan, such as the Atera Fault (70km) and the Median Tectonic Line (300km).

Active faults except for the fault system in Izu Peninsula are intensely developed along the northern border of Izu block (Figs. 2 and 23). They connect Suruga and Sagami troughs surrounding Izu Block from the north. This fault zone consists of many short faults. The geometric and kinematic pattern of these faults, such as the strike of the faults and the sense of fault movement, differs from place to place systematically.

In the western part, to the north of Suruga Bay, a number of N-S trending faults have developed in the Neogene deposits since early Pliocene. Among these faults, the active ones are found in the eastern side. This active fault system is expressed as zigzag lines running from south to north, where N-S

Table 5 Data list of the active faults in the Izu Borderland.

Name of the fault system	Fault name	Fault length and strike		Fault reference	Displacement (m)		Age (Ka)	Slip rate (m/10³y)	Paper Features
		(km)							
1. Iriyama-Shibakawa fault system		30+	N-S						
	1.1 Iriyama thrust	12+	N-S	River terrace deposit	5	W	20	0.25	Sugiyama & Shimokawa (1982)
	1.2 Shibakawa thrust	18+	N-S	Fuji lava SW-1	20	W	10	2	Yamazaki (1979)
				Fuji lava SW-3	30-40	W	10	3-4	Northern part
				Older Fuji Mudflow-I (Mf-I)	50	W	50	1	near Shibakawa
	1.3 Noshita thrust	6+	N-S	Mf-III	50+	W	2.5+		
2. Iriyamase-Agoyama fault system		23+	N-S						
	2.1 Iriyamase fault	10+	NNE	Fuji lava SSW-1	100	W	14	7.1	Yamazaki *et al.* (1981)
				Alluvium	46	W	8	5.7	
				Ah ash	31.5	W	6.3	5	
	2.2 Omiya fault	7	NW	Mf-III	80	SW	20	4	Normal fault
				Fuji lava SW-5	80?	SW	10	8?	
	2.3 Agoyama fault	14+	N-S	OMF base	410+	W	80	5+	
				Fuji lava SSW-3	50	W	10	5	
	2.4 Matsuno fault	6	NW	Structure of Saginota gr.					Normal fault?
3. Kannawa fault system		25	E-W						
	3.1 Kannawa thrust	--	E-W	Tanzawa G / Ashigara G boundary		N			
	3.2 Shiozawa fault	5+	NE	Suruga gravels	100 (V)	NW	80	1.2	Machida *et al.* (1975)
	3.3 Nakatsugawa f.	5+	NW	Tanzawa G / Ashigara G					
	3.4 Matsuda Sanroku fault	5-	N-S	Ashigara G / Matsuda gravels		N			Yamazaki & Machida (1981)
	3.5 North Matsuda fault	5-	N-S	Matsuda gravels	?	N			Yamazaki & Machida (1981)
	3.6 Hirayama fault	10+	NE	Hakone OS	<500	NW	300	1.7	Ito *et al.* (1989)
					7	NW	21.5	0.3	
4. Kozu-Matsuda fault		11+	NW	T-c formation	600+	NE	300	2	
				M2 deposit	135	NE	60	2.3	
				Ah ash	22	NE	6.3	3.5	
				M3 terrace	50+	NE	45	1.1+	

trending reverse faults arranged in sinistral en echelon configuration are connected by NW-SE trending normal faults. The activity of individual faulting increases from west to east.

In the central part, to the south of Tanzawa Mts., a major reverse fault trending E-W (Kannawa thrust) and its conjugate strike-slip faults trending NE-SW and NW-SE compose an active fault system (Kannawa fault system). The strike-slip faults stretch into the Tanzawa and Ashigara Mts. across the Kannawa thrust. Several active faults run parallel to the Kannawa thrust in its southern side along the border zone between Ashigara Plain. The southern most one, extending to the Kozu-Matsuda fault is the most active among them.

The Kozu-Matsuda fault has approximately straight NW-SE trending fault trace with a slight undulation. Reversal dip-slip dislocation seems to be predominant on this fault. Many minor faults run in the Oiso Hills parallel or diagonally to the Kozu-Matsuda fault, but most of them are not evident in the fault topography. Therefore, these minor faults can be regarded as insignificant subsidiary faults, such as branching or superficial ones, induced by the movements of the Kozu-Matsuda fault.

In all these three regions, the active fault systems are located exactly on the boundary between subsiding areas on Izu side and uplifting areas fringed with older basin-fill type deposits.

7.3 The evolution of crustal movements estimated from the changes of fault activity

The change of fault activity in time was reconstructed on the basis of the relative dislocation of two blocks bounded by each fault. Figure 21 shows the track of vertical movement rate in each tectonic block. The Quaternary sediments can evidence the crustal movement, subsiding, stable, or uplifting, of the covered areas during their depositional ages. The tectonic evolution of both sedimentary basins and fault systems in time and space was revealed as in Fig. 21.

The relation between sedimentation and crustal movement is summarized as follows; a) Basin-fill sediments (type 1a and 1b) indicate the predominancy of subsidence over the basin, or the area of deposition. b) Development of terrace deposits (type 2b) or overall erosion evidences the predominancy of uplifting in the area. c) Accumulation of non-basin-fill type deposits (type 2a) indicates the transitional period between subsidence and uplifting. In all three cases above, the duration of each crustal movement is indicated by the depositional age of the sediments. The affects of the eustatic sea level changes are not taken into account.

The screened spaces between two lines in Fig. 21 indicate the rate of relative displacement of adjoining blocks. For instance, the change of the space between the Kambara Hills and the mountainous area to the west represents the decline of the activity of the Iriyama-Shibakawa faults; the western

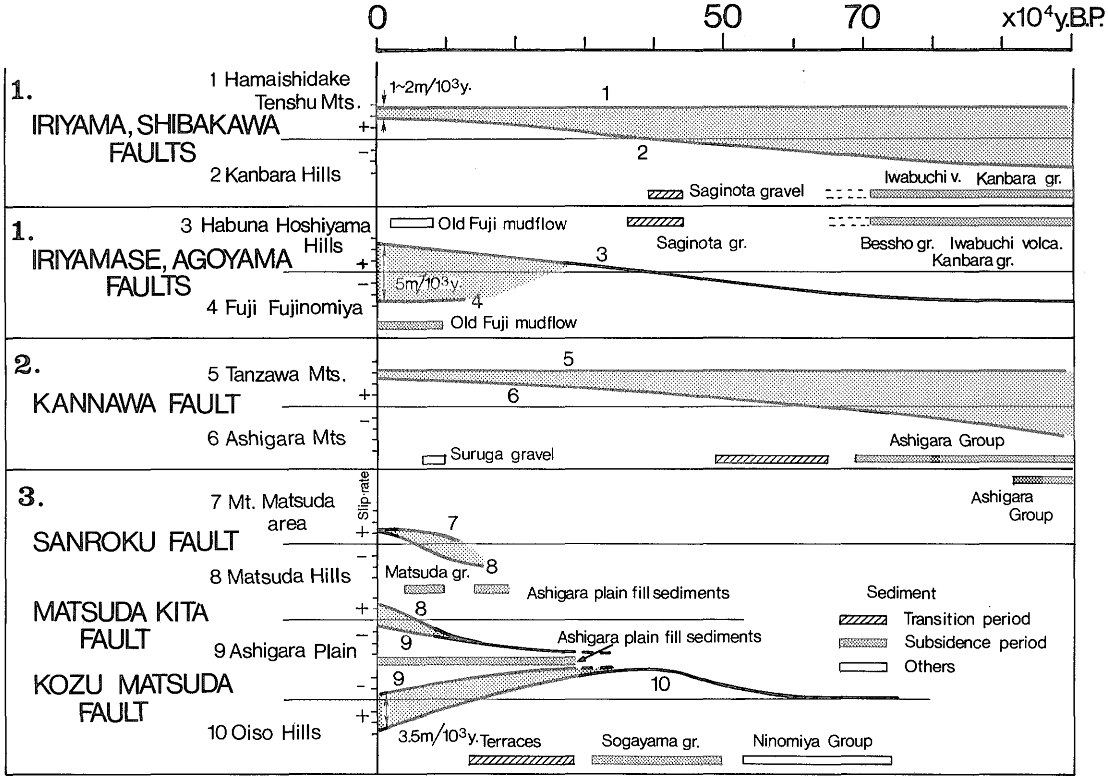


Fig. 21 Diagram showing the regional variation of tectonic evolution along the Izu Borderland. Bold-solid line represents the trace of the absolute crustal movement on each tectonic block. Screened part show the transition of relative slip rate of the active fault bounding two blocks.

mountains have been continuously uplifted in the Quaternary. So the track remains always the plus side. On the other hand, the track of the Kambara Hills stays on the negative side in the early Pleistocene judging from the deposition of basin-fill type Kambara conglomerate, which evidences subsidence of the region. Then the movement of the Kambara Hills was converted to uplift in the middle Middle Pleistocene. The alluvial fan deposits of the Saginota gravels in the Kambara Hills marks the transitional epoch. The Saginota gravels is as thick as 200 m to suggest gentle subsiding during the depositional age. However, it was emerged just after the deposition and have never been covered with younger sediments until present. The Holocene marine terraces in the hills also indicate that active uplifting has been continuing from the middle Pleistocene.

The track of the Kambara Hills, therefore, shifts from minus to plus in the middle Pleistocene as shown in Fig. 21 It is thus concluded that the activity of the Iriyama-Shibakawa fault had culminated in the Early Pleistocene and have declined since the Middle Pleistocene. The Kannawa thrust and the Matsuda-sanroku fault have also declined in the Pleistocene. On the contrary, the Iriyamase-Agoyama faults and North Matsuda fault have become more active. Though any drastic change has not occurred to the relative movement along the Kozu-Matsuda fault, the absolute movements of the Ashigara Plain and the Oiso Hills have changed in the late Pleistocene. In the middle Pleistocene, the Ashigara Plain had subsided rapidly beside the Oiso district which had been stable relative to sea level, but in the late Pleistocene, the Oiso Hills started to uplift according as the decline of subsidence in the Ashigara Plain.

The growth of Kozu-Matsuda fault scarp also indicates this change. The fault scarp had not appeared in the middle Pleistocene due to the one-sided subsidence of the Ashigara Plain, as in the case shown in Fig. 3. Then it emerged in the late Pleistocene with the uplift of the Oiso Hills. This change can explain the discrepancy between the constant activity of the fault and the topographic evidence.

The above-mentioned examples show the migration of the front of active faulting which is commonly observed in Izu Borderland. A younger fault develops along the Izu side of an older fault which becomes inactive or less active after the emergence of younger one. Such migration of active faults induces the shift of tectonic basins, as the active faults are usually located between the uplifted basin-fill deposits on the Honshu side and the active subsiding basin on the Izu side.

8. DISCUSSION

8.1 Plate tectonic implication of active faults in the Izu Borderland

(1) A model of tectonic evolution

Case studies of active faults and crustal movements in the Izu border land led to a common feature of tectonic evolution in this region. It is the Izu-oriented migration of active faults and sedimentary basins. The typical field of this migration is the area to the north of Suruga Bay. In this area, the following processes of tectonic evolution were recognized. 1) Thick sediments of the Kambara-Bessho gravels were deposited in basin developed on the downthrown Izu side of a fault system. 2) A new fault system (Iriyamase fault) was formed inside or along the Izu-ward margin of the basin. 3) A new subsiding area (Fuji lowland) has developed in front of the Iriyamase fault replacing the older basin of the Kambara Hills, where fluvial Saginota gravels were deposited unconformably to the former basin-fill sediments. Yamazaki (1984) proposed a model of the tectonic evolution in Izu Border land according to the three processes above. Here, the author proposes a new model consisting of four stages in a cycle and two substages, improving the previous model in order to make it applicable to the entire Izu Borderland (Fig. 22).

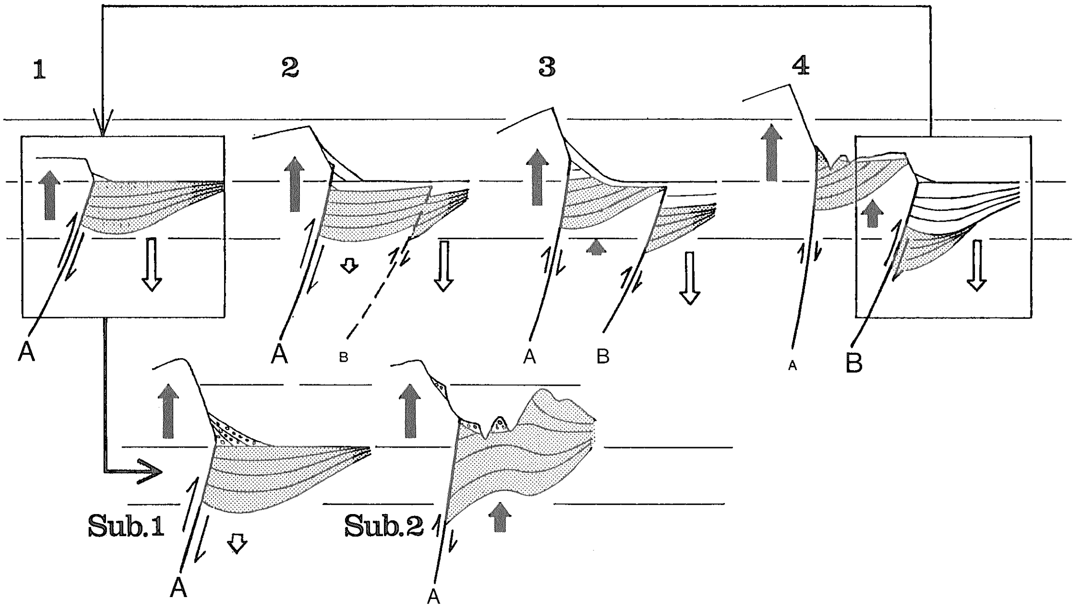


Fig. 22 The cyclic development of the geological structure associated with the Izu-ward migration of faulting and tectonic depression. Arrows represent the direction and rate of the absolute crustal movement. Fine dotted part show the same formation.

Those stages and substages are as follows:

Stage 1: The upthrown side of a thrust fault A in Fig. 22 upheaves constantly and the downthrown side subsides, where the terms upthrow and downthrow denote relative motions along the faults and "upheaval" and "subsidence" are measured relatively to the sea-level. The upheaval and subsidence share the net displacement of the fault A. The active faults systems from Suruga trough to the southwestern foot of Mt. Fuji are now on this stage 1 ; the Iriyamase fault and Agoyama fault correspond to the fault A in Fig. 22. The subsiding portion of the axis of Suruga trough, Ukishimagahara, and Fuji Fujinomiya lowlands are the tectonic depressions of the downthrown side of the active faults. The thick basin-fill sediments such as the Kambara conglomerate, Bessho gravels, Ashigara Groups, Sogayama gravels, and so on, which now compose hills or mountains, were accumulated in the previously subsiding areas at stage 1.

Stage 2: The subsiding area in front of the fault A is divided into two blocks by a new fault occurred in the basin. The upthrown side of the fault A continues to rise. Both blocks bounded by the fault B continue to subside. The subsiding rate of the strip between faults A and B decreases, while the downthrown side of the fault B subsides very rapidly. As to the faults scarps, this differential movements of three blocks bring about a sharp contrast between fault A and B. The scarp of the fault A continues to grow as a boundary between the uplifting and the subsiding area. On the other hand, no scarp emerges along the fault B, as both sides are subsiding to bury the fault topography.

The present Kozu-Matsuda fault corresponds to the fault A in the stage 2, judging from the rapid growth of the fault scarp in the late Pleistocene and from the decreasing subsiding rate in the Ashigara Plain. A concealed fault, namely B, is expected in the Ashigara Plain or on the eastern foot of Hakone volcano to the west of the Kozu-Matsuda fault. This fault, which has not yet been recognized, grows possibly farther west of the River Sakawa. Ota *et al.* (1982) supposed an active fault along the western flank of Chiyo Upland (Fig. 16), which is composed of pyroclastic flow deposits, in the eastern part of Ashigara Plain. This fault might be regarded as fault B. However, the altitude of K-Ah ash layer laid down in blackish water does not change across the cliff assumed to be a fault scarp. So it seems that this linear feature is not a fault scarp but the erosional topography of a fluvial terrace cliff, and no concealed fault can be expected between the River Sakawa and the Kozu-Matsuda fault.

Stage 3: The block between faults A and B is being uplifted (in an absolute sense) by the activity of fault B. This makes the fault A a fault between two uplifting block and its slip rate decreases. The uplifting block between faults A and B is covered unconformably with thin deposits from the upthrown side of the fault A, due to the slow rate of rising.

The Iriyamase fault near the mouth of River Fuji is regarded as the fault B in the stage 3. Alluvial fan type deposits, such as the Saginota gravels in the Kambara Hills, the Older Fuji Mudflow deposits in the Hoshiyama and Habuna Hills, fluvial terrace deposits of T-e to T-a Stages in the Oiso Hills, were deposited in the gently subsiding or uplifting areas between faults A and B in this stage 3.

Stage 4: The uplifting rate of the block between the faults A and B is accelerated and consequently the sedimentary surfaces on this block are emerged to be dissected. The activity of fault B becomes more intense with the growth of a fault scarp, differentiating the former subsiding area into terraces and hills in upthrown side. Meanwhile, fault A becomes less active, as the difference of uplifting rate decreases between the downthrown and the upthrown side. The present crustal movement on the western foot of Mt. Fuji exactly corresponds to this stage. The Iriyama-Shibakawa faults and the Iriyamase-Agoyama fault system in the east fall under the fault A and the fault B in the model respectively. While the three topographic units bounded by these two fault systems correspond to the three zones divided by faults A and B. They are the Hamaishidake Mts., the Kambara-Hoshiyama-Habuna Hills, and the lowlands of Ukishimagahara and of Fuji-Fujinomiya.

The fault B in the stage 4 is the equivalent of fault A in the stage 1, with the same crustal movement on both sides; so, a cycle of tectonic evolution is completed in these four stages. The next cycle is marked by the occurrence of new fault A derived from the fault B in the previous cycle. That is to say, the most active fault zone migrates from Honshu side to Izu side accompanying a sedimentary basin in downthrown side and a uplifted area in upthrown side.

Some cases of deviation from this cycle led to the information of the following substages: substage 1 follows the stage 1 without the formation of a fault B or a new subsiding area in the downthrown side of the fault A; its hanging wall continues to uplift. The recent crustal movement along the Kozu-Matsuda fault may correspond to this substage, supposing the concealed faults to the west of Sakawa River do not exist. In this region, the fault scarp of the Kozu-Matsuda fault grows continuously without any older fault A behind it. Meanwhile, the rate of subsidence in the Ashigara Plain decreases. Such evidence may be interpreted as deviation from stage 1 to substage 1.

Substage 2 is characterized by the extinction of the fault A without migration. As compressive stress increases, the downthrown side of the fault A (thrust fault) is deformed severely, and finally rises from the subsiding basin. This deformation results in weakening the activity of the fault A. This is a consequence of the augmentation in the rising of the downthrown block, which makes the rate of displacement along the fault smaller and the dip of the fault plane steeper. Excess shortening of a region induced by very large horizontal compression explains the phenomena described above. Recent deformation in the Tanzawa Mts. and the Ashigara Mts. fall under this substage 2, where the Kannawa thrust corresponds to the fault A. At last the fault A becomes extinct and both adjoining blocks uplift uniformly.

(2) Plate tectonic implication of active faults

In the Izu Borderland, fault systems and tectonic basin have migrated continually toward Izu Peninsular during middle to late Quaternary. This migration resembles to the evolution observed at thrust fronts in margins of inland basins (Ikeda, 1983, Ota & Sangawa, 1984). However, the migration in the Izu Borderland is quite different from that in inland basins because of the lack of the MBF (main boundary fault), which at depth is singularly expressed and its low-angled branch appears as a migrated frontal thrust in inland basins. In the Izu Borderland, the direction of the migration always oriented to the Izu Peninsula. Rapidly subsiding zones which extend to the axes of the troughs develop in front of the most active faults. The basin fill sediments in these zones will be differentiated by new faults, certain parts of which will emerge as upthrown blocks on the Honshu side being folded or tilted toward Honshu.

The Izu-ward migration of tectonic depressions and the deformation of uplifted older basin fill sediments are the characteristics of the tectonic evolution in the Izu Borderland. This evolution is the same as the growth of accretionary prism which takes place along a trench axis at the foot of a continental slope, where trench fill sediments are continuously accreted on continental slope and deformed by imbricated thrusts. The thrust develops successively into younger accreted mass. In the Izu Borderland, this accretion process occur not in deep sea bottom but in shallow sea or on land, while the process of sedimentation and tectonics are quite similar to normal accretion. This exceptional occurrence of accretion on land or shallow sea is possibly ascribed to the form of plate convergence in this area. Plate dynamics will be discussed in the section 8.2. (2).

The trough fill sediments on the northern extension of Suruga and Sagami troughs, therefore, are considered to have been accreted to Honshu and deformed along with the subduction of the PHS during at least these hundreds of thousands years. And the deformation of the accretionary prism along Nankai trough continues through Suruga trough to the Izu Borderland on land. Consequently, the crustal deformation in this region can not be regarded as interplate deformation, that is to say, none of the active faults is a superficial expression of a plate boundary, but it is deformation of accretiorary prism, where imbricated thrusts system develop in the hanging wall over the subducting plate (Kagami *et al*., 1983).

Seely *et al*. (1974) proposed on the mechanism of migration that the underthrusting of wedge-shaped slices composed of younger trench fill sediment made the dip of the thrust steeper finally to immobilize it, and then new thrust developed in front of the older ones. Besides this mechanism, the author supposes that in case of buoyant subduction, strong compressional stress in accretionary prism tends to immobilize older thrusts. The stress can only be released by generating new thrusts in front. Tsuchi (1984) concluded that Neogene series had successively accreted to the west at the Suruga trough in the South Fossa Magna region west of Suruga Bay, because the tectonic units divided by N-S trending faults got younger from west to east. Accordingly, the author thought that the formation of accretionary prisms has continued since the Miocene until present repeating the migration and regeneration of fault systems and sedimentary basins.

8.2 Regional characteristics of crustal movements and their origin

(1) Regional difference of the crustal movement

The active tectonics in the Izu Borderland can be regarded as deformation of the sedimentary prism in an accretion process, as it was concluded in the previous section. Nevertheless, the crustal movements here are not uniform in time and space for their extent or duration and they sometime deviate from the model. As to the extent and duration of accretion process, the one on land to the north of Suruga Bay has more closely-spaced imbricated thrusts (as much as a few kilometers) and much shorter time period of reactivation (about several hundred thousand years) than that of Nankai trough and southern Suruga trough, where it is 5 to 10 km (Kato *et al.*, 1983) and several million years, respectively (Shimamura, 1986).

Typical deviation from the circular model (Fig. 22) was observed in the area of the southern margin of Tanzawa Mts., where the tectonic evolution has developed from the stage 1 to the substages 1 and 2. Notwithstanding the conversion of the crustal movement from the subsidence to upheaval in the sedimentary depression of Ashigara Group, which had occurred during middle Quaternary time, neither new fault system nor basin have developed in front of the depression. Consequently, the uplift of the Ashigara Group has continued to convert it to a dissected mountainous area (Ashigara Mts.). Accordingly, the fault between the two uplifting blocks, here the Tanzawa Mts. and Ashigara Mts., became less active and finally ceased to move. This transition of the fault movement presumably was induced by the decrease of relative slip due to the rapid uplift of the Ashigara Mts. The dip of the reverse faults has also become steeper because of the shortening of the block with increasing compressive stress.

The crustal movement between Yamakita and Matsuda along the southern foot of the Matsuda Mts. agrees with the circular model. But the width of each block between two faults is very short, up to 1 km and the duration of one cycle is also very short up to one hundred thousand years. So, the horizontal spacing and the time interval for the fault migration in this region are the smallest in the studied area.

The tectonic evolution in the Oiso Hills and the Ashigara Plain is characterized by the lack of an older cycle of accretionary prism. No imbricated structure is found behind the present active zone. The author considers that an accretion process begun in the middle Quaternary in this region and a different tectonic regime had been predominant before the initiation of the accretion.

(2) The origin of the regional difference

The regional characteristics of the crustal movements in the Izu Border land can be ascribed to the difference in the form of plate convergence. In this sense, the Izu Borderland is no longer an uniform collision zone as has been supposed by Sugimura (1972) or Matsuda (1978) and others. This widely accepted collision has never been studied in detail to substantiate. For example, Matsuda (1984) defined the beginning of collision merely by the disappearance of the open sea between Izu and Honshu due to the northwestward shift of Izu Block. Only Ishibashi (1896a) discussed the evolution of the form of convergence in time. He concluded that subduction, buoyant subduction and collision have been repeated in this order since the Middle Miocene in the South Fossa Magna.

Now, the author proposes to apply Ishibashi's three variation of the convergence form not only to the historic development but also to the regional difference of crustal movements. On the solid basis of active tectonics, the so-called collision zone of the Izu Borderland can be subdivided into collision zone sensu stricto, subduction zone and buoyant subduction zone.

In the area to the north of Suruga Bay, the crustal movement has been subjected to the subduction or buoyant subduction of the PHS. The migration of fault system and the formation of sedimentary basin are common tectonic results of both subduction styles. With reference to the these two subduction style, Ishibashi (1986 a) took the cumulative uplift of hinterland as evidence of the buoyant subduction. The subduction style in the area to the north of Suruga Bay is supposed to be buoyant because the distinctive and extensive uplift (4mm/yr) is recognized in the Akaishi Mts., the hinterland of this area (Danbara, 1971). This feature is distinguished from normal subduction such as along Nankai trough, where coseismic uplift has been repeated without conspicuous cumulative upheaval of the accretionary prism and frontal arc. Along the southern margin of Tanzawa Mts., both sides of the Kannawa fault system have been uplifted without generating younger basin, and the fault activity itself is not so high. Intense horizontal compressive stress raises all this area, and the former main fault is no longer a boundary fault between blocks, being truncated by a number of strike-slip faults. This may indicate that brittle disruption of the blocks is occurring, or about to occur in this region. This style of crustal deformation exactly correspond to the collision *sensu stricto* defined by Ishibashi (1986a). Therefore, Izu Block collides against Honshu only along the southern margin of the Tanzawa Mts. in the Izu Borderland.

The active accretion process around the Matsuda Mts., the Oiso Hills and the Ashigara Plain indicate the underthrusting of the PHS beneath these areas. The rapid uplift of the Tanzawa Mts. area behind the Matsuda Mts. can be ascribed to buoyant subduction in this part. However, the spatial intervals of active faults here are much shorter than those to the north of Suruga Bay and also the migration of active fault front has occurred more frequently. Therefore, the transition from buoyant subduction to collision may be under way in the Matsuda Mts. area. These regions lack older accreted block in Honshu side behind recent active zone, and now we can observe the first and the latest cycle of accretionary evolution. This cycle commenced in the middle Pleistocene because of a new plate convergence system that had occurred at that time. But this convergence as well as the possible transition in the Matsuda Mts. area has not been evidenced geologically to discuss its cause. These regional characteristics above are summarized in Table 6.

The arrangement of plate convergence forms seems to be systematic in the Izu Borderland. That is, the collision *sensu stricto* occurs between the Tanzawa Mts. and the northern most part of Izu Block. The

Table 6 Regional tectonic variation along the plate convergence zone.

	Subduction Zone	Buoyant Subduction Zone	Transitional Zone	Collision Zone
Rigion	Nankai-Southern Suruga trough	Northern Suruga trough to SW foot of Fuji Volcano	Southern foot of the Matsuda Mts.	Northern Hakone and S. margin of W. Tanzawa Mts.
Dip of subducting slab (degree)	13-14$^{1)}$	More than 23° $^{1)2)}$	?	?
Distance of imbricated thrusts	30-10 km$^{3)}$	less than 10 km	1km+	0
Age of the youngest accretionary prism	Miocene to Lower Pliocene$^{4)}$	Lower to Middle Pleistocene	Middle to Upper pleistocene	-
Time interval of major fault migration	a few Ma	less than 1 Ma	less than 0.1 Ma	0
Other features				Upheaval of plate boundary region

Reference cited $^{1)}$Kato *et al.* (1983), $^{2)}$ Ishida(1986), $^{3)}$ R.G.A.F.J.(1980), $^{4)}$ Shimamura(1986) buoyant subduction occurs both in the west and in the east of the collision zone, north of Suruga Bay and the Matsuda Mts. area respectively, and then normal subduction occurs in both extensions of the Izu Borderland. This symmetrical arrangement of three convergence forms must be originated from the steepening of the subducting slab. Figure 23 is an isobath map of the upper surface of the subducting slab of PHS, with submarine active faults (R.G.A.F.J., 1980) overlaid to show the intervals of imbricated thrusts. The dip of the subducting slab becomes steeper from Nankai trough to Suruga trough (Kato *et al.*, 1983). The absence of isobath further north of central Suruga trough is because the dip is too steep to recognize the slab surface by seismic reflection profiles. The relationship between the forms of convergence and the dip of slab is supposed as follows: as the dip becomes steeper, the form varies from normal subduction to buoyant subduction, and finally to collision and in the meantime the intervals of imbricated thrusts get narrower. The steepening of the slab dip toward the collision boundary should mainly be originated from the buoyancy of Izu Block. Beside, the steeper subduction results in tighter coupling of the blocks on both sides, where the tectonic stress induced by the plate

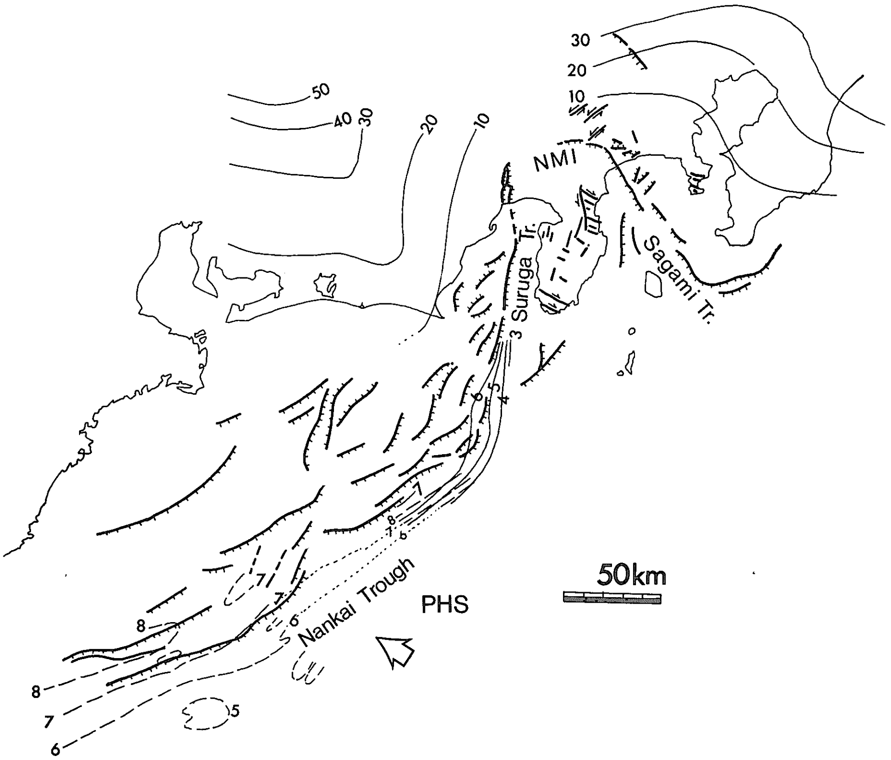


Fig. 23 Relationship between regional variation of the subduction angle of the PHS plate and tectonic deformations including the active fault movements.
Bold lines : Active faults along the plate convergence zone (after R.G.A.F.J., 1980). Thin-solid lines along the Nankai trough : Contours of depth to the basement of Izu Spur. Numeral is in kilometers below sea level (after Kato *et al.*, 1983). Thin-broken lines along the Nankai trough : Contours of depth to oceanic basement (after Kato *et al.*, 1983). Thin-solid line in land : Contours of the upper surface of the subducting Philippine sea plate (after Ishida, 1986).

motion is easily transmitted to Honshu to bring about intense crustal movement in the hinterlands.

8.3 Seismotectonics of the Izu Borderland

Large vertical slip rate disproportionate to the length distinguishes the active faults in the Izu Borderland from the other major inland active faults in Japan. Frequent occurrence of large earthquakes is usually expected from faults in order to maintain this high activity. Nevertheless, no earthquake has been recorded in this region except for the Ansei-Tokai earthquake of 1854, when the Iriyamase fault moved around the mouth of the River Fuji.

The mode of seismic activity, i.e. recurrence interval of earthquakes from a fault and their magnitude or amount of slip, has been estimated only for the Kozu-Matsuda fault in the Izu Borderland. Matsuda *et al.* (1978) identified the Kozu-Matsuda fault to the source fault of the Oiso-type earthquake. Furthermore Matsuda (1985) estimated its recurrence interval at 170 years and the vertical slip per event at 0.5 to 1.0m, based on the assumption that the magnitude is $M=7$ considering that the fault length (10 to 20km) is not large.

On the other hand, Yamazaki (1985) proposed a quite different estimation that the interval is as long as 2,000 years and the vertical slip more than 7 m. These values were drawn on the basis of geological and geomorphological evidences. They are: 1) The Ashigara Plain has been subsiding constantly at a rate of 0.65 m/10^3 years since middle Late Pleistocene. 2) Both the Oiso Hills and the Ashigara Pain were uplifted by the great Kanto earthquake of 1923. 3) Three levels of the Holocene marine terrace surfaces are recognized along the Oiso Hills. Accordingly, two modes of coseismic uplift, the first being the Oiso-type earthquake with long recurrence interval and the second the Kanto-type earthquake with shorter interval (about 800 years), were considered to overlap in the Ashigara Plain and the Oiso Hills. The model of the crustal movement in Fig. 24 explains well this overlapping and the three pieces of evidence above. The step-like lines in Fig. 24 show the vertical movements of the Oiso Hills (upper, uplifting) and the Ashigara Plain (lower, subsiding). This demonstrates that the latest Oiso-type earthquake is dated ca. 2,300 yr B.P. and there after this region has been uplifted only by Kanto-type earthquakes.

The other active faults seems to have similar characteristics of seismicity to the Kozu-Matsuda fault judging from their large slip rate and absence of earthquake record in the last 1,000 years. These active faults are imbricated thrusts in accretionary prisms and can be regarded as subsidiary faults branching from the main fault. The main fault itself is the plate boundary between the PHS and EUR and only this fault acts as earthquake source. Therefore, the recurrence intervals of earthquakes cannot be proportional to the activity and the length of each surface active faults. The seismicity along the plate boundary in the Izu Borderland is not so active as

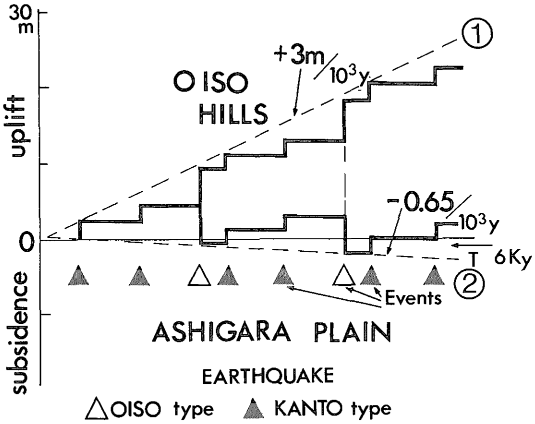


Fig. 24 Diagram showing the relationship between the crustal movements on the Oiso Hills and Ashigara plain and the occurrence of the Oiso-type earthquakes.
1: Uplift rate of the Oiso Hills. 2: Subsidence rate of the Ashigara Plain. Filled triangles: Occurrence of the Kanto-type earthquakes. Open triangles: Occurrence of the Oiso-type earthquakes.

along the Nankai trough or the southern Suruga trough. The difference of the form of plate convergence again well explains the longer recurrence interval in the Izu region. That is to say, the buoyant subduction and the collision in the Izu Borderland consume much less energy in faulting along the plate boundary than a normal subduction. So, slow rates of stress accumulation along the plate boundary faults causes the recurrence interval to be longer than that of the boundary along Nankai trough.

Ishibashi (1988a, b) proposed the N-S trending fracture zone, West Sagami Bay fracture zone, splitting the PHS on the east of Izu Peninsula for the source of M=7 size earthquakes which have caused serious damage on Odawara city with about 73 years interval during historical times. This proposal is mainly based on the analysis of the crustal movement at great Kanto earthquake of 1923, of tsunami sources and of damage distribution of several historical earthquakes. In spite of the obvious structure of the proposed model of the fracture zone, no evidence supporting the proposal is found except the uplift of the Hatsushima Island off Atami coast and submarine scarps in Western Sagami Bay. Although the fracture zone is inferred beneath the western margin of the Ashigara Plain, any supporting evidence can not recognized in this area at present time. Accordingly, it is difficult to comment on this fracture zone from the viewpoint of the Quaternary tectonics on land.

9. CONCLUSIONS

The Izu Borderland is a convergent plate boundary on land that combines Suruga trough with Sagami trough. The tectonic evolution and recent crustal movement along this boundary are discussed on the basis of geological and geomorphological research from the viewpoint of plate tectonics. Through this research, the author revealed the significance of the regional Quaternary faulting in the setting of plate tectonics in the Izu Borderland and interpreted that the active faults in the region are characteristically the imbricated thrusts with short length and high slip-rate occurred in the accretionary prism. This study also revealed that the Izu Borderland, previously believed to be a uniform collision zone between the PHS and EUR, can be divided into two zones, the zone of collision *sensu stricto* and the buoyant subduction zones, on the basis of the regional features of Quaternary tectonics. Besides, the author discussed the style and recent activity of an active fault in this area with respect to the coseismic crustal movement. Consequently, this study may be useful in the advancement of the knowledge on the seismotectonics in the Izu Borderland which is indispensable for the earthquake prediction in Japan.

The main results are as follows.

1) The study area to the north of Izu Block is divided into three areas according to their tectonic characteristics. In each area, the Quaternary chrono-stratigraphy, geologic structures and active faults, especially with respect to their history of activity and the crustal movement in both sides of the fault, were described.

2) Distinctive active fault systems have developed in the Izu Borderland surrounding the northern margin of Izu Peninsula. Thrust type dip slip faults are predominant in this region with the highest class slip-rate in Japan. In the area to the north of Suruga Bay, there are two N-S trending fault systems which consist of several short faults arranged en echelon. The eastern, Izu side system is younger and more active than the western system in the Quaternary. This indicates that the place of intense fault activity migrates Izu-ward from west to east. The same phenomena was recognized in the southern foot of Tanzawa Mts. The length of each fault, less than 20 km, is very short disproportionately to its high activity (slip-rate more than 1 m/10^3 years) as compared with the same type of active faults in other regions of Japan.

3) The Quaternary system in the study area is classified into basin fill type and non basin fill-type deposit on the basis of their lithofacies, thicknesses and tectonic features. The active faults develop on the boundary between older uplifted deposits in the Honshu side and present sedimentary basin in the Izu side. Subsiding areas have migrated towards Izu Peninsula along with the migration of fault systems.

4) The Quaternary tectonics in most parts of the Izu Borderland are controlled by buoyant subduction of the Philippine Sea Plate except for a small portion where exact collision occurs. That is, the Izu Borderland is not a uniform collision zone as has been supposed widely. The buoyant subduction is evidenced by the formation of accretionary prism on land in this region. Accordingly, the active faults in the Izu Borderland are imbricated thrust faults caused in accretion process, as branched fault from the concealed boundary fault of plates. This is one of the reasons why the active faults in the Izu Borderland have higher slip-rate than those in other region of Japan independent of their fault length.

5) It is impossible to interpret all of the active faults and crustal movement from the viewpoint of the accretion process. The three regions divided in the conclusion 1) show distinct regional tectonic difference. This difference is ascribed to the variety of the form of plate convergence. The form changes from collision *sensu stricto* in the southern margin of Tanzawa Mts., to buoyant subduction in both eastern and western flanks of the Borderland, and finally normal subduction along the Suruga and Sagami troughs. Beside this difference in space, the transition of convergence form were recognized: in the southern margin of Tanzawa Mts., buoyant subduction was converted to collision at the end of Early Pleistocene. In the Oiso Hills and the Ashigara Plain, buoyant subduction commenced in early Middle Pleistocene.

6) The active faults in the Izu Borderland have a recurrence interval of several thousand years and the displacement by an event should be more than several meters. They are essentially imbricated thrusts in the accretionary prisms: therefore, it is the megathrust along the upper surface of the subducting slab which is the controlling force of the activity of the above mentioned faults. The seismic activity represented by the active fault movement along the northern tip of the PHS decreases from the normal subduction zone of Suruga and Sagami troughs to the collision area of the southern margin of Tanzawa Mts. due to the steepening and the buoyancy of the subducting slab. This decrease accords with the low frequency of earthquakes in the Izu Borderland.

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伊豆半島北縁プレート境界域の地殻変動

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要旨

フィリピン海プレートとユーラシアプレートの衝突境界と考えられる伊豆半島の北縁部地域は，衝突運動を反映した第四紀の活発な地殻運動の存在が知られている。しかし，従来の研究では極めて広域的なプレート運動と，実際に野外で観察される活断層の運動やそれに関連する地殻変動との具体的な関係の解明は不十分であった。このため，地震予知上重要な地震テクトニクスの研究もあまり進捗していなかった。

広域テクトニクス上での活断層の運動の意味を明らかにするため，本論では伊豆半島北縁部を１．駿河湾北岸内陸域，２．丹沢山地南縁地域，３．大磯丘陵・足柄平野地域に分け，各地域の第四系の層序，層相，及び断層運動の調査等を通じて第四紀中・後期の地殻変動史を復元した。この過程では，断層活動の考察において，従来からの相対的な断層変位速度だけでなく，断層に境される各地塊の隆起・沈降などの絶対運動にも着目して調査を進めた。これから第四系を堆積時及びその後の地殻変動の特徴によって大きく４つに区分した。

地殻変動史の調査から，各地域に共通するいくつかの広域的な地殻変動の特徴と，他地域とは一致しない独自の特徴が認められた。広域的な特徴は激しい沈降域が徐々に隆起域に変化することと，活断層や沈降域などが規則的，周期的に伊豆側に移動することである。この特徴に基づいて地質構造の発達モデルが構築された。

このモデルの成因の考察，並びにモデルに当てはまらない諸特徴の原因の考察から，伊豆北縁部での地殻変動は，基本的には陸的な性格をもつ軽いスラブの沈み込み（浮揚性沈み込み）が従来衝突域と考えられていた内陸地域にも起きているため，そこに付加体が形成されること，そして，更にその運動の進行の結果沈み込み帯が衝突域に変化することで説明できる。すなわち，現在の駿河，相模両トラフの陸側延長域では浮揚性の沈み込み運動が進行し，古い沈降域の隆起と新しい沈降域及び断層運動の伊豆側への移動が起きていると考えられる。これに対し，丹沢山地南縁は伊豆地塊の沈み込みが困難となったために衝突境界に変り，上記の沈降域の形成などの沈み込み帯の特徴が全く認められなくなっている。

これから，この地域に存在する活断層の多くは付加体中に発達する覆瓦スラストと考えられ，これを支持するデータやその特徴を提示した。更に，この考えに立って国府津・松田断層の活動周期，変動様式を考察し，従来の内陸活断層とは断層長と変位量の関係などを同列に論じられないことを示した。

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