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Tectonic Evolution of the Northern Koma Mountains, Southern Fossa Magna, Central Japan

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(With 11 Figures, 4 Tables, 3 Plates, 4 Appendix Figures and 3 Appendix Tables)

Abstract

The Northern Koma Mountains are situated in the north-westernmost part of the Southern Fossa Magna, central Japan, where pre-Miocene terranes show a northward convex structure. The Koma Mountains, bounded by the Itoigawa Shizuoka Tectonic Line (I.S.T.L.) to the west, are made up of the early to middle Miocene Koma Group which may be subdivided into a lower (Kushigatayama) and an upper (Momonoki) subgroups.

In the Northern Koma Mountains, the Kushigatayama Subgroup is mainly composed of pyroclastic rosks of over 3800 m thick, which gives them their shape. The Momonoki Subgroup chiefly consists of fine-turbidites and hemipelagic sediments of over 2100 m thick, which are deposited in or near the paleo-trench, situated to the west of the Kushigatayama block.

The Kushigatayama block, assumed to have been the northernmost tip of the Izu-Mariana arc, collided with the Honshu arc during from the latest Early to early Middle Miocene, probably in conjunction with the opening of the Sea of Japan. Severe contraction associated with this collision is responsible for the deformation zone of phyllitic shale and chert of the lower Momonoki Subgroup which extends up to 2 km in width. In the Kushigatayama block, however, many normal faults were formed, probably by bending of the down-going plate. The bend of the pre-Miocene terrane can be assumed to be promoted by this collision.

Intrusive activity occurred within both the pre-Miocene terranes (Kaikoma-Hoo and Yakejizo Granites) and the Koma Mountains (Dikes and Tsuburai Quartz Diorite) during the Middle to Late Miocene.

Reverse faulting (mechanically west up) of the I.S.T.L. probably occurred during the Late Miocene to Pliocene. The faulting probably diminished in the Early Quaternary, while a thrusting at the eastern piedmont of the Koma Mountains (westernmost part of the Kofu Basin) became active.

Contents

Introduction

The progess of oceanic earth science has been conspicuous of late, and this enables us to reconsider many problems of land geology. Combined with this progress, re-examination of tectonic evolution of the mobile belt as well as plate tectonics have been carrying out in Japan in the last twenty years. The Southern Fossa Magna is one of the most prominent mobile belt in Japan, after the Tertiary. Disputes over the tectonic evolution of this region ever since NAUMANN (1885) are now too many to count. OKAYAMA (1961) suggested that the southernmost part of the Fossa Magna is of the northern tip of the Izu-Mariana arc, and this tip became a primary factor in the bend of the Akaishi and Kanto Mountains. Recently, the geologic structure of the Southern Fossa Manga is thought to have been formed by the collision of the Honshu and Izu-Mariana arcs (SUGIMURA, 1972; KAIZUKA, 1975; MATSUDA, 1978; NIITSUMA and MATSUDA, 1985; NIITSUMA and AKIBA, 1986). This collision was also responsible for interactions between the Philippine Sea plate and the Eurasian plate (Fig. 1). The Izu block (Fig. 2), which belongs to the Izu-Mariana arc, collided with the Honshu arc in the Early to Middle Quaternary, and consequently, the Ashigara Group which shows coarsening upward deposited in the region of the collision (HUCHON and KITAZATO, 1984; AMANO *et al.*, 1986). The Tanzawa block (Fig. 2), situated to the north of the Izu block, in turn situated at the northern end of the Izu-Mariana arc and belonged to this arc by virtue of the resemblances in its lithology and sequences to those of the Izu block, presumably collided with the Honshu arc at some time before 5 Ma (SOH, 1986). Furhtermore, both the Misaka and Koma blocks (Fig. 2), situated in the north-westernmost part of the Southern Fossa Magna, were in all likelihood once members of the Izu-Mariana arc but then collided with the Honshu arc (SOH, 1986; AMANO, 1986). MATSUDA (1989) mentioned that the subduction of the Izu-Ogasawara arc had probably occurred along the Itoigawa Shizuoka Tectonic Line (I.S.T.L.), and the Tohnoki Aikawa Tectonic Line until 12 or 15 Ma. As mentioned above, the Southern Fossa Magna would seem to be a mobile belt of the multiple collision type.

The Koma block, which shapes the Koma Mountains, is made up of the Kushigatayama Subgroup (the lower one and constructing the Kushigatayama block) and the Momoniki Subgroup (the upper one). This block is bounded by the I.S.T.L. to the west, and by the some active faults of the western margin of the Kofu Basin. Quaternary sediments are distributed to the east of the block (Fig. 3). The former is mainly composed of volcanic and pyroclastic rocks, which is known as a member of the "green-

Table 1 Stratigraphical correlation table in the Southern Fossa Magna. Following documents were referred as to the geological time. Chiji and Konda (1978), Fukuda and Shinoki (1952), Higuchi (1969), Huchon and Kitazato (1984), Ikebe and Chiji (1971), Kano *et al.* (1985), Kosaka and Tsunoda (1969), Nishimiya and Uyeda (1976), Oda *et al.* (1987), Okada (1987), Ujiie and Muraki (1976)

		KOMA 巨摩	FUJIKAWA 富士川	MISAKA 御坂	NISHIKATSURA 西桂	TANZAWA 丹沢	ASHIGARA 足柄	IZU 伊豆
Pleistocene							Ashigara Group	
Pliocene			Fujikawa Group		Nishikatsura Group			
Miocene	Upper							Yugashima Group
	Middle	Momonoki Subgroup Kushigatayama Subgroup		Nishiyatsushiro Group		Tanzawa Group		
	Lower							

tuff formation". The lithology and age of this subgroup is similar to that of the Tanzawa Group of the Tanzawa block and the Yugashima Group in the Izu block (Table 1). The latter consists of clastic rocks and stretches between the Shimanto Terrane and the Kushigatayama block. The Kushigatayama block is situated in the norhtwesternmost part among some Neogene pyroclastic blocks in the Southern Fossa Magna, and appears to have thrust into the bend of the pre-Miocene zonal structure of the Honshu arc (Fig. 2).

The author has investigated the geology and geologic structure of the Koma Mountains. In keeping with what is mentioned above, special attention has been given to the Norhtern Koma Mountains, because this area is expected to have been a collision front between the Kushigatayama block and the Honshu arc. In this paper describes the geology, tectonic features and results of fault analysis of the Northern Koma Mountains. The following results are presented: The Kushigatayama block was likely to have collided with the Honshu arc in the E-W to NW-SE direction during the Middle Miocene.

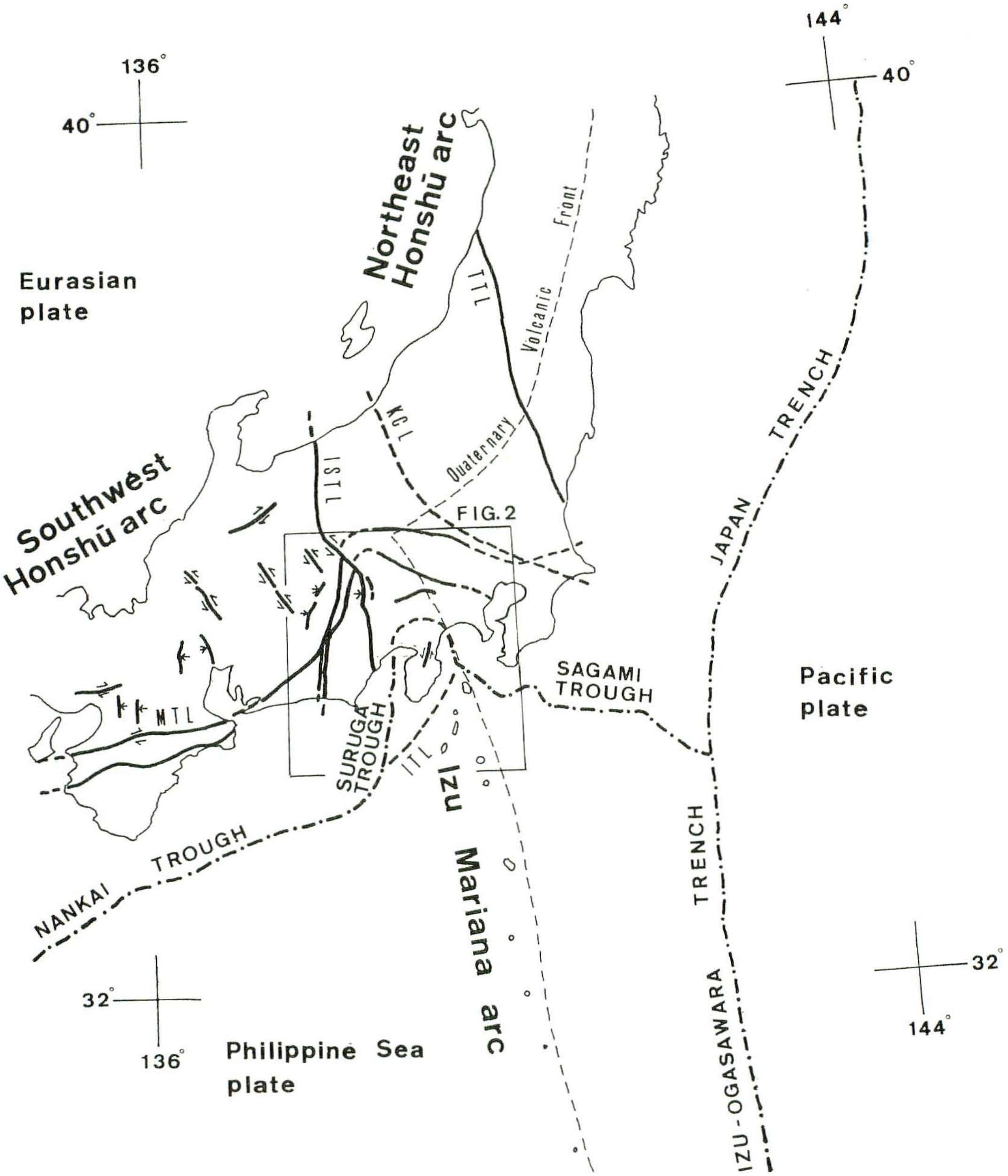

Fig. 1 Tectonic setting map of central Japan and its surrounding area. The Izu-Mariana arc and the Honshu arc assemble together at the central part of Japan (Fossa Magna region). I.S.T.L.: Itoigawa Shizuoka Tectonic Line, MTL: Median Tectonic Line, KCL: Kashiwazaki Choshi Line, TTL: Tanakura Tectonic Line, ITL: Izu Toho Line.

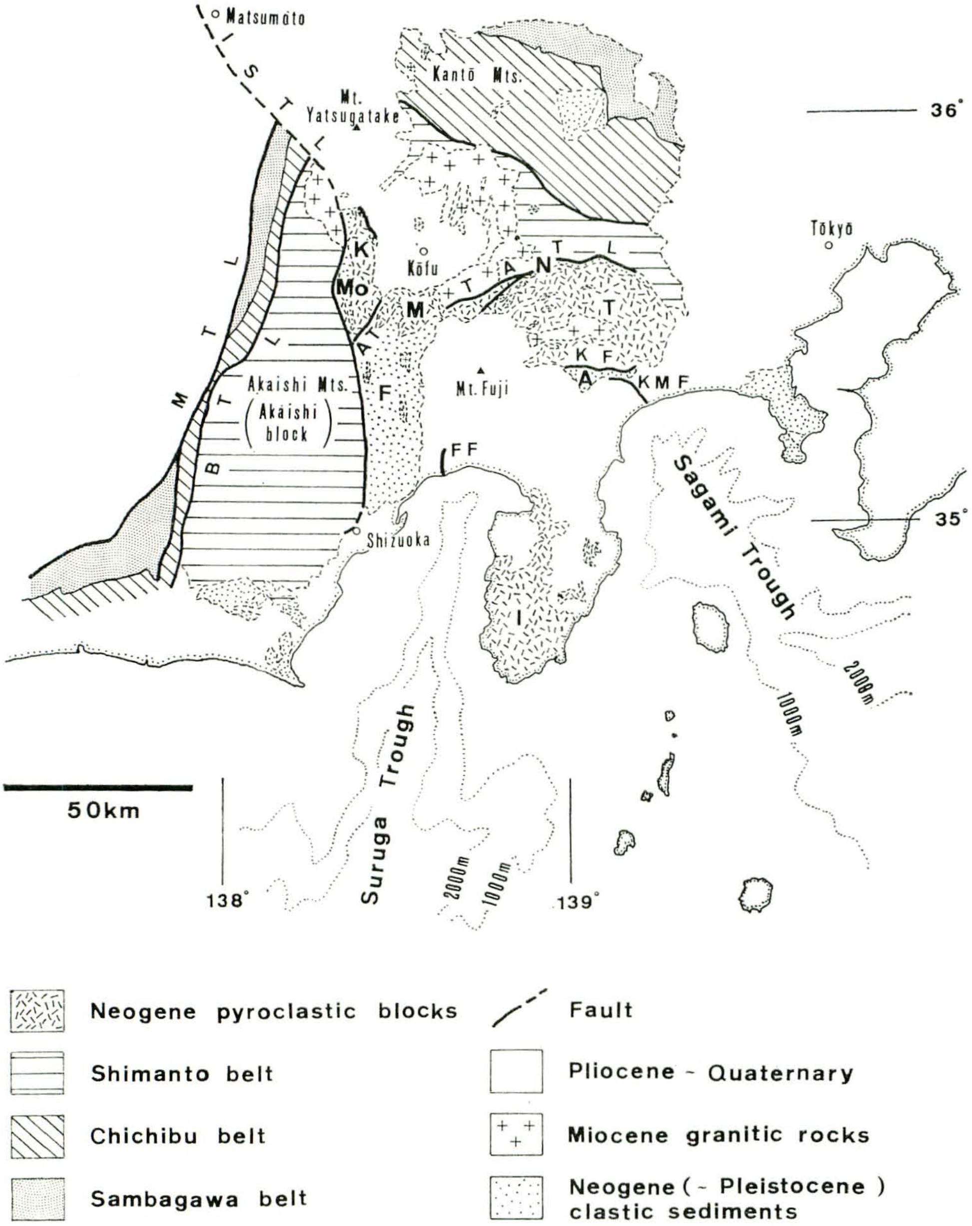

Fig. 2 Tectonic map of the Southern Fossa Magna and its vicinity, showing the bend of the pre-Miocene terranes (Sambagawa, Chichibu and Shimanto belts) and the distribution of the Neogene pyroclastic blocks. K: Koma block, M: Misaka block, T: Tanzawa block, I: Izu block, Mo: Momonoki area, N: Nishikatsura area, F: Fujikawa area, A: Ashigara area, I.S.T.L.: Itoigawa Shizuoka Tectonic Line, MTL: Median Tectonic Line, BTL: Butsuzo Tectonic Line, AT: Akebono Thrust, TATL: Tohnoki Aikawa Tectonic Line, KF: Kan'nawa Fault, FF: Fujikawa Fault.

After the Neogene, the Koma block united with the Akaishi block which composes of Shimanto Terrane. The leading area of deformation shifted from the western part of the Kushigatayama block (I.S.T.L. and the Momonoki Subgroup) to the boundary area between the Koma Mountains and the Kofu Basin.

Outline of geology of the Koma Mountains and their environs

The area investigated is divided by the N-S running I.S.T.L. (Fig. 3). To the west are distributed the Shimanto Complex, the Kaikoma-Hoo Granite and the Yakejizo Granite. The Shimanto Complex in the studied area is considered to be Paleogene. It is composed of slate, phyllite, sandstone, and an alternation of sandstone and slate with thin beds of chert and greenstone. The complex trends nearly N-S and dips west steeply in general. The Kaikoma-Hoo Granite intruded into the Shimanto Complex during the Middle to Late Miocene. The Yakejizo Granite intruded along the I.S.T.L. before the Kaikoma-Hoo Granite or the same time.

The area east of the I.S.T.L. is underlain by the Neogene and Quaternary systems in the Southern Fossa Magna, namely the Koma Group, the Fujikawa Group, the Tsuburai Quartz Diorite and the Quaternary. The Koma Group (KOSAKA and TSUNODA, 1969) is further subdivided into the lower (Kushigatayama), mainly composed of lavas and pyroclastic rocks such as tuff and tuff breccia and the upper (Momonoki) consisting of mudstone, sandstone and conglomerate with thin beds of acidic tuff. Thick conglomerate ("Mogura Conglomerate") up to 700 m thick is distributed in the southernmost part (Southern Koma Mountains) of the Momoniki subgroup (KOYAMA, 1984). The clast of this conglomerate is of chert, sandstone and mudstone of the Honshu arc origin, pyroclastic rocks of the Kushigatayama Subgroup origin and rarely granite. The Koma Group is assigned to the Lower Miocene based on larger foraminifera, such as *Lepidocyclina japonica* YABE and *Miogypsina ozawai* HANZAWA (KOSAKA and TSUNODA, 1969; HIGUCHI, 1969). IKEBE and CHIJI (1971) and IKEBE (1978) have stated that *Lepidocyclina-Miogypsina* populations in Japan occur in the interval between zones N8 to N10 of Blow. Thus, the age of the Koma Group must range from the Early to Middle Miocene. The beds of the Kushigatayama Subgroup trend N-S to NE-SW, and dip west. The beds of the Momonoki Subgroup trend N-S and dip west in general. Many folds of this subgroup can be seen in the Central Koma Mountains. The relationship between the Kushigatayama and the Momonoki Subgroups is either in conformity or fault. The Tsubruai Quartz Diorite intruded into the northeastern part of the Kushigatayama Subgroup during the Middle Miocene.

Since the pioneering study of OTSUKA (1941), the geology and stratigraphy of the Koma Mountains have been most helpfully treated by KOSAKA and TSUNODA (1969), HIGUCHI (1969), YAMANASHIKEN (1970), TSUNODA (1973), KOYAMA (1984) and TAMURA *et al.* (1984). HIGUCHI (1969) and SUGIYAMA (1971) studied the rock alteration of the

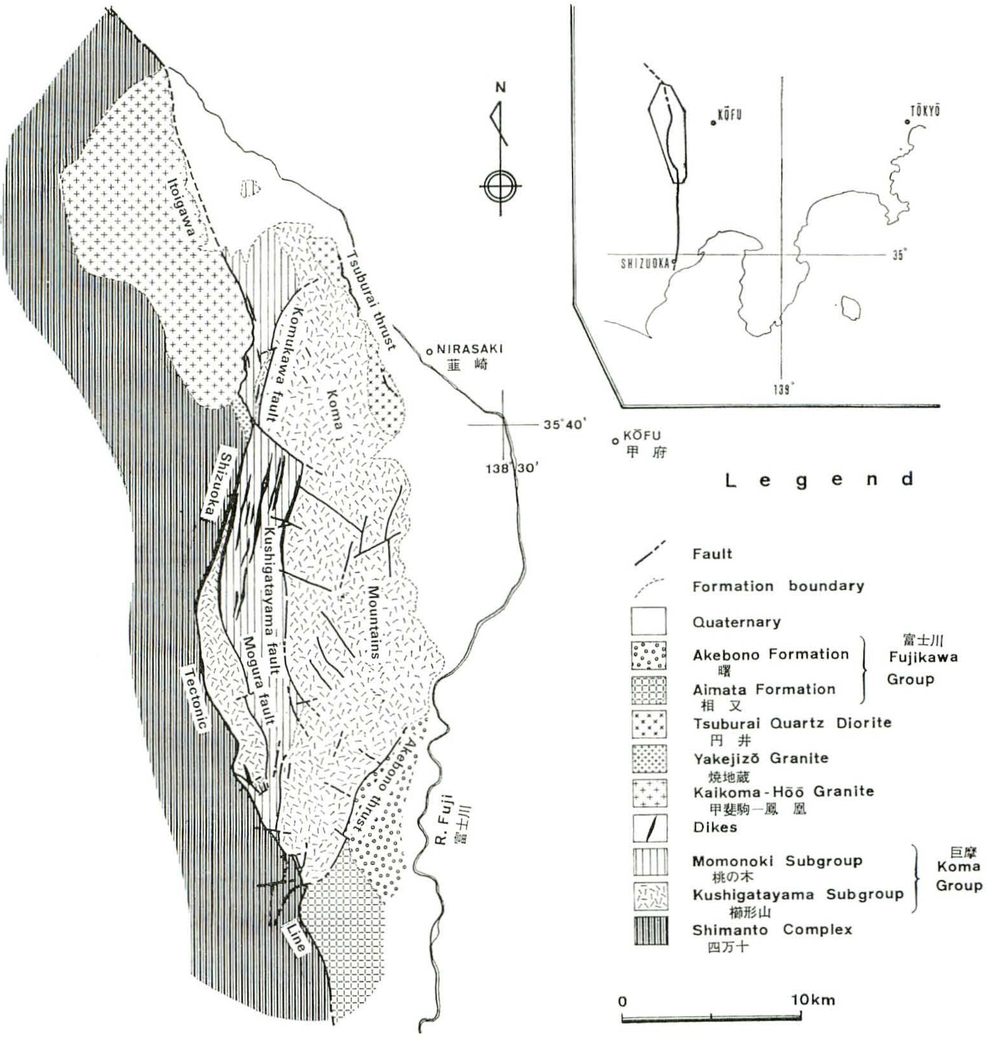

Fig. 3 Generalized geological map of the Koma Mountains and vicinity.

Koma Group. Studies on the folds of the Momonoki Subgroup were carried out by Tsunoda (1971a, b; 1973).

The Fujikawa Group (Matsuda, 1961) in the area investigated is subdivided into two formations: The lower (Aimata Formation) is chiefly made up of pyroclastic rocks with intercalations of clastic rocks, while the upper (Akebono Formation) is mainly conglomerate. The Fujikawa Group ranges in age from the Late Miocene to Pliocene. Quaternary sediments also lie along the foot of the Koma Mountains.

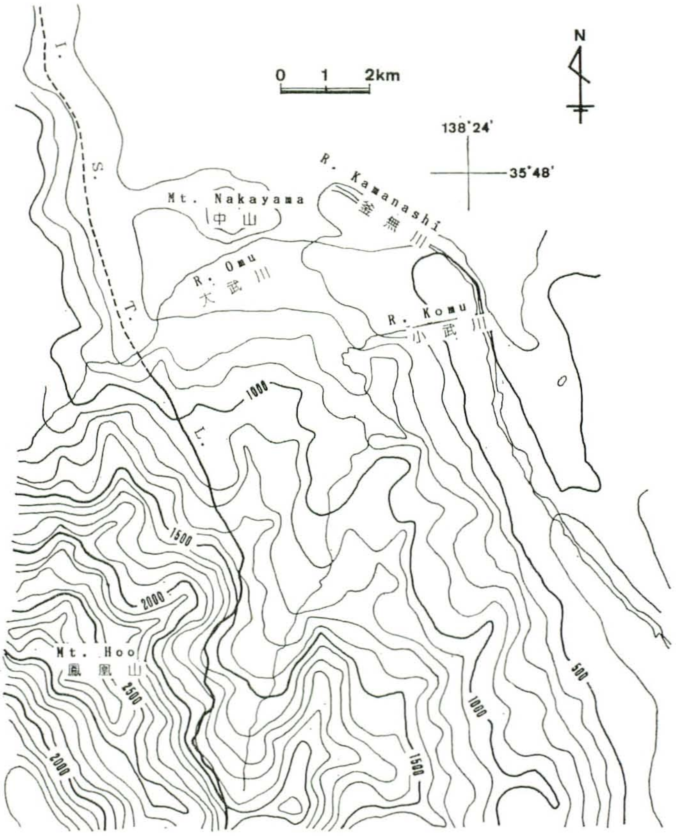

Fig. 4 Summit level map of the Northern Koma Mountains and vicinity. I.S.T.L.: Itoigawa Shizuoka Tectonic Line.

Geology of the Northern Koma Mountains

The Northern Koma Mountains are bounded both geologically and geographically by the I.S.T.L. to the west (Figs. 3 and 4). Geological map and the profiles of the investigated area are shown in Fig. 5; an index map of place names, and localities of the route of the columnar section and the main fault outcrops are shown in Fig. 6. The geologic succession of the Northern Koma Mountains is listed in Table 2.

Kaikoma-Hoo and Yakejizo Granite

In the western part of the I.S.T.L., both the Kaikoma-Hoo and Yakejizo Granite intruded into the Shimanto Complex. The former is 5 to 8 km in width in an E-W direction, and 20 km in length in N-S direction. The easternmost part of these granitic rocks is cut off by the I.S.T.L. The former is mainly composed of leucocratic, medium to coarse granite with some basic xenoliths. Flow structure occasionally can be seen near the I.S.T.L. (FUJIMOTO *et al.*, 1965). Cataclasite or cataclastic granite are obser-

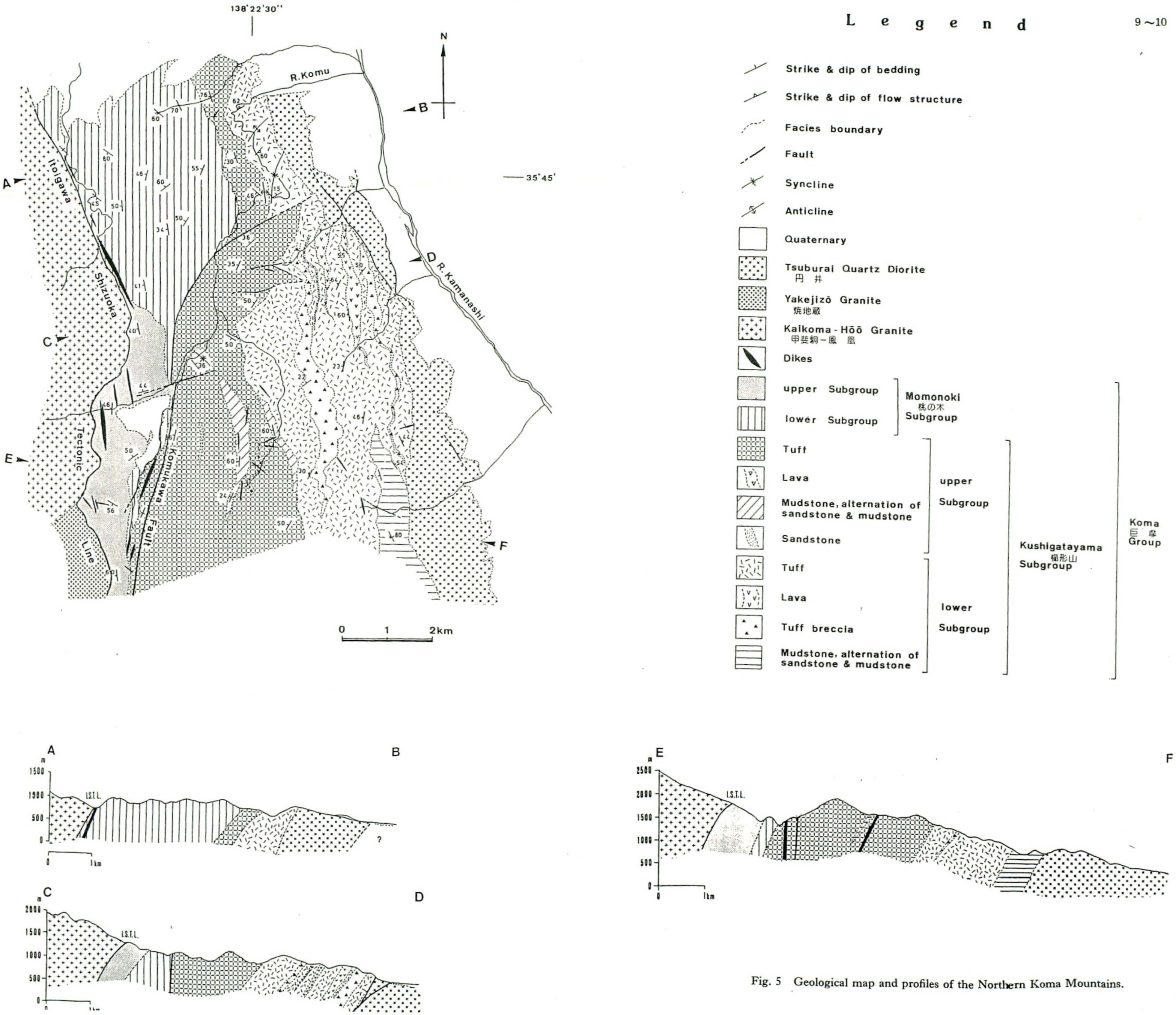

Fig. 5 Geological map and profiles of the Northern Koma Mountains.

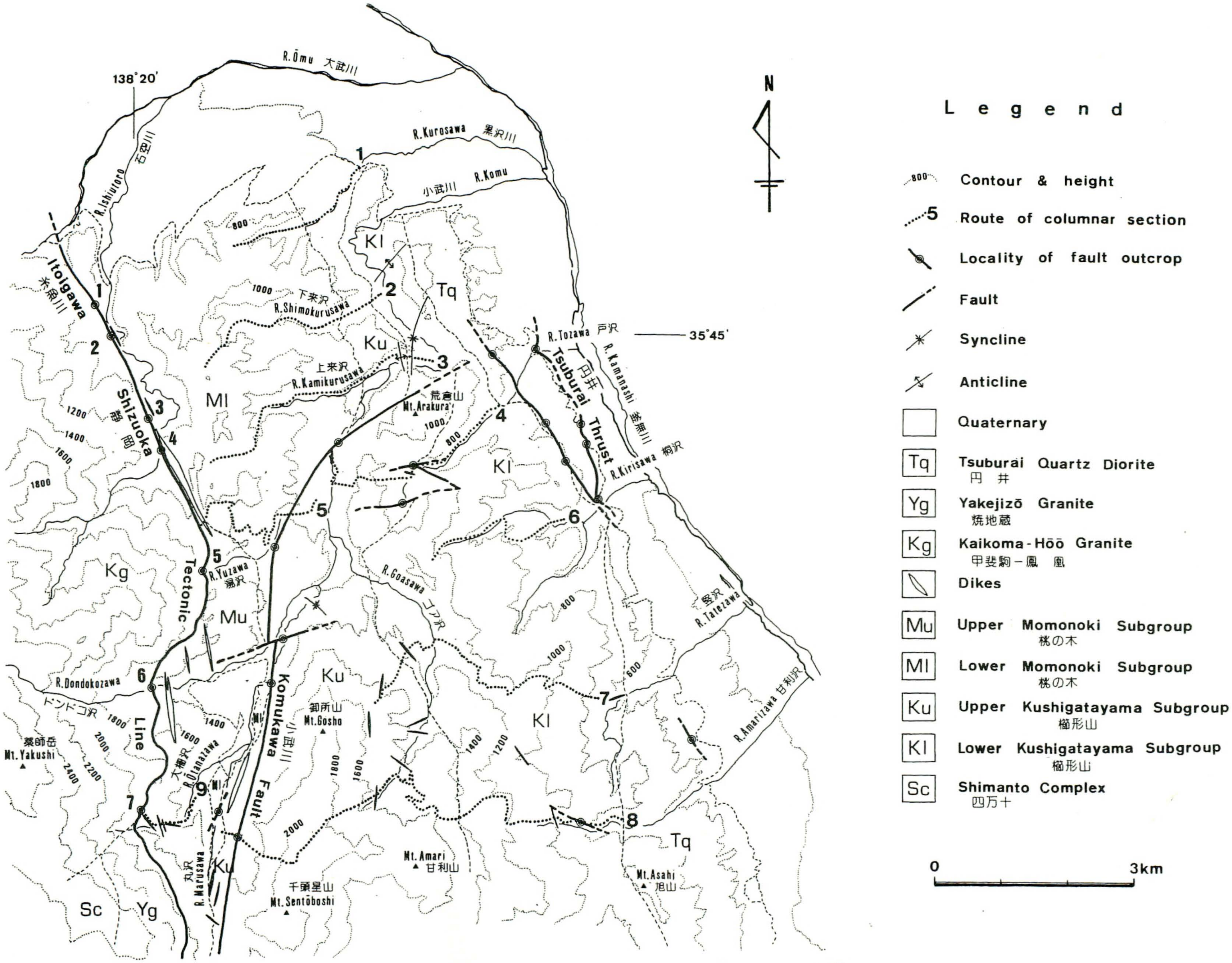

Fig. 6 Locality map showing the route of columnar sections and the outcrops of main faults. Numbers on the I.S.T.L. are the same in Tabe 4.

Table 2 Table showing the stratigraphic succession in the Northern Koma Mountains

GEOLOGIC TIME	STRATIGRAPHY	INTRUSION	LITHOFACIES	TECTONIC FEATURE	THICKNESS
Quaternary	Allivium Terrace deposits Debris flow flow deposits Fan deposits		Gravel, Sand		Few meters ~ 70 m
Pliocene ~ late Miocene		Tsuburai Quartz Diorite	Medium quartz diorite	Thrusts over the Quarternary at the easternmost part	
middle Miocene		Yakejizo Granite	Leucocratic mylonitic granite		
		Kaikoma-Hoo Granite	Medium ~ fine granite	Cataclasite near the Itoigawa-Shizuoka Tectonic Line	
		Dikes	Porphyrite, diorite, granophyre		
early ~ middle Miocene	Koma Group Momonoki Subgroup		Phyllitic shale, alternation of sandstone and mudstone, chert	Bedding slip, kink band, tectonic fish, pinch-and-swell structure	2100m+
	Kushigatayama Subgroup		Andestic and basaltic tuff, lava, tuff breccia, alternation of sandstone and mudstone, conglomerate, calcareous mudstone	Many high angle normal faults at lower portion of this subgroup	3800m+
Paleogene	Shimanto Complex		Slate, phyllite, psammitic semi-schist	Kink band	

vable beside the I.S.T.L. This granite has been dated at about 11 Ma by the K-Ar method (KAWANO and UEDA, 1966; SATO *et al.*, 1989).

The latter distributes to the south of the former along the I.S.T.L. This is a pinkish, fine-grained mylonitic granite. Fluxion structures occur generally. SATO *et al.* (1989) inferred that this granite intruded before the Kaikoma-Hoo granite or the same time. FUJIMOTO *et al.* (1965) stated that the Momoniki Subgruop underwent contact metamorphosis through with this granite.

Koma Group

The Koma Group (Early to Middle Miocene) is distributed on the eastern side of the I.S.T.L. Columnar sections of this group are shown in Fig. 7. It is divided into two subgroups, the Kushigatayama and the Momonoki. The former is composed of thick pyroclastic rocks with intercalations of lavas and clastic rocks. Judging from its facies and fossil foraminifera the subgroup is of thick submarine sediments. The latter is made up of fine clastic rocks with a few amounts of pyroclastic rocks. The latter is generally in fault contact with the former, however, these subgroups are conformable in the Northernmost Koma Mountains.

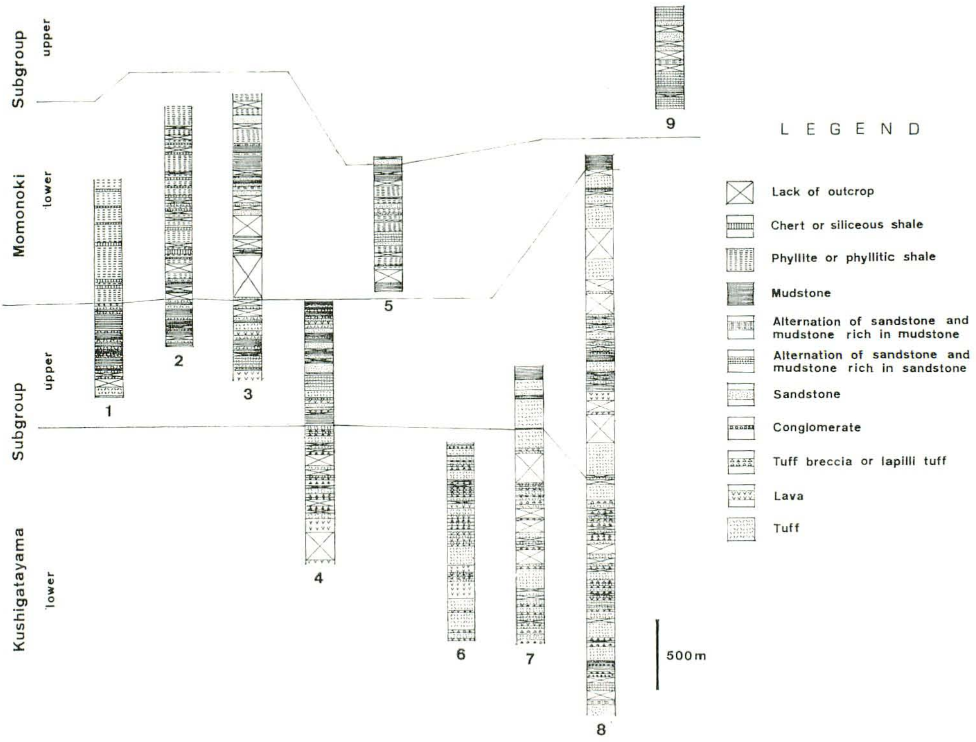

Fig. 7 Columnar sections of the Koma Group in the Northern Koma Mountains. The course of each number is shown in Fig. 6.

Kushigatayama Subgroup

The Kushigatayama Subgroup is subdivided into the lower and the upper. The lower is mainly composed of basaltic to andestic tuff with some lavas and tuff breccias, over 1700 m thick (Figs. 5 and 7). Hyaloclastites and pillow lavas are occasionally seen in the lower subgroup. The tuff is generally fine to medium-grained, grayish-green colored, and the content ratio of the phenocryst is less than 20%. The lava is generally of few phenocryst and occasionally yields zeolite in carity. The tuff breccia consists of rock fragments of andestic lava and tuff, probably derived from the same subgroup, up to 25 cm in diameter. Alternating beds of sandstone and mudstone are distributed west of Mt. Asahi. The beds of the lower subroup trend generally NNE-SSW, and dip 20° to 50° west. Alternating beds of sandstone and mudstone west of Mt. Asahi, dip nearly vertically and are partly overturned. One set of syncline and anticline, trending NE-SW to NNE-SSW, is to be recognized along the lower reaches of the River Komu.

The upper subgroup consists of tuff, mudstone and sandstone with intercalations of lava and alternating beds of sandstone and mudstone, about 2100 m thick. The tuff is mainly basaltic to andestic, fine to medium-grained, grayish to pale green, and the content ratio of phenocryst is less than 20%. The sandstone is mainly of fine-grained, including medium-grained, occasionally parallel laminated and cross-bedded. Conglomerate and calcareous mudstone can be seen at the upper reaches of the River Tozawa. The conglomerate comprises mostly angular to sub-angular clast, set in a fine-grained sand to silt matrix of 30 to 50%. The clasts consist of andestic tuff, sandstone and mudstone up to 30 cm in diameter as well as the occasional pebble of limestone. Based on the shape of much of the mudstone and sandstone clasts and obscure boundaries between the clast and the matrix, the clasts have been reworked. Slump folds can be recognized at the upper reaches of the River Tozawa. The beds of the upper subgroup trend NE-SW to NNE-SSW, and dip 30° to 60° west in general but nearly vertical nearby the Kushigatayama fault.

Momonoki Subgroup

The Momonoki Subgroup is also subdivided into the lower and the upper. The lower is mainly composed of phyllitic shale, mudstone with intercalations of sandstone, chert and siliceous shale, about 1400 m thick. The phyllitic shale is characterized by bedding slip and bedding schistosity. This phyllitic shale zone is about 2 km in width east of the I.S.T.L. The sandstone occasionally shows boudin-like structure and tectonic fish. The chert and siliceous shale can be seen in the northern part of the studied area. On the middle reaches of the River Shimokurusawa, bedded chert beds occasionally occur up to an apparent thickness of about 100 m (Fig. 8). This chert (Shimokurusawa chert) will be discussed in detail in the following section. Based on the facies, the lower mainly consists of hemipelagic sediments west of the Kushigatayama

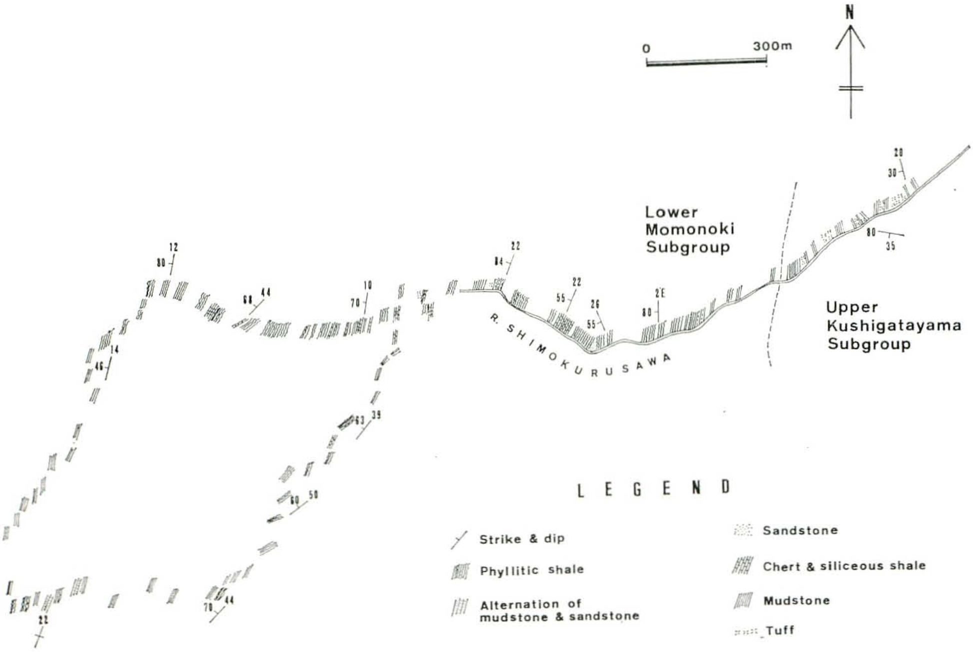

Fig. 8 Route map of the River Shimokurusawa.

block. The beds of the lower subgroup trend from NE-SW to N-S, and dip west over 50° generally, but subparallel in trend nearby the I.S.T.L. The lower subgroup overlies conformably the upper Kushigatayama Subgroup in the northern area studied, however, both subgroups mostly make full contact each other at the Komukawa fault (Fig. 3).

The upper is exposed between the I.S.T.L. and the Komukawa fault. This is composed mainly of rhythmically alternating beds of sandstone and mudstone rich in sandstone, over 700 m in thickness. The sandstone is made up of fine-grained and angular grained quartz>plasioclase, K-felspar> rock fragment. Thickness of a unit of sandstone and mudstone is 10 cm to 1 m, but mostly 15 to 30 cm. Normal grading is recognized in most sandstone units. Lateral continuity of an individual bed is very marked. The sandstone beds rarely contain rip-up clast of mudstone. From these facies, the upper mainly consists of a fine-turbidite. The westernmost part of this subgroup is cut by the I.S.T.L. The beds of the upper subgroup trend nearly N-S, and commonly dip over 40° west.

Dike rocks

Dike rocks are mainly of porphyrite, and of few granodiorite, diorite and lamprophyre. The porphyrite looks whitish-gray, occasionally tinged with green, about 50 m in the maximum width. Small amounts of phenocryst of quartz and plasioclase are scattered in the microcrystalline groundmass. The dikes are scattered within the Koma Group,

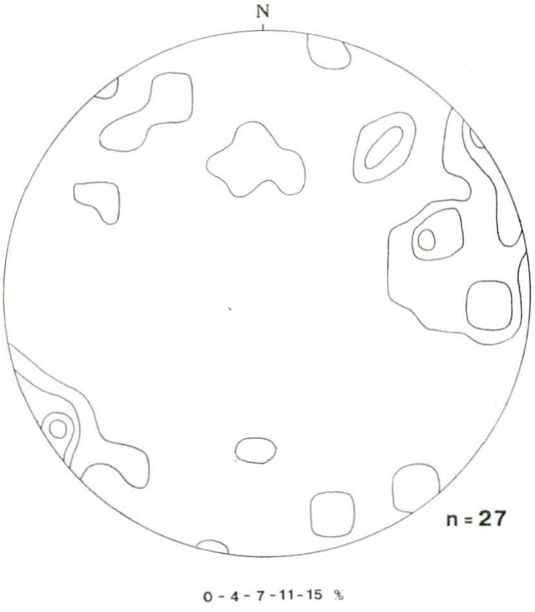

Fig. 9 Pole to intrusion plane of dikes in the Koma group, lower-hemisphere, equal-area projection.

however, it is slightly predominant along the main faults, such as the I.S.T.L. and the Komukawa fault. The sandstone near the I.S.T.L. has occasionally been altered by the dikes. The intrusion planes trend predominantly NW-SE (Fig. 9). Based on the field observation, the dikes intruded after the deformation of the lower Momonoki Subgroup. SATO *et al.* (1989) reported that the dikes near the I.S.T.L. has suffered contact metamorphism by the Kaikoma-Hoo Granite.

Tsuburai Quartz Diorite

This plutonic rock intruded into the Kushigatayama Subgroup, and contact metamorphism occurred. It is composed mainly of medium-grained plasioclase, hornblende and quartz with subordinate amount of hyperthene. Quartz grain is scattered interstitially. Recently, ITO *et al.* (1989) reported that the age of this plutonic body was 15± 0.6 Ma by fission track dating.

The easternmost part of this body is bounded by active thrust fault (Tsuburai thrust) or covered by the Quaternary. The faulting of the Tsuburai thrust probably occurred in early Pleistocene time and continued until recently (KOYAMA, 1989).

Quaternary sediments

The Quaternary sediments are distributed mostly in the eastern piedmont of the Koma Mountains. These are composed of alluvial fan deposits, debris flow deposit, terrace deposits and alluvium, less than several tens meters in thickness.

Shimokurusawa chert

In the River Shimokurusawa, the tributary of the River Komu, chert beds often crop out (Plate 1–2). Maximum thickness of individual chert bed apparently approaches 50 m. These cherts are evenly bedded with thin partings of dark shale, and most chert is dark gray or grayish-black, very hard and dense, subvitreous in luster, with subconcoidal fracture. Individual beds of chert are 3 to 10 cm, but mostly 3 to 5 cm thick, and shale parting is ordinary 1 cm> thick. The chert changes gradually to phyllitic shale through siliceous shale. The geologic structure of chert is generally concordant with that of surrounding rocks. These features show that the chert is not an allochthonous block but an autochthonous sequence. The individual bed of chert often shows a pinch-and-swell structure. Bedding slip is conspicuous along the shale parting. Well-polished shear surfaces are often seen. X-ray diffraction pattern of the siliceous part shows that it is composed of nearly pure quartz.

Observasion in thin sections is as follows. Siliceous part of chert bed is mainly composed of well matched microcryptocrystalline quartz. There is no crystal larger than matrix, so it is not conceivable that the chert is of volcanic origin. Graded bedding and laminations characterized by uneven coloring part are occasionally seen in the siliceous part of chert. Radiolarian and foraminifer-like tests are sparsely scattered in both siliceous part and shale parting.

Quartz veinlets, up to 1 mm in width, are often intruded mostly perpendicular or high angle to the bedding plane (Plate 3–2). The intrusion planes are generally clear and sharp, and slip is not recognized along these planes. Quartz grain of the veinlet is up to 0.5 mm, mainly up to 0.2 mm in diameter, and does not show wavy extinction except for in a shale parting. Ptygmatic fold of quartz veinlet is rarely seen.

There are many planeless micro-faults cutting the lamination. Bedding parallel slip is conspicuous at the shale partings which cut the quartz veinlets. Quartz grains of the veinlet and radiolarian test in the shale parting are elongated subparallel to the bedding.

Deformation of the lower Momonoki Subgroup

The phyllitic shale zone in the lower Momonoki Subgroup distributes about 2 km in width east of the I.S.T.L., although southern part of this zone has been lost by the Komukawa fault. Mudstone is frequently intercalated in the Kushigatayama Subgroup and the upper Momonoki Subgroup, however, is not phyllitic. Schistosity, characterized by the bedding slip, closely develops throughout the whole phyllitic shale zone (Plate 1–1). In thin sections of the phyllitic shale, bedding-parallel cleavages are clearly seen and the long axis of the clast in the matrix is rearranged along the cleavages (Plate 3–1). Well-polished shear planes of the bedding slip can be frequently seen. Striations or grooves on the shear planes are nearly pure dip-slip type in most cases (Table 3), and the sense of displacement is almost a reverse-fault type judging from the pinnate fracture pattern near the bedding schistosity plane and fracture steps. The maximum compressive principal stress (σ_1) axis constructed from the net slips generally strikes E-W to NW-SE and dips west gently.

Table 3 Table showing the direction of the bedding schistosity and the lineation in the lower Momonoki Subgroup. The value in the parenthesis is a plunge of the lineation. Data were collected from 15 points (Shimokurusawa, Kamikurusawa, Gozaishi)

Bedding schistosity	Lineation
N20° W, 60° W	N16° W(10)
N26° E, 55° W	NEARLY PURE DIP-SLIP
N16° E, 50° W	N56° W(50)
N50° W, 50° W	NEARLY PURE DIP-SLIP
N14° W, 36° W	N76° W(30)
N40° E, 70° W	N40° W(70)
N20° W, 74° W	N69° W(68)
N26° W, 50° W	NEARLY PURE DIP-SLIP
N-S, 76° W	N42° E(63)
N11° W, 44° W	NEARLY PURE DIP-SLIP
N38° W, 70° W	N32° W(30)
N22° E, 55° W	NEARLY PURE DIP-SLIP
N2° E, 80° W	ditto
N14° E, 58° W	ditto
N16° W, 50° W	ditto

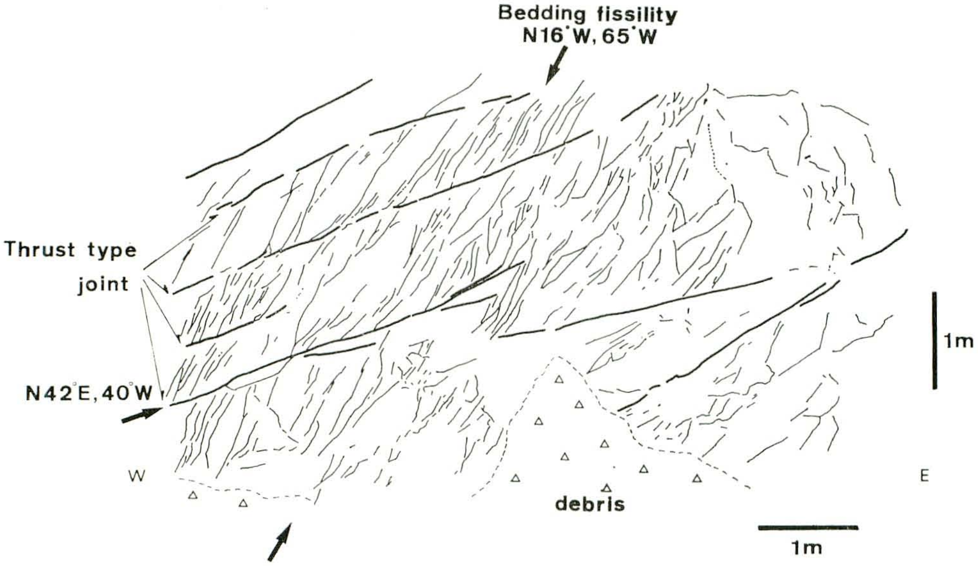

Fig. 10 Systematic joint developed within the phyllitic shale of the lower Momonoki Subgroup.

Systematic joints, which commonly strike N-S to NE-SW and dip west gently over several meters long, are occasionally associated with the phyllitic shale (Fig. 10). Joint surface is rather sharp and planar. Bedding schistosity is occasionally dragged near the joint surface. The trend of the joints is concordant with that of the maximum compressional principal (σ_1) stress axis deduced from the net slip on the bedding schistosity. These characteristics suggest that the systematic joints probably formed when the bedding slip occurred.

In conclusion the lower Momonoki Subgroup is almost of compressional deformation zone of the phyllitic shale characterized by a layer parallel shear developing on the bedding schistosity. This deformation was completed before the intrusion of porphyrite dikes because the dikes cut the bedding schistosity. SATO *et al.* (1989) stated that the dikes had formed before the intrusion of the Kaikoma-Hoo Granite. Hence, the time of the deformation ranges from the latest Early Miocene to early Middle Miocene.

Mode of faulting and history of the I.S.T.L. in the studied area

The I.S.T.L. (YABE, 1918) is one of the largest fault in the Southern Fossa Magna and bounds the western margin of the Koma Group. In the Northern Koma Moutnains, the Momonoki Subgroup is cut by this fault. Some fault elements are listed in Table 4. The I.S.T.L. is expected to be responsible for the compressional deformation zone of the lower Momonoki Subgroup.

Table 4 Table showing some fault elements of the Itoigawa-Shizuoka Tectonic Line in the Northern Koma Mountains. Locality number is the same in Fig. 6.

locality	fault plane angle	gouge	fault breccia	cataclasite	mylonite	hanging wall	foot wall (Momonoki subgroup)
1	N18° W, 65° W			10～15cm (west)		Kaikoma-Hoo granite	phyllitic siltstone
2	N21° W, 50°～70° W			1.3m± (west)	10cm> (west)	ditto	fine sandstone
3	N14° W, 70° W			4.2m± (3.7m± west) (0.5m east)		ditto	siltstone
4	N23°～36° W, 80°～90° W	20cm± (west) soft		1m± (west)		ditto	phyllitic shale
5	N1° W, 45° W	1～25cm (west), indurated 1～10cm (east), soft				porphyllite dyke	siltstone and fine to medium tuff
6	N19° E, 55° W	3～5cm (west), soft			1.8～1.9m (west)	Kaikoma-Hoo granite	siltstone
7	N24° E, 26° W	3～5cm (east) indurated			16m± (west)	ditto	siltstone with intercalation of sandstone

The shear zone along the I.S.T.L. is much broader in the west than in the east (Table 4). Therefore, larger amount of movement of the west block (hanging wall) of the I.S.-T.L. can be expected than that of the east, though difference in lithology is exists. It is mostly composed of cataclasite and mylonite of the hanging wall (Kaikoma-Hoo Granite), with a small amount of gouge. Cataclasite and mylonite are considered to be fault products of middle crustal level (ca. 5–15 km), mainly on the basis of the experimental study of rock failure and the textural study of cataclastic rocks (SIBSON, 1977; ANDERSON *et al.*, 1983; SIMPSON, 1986). Appearance of such cataclastic rocks means deep denudation of the fault. This notion is consistent with estimations of large amounts of uplifting (over 1000 m) around the Akaishi Mountains since the Miocene supposed by MATSUDA *et al.* (1967) and KAIZUKA *et al.* (1969). These structural feautres of the shear zone show that it cannot have been produced in the uppermost crustal level at all recently (probably not in the Late Quaternary). Major relief such as the large difference in summit level between both sides of the I.S.T.L., shown in Fig. 4, is conspicuous, however, distinct fault topography along the I.S.T.L. is not seen (R.G.A.F., 1980). On the other hand, the shear zone of the foot wall (east side, Momonoki Subgroup) is narrow (less than 50 cm in width). Consequently, it is difficult to consider that the I.S.T.L. is a main cause to the wide deformation zone of the lower Momonoki Subgroup. The faulting of the I.S.T.L., produced the shear zone of the investigated area, should date between the Late Miocene and Early Quaternary. The style of faulting has probably been of dip-slip type (west up, kinematically reverse fault), because of the unbalanced width of the shear zone. HIRAKAWA

(1981) reported that the I.S.T.L. is an active fault of class A in its vertical displacement during last 20000 years (a long-term rate of faulting ranges from 0.1 to 1 m/1000 yrs based on MATSUDA (1975)).

The Koma Mountains are a frontal range of the Akaishi, one of the highest ranges in Japan. They have shown the largest rate of vertical movement in Japan during the last 70 years—at 4 mm/year (DAMBARA, 1971). Vertical displacement of the Akaishi Mountains and their vicinity during the Quaternary surpasses 1000 m (R.G.Q.T.M., 1968). Where is this displacement undertaken? The most likely locality is in the eastern piedmont of the Koma Mountains. In this area has obvious tectonic reliefs such as a fault scarplet and a lineament (R.G.A.F., 1980; SAWA, 1981; ASAKAWA and HIRAKAWA, 1986). Summit level map (Fig. 4) shows straight and steep escarpments of 300–400 m in relative elevation at the easternmost part of the investigated area. There is the active fault system of the Tsuburai thrust in the foot of the scarp, which has been active at least since early Pleistocene times (KOYAMA, 1989).

The I.S.T.L. is not responsible for the compressional deformation zone of the lower Momonoki Subgroup. How then was this deformation zone, with its maximum width of 2 km, formed? This will be discussed in the following section.

Normal faults in the Kushigatayama Subgroup

Faults analysis was carried out all over the area surveyed. Faults elements of all faults, type of fault, estimation of period of faulting of each fault type and restored principal stress axis are described in the appendix.

Based on the sense of displacement and the degree of induration of the shear zone, most of the faults are divided into four types in general (See appendix). Among these types normal faults (type B in the appendix) are considered to have been active during the Middle Miocene (latest Early Miocene to early Middle Miocene) based on the indurated shear zone and the distribution of the fault (See appendix). Normal faults are mostly distributed in the Kushigatayama Subgroup, especially in the lower Kushigatayama Subgroup, but not in the Tsuburai Quartz Diorite. Other types of fault except for these normal faults were expected to have been active since the Quaternary.

The fault plane of the normal faults is high angle over 60° in general. The shear zone of normal faults is wider than that of other types of fault and mainly consists of indurated fault breccia (Plates 2–1 and 2–2). The strike of normal faults is mostly in NE-SW, and also few in NW-SE. The restored maximum compressive principal stress (σ_1) axis is subvertical (See appendix). It is unknown whether the tilting of the Kushigatayama Subgroup occurred after the formation of the normal faults or not. If the general bedding plane (N-S, 40°W) is restored to the horizontal, the axis trends E-W to NW-SE and dips moderate.

In conclusion extensional tectonics responsible for the normal fault is considered to have been presented in the Kushigatayama Subgroup during the Middle Miocene (latest Early Miocene to early Middle Miocene). This is markedly contrast to the compressional tectonics in the nearly same time of the lower Momonoki Subgroup.

Mode and origin of the deformation of the Koma Group during the Miocene

Mode of deformation of the Koma Group during the Middle Miocene is characterized by normal faults chiefly in the lower Kushigatayama Subgroup and by the reverse-type layer parallel shear in the lower Momonoki Subgroup. The former must have been formed before the intrusion of the Tsuburai Quartz Diorite (about 15 Ma). The latter formed before the intrusion of the porphyrite dikes and the faulting of the I.S.T.L. which produced the present shear zone, therefore, ranging from the latest Early Miocene to early Middle Miocene. Why are there two different modes of deformation in the neighboring areas and at the same time? In this section, geologic and tectonic circumstances arranged to consider this problem.

HIGUCHI (1969) reported that many molluscan fossils occurred in the lower Kushigatayama Subgroup, and inferred that this subgroup deposited in a relatively shallow sea of about 200 to 800 m in depth. This sea is almost apart from the course of supply of coarse terrigenous sediments from the Honshu arc, because there is no coarse clastic rocks in the Kushigatayama Subgroup, except for the Southern Koma Mountains. These characteristics are similar to other volcanic blocks such as the Tanzawa and Izu in the Southern Fossa Magna. Based on the distribution of igneous activity and the similar polarity of alkali content of the volcanic rocks between the Southern Fossa Magna region (TANZAWA and NISHIKATSURA Group) and the Izu region, MATSUDA (1976) and KANMERA *et al.* (1980) stated that the Southern Fossa Magna was part of the volcanic belt of the Izu-Mariana arc. Based on a chemical analysis of volcanic rocks, SHIMAZU and ISHIMARU (1987) and TAKAHASHI (1989) supposed that the magmatism of the Kushigatayama Subgroup was an island-arc origin of the paleo-Izu arc. By reasoning these opinions and those others mentioned above, the Kushigatayama Subgroup can safely be considered to be a member of the Izu-Mariana arc and formed a thick volcanic sedimentary body, such as a seamount.

On the other hand, the Momonoki Subgroup is mostly composed of relatively fine-grained clastic rocks. The lower Momonoki Subgroup is composed of hemipelagic sediments. While the upper Momonoki Subgroup consists of fine turbidite. From these facies and sequences, the Momonoki Subgroup is conceivable as a trench or trough with sedimentary environment (KANMERA *et al.*, 1979; BLATT *et al.*, 1980).

The Shimokurusawa chert is a small-scale autochtohnous bedded chert intercalated in the lower Momonoki Subgroup. The age is presumed to be Early to Middle Miocene based on the surrounding shale yielding fossil foraminifera. Miocene chert is rare in Japan (MIZUTANI *et al.*, 1987). The Early to Middle Miocene bedded chert up to about 250 m in total thickness is known to occur in the Okabe Formation of the Setogawa

Terrane about 90 km south from the surveyed area (IIJIMA *et al.*, 1981), however, many siliceous deposits in the same age (e.g. a hardshale in the North-East Honshu arc) have not progressed in diagenesis up to a chert. Some special factors are presumed to facilitate a genesis of Miocene chert. As mentioned above, the Shimokurusawa chert is conceivable to have been settled in or near a trench between the Kushigatayama block and the Shimanto Terrane. It is ascertained by deep sea drilling that the Pleistocene lower trench-slope sediments are dewatering, compacted and given a distinct cleavage associated with subduction of oceanic plate (von HUENE *et al.*, 1971; INGLE *et al.*, 1973). von HUENE and KULM (1973) reported that the early Pleistocene mudstone in the Aleutian trench also folded. von HUENE (1972) assumed that the trench sediment had been compressed into a fold against the continental slope based on the analysis of seismic profile data in the Aleutian trench. Considering these geologic evidences near the trench where active subduction is occurred, it can be assumed that the Shimokurusawa chert was formed by rapid dewatering at relatively high pressure caused by the convergence of plates near the trench. However, to support this estimation further experimental studies are required concerning the effect of pressure on a diagenesis of chert.

The tectonic setting is analogous to the relation between a seamount or a marginal swell colliding at a trench and trench-fill sediments or trench wedge sediments near a trench. In the former, a normal fault would be produced (e.g. IDA, 1985) and normal fault-type earthquakes are known such as in the Aleutian trench corresponding to the bending of oceanic lithosphere under the trench (STAUDER, 1968). In the latter, thrusts or reverse-faults associating with bedding slip or cleavage are known by seismic profile and deep sea drilling (e.g. INGLE *et al.*, 1975: DAVEY *et al.*, 1986; LEWIS *et al.*, 1988).

In conclusion it may be said that the Kushigatayama block was probably a seamount-like high beyond the reaches of terrigenous sediment. The hemipelagic sediments were then deposited around it. The block reached a trench with underlying plate which had existed offshore the Shimanto Terrane during the Middle Miocene, and started to subduct. The block also collided with the Shimanto Terrane (Honshu arc) because of its large volume. The hemipelagic sediments suffered salient contracting deformation (mainly layer parallel shear). Phyllitic shale and chert presumably formed under high pressure probably near the paleo-trench caused the collision of the Kushigatayama block. On the other hand, normal faults in the Kushigatayama block were formed in relation to the bend of underlying plate. Recently, SATO *et al.* (1989) stated that the Momonoki Subgroup had rapidly subducted enough to suffer a contact metamorphism of the Kaikoma-Hoo granitoid, and hence inferred a large crustal movement during from latest Early Miocene to early Middle Miocene.

Tectonic evolution of the Koma Mountains

In this section, the author would like to give an account of the tectonic evolution of the Koma Mountains including their southern part (KOYAMA, 1984), referring to the tectonic circumstances of the surrounding area. (See Table 1 for a stratigraphical correlation of the Southern Fossa Magna.)

Stage 1 (Early to Middle Miocene)

The Shimanto Complex had formed and its tectonic arrangement was almost accomplished before this stage. This complex is mainly composed of trench deposits accreted with the Honshu arc by plate motion (TAIRA, 1981). Polarity in age of strata shows that the northward accretion took place. So there was a trench nearly parallel to the trend of the Shimanto Terrane offshore (to the south) this terrane.

The Shikoku basin was still opening until about 17 Ma (KOBAYASHI and NAKADA, 1978). The Izu-Mariana arc was at that time situated at its present longitude (MATSUDA, 1978; SENO and MARUYAMA, 1984). SENO and MARUYAMA (1984) also pointed out that the Philippine Sea plate did not rotate significantly since 17 Ma, when it moved North-North-Westward along the strike of the Izu-Marinana trench until about 4 Ma.

The Kushigatayama Subgroup was deposited on the sea floor basin, probably situated in the northern extremity of the Izu-Mariana arc (Fig. 11). Volcanism of this subgroup was mainly composed of basaltic andesite in the early stage, and basalt in the later stage (KOSAKA and TSUNODA, 1969). At the same time, the North-East Honshu arc rotated anti-clockwise, and the South-West Honshu arc subsequently rotated clockwise by an angle of 47° at 15 Ma (TORII *et al.*, 1985). This was associated with the opening of the Sea of Japan. The I.S.T.L. at an early stage cut the tectonic trend of the Shimanto Complex, and probably had a left-lateral component because of the synsedimentary drag structure near I.S.T.L. in the Kushigatayama Subgroup of the Southern Koma Mountains (KOYAMA, 1984). At this time, the Kushigatayama volcanic block might have been situated near the Honshu arc (Shimanto Terrane), because conglomerate of the Koma Group in the Southern Koma Mountains contains clasts derived from the Honshu arc.

Opinions are diverse concerning the time when began to form the bend of the pre-Miocene terranes (Fig. 2)., and the northward convex structure of the Neogene terrains in the Southern Fossa Magna. MATSUDA (1978, 1984) considered that the bend of pre-Miocene terranes of the Akaishi and Kanto Mountains was formed in the pre-Miocene time, and the convex structure of late Miocene sedimentary basins in the Southern Fossa Magna was inherent. NIITSUMA (1982), NIITSUMA and MATSUDA (1985), however, stated that the bend of the pre-Miocene terranes was formed by the collision of the Tanzawa block with the Honshu arc only after 6 Ma. ISHIBASHI (1986) considered that the bend of the pre-Miocene terranes was shaped at 15 Ma by collision of the Izu-Mariana and the Honshu arcs corresponding to the opening of the Sea of Japan. It is appropriate to consider the bend of the pre-Miocene terranes around the Southern Fossa Magna as being formed at least in the Middle Miocene, if the conclusions of the previous section are taken into consideration.

Stage 2 (Middle Miocene; about 15 Ma)

After a while the southern Kushigatayama block collided with the Honshu arc (Shimanto Complex) (Fig. 11). The paleo-trench between the Kushigatayama block and the

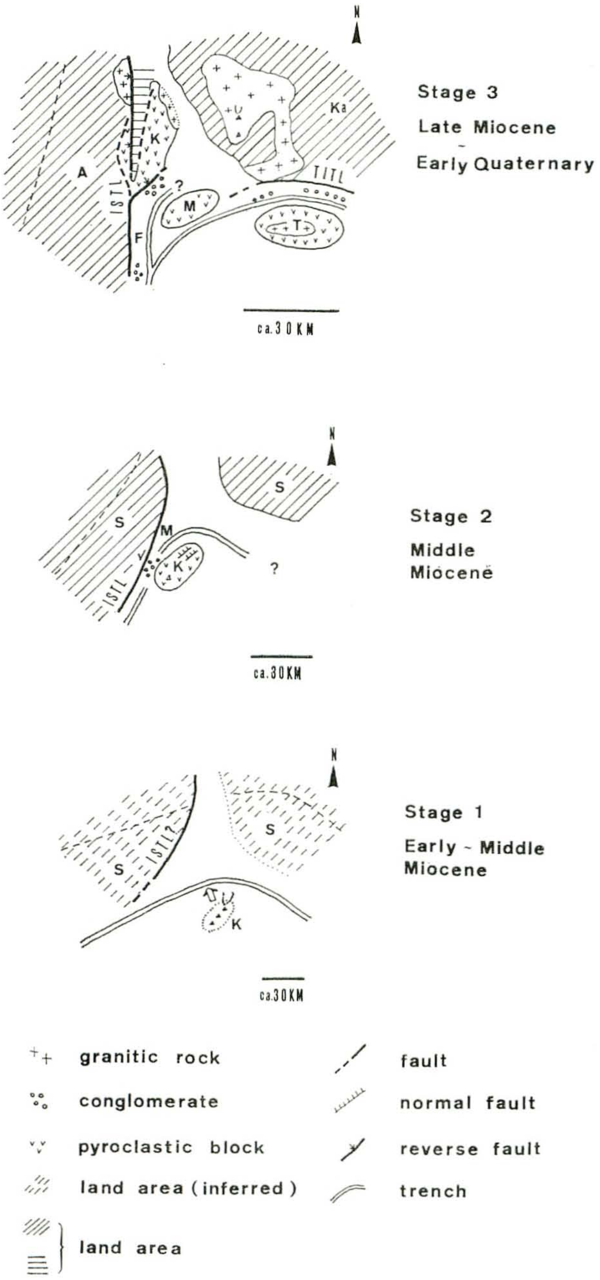

Fig. 11 Schematic reconstruction map showing the tectonic evolution of the Koma block and surrounding area. See text for explanation. S: Shimanto Terrane, K: Koma block, Mo: Momonoki area, M: Misaka block, T: Tanzawa block, F: Fujikawa area, A: Akaishi Mountains, Ka: Kanto Mountains, ISTL: Itoigawa Shizuoka Tectonic Line, TITL: Tohnoki Aikawa Tectonic Line.

Honshu arc filled with thick conglomerate of the lower Momonoki Subgroup (deposition of so called "Mogura Conglomerate"). Most of the clast of this conglomerate were from the Kushigatayama block, which indicates rapid uplift of the south-western part of the Kushigatayama block in relation to the collision. The origin of cobble of granite is unknown (probably from the Ryoke Terrane).

In contrast in the northern Kushigatayama block, the western paleo-trench filled with hemipelagic sediments and fine-turbidite beds. With the northward moving of the Kushigatayama block, the north-western part of the block collided and subducted against the Honshu arc. Normal faults in the Kushigatayama block is ascribed to the subduction of this block. By contrast, trench-fill sediments of the Momonoki Subgroup, especially the lower one, suffered severe contraction associated with the collision of the Kushigatayama block, resulting in the formation of phyllitic shale, chert and broad bedding slip zone. Folding of the Momonoki Subgroup (KOSAKA and TSUNODA, 1969) developed in the Central Koma Mountains might have occurred at this time, accompanying this collision. The direction of collision estimated from the net slip on the bedding slip in the Momonoki Subgroup, is NW-SE to E-W. However, it might also have been a northerly direction if further anti-clockwise rotation of west limb of the bend of the Southern Fossa Magna region after this time is considered.

Porphyrite dikes intruded into the Koma Group, especially into the Momonoki Subgroup, in the direction of N-S to NW-SE after the deformation of the Momonoki Subgroup had almost ceased.

In the eastern part of the Kushigatayama block, the Tsuburai Quartz Diorite intruded into the Kushigatayama Subgroup and gave a contact metamorphism.

Stage 3 (Late Miocene to Early Quaternary)

In the Akaishi block, the Kaikoma-Hoo Granite intruded into the Shimanto Complex near the I.S.T.L. about 11 Ma. After this intrusion, the Kaikoma-Hoo Granite thrust up over the Momonoki Subgroup (SATO *et al.*, 1989) and cataclasites of this granite near the I.S.T.L. were formed. At the same time, the Yakejizo Granite, showing a mylonitic texture, probably intruded into the Shimanto Complex along the I.S.T.L.

There is no clastic sediment of this stage between the Kushigatayama block and the Shimanto Complex. However, to the south of the Koma block, the Fujikawa Group is distributed, consisting mainly of clastic sediments of 6000 m thick (MATSUDA, 1961; SOH, 1986). Furthermore, to the east of the Koma Subgroup, the Nishikatsura Group (FUKUDA and SHINOKI, 1952)., consisting of clastic rocks, is distributed around the northern part of the Tanzawa block. Both groups contain a thick conglomerate in their upper parts, such as the Akebono Conglomerate in the former and the Katsuragawa Conglomerate in the latter. SOH (1986) demonstrated that the Fujikawa Group was made up of trough-fill sediments, and that there was a continuous channel system between the Nishikatsura area and the Fujikawa area. It is considered that these trough-and-channel systems developed with the advance of collision between the Tanzawa block and the Honshu arc starting from the Late Miocene (AMANO, 1986; SOH, 1986). It appears from the above that the paleo-trough between the Kushigatayama block and the Shimanto Terrane shifted to the south, that is, the Fujikawa and the Nishikatsura area.

Stage 4 (after Middle Quaternary)

Until this time, reverse faulting of the I.S.T.L. probably diminished, or almost ceased, except for a part of the fault strand. While at the easternmost part of the Koma block, many active thrust-faults (type A in the appendix) such as the Tsuburai thrust system and conjugate strike-slip fault system (type C and D in the appendix) can be seen (Fig. A–3). Tectonic relief associated with faulting is most conspicuous in this area (Fig. 4). So, it might be stated that during this time the Koma block coupled with the Akaishi block, and tectonic deformation zone shifted from near the I.S.T.L. to the easternmost part of the Koma block. The slickensides on active faults show that the Koma block moved eastward and lifted up (KOYAMA, 1989). There are many active fault-systems in the eastern piedmont of the Central and Southern Koma Mountains (SAWA, 1981).

Concluding statement

The author obtained the following concluding remarks mainly based on the field survey; The Kushigatayama block, belonging to the Izu-Mariana arc and consisting of mostly pyroclastic sediments, collided with the Honshu arc at the paleo-trench off-shore the Shimanto Terrane during the Middle Miocene (latest Early Miocene to early Middle Miocene). It is possible to consider that the collision has a large responsibility to the formation of the bending of pre-Miocene terranes (Honshu arc). The Kushigatayama block coupled with the Honshu arc since the late Miocene.

Future problems will be enumerate as follows; 1) an amount of collision of the Kushigatayama block. This will be highly concerned with the left-lateral movement of the I.S.T.L.. 2) More detailed verification of geologic phenomena in relation to the collision through time. 3) The Kushigatayama block is of the northernmost tip of the Izu-Mariana arc, or not. This problem will be relevant to the tectonics of the Northern Fossa Magna during the Miocene.

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(Appendix)

Fault analysis

In this section, faults in the field, except for the I.S.T.L., are described giving the sense of displacement, characteristics of shear zone, distribution of faults and restored stress field. All faults investigated have shear zones except those which cut off the Quaternary. As the result of fault analysis, four groups were recognized. Details are as follows. Table A–1 gives elements of each fault, such as fault plane angle, width of shear zone, degree of induration of the shear zone, shear plane, striation, sense of fault, wall rock type and presence of water seepage. Some terms used here should be explained at once in order to avoid a confusion.

shear zone: A domain which consists of intra-fault materials such as gouge, fault breccia (based on Dennis (1967)). It does not contain a closely jointed part of wall rock.

gouge: A fine material produced by fracturing along the fault plane. The particles of this material are mostly of clay size, but include sandy size. Content ratio of clast larger than 2 mm in diameter is less than 30% (Higgins, 1971).

fault breccia: A material produced by fracturing near the fault plane. It consists of clast larger than 2 mm in diameter and finer particles (Kodama, 1970). Content ratio of clast larger than 2 mm in diameter is more than 30% (Higgins, 1971).

1. Procedure for decision of the sense of fault movement

Referential markers are commonly used to decide the sense of fault. The same bed is one such. If there was no useful marker, the author used a fracture step on the fault plane and a pinnate fracture to decide the sense of fault movement. Both are drawn schematically in Fig. A–1. Fracture steps can commonly be recognized if the fault plane is not highly weathered. Fracture step is a step-like break on the fault plane. The outline of the step is like an isosceles triangle or a chestnuts. A criterion known as the "smoothness principle" is generally used for interpreting the sense of fault movement. It has been conventionally considered that the smoother touch of the slickensided surface corrsponds to the movement of the adjoining block (e.g. Billings, 1972). Since reexamination of this criterion by Paterson (1958), however ,it has been substantiated by many experimental and field geological studies (TIJA, 1964, 1967, 1972; NORRIS and BARRON, 1969; GAY, 1970; UEMURA, 1977) that a concave fracture step is incongruous with the "smoothness principle". The riser of the step faces at right-angles to the direction in which the opposite side wall moved. The height of the riser is commonly less than 1 cm. So, the author used concave fracture step among fracture steps.

Pinnate fracture is a systematic joint or a fracture developing near a fault plane (Fig. A–1). The trend of this fracture is concordant with that of the maximum compressive principla stress. Thus, the sense of fault movement can be deduced indirectly.

2. Four types of fault

Four types of fault are recognized in the field, in terms of the sense of fault movement and the degree of induration of the shear zone. There are called types A,B,C and D. All fault planes listed in Table A–1 are plotted in Fig. A–2 with an enclosed line showing each group of faults. The characteristics of each group of faults are listed in Table A–2.

Type A contains relatively low angle reverse faults or thrusts which stirke nearly N-S. Some active faults thrusting over the Quaternary at the eastern piedmont of the Koma Mountains, such as the Tsubruai thrust, are of this type. The width of the shear zone is in general less than 20 cm. Material consisting of the shear zone is not indurated. The faults categorized as type A' are considered to be a back-thrust of type A, since the characteristics of the shear zone and the strikes of the fault plane are similar to that of type A. The faults of type A are mostly distributed in the lower Kushigatayama Subgroup and the Tsuburai Quartz Diorite (Fig. A–3).

Type B contains high angle normal faults striking NE-SW to NNE-SSW. The shear zone of this type is wider than that of other types and mainly consists of fault breccia up to 5 m in width. The clast of fault breccia is angular or subangular up to 30 cm in diameter, and it shows a random fabric (Fig. A–4; Plates 2–1 and 2–2). The material of the

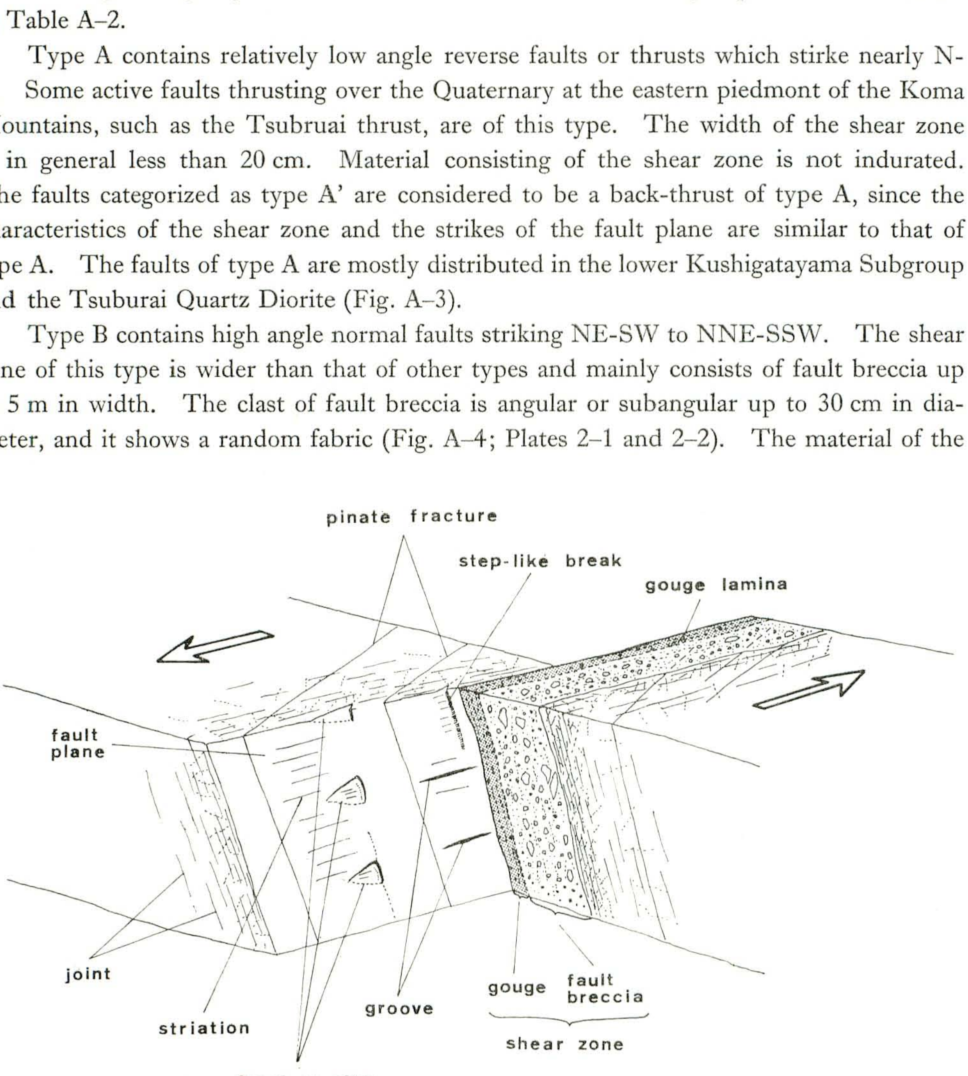

Fig. A–1 Schematic diagram showing fault elements in mesoscopic scale. Arrow indicates the direction of each block moved.

Table A–1 Table showing fault elements of faults in the Northern Koma Mountains. See text for the type of fault. Star symbol on the fault number shows the fault which a stress field can be reconstructed (Table A–3). (degree of induration; ×: not indurated and soft, △: somewhat indurated, ○: indurated), (shear plane; ◎: clear and well polished, ○: somewhat clear and poorly polished), R: reverse type, N: normal type, R.L.: right-lateral slip type, L.L.: left-lateral slip type, QD: quartz diorite, CONGLO: conglomerate, AN: andesite, AN TFBRE: andestic tuff breccia, AN LPTF: andestic lapilli tuff, SILTST: siltstone, SANDST: sandstone, BA: basalt, ALT: alternating bed of sandstone and mudstone, LAMPRO: lamprophyre,

no.	fault plane angle	width of shear zone	width of gouge	width of fault breccia	degree of induration	shear plane	striation (net slip)	sense of fault	hanging wall	foot wall	water seepage	type
1	N9E,40W	(6m˜- shattered rock)			×	?	?	R	QD	QD,CONGLO	×	A
2	N31W,80W	5cm	5cm		△	○	?		QD	QD	○	
3	N18E,84W	3cm	3cm		×	○	?		AN	AN	○	
4	N44E,60W	5cm		5cm	×	◎	N54E (10)		AN TUFF	AN TUFF	○	
5*	N76W,82N	25cm		25cm	○	◎	N13W (86)	R	AN TUFF	AN TUFF	×	
6*	N89W,70S	2cm	2cm		×	○	N80W (12)	R.L.	SILTST	AN TUFF	○	D'
7	N76E,44S	21cm	1cm	20cm	○	◎	?		SILTST	AN TUFF	×	
8	N10W,88E	3cm	3cm		○	◎	N38E (60)		QD	QD	×	
9	N30W,55E	35cm		35cm	○	◎	?		QD	QD	×	
10	N10W,40W	2cm	2cm		×	◎	?		QD	QD	○	
11	N31W,70W	25cm	25cm		×~△	◎	?	R?	QD	QD	×	
12	N18W,74W	68cm	8cm	60cm	○	○	?		AN TUFF	AN TUFF	×	
13*	N86W,58S	16cm	6cm	10cm	×~△	○	N27E (70)	N	QD	QD	×	
14	N40W,52W	165cm		165cm	○	○	?		AN LAVA	AN LAVA	×	
15*	N14E,62W	250cm±	1cm	250cm ±	×~△	○	DIP SLIP	R	AN TFBRE	AN TFBRE	×	A
16	N11W,70W	60cm		60cm	○	?	?		AN LAVA	AN LAVA	×	
17*	N21E,36W	0.5cm	0.5cm		×	◎	N40W (36)	R	AN TUFF	AN TUFF	×	A
18*	N39W,40W	25cm		25cm	○	○	N66W (25)	R	AN LAVA	AN LAVA	×	A
19	N22E,80E	3cm		3cm	○	?	?		AN LAVA	AN LAVA	×	
20*	N84E,56N	5cm		5cm	×	○	N81W (10)	L.L.	AN TUFF	AN TUFF	×	C'
21*	N61W,72N	500cm		500cm	○	○	N20W (55)	N	AN LAVA	AN LAVA	×	
22*	N26E,42W	30cm		30cm	△, ○	◎	N45W (50)	R?	AN LAVA	AN LAVA	×	A
23	N16W,35W							R	QD	CONGLO	×	A
24	N22E,30W					?		R	QD	CONGLO	×	A
25*	N43W,52W	25cm	10cm	15cm	×	◎	N66E (32)	R	QD	QD	○	A
26	N36W,80W	150cm		150cm	○	○	?	N?	AN TUFF	AN TUFF	×	
27*	N11W,45W	1cm	1cm		×	◎	N84W (45)	R	QD	QD,CONGLO	×	A
28*	N50E,85N	5cm		5cm	△	◎	N52E (20)	R.L	AN TUFF	AN TUFF	○	D
29*	N56W,40S	12cm	12cm		×	◎	N34E (30)	R	AN TUFF	AN TUFF	×	A
30*	N30W,68E	50cm		50cm	△	◎	N30W (5)	R.L.	AN TUFF	AN TUFF	×	
31*	N31W,50E	0.3cm	0.3cm		△	◎	N34E (40)	R	AN TUFF	?	×	A'
32	N24E,60W	27cm	2cm	25cm	×	○	N54E (25)		AN TUFF	AN TUFF	×	
33*	N40W,60W	100cm		100cm	△	○	N64E (55)	N	AN LAVA	AN LAVA	×	
34*	N18E,60W	10cm	10cm		×	◎	N60E (40)	R	AN TUFF	AN TUFF	×	A
35	N-S,54W	40cm		40cm	○	○	N51W (30)?		AN LAVA	AN LAVA	×	
36	N12W,66E	35cm		35cm	○	○	?	N	AN LAVA	AN LAVA	×	
37*	N21W,60E	130cm		130cm	○	◎	N84E (60)?	R	AN LAVA	AN LAVA	×	A'
38	N44E,70E	500cm±		500cm ±	○	○	?	N	AN LAVA	AN LAVA	×	B
39*	N11W,60W	15cm		15cm	△	◎	N86W (50)	R?	AN LAVA	AN LAVA	×	A
40	N24E,88E	61cm	1cm	60cm	×	○	?		AN LAVA	AN LAVA	○	
41*	N76W,63N	2cm	2cm		×	◎	E-W (12)	L.L.	AN LAVA	AN LAVA	×	C'
42*	N46E,85N	120cm	1cm	120cm	○~×	◎	N56E (80)	N	AN LAVA	AN LAVA	×	B
43	N4E,82E	35cm	5cm	30cm	○	◎	?		AN LAVA	AN TUFF	×	
44	N11E,70W	80cm		80cm	○	◎		N	AN LAVA	AN TUFF	×	B
45*	N22E,80E	7cm		7cm	○	◎	N60W (80)	N	AN TUFF	AN TUFF	○	B
46*	N1W,47W	7cm	7cm		×~△	◎	N49E (36)	R	AN TUFF	AN TUFF	○	A
47	N32E,44W	15cm	0.3cm	15cm	×, ○	◎			AN TUFF	AN TUFF	?	
48	N9E,56W	30cm		30cm	○	○		N	AN LAVA	AN TUFF	×	B
49	N58E,60S	130cm		130cm	○	○		N	AN LAVA	AN LAVA	×	B
50	N11W,90	20cm		20cm	○	○			AN TUFF	AN TUFF	×	
51	N34W,80E	130cm±	3cm	130cm ±	△	◎	?	N?	AN TUFF	AN TUFF	×	

Table A–1 Continued

no.	fault plane angle	width of shear zone	width of gouge	width of fault breccia	degree of induration	shear plane	striation (net slip)	sense of fault	hanging wall	foot wall	water seepage	type
52*	N80W,54N	12cm		12cm	○	◎	N36W (15)	R.L.	AN TUFF	AN TUFF	×	
53*	N40E,56S	2cm	2cm		×	◎	N86E (36)	R	AN TUFF	AN TFBRE	○	A'
54*	N34W,90	6cm	1cm	5cm	△	◎	DIP SLIP	WEST UP	AN TUFF	AN TUFF	○	
55*	N66W,60N	5cm	5cm		△	◎	N54E (60)	R	AN TUFF	AN TUFF	○	
56	N58W,64N	20cm		20cm	×	◎		L.L.	AN TUFF	AN TUFF	○	C'
57*	N34E,22W	5cm	5cm		×~△	◎	N82E (20)	R	AN LAVA	AN TUFF	×	A
58*	N70E,60N	30cm		30cm	○~×	◎	N63W (40)	R	AN TUFF	AN TUFF	○	
59*	N14E,46E	2cm	2cm		×	◎	N68W (46)	R	AN TUFF	AN TUFF	×	A'
60	N20W,88E	10cm		10cm	△~○	○	?		AN TUFF	AN TUFF	○	
61*	N74E,65S	5cm	5cm		×	◎	E-W (44)	R.L.	AN LAVA	AN LAVA	○	D'
62*	N10W,40E	12cm	12cm		×	◎	N56E (32)	R	AN TUFF	AN TUFF	×	A'
63	N61W,80S	60cm		60cm	○	○	?		AN TUFF	AN TUFF	×	
64*	N30E,67W	22cm	2cm	20cm	×, ○	◎	N34E (0)	R.L.	AN TUFF	AN TUFF	×	D
65	N7E,20W	15cm	15cm		×~△	◎	DIP SLIP		AN TUFF	AN TUFF	?	
66	N36W,20E	0.5cm	0.5cm		×	◎	N76W (10)		SANDST	SANDST	×	
67*	N14E,74W	5cm		5cm	○	◎	N34E (46)	N	AN LPTF	AN LPTF	×	B
68*	N82E,50S	10cm		10cm	○	◎	N5W (60)	N	AN TUFF	AN TUFF	×	
69	N44E,80E	2cm	2cm		×	○	DIP SLIP?		QD	QD	○	
70*	N36W,80W	13cm	3cm	10cm	×	◎	N14E (70)	R	QD	QD	○	
71*	N56W,50S	5cm	5cm		×	◎	N63W (10)	L.L.	AN TUFF	AN TUFF	×	C
72*	N50W,62S	1cm	1cm		×~○	○	N40W (22)	R.L.	AN TUFF	AN TUFF	×	
73*	N24W,75W	15cm		15cm	△	○	N38W (10)	L.L.	AN LAVA	AN LAVA	×	C
74*	N20E,30E	20cm		20cm	×	◎	N70W (24)	R?	AN LAVA	AN LAVA	×	A'
75*	N29E,34W	13cm	3cm	10cm	×	◎	N76W (25)	R?	AN LAVA	AN LAVA	×	A
76*	N76W,50S	10cm	10cm		×	◎	N60E (30)	R.L.	BA LAVA	BA LAVA	○	D'
77	N76W,45N	15cm		15cm	△~×	◎	N86W (20)		BA LAVA	BA LAVA	×	
78*	N14E,30W	1cm	1cm		×	○	N72E (20)	R	AN TUFF	AN TUFF	×	A
79*	N46W,76S	63cm	3cm	60cm	×	◎	N32W (16)	L.L.	AN TUFF	AN TUFF	×	C
80	N76W,85S	5cm	5cm		×	○	?		AN TUFF	AN TUFF	×	
81*	N86W,64S	10cm		10cm	×~△	○	N18W (60)	R	AN TUFF	AN TUFF	○	
82*	N36W,70W	7cm		7cm	×	○	N50W (12)	L.L.	AN TUFF	AN TUFF	×	C
83*	N18W,55W	21cm	18cm	3cm	×	◎	N67E (84)	R	AN TUFF	AN TUFF	×	A
84*	N66W,74S	0.5cm	0.5cm		×	◎	N60W (14)	L.L.	AN TUFF	AN TUFF	×	C
85	N56W,40S	30cm	30cm		×	◎	?		QD	QD	×	
86	N16W,65W	5cm	5cm		△	?	?		QD	QD	×	
87*	N30E,60W	10cm	10cm		×	◎	N34E (10)	R.L.	QD	QD	○	D
88*	N30W,50W	10cm	10cm		×	◎	N18E (30)	R	QD	QD	×	A
89*	N10W,34W	1cm	1cm		×	◎	N76W (42)	R	QD	QD	×	A
90*	N60W,80S	25cm		25cm	○	○	N42E (75)	N	MUD	MUD	○	
91*	N58E,50N	8cm	8cm		×	◎	N59E (20)	R.L.	BA TUFF	BA TUFF	×	D
92*	N26W,80W	10cm	10cm		×	○	N72E (85)	R	ALT	ALT	○	
93*	N58E,84S	20cm		20cm	○	◎	N42W (66)	R	AN TUFF	AN TUFF	×	
94	N49W,40E	30cm	30cm		×	○			ALT	MUD	×	
95	N46W,35W	250cm	250cm		×	?			SILTST	?	○	
96*	N10E,30E	1cm	1cm		×	◎	N89E (35)	R	MUD	AN TUFF	×	A'
97	N40E,85E	12cm	2cm	10cm	○	○		R	AN TUFF	MUD	×	
98	N62E,90	35cm		35cm	○	○		EAST UP	MUD	MUD	○	
99	N20E,40W	3cm	3cm		×	◎			LAMPRO	LAMPRO	○	
100*	N32E,60W	5cm		5cm	○	◎	N86W (40)	N	MUD	MUD	×	B
101*	N34E,78W	20cm		20cm	△~○	○	N76W (75)	N	AN TUFF	AN TUFF	×	B
102	N19E,80E	590cm	3cm	590cm	○	○		L.L.	AN TUFF	AN TUFF	?	

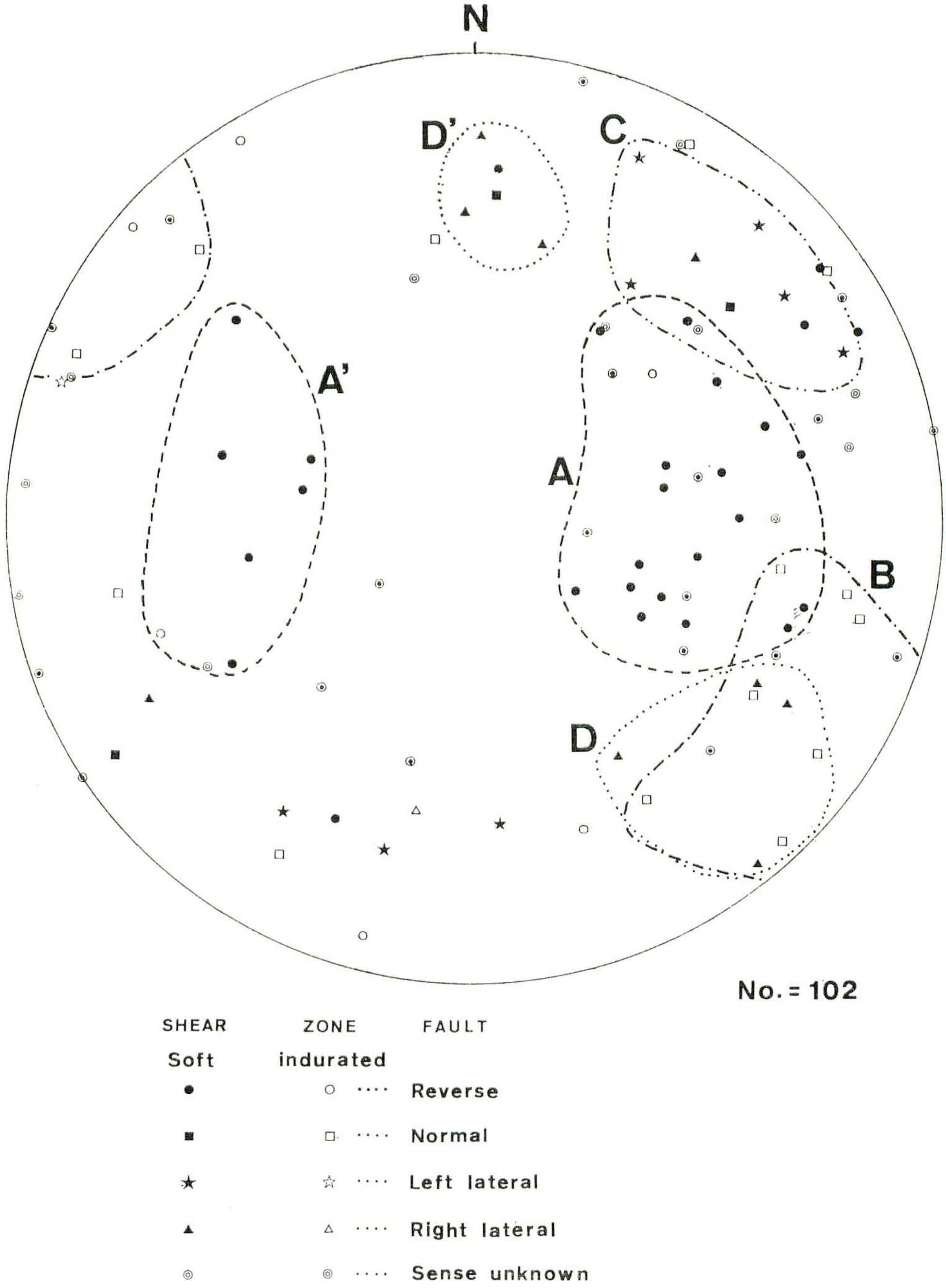

Fig. A–2 Pole to fault plane of all faults in the Northern Koma Mountains, referred to the sense of movement, lower-hemisphere, equal area projection. See text for explanation of A,A′, B, C, D and D′ (data from Table A–1).

Table A–2 Table showing some characteristics on each type of fault in the Northern Koma Mountains and the direction of the maximum (σ_1) and minimum (σ_3) principal compressive stress axis, respectively.

type	strike	dip	sense	degree of induraton	σ_1	σ_3
A	N-S	60° > W	reverse	soft～half indurated	E-W to WNW-ESE, horizontal	high angle
A'	ditto	60° < E	reverse	ditto	E-W, horizontal	ditto
B	NE-SW to N-S	60° <	normal	indurated	high angle	WNW-ESE to E-W
C	NW-SE	60° < ,W	left lateral	soft	E-W to WNW-ESE, horizontal	N-S, 40° >
C'	ditto	60° < ,E	ditto	ditto	WSW-ENE, low angle	NNW-SSE, low angle
D	NE-SW	50° < ,W	right lateral	ditto	E-W, horizontal	N-S, low angle
D'	E-W	60° < ,S	ditto	ditto	E-W to WNW-ESE, low angle	NNE-SSW, low angle

shear zone is mostly indurated. Faults of this type are mostly distributed in the lower Kushigatayama Subgroup 2 to 3 km east from the Komukawa fault, but not in the Tsuburai, Quartz Diorite (Fig. A–3).

Type C contains left-lateral faults striking NW-SE to WNW-ESE and dipping with a high angle. The material of the shear zone is not indurated.

Type D contains high angle right-lateral faults striking NE-SW to ENE-WSW. The material of the shear zone is not indurated. Type D' has similar characteristics in the shear zone to that of the type D, but is slightly different in its strike and dip.

3. Stress field

If both net slip and sense of displacement can be obtained, we can decide the stress field by means of the method introduced by HOBBS *et al.* (1976). The angle of shear (2θ) was presumed to be 60°, since this value is reasonable empirically (JAEGER and COOK, 1976). Reconstructed stress fields are listed in Table A–3 together with the sense of fault, degree of induration of shear zone and type of fault.

Similar stress fields are obtained from both type A and A', that is, the maximum compressive principal stress (σ_1) axis is nearly E-W and horizontal, and the minimum compressive principal stress (σ_3) axis is of a high angle. From the type B, the maximum compressive principal stress (σ_1) axis is high angle and the minimum compressive principal stress (σ_1) axis is nearly horizontal. From both type C and C', the trend of the maximum compressive principal stress (σ_1) axis is nearly E-W and horizontal to low angle. From both type D and D', the maximum compressive principal stress (σ_1) axis is nearly E-W and horizontal to low agnle.

4. Estimation of period of faulting

Generally speaking it is difficult to decide the period of movement of an individual fault. But the estimation becomes more easy when considering a group of similar faults,

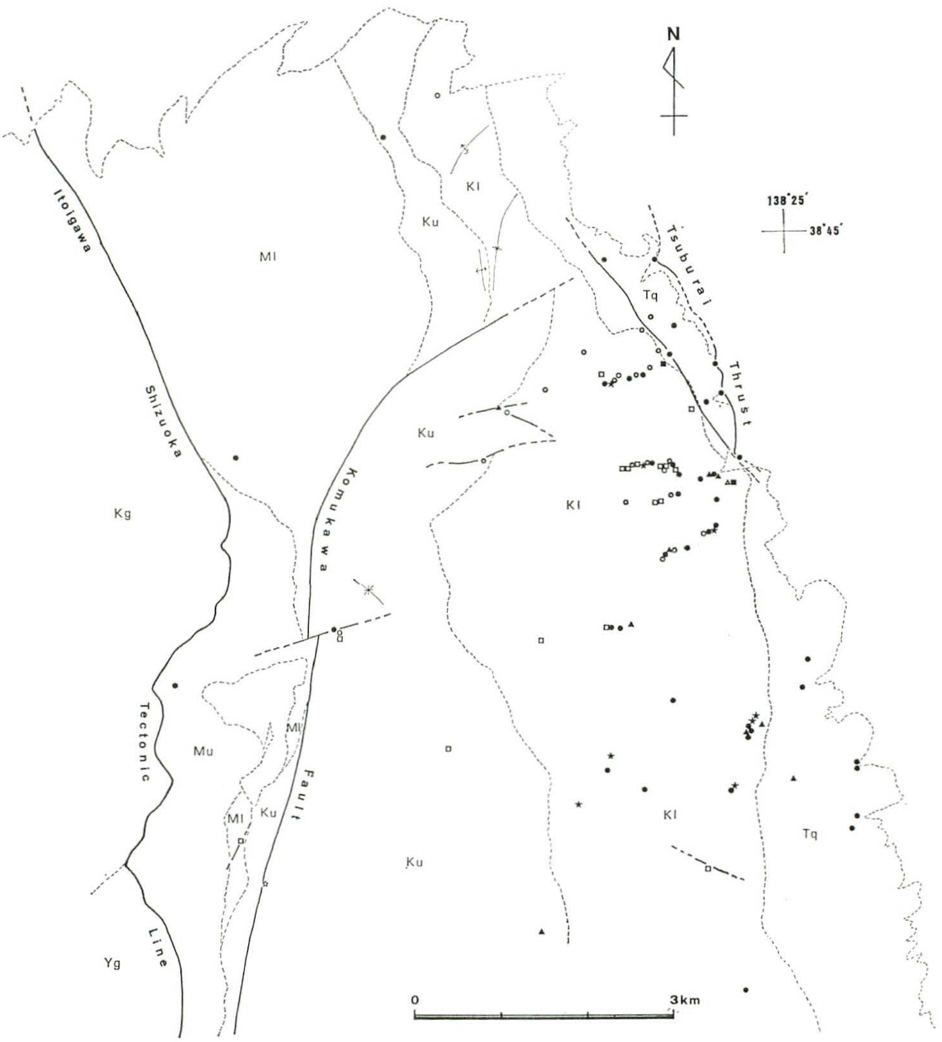

Fig. A–3 Locality map of fault outcrop referred to the sense of movement. Kl: lower Kushigatayama Subgroup, Ku: upper Kushigatayama Subgroup, Ml: lower Momonoki Subgroup, Mu: upper Momonoki Subgroup, Kg: Kaikoma-Hoo Granite, Yg: Yakejizo Granite, Tq: Tsuburai Quartz Diorite. Symbols are the same in Fig. A–2.

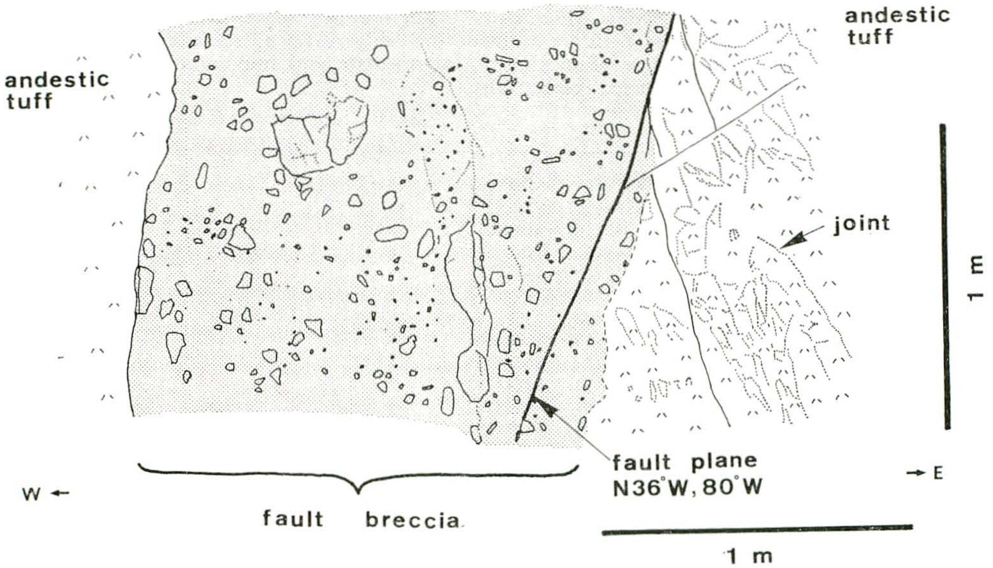

Fig. A–4 Sketch showing an example of type B fault (normal fault).

since available data increases. As already mentioned above, most faults can be grouped into one of four types, based on the attitude of their fault planes, the sense of fault movement and the characteristics of the shear zone.

Faults of type A have soft shear zone, and in most cases clear and well polished shear planes are observed. These characteristics suggest that the faults of type A moved recently and the shear zone was produced nearer under the surface of the earth. It is too well known to mention more than in passing that active faults or faults associated with earthquakes have soft intra-fault materials (e.g. Reed, 1964; Matsuda and Yamashina, 1974; Okada, 1980; Koyama, 1988). These items of field evidence should imply that the faults of type A move up to the late Quaternary. The thrusting over the Quaternary by some faults of type A, such as the Tsubruai thrust support this notion.

Faults of type B are characterized by the indurated intra-fault material and the generally broader shear zone. These field investigations imply that the period of faulting of type B is older than that of all other types. Although there are many faults of type B in the lower Kushigatayama Subgroup near the Tsuburai Quartz Diorite, there is none in the quatrz diorite (Fig. A–3). This should indicate that faulting of type B had already terminated before the intrusion of the Tsuburai Quartz Diorite.

Faults of types C and D have the same characteristics of shear zone and fault plane as type A. Reconstructed trends of the maximum compressive principal stress (σ_1) axis is the same as type A. These facts suggest that the period of faulting of types C and D and that of type A may overlap, especially in the Quaternary. Faults of types C and D might constitute conjugate fault sets of each other.

Table A–3 Table showing the reconstructed attitude of stress axis from some faults in the Northern Koma Mountains. Fault number, sense, degree of induration and type of fault are the same in Table A–1. σ_1, σ_2, and σ_3 are the trend and plunge of maximum, intermediate and minimum compressive principal stress axis, respectively.

fault no.	σ_1	σ_2	σ_3	sense	degree of induration	type
5	N8E(52)	S77E(6)	S16W(38)	R	○	
6	S52E(10)	S53W(59)	N33E(28)	R.L.	×	D'
13	E-W(79)	S79E(10)	N10E(2)	N	×~△	
15	N76W(32)	N14E(0)	S76E(60)	R	×~△	A
17	N59W(4)	S41W(14)	N56E(76)	R	×	A
18	S83E(4)	S10W(32)	N19E(57)	R	○	A
20	S69W(36)	N34E(48)	S35E(18)	L.L.	×	C'
21	S81W(68)	S67E(19)	N20E(10)	N	○	
22	N52W(11)	S37W(9)	N87E(75)	R?	△, ○	A
25	S58W(3)	S33E(14)	N22W(75)	R	×	A
27	E-W(14)	S2E(10)	N54E(74)	R	×	A
28	S84W(15)	N38E(68)	S10E(13)	R.L.	△	D
29	S34W(10)	S56E(1)	N30E(80)	R	×	A
30	S2E(10)	N59E(68)	N89W(20)	R.L.	△	
31	N44E(18)	S42E(12)	S82W(68)	R	△	A'
33	N37W(84)	S37E(6)	N53E(0)	N	△	
34	S80W(24)	N3E(25)	S46E(55)	R	×	A
37	N76E(30)	N17W(6)	S62W(60)	R	○	A'
39	S86W(29)	S7E(7)	N70E(60)	R?	△	A
41	S64W(4)	N19W(58)	S28E(32)	L.L.	×	C'
42	N6W(56)	S42W(25)	S59E(22)	N	○~×	B
45	N72W(70)	N23E(2)	S66E(20)	N	○	B
46	S62W(12)	N22W(22)	S53E(65)	R	×~△	A
52	S18E(9)	N65E(38)	S82W(50)	R.L.	○	
53	S76E(20)	S22W(24)	N22W(58)	R.L.	×	A'
54	S54W(60)	N34W(0)	N56E(30)	WEST UP	△	
55	N39E(28)	N58W(14)	S8W(58)	R	△	
57	S77E(10)	N11E(8)	S56W(76)	R	×~△	A
58	N44W(25)	N57E(21)	S2W(56)	R	○~×	
59	S70E(17)	N18E(3)	N85W(74)	R	×	A'
61	S63E(14)	S42W(48)	N16E(38)	R.L.	×	D'
62	N64E(9)	S24E(12)	N66W(76)	R	×	A'
64	S61E(4)	N38W(65)	S28E(24)	R.L.	×, ○	D
67	S14E(54)	N2E(34)	S87W(8)	N	○	B
68	S4W(80)	N83E(2)	N7W(10)	N	○	
70	S44W(50)	N37W(7)	N59E(40)	R	×	
71	S86E(12)	S17W(49)	N5W(40)	L.L.	×	C
72	S14E(2)	S79W(55)	N75E(35)	R.L.	×~○	
73	N67W(1)	S20W(70)	N24E(20)	L.L.	△	C
74	S70E(0)	N20E(0)	——(90)	R?	×	A'
75	N72W(4)	N18E(7)	S12E(82)	R?	×	A
76	N85W(61)	S52E(25)	N31E(14)	R.L.	×	D'
78	N80E(3)	N11W(13)	S2W(76)	R	×	A
79	S62E(21)	N82W(67)	N25E(7)	L.L.	×	C
81	S7E(36)	S89W(10)	N10E(54)	R	×~△	
82	N88W(1)	S10W(64)	N11E(24)	L.L.	×	C
83	S69W(25)	N21W(3)	N76E(65)	R	×	A
84	N88E(24)	S76W(64)	N4W(5)	L.L.	×	C
87	N61E(4)	N44W(59)	N28E(24)	R.L.	×	D
88	S33W(14)	N51W(22)	S86E(63)	R	×	A
89	N82W(2)	S8W(12)	N15E(78)	R	×	A
90	N25E(70)	S59E(3)	S32W(20)	N	○	
91	N84E(1)	N35E(68)	S5E(43)	R.L.	×	D
92	S66W(50)	S26E(2)	N62E(40)	R	×	
93	S34E(56)	S58W(4)	N31W(34)	R.L.	○	
96	N88W(0)	S1W(5)	N14E(85)	R	×	A'
100	S62W(65)	N21E(20)	S64E(16)	N	○	B
101	S48E(68)	N33E(4)	N59W(22)	N	△~○	B

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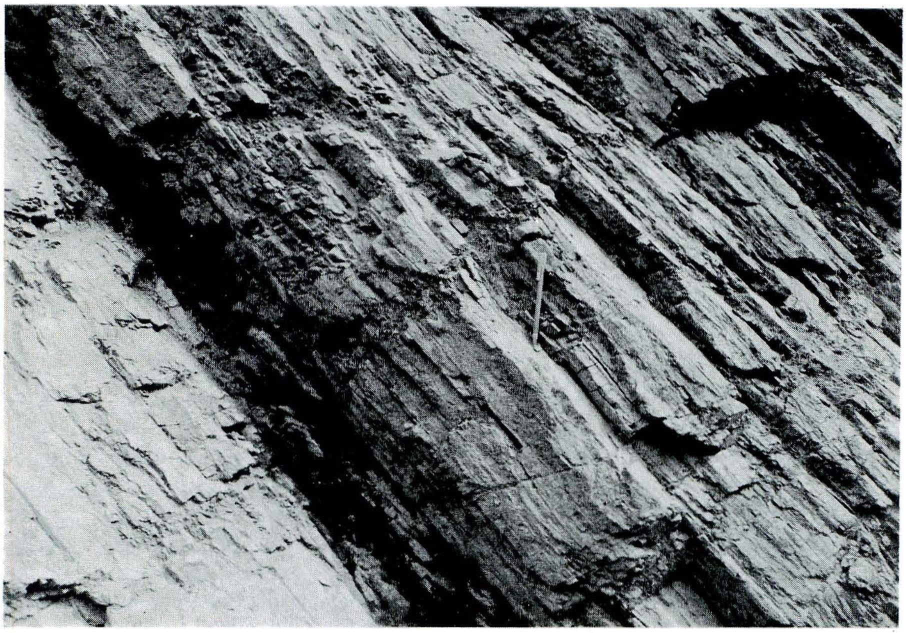
* in Japanese with English abstract

** in Japanese

Explanation of Plates 1

Plate 1–1 Phyllitic shale within the lower Momonoki Subgroup of the Northern Koma Mountains. Bedding schistosity dipping west is closely developed (from upper left to lower right). Lineations such as striation and groove of nearly dip-slip type are seen on the bedding schistosity. Scale is 14 cm.

Plate 1–2 Bedded chert in the River Shimokurusawa. Apparent total thickness of this outcrop is about 50 m. Bedding slip is developed between siliceous part of the chert and shale parting. Scale is 50 cm.



1

2

Explanation of Plates 2

Plate 2–1 An outcrop of the normal fault in the Kushigatayama Subgroup of the Northern Koma Mountains. Shear plane is visible to the right side of hammer.

Plate 2–2 An outcrop of the normal fault in the Kushigatayama Subgroup of the Northern Koma Mountains. Indurated fault breccia can been seen to the left side of hammer.

1

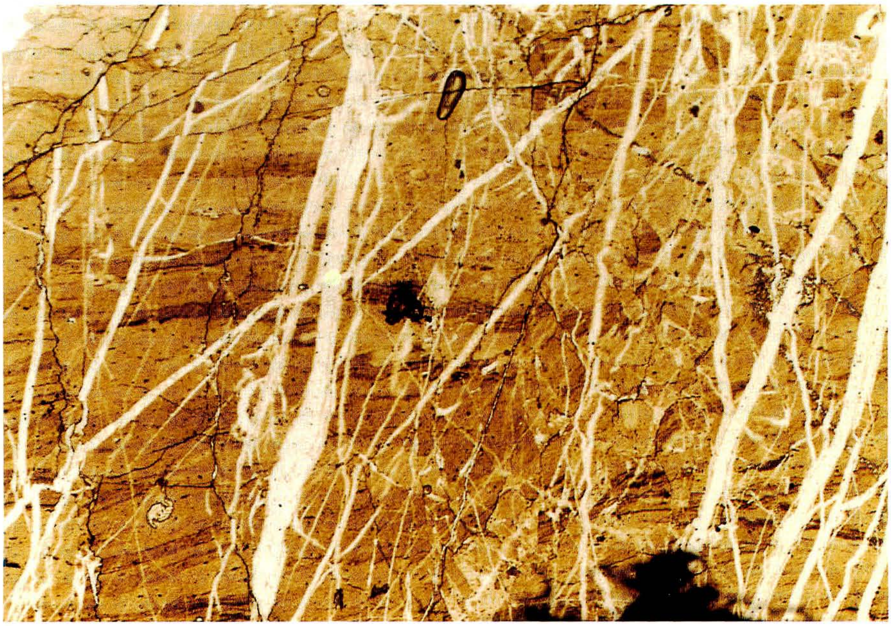
2

Explanation of Plates 3

Plate 3–1 Photomicrograph of phyllitic shale in the lower Momonoki Subgroup, crossed nicols. Cleavages parallel to the bedding schistosity are sufficiently closely spaced. Pressure fringes around microfossils are elongated parallel to the cleavage. Scale is 1 mm.

Plate 3–2 Photomicrograph of siliceous part of bedded chert in the lower Momonoki Subgroup (River Shimokurusawa), open nicols. The orientation of dark colored part is approximately parallel to the bedding. Quartz veinlets are pervasive nearly perpendicular and oblique to the bedding. Scale is 1 mm.

1



2