Orignal Article

Stratigraphy and Tectonics of the Ashigara Group in the Izu Collision Zone, Central Japan

Isamu IMANAGA

Kanagawa Prefectural Museum of Natural History, 499 Iryuda, Odawara, Kanagawa, 250-0031, Japan

Abstract. A stratigraphical study of the Plio-Pleistocene Ashigara Group in the Ashigara Mountains, including an inquiry into its age, depositional environment, and volcanic activity, has elucidated the tectonic history of the Izu collision zone. The results are summarized as follows:

1) The Philippine Sea Plate began to subside along a trough to the south of the Tanzawa Mountains prior to 2.0 Ma, when the Ashigara Group began to be deposited.

2) The Philippine Sea Plate (PHS Plate) moved in a NNW direction during deposition of the Hinata and Seto Formations (in the lower part of the Ashigara Group). The direction of PHS Plate motion changed to WNW at around 1.72 Ma, after deposition of the Hinata and Seto Formations.

After the change in plate motion, uplift of the Tanzawa Mountains lessened, providing less clastic sediments to the south and to the Hata Formation.

3) The Philippine Sea Plate changed its direction of motion from WNW to NNW along with the North American Plate at about 1.0 Ma.

4) Pyroclastic rocks and lavas effused onto the deep-sea plain and continental slope during deposition of the Hinata and Seto Formations. A subaqueous explosion also occurred during deposition of the Hata Formation. Pyroxene andesite and hornblende andesite dikes and sheets were simultaneously intruded during deposition of the Hinata, Seto and Hata Formations.

5) The E-W trending Kannawa Fault or a similar one had been active since the time of conglomeratic deposition of the Seto Formations.

Key words: Ashigara Group, Kannawa Fault, Philippine Sea Plate, collision, plate motion, conglomerate

Contents

1. Introduction

It has been thought that the depositional basin of the Ashigara Group is located within a collision zone in the northern part of the Izu Peninsula on the Philippine Sea Plate (Fig. 1). The Kannawa Fault, which separates the Ashigara Group from the Tanzawa Group, is thought to be a plate boundary between the Philippine Sea Plate and the Honshu Arc of the Eurasian Plate (Sugimura, 1972).

The Ashigara Group is well known from a sedimentological view and is characterized by a huge amount of conglomerate. This group exhibits two cycles of coarsening upward, from muddy sediments of the Hinata and Hata Formations to

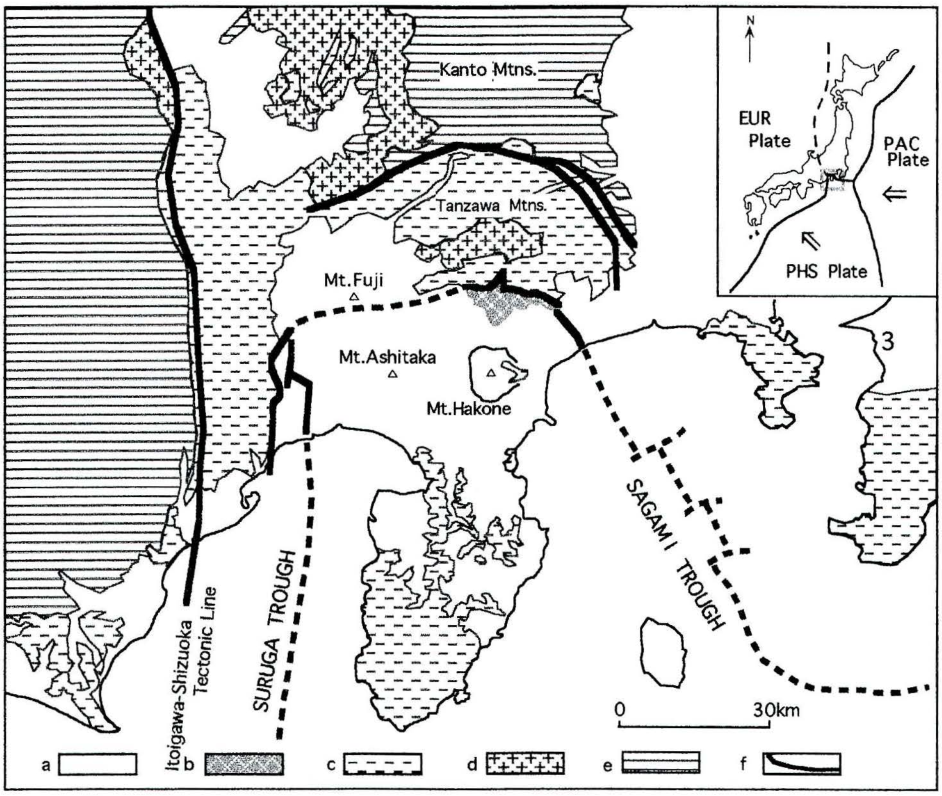


Fig. 1. Geological map of Izu-Tanzawa area as simplified from Kakimi et al. (1982).
a : Quaternary, b : Plio-Pleistocene Ashigara Group, c : Neogene d : Neogene intrusive rocks,
e : Pre-Neogene, f : Major faults

conglomeratic sediments of the Seto and Shiozawa Formations. These depositional sequences reveal the detailed tectonic history of the collision processes between the Izu block and the Tanzawa Mountains of the Honshu Arc.

Igneous activity occurred throughout deposition of the Ashigara Group as a result of this collision, and resulted in extrusion of a huge breccia in the middle part of the Hata Formation as well as intrusion of the Yaguradake quartz diorite. The Ashigara Group was cut by the Kannawa Fault and several others and subsequently underwent intensive folding.

I discuss the depositional history of the Ashigara Group, including its igneous activity, and clarify the tectonics of the Ashigara area on the basis of a refined geologic time scale that is evaluated by means of K-Ar dating of igneous rocks and calcareous nannofossils.

This paper is a partially revised version of the doctoral dissertation to the University of Tsukuba.

2. Review of previous studies

Hirabayashi (1898) first described the Ashigara Group and said that the Bed in the Yamakita - Oyama area is composed of conglomerate, sandstone and mudstone with monoclinal folding to the northwest. The Ashigara Tertiary Bed contains shallow marine molluscs and unconformably covers the Misaka Bed in the north.

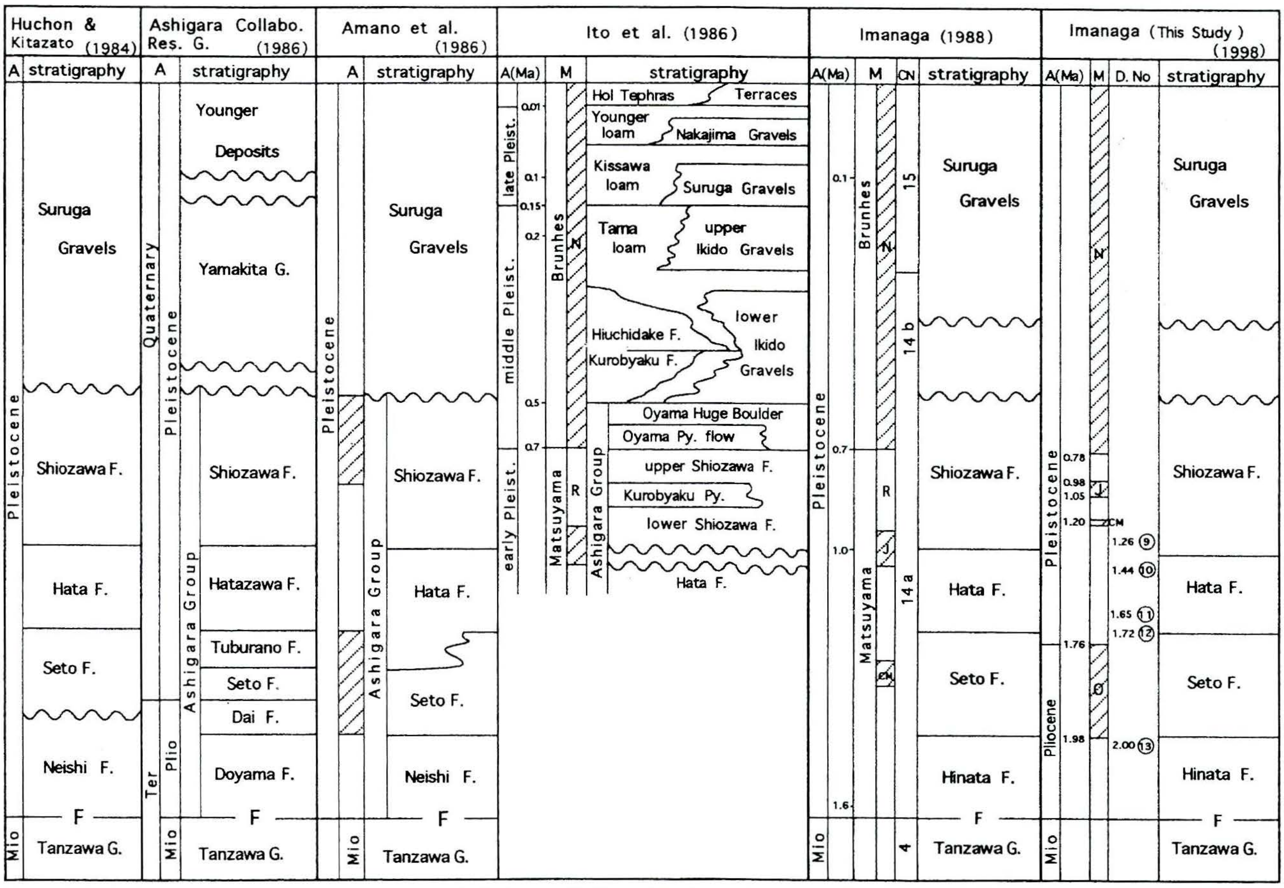
Kato (1910) first assigned the Ashigara Bed a late Tertiary age, based on molluscan fossils, and noted that it was in thrust fault contact with the Misaka Bed.

Tsuya (1942) divided the Ashigara Group into upper and lower horizons based on its lithic character. The upper horizon is characterized by alternations of sandstone and conglomerate, including a large amount of both quartz dioritic and greenish metamorphic rocks, and the lower horizon consists of an conglomerate that is almost devoid of quartz dioritic pebbles. The boundary of these two horizons is coincident with that of the Hata Formation and Shiozawa Formation in this study.

Kuno (1951) subdivided the Ashigara Bed into upper, middle, and lower zones. He inferred that "the dikes intruded and pyroclastic rocks were laid down in water and followed by the deposition of the sediments without any time intervals, and the quartz diorite plug of Yagura-dake intruded at a comparatively shallow depth, probably not much greater than that at which the dikes intruded." From the view point of plate tectonics, Sugimura (1972) noted that the Ashigara area is a possible location of the plate boundary between the Eurasian and the Philippine Sea Plates. Niitsuma and Matsuda (1984) pointed out that the South Fossa Magna had been an actively subsiding area since the Miocene and that dynamic changes might be related to the collision of Izu-Bonin Arc. Moreover, they suggested that exposures of the Miocene crystalline schist in the Tanzawa Mountains indicate deep denudation due to strong uplifting after Miocene burial.

The depositional environment of the Ashigara Group was discussed as follows by Huchon and Kitazato (1984), Kitazato (1997) and Ito (1985), based on benthic foraminifers and sedimentary facies: the lowermost part, the Neishi Formation

Table 1. Comparison table of the stratigraphical studies in the Ashigara area.



A : GeologicalAge, M : Magnetic Polarity Chron, CN : Calcareous nanno fossil age (Okada and Bukry, 1980), D. No. : Datum No. of Calcareous Nannofossils and their age (Sato and Kameo, 1996).

(the Hinata Formation of this study) formed on a lower slope or abyssal plain at 1,000-2,000 m depth; the Seto Formation was a submarine fan at 200-600 m depth; the Hata Formation represents a shelf edge at 100-300 m depth; the Shiozawa Formation represents a shallow marine environment in less than 30 m depth. Ito (1985) suggested that the Ashigara Group represents the regressive phase of a progradation as it changed from a lower submarine fan/basin plain, through submarine volcano-mid-upper submarine fan/slope, to a fan delta system.

A peculiar deposit in the Hata Formation, consisting of huge boulders and conglomerates of andesitic rock 2 km northwest of the Yaguradake intrusion, has been discussed by many workers. For instance, Imanaga (1977) interpreted it to be an olistostrome. These sediments have also been regarded as volcanic collapse deposits (= the Yamakita Group) that unconformably cover the Ashigara Group, as described by the Ashigara Collaborative Research Group (1983). Ito et al. (1985) thought they were explosive vent fills (= the Hatazawa Vent Fill) in what were once the source of the Ikudo Pyroclastic Flow in the uppermost part of the Shiozawa Formation. Amano et al. (1986) and Ito (1985) considered the Hata Formation deposit to be a diatreme-like body (= the Hatazawa Breccia) and a subaqueous caldera collapse breccia, respectively. According to Amano et al. (1986), hornblende andesite dikes related to this conglomerate shows random strikes, and occur near to the central conduit, the pyroxene andesite dikes have nearly parallel strikes, and the dominant direction of σ Hmax is N52° W. Amano et al. (1986) also observed that the direction of the maximum compressive stress (σ 1) obtained from analysis of the sets of conjugate minor faults is N30-40° W, is nearly horizontal, and that the direction of the minimum compressive stress (σ 3) is NE-SW and horizontal; the σ Hmax obtained from the dikes correlates with the direction of σ 1 and is identical with that of the movement of the Philippine Sea Plate (PHS Plate); the eastward and westward bending of the PHS Plate would have affected this stress field.

Huchon and Kitazato (1984) studied the stress field by using fault systems and separated the successive events as follows: after final deposition of the beds, the area was overthrust by the Tanzawa Mountains along the Kannawa Fault and folded by a NW-SE compressional stress field; the direction of compression changed to N-S or NE-SW from NW-SE when the collision of the Izu Peninsula transpired at about 0.3 Ma. Someno et al. (1984) and Ito et al. (1986) subdivided the Shiozawa Formation into the Lower Shiozawa Formation, the Upper Shiozawa Formation, the Oyama Conglomerate Bed, and the Tama Loam Bed (or equivalent beds), in ascending order.

The molluscan fossils were investigated by Otuka (1931), Kuno (1951), and Matsushima (1982).

Otuka (1931) pointed out that Umbonium suchiense Yokoyama in the middle zone of the formation is characteristic of the early Pliocene.

Matsushima (1982) suggested that the fossil fauna in the middle part of the group is dominated by an upper bathyal assemblage, and that the fauna in the lower horizon of the upper part is dominated by an assemblage representing the subtidal and intertidal zone. The geologic age of the Ashigara Group is thought to be early to middle Pleistocene.

Imanaga (1976, 1977) studied the stratigraphy of the Ashigara Group and gave a diagram showing the direction of dikes in the Ashigara Group (Imanaga, 1980). Imanaga (1982) discussed the deformation of the Ashigara Group from the view point of collision tectonics and considered the dome-like folded structure of the Ashigara Group to have been formed by wedging between the Izu Block and the Honshu Arc.

Ito et al. (1986, 1989) discussed the tectonic evolution of the northern border of the Philippine Sea plate.

Studies on the motion of the Philippine Sea Plate are as follows:
Tanahashi(1986) noted on the study along the Sagami Trough to the south of Boso Peninsula that the relative motion of the PHS Plate to Eurasian Plate changed from N to WNW in 1-2Ma and from WNW to N at 0.5Ma. Sugiyama (1989) noted that the relative motion of the Philippine Sea Plate with respect to southwest Japan was thought to have changed from NNW to nearly west in the middle Pliocene and from nearly west to WNW in the middle Pleistocene.

Sugiyama and Shimokawa (1982) suggested that in the Ihara area on the western side of the Izu collision zone, the σ Hmax stress changed from E-W to NW-SE in the middle Pleistocene.

Yamazaki (1992) described the regional diversity of Quaternary tectonics along the northern margin of the Izu Peninsula, including intense regional uplift along the southwestern margin of Tanzawa Mountains since the middle Pleistocene.

3. Topographic setting

The Ashigara Mountains is located between the Tanzawa Mountains to the north and the Hakone Volcano to the south, and faces the Ashigara Alluvial Plain to the southeast (Fig.2). The mountains are present in Matsuda Town, Yamakita Town, and Minami-Ashigara City in Kanagawa Prefecture and Oyama Town in Shizuoka Prefecture.

The Sakawa River runs eastward through the Ashigara Mountains and forms deep valleys (Figs. 2, 3). The Kochi, Minase, and Hisari Rivers are the tributaries of the Sakawa River (Fig. 3) and flow southward down from the Tanzawa Mountains to the north. The Ayusawa and Shiozawa Rivers are tributaries of the Sakawa River and flow eastward from the western part of the Ashigara Mountains.

The Uchikawa and Karikawa Rivers (Fig. 3) have a NE-SW orientation in the southern parts of the Ashigara Mountain and flow along the border between the Ashigara Mountains and Hakone Volcano.

Planation surfaces at about 250 m to 300 m, about 320 m to 350 m, and about 350 m to 400 m above sea level occur along the Sakawa River.

The Ashigara Mountains are flat-topped and mostly 500-800 m above sea level. Steep NE-SW trending V-shaped valleys, such as the Hatazawa and Shasuinotaki Valleys, and NE-SW trending summits predominate in the Ashigara Mountains.

Mt. Yaguradake, 870 m (Fig. 2) high, is the highest peak in the Ashigara Mountains. Isolated hills such as the Shiroyama (220 m), Sengenyama (240 m) and Maruyama (250 m) extend east and west, and lie between Yamakita Town and the Sakawa

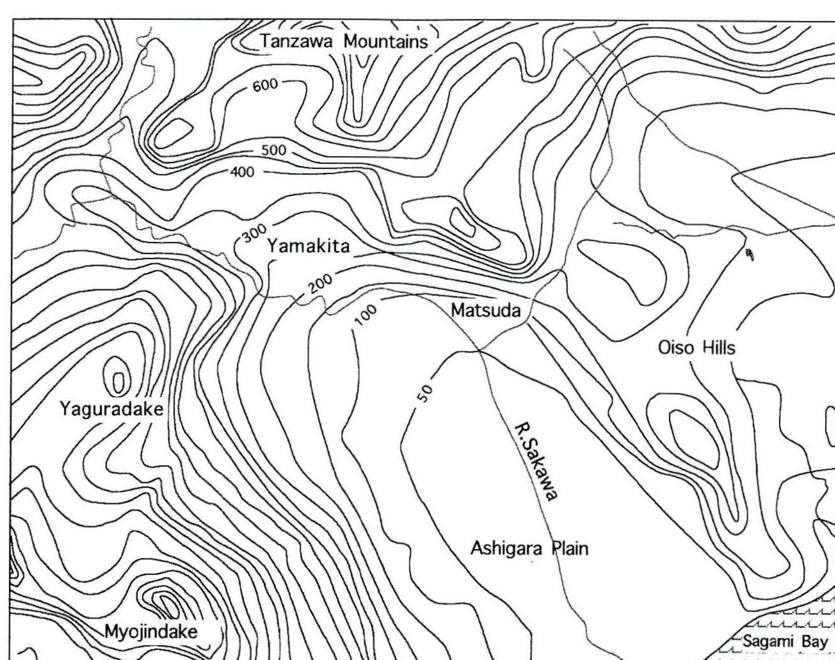


Fig. 2. Summit level map of the Ashigara area and its vicinity.

Table 2. Stratigraphical section of the Ashigara Group.

Age		Magnetic Polarity Chron	Formation		Columnar Sec.	Lithofacies	Thickness
Quaternary	0.08Ma	Brunhes	Suruga gravels			gravels	
Quaternary	0.78Ma	Matuyama	Ashigara Group	Shiozawa F.		dacitic py. rock andesitic py. rock alt. (cong. /s. s.) fossil shells	2300m+
Quaternary	1.26Ma	Matuyama	Ashigara Group	Hata F.		alt. (s. s. /silt st.) breccia dacitic py. rock cong., lava qt. dio. mass	600~ 1000m
Pliocene	1.72Ma	Matuyama	Ashigara Group	Seto F.		cong., lava lava lava alt. (cong. /s. s.)	1300m
Pliocene	1.98Ma 2.0Ma	Matuyama	Ashigara Group	Hinata F.		pumice tuf. s. s., alt. (md. st. /s. s.)	650m+
Miocene			Tanzawa Group			vol. breccia & tuff	

Magnetic Polarity Subchron : after Amano et al. (1986)
cong. : conglomelate, s. s. : sandstone, silt st. : silt stone, md. st. : mudstone,
qt. dio. : quartez diorite, py. rock : pyroclastic rock, tuf. s. s. : taffaceous sandstone,
vol. breccia : volcanic breccia, alt. : alternation.

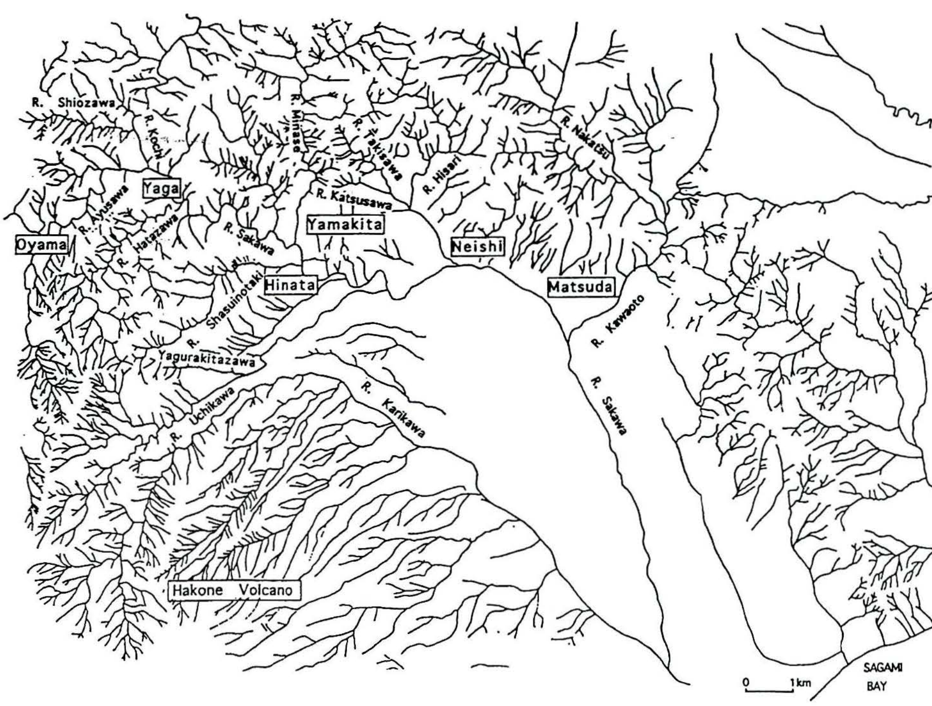


Fig. 3. A map showing the drainage system of the Ashigara Mountains.

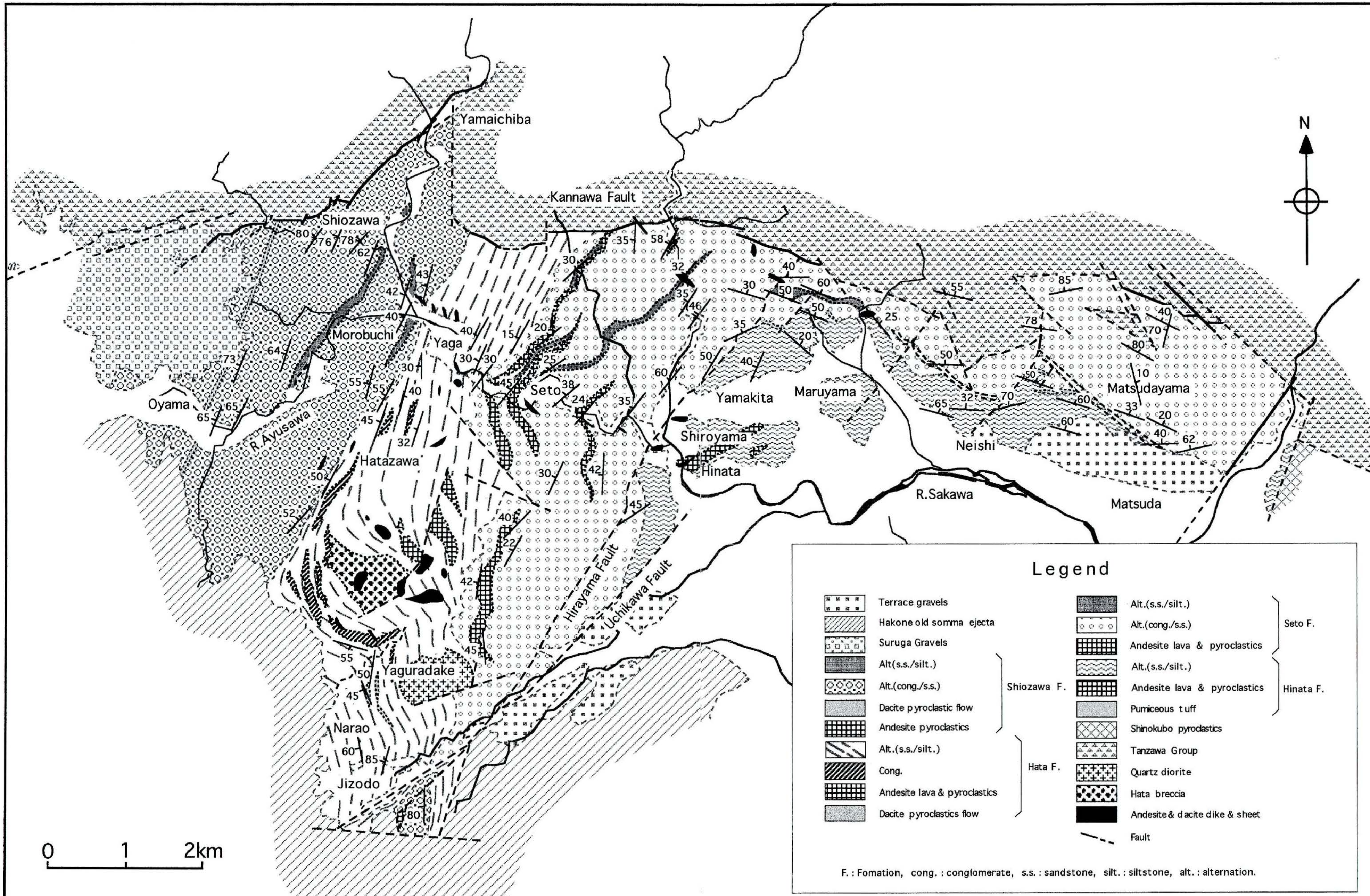


Fig. 4. Geological map of the Ashigara Group.

River (Fig. 5).

Summit levels indicate that E-W and NE-SW structures predominate in the Ashigara Mountains, and acute height differences from 400 m to 700 m along an E-W direction to the north of Yamakita suggest rapid uplift of the Tanzawa Mountains (Fig. 2).

NE-SW stream patterns in the Shiozawa Valley is concordant with the strike direction of the group in this area (Fig. 3).

4. Outline of geology

The Ashigara Group in the Ashigara Mountains embraces the northwestern tip of Oiso Hill and the southern limb of the Tanzawa Mountains. The Ashigara Group is characterized by a huge amount of conglomerate that accumulated from the Olduvai Subchron (2.0 Ma) to the Brunhes Normal Epoch (0.78 Ma) along the boundary between the Philippine Sea Plate and the Eurasian Plate.

From a plate tectonics point of view, Nakamura and Shimazaki (1981), Nakamura et al. (1984) and Seno (1987) pointed out that the change in the direction of convergence of the Philippine Sea Plate in the early to middle Pleistocene and late Pleistocene should have taken place during the deposition of the Ashigara Group.

Igneous activity was vigorous during deposition of the Ashigara Group. Many dikes and sheets were intruded into the group, and pyroclastic rocks were deposited mainly in the lower part of the group (the Hinata and Seto Formations). Explosive eruption of a subaqueous volcano during deposition of the Hata Formation produced thick pyroclastic rocks associated with a huge bed of boulder conglomerate. The Ashigara Group was intruded by more than 30 andesitic and dacitic dikes and sheets, along with a quartz diorite mass.

The Kannawa Fault separating the Plio-Pleistocene Ashigara Group from the middle Miocene Tanzawa Group runs in an E-W direction on the northern border of the Ashigara Mountains (Matsushima and Imanaga, 1968). Aside from the Kannawa Fault the main faults in the Ashigara Group are the Uchikawa and the Hirayama Faults.

5. Stratigraphy

The Ashigara Group probably lies unconformably on Miocene and Pliocene strata such as the Tanzawa Group in the Tanzawa Mountains (Mikami, 1961, 1962), the Pliocene Hayakawa Tuff Breccia, and the Miocene Yugashima Group which is mainly composed of pyroclastic rocks of marine origin and which comprises the basement rocks of Hakone Volcano on the Izu Peninsula (Kuno,1951). However, an exact point showing the stratigraphic relationships between these groups has never been found. The Ashigara Group contacts the Miocene Tanzawa Group in the study area along the Kannawa Fault. The Ashigara Group is composed of alternating beds of mudstone, tuffaceous sandstone and conglomerate, and it has been subdivided into the Hinata, Seto, Hata and Shiozawa Formations, in ascending order (Imanaga,1989).

The Ashigara Group is overlain by the upper Pleistocene Suruga Gravels on its western border, and by the Pleistocene Hakone volcanic ejecta on its southern border (Fig. 4, Table 2).

5-1. Hinata Formation

The Hinata Formation is the lowest unit of the Ashigara Group and is present in the central area as a dome-like folded structure. The formation was first named and defined by Imanaga (1989). The Hinata tuffaceous sandstone mudstone

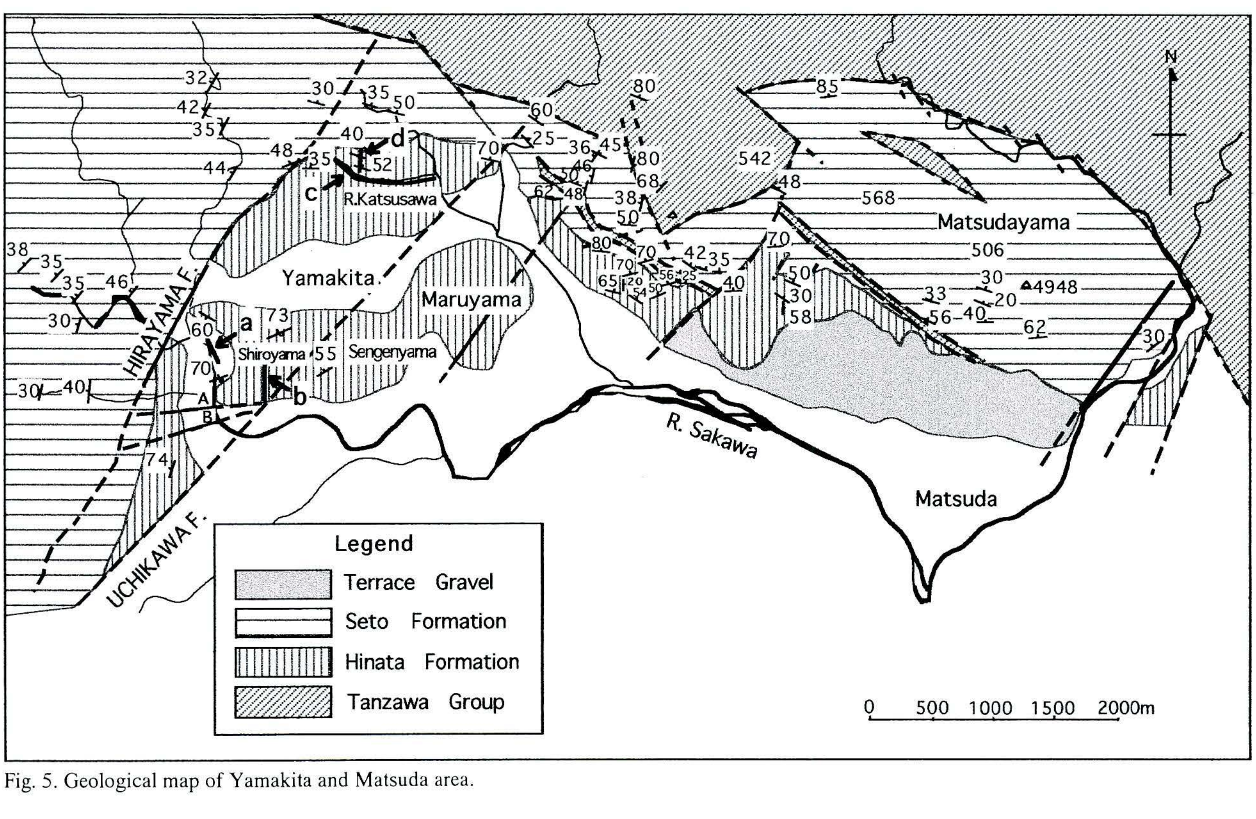


Fig. 5. Geological map of Yamakita and Matsuda area.

bed (Imanaga, 1976, 1977), the Neishi Formation (Huchon and Kitazato, 1984; Amano et al., 1986) and the Doyama Formation (Ashigara Research Group, 1986) are equivalent to the Hinata Formation.

[Type locality]

The type locality of this formation is exposed along banks of the Sakawa River near Hinata, in the western margin of Shiroyama Hill.

At its type locality, the Hinata Formation is composed of an alternation of mudstone and tuffaceous sandstone interbedded with pyroclastic rocks (Fig. 6-a).

[Thickness]

The thickness of the formation is over 650 meters.

Although the relationship between this formation and underlying strata is not observed in the field, it is thought to unconformably overlie the Tanzawa Group.

[Lithofacies and distribution]

The Hinata Formation is well exposed in the foothills of

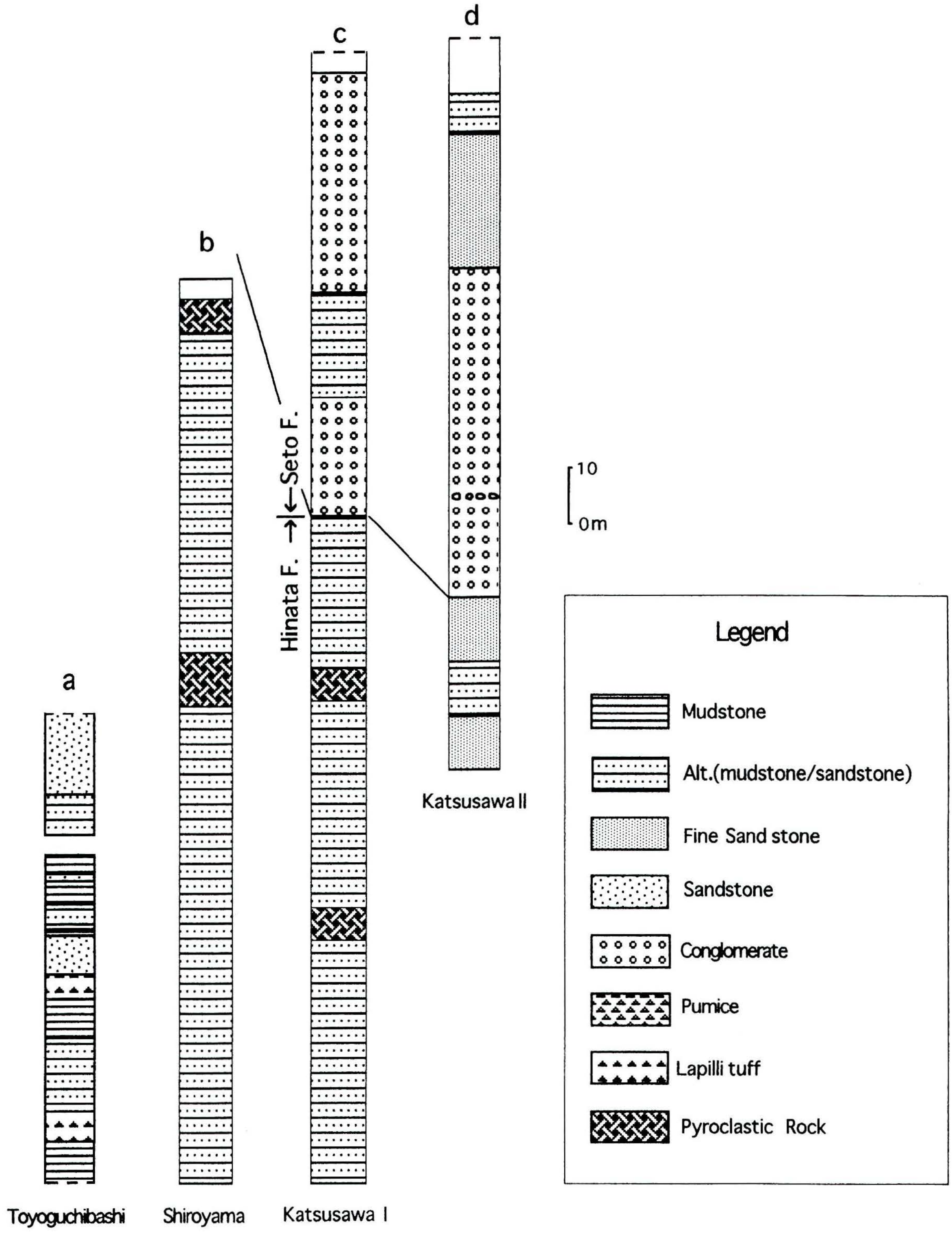


Fig. 6. Columnar section of the Hinata Formation. Localities (a, b, c, d) are seen in Fig.5.

Matsudayama Mountain (250 to 300 m high) to the north of Yamakita and Matsuda Towns, and in hills such as Shiroyama (225.1 m), Sengenyama (250.6 m) and Maruyama (225.1 m) in Yamakita Town (Fig. 5).

The Hinata Formation consists mainly of alternating gray mudstone and tuffaceous sandstone of distal turbidite origin (Fig. 6,). Tuffaceous sandstones contain yellowish-gray or bluish-gray pumice and red-brownish scoria. Lapilli tuffs and tuffaceous sandstones predominate in the eastern part of its distribution area (Plate 1a and 1c). Volcanic breccias with lavas crop out in places in the southern and northern distribution areas, including at such places as Hisari, Katsusawa, Shiroyama and Hinata. Volcanic breccias associated with lavas are typically crop out in the bed of the Sakawa River, 100 m upstream from the Takase Bridge near Hinata (Figs.7, 8, Plate 1b). Distribution of these volcaniclastic rocks extends over 1,300 m in an ENE direction to Shiroyama Hill. These volcanic breccias are composed of pyroxene andesite that shows a homogeneous ground mass, and the diameter of their clasts is mostly 10-30 cm, although they reach 100 cm in diameter. These lava flows were intruded by zeolite and calcite veinlets, and intercalated with volcaniclastic rocks, and they

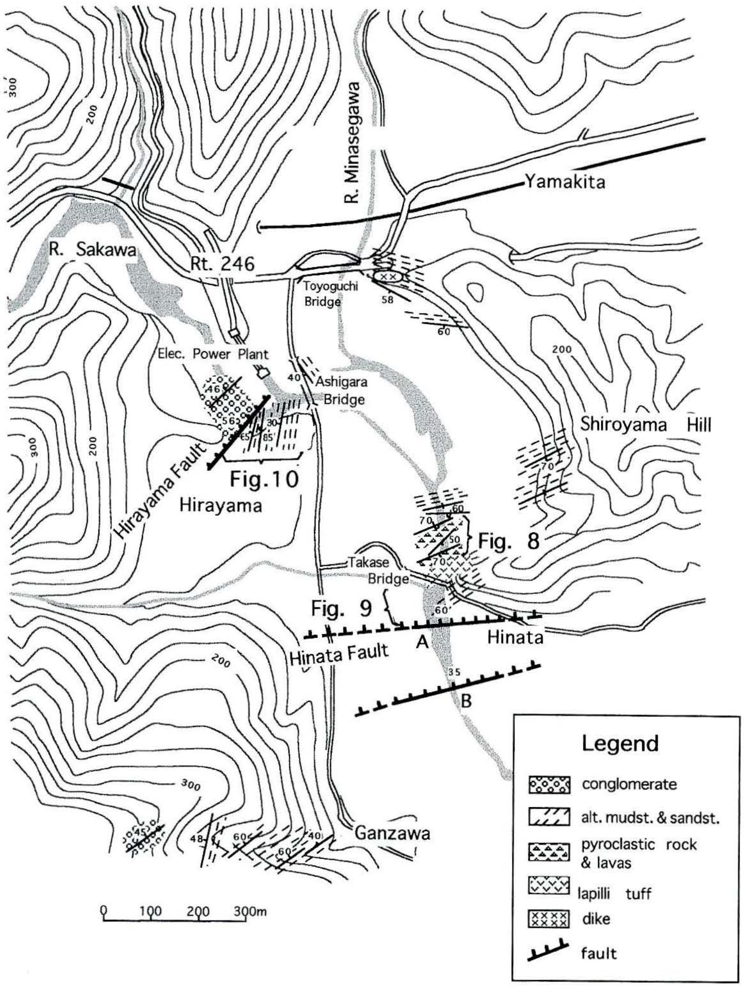


Fig. 7. Route map of Hirayama-Hinata area showing detailed studied localities of Figs. 8 -10.

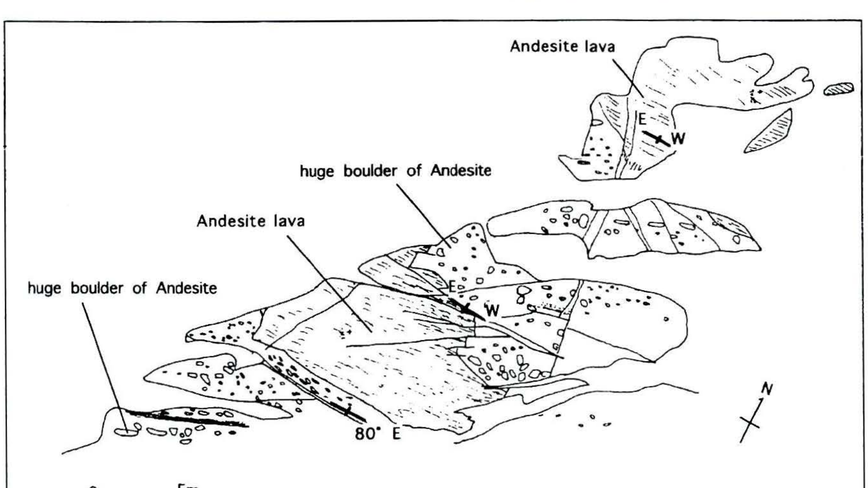


Fig. 8. Volcaniclastic rocks and lavas of the Hinata Formation at upstream of the Takase Bridge.

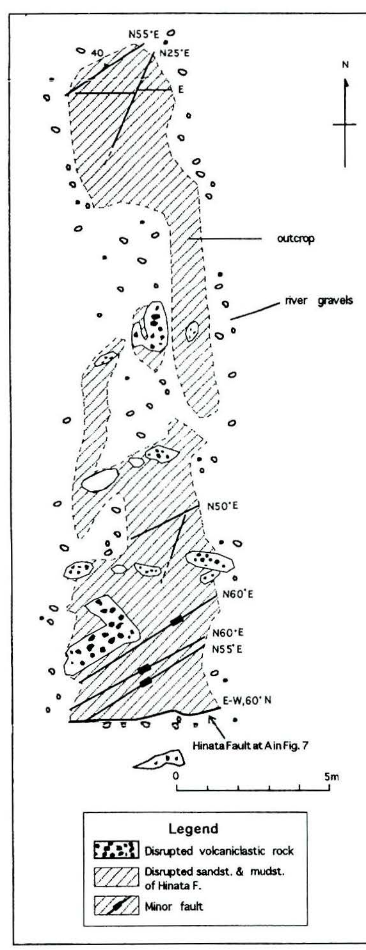


Fig. 9. Hinata Fault and disrupted sandstone and mudstone of the Hinata Formation at the river floor in 100m downstream of the Takase Bridge.

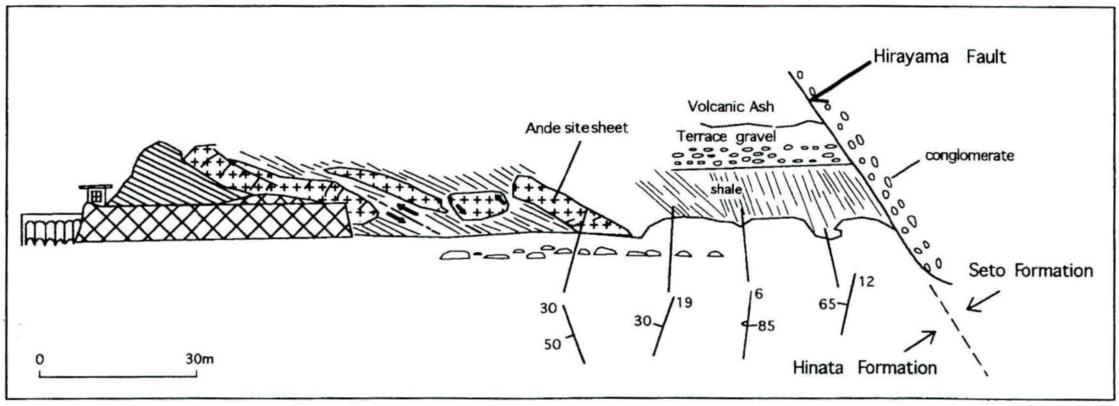


Fig. 10. Outcrop of the Hirayama Fault at 100m upstream from the Ashigara Bridge.

attain thicknesses of 15 m and 5 m, respectively (Fig. 8). At Hirayama Hamlet, the western end of the occurrence area, the formation is cut by the Hirayama Fault (Ito et al., 1987, 1989) in a left-lateral sense and with dip-slip movement (Figs. 5, 10). At the southern end of its occurrence area the Hinata Formation is cut by the Hinata Fault in the bed of the Sakawa River (Soh, 1995) (Figs. 7, 9).

[Fossils]

Molluscan fossils rarely occur.

[Environment]

The depositional environment of this formation was in the middle bathyal zone at 1,000 m to 2,000 m according to Huchon and Kitazato (1984), based on benthic foraminiferal assemblages. In addition, Ito (1985) interpreted these rocks as a lower submarine fan or basin plain. It is possible to say that the Hinata Formation was deposited in a lower fan far from the feeder channel, in association with submarine andesitic volcanics in several places.

5-2. Seto Formation

The Seto Formation was first named by Ishikawa et al. (1983) and used by Huchon and Kitazato (1984), Amano et al. (1986) and Imanaga (1989). This formation can be correlated with the A1 Bed (Imanaga, 1976, 1977) and the Seto Conglomerate (Imanaga, 1978, 1986). Ashigara Collaborative Research Group (1986) subdivided this formation into the Dai, Seto and Tuburano Formations.

[Type locality]

The type locality of the Seto Formation is the bank of the Sakawa River exposed from Hirayama to Seto Hamlets in Yamakita Town.

[Thickness]

The Seto Formation is about 1,300 m thick.

[Stratigraphic relation]

The Seto Formation conformably overlies the Hinata Formation in its eastern area of distribution, and is in contact with the underlying Hinata Formation by virtue of the Hirayama Fault along the Sakawa River. Ishikawa et al. (1983) and Huchon and Kitazato (1984) emphasized that the formation unconformably overlies the Neishi Formation, although evidence of this unconformity cannot be found in the field.

[Lithofacies and distribution]

The Seto Formation is distributed in an area from Matsudayama Mountain in the east, through the valley of the Minasegawa River, the Sakawa River, Shasuinotaki Valley, Nijuisseikinomori Park and Yaguradakekitazawa Valley to Yagurazawa Hamlet, as shown in Figures. 4 and 5.

The Seto Formation mainly consists of conglomerate and andesitic pyroclastics intercalated with sandstone and mudstone (Fig. 11). Each conglomerate bed is up to several tens of meters in thickness . The conglomerate clasts are mainly composed of tuff, tuff breccia, volcanic breccia, andesite, diabase and basalt supplied from the Tanzawa Mountains. Clasts range from boulders to pebbles in size and are subangular

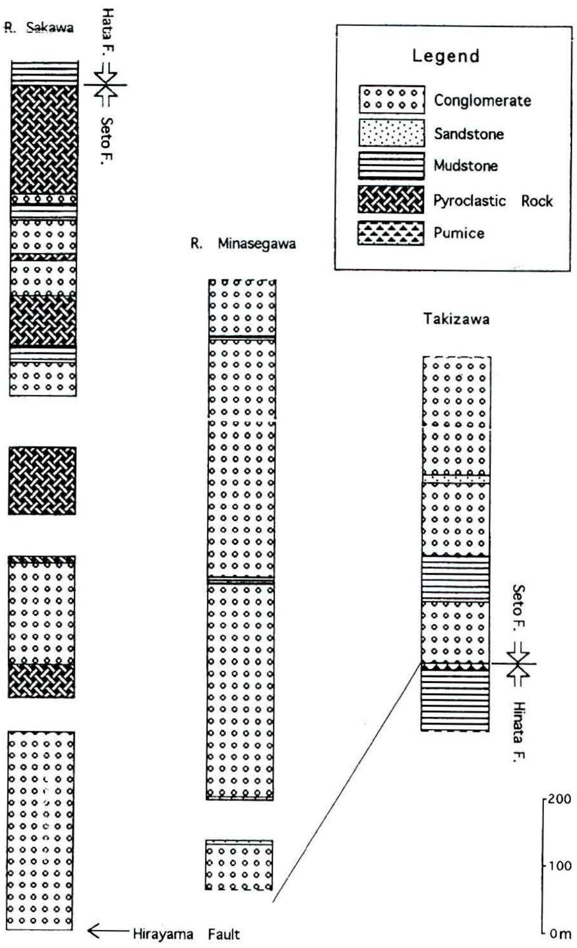


Fig. 11. Columnar sections of the Seto Formation.

to subrounded (Plate 2c, 2d, 2e). Cobble- to boulder-sized clasts of andesite are not from the Tanzawa Mountains but from an autobrecciated in situ lava mound (Plate 2a).

Some conglomerates show well-developed imbrication and have their long axis parallel to the flow with a NW to SE orientation (Ito,1985)

Some characteristic internal texture of the conglomerate beds are shown in Plate 2; disorganized (Plate 2c), inversely graded or inverse-to-normally graded (Plate 2d, 2e, 2f), thin-bedded turbidite on a levee (Plate 2b), and debris flows (Plate 2c).

Mudstones and sandstones intercalated in the conglomerate are up to 30 m thick and predominate in the middle part of the formation. Pebble- to cobble-sized clasts of chert, shale and sandstone derived from the Kanto Mountains occur to some degree in the conglomerate, as also does sandstone interbedded with conglomerate beds (Plate 2b). Quartz diorite clasts derived from the Tanzawa Mountains exceptionally occur in the Seto Formation in the area of Mt. Matsudayama, along the eastern margin of the formation's distribution area.

Autobrecciated lavas of pyroxene andesite are intercalated in the middle and upper parts of the formation (Fig. 11, Plate 2a). Boulders and cobbles of pyroxene andesite intercalated in the conglomerate in the middle and upper part of the formation are well exposed along the Sakawa River (Plates 2a, 2c). There is conspicuous rhythmic deposition of andesitic cobble-boulder conglomerates in the upper part of the formation.

[Fossils]

Molluscan fossils are rare.

[Depositional Environment]

This formation is thought to have formed as a middle-upper submarine fan (Ito, 1985), in depths between 200 and 600 m, based on a benthic foraminiferal study (Huchon and Kitazato, 1984). A huge amount of gravel might have been supplied from the Tanzawa Mountains as density flows and deposited in feeder channels of a middle-upper submarine fan. Igneous extrusion was active during deposition of the conglomerate. It can be inferred from the depositional process that andesitic to dacitic lavas intruded into the conglomeratic submarine fan and made subaqueous lava flows, and that debris flows of hyaloclastites and conglomerate flowed down into the conglomeratic deposits. These processes are suggested by occurrences of autobrecciated lavas and pyroclastic deposits in the Seto Formation.

5-3. Hata Formation

The Hata Formation was defined by Ishikawa et al. (1983) and has been used by Huchon and Kitazato (1984), Amano et al. (1986), and Imanaga (1989). This formation is equivalent to the A2 Bed (Imanaga, 1976, 1977), the Hata sandstone and mudstone (Imanaga, 1978) and the Hatazawa Formation (Ashigara Collaborative Research Group., 1986). Although Kano et al. (1988) understood the Hata Formation to include

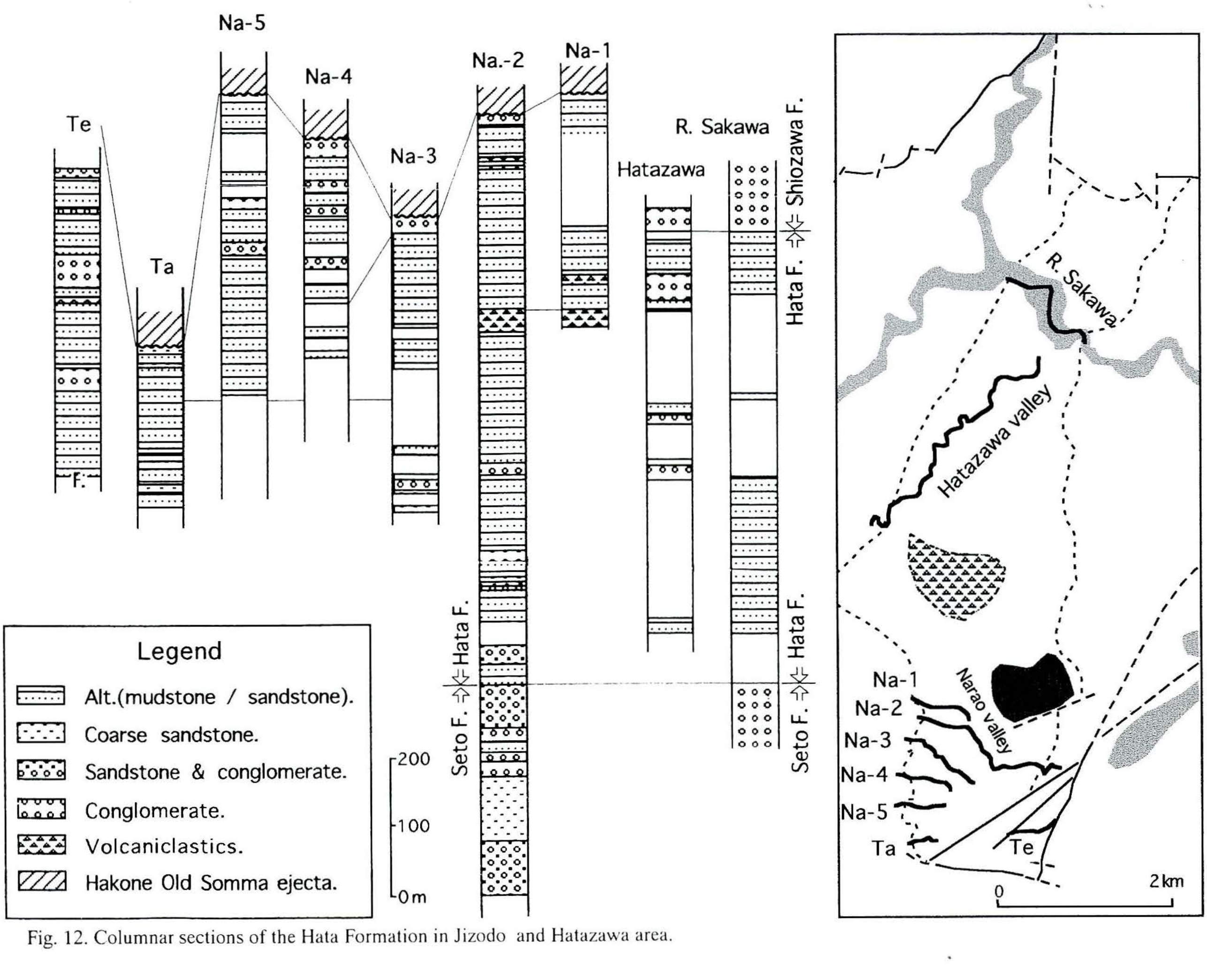


Fig. 12. Columnar sections of the Hata Formation in Jizodo and Hatazawa area.

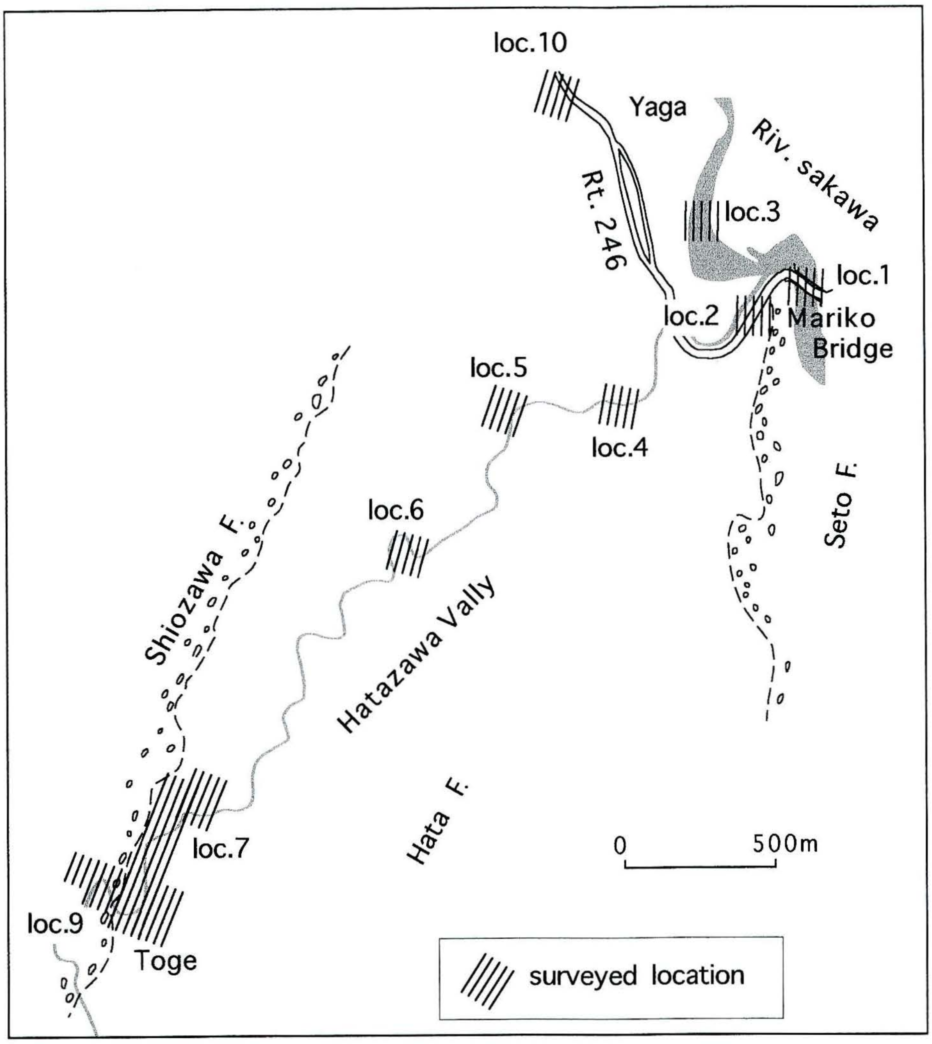


Fig. 13. Location map of columnar section of Hatazawa valley and its vicinity.

the lower part of Shiozawa Formation, I use it as originally defined by Ishikawa et al. (1983).

[Type locality]

The type locality of this formation is the Hata Valley at Yaga Hamlet (Figs. 13, 14). The formation at the type locality is composed of an alternation of sandstone and mudstone intercalated with thin conglomerates.

[Thickness]

The thickness is 600 meters in the northern area and 1,000 meter in the southern area.

The Hata Formation conformably overlies on the Seto Formation. The boundary between the Seto Formation and Hata Formation is well exposed in a cliff along the Sakawa River, 100 m upstream from the Marikobashi Bridge near Yaga Hamlet.

[Lithofacies and distribution]

The formation is distributed in the Hatazawa Valley (Fig. 13), Fukazawa and Arashi and Yaga Hamlets, and Narao Valley and Jizodo Hamlet, from north to south as shown in Fig. 4.

The Hata Formation consists of an alternation of gray mudstone and sandstone intercalated with conglomerate (Fig. 12 Plate 3d). The thickness of the mudstone and sandstone beds varies from several tens of centimeters to 4-5 meters. The conglomerate beds vary in thickness from several tens of centimeters to 120 meters. Conglomerate beds of 90-120 m thickness can be traced laterally in the uppermost part of the formation. The diameters of the clast of the conglomerates ranges in size from cobbles to pebbles, which are well rounded. The clasts consist of tuff, tuff breccia, andesite, and diabase, with rare quartz diorite derived from the Tanzawa Mountains. The clasts of chert, sandstone and shale derived from Kanto Mountain rarely occur in the conglomerates. There are very few clasts of andesite in the conglomerate of the Hata Formation.

A chaotic conglomerate bed which consists of huge boulder of andesites, sandstones and mudstones crops out in the Ninokurakaihatu Co. Quarry at the end of Hatazawa Valley. The bed is up to 500 m in thickness and 1,200 m in width. The boulders are several tens of centimeters to over 10 meters in diameter (Plate 3a. 3b). This conglomeratic bed is discussed in a later section.

A dacitic pyroclastic bed named the Narao Pyroclastic Flow (Imanaga, 1989) is intercalated in the middle part of the Hata Formation in Narao Valley in the western foothills of Mt. Yaguradake. The flow is intermittently exposed in the Narao Valley in a N-S direction. The maximum thickness is about 30 m, which decreases rapidly toward the northwest and south-east. The flow is composed of hornblende dacite gravels, yellowish pumice and angular siltstone blocks. The Narao Pyroclastic Flow is subdivided into upper and lower units. The

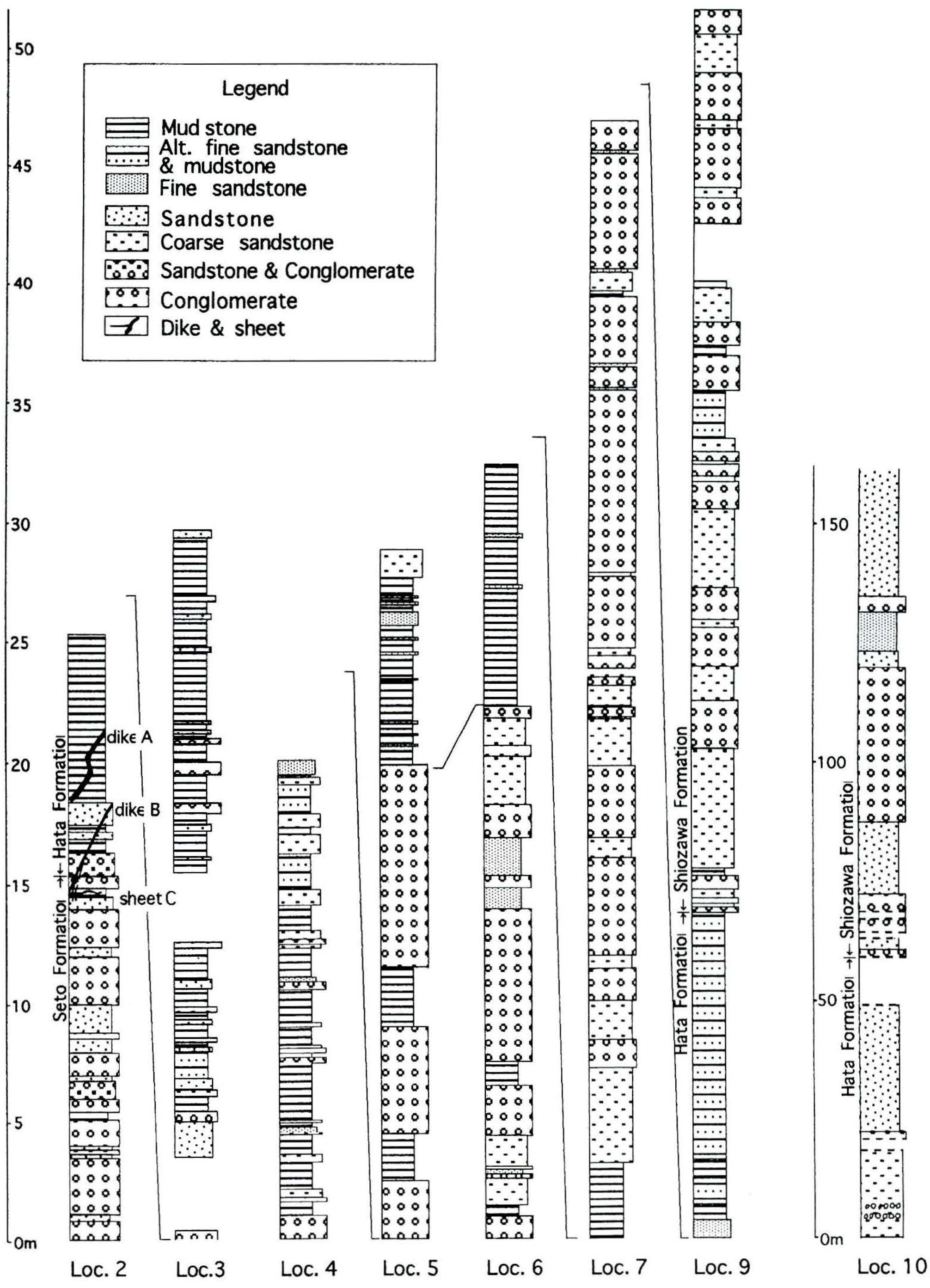


Fig. 14. Columnar sections of the Hata Formation in Hatazawa area and it vicinity (locations are in Fig. 13).

lower bed is strongly solidified and is composed of dacitic pumice, mudstone fragments and andesite breccias about 5 cm in maximum diameter. The ground mass is granules of pumice and mudstone fragments. Dacitic pumice is characterized by occurrence of quartz crystals, bytownite (70-90% anorthite) and hornblende. The upper unit is weak in solidification, is about 4 m thick, and mainly consists of siltstone blocks up to 50 cm in diameter, with subordinate dacitic pumice fragments up to 5-10 cm in diameter (Fig. 15). The matrix is composed of granules of the same dacitic pumice and siltstone fragments. Siltstone fragments are prominent and dacitic pumice fragments are less prominent. The Narao Pyroclastic Flow is interpreted as a debris flow related to an explosive eruption in the sea during deposition of the Hata Formation. That is, hyaloclastic dacitic ejecta mixed with huge mudstone boulders and flowed down as a gravity slide not far from the explosive center.

[Fossils]

Molluscs such as *Acila divaricata*, *Yoldia glauca*, and *Macoma calcarea* occur as in situ within the alternating beds of mudstone and sandstone. This association suggests the upper bathyal zone (Matsushima, 1982). However, some molluscan fossils in the intercalated conglomerate layers suggest a shallow conditions (Matsushima, 1982).

[Environment]

The paleodepth of the formation is inferred from benthic foraminifers to range from 100 to 300 m in depth (Ishikawa et al., 1983; Huchon and Kitazato, 1984). Volcanic activity was explosive and is considered to have been less active than in the Hinata and Seto Formations, although the Hata Formation was intruded by andesitic dikes and sheets.

5-4. Shiozawa Formation

The Shiozawa Formation is the uppermost unit of the Ashigara Group. The formation was defined by Ishikawa et al. (1983) and followed by Amano et al. (1986), and Imanaga (1989). This formation is equivalent to the A3 Bed of Imanaga (1976, 1977) and the Shiozawa Conglomerate Bed of Imanaga (1978, 1982, 1986). Someno et al.(1984) subdivided the formation into the Lower Shiozawa Formation, the Upper Shiozawa Formation, the Oyama Conglomerate Bed and a bed equivalent bed to the Tama Loam.

[Type locality]

The formation is exposed well in Shiozawa Valley, where it exhibits a nice alternation of conglomerate and sandstone.

[Thickness]

The thickness of the formation is over 2,300 m.

[Stratigraphic relation]

The Shiozawa Formation conformably overlies the Hata Formation. The boundary between two formations is exposed 100 m south of Shinshimizu Bridge (Fig. 13-Loc.10). The formation is unconformably overlain to the west by the Pleistocene Suruga Gravels (Machida et al., 1975).

[Lithofacies and distribution]

The Shiozawa Formation is mainly present in Yamaichiba Hamlet, Shiozawa Valley, and Morobuchi and Sukima Hamlets in the western part of the Ashigara Mountains, plus a small occurrence in Jizodo Hamlet in the southern part of the Ashigara Mountains. The formation is mainly composed of an alternation of conglomerate and sandstone (Fig. 16). The clasts of conglomerate are subrounded or subangular and poorly sorted and the diameters of the clasts range from cobbles to boulders in size. The clasts of conglomerate are dominantly composed of quartz diorite, amphibolite schist, actinolite schist, chlorite schist and hornfels, all of which are derived from the central part of the Tanzawa Mountains. This groundmass is mainly composed of sand grains of quartz diorite and volcaniclastic rocks of the Tanzawa Group (Plate 4a, 4e). The color of the

Fig. 15. Sketch of upper horizon of the Narao Pyroclastic flow deposits.

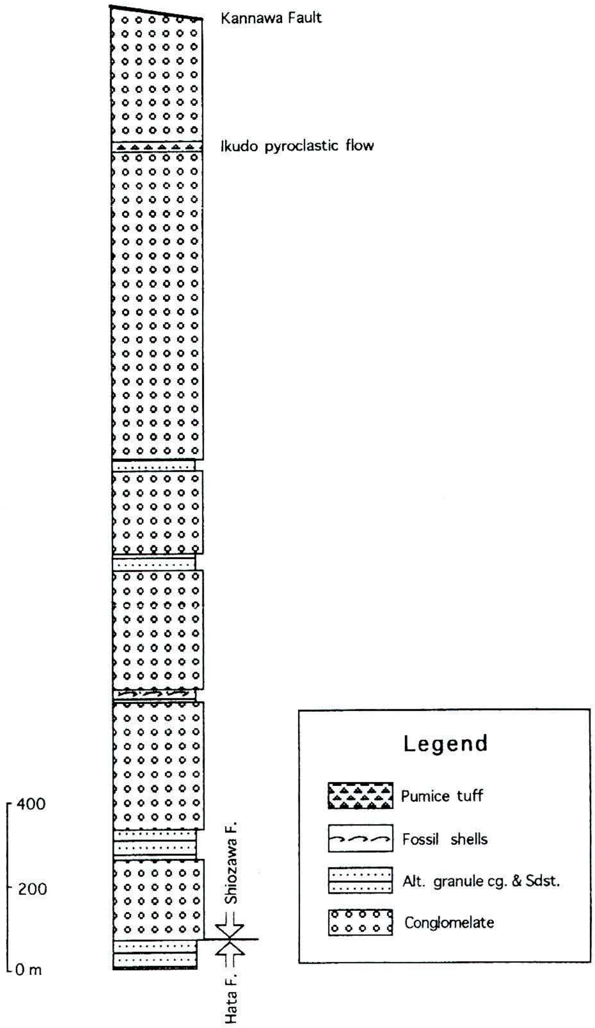


Fig. 16. Columnar section of the Shiozawa Formation

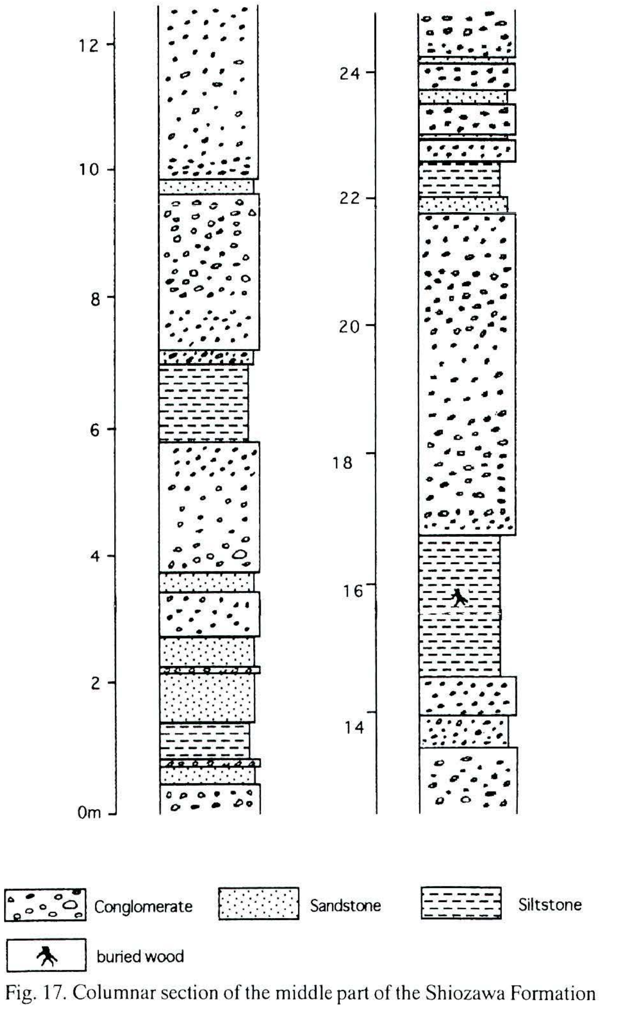


Fig. 17. Columnar section of the middle part of the Shiozawa Formation at Morobuchi quarry.

formation is relatively whitish compared with underlying formations. This formation is easily distinguished from others by the dominant occurrence of fragments of quartz diorite and schist (Plate 4). The alternations of sandstone and pebbly conglomerate are abundant in the lower part, whereas the conglomerate becomes dominant in the upper part of the formation. The sandstone exhibits cross-bedding and graded bedding (Plate 4b).

The ratio of sandstone to conglomerate is 1 : 2.5 at the outcrop in a quarry in Morobuchi that corresponds to the middle horizon of the formation (Fig.17).

Imbrication of the gravel in the conglomerate at the quarry suggests that the flow direction was from east to west (Ito,1985).

The Shiozawa Formation displays a monoclinal structure dipping to the west. However, the lower 500 m of the Shiozawa Formation show dips of 40-55° NW, while the upper 1800 m shows dips between of 65 to 80° NW.

[Pyroclastic rocks]

Two pyroclastic beds are interbedded in the upper part of the formation. One is the Ikudo Pyroclastic flow (Someno et al., 1984; Ito et al, 1985) exposed in the bed of the Ayusawa River in the vicinity of the Ikudo Electric Power plant. It is 25m and more in thickness and is composed of dacite breccia. This unit can be traced up to 1.5 km to the northeast, to the

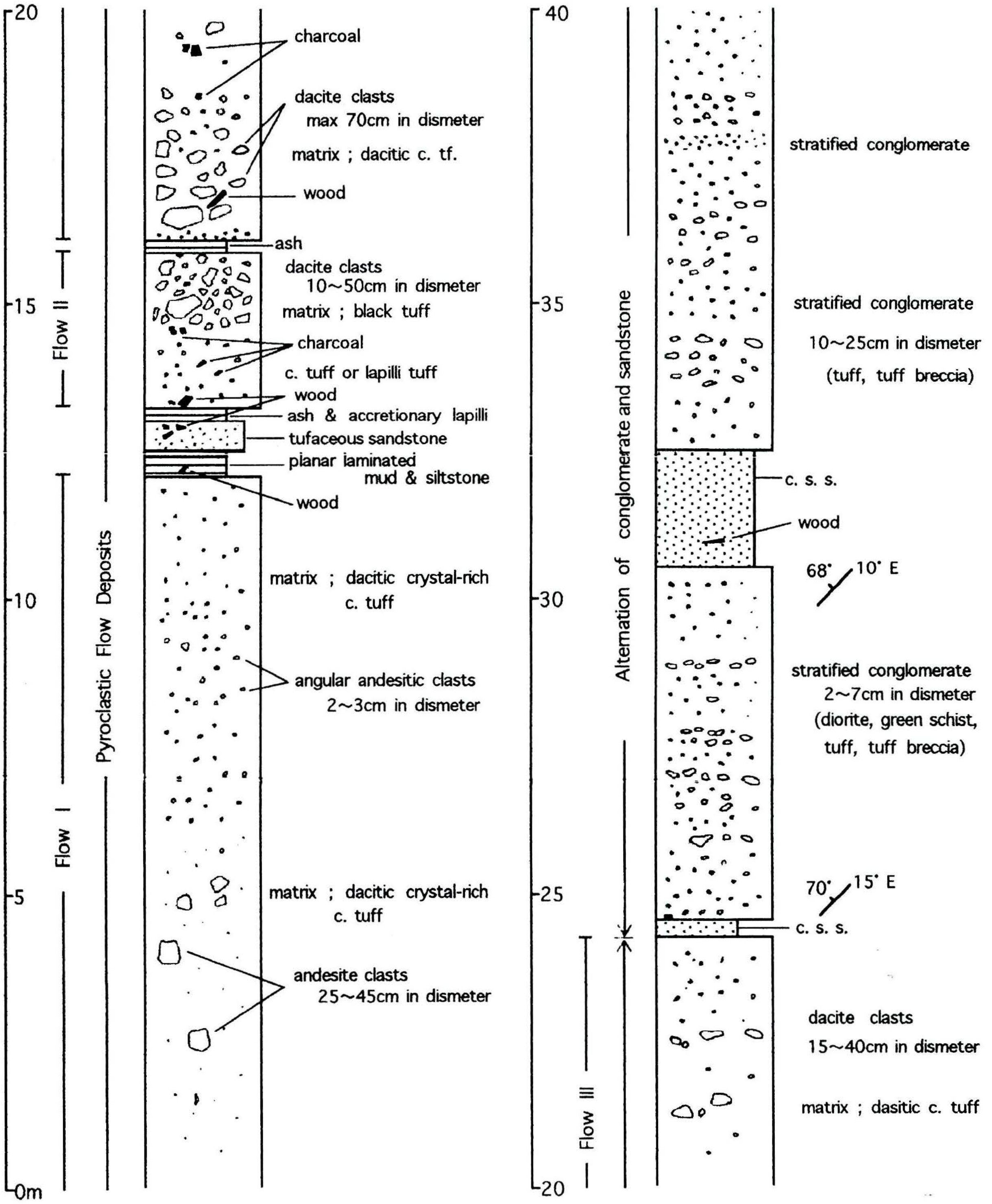


Fig. 18. Columnar section of the Ikudo Pyroclastic Flow.

Shiozawa Valley. This pyroclastic flow can be subdivided into three units in the river bed (Fig. 18), as described below:

Flow unit 1: The total thickness of the Flow unit 1 is more than 12 meters and it can farther be divided into lower, middle and upper parts. Dacitic coarse tuff with scattered boulders of andesites is six meters thick and more in the lower part. Dacitic coarse tuff with andesitic lapilli of 2~3 cm in size, occur in the middle part. Dacitic coarse tuff, 5 meters thick, is present in the upper part. Gray tuffaceous siltstone beds with parallel laminations, tuffaceous sandstone and fine tuff with accretionary lapilli overlie the Flow unit 1.

Flow unit 2: Flow unit 2 is three meters in thickness. Coarse to lapilli tuff with fossil wood occupies the lower part. Black tuffaceous sandstone in association with dacite breccias, which are 20-50cm in diameter, occupies the upper part.

Flow unit 3: Flow unit 3 is an 8-m-thick pyroclastic flow. The basal part is 3 m thick and is composed of dacitic boulders containing fossil wood. The upper part of this unit consists of cobble-sized dacitic clasts.

In Shiozawa Valley, about 1.5 km north of the outcrops in the Ayusawa River, a two-meter-thick dacitic coarse tuff bed is present which consists of the same mineral assemblages as that of the Ikudo Pyroclastic Flow. This tuff bed that contains quartz, plagioclase, hypersthene and hornblende exhibits parallel lamination and includes charcoal fragments. This coarse tuff is thought to be a northern extension of the Ikudo Pyroclastic Flow.

The Kurobyaku pyroclastic deposit (Someno et al., 1984), which is intercalated in the Shiozawa Formation, is present in the Jizodo area in Minami-Ashigara City. This deposit is mainly composed of andesite breccias and is more than 100 m thick. Two pumice beds are recognized in this deposit. The upper one is a 30-cm-thick white pumice tuff and is characterized by the mineral composition of quartz, biotite, and Na-rich plagioclase.

[Fossils]

About 550 m above the base of the Shiozawa Formation, a shallow molluscan fossil bed is found in fine sandstone to pebbly conglomerate bed that is intercalated in a thick conglomerate. The fossil bed is several meters thick and extends up to 1.8 km along the Kochi River Valley from Yozawa in the north through the entrance of Shiozawa Valley and Morobuchi in the south along the Ayusawa River. The occurrence of fossils of *Crassostrea gigas* (Plate 4c) indicates a shallow embayment (Matsushima, 1982). The proboscidian *Parastegodon* sp. has been found at a quarry in Sukima, in the middle part of the formation (Hasegawa et al., 1986). Fossil wood trunks are also found in the middle and upper portion of the formation (Plate 4f). Calcareous nannofossils do not occur in the formation.

[Environment]

The depositional environments of the Shiozawa Formation can be assigned to shallow marine (about 30 m in depth) in the lower part, and estuarine or terrestrial or a braided river system in the upper part.

6. Igneous activity in the Ashigara Group

Igneous activity was vigorous during deposition of the Ashigara Group, which might have occurred in the region of the plate boundary. A large quantity of andesitic and dacitic pyroclastics and lava flows is present in the group along with

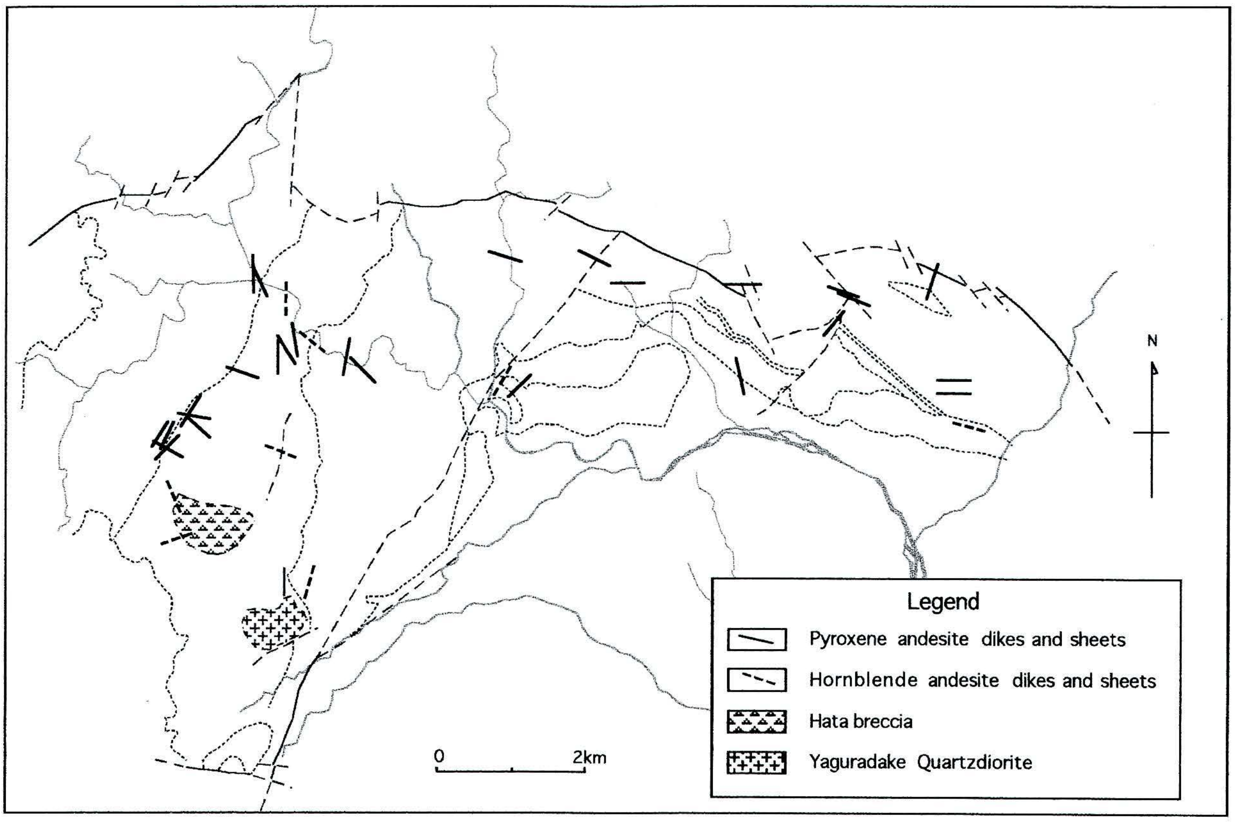


Fig. 19. Distribution and direction of dikes and sheets in the Ashigara Group.

intruded dikes and sheets. The whole rock analyses of the igneous rocks from the Ashigara Group are shown in Table 3.

6-1. Dikes and sheets

More than 30 andesitic dikes and sheets are present in the lower and middle parts of the Ashigara Group (Fig. 19). The thickness of the dikes is commonly up to six meters.

The dike rocks are classified in the pyroxene andesite group, which contains pyroxene phenocrysts, and a hornblende andesite group, which contains hornblende phenocrysts. The pyroxene andesite group is present in the whole study area. Dikes of the hornblende andesite group occur in a restricted area compared to the pyroxene andesite group and is found in the vicinity of the Hatazawa quarry. The SiO_2 content of the hornblende andesite group ranges from 60 to 65 wt%, and that of the pyroxene andesite group from 50 to 62 wt%. The pyroxene andesite group belongs to the tholeiitic rock-series whereas the hornblende andesite group belongs to the calc-alkalic rock series(Figs. 20, 21).

The intrusion of two dike groups within the same time period has been deduced from K-Ar age determinations, as shown in Table 4 and Fig. 22. The boundaries between dikes and sedimentary rocks show straight planes or irregular crooked planes. The irregular crooked planes are thought to have been formed under lower confining pressures and intruded into the Ashigara Group in a semi-solid state. The dikes with straight planes are thought to have intruded under deep confining pressures. This igneous activity may have occurred during or after deposition of the Ashigara Group (Fig. 22). The dominant orientation of the dikes is NW-SE, which suggests maximum horizontal stress in the area when they were intruded (Imanaga, 1980; Amano et al., 1986), although the orientation of the dikes varies between NNW and WNW(Imanaga, 1980).

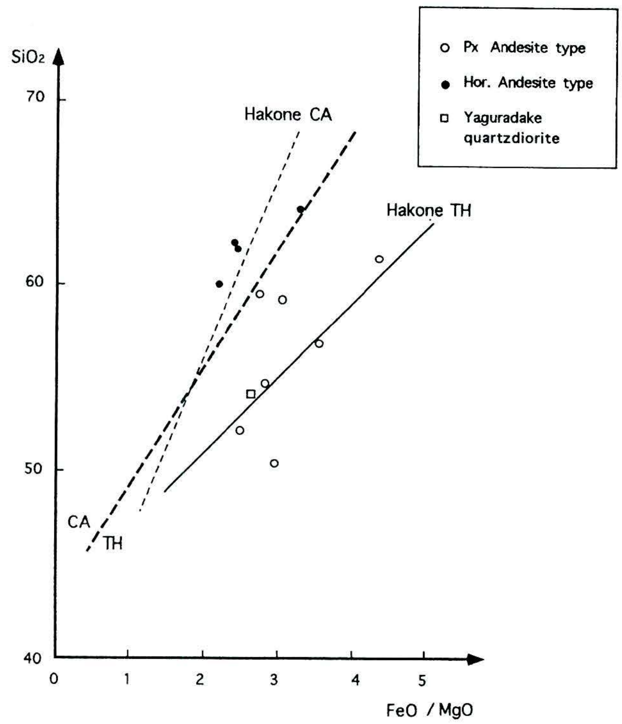


Fig. 20. FeO/MgO-SiO_2 diagram for the rocks of the Ashigara Group.

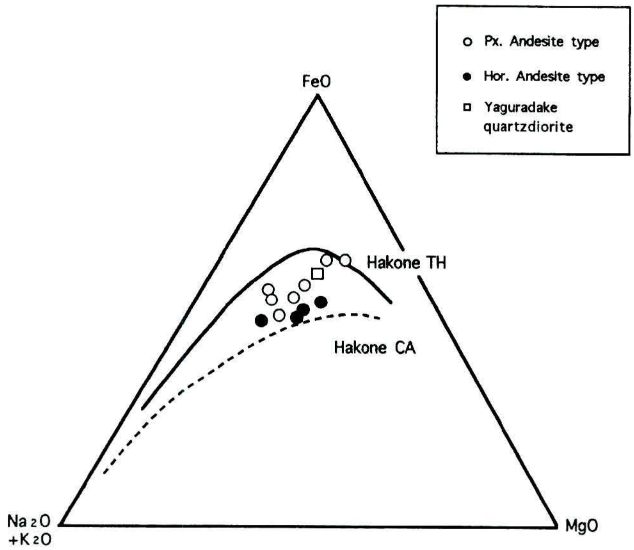


Fig. 21. AMF diagram for the rocks of the Ashigara Group.

6-2. Yaguradake intrusive body

Mt. Yaguradake is 870 m high and tributaries from it have developed in every direction except west, as shown in Fig.23. The Yaguradake intrusive body comprises a quartz diorite mass exposed above the height of 600 m along the tributaries. The boundaries between the intrusive body and its surroundings can be seen along the tributaries. The inclinations of the contact planes between the quartz diorite mass and the Hata Formation are concordant with the bedding planes of the Hata Formation along tributaries Y5, Y7 and Y8 (Figs. 23, 24). The contact of the quartz diorite mass and the surrounding beds shows a lateral slip fault striking N75° E and dipping 48° N at Y9, which is the one of the more southeasterly tributaries. Contact metamorphism of the surrounding mudstone can rarely be observed, although mudstone at the contact on tributary Y9 is weakly metamorphosed.

The central part of the Yaguradake intrusive body consists of medium-grained quartz diorite, and its rim is composed of porphyry. The mineral composition of the mass is hornblende, hypersthene, plagioclase and quartz. The colored mineral is mainly composed of hypersthene. The plagioclase is 70-85% anorthite.

The Yaguradake quartz diorite intruded into the lower part of the Hata Formation. The strikes of the Hata Formation are not so disturbed on the north and south sides of the intrusive mass, while the strikes of the formation deviate as they surround the mass on its eastern and western sides. The beds commonly dip 35 to 50 degrees to the west. Based on these observations, it is inferred that the Yaguradake quartz diorite mass intruded parallel to the dip along a bedding plane of the Hata Formation.

The age of the intrusive mass is thought to be 1.15 Ma based on K-Ar dating (Kurasawa et al., 1988) while the deposition of Hata Formation occurred between 1.65 to 1.44-1.26 Ma based on calcareous nannofossils in the present study.

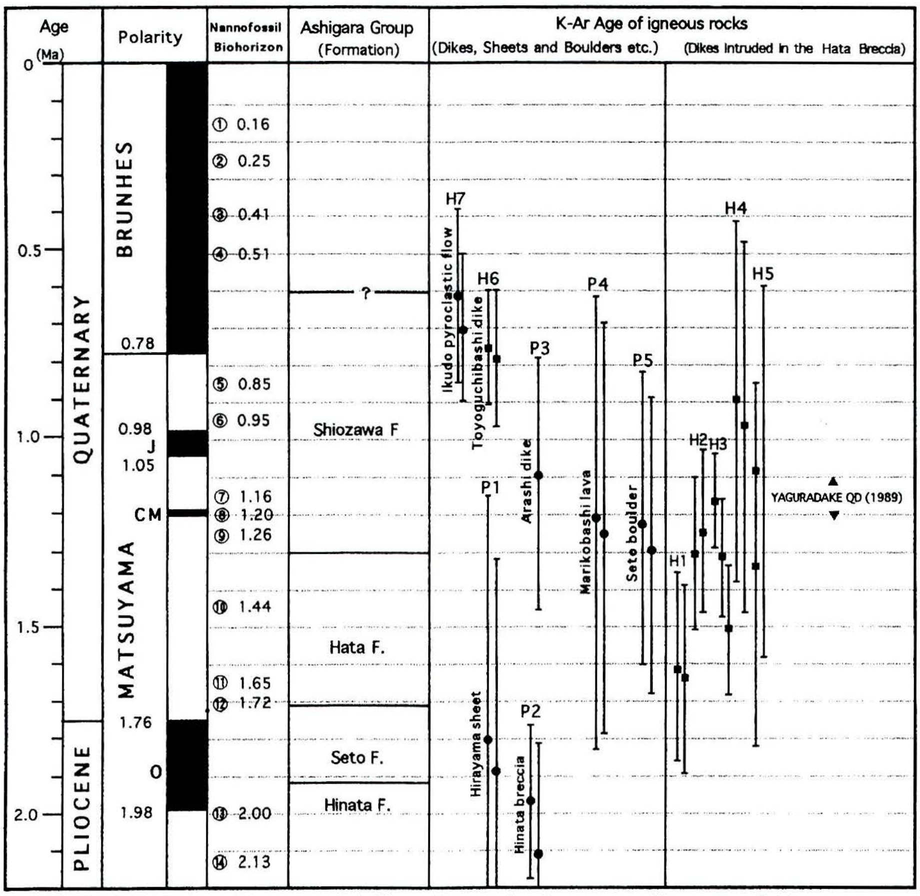


Fig. 22. Geological ages of the strata of Ashigara Group showing ranges of igneous activities.

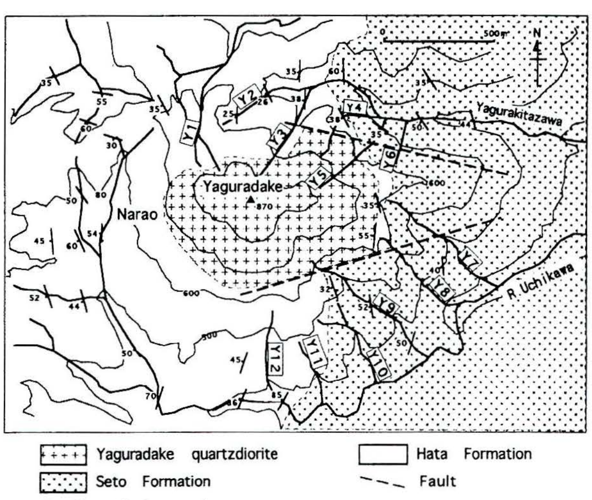


Fig. 23. Geological map of the Yaguradake area.

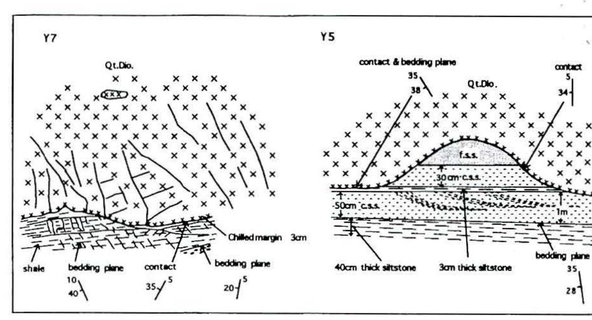


Fig. 24. Contact relationship between the Yaguradake quartzdiorite and the Hata Formation at Y5 and Y7.

6-3. Hata vent breccia

The Hata vent breccia is present in the Ninokurakaihatu Co. Quarry, located 2.5 km south of the Sakawa River and 2 km northwest of Mt. Yaguradake. The Hata vent breccia consists of huge boulders of siltstone and andesite (Imanaga, 1977), with the largest boulder over 10 m in diameter. The matrix is poorly sorted and is composed of the same kind of fragments as the huge boulders. Hornblende andesite dikes and sheets were intruded into the Hata vent breccia. The ages of the intruded dikes were determined by K-Ar dating in this study (Table 4 and Fig.22). The bed occurs in an area 1,200 m wide and 500 m high in the middle part of the Hata Formation.

The bed has been interpreted by several authors in various ways, as previously mentioned. These include: sedimentary slumping deposits (Imanaga, 1977); volcanic collapse basin deposits (the Yamakita Group) unconformably covering the Ashigara Group (Ashigara Collaborative Research Group, 1983); explosive vent fill (the Hatazawa Vent Fill); a source volcano for the Ikudo Pyroclastic Flow in the uppermost part of the Ashigara Group (Ito et al., 1985); a vent breccia or a diatreme-like body (the Hatazawa Breccia) (Amano et al., 1986); subaqueous caldera collapse breccias (Ito, 1985); the Yamakita Breccia Pipe (Ishida, 1991). The ages of dike rocks intruding into the bed are concentrated between about 1.7 and 0.7 Ma on the basis of whole rock K-Ar age dating (Table. 4; Fig. 22).

The Hata vent breccia is considered to be a subaqueous volcanic breccia that was interbedded in the Hata Formation, while dikes were intruded during and after deposition of the bed. This bed was formed due to subaqueous volcanism, as follows: a subaqueous volcano erupted and made mounds near

Table 3. Chemical composition of the igneous rocks in the Ashigara Group.

		SAMPLE ID	SiO2(wt%)	TiO2(wt%)	Al2O3(wt%)	Fe2O3(wt%)	MnO(wt%)	MgO(wt%)	CaO(wt%)	Na2O(wt%)	K2O(wt%)	P2O5(wt%)	Total(wt%)
1	Takizawa / dike	96040801	52.22	0.83	18.98	10.93	0.18	4.43	10.21	2.07	0.1	0.056	99.99
2	Hinata/ pyroclastic rock	95072807	54.76	0.81	21.36	6.43	0.25	2.28	9.37	3.35	0.73	0.16	99.49
3	Hisari/ lava	95111205	50.59	0.74	22.88	7.73	0.15	2.61	13	1.67	0.22	0.06	99.63
4	Fukazawa/ dike	96122908	59.31	0.79	17.84	8.32	0.19	2.77	6.91	3.05	0.53	0.08	99.78
5	Seto/ dike	97010102	57.07	0.62	20.2	7.36	0.16	2.1	7.33	3.85	0.6	0.1	99.39
6	Tsuburano/ pyroclastic rock	96123004	59.66	0.71	18.06	7.35	0.12	2.72	7.51	3.17	0.59	0.13	100.04
7	Marikobashi/ lava	PL-1	61.77	0.68	16.78	7.34	0.08	1.7	6.88	3.29	0.79	0.11	99.41
8	Ninokura Kaihatsu/ dike	77030804	60.32	0.54	17.81	7.14	0.14	3.39	7.28	2.56	0.43	0.06	99.66
9	Yagurakitazawa/ dike	93030505	64.61	0.41	17.51	5.09	0.21	1.56	6.12	3.25	0.51	0.13	99.39
10	Ninokura Kaihatsu/ dike	95111106	62.26	0.48	17.53	6.18	0.15	2.63	7.31	2.63	0.4	0.08	99.65
11	Ninokura Kaihatsu/ dike	95111106e	62.36	0.49	17.79	6.11	0.15	2.63	6.71	2.89	0.47	0.08	99.67

the explosive vent; the mounds might then have collapsed, so that breccias flowed down into the silty deposits during deposition of the Hata Formation (1.65-1.26 Ma).

7. Geologic Age

It was once thought that the age of the Ashigara Group was Miocene or Pliocene, because intense folding and solidification can be observed in the strata (Kuno,1951). In the 1980's, however, some geologists argued that the age of deposition was early to middle Pleistocene. Mastodon fossils (Parastegodon sp.) were found in the middle part of the Shiozawa Formation (Hasegawa et al., 1986). Furthermore, the shallow water molluscan fauna in the group does not contain extinct species, such as Umbonium costatum that range younger than the middle Pleistocene (Matsushima, 1982). Ishikawa et al. (1983) and Huchon and Kitazato (1984) insisted that the Ashigara Group was deposited in the early to middle Pleistocene based on calcareous nannofossils. Okada (1987) concluded that the Neishi Formation, the lowest part of the Ashigara Group, is early Pleistocene, whereas the Seto Formation in the middle part of the Ashigara Group belongs to the middle Pleistocene. Koyama (1986) examined paleomagnetic polarity in the Ashigara Group and found both normals and reversals in the Shiozawa Formation. Koyama (1986) correlated the change from reversed to normal polarity in the upper Shiozawa Formation with the change from the Matuyama reversed polarity chron to the Brunhes normal polarity chron (0.78 Ma). Amano et al. (1986) considered the paleomagnetic polarity of the group and concluded as follows: the lowermost Neishi Formation has reversed polarity; the Seto Formation has normal polarity; the Hata Formation and lower Shiozawa Formation have reversed polarities and the upper Shiozawa Formation has normal polarity. Amano et al. (1986) correlated the change from reversed to normal polarity in the

Table 4. K-Ar age (whole rock) of igneous rocks in the Ashigara Group.

NO.	ROCK FACES	ROCK TYPE	LOCALITY	NUMBERS IN LABORATORY	SAMPLE TYPE	POTASSIUM (K wt%)	Rad. 40 Ar (10-8 cc/g)	K-Ar AGE (Ma)	AIR CONT. (%)
P.1	Sheet	Andesite	Hirayama	SH7-330 -345	Whole Rock	0.45 0.05	3.28±0.91 3.19±1.08	1.88±0.56 1.80±0.64	94.9 95.7
P.2	Breccia	Andesite	Hinata	SH7-312 -313	Whole Rock	0.58 ±0.04	4.38±0.57 4.68±0.57	1.96±0.28 2.10±0.29	89.2 88.5
P.3	Dike	Andesite	Arashi	S12-324	Whole Rock	0.3 ±0.00	1.29±0.02	1.11±0.33	92.7
P4	Dike	Andesite	Marikobashi	SH7-352 -353	Whole Rock	0.61 ±0.04	2.88±1.42 2.90±1.27	1.22±0.60 1.23±0.54	96.7 96.7
P.5	Dike	Andesite	Minasegawa	SH7-314 -315	Whole Rock	0.4 ±0.04	1.99±0.57 1.87±0.57	1.28±0.39 1.21±0.39	94.8 95.1
H.1	Dike	Andesite	Ninokura quarry		Whole Rock	0.29 ±0.04	1.80±0.06 1.84±0.11	1.60±0.25 1.63±0.26	94 94.4
H.2	Dike	Andesite	Ninokura quarry		Whole Rock	0.29 ±0.04	1.47±0.06 1.40±0.11	1.30±0.20 1.24±0.21	94.8 95.8
H.3	Dike	Andesite	Ninokura quarry		Whole Rock	0.37 ±0.04	1.66±0.06 1.58±0.09 2.16±0.12	1.16±0.12 1.31±0.15 1.50±0.17	92.2 92.4 92.1
H.4	Dike	Andesite	Ninokura quarry	SH7-346 -347	Whole Rock	0.22 ±0.03	0.74±0.39 0.80±0.39	0.89±0.48 0.96±0.49	97 96.8
H.5	Dike	Andesite	Ninokura quarry	SH7-350 -351	Whole Rock	0.23 ±0.03	1.16±0.38 0.95±0.41	1.33±0.48 1.08±0.49	95.5 96.5
H.6	Dike	Andesite	Toyoguchi, Yamakita	SH7-348 -349	Whole Rock	0.7 ±0.04	213±0.46 2.04±0.37	0.79±0.18 0.76±0.15	90.5 91.2
H..7	Ikudo py. flow	Dacite	Ayusawagawa, Oyama	SH7-354 -356	Whole Rock	0.33 ±0.03	0.90±0.22 0.78±0.28	0.71±0.19 0.62±0.23	92.8 95

H.1, H.2 and H.3 are data of Hot Spring Research Institute of Kanagawa prefecture(1992) upper part of the Shiozawa Formation with the change from the Matuyama reversed polarity chron to the Brunhes normal polarity chron (0.78 Ma), but they evidently did not assign the Seto Formation to any magnetic polarity chron.

K-Ar ages of andesitic dikes, sheets and pyroclastic rocks in the Ashigara Group were analyzed with the help of the Mitubishi Material Co. (Imanaga & Yamashita, in press)(Table 4).

Three samples, P.1, P.2 and H.6, are evaluated from the Hinata Formation as follows: 1.88 ± 0.56 and 1.80 ± 0.64 Ma from a pyroxene andesite sheet at Hirayama; 1.96 ± 0.28 and 2.10 ± 0.29 Ma from pyroclastic rocks at Hinata; and, 0.79 ± 0.18 and 0.76 ± 0.15 Ma from a hornblende andesite dike at Toyoguchi, Yamakita Town, respectively. From the Seto Formation, 2 samples, P.4 and P.5, are evaluated as follows: 1.22 ± 0.6 and 1.23 ± 0.54 Ma from brecciated lava at Marikobashi; and, 1.28 ± 0.39 and 1.21 ± 0.39 Ma from andesitic conglomerate boulder at Minase. From the Shiozawa Formation, 2 samples, H.7 and P.3 are evaluated as follows: ages of 0.71 ± 0.19 and 0.62 ± 0.23 Ma are reported from the Ikudo pyroclastic flow and an age of 1.11 ± 0.33 Ma is reported from a pyroxene andesite dike at Arashi.

Calcareous nannofossils were examined from the bottom to the top of the Ashigara Group at 53 points with the help of Dr. Tokiyuki Sato of Akita University (Fig. 25). Although the Ashigara Group does not contain calcareous nannofossils in abundance, several datum planes were identified (Table 5).

Samples Sa-1, -2, -5, -6, and Tk-2: Sa-1 and Sa-2 were collected from the Hinata Formation and samples Sa-5, -6 and Tk-2 were collected from the Seto Formation (Fig. 25). These samples contain small *Gephyrocapsa* sp. but not *Gephyrocapsa caribbeanica* or *Gephyrocapsa oceanica* at all, and they also yield *Calcidiscus macintyrei*. The samples collected from the Hinata and Seto Formations indicate placement in the uppermost Pliocene. Hence, these formations are assigned an age earlier than the first appearance datum of *G. caribbeanica* (1.72 Ma).

The samples Sa-10, -11, -12, -13, -14, Hz-1, -3, Ji-4, -5, and Hw-2, -5 and -6 were collected from the Hata Formation (Fig. 25). They contain *G. caribbeanica* and *G. oceanica* but not the large *Gephyrocapsa* sp. that are the characteristic of the middle Pleistocene. These samples also yield *Helicosphaera sellii* which is a fossil representative of the middle Pleistocene. Therefore, these samples are assigned an age between 1.65 and 1.44 Ma. The Pliocene-Pleistocene boundary is put between the samples Sa-6 and Sa-10, which coincides with the boundary between the Seto and the Hata Formations (Table 5).

In samples Hw-7, -8, -9, -10, -11 and -13 (Fig.25) large *Gephyrocapsa* which are over 6 microns along major axes, and *H. sellii*, are found. They are assigned to the period between the first appearance datum (FAD) of large *Gephyrocapsa* (1.44 Ma), and the last appearance datum (LAD) of *H. sellii* (1.26 Ma), or middle Pleistocene.

Samples Sa-16, -17, -18, -19, -20, -21, -22 and -23 (Fig. 25) from the middle and upper parts of the Shiozawa Formation yield no calcareous nannofossils. The upper Shiozawa Formation is thought to have been deposited in the tidal zone or on the alluvial plane.

The K-Ar age determinations for P.4 and P.5 show a difference from the nannofossil biostratigraphical ages (Fig.22). However, the results of other K-Ar age determination almost directly contradict those based calcareous nannofossils. The combined results of calcareous nannofossils, K-Ar ages and palaeomagnetic studies assign the Ashigara Group to the Plio-Pleistocene. The Hinata Formation (= Neishi Formation of Amano et al., 1986) is estimated to be older than the Olduvai subchron, judging from its reversed polarity (Amano et al.,

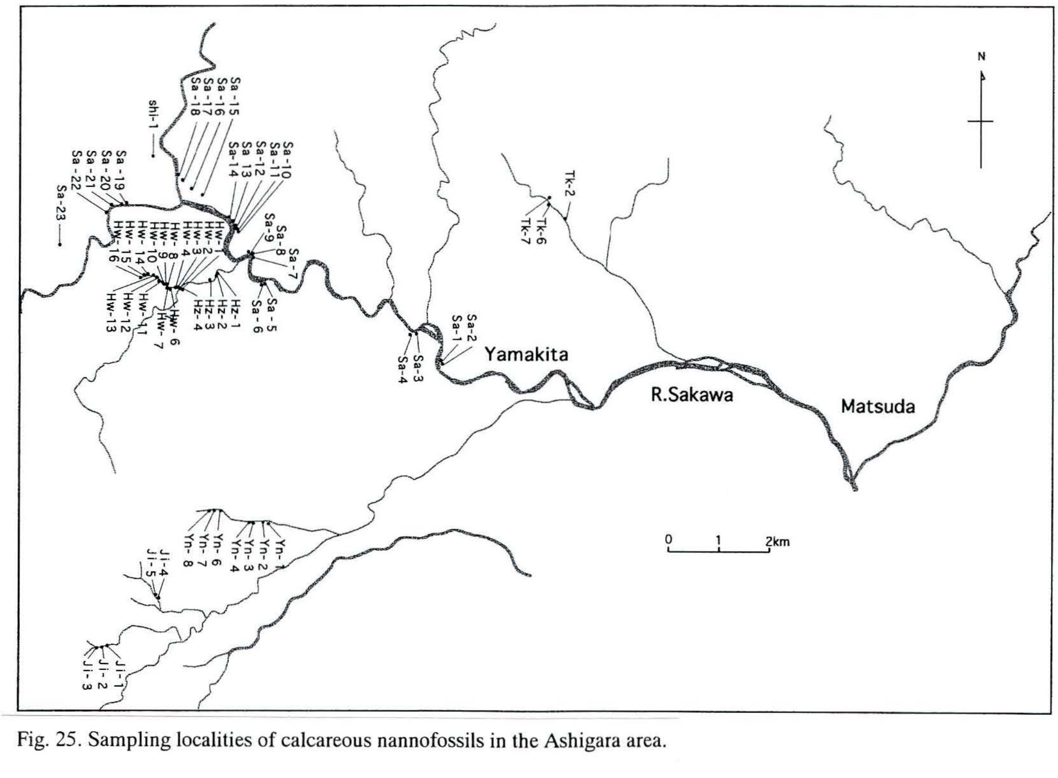


Fig. 25. Sampling localities of calcareous nannofossils in the Ashigara area.

Table 5. Distribution of calcareous nannofossils in the Hinata, Seto, Hata and Shiozawa Formations.

identified by T. Sato of Akita University

Age	Formation	Sample No.	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Coccolithus pelagicus*	*Discolithina japonica*	*Discolithina* cf. *japonica*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa caribbeanica* (large)	*Gephyrocapsa oceanica*	*Gephyrocapsa oceanica* (large)	*Gephyrocapsa* sp. (small)	*Helicosphaera carteri*	*Helicosphaera sellii*	*Pseudoemiliania lacunosa*	*Reticulofenestra* sp. (small)	*Umbilicosphaera sibogae*	*Discoaster surculus*	*Discoaster* sp.	nannofossil datum
PLEISTOCENE	Shiozawa	Hw-13				X		X	X	X	X	X	X	X	X	X				Top of *H. sellii*
	Shiozawa	Hw-11	X					X	X	X	X	X	X	X	X					
	Shiozawa	Hw-10	X		X			X	X	X	X	X		X						
	Shiozawa	Hw-9	X		X			X	X	X	X	X		X						
	Shiozawa	Hw-8	X		X			X	X	X	X	X		X						
	Hata	Hw-7	X		X		X	X	X	X	X	X			X					Bottom of large *Gephyrocapsa*
	Hata	Hw-6			X			X		X		X								
	Hata	Hw-5	X		X	X	X	X		X		X	X	X	X					
	Hata	Hw-2						X		X		X								
	Hata	Ji-5	X					X		X		X	X		X	X				
	Hata	Ji-4	X					X		X		X				X		R		
	Hata	Hz-3	X		X			X		X		X		X		X				
	Hata	Hz-1	X		X			X		X		X	X	X	X	X			R	
	Hata	Sa-15	X		X			X		X		X	X	X	X	X	X			
	Hata	Sa-14	X		X			X		X		X	X	X		X				
	Hata	Sa-13	X		X			X		X		X	X		X	X				
	Hata	Sa-12	X		X			X		X		X			X	X				
	Hata	Sa-11	X		X			X		X					X	X				Bottom of G. oceanica and
	Hata	Sa-10	X		X			X		X					X	X				Top of C. macintyrei
UPPER PLIOCENE	Seto	Sa-6			X							X			X	X				Below Bottom of
	Seto	Sa-5	X		X							X	X			X	X			*G. caribbeanica*
	Seto	Tk-2	X	X	X							X		X	X	X				
	Hinata	Sa-2	X	X	X								X			X				
	Hinata	Sa-1	X	X	X							X				X				

1986) and calcareous nannofossils (Table 5). The Seto Formation is reported as a normal polarity chron (Amano et al., 1986) and is assigned an age greater than 1.72 Ma using calcareous nannofossils. The normal polarity chron of the Seto Formation is correlated with the Olduvai subchron. The Seto Formation is assigned an age ranging from 1.98 Ma to 1.72 Ma (Table 2). Most of the Hata Formation is placed between 1.72 and 1.44 Ma based on calcareous nannofossils. The uppermost part of the Hata Formation and the lowest part of the Shiozawa Formation are estimated as 1.44 Ma to 1.26 Ma from calcareous nannofossils. Kano et al. (1988) suggested that the lower part of the lower Shiozawa Formation has normal magnetic polarity. The change from reversed to normal polarity is placed in the upper Shiozawa Formation as previously mentioned. This magnetic change may be correlated in three cases ways: 1) Matuyama reversed polarity chron to Cobb Mountain normal polarity subchron or 2) Matuyama reversed polarity chron to Jaramillo normal polarity subchron, and or 3) Matuyama reversed polarity chron to Brunhes normal polarity chron. A K-Ar age of 0.71-0.62 Ma was measured in the upper part of the Shiozawa Formation (Ikudo pyroclastic flow). As a result, the magnetic change in the upper Shiozawa Formation may be correlated with the Matuyama reversed to Brunhes normal chron. The youngest age of the Ashigara Group is 0.78 Ma. for the Shiozawa Formation.

8. Geological structure

8-1. Folding

The Ashigara Group has a half-dome structure that plunges to the northwest (Fig. 26). The northern end of the group is set off by the Kannawa Fault (Figs. 26). The half-dome structure is divided into eastern and western parts by a NW-SE anticlinal axis (Fig. 26). The east wing of the half-dome has a strike that runs WNW-ESE and dips 20 to 80 degrees to the north. The west wing has a general strike of NNE to SSW and the dips vary from low angle to nearly vertical.

Strike lines encircle the Yaguradake intrusive mass to both the east and west (Figs. 23, 27). The intrusive mass is estimated to incline 35-55 degrees to the west. Southern border of the intrusive mass is in contact with the deposits by a small strike slip fault, running in an ENE to WSW direction with a dip 48 degrees toward the north.

To the north and south of the Yaguradake quartz diorite mass two synclines plunge SW or WSW. One is to the north of the Yaguradake quartz diorite mass. The east-west trending ridge from the northern foot of the Yaguradake diorite mass is concordant with the strikes on the northern wing of the syncline (Figs. 26 and 27). The other synclinal structure extends from the south of Mt. Yaguradake to Ashigara Pass (Fig. 27).

The structure of the Ashigara Group in the southern part of its area of occurrence, in the vicinity of Jizodo, is complicated

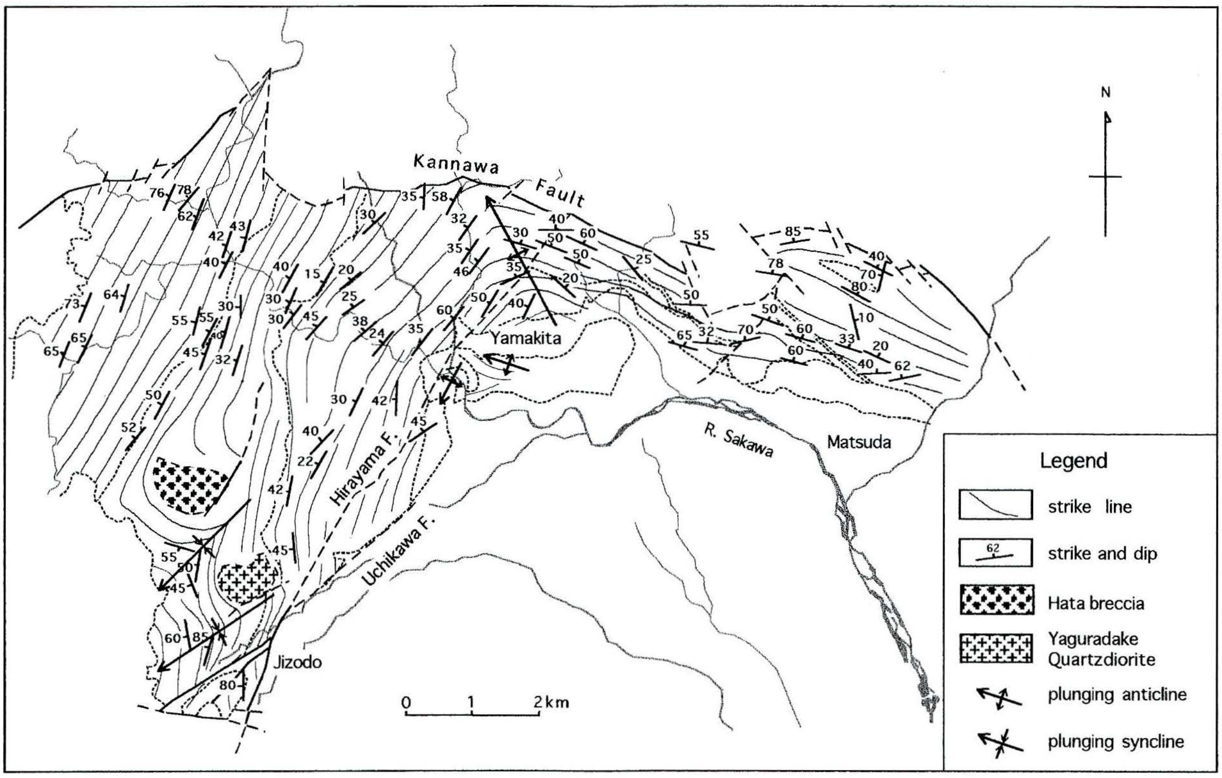


Fig. 26. Structure of the Ashigara Group.

due to lateral faults such as the Uchikawa, Joyama (formerly named Teizan), and Hirayama Faults that run in NE-SW or NNE-SSW directions (Fig 27). The Uchikawa and Joyama Faults, with ENE-WSW trends, separate the strata of the Ashigara Group into three parts. Beds to the north of the Uchikawa Fault strike N-S or NNE-SSW with dips to the west. The strata between the Uchikawa Fault and Joyama Fault strike from E-W to ENE-WSW and dip to the south or are nearly vertical (Fig. 27). The strata of the southern block, south of the Joyama Fault, strikes in a N-S direction and dips from west to almost vertical.

The Ashigara Group in the south of the distribution area is unconformably overlain by the Hakone old somma lavas, but in some places these units have a fault contact.

In the eastern part of its distribution area, in and around Mt. Matsudayama, the structure of the Ashigara Group is complicated. Two lenticular block of the Tanzawa Group are present in the mountain. One of these extends in a NW-SE direction and covers the northeast flank of Mt. Matsudayama, separated from the Ashigara Group by faults (Kanagawa Pref. Gov., 1957). The other long and narrow lenticular strip of the Tanzawa Group exposed between the faults in the southern slope of Mt. Matsudayama extends in a WNW-ESE direction (Imanaga, 1986). A number of small faults trending NE-SW are present on Mt. Matsudayama (Imanaga, 1972). Another NE-SW trending fault along the Neishi Valley displaces the Hinata and Seto Formations for about 0.5 km left laterally. Tsunoda (1997) insisted that the upper Miocene Matsudayama Formation is present on Mt. Matsudayama, but it can merely a lenticular block of the Tanzawa Group which is separate from the Ashigara Group.

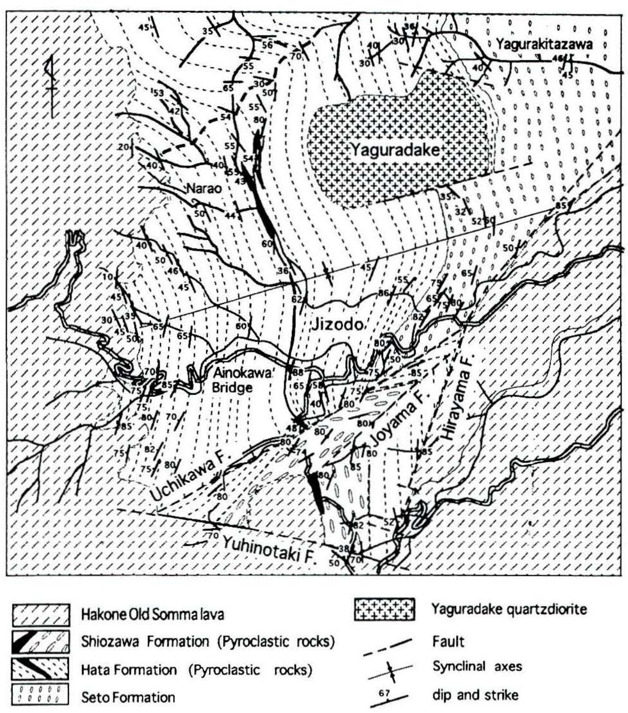


Fig. 27. Geological map of Jizodo area.

8-2. Faults

Among many faults developed in the Ashigara area, the major ones are the Kannawa, Hirayama, Joyama, Uchikawa and Yuhinotaki Faults.

8-2-1. Kannawa, Hirayama, and Uchikawa Fault

The Kannawa Fault is traced in an E-W direction of the southern slope of the Tanzawa Mountains about 20 km from Matsuda Town in the east to Oyama Town in the west (Fig. 28), then it disappears in the upper Pleistocene Suruga Gravels in the vicinity of Oyama Town. It buries itself under the Hakone and Fuji volcanic ash to the northwest of Oiso Hill. It is a reverse fault which separates the Miocene Tanzawa Group from the Pliocene to Pleistocene Ashigara Group. The Kannawa Fault is also thought to be the boundary between the Philippine Sea Plate and the Eurasian Plate (Sugimura,1972).The fault planes appear clearly west of the Kouchi River (Fig. 28). The Kannawa Fault trace traverses the upper part of the Seto Formation and all of the Hata and Shiozawa Formations (Fig. 4).

The thickness of the Hata and Shiozawa Formations are more than 2900 m thick and the amount of dislocation is estimated at over 3,000 m.

The Kannawa Fault or a similar fault first appeared during deposition of the Seto Formation and continued its movement during deposition of the Shiozawa Formation.

There exist some NE-SW trending sinistral slip faults showing dip-slip movement in the western part of the Kannawa Fault (Shiozawa fault system). These coexist with NW-SE trending dextral faults that have dip-slip movement (Nakatugawa fault system) in the eastern part of the Kannawa Fault, and cut and dislocate the Kannawa Fault laterally (Sato, 1976; Hoshino and Hase, 1977; Kano et al., 1978; Kano et al., 1984). Figs. 28, 29and 30 show the distribution of strikes and dips observed along the western trace of the Kannawa Fault. The striations observed on the E-W trending fault plane suggest NW-SE trending compressive stress, whereas striations on the NE-SW sinistral fault plane indicate NNE-SSW compressive stress as shown in Figure 30.

The NE-SW or NNE-SSW faults are developed in the Ashigara area as shown in Figures 4 and 5.

The Uchikawa Fault exposed along the Uchikawa River extends in the N60° E direction and dips vertically, and it cuts the Ashigara Group left-laterally. The eastern extension of the fault is buried under the Hakone pumice flow deposits that have a 50,000 B.P. age.

The Hirayama Fault is well exposed at a cliff of the Sakawa River near an electric power plant in Hirayama Hamlet where

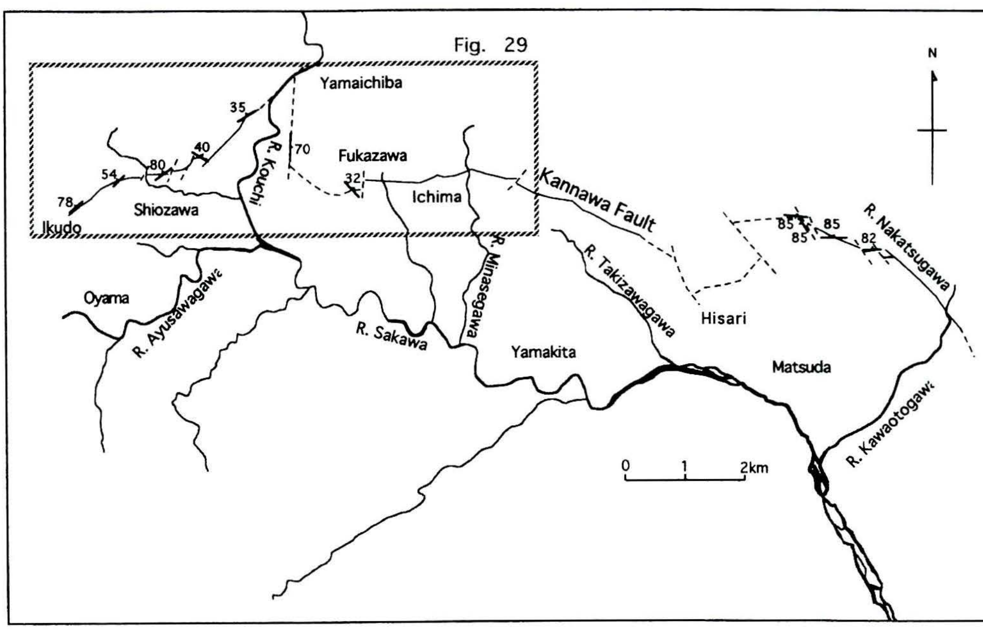


Fig. 28. E-W extension of the Kannawa Fault in the Ashigara area.

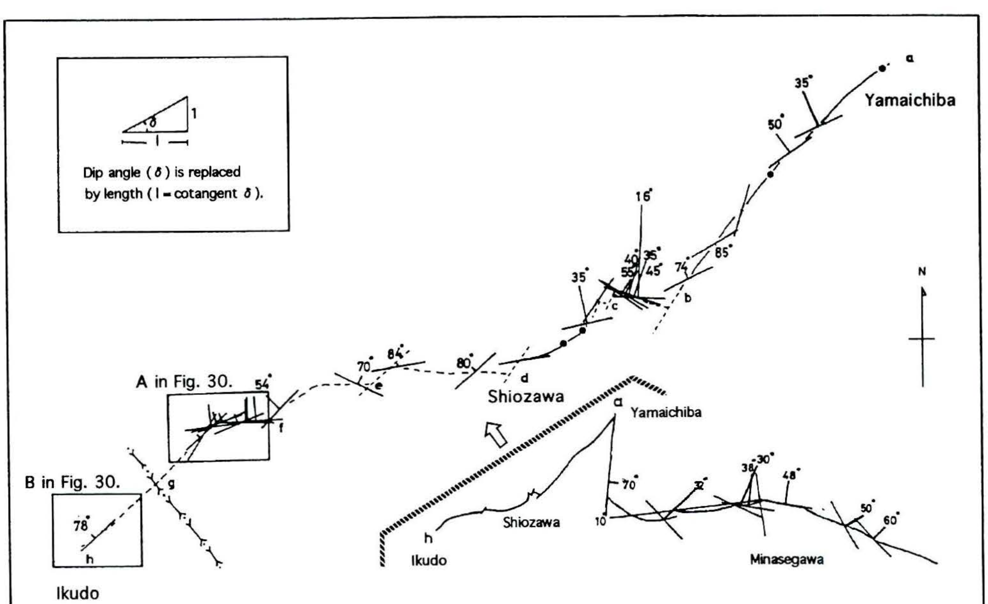


Fig. 29. Strike and dip angles of the fault plane on the Kannawa Fault.

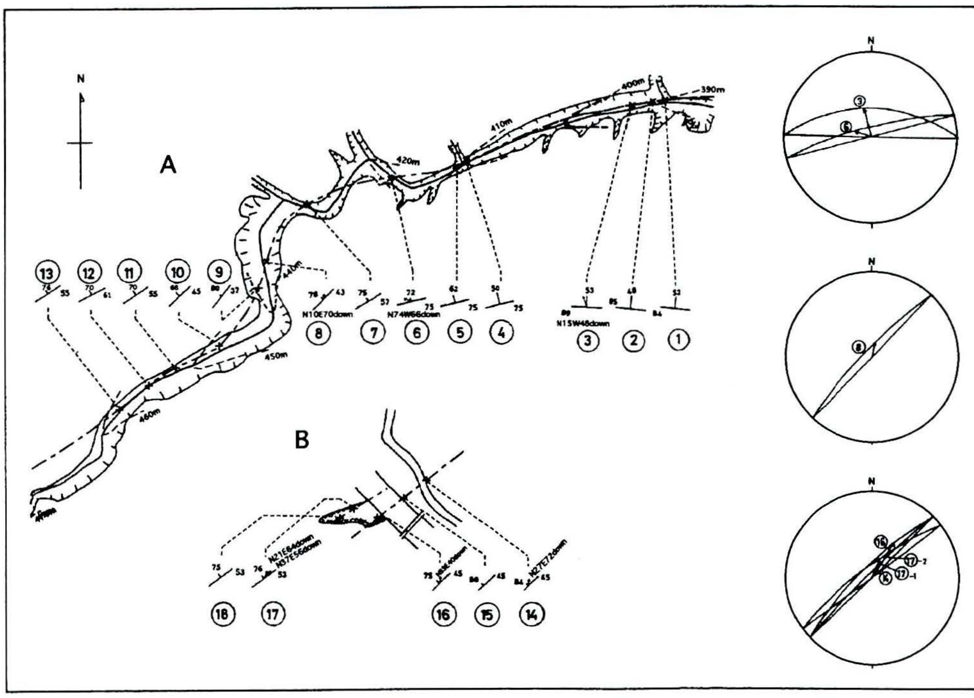


Fig. 30. Strike and dip of the fault plane along the western extension of the Kannawa Fault at Shiozawa Valley (A) and Ikudo Valley (B).

the fault shows the N30° E strike and 60° W dip (Imanaga, 1981, Ito et al., 1987, 1989). The Seto Formation contacts the Hinata Formation along the Hirayama Fault. The hanging wall of the Hirayama Fault is the Seto Formation, and the foot wall is the Hinata Formation (Figs. 4, 5, 7). The Hinata Formation was deformed due to compressive stress as shown in Fig. 10. An andesitic sheet which intruded into the shale of the Hinata Formation on the foot wall was cut by a set of minor thrust faults, and segments of the sheet rock were dislocated. The Hirayama Fault extended southwest from Hirayama to the Jizodo area (Amano et al.,1984).

The Seto Formation rode over the old Hakone somma ejecta along the Hirayama Fault in the area to the east of Jizodo (Fig.27).

The Yuhinotaki Fault is in the Jizodo area, which separates the Ashigara Group from the old Hakone somma ejecta, and is a normal fault striking N80° W and dipping 70 degrees to the south.

8-2-2. Hinata Fault

The Hinata Fault is a thrust fault with strike slip movement extending in an E-W direction (Soh, 1995). The Hinata Fault is well exposed along the river bed south of the Takase Bridge near Hinata Hamlet (Figs.5 and 7). The Hinata Formation of an alternation of sandstone and siltstone striking in a NE-SW direction and dipping at a high angle to the south, thrust up to the south at localities A (95 m downstream from Takase Bridge) and B (140 m downstream from A point) (Fig. 7). The Hinata Fault was considered to be the southern border of the Ashigara Group by Soh (1995), but I think that this fault is not a main boundary fault. The Ashigara Group is distributed in the south of the Hinata Fault at Ganzawa Valley , southwest of Hinata (Fig. 7).

9. Fossils

The calcareous nannofossil flora in the Ashigara Group was reexamined with the help of Dr. Tokiyuki Sato of Akita University. As a result, the Ashigara Group is assigned to the upper Pliocene to lower Pleistocene.

Molluscan fossils occur in the middle and upper parts of the Ashigara Group. The Hata Formation yields a number of molluscan fossils that indicate an upper bathyal zone, such as *Acila divaricata*, *Yoldia glauca*, and *Macoma calcarea*, and the Shiozawa Formation yields fossils such as *Meretrix lussoria*, *Dosinorbis japonicas*, *Dosinella penicillata*, *Paphia euglypta*, *Crassostrea gigas* and *Trapezium liratum* that indicate a shallow or brackish embaymental environment (Matsushima, 1982). The upper part of the Shiozawa Formation yields fossil plants.

A detailed account of fossils and their locations of the Ashigara Group documented mostly by Matsushima (1982) is summarized as below.

Loc. A, riverbed of the Kochi River at Yozawa, Yamakita Town. Fossil beds are intercalated in sandstone and produce *Crassostrea gigas*.

Loc. B, riverbed of the Kouchi River at Kawanishi, Yamakita Town. Molluscan fossils are of subtidal and inter tidal zone characterized by *Meretrix lusoria*, *Dosinorbis japonicus*, *Macoma incongrua*, *Nitidotellina nitidula* and *Mya arenaria oonogai*.

Loc. C, entrance of Shiozawa valley in Yamakita Town. *Dosinella penicillata*, *Dosinorbis japonicus*, *Panopea japonica*, *Mya arenaria oonogai*, *Macoma tokyoensis*, *Meretrix lusoria* and *Umbonium costatum* were reported from this locality.

Loc. D, Morobuchi, Yamakita Town. It yields mollusca such as *Crassostrea gigas*,*Trapesium liratum* and *Macoma incongrua*, *Chiazacmea pygmaea lampanicola* and *Littorina brevicula*,.

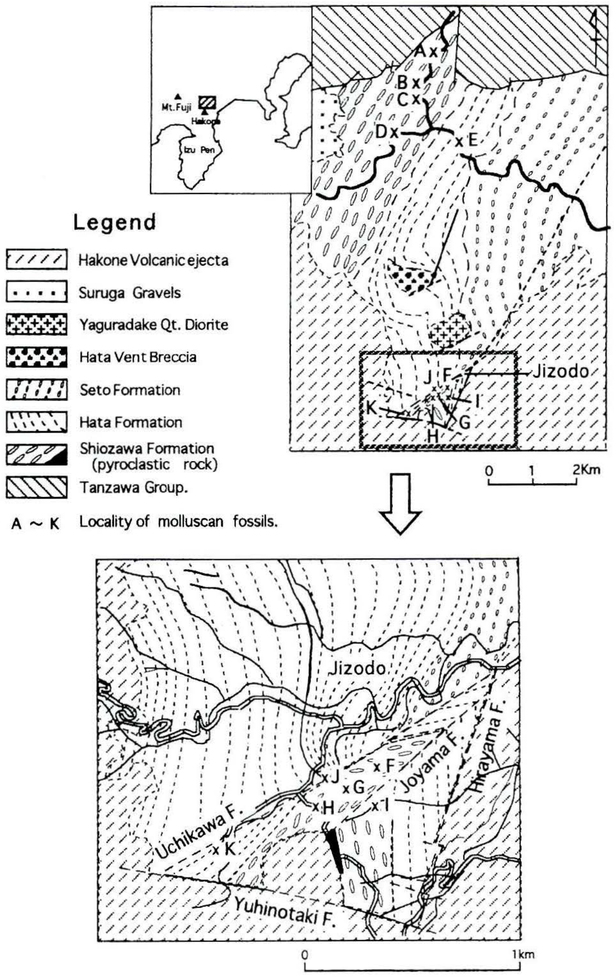


Fig. 31. Molluscan fossil localities in the Ashigara Group.

Loc. E, Arashi, Yamakita Town. Conglomerate bed produce fossils such as *Umbonium costatum*, *Cryptonatica janthostomoides*, *Buccinum* cf. *Leucostoma*, *Atrina pectinata japonica*, *Chlamys* sp., *Acesta goliath* and *Ostrea* sp. The fossils also found in the alternation of mudstone and sandstone such as *Acila divaricata*, *Yoldia glauca*, *Yoldia* sp., *Nuculana yokoyama* and *Macoma calcarea*.

Loc. F, Hamagurizawa in Jizodo, Minami-Ashigara City. Fossil beds are intercalated in sandy mud beds and produced *Crassostrea gigas*, *Trapesium liratum*, *Dosinorbis japonicus*, *Meretrix lusoria* and *Mya arenaria oonogai*. This assemblage indicates a muddy bottom condition of a inner bay.

Loc. G, Joyama in Jizodo. Two molluscan fossil beds are found and they are probably the western extension of the Hamagurizawa beds. Molluscan fossils such as *Crassostrea gigas*, *Trapesium liratum*, *Macoma incongrua*, *Tapes philippinarium*, *Littorina brevicula*, *Reticunassa festiva*, *Meretrix lusoria*, *Dosinorbis japonicus*,and *Umbonium costatum*, were yielded. The molluscan association indicates a inner bay or tidal zone of sandy mud bottom environment.

Loc. H, road-side of Kokubyakurindo. It yields *Dosinella penicillata*, *Paphia euglypta*, *Paphia chnelliana*, *Clementia vatheleti*, *Macoma praetexta* and *Panopea japonica*.

Loc. I, a tributary of the River Karikawa at south of Joyama, southern area of Joyama Fault. Molluscan fossils are of subtidal and intertidal zone such as *Meretrix lusoria*, *Dosinorbis japonicus*, *Mya arenaria oonogai*, *Solen strictus*, *Panopea japonica* , *Rapana venos* and *Tonna luteostoma*.

Loc.J, a ruin of quarry at Joyama. Molluscan fossils are characteristic of upper bathyal zone such as *Acila divaricata*, *Nuculana yokoyamai*, *Yoldia glauca*, *Yoldia* sp., *Limopsis tokaiensis* ? and *Solamen* cf. *Spectabilis*.

Loc.K, the entrance of the Yuhinotaki fall. The bed yields molluscan fossils that indicate a upper bathyal zone such as *Ennucula niponica*, *Sarepta speciosa*, *Volutharpa perryi*, *Umbonium* sp. and *Clementia vatheleti*.

10. Tectonic history of the Ashigara area

Sedimentation of the Ashigara Group took place in the late Pliocene, earlier than 2.0 Ma as evaluated from calcareous nannofossil biochronology, K-Ar dating and a paleomagnetic study. At that time, the Philippine Sea Plate started to subside along a trough located to the south of the Tanzawa Mountains. The Hinata Formation, the lowest part of the Ashigara Group, which is mainly composed of alternations of sandstone and mudstone of turbidite origin carried from land to the north, was deposited on a deep sea plain in depths of 1,000 to 2,000 meters (Huchion and Kitazato, 1984). Coarse tuff and volcanic breccia which are intercalated in the Hinata Formation suggest subaqueous andesitic volcanic activities occurred in the depositional area at that time.

The Seto Formation, mostly composed of conglomeratic deposits up to 1,300 m thick, and overlying the Hinata Formation, was deposited as a submarine fan in about 600 to 200 meters depth (Huchion and Kitazato, 1984) at 2.0-1.72 Ma. These thick conglomerate beds were subjected to rapid elevation of the Tanzawa Mountains caused by the collision of Izu Peninsula with the Honshu Arc. The conglomerate clasts mainly consist of basaltic to andesitic pyroclastic rocks of the Tanzawa Group. The rapid uplifting of the Tanzawa Mountains may suggest the beginning of movement on the Kannawa Reverse Fault or a similar fault. The plate motion is estimated to have had a NNW-SSE direction during deposition of the Hinata and Seto Formations.

Subaqueous andesitic pyroclastic rocks and lavas were extruded into the conglomerates of the Seto Formation.

The Hata Formation is mainly composed of sandstone and mudstone that was deposited on the sea floor at a depth of 100 to 300 meters in a shelf-edge environment (Huchon and Kitazato, 1984). Huge mud and sand deposits of the Hata Formation range from 600 to 1,000 meters in thickness and accumulated at 1.65-1.26 Ma.

The change of depositional environments from conglomeratic to sand and mud, that is from the Seto Formation to the Hata Formation, occurred at about 1.72-1.65 Ma. This change was caused by a reduction of PHS Plate motion or by a change in its direction. I concur that the PHS Plate changed its direction from NNW to WNW at 1.72-1.65 Ma, as Tanahashi (1986) has pointed out.

At the beginning of Hata Formation deposition, uplift and denudation of the Tanzawa Mountains were not active as a result of the change in motion of the PHS Plate.

A huge boulder conglomerate is exposed in the Ninokurakaihatu Co. Quarry near the end of the Hatazawa Valley. The conglomerate consists of angular boulders of andesite, mudstone and sandstone. The boulders have a maximum diameter of over 10 meters and are intercalated in the alternation of mudstone and sandstone of the Hata Formation. These huge conglomeratic boulders indicate that a submarine phreatomagmatic eruption occurred during deposition of the Hata Formation. These explosive events might be due to the change in direction of the plate motion.

During deposition of the Shiozawa Formation, the Honshu Arc separated into two parts, the North America Plate and Eurasia Plate, along the Itoigawa Shizuoka Tectonic Line at about 1.0 Ma. The motion of the Philippine Sea Plate relative to the North American Plate changed direction from WNW to NNW. The Tanzawa Group was again thrust up to the Ashigara Group owing to a change in collision of the Izu Peninsula against the Honshu Arc from a WNW direction to a NNW one. The elevated Tanzawa Mountains was denuded and provided gravels of quartz diorite and green schist from the Tanzawa Group. Clasts were carried to a southern shallow sea or estuary to the depth of about 30-0 meters (Huchion and Kitazato, 1984, Matsushima, 1982), as a fan-delta or alluvial fan.

The depositional duration of the Shiozawa Formation was from 1.26 Ma to sometime after 0.78 Ma.

The whitish conglomerate and sandstone of the Shiozawa Formation is composed of quartz diorite, green schists and hornfels of the Tanzawa Mountains and exceeds 2,300 meters in thickness. The gravels present in the conglomerate suggest that the Kannawa Fault was active and caused a rapid uplifting of the Tanzawa Mountains, and subsequently caused a rapid denudation, especially at the central part of Tanzawa Mountains.

The Yaguradake quartz diorite mass intruded into the lower part of the Hata Formation at about 1.15 Ma (Kurasawa et al.,1988) during deposition of the Shiozawa Formation.

The Ikudo Pyroclastic flow deposits was supplied by a terrestrial volcanic eruption at about 0.78 Ma (Ito et al., 1985). The sharp reduction is seen in the thickness of this pyroclastic flow between the Ayusawa River and the Shiozawa Valley about 2 km north. The conduit of the Hatazawa breccia is estimated to be the source volcano in the south (Ito et al., 1985).

The Ashigara Group was folded and deformed, and these processes were accompanied by uplift of the Ashigara Mountains.

Finally, the Hakone volcanic eruption occurred at about 0.4

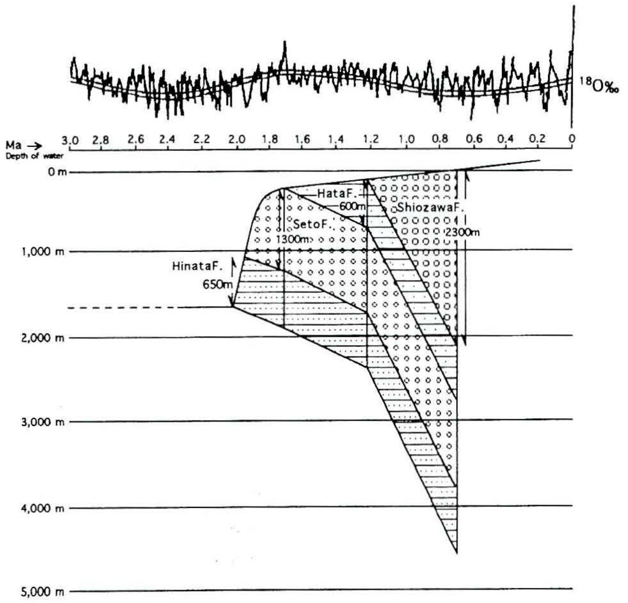


Fig. 32. Change of depositional environment showing the accumulation rate of the Ashigara Group.

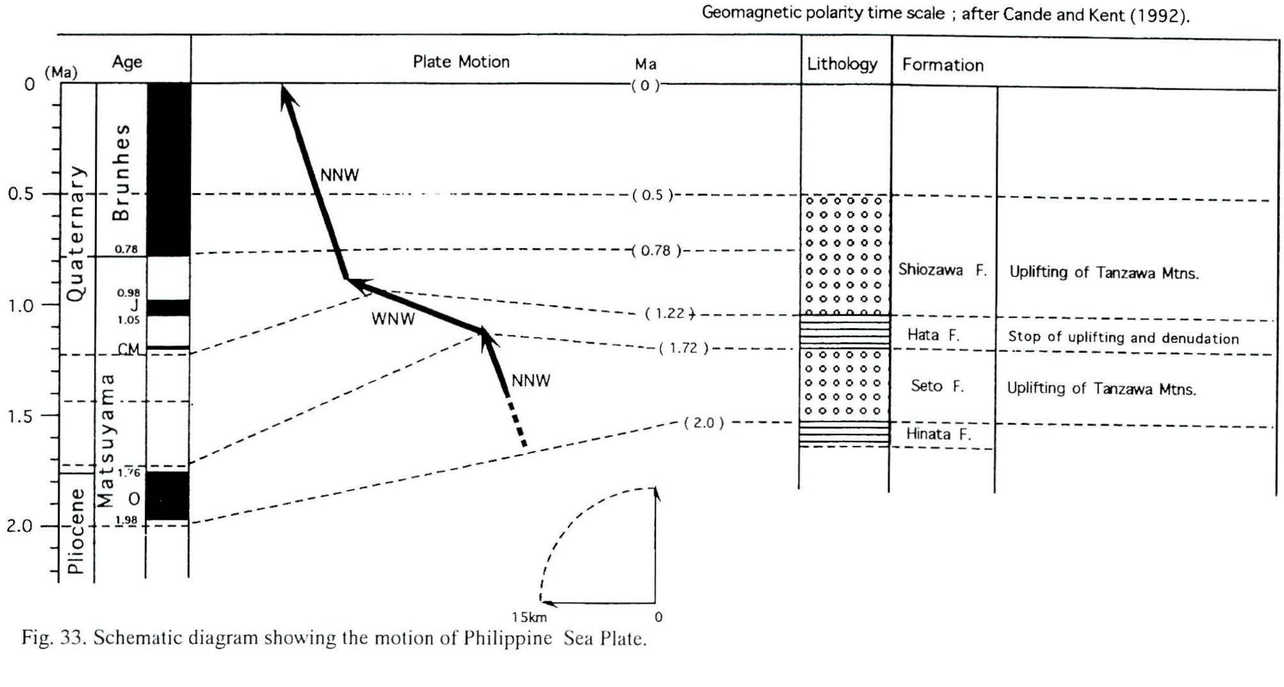


Fig. 33. Schematic diagram showing the motion of Philippine Sea Plate.

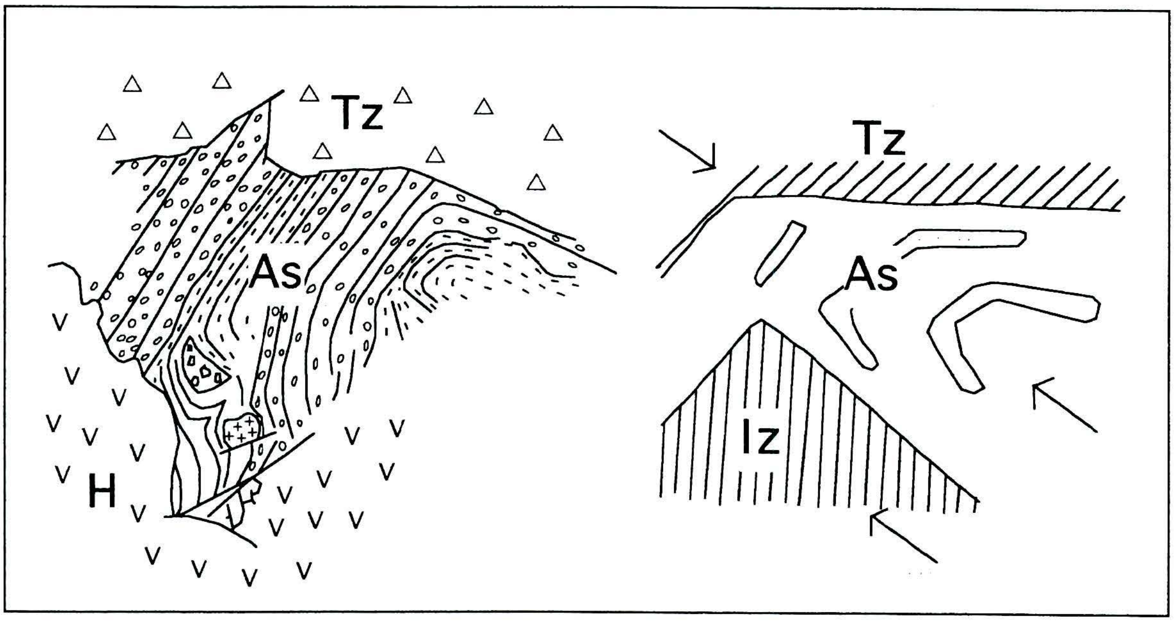


Fig. 34. Schematic diagram showing the structural deformation of the Ashigara Group. Tz; Tanzawa Group, As Ashigara Group, H; Hakone Vlcanic ejecta, Iz :Izu Peninsula.

Ma and the Suruga Gravels were deposited at about 0.08 Ma in the western part of Ashigara Mountain (Machida et al., 1978). The NE-SW and NW-SE fault systems which cut the Ashigara Group are estimated to have been made by compressive stress induced by NNW-SSE plate motion after 1.0 Ma.

The changes in the depositional environment, tectonic history and deformation of the Ashigara Group are summarized in Table 6 and Figs. 32,33 and 34.

11. Conclusions

The Ashigara Group is comprised of sediments in a collision zone located between the Izu Peninsula and the Tanzawa Mountains, and consists of conglomeratic deposits over 5,000 m thick. The following conclusions are based on the present stratigraphic study, which incorporates new K-Ar dating and calcareous nannofossil ages.

Table. 6. Compiled table of the stratigraphy of the Ashigara Group.

Age	(Ma)	Formation	Column	Thickness	Lithofacies	Depositional Environment	Volcanic Activity	Plate Motion	Fault Activity
Quaternary	0.5		Fuji Volcanic ejecta Suruga Gravels Hakone Volcanic ejecta						NE-SW NW-SE N-S LLF RLF RLF
	0.78 1.26	Shiozawa F.	Kurobyaku Pyroclastic Ikudo Py.flow	2300m+	dacitic py. rock andesitic py. rock alt. (cong. /s. s.) fossil shells	alluvial fan estuary -30m ~ 0m	Ikudo Py. flow Kurobyaku Py. Hor. And. Yaguradake Qt. Dio. Py. And. Hor. And.	NNW 1.0Ma	
	1.44 1.72	Hata F.	Hata breccia Narao Pyoclastics Yaguradake Diorite	600~ 1000m	alt. (s. s. /silt st.) breccia dacitic py. rock cong., lava qt. dio. mass	shelfedge -300m~-100m	Py. And. Hata breccia	NWW 1.72Ma	
Pliocene		Seto F.	Lava flow Lava flow	1300m	cong., lava lava lava alt. (cong. /s. s.)	submarine fan -600m~-200m	Py. And.	NNW	
	2.0	Hinata F.	Neishi Pumice Lava flow	650m+	pumice tuf. s. s., alt. (md. st. /s. s.)	deep sea plain -2000m ~-1000m	Py. And.		KRF

Conglomerate; Sandstone; Mud st. sand st. alt.; Shell fossils; Hata breccia; Pyoclastics; Pumice; Lava flow; Quartzdiorite

KRF. : Kannawa Reverse Fault, LLF. : Left Lateral Slip Fault, RLF. : Right Lateral Slip Fault.

Qt. Dio. : Quartzdiorite intrution, Py. And. : Pyroxene andesite activity, Hor. And. : Hornblende andesite activity, Py : Pyroclastics, Py. flow : Pyroclastic flow.

1. The collision of the Izu Peninsula against the Honshu Arc took place at 2.0-1.72 Ma.

2. Two coarsening-upward cycles in the Ashigara Group, from muddy to conglomeratic sediments, seem to be related to the change in motion of the PHS Plate relative to the Honshu Arc.

3. Subaqueous volcanic activities occurred during deposition of the Ashigara Group. Tholeiitic and calcalkalic igneous activity occurred simultaneously in the collision zone .

4. Faults developed in and around the Ashigara Group. The Kannawa Fault began to act as the Seto Formation was deposited.

5. The tectonic history of the Ashigara Group is interpreted as follows:

1) Prior to 2.0 Ma : The Philippine Sea Plate is inferred to have moved in a NNW direction, and the plate began to subside along a trough to the south of the Tanzawa Mountains prior to 2.0 Ma.

2) At 2.0-1.72 Ma : The motion of the Philippine Sea Plate was in a NNW direction. Muddy and sandy turbidites were deposited from a northern land mass in a trough at a depth of about 1,000-2,000 m to the south of the Tanzawa Mountains, and this process produced the Hinata Formation, the lowest formation of the Ashigara Group. Subaqueous volcanic eruptions and lava flows occurred in the trough. Collision of the Izu Block (Izu Peninsula) against the Honshu Arc began at this time. The Kannawa Fault or a similar fault may have become active then. The Tanzawa Mountains were uplifted and supplied conglomeratic materials southward to the sea. The Seto Formation, which consists of an alternation of conglomerate and sandstone, was deposited on a deep sea fan at depths of 600-300 m. Pyroclastic rocks and lavas effused onto the deep sea fan during deposition of the Seto Formation.

3) At 1.72-1.26 Ma : The Philippine Sea Plate changed direction from NNW to WNW at around 1.72 Ma. The uplift of the Tanzawa Mountains was reduced and so provided less clastic material southward to the sea. The Hata Formation, consisting of an alternation of sandstone and mudstone with conglomeratic lenses, was deposited on the continental slope in depths of 300-100 m.

4) At 1.26-0.78 Ma and after: The Eurasia Plate to the east of the Itoigawa-Shizuoka Tectonic Line changed to the North American Plate at about 1.0 Ma. In connection with the motion of the Philippine Sea (PHS) Plate relative to the North American Plate, the PHS Plate changed direction from WNW to NNW at about 1.0 Ma, when the Honshu Arc separated into two parts consisting of the North American Plate and Eurasia Plate.

Related to this change in movement to a NNW direction, the Izu Block (Izu Peninsula) on the Philippine Sea Plate collided against the Honshu Arc again, and uplift of the Tanzawa Mountains took place. As a result, the Shiozawa Formation, which is characterized by conglomeratic sediments, was formed at 1.26.-0.78 Ma and after.

5) The Yaguradake quartz diorite mass intruded at about 1.15 Ma, during deposition of the Shiozawa Formation.

6) The NE-SW and NW-SE lateral fault systems, namely the Shiozawa and Nakatsugawa fault systems, developed along the Kannawa fault, the junction of two plates at the end of collisional movement.

12. Acknowledgments

I would like to express my sincere gratitude to Professor Kenshiro Ogasawara of the University of Tsukuba for his supervision and critical reading of this manuscript. I am also grateful to Professor Yujiro Ogawa of the University of Tsukuba for his continuous encouragement. Deep appreciation is due to Professor Toshio Koike of Yokohama National University for his helpful comments on an earlier draft of this paper. Deep appreciation is also due to Professor Makoto Arima and Associate Professor Tetsuto Eto, of Yokohama National University, for their consistent support. I thank to Dr. Louie Marincovichi, Jr. for his critical reading of the manuscript. I am also indebted to Professor Kiyoshi Okumura of Naruto Educational College and to Professor Tokiyuki Sato of Akita University for their kind support. I am also indebted Dr. Satoru Haraguchi of Ocean research Institute of University of Tokyo for helpful support. I am also grateful to Dr. Takashi Hamada, Emeritus Professor of University of Tokyo and President of the Kanagawa Prefectural Museum of Natural History, for useful discussions. I would like to express my thanks to several individuals for their cooperation with and encouragement during the preparation of this manuscript: Dr. Yoshiaki Matsushima, former chief of the Natural Science Department, and Mr. Masaru Hirota, chief of the Executive Department, of the Kanagawa Prefectural Museum of Natural History, for their valuable suggestions and moral support; and colleagues at the Kanagawa Prefectural Museum of Natural History for their warm assistance during the completion to this thesis.

13. References

Amano. K., K. Yokoyama & T. Tachikawa, 1984. Hirayama fault which cuts an older somma of Hakone volcano. Jour. Geol. Soc. Japan, 90 (11): 849-852. (in Japanese)

Amano, K., H. Takahashi, T. Tachikawa, K. Yokoyama, C. Yokota & J. Kikuchi, 1986. Geology of Ashigara Group -Collision tectonics of Izu micro-continent with Eurasian plate-. Professor Nobu Kitamura Commemorative volume Essays in Geology p.7-29. (in Japanese with English abstract)

Ashigara Collaborative Research Group for late Miocene-Pliocene series in Ashigara mountainland, 1983. On the Volcano Sedimentary Basin in the Ashigara Area - A study of the Tertiary and Quaternary system in the Ashigara Area (1)-. Earth Science, 37 (4): 194-204. (in Japanese with English abstract)

Ashigara Collaborative Research Group, 1986. Stratigraphy and Geological Structures of the Ashigara Group - Study of the Tertiary and Quaternary systems in the Ashigara Area (2)-. Earth Science, 40 (1): 47-63.(in Japanese with English abstract)

Hasegawa, Y., Y. Matsushima, & K. Mikami, 1986. Parastegodon tooth from the Ashigara Group. Memory of Institute Field Education of Yokohama National University, 4: 51-55. (in Japanese)

Hirabayashi, T., 1898. Geological report of Hakone and Atami Volcano. Reports of the Imperial Earthquake Investigation Committee 16: 4-78. (in Japanese)

Hoshino, K. & H. Hase, 1977. The N-S trending faults to shift the Kannawa fault. Jour. Geol. Soc. Japan., 83 (1): 62-64. (in Japanese).

Hot Springs Research Institute of Kanagawa Prefecture , 1992. K-Ar Age results of Kanagawa Prefecture in 1991, Operational Report of the Hot Springs Research Institute of Kanagawa Prefecture p.72 (in Japanese)

Huchon, P. & H. Kitazato, 1984. Collision of the lzu block with central Japan during the Quaternary and geological evolution of the Ashigara area. Tectonophysics, 110: 201-210.

Imanaga, I., 1972. Minor Faults Associated with the Kannawa Reverse Fault along the Nakatsu River, Matsuda Town, Kanagawa Prefecture. Bull. Kanagawa Prefect Mus. (Nat. Sci.), (5): 27-29. (in Japanese)

Imanaga, I., 1976. Stratigraphy and geological structure of Jizodo area north of Hakone Volcano. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (9): 77-84. (in Japanese with English abstract)

Imanaga, I., 1977. Geology of Hatazawa. north of Mt. Yagura in Ashigara Mountains. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (10): 37-42. (in Japanese with English abstract)

Imanaga, I. 1978. The Ashigara Mountains. Excursion Guide Book for Hakone and Tanzawa Mountains, Miura Peninsula and Oiso Hill. Kanagawa Chigakukai p. 14-22. (in Japanese)

Imanaga, I., 1980. Direction of dikes in Ashigara Group at the base of lzu peninsular. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (12): 35- 41. (in Japanese with English abstract)

Imanaga, I., 1981. Reverse fault on the riverbank of opposite side of Yamakita electric power plant, Yamakita Town, Kanagawa prefecture. Natural History Report of Kanagawa, (2): 66. (in Japanese)

Imanaga, I., 1982. Deformation of the Hakone Volcano Basement Rocks and the Ashigara Group. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (13): 75-81. (in Japanese with English abstract)

Imanaga, I., 1986. Stratigraphy and structure of the Ashigara Group. Monthly Chikyu, 8 (1): 637-641. (in Japanese)

Imanaga, I., 1987. Geological structure of Hinata area, Yamakita-cho, Kanagawa prefecture. Natural History Report of Kanagawa, (8): 23-26. (in Japanese)

Imanaga, I., 1989. Geology of the Ashigara Group. Modern Geology, 14: 99-112.

Imanaga, I., 1994. On the Shinokubo Pyroclastic Rocks in the Oiso Hill. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (23) 87-90. (in Japanese with English abstract)

Imanaga, I. & H. Yamashita, 1999. K-Ar age new data from Kanagawa Prefecture. Research Report of the Kanagawa Prefectural Museum Narural History (in Japanese)(in press)

Ishida, T., 1991. Linear Arrangement of Explosive Breccia Pipes in the Eastern part of the South Fossa Magna region. Modern Geology , 15 (4): 401-411.

Ishikawa, C., N. Okada, & H. Kitazato, 1983. Stratigraphy and geological age of the Ashigara Group. Geological Society of Japan. Abstract of the 90 th Annual Meeting, p. 98. (in Japanese)

Ito, M., 1985. The Ashigara Group: a regressive submarine fan-fan delta sequence in a Quaternary collision boundary, north of lzu Peninsula, central Honshu, Japan. Sediment. Geol., 45: 261-292.

Ito, T., T. Fujii, M. Yui, Y. Uesugi, M. Someno & K. Kano, 1985. Ikudo Pyroclastic flow (-0.7 Ma) in the Ashigara Group, central Japan and estimation of its source volcano. Bull. Volcanic Soc. Japan, 30 (4): 319. (in Japanese)

Ito, T., Y. Uesugi, K. Kano, T. Chiba, H. Yonezawa, M. Someno & M. Honma, 1986. Paleogeographical and tectonic changes of Ashigara-Oiso area, in the recent one million years. Monthly Chikyu, 8 (10): 630- 636. (in Japanese)

Ito, T., Y. Uesugi, H. Yonezawa, K. Kano, M. Someno, T. Chiba & T. Kimura, 1987. Analytical method for evaluating superficial fault displacements in volcanic air fall deposits: case of the Hirayama Fault, south of Tanzawa Mountains, central Japan, since 21,500 years B P. Jour. Geophy. Res., 92 (10): 683-695.

Ito, T., K. Kano, Y. Uesugi, K. Kosaka & T. Chiba, 1989. Tectonic evolution along the northernmost border of the Philippine Sea plate since about 1 Ma. Tectonophysics, 160: 305-326.

Kakimi, T., H. Yamazaki, A. Sangawa, Y. Sugiyama, K. Shimokawa & S. Okra, 1982. Neotectonic Map of Tokyo I: 500,000. Geological Survey of Japan.

Kanagawa prefectural government, 1957. Soil-Erosion Control Reports; The Shijuhasse, the Nakatsu, the Hisari, the Minase and the Kajiyashiki pp. 39. (in Japanese)

Kano, K., T. Ito, & T. Kimura, 1978. Meaning of Kannawa thrust fault in lzu -Tanzawa fault system. 15th Symposium of Natural Disaster Science, p. 89-92. (in Japanese)

Kano, K., Y. Uesugi, T. Ito, T. Chiba, H. Yonezawa & M. Someno, 1984. Active Faulting in and around the Southern Tanzawa Mountains and the Oiso Hills, South Fossa Magna Region, Japan. The Quaternary Res., 23 (2): 137-14. (in Japanese with English abstract)

Kano, K., M. Someno, Y. Uesugi, & T. Ito, 1988. Fault movement in the northwestern Ashigara area, central Japan, since the Middle Pleistocene - Process of superficial deformation along a mechanical plate boundary-. Geoscience Reports of Shizuoka Univ., (14): 57-83. (in Japanese with English abstract)

Kato, T., 1910. General report of the geology of Yamakita Town and its vicinity in Sagaminokuni. Geological Report, (18): 47-73.

Kitazato H., 1997. Paleogeographic changes in central Honshu, Japan, during the late Cenozoic in relation to the collision of the Izu- Ogasawara Arc with the Honshu Arc. Island Arc, 6(2): 144-157.

Koyama, M., 1986. Geological history of lzu Peninsula and Pleistocene of Ashigara-Ooiso area. Monthly Chikyu, 8(12): 743-752. (in Japanese)

Kuno, H., 1951. Geology of Hakone volcano and adjacent areas. Part 2. Journal of Faculty of Science University of Tokyo. Section 2, 7: 351-402.

Kurasawa, H., I. Imanaga, A. Matsumoto & K. Shibata, 1988. K-Ar age and chemical and strontium isotropic compositions of the Yagura-dake Quartzdiorite, Ashigara, central Japan. Jour. Geol. Soc. Japan, 95(4): 331-334. (inJapanese)

Machida, H., Y. Matsushima & I. Imanaga, 1975. Tephrochronological study on eastern foot of Mt. Fuji volcano. With special reference to geomorphological development accompanied with growth of Mt. Fuji and displacement of the Kannawa fault. Quarternary Research, 14 (2): 77-89. (in Japanese with English abstract)

Matsushima, Y. & I. Imanaga, 1968. Notes on the Kannawa reverse fault. Bull. Kanagawa Prefect. Mus. (Nat. Sci.), (l): 65-73. (In Japanese with English abstract)

Matsushima. Y., 1982. Molluscan fauna from the middle and upper parts of the Ashigara Group. Memoirs of National Science Museum, (15): 53-62. (in Japanese with English abstract)

Mikami, K., 1961. Geological and petrographical studies on the Tanzawa

Mikami, K., 1961. Geological and petrographical studies on the Tanzawa Mountainland Part I. Science Report of Yokohama Nat. Univ. Section 2, p. 57-110.

Mikami, K., 1962. Geological and petrographical studies on the Tanzawa Mountainland Part 2. Science Report of Yokohama National University Section 2, p. 59-108.

Nakamura, K. & K. Shimazaki, 1981. Sagami Trough, Suruga Trough and Subduction of Plate. Kagaku, 51 (8): 490- 498. (in Japanese)

Nakamura, K., K. Shimazaki & N. Yonekura, 1984. Subjection, bending and eduction. Present and quaternary tectonics of the northern border of the Philippine sea plate. Bull. Soc. Geol. France, 26 (2): 224-243 .

Niitsuma, N. & T. Matsuda, 1984. Collision in the South Fossa Magna Area, Central Japan. Recent Progress of Natural Sciences in Japan, (9): 41-50.

Okada, H., 1987. Calcareous nannofossil biostratigraphy and paleoenvironmental analysis of marine formations exposed in the south Fossa-Magna region. Fossil, 43: 5-8. (in Japanese)

Otuka, Y., 1931. On the Tertiary Ashigara Bed. Jour. Geol. Soc. Japan, 38: 322-323

Sato, T., 1976. Nakatsugawa right-lateral fault (new name). Jour. Geol. Soc. Japan, 82 (10): 617-623 . (in Japanese with English abstract)

Sato, T. & K. Kameo, 1996. Pliocene to Quaternary calcareous nannofossil biostratigraphy of the arctic ocean, with reference to late Pliocene glaciation. Proceedings of the Ocean Drilling Program, Scientific Results, 151: 39-59.

Seno, T., 1987. New plate boundaries around Japan and tectonic movements at 0.5 Ma. Kagaku, 57 (2): 84-93. (in Japanese)

Seno, T., S. Stein & A. E. Gripp, 1993. A Model for the Motion of the Philippine Sea Plate Consistent With NUVEL-1 and Geological Data. Jour. Geophy. Res., 98 (B 10): 17941-17948.

Soh, W., 1995. A thrust (Hinata Thrust) demarcating the southern margin of the Ashigara Group, central Japan and its seismotectonic implication. Jour. Geol. Soc. Japan, 101 (4): 295-303. (in Japanese with English abstract)

Someno, M., Y. Uesugi, T. Chiba, K. Kano & T. Ito, 1984. Stratigraphy, ages and geological structure of upper Ashigara group-lower Tama Loam Formation, Geol. Soc. Japan. Abstract of 91 Annual Meeting p. 511. (in Japanese)

Sugimura, A., 1972. Plate boundaries in and near Japan. Kagaku, 42 (4): 192-202. (in Japanese)

Sugiyama, Y. & K. Shimokawa, 1982. The geologic structure of the Ihara district and the Iriyama fault system in the South Fossa Magna region, Central Japan. Bull. Geological Survey of Japan, 33 (6): 293-320. (in Japanese with English abstract)

Sugiyama, Y., 1989. Bend of the zonal structure of island arcs and oblique subduction as the cause of the bending. Part 2 - Bending structures of the outer zone of Southwest Japan and the history of relative motion of the Philippine Sea Plate with respect to Southwest Japan -. Bull. Geological Survey Japan, 40 (1): 543-564. (in Japanese with English abstract)

Tanahashi, M., 1986. Sedimentary Structure and Tectonics of Sagami Trough. Monthly Chikyu, 8(4): 238-245. (in Japanese)

Tsunoda, F., 1997. On the Upper Miocene Matsudayama Formation and the Kannawa Fault in the eastern part of the Ashigara Hill, central Japan. Jour. Geol. Soc. Japan. 103(5): 435-446. (in Japanese with English abstract)

Tsuya, H., 1942. Notes on the Ashigara Beds. Bull. Earthquake Res. Institute University of Tokyo, 20: 316-321.

Yamazaki, H. 1992. Tectonics of a plate collision along the northern margin of Izu Peninsula, central Japan. Bull. Geol. Survey of Japan. 43(10): 603-657.

摘　要

今永　勇, 1999. 伊豆衝突帯の足柄層群の層序と構造. 神奈川県立博物館研究報告（自然科学）, 28: 73-106 (I. Imanaga, 1999. Stratigraphy and Tectonics of the Ashigara Group in the Izu Collision Zone, Central Japan. Bull. Kanagawa prefect. Mus. (Nat. Sci.), 28: 73-106.)

足柄層群は、鮮新世末から更新世中期にわたって形成され、その層厚は5000ｍを越える。本層群は、下位から上位に、砂岩泥岩互層から礫岩層を経て再び砂岩泥岩互層から礫岩層へと、大きく２回の上方粗粒化を繰り返している。またその堆積場は、深海底から陸域へと変化している。この足柄層群の形成過程は、2Ma以前にフィリピン海プレートの沈み込み帯が丹沢南部にジャンプし、足柄層群最下部層の堆積が始まる。伊豆地塊の衝突は、2Maから1.72Maの間に始まり、神縄断層のような逆断層の活動が始まり、丹沢山地の急激な隆起・削剥が起こり、厚い堆積物が形成され始めた。1.72Maごろに、それまで北北西に運動していたフィリピン海プレートが西北西に向きを変える。ついで1Ma頃に糸魚川ー静岡構造線の東側が北米プレートに移り変わった時期を境に北米プレートに対するフィリピン海プレートの相対的運動方向が北北西に変わり、再び丹沢山地との衝突が強まっていった。このように堆積時のプレート運動の変化に関連して２回の上方粗粒化が起こったと考えられる。また足柄層群の堆積時には、ソレイアイト岩系とカルクアルカリ岩系の火成活動が同時に行われ、多くの岩脈・岩床・岩株が貫入し、溶岩・火砕流が形成された。

（受付：1998年12月1日, 受理：1998年12月3日）

PLATE 1

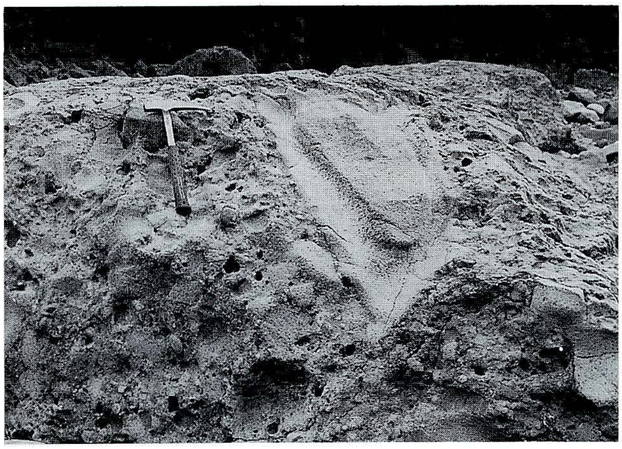
1-a. Turbidite unit of the Hinata Formation, cropped out in the Katsusawa valley, Yamakita Town, Kanagawa Prefecture.

1-b. Andesitic volcaniclastic rocks intercalated in the Hinata Formation, near the Takase Bridge, River Sakawa, Yamakita Town, Kanagawa Prefecture.

1-c. Debris flow deposits of the Hinata Formation, showing volcanic lithic clasts embedded in scoliaceous and pumicious sandstone matrix. At Mt. Maruyama, Yamakita Town Kanagawa Prefecture. Film box represents the scale.

1-d. Distortion and fluidization occurred in the alternation of sandstone and mudstone of the Hinata Formation at Hinata Hamlet, Yamakita Town, Kanagawa Prefecture.

PLATE 2



2-a. A detached lava lobe in the conglomerate bed along the River Sakawa, Setoyonkenya Hamlet, Yamakita Town, Kanagawa Prefecture.

2-b. An alternation of fine sandstone and pebble-cobble conglomerate of the Seto Formation at Fukazawa Hamlet, Yamakita Town, Kanagawa Prefecture.

2-c. Matrix supported andesite rich conglomerate of debris flow deposits of the Seto Formation exposed along the River Sakawa , Setoyonkenya Hamlet, Yamakita Town, Kanagawa Prefecture.

2-d. Another exposure of the Seto Formation showing the graded conglomerate of channel deposits, at Fukazawa Hamlet, Yamakita Town, Kanagawa Prefecture.

2-e. Seto Formation exhibiting inverse to normally graded conglomerate of channel deposits at Yagurakitazawa, Minami-Ashigara City, Kanagawa Prefecture.

2-f. Inverse to normally graded conglomerate of channel deposits of the Seto Formation. Tuburano Hamlet, Yamakita Town, Kanagawa Prefecture.

PLATE 3

3-a. Explosive breccia at Ninokurakaihatsu Co. Quarry, Hata valley, Yamakita Town, Kanagawa Prefecture.

3-b. Close-up of the explosive breccia showing an angular huge boulder of siltstone over 3 meter at Ninokurakaihatu Co. Quarry, Hata valley, Yamakita Town, Kanagawa Prefecture.

3-c. Hata Formation showing current ripple, exposed along the River Sakawa, Yaga Hamlet, Yamakita Town, Kanagawa Prefecture.

3-d. Alternation of sandstone and mudstone of the Hata Formation exposed along the River Sakawa in Yaga Hamlet, Yamakita Town, Kanagawa Prefecture.

PLATE 4

4-a. Steeply bedded conglomerate bed of upper portion of the Shiozawa Formation exposed in Shiozawa valley, Yamakita Town, Kanagawa Prefecture.

4-d. Conglomerate bed in a quarry of Morobuchi, belonging to the upper part of the Shiozawa Formation, Yamakita Town, Kanagawa Prefecture.

4-b. Alternation of sandstone and conglomerate of shallow marine deposits found in the Shiozawa Formation along the Ayusawagawa River, Morobuchi Hamlet, Yamakita Town, Kanagawa Prefecture.

4-e. A close-up view of the conglomerate bed (Fig. d, Plate 4), at Morobuchi, Yamakita Town, Kanagawa Prefecture. Imbrication show the current direction to the west.

4-c. Oyster bed (Crassostrea gigas) in the Shiozawa Formation which indicates a shallow embayment, exposed along the Kochi River, Yozawa Hamlet, Yamakita Town, Kanagawa Prefecture.

4-f. Wood trunk buried in living position found in a quarry of Morobuchi, in upper part of the Shiozawa Formation, Yamakita Town, Kanagawa Prefecture.