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Sedimentological Analysis of the Neogene Basins in the Central Part of the Northern Fossa Magna Region, Central Japan

By

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Contents

Abstract

The Development of the Neogene sedimentary basins in the Northern Fossa Magna region was examined mainly on the basis of stratigraphic and sedimentologic viewpoints.

The Fossa Magna region, an important geologic province which divides the Japanese Islands into Northeast Japan and Southwest Japan, is characterized by strong volcanism and subsidence which resulted in very thick Neogene volcaniclastic and terrigenous accumulation. The western boundary of the region is marked by a remarkable fault called Itoigawa-Shizuoka Tectonic Line, and the eastern one is called Kashiwazaki-Choshi Tectonic Line. Further, this region is divided into two parts, north and south. The basin analysis indicates that the Northern Fossa Magna region is included in the inner arc of Northeast Japan, being separated by the central massif from the Southern Fossa Magna region which is believed to be a continuation of the Izu-Bonin arc.

Thick Neogene sequence in the Northern Fossa Magna region is composed mainly of flysch-type

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alternations of sandstone and mudstone, mudstones, thick-bedded sandstones, large-scale cross-laminated sandstones and conglomerates with intercalations of volcanic rocks, and altered pyroclastics. These are divided into seven formations, the Moriya, Uchimura, Bessho, Aoki, Ogawa, Shigarami and Sarumaru Formations in ascending order. The former five belong to Miocene and the latter two to Pliocene. Based on the lithofacies characters, three stages of geologic development are discriminated, that is, initial volcanism stage (Moriya and Uchimura Formations), flysch stage (Bessho and Aoki Formations), and molasse stage (Ogawa, Shigarami and Sarumaru Formations). Lower Neogene formations of gently folded are distributed in the Central (southern) and Otari (northern) Upheaval Zones, whereas thick and moderately folded formations of middle to upper Neogene are distributed in the Subsidence Zone situated between the above two Upheaval Zones.

Three coarsening-upward mega-sequences can be recognized in the Neogene strata. Each sedimentary sequence is composed of several formations which begins with mudstone or muddy alternations, and terminates with massive and/or thick-bedded sandstone and conglomerate through sandy alternation. The first mega-sequence indicates the extinction of the initial volcanic basin, and second one corresponds to the transition from flysch to molasse stage, reflecting gradual filling-up of the southern half of the molasse basin. The third one corresponds to the extinction of the molasse basin.

Paleocurrents shown by sole markings in the flysch sequence and clastic intercalations of initial volcanism stage are generally northeastward. In the molasse stage the paleocurrent directions deduced from the cross-laminations are variable such as from south, east and west.

The Neogene geoyncline in the Northern Fossa Magna region is not a simple basin but much complicated one constituted by many small basins, therefore, thickness variation of each formation is conspicuous. The first-order migration is northwestwardly from initial volcanism site to flysch and molasse sedimentation site, and such migration can be recognized throughout the Inner arc province of Japan and is assigned to be general in the course of Neogene sedimentary basins. Second- and third-order migration in the molasse basin is a movement of rather small-scale and the trend of migration is a reflection of local upheaval within the Shin'etsu mega-sedimentary basin.

I. Introduction

The Fossa Magna region situating in Central Japan, is an important geologic province which divides the Japanese Islands into Northeast Japan and Southwest Japan. It belongs to the area where the Green Tuff orogenic movements of the Neogene took place (MINATO et al., 1965). The Green Tuff orogenic movements started at the earliest Miocene and the characters were summarized briefly as follows; 1. Older geologic structures seem to have been greatly modified in this age. 2. Numerous subparallel faults newly appeared along the arcuate trend of the present island arc, and the Japanese Islands were differentiated into two distinct regions, the outer, non-Green Tuff region, and the inner, Green Tuff region, respectively. These faulting movements marked the beginning of the formation of island arcs in the Japanese Island region. 3. Simultaneously intense volcanic activities were followed by the faulting, and inner belt was subjected to sinking.

The Fossa Magna region, like the other Green Tuff regions, was born at the dawn of Miocene, and is characterized by strong volcanism and subsidence, resulting in very thick volcaniclastic and terrigenous accumulation. Acidic plutonism occurred in this region in the later stage. This region is divided into two parts, the northern and the southern provinces. The former belongs to the inner arc of Northeast Japan and the latter is a continuation of the Izu-Bonin arc (MINATO et al., 1965).

Concerning the geology of the Fossa Magna region, hitherto there have been published many papers. Neverthles, most of them have mainly dealt with its stratigraphy and geologic structure, and only a few sedimentological studies have been done. Such being the case, previous works on the basin analysis were mainly based on stratigraphical and structural viewpoints. One of the important results is that by Kobayashi and his colleagues (KOBAYASHI, 1957), who clarified the evidence of intermittent northward migration of Neogene sedimentary basins in the area. Recently, the Neogene formations were reexamined by the NORTHERN FOSSA MAGNA RESEARCH GROUP (1976), in which the present writer is included, and also by the present author himself (SUZUKI, 1977). The problem of sedimentary basins migration was discussed in them based on the detail isopach maps surveyed.

As to the Green Tuff orogeny, FUJITA (1972) summarized and divided it into three stages, that is, the generative stage, the developing stage and the geanticlinal stage. He also pointed out that the character of the migration of each sedimentary basin during the developing stage is the most important in this orogenic movements, although such phenomena in each basin have not yet been clarified in detail until now. It has been known that thick sedimentary sequence of the developing stage are distributed in central part of the Northern Fossa Magna region. Consequently, this area is the most preferable place for making analysis of the sedimentary basins migration. Concerning the migration and geologic development of the sedimentary basins, tectonosedimentological study is most important as noticed by KRUMBEIN and SLOSS (1963). For this purpose, it is necessary to make clear the lithofacies, its lateral and vertical changes, thickness variations, paleocurrents and others. Such study plays an important role in the present discussion.

II. General Geology

The Fossa Magna region has been considered to be one of the biggest "Graben" structures in the world. In the Central Japan, it crosses the zonal arrangements of the Pre-Neogene basement rocks of the Japanese Islands, which are divided into (A) Hida Metamorphic Belt, (B) Circum-Hida Tectonic Zone, (C) Mino-Tanba Belt and so forth from north to south (Fig. 1). The western boundary of the Fossa Magna region is marked by a remarkable fault called Itoigawa-Shizuoka Tectonic Line. Its eastern boundary, which is concealed beneath younger sedimentary and volcanic covers, is called Kashiwasaki-Choshi Tectonic Line (YAMASHITA, 1970). A block of Pre-Neogene basement rocks is found in the midst of the Fossa Magna region,

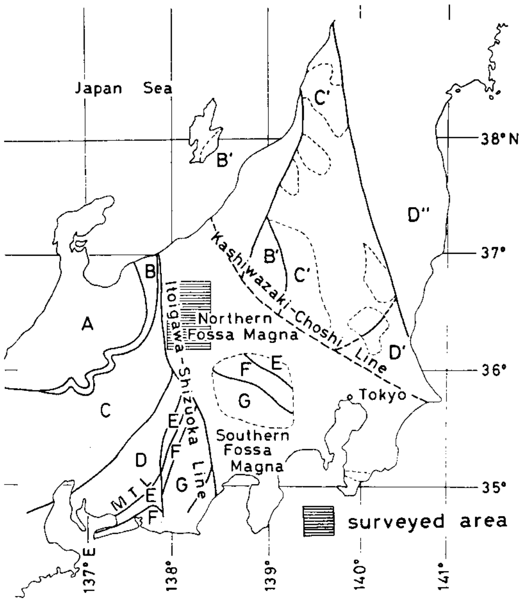

Fig. 1. Index map of the surveyed area.
Inner zone, A: Hida belt, B: Circum Hida tectonic zone, B′: Joetsu belt, C: Tanba-Mino belt, C′: Ashio belt, D: Ryoke belt, D′: Tsukuba belt, D″: Abukuma belt, Outer zone, E: Sanbagawa belt, F: Chichibu belt, G: Shimanto belt, MTL: Median tectonic line, after ISOMI and KAWADA (1968).

dividing the region into north and south provinces. This block is assigned as continuation of the Outer Zone of Southwest Japan. The birth of the Fossa Magna is safely regarded as at the beginning of Neogene, because the Cretaceous-Paleogene Shimanto Supergroup of the basement (G belt in Fig. 1) is cut and dislocated by the Itoigawa-Shizuoka Tectonic Line, whereas the lower Miocene strata are the oldest sediments which formed the Fossa Magna region. Thick and moderately folded strata of the Miocene and Pliocene are extensively distributed in the Fossa Magna region.

The Neogene sequence in the Northern Fossa Magna region is divided into three zones of NE-SW trend, i.e., Otari Upheaval Zone, Subsidence Zone, and Central Upheaval Zone (HIRABAYASHI, 1969) (Fig. 2). In the both two upheaval zones there are gently folded lower Neogene formations, and these are intruded by the so-called "Tertiary Granites" (petrographically quartz-diorite). In the Subsidence zone situated between two zones stated above, thick and moderately folded formations of middle to upper Neogene are distributed. The standard stratigraphy of the Neogene sequence in the Northern Fossa Magna region was established by

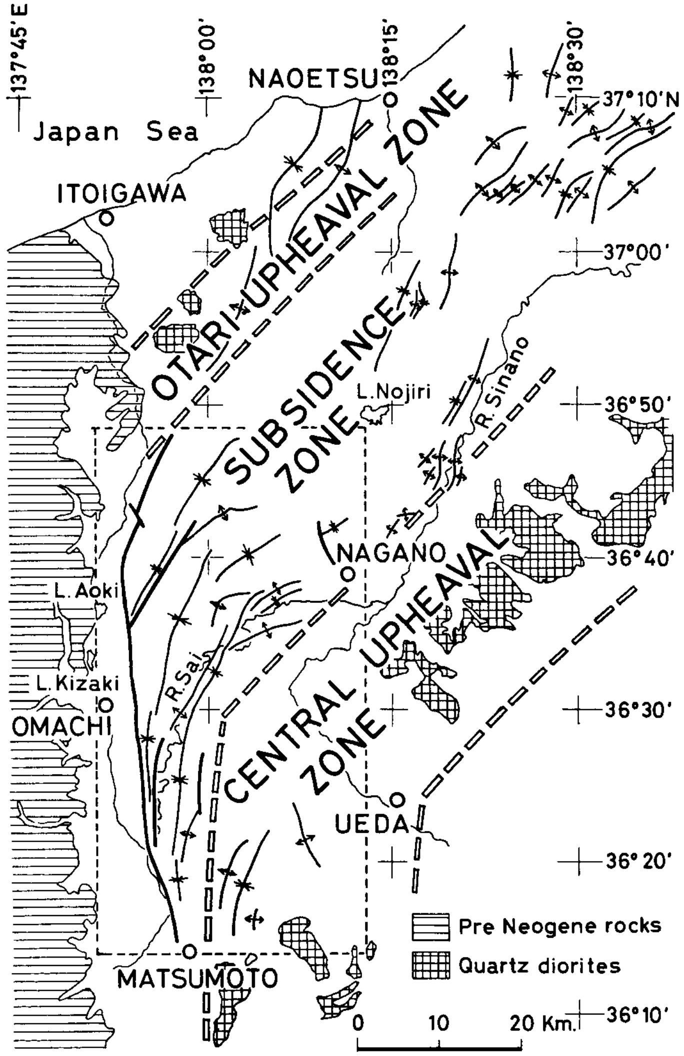

Fig. 2. Structural outline of the Northern Fossa Magna region. The studied area is shown by quadrangle.

Homma (1931) for the first time, and, based on detailed collaborative field works by many geologists, the geologic map of the Nagano Prefecture was published in 1959. Founded on these works the development of the Neogene basins in the Northern Fossa Magna region was discussed by Kobayashi (1957).

The surveyed area of the present report covers the Subsidence Zone and western part of the Central Upheaval Zone as shown in Fig. 2. The geologic map and

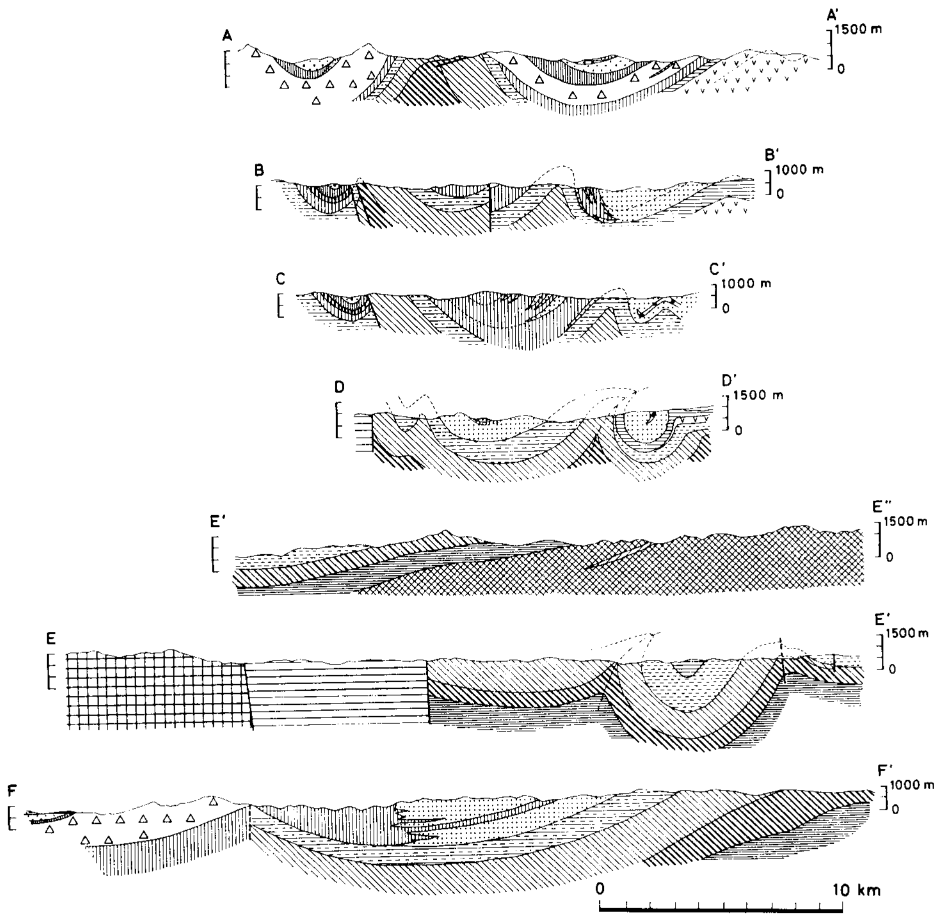

Fig. 4. Cross sections of the central part of the Northern Fossa Magna region. (for legend, see Fig. 3.)

cross sections of the area are shown in Figs. 3 and 4. The Nakayama fault of N-S trend is a remarkable fault limiting the western margin of the surveyed area. To the east of it, thick Miocene to Pliocene sequences are distributed, where several folds plunging northward are found *en echelon*. The Neogene sequence in the Northern Fossa Magna region is divided into seven formations, that is, Moriya, Uchimura, Bessho, Aoki, Ogawa, Shigarami, and Sarumaru Formations in ascending order. The former five belong to Miocene, and the latter two to the Pliocene by molluscan fossil evidence. Generally speaking, the Bessho and Aoki Formations show typical flysch facies, while the Ogawa, Shigarami and Sarumaru Formations represent molasse facies.

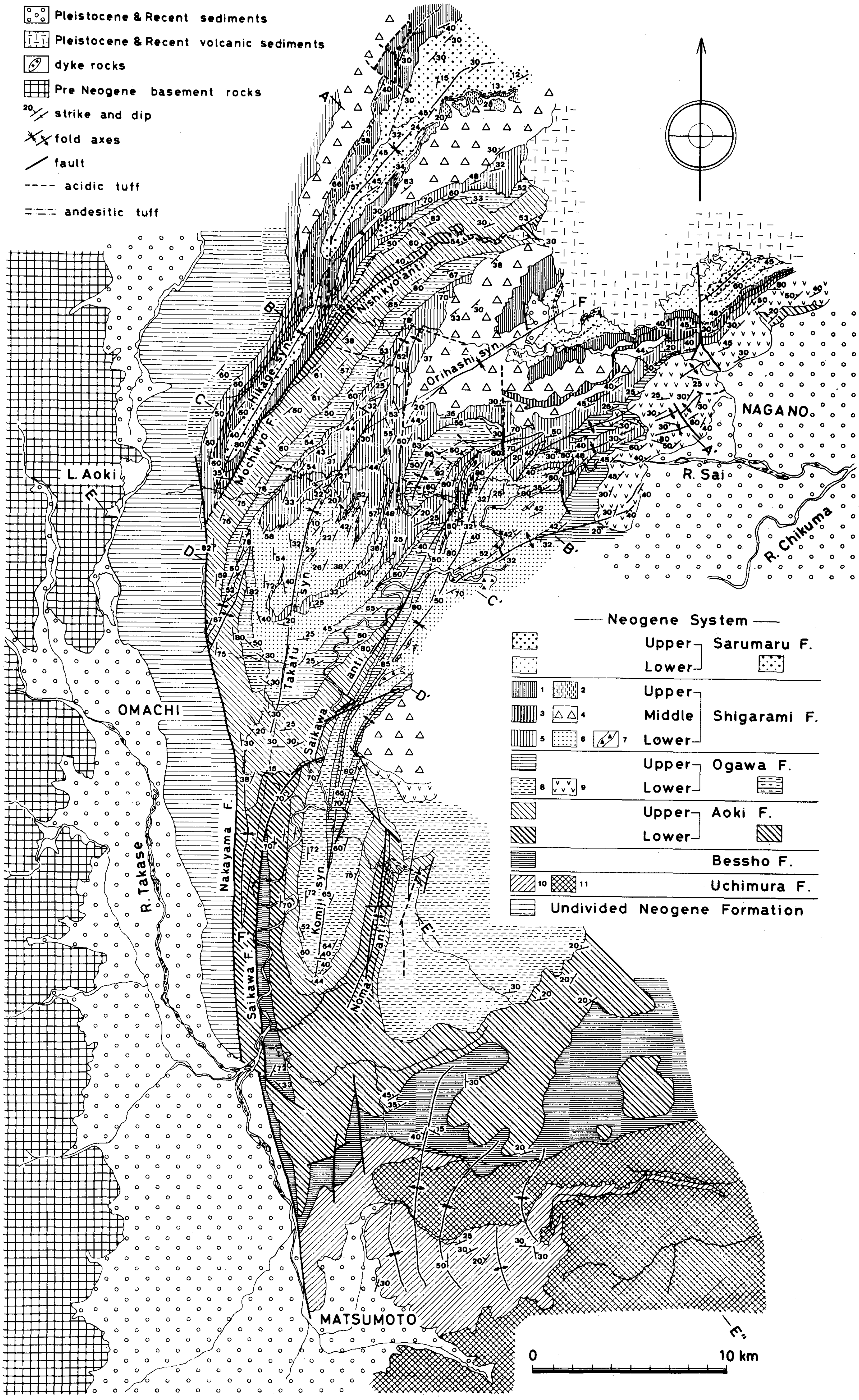

Fig. 3. Geological map of the central part of the Northern Fossa Magna region.
1; mudstone 2; sandstone and conglomerate 3; mudstone 4; volcanic rocks 5; mudstone 6; sandstone and conglomerate 7; volcanic rocks 8; clastic sediments 9; volcanic rocks 10; clastic sediments 11; volcanic rocks (after Northern Fossa Magna Research Group, 1976 and Geological Association of Nagano Prefecture, 1962).

Table 1. List of fossils from the Neogene formations in the central part of the Northern Fossa Magna region. after TANAKA and SEKI (1966), TANAKA and HIRABAYASHI(1963) and TOMIZAWA (1962).

	U	B	AOKI F.				OGAWA F.						L.SHIGARAMI F.								M.S			U.S		SA	
			4	5	6	27	12	13	35	36	37	38	14	15	16	26	31	32	33	39	1	25	40	22	23	20	21
Adulomya uchimuraensis		O																								
A. sp.	O																									
Nucula (Eunucula) akitana			O																							
Acila (Acila) divaricata	O		O																							
A. (Truncacila) pitulata	O																									
A. submirabilis			O																							
Malletia sp.	O																									
Saccella confusa kongiensis		O	O																							
S. omori			O																							
Portlandia cf. *watasei semiovata*	O			O																						
P. sp.	O																									
Yoldia sp.															O											
Arca sp.																									O		
Anadara watanabei			O																							
A. amicula													O		O	O		O	O	O	O	O		O			O
A. amicula tazawaensis			O																							
A. setoensis			O																							
A. kurodai			O																							
A. makiyamai	O		O																							
Glycymeris yamasakii									O			O						O	O	O				O	O		O
G. minochiensis														O	O				O	O							
G. k-suzukii			O																							
G. sp.	O							O														O					
Crenella formicata																											O
Volsella difficilis												O																
V. akanudaensis		O																								
Mytilus grayanus										O		O																
Chlamys cosibensis																											O
C. swiftii etchegoini																											O
C. sp.																								O	O		
Palliolum (Delectopecten) peckhami		O																								
Patinopecten yesoensis													O		O	O			O	O							
P. tryblium																O					O	O		O	O	O	O
P. yamasakii																		O	O				O			O
P. sp.		O	O																			O				
Ostrea gigas													O	O	O	O			O									
O. sp.	O		O	O																							
Calyptogena akanudaensis		O																								
Corbicula japonica									O																	
Felaniella usta			O																							
Conchocelle nipponica		O		O		O							O	O	O				O	O	O				O		
C. disjuncta																						O					
Lucinoma mochizukii										O																		
L. acutilineata		O	O	O														O									
L. otukai		O																								
Laevicardium angustum			O																			O				
Clinocardium ciliatum															O				O	O				O			
Trachycardium shiobarense			O																							
Cardium sp.				O									O											O		O		
Microcardium sp.																									O		
Callista sp.			O																							
Saxidomus purpuratus												O					O		O									
Dosinia chikuzenensis			O																							
D. ovata			O																							
D. (Kaneharaia) kaneharai			O							O																	
D. japonica												O							O					O			
D. angulosa																											O
D. sp.			O															O									
Serripes makiyama											O																	
S. sp.										O																		
Pitar sp.	O																									
Callista brevisiphonata	O																									
Venus ? sp.	O																									
Mercenaria y-iizukai	O		O																							
M. chitaniana												O							O					O			
M. yokoyamai												O	O															
M. sigaramiensis							O																	O			O
M. sp.															O				O									
Liocyma cf. *terrera*		O																								
Siratoria sp.	O							O																			
Paphia sp.		O																								
Mactra sp.													O		O				O									
Spisula polynyma alaskana													O															
S. sachaliensis											O	O							O	O	O							
S. cf. *voyi*											O																	
S. sp.																							O				
Schizothaerus keenae										O																		
Lutraria sp.																					O							
Sanguinolaria olivacea																								O			
S. sp.																									O		
Macoma (s.s) *praetexta*																							O				
M. sp.	O								O		O							O			O			O			
Siliqua ryokamiensis	O																									

	U	B	AOKI F.				OGAWA F.						L.SHIGARAMI F.								M.S			U.S		SA	
			4	5	6	27	12	13	35	36	37	38	14	15	16	26	31	32	33	39	1	25	40	22	23	20	21
Solen grandis																											O
S. sp.																										O	
Panomya sp.																									O		
Panope japonica			O								O														O	
Mya japonica											O																O	
M. donaciaeformis												O	O						O									
Pandra pulchella																				O							
Dentalium fisidentalium yokoyamai		O	O																							
Turritella chichibuensis	O																									
T. saishuensis																			O			O			O		
T. sp.																								O			
Tectura cf. *asmiiformis*			O																							
Margarites sp.		O																								
Calyptraea tokunagai			O																							
C. cf. *aokii*		O																								
Buccinum shinanoense			O							O				O						O				O		
B. koyamai		O																								
Fulgoralia sp.		O																								
Crepidula aff. *zyobanica*	O																									
Tectonatica janthostomoides	O	O	O																							
Natica severa																											O
Eunatica festiva										O																		
Cylichna cf. *kozukensis*		O																								
Neverita didyma	O		O																							
N. kiritaniana	O																									
N. fissuratus			O																							
N. sp.			O																							
Fusitoriton oregonensis												O																
F. sp.			O																							
Siphonaria sp.			O																							
Nassarius nakamurai	O		O							O																	
N. sp.	O																									
Fusinus sp.			O																							
Neptunea modesta													O						O									
Canceralia akashinensis			O																							
Copthyris grayi			O																							
Haliotis kamtschtkana koyamai																											O
Acmaea sigaramiensis																										O	
Polinices (Glossaulax) sp.														O												O	
Ancistrolepis fragilis													O						O									
Lunatia sp.																			O									
Neptunus ozawai											O																	
Cultellus asoensis			O																							
Trophonopsis solitarium														O														
T. makiyamai	O																									
Eocylichina affablis	O																									
Linthia nipponica																			O			O					
Echinarachnius naganoensis																			O									

	AOKI F.				L.S			U.S
	8	9	28	29	17	18	19	30
Cyclamina pusilla	O			O		O		O
C. japonica							O	
C. sp.	O	O						
Haplophlagmoides cf. *subglobosum*			O	O	O	O		O
H. cf. *evoluta*				O		O		O
H. compressa							O	
H. cf. *reuzi*	O							
Martinottiella bladyana tarubiensis				O	O	O		O
M. communis					O			O
Cibicides lobatulus		O						
Rotalia beccarri		O						
R. japonica					O			
Bulimina pyrula				O		O		
Uvigerina hootsi							O	
U. excellence							O	
U. akitaensis					O	O		
U. sp.				O				O
Cassidulina japonica						O		
C. yabei						O		O
C. cf. *brydyi*					O			
C. kashiwazakiensis					O			
C. subglobosa					O			
Nonion pompiloides				O		O		O
Anomalina sp.							O	
Nodogenerina depidula							O	
Elphidium hughesi framinesum					O			
E. subgranulosum					O			
Globigerina inflata							O	
G. sp.				O	O			O

III. Stratigraphy and Geologic Structure

1. Stratigraphy

The geology of the studied area will be described briefly in the following based on the works of the NORTHERN FOSSA MAGNA RESEARCH GROUP (1976) and SUZUKI (1977). The Neogene sequence in the Northern Fossa Magna region is divided into seven formations as mentioned above, among which the lowermost one (Moriya Formation) is not found in the surveyed area. These are simplified in Fig. 5. There have been discovered not a few fossils from the Neogene sequence, but the precise examination and faunal analysis have scarcely been done. The fossils, of which occurrences were reported, are collectively listed up in Table 1. Many molluscan fossils and less amount of benthonic foraminifers are found in the Neogene sequence, while planktonic forminifers are rare. Plant fossils were reported from the Ogawa Formation in the eastern part of the surveyed area.

Uchimura Formation

The Uchimura Formation is distributed in the southernmost part. It is composed mainly of basic to acidic pyroclastics intercalated with terrigenous layers. Due to hydrothermal alteration these pyroclastics have greenish color, and have been customarily called the "Green Tuff" by Japanese geologists. The UCHIMURA RESEARCH GROUP (1953) divided the Formation into four Members; the Takeshi, Ichinose, Kokuzo and Fujisan in ascending order. It is well known that the Formation consists of two volcanic cycles, each of which is composed of basic rocks in the lower and acidic ones in the upper. The lower cycle contains basic volcanics of Takeshi Member in the lower part, and acidic ones of the Ichinose Member in the upper part. The upper cycle contains the basic Kokuzo and acidic Fujisan Members. The total thickness of the Formation attains to 4,000 m. The Takeshi and Ichinose Members change their lithofacies westward, and interfinger with terrigenous sequences which consist mainly of alternations of sandstone and mudstone. These were collectively called the Hongo Member by the UCHIMURA RESEARCH GROUP (1953), and is further subdivided into four units by TANAKA (1963) as shown in Fig. 5. It attains to 1,200 m in total thickness.

Bessho Formation

The Bessho Formation is characterized by massive and monotonous mudstones. Several limestone lenses are found in the lower part of the Formation and glauconite seams are also interbedded in the same part. Mudstone-rich alternations, granule conglomerates and pebbly mudstones are interbedded in mudstones in the upper part. The Formation attains to 1,350 m in thickness. Slump folds are sometimes found.

	Stratigraphic division			Hikage Komiji Takafu Matsumoto	Maximum thickness (m)	Lithology	
Pliocene	Sarumaru F.	Upper M.	Sa 2		550	conglomerate and sandstone	
		Lower M.	Sa 1		600	sandstone, sandy flysch and mudstone	
	Shigarami F.	Upper M.	Sh 4		1400	mudstone, muddy flysch and sandstone	
		Middle M.	Sh 3		1600	andesitic tuff, tuff breccia, lava, and mudstone	
		Lower M.	Sh 2		800	conglomerate, sandstone and mudstone	
			Sh 1		1000		
Miocene	Ogawa F.	Upper M.	Og 4		410	mudstone and muddy alternation	
			Og 3		620	sandstone, conglomerate and mudstone	
		Lower M.	Og 2		660	conglomerate, sandstone, mudstone, lignite beds, and acidic tuff and lava	
			Og 1		440		
	Aoki F.	Upper M.	A 4		780	mudstone and muddy alternation	
			A 3		780	muddy flysch, sandy flysch, bedded sandstone, thick massive sandstone and conglomerate	
			A 2		800	muddy flysch, sandy flysch and thick massive sandstone	
		Lower M.	A 1		600	mudstone and muddy flysch	
	Bessho F.				1350	mudstone and muddy alternation	
	Uchimura F.	Fujisan M.			4000	andesitic and rhyolitic tuff breccia and lava	
		Kokuzo M.				basaltic lava	
		Hongo M.	H 4	Ichinose M.	1200	conglomerate	rhyolitic tuff and lava
			H 3			muddy alternation and mudstone	
			H 2			sandy alternation and sandstone	basaltic tuff and lava
			H 1	Takeshi M.		mudstone and muddy alternation	

Fig. 5. Schematic stratigraphy and lithology of the Neogene formations in the Northern Fossa Magna region. (after NORTHERN FOSSA MAGNA RESEARCH GROUP, 1976, UCHIMURA RESEARCH GROUP, 1953, and TANAKA, 1963).

Aoki Formation

The Aoki Formation is widely distributed in the surveyed area. The Formation changes in thickness and lithofacies from the Subsidence Zone to the Central Upheaval Zone. In the former zone it is 2,900 m in total thickness, and subdivided into four Members, A-1, A-2, A-3 and A-4. Members A-1 and A-4 are composed of mudstones and muddly flysch, while Members A-2 and A-3 are composed mainly of sandy flysch and thick-bedded sandstones. Conglomerates are sometimes intercalated in Member A-3. In the Central Upheaval Zone it is 1,000 m thick consisting predominantly of monotonous mudstone. Excepting the lowermost conglomerate Member, about 200 m thick, further subdivision is beyond the reach. It should be mentioned that the Formation in the Subsidence Zone has typical flysch-type sedimentary features such as sole markings.

Ogawa Formation

The Ogawa Formation is composed mainly of sandstones, conglomerates and mudstones, and is subdivided into four Members, Og-1, Og-2, Og-3 and Og-4. Its total thickness is 2,100 m. At the top of Member Og-2 there are intercalated acidic pyroclastics which are traceable as a marker bed. Remarkable facies-changes are found in Members Og-1, Og-2 and Og-3. These Members are rich in sandstones and conglomerates in the southern part, but predominant in mudstones and muddy flysch in the northern part. Member Og-4 consisting of mudstones and muddy flysch is distributed only in the northern part. Along the boundary between the Subsidence Zone and Central Upheaval Zone in the northern part there exist a thick pile of acidic volcanic rocks (mainly of rhyolite and partly of dacite). These can be safely correlated to the Og-1 and Og-2 in the Subsidence Zone. It is to be mentioned here that a marginal unconformity is observed at the top of Member Og-2 in the northeastern part of the surveyed area. The lithologic characters indicate that molasse sedimentation started during deposition of the Ogawa Formation.

Shigarami Formation

The Shigarami Formation is distributed mainly in the northern part and is divided into four Members, Sh-1, Sh-2, Sh-3 and Sh-4. Members Sh-1 and Sh-2 are composed mainly of sandstones and conglomerates. Member Sh-3 is composed of mudstones intercalated with many andesite lavas and pyroclastics, while Member Sh-4 is composed mainly of mudstones. As in the case of the Ogawa Formation the facies-change is remarkable. Coarser clastics predominate much more in the southern part than in the northern part. Partial unconformity due to tectonic movement is observed at the boundary between Members Sh-2 and Sh-3 in the northwestern half of its distribution.

Sarumaru Formation

The Sarumaru Formation is distributed in the northernmost part of the surveyed area. It is divided into lower (Sa-1) and upper (Sa-2) Members. The former is composed of sandstones and mudstones, while the latter is composed of conglomerates and sandstones. A layer of welded tuff is intercalated in the upper part of Member Sa-2.

2. Geologic Structure

As previously mentioned, the surveyed area is constituted by the Subsidence Zone and the western part of the Central Upheaval Zone, and is cut along its western boundary by the Nakayama fault which is one of the most conspicuous faults in the Northern Fossa Magna region. These structures are parallel to the trend of the inner arc of Northeast Japan. In the Central Upheaval Zone there are gently folded lower Neogene formations, whereas moderately folded middle to upper Neogene formations are in the Subsidence Zone. Generally speaking, the former show an anticlinolium, and the latter show a synclinolium. In the Subsidence Zone synclinal structures are developed compared with anticlinal structures which are often cut by longitudinal faults.

a) Faults

As clearly shown in the geologic map (Fig. 3), Nakayama, Mochikyo and Saikawa faults are the major faults in the surveyed area cutting the Neogene sequences. Roughly speaking, Saikawa, Mochikyo and other second-order faults have NE-SW or NNE-SSW directions which are roughly parallel to the trend of fold axes. Not only such large faults but also several minor faults run parallel to the fold axes. This fact suggests an intimate genetical relation between these faults and folds. On the contrary, the Nakayama fault running in N-S trend cuts obliquely the Hikage syncline. In addition, several transverse faults can be observed.

Nakayama fault

To the east of the Nakayama fault there are distributed thick Neogene strata ranging from the lower Miocene to upper Pliocene, whereas only Pliocene and Pleistocene sediments are distributed in the area of the opposite site. Fault scarps are well developed along the Nakayama fault. The shear zone is about 20 m in width.

Saikawa fault

The Saikawa fault is located in the central part of the area, running in N-S trend. The shear zone is observed along the fault in the southern part. It cuts the Saikawa anticline and is cut in turn diagonally by several transverse faults that have NE-SW direction. As will be mentioned later, the Saikawa fault coincides with the Saikawa anticlinal plane in the central part. Judging from structural and stratigraphical evidence it is apparent that the eastern block upheaved against the western one and that the amount of dislocation is larger in the southern part of the fault than in the northern part.

Mochikyo fault

The Mochikyo fault is located in the northern part of the area, running in NE-SW trend. It is cut obliquely by the Nakayama fault at its southern end, while it cuts the Nishikyo anticline in the northern part. This fault can be traced in the topography throughout its distirbution. The fault plane dips steeply to the east. The shear zone is about 10 m in width, usually accompanied with fault breccia and/ or fault clay. Stratigraphically it is estimated that the eastern block was upheaved against the western one and that dislocation is larger in the southern part of the fault.

Other faults

The fault cutting the Nishikyo anticline is called Nishikyo fault. It is located in the northern part of the surveyed area, running in NE-SW direction. As will be mentioned later, in the central part of the Nishikyo anticline the axis is represented by Nishikyo fault. Judging from structural and stratigraphical evidences it is apparent that the northwestern block of the fault was upheaved against the southeastern one. The fault plane dips to the west at about 40 degrees.

There are observed several faults of NW-SE, NE-SW and N-S trends cutting diagonally or transversely the main folds and longitudinal faults in the subsidence Zone. These are traceable for less than several kilometers and their dislocations are estimated at approximately several hundred meters.

b) Folds

As clearly shown in the geologic map, cross sections and strike-line map of Figs. 3, 4 and 6, the Neogene formations in the surveyed area are moderately folded, and there exist first-order and second-order folds. In the main part of the Subsidence zone the first-order folds are of asymmetric type and are arranged *en echelon* in N-S direction. These folds are plunging northward, and in some of which axes can be traceable for about 25 km in length. These are represented by Komiji, Takafu and Hikage synclines and Noma, Saikawa and Nishikyo anticlines. Near anticlinal axes strata stand steeply and are sometimes overturned, and minor faults are often observed along their axial parts. On the contrary, strata near and around synclinal axes have gentle dip as usual. At the marginal area of the Subsidence Zone gentle

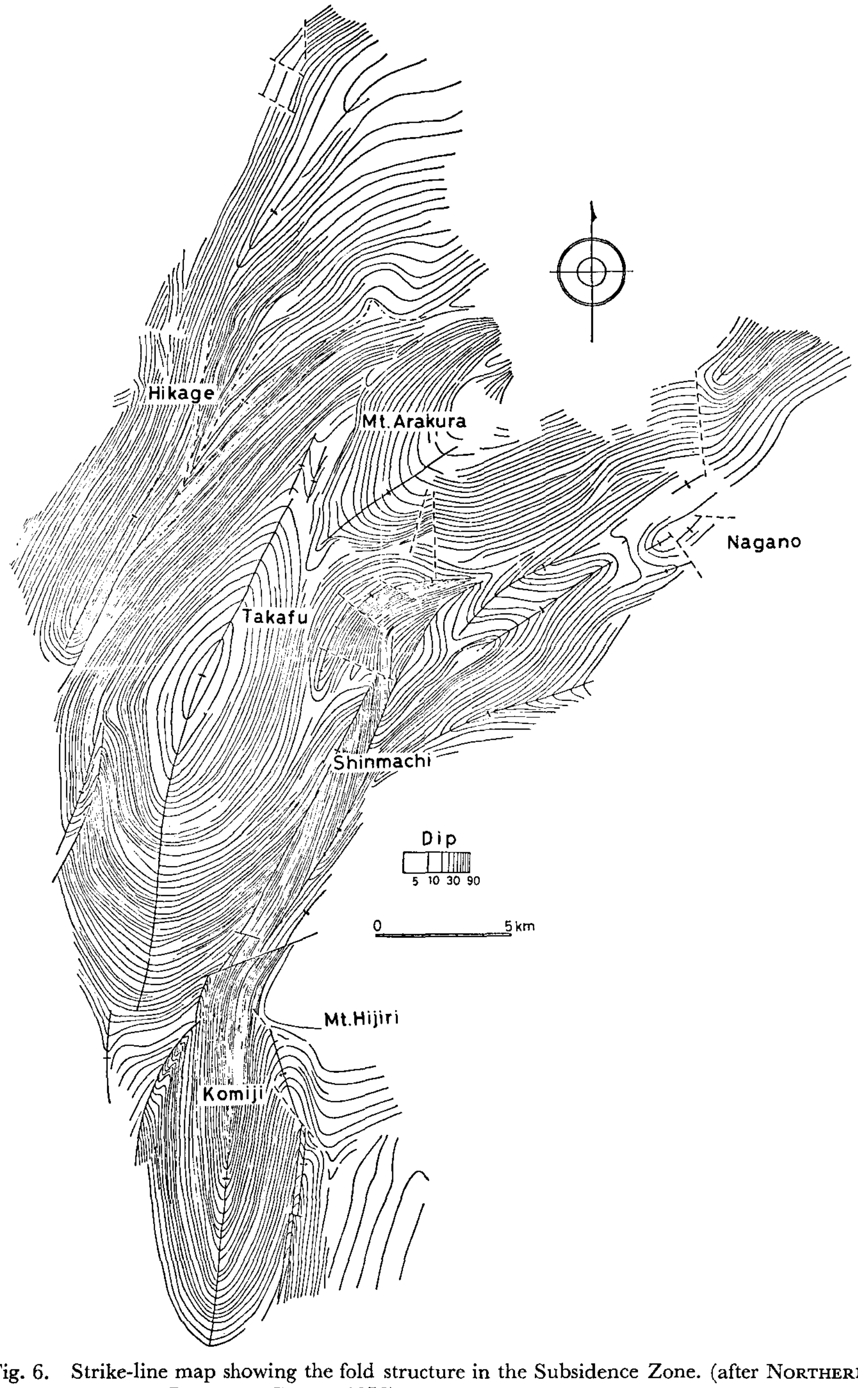

Fig. 6. Strike-line map showing the fold structure in the Subsidence Zone. (after NORTHERN FOSSA MAGNA RESEARCH GROUP, 1976).

folds of second-order are found and axes of which plunging southwesward are traceable for less than 10 km in length. These are represented by Jinda and Odagiri anticlines, Naniai and Orihashi synclines and others.

Komiji syncline

The Komiji syncline is located in southern part of the surveyed area. It runs in N-S trend, changing gradually in NE-SW trend northeastward. The axial plane is nearly vertical in the south, whereas it dips steeply to the west in the north. The Komiji syncline is symmetrical in the south with 60 degrees dip-angle. On the contrary the feature of this syncline changes gradually to asymmetry in the northern area where the western wing dips steeply or sometimes overturned compared with the moderate dip (40–50 degrees) of the eastern wing.

Takafu syncline

The Takafu syncline is located in the central part of the surveyed area. It runs in N-S trend, changing in NE-SW trend northward. The axial plane is nearly vertical and both wings have dip with about 40–50 degrees to the opposite sides.

Hikage syncline

The Hikage syncline is located in the northeastern part of the area, running in NE-SW trend. It is symmetrical with a vertical axial plane. Both wings dip at about 60 degrees in the south, whereas they become more gently northward up to about 30 degrees.

Noma anticline

The Noma anticline is located in the southern part of the surveyed area. The structure is variable for place to place. In the northern part, the trend is NE-SW and the axial plane dips moderately to the southeast. The western wing has steep or sometimes overturned structure compared with the gently-dip (20–30 degrees) eastern wing. The Noma anticline has NW-SE trend in the central part, and it changes gradually to N-S trend to the south. In the central and southern parts both wings dip at 40–60 degrees to the opposite sides.

Saikawa anticline

The Saikawa anticline is located in the central part of the area, running in NNE-SSW trend. It can be divided into the southern, central and northern parts. In the northern part it is asymmetrical. Compared with the moderate-dip (40–50 degrees) of the western wing the eastern wing has steep or sometimes overturned structure. The axial plane is represented by a fault, called the Saikawa fault. The fault plane dips steeply to the west. The strata in the west dip at about

30 degrees westward, while those in the opposite side dip steeply eastward. In the southern part the western wing of the anticline dips at about 30 degrees and structure of the eastern wing is steep or overtured. It is apparent that the axial plane dips more gently in the southern part than in the northern part as shown in the cross sections of Fig. 4.

Nishikyo anticline

The Nishikyo anticline is located in the northern part of the area, running in NE-SW trend. The central part of the anticline is cut by a thrust fault dipping moderately to the west. The southern end of the anticline is also cut by the Mochikyo fault. Compared with the moderate-dip (40–50 degrees) of the western wing the dip of the eastern wing is more steep. The axial plane dips steeply to the west.

IV. Descriptive Data for Basin Analysis

Generally speaking, it is not so easy to find out time-stratigraphic units ultimately in the Neogene sequence in the Northern Fossa Magna region. The reason, is first, due to the remarkable facies-change in the Neogene basins, and secondly, gradual migration of depocenters. Unfortunately, there are neither useful key beds like continuous volcanic tuff layers which are traceable throughout the surveyed area nor time-markers like planktonic foraminifers available for biostratigraphic zonation. However, the continuity of sandstone or conglomerate bed, tuff layer and key succession can be used as marker bed or beds at least as far as the traceable. Based on geological mapping by tracing these marker beds in detail, it is likely that all Formation and Member boundaries, especially in the case of Shigarami Formation, are roughly coincident with representation of time planes. Therefore, these lithostratigraphic units obtained here are regarded as time parallel in analysis and discussion of the facies and thickness changes.

As stressed by POTTER and PETTIJOHN (1963), plaeocurrent analysis is useful tool for basin reconstruction. But hitherto, very few works have been done in the Northern Fossa Magna region. In addition to vertical and spacial facies and thickness analysis, paleocurrent analysis by means of sole markings and cross-lamination or bedding was taken as an important role in the present study. Molluscan fossils and benthonic foraminifers are also taken in consideration for environmental analysis.

At first, basic data used for basin analysis will be described in each formation and/or member as follows.

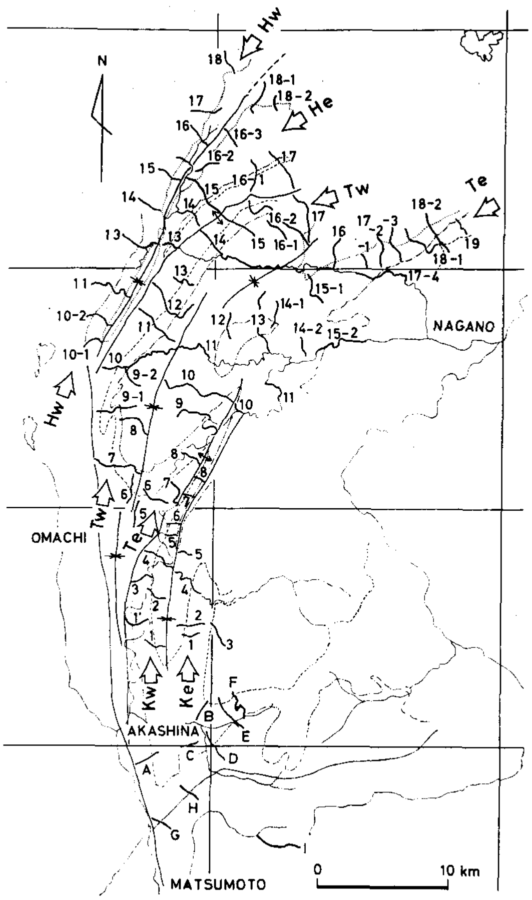

Fig. 7a. Index map showing the routes of columnar sections.

A. Uchimura Formation

Distribution and thickness: The Uchimura Formation is distributed extensively in the Central Upheaval Zone. The Formation consists mainly of volcanic rock sequences of Ichinose, Kokuzo, Takeshi and Fujisan Members. It is apparent that the Uchimura Formation has a maximum thickness in the neighbourhood of Mt. Kokuzo (UCHIMURA RESEARCH GROUP, 1953), attaining to more than 3,000 m. As the maximum thickness of the Formation is estimated to be approximately 4,000 m, the depocenter of the Uchimura Formation might be situated at that area. The Uchimura Formation in the western marginal part is composed mainly of muddy alternations, attaining to 1,200 m in thickness. It remains to be solved whether the Uchimura Formation lies under the younger sediments in the Subsidence Zone or

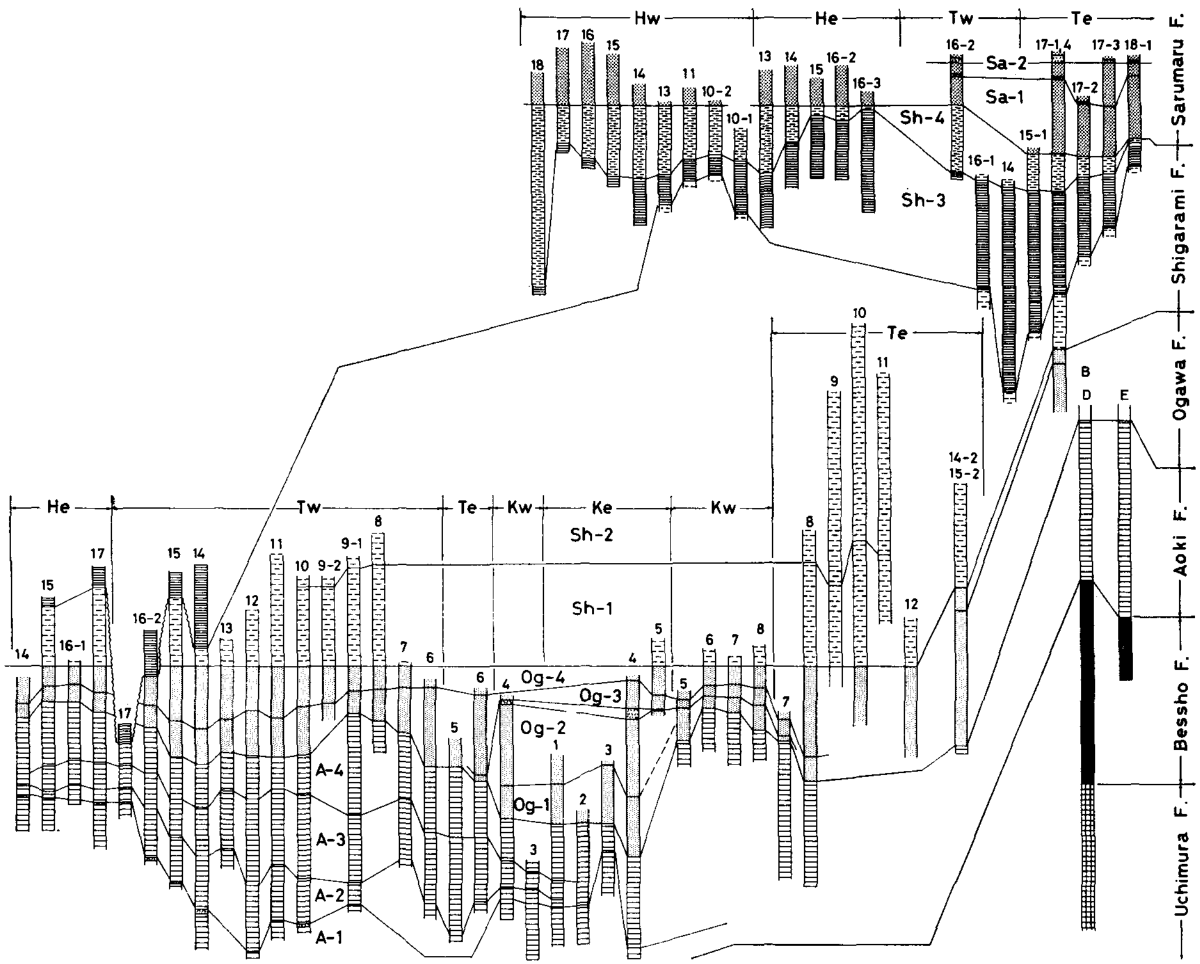

Fig. 7b. Columnar sections of the Neogene formations.
Adapted from NORTHERN FOSSA MAGNA RESEARCH GROUP (1976), SHIBATA et al. (1976), YANO and MURAYAMA (1976), TAKEUCHI and SAKAMOTO (1976) and the present writer (SUZUKI, 1976)

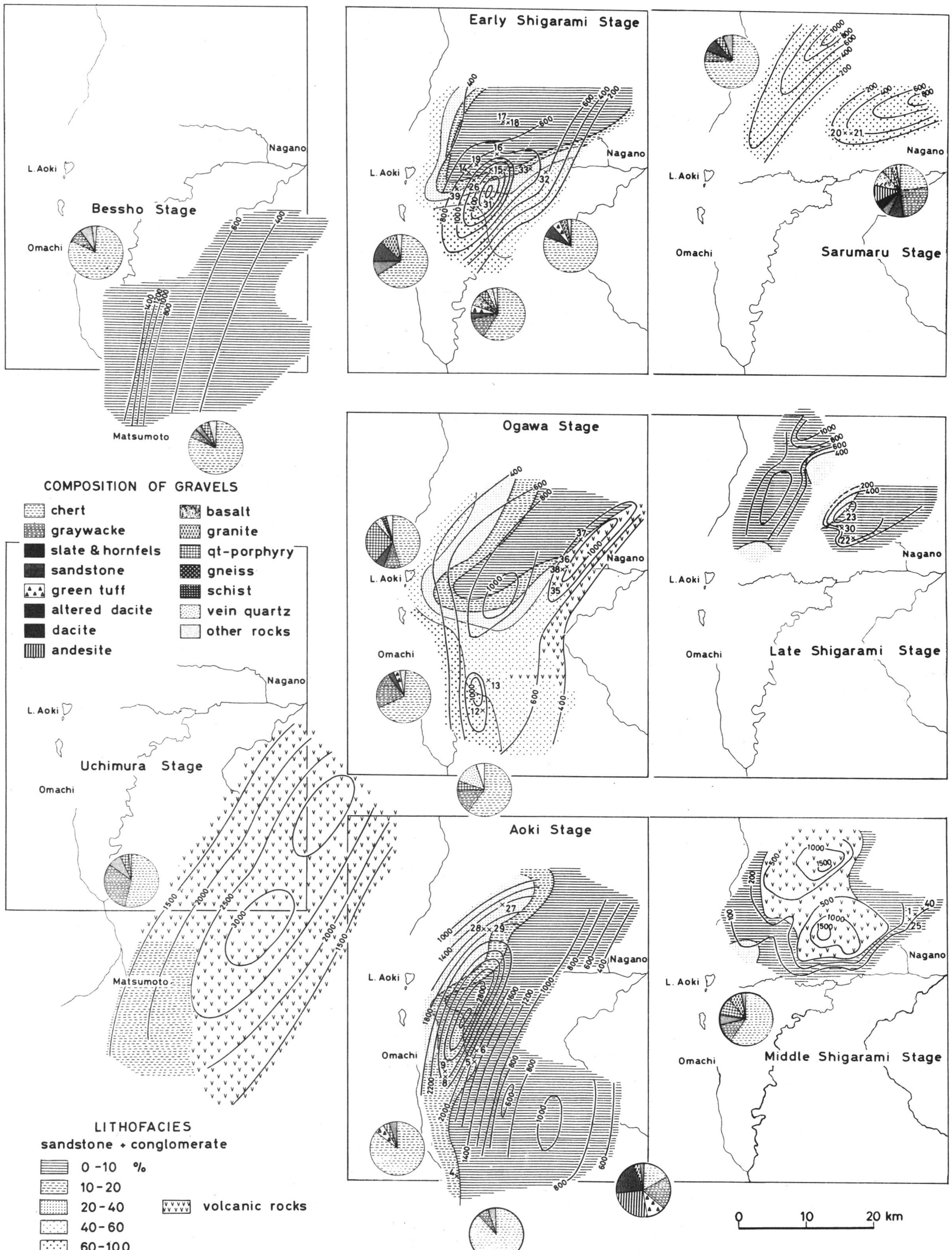

Fig. 8. Lithofacies, thickness and composition of gravels of each stage.
The number of cross symbol show fossil locality of Table 1. Composition of gravels is cited from HIRABAYASHI (1970). Isopach lines of the Middle and Upper Shigarami and Sarumaru Formations are cited from YANO (1976 MS).

not, but it should be noted that the seismological data suggest the Uchimura Formation is missing there. The depth of the basement rock (the layer of 6 km/sec.) in the Subsidence Zone is calculated at about 4 km under the surface (ASANO et al., 1969), and folded Neogene sequence (younger than the Uchimura Formation) attains to 4,000 m in total thickness, then there remained no room for the accumulation of the Uchimura Formation in the Subsidence Zone. The assumption stated above is also supported by the fact that the Uchimura Formation decreases its thickness northwestward in the Central Upheaval Zone.

Lithofacies: The Uchimura Formation is composed mainly of pyroclastic rocks, and two volcanic cycles are found in the sequence (UCHIMURA RESEARCH GROUP, 1953). The Hongo Member consisting of terrigenous sediments is developed in the western part of the Central Upheaval Zone, and makes interfinger with pyroclastic rocks in the northeast area. The Hongo Member is divided into four submembers of mudstone (H-1), flysch-like alternations of sandstone and mudstone (H-2 and H-3), and sandstone and conglomerate (H-4). The submember H-3 consists mainly of mudstones in the western part, while sandstone layers are frequently intercalated in it in the eastern part. In flysch-like alternations (in beds of 10 cm to 2 m in thickness) sole markings are frequently found. Parallel lamination is dominant but graded bedding is poorly developed in them. Pebble- to cobble-conglomerates are frequently intercalated in the submember H-4. These are constituted by well-sorted, rounded gravels of chert and subordinate greywacke and quartz porphyry. The largest gravel attains to 20 cm in diameter.

Paleocurrents: Sole markings are found in flysch-like beds in the Hongo Member in the southern part of the surveyed area. These are from SSW to NNE, indicating longitudinal currents in the Uchimura basin. In addition, there exist several westward lateral currents in the submember H-2 in the east of Matsumoto City.

Fossils: Molluscan fossils such as *Acila (Acila) divaricata, Glycymeris* sp., *Callista brevisiphonata, Nassarirus nakamurai* are found in the Uchimura Formation (TANAKA and SEKI, 1966). Judging from the bathymetry of molluscan fossils by OYAMA (in MINATO, 1953), most of them are assigned to be neritic biotope.

B. Bessho Formation

Distribution and thickness: The Bessho Formation is widely distributed in the Central Upheaval Zone, but, in the Subsidence Zone, its distribution is restricted only in the southern part (the area to the north of Matsumoto City). The thickness is about 350 m in the main part of the Central Upheaval Zone, thickening toward the western boundary up to 650 m. Moreover, it rapidly increases the thickness to the Subsidence Zone, attaining to 1,350 m in maximum (GEOLOGICAL ASSOCIATION of NAGANO PREFECTURE, 1962). It is a remarkable fact that the thick-

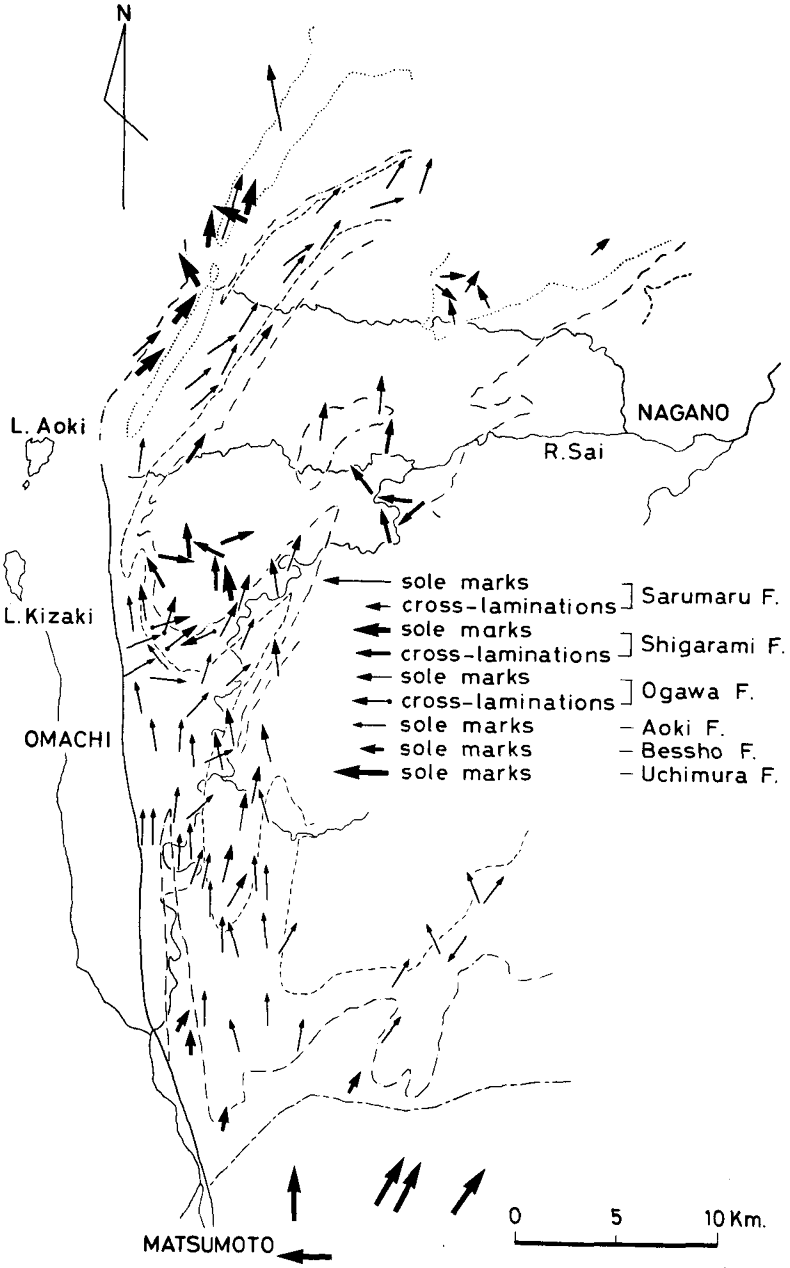

Fig. 9a. Paleocurrent direction of each Formation.

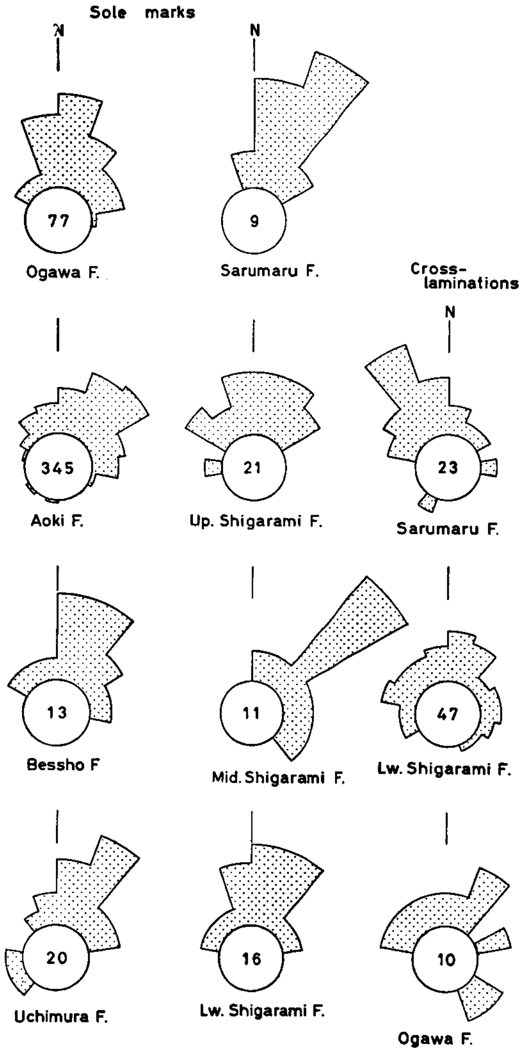

Fig. 9b. Rose diagram showing the paleocurrent direction of each Formation.

ness of the Bessho Formation changes rapidly near the boundary between the Central Upheaval Zone and Subsidence Zone, running in NE-SW trend.

Lithofacies: The Formation is composed mainly of massive, black mudstone. In the basal part of the Formation, lenticular limestones are intercalated, and muddy alternations are intercalated in the uppermost part. Sandstone layers are in beds of 10 to 30 cm thick and internal sedimentary structures and sole markings are sometimes found. The Bessho Formation is characterized by monotonous mudstone facies, especially in the eastern part. Sandy intercalations are sometimes developed in the western part.

Paleocurrents: As usual in muddy facies, sole markings are poorly found in the Formation. Flute casts are sometimes observed in muddy alternations in the upper part. These are found in the Subsidence Zone but not discovered in the Central Upheaval Zone. Longitudinal currents from SW to NE are dominant but no lateral ones are observed.

Fossils: Molluscs and foraminifers are reported in the Bessho Formation by TANAKA and SEKI (1966) and MASATANI and ICHIMURA (1970), respectively. Judging from the bathymetry of molluscan fossils by OYAMA (in MINATO, 1953), neritic species are dominant, but neritic to upperbathyal ones such as *Volsella akanudanesis, Lucinoma acutilineata, Buccinum koyamai* are reported from the Bessho Formation (TANAKA and SEKI, 1966). Foraminifers such as *Uvigerina* sp., *Epistominella* sp., *Cassidulina* sp. are found in the eastern part, but not discovered in the western part. These facts suggest that the western part was more deeply situated in environment than the eastern part as insisted by MASATANI and ICHIMURA (1970).

C. Aoki Formation

Distribution and thickness: The Aoki Formation is distributed widely in the surveyed area. The Formation is about 1,000 m thick in the Central Upheaval Zone and 2,000–3,000 m in the Subsidence Zone. In the latter zone the depocenter is located nearly along the N-S axis of the Takafu syncline.

Lithofacies: Flysch facies are developed in the Formation, especially in the Subsidence Zone. These consist of rhythmic alternations of sandstone and mudstone, occasionally accompanied with conglomerates. The Formation in the Subsidence Zone is composed of four Members, namely mudstones and muddy flysch (Member A-1), mudstones, sandy flysch and thick-bedded sandstones with conglomerates (Member A-2 and A-3), and mudstones and muddy flysch (Member A-4). The conglomerates are constituted by rounded pebbles and cobbles. The clasts are mainly chert, greywacke and the so-called green tuff. Boulders of acidic volcanic rocks similar to the late Mesozoic igneous rocks were contained in the Member A-3. In the Central Upheaval Zone the Formation is composed mainly of muddy alternations and conglomerates are frequently intercalated in the basal part. In the Subsidence Zone lithofacies becomes coarser to the northwest, where thick-bedded sandstones are frequently intercalated. On the contrary, mudstones and muddy flysch are dominant in the southern part of the Subsidence Zone (east of the Takafu syncline). Lateral change of the facies was described precisely by SUZUKI (1977).

Paleocurrents: Sole markings are well developed in the Aoki Formation. Most of the sole markings are flute casts. Crescent casts, groove casts, bounce casts, and prod casts are also found. Longitudinal currents from south to north or from southwest to northeast are dominant not only in the Subsidence Zone but also in the Central Upheaval Zone. Lateral currents from west to east are often observed in Member A-2 and A-3 in the western wing of the Takafu syncline in the Subsidence Zone. Slump structures are often observed along the axial part of the Nishikyo and Saikawa anticlines in the Subsidence Zone. These have an axis with roughly trending in NNE-SSW direction, concordantly to the geologic structures of the area. The paleoslope of the basin may have been perpendicular to this direction, although the feature of its face remains unknown.

Fossils: Judging from the bathymetry of molluscan fossils by OYAMA (in MINATO, 1953), neritic molluscan fossils such as *Anadara amicula, Trachycardium shiobarense, Laevicardium angustum, Dosinia kaneharai, Panope japonica,* are found in the Formation (TANAKA and SEKI, 1966). These indicate a shallower environment than in the Bessho Formation (TANAKA, 1973). MASATANI and ICHIMURA (1970) reported the occurence of foraminifers in the southern part of the basin, and proposed two zonules, that is, *Dorothia* sp.- *Haplophragmoides* sp. Zonule in the lower and *Cribrostomoides* sp.- *Trochammina* sp. Zonule in the upper. Moreover a shallowing upward environment during the Aoki stage was inferred by them.

D. Ogawa Formation

Distribution and thickness: The Ogawa Formation is distributed in the Central Upheaval Zone and Subsidence Zone. Unlike the Aoki stage, the depocenter is inferred to have migrated intermittently during the deposition. It is located in the eastern wing of the Komiji syncline at Og-1 substage, in the western wing at Og-2 substage, while it is located in the eastern and western wings of the Takafu syncline at Og-3 and Og-4 substage, respectively. These are shown in Fig. 12.

Lithofacies: The Ogawa Formation is represented mainly by molasse facies. The lithofacies is very variable throughout the surveyed area (Fig. 10). Sandstones and conglomerates are dominant in the southern part, but mudstones and muddy alternations are superior to in the northern part. The details of facies-change is referred to the explanation by SUZUKI (1977). In the southern part, Cross-beddings of tabular and trough type are frequently found in conglomerates and sandstones (Plate 2). Several cyclothems accompanied with lignite beds are developed there. The conglomerates yield abundant chert gravels, which were transported obviously from the surrounding basement rocks of the Paleozoic or early Mesozoic. It is characteristic that abundant gravels of acidic volcanic rocks and quartz diorite are found in conglomerates in the eastern part of the Central Upheaval Zone. The volcanics were originated obviously from the Uchimura Formation to the southeast, and the quartz diorites were as same rocks as intruded into the Uchimura Forma-

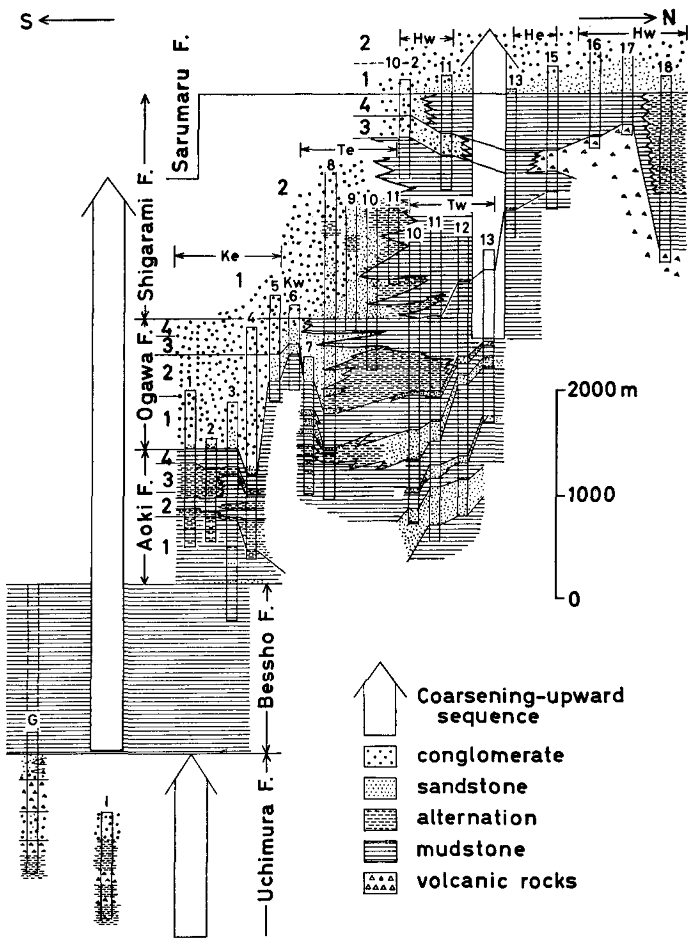

Fig. 10. Schematic figure showing lateral and vertical lithofacies changes of Neogene formations.

tion.

Paleocurrents: Sole markings, mostly flute casts, are found in alternations of sandstone and mudstone, but generally poorly developed. Sometimes these are also detected in thick-bedded sandstones in the lower part. In the lower part of the Ogawa Formation, sole markings show longitudinal currents from south to north. In the upper part, general currents are from SW to NE, but some local deviations are seen in the paleocurrent direction. These are northward currents in the Takafu syncline and northeastward currents in the western wing of the Hikage syncline, both of which are roughly parallel to the trend of local geologic structures. The directions deduced from cross-bedding in the upper part are variable, but dominant currents were northeastward in the western wing of the Takafu syncline and northwestward in the eastern wing. Slump structures are sometimes observed, especially in muddy alternations in the upper part of the Formation which is distributed in the area of Nishikyo anticline and Hikage syncline. Slump axes are roughly in N-S direction, but their faces were not able to be ascertained.

Fossils: In addition to molluscan fossils (Table 1), abundant plant fossils are found in the southeastern part of the area. Molluscan-fossil localities shown in Table 1 mostly occupy the marginal part of the basin. Judging from the bathymetry of molluscan fossils by OYAMA (in MINATO, 1953), most of fossils show a neritic environment. On the contrary, in the central and northern parts of the basin the presence of foraminiferal fauna characterized by *Martinottiella communis* and *Trochammina* sp. (MASATANI and ICHIMURA, 1970) suggests much deeper enviornment than that of marginal part.

E. Lower Shigarami Formation

Distribution and thickness: The Lower Shigarami Formation is distributed mainly in the northern part of the Subsidence Zone. The thickness changes considerably from about 100 m to as much as 1,800 m. The depocenter of the Lower Shigarami Formation exists in the eastern wing of the Takafu syncline. The thickness variation along the transverse direction is greater than that along the longitudinal one.

Lithofacies: The Formation is composed mainly of sandstones, conglomerates, mudstones and thin intercalations of muddy alternation. Facies change is remarkable, and coarse clastic rocks are well developed in the northern part of its distribution, where conglomerates are abundantly intercalated. The variation is well shown in columnar sections of Te 8 to Tw 12 in Fig. 10. Generally the conglomerates in Member Sh-2 are coarser than those in Member Sh-1. Gravels in the conglomerates are chert, greywacke, slate, porphyrite, the so-called green tuff, etc. The gravels of the so-called green tuff are obviously referred to have been transported from the Uchimura Formation. Sedimentary structures in sandstones, conglomerates and mudstones were already described in detail by SUZUKI (1977).

Paleocurrents: Most of sole markings are represented by flute casts, but very poorly developed. These are generally discovered in the alternations in the central area. Paleocurrents inferred from sole markings indicate the longitudinal trend dominantly from SSW to NNE. On the contrary, paleocurrents deduced from cross-beddings are variable as shown in Fig. 9 b. However a precise examination led to the conclusion that the dominant direction was northeastward in the western wing of the Takafu syncline, and northwestward in the eastern wing as in the case of the Ogawa Formation.

Fossils: Molluscan fossils are abundant in the boundary area between the southern part (dominant in sandstone and conglomerate) and the northern part (dominant in mudstone). These are rich in neritic species, and intertidal or subtidal molluscs such as *Ostrea gigas* etc. are also contained in considerable degree. On the other hand, in the central and northern parts of the area, where muddy facies is predominant, foraminifers such as *Epistominella pulchella, Cribrostomoides* cf. *subglobosum* were reported, these indicate much deeper environment than in the region mentioned above (MASATANI and ICHIMURA, 1970).

F. Middle Shigarami Formation

Distribution and thickness: The distribution of the Middle Shigarami Formation is restricted to the area of the Orihashi and Hikage synclines, situating in the northern part of the Subsidence Zone. It attains 1,500 m in maximum thickness.

Lithofacies: The Formation is composed mainly of andesitic volcanic rocks and mudstones. As shown in the geologic map (Fig. 3), in the eastern wing of the Orihashi syncline the Formation is entirely composed of volcanic rocks, whereas it changes into monotonous mudstone eastward. In the southernmost part of the Hikage syncline, the Formation is composed mainly of sandstones and conglomerates. It is apparent that the Formation is rich in coarse materials in the southern part. Pebbles in the conglomerates are chert, greywacke, quartz porphyry, granite, sandstone and others (HIRABABAYASHI, 1970).

Paleocurrents: Sole markings, mostly flute casts, are very poorly developed. These are found in alternations in the southernmost part. Cross-laminations are sometimes observed, but not measurable. Sole markings indicate the presence of the currents from SW to NE or from WSW to ENE, which are slightly oblique to the general trend of longitudinal currents in the surveyed area.

Fossils: Molluscan fossils are found in sandstones in the eastern part of the basin, such as *Anadara amicula, Spisula* cf. *sachalinensis, Macoma praetexta* from the Middle Shigarami Formation (TOMIZAWA, 1962). These are neritic species according to the bathymetry of OYAMA (in MINATO, 1953).

G. Upper Shigarami Formation

Distribution and thickness: As same as the Middle Shigarami Formation, the Upper Shigarami Formation is distributed in the area of Hikage and Orihashi syncline. The thickness is largest along the route Hw 17, attaining to 1,400 m (SHIBATA et al., 1976). As shown in Fig. 8 and by YANO (1976 MS), depocenters are detected in the northern part of the Hikage syncline and in the central part of the Orihashi syncline.

Lithofacies: The Formation is composed mainly of mudstones and muddy alternations. However, in the area from the route Hw 10–1 to Hw 10–2, it is represented by sandstones and conglomerates. Gravels in conglomerates are mainly andesite, which was derived from the underlying Middle Shigarami Formation. Along the routes Tw 16–2 and 17, the Formation is composed mainly of mudstone and sandstone, containing andesite boulders. These andesite boulders, about 1 to 10 m in diameter, are derived from the Middle Shigarami Formation (YANO and MURAYAMA, 1976).

Paleocurrents: Compared with the Lower and Middle Shigarami Formation, sole markings are well developed in the Upper Shigarami Formation. These are found in the western part of the surveyed area. Cross-laminations are sometimes observed in the Upper Shigarami Formation, but not measurable. Sole markings show the paleocurrent from south to north, which coincides with the general trend of longitudinal currents in the surveyed area.

Fossils: Molluscan fossils are reported from sandstones in the eastern part of the basin (TOMIZAWA, 1962). They are *Anadara amicula, Spisula* cf. *sachalinensis, Macoma praetexta,* all of which belong to neritic species of OYAMA (in MINATO, 1953).

H. Sarumaru Formation

Distribution and thickness: The Sarumaru Formation is distributed in the area of the Hikage and Orihashi synclines. The maximum thickness attains to 1,600 m in the northeastern part of the Hikage syncline (SHIBATA et al., 1976). In the area of the Orihashi syncline the Sarumaru Formation is subdivided into Member Sa-1 and Sa-2, which have the maximum thickness of 500 m and 400 m, respectively (YANO and MURAYAMA, 1976).

Lithofacies: The Formation is represented dominantly by sandstone in the lower part (Sa-1) and by sandstone and conglomerate in the upper part (Sa-2). Lateral change of lithofacies is not so conspicuous to be compared with that of the underlying formations. Conglomerate beds are a few meters thick and have pebbles of chert, greywacke, quartz porphyry, shale and others (SHIBATA et al., 1976). Andesite pebbles derived from the Middle Shigarami Formation are also found in the area of the Orihashi syncline. Sandstones in Member Sa-1 are of medium-grained and massive, while those in Member Sa-2 are of medium- to coarse-grained and cross-bedded. Graded-bedding is not so well developed.

Paleocurrents: Sole markings are poorly developed in the lowermost part of the Formation in the Hikage syncline area, and ripple-marks are found dominantly in the middle to upper parts. By paleocurrents inferred from sole markings longitudinal trend from SSW to NNE is general, but sometimes lateral one from SE to NW is known. Paleocurrents deduced from asymmetric ripple-marks indicate the northward or north-northwestward direction. In the Orihashi synclinal area, cross-bedding is commonly observed in the Upper Sarumaru Formation. As in the case of the Ogawa and Lower Shigarami Formation, a precise examination of cross-bedding resulted in that dominant direction is northeastward in the western wing of the Orihashi syncline and northwestward in its eastern wing (YANO, 1976 MS).

Fossils: Molluscan fossils are sometimes found in the Sarumaru Formation, but no foraminiferal fossils are found (MASATANI and ICHIMURA, 1976). Judging from the bathymetry of molluscan fossils by OYAMA (in MINATO, 1953), neritic species, such as *Anadara amicula, Glycymeris yamasakii, Chlamys swiftii etchegoini,* and *Panope japonica,* are found in the Formation (TOMIZAWA, 1962).

V. Reconstruction of the Sedimentary Basins

From the above-mentioned data, the sedimentary basin in each stage can be reconstructed as in the following. Paleogeographic reconstructions of the basins of the Uchimura, Aoki, Ogawa and Late Shigarami stages, are shown in Fig. 11.

A. Uchimura Stage

The initial volcanic activities of the Green Tuff geosyncline occurred extensively during the Uchimura stage, and thick pyroclastic materials were accumulated in the main part of the basin. Terrigenous sediments were deposited only in the south-

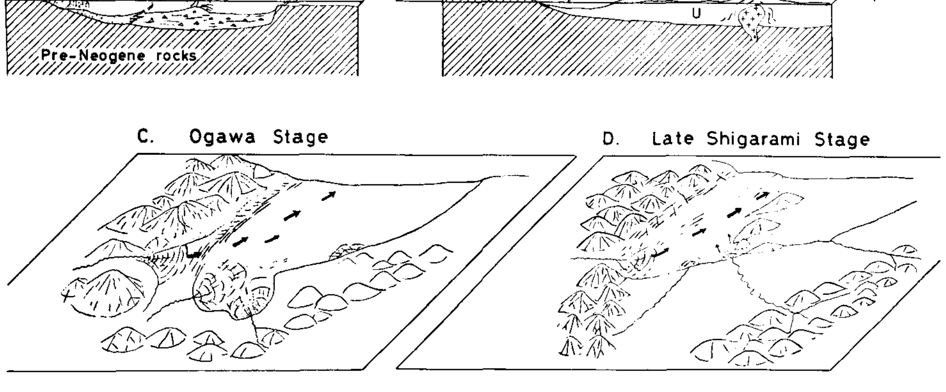

Fig. 11. Reconstructed illustrations of the sedimentary basins. The arrows indicate the turbidity currents.

western part of the basin. The materials were derived from the upland area situated to the southwest. At first, these are considered to have been accumulated at the river mouth as delta sediments, and were deposited in the basin with the northeastward longitudinal turbidity current. It is apparent that these longitudinal turbidity current could not reach further eastward, bacase a volcanic barrier had already been formed at that time. On the contrary, some turbidite sandstones rich in volcanic materials are found in Member H-3. They show a paleocurrent from east to west. These facts indicate that the lateral turbidity currents from the eastern volcanic area occurred to have transported volcaniclastic materials to the western depositional area. Molluscan fossils are mostly neritic, and these are considered to have been transported from the surrounding shelf area.

B. Bessho Stage

The Bessho Formation is composed of monotonous mudstones, and it is inferred that a deeper environment continued from the Uchimura stage dominated thoughout the Bessho stage. No marginal facies can be observed in the surveyed area, and it is likely that the sea invaded very extentsively into the Northern Fossa Magna region. The evidence from molluscan fossils also supports an idea of relatively deep sea environment of the Bessho stage, Paleocurrent analysis show that sand-sized clastic materials were sometimes supplied by longitudiual turbidity currents from southwest to northeast. Although the precise reconstruction of the basin is not yet illustrated, it is presumed that the environment was not to different from that of the succeeding Aoki stage. It is inferred that at the Bessho stage the embryoic uplift started in the eastern part of the basin, which developed later to the Central Upheaval Zone.

C. Aoki Stage

The basin of the Aoki stage is assigned as a typical flysch basin filled with abundant sandy turbidites. Graded-bedding and sole markings are commonly developed in them. Judging from the paleocurrent analysis, the sediments were obviously transported by longitudinal turbidity currents from southwest to northeast. Lithofacies analysis also show that proximal facies is present in the southwestern part and distal one in the northeastern part. Two main outwash gates can be estimated in the source area. One is located to the southwest of Matsumoto and the other to the southwest of Lake Aoki. At substage A-3, coarse-grained turbidites are found in the western part of the basin near Lake Aoki. These were transported by eastward lateral currents which originated at the southwest to Lake Aoki. Succeeding to the Bessho stage, gradual uplifting of the eastern area contrasting to a general subsidence of the whole area had an effect on the transformation of the area of the Uchimura Formation to the Central Upheaval Zone which was subjected to subaerial erosion during the Aoki stage. Pebbles and cobbles originated in the Uchimura Formation were transported westward from this land area, although these could not reach the Subsidence Zone. Due to the differential subsidence between the Subsidence Zone and Central Upheaval Zone, there occurred frequently slumping along the boundary zone. From the molluscan fossil evidence as well as the lithofacies change it is proved that the environment became to shallower than that of the preceding stage.

D. Ogawa Stage

The situation was considerably changed from that of the Aoki stage. The Ogawa Formation is characterized by the presence of a proximal facies consisting of conglomerates and sandstones. Large-scale cross-bedding suggesting a very shallow environment is well developed in the southern part of the basin. Clastic materials of Members Og-1 and Og-2 were transported from the east and west as well as from the south. In the northwestern part of the basin, the Formation is characterized by mudstones and alternations which were formed by northward turbidity currents. Their source area can be assigned to the west of the Lake Aoki, which was a perennial provenance from the Aoki stage. As clearly shown in association of fossil contained, the central and northern parts of the basin were deeper than the southern part.

E. Early Shigarami Stage

The Lower Shigarami Formation is characterized by a proximal facies consisting of conglomerates and sandstones in the southern part of the basin, while massive mudstone facies is predominates in the northern part. Large-scale cross-bedding is well developed in the southern part. These sediments were probably deposited under deltaic and/or inland sea environments encircled by mountains. The basin became to shallow in this stage and no turbidites were formed in the southern part of the basin. The paleogeography is similar to that of the preceding stage, but deltaic and inland sea environments prevailed more in this stages. The fossil occurences clearly show that the central and northern parts of the basin are deeper than the southern part, as in the case of the Ogawa stage.

F. Middle Shigarami Stage

The sedimentary basin migrated northward in this stage, and two depocenters were recognized in the basin. One is located in the Hikage synclinal area in the western part of the basin and the other one is in the Orihashi synclinal area in the eastern part. A marginal facies made of conglomerates and sandstones is developed in the southern part of the basin. On the other hand, alternations and mudstones are developed in its northern and central parts. The materials were transported by northeastward turbidity currents. The main source area was presumed to be westward of Lake Aoki. Facies change in the Middle Shigarami Formation also supports the above estimation. In the central and northern parts of the basin there occurred volcanism which deposited andesitic volcaniclastics. A partial unconformity at the base of Member Sh-3 in the central part of the distribution area indicated the upheaval of this area before the volcanic activity.

G. Late Shigarami Stage

In the Late Shigarami stage an upheaval area appeared along a part of the Nishikyo anticlinal zone, where the Middle Shigarami Formation was eroded subaerially to have supplied andesite gravels to the surrounding area. In the western part of the basin sediments were transported by longitudinal turbidity current from SSW to NNE. The source area is estimated to have been as same as in the middle Shigarami stage. The deposition of marginal conglomerates continued in the southernmost part of the basin.

H. Sarumaru Stage

At the beginning of the Sarumaru stage flysch-sedimentation occurred in small scale as represented by alternations of sandstone and mudstone in the lowest part of the Sarumaru Formation. Thereafter, the basin was abruptly changed to the site of fan-sedimentation, where thick sandstones and conglomerates having large-scale cross-bedding were piled up, and at last, the basin was filled up completely by them. Coarse clastic materials were suplied mainly southerly from the southern and southeastern mountainuous areas. The exsistence of subaerial volcanic activities inferred from the intercalations of a layer of welded tuff at the top of the Sarumaru Formation.

VI. Several Considerations on the Development of the Sedimentary Basins

The surveyed area is located in the southern part of the inner arc of the Northeast Japan, and is one of the most remarkably subsiding area in the Green Tuff orogenic belt, where thick terrigenous sediments and volcaniclastics were accumulated. Generally speaking, the geosynclinal sediments in this area can be divided into three different sequences, each of which reflects initial volcanism stage (Uchimura Formation), flysch sedimentation stage (Bessho and Aoki Formations), and molasse sedimentation stage (Ogawa, Shigarami and Sarumaru Formations), respectively. These stages nearly correspond to three stages of Green Tuff orogeny by FUJITA (1960, 1972), that is, generative, developing and geanticlinal stages. As clearly shown in Fig. 12, the Neogene geosyncline in the Northern Fossa Magna region is not a simple basin but a complex one constituted by many small basins. It can be recognized

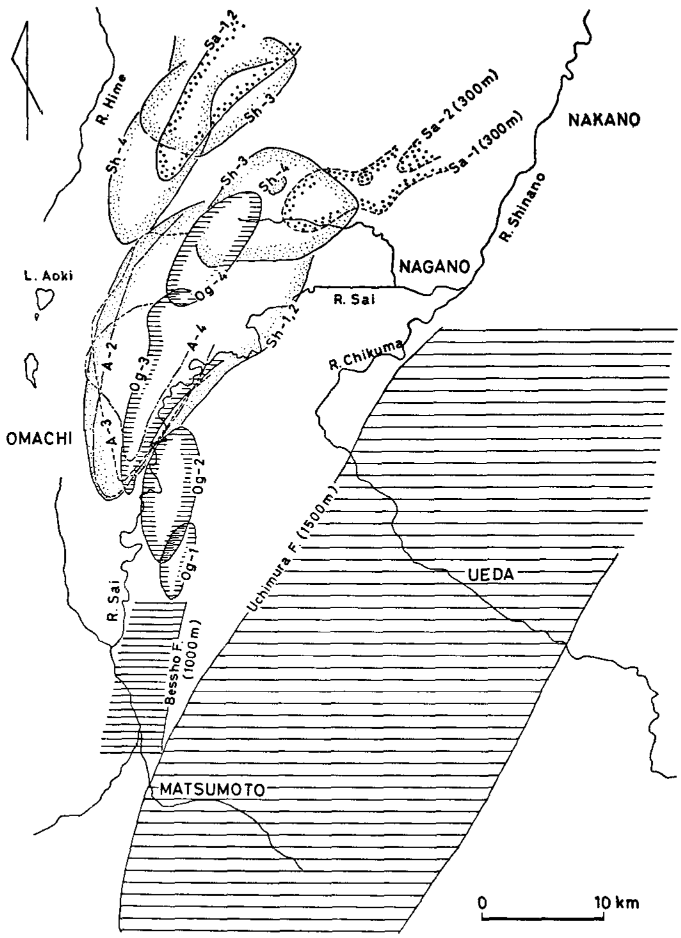

Fig. 12. Distribution of sedimentary basins in terms of Member or Formation. Outline of basin is shown by the 500 m isopach line unless otherwise indicated.

that there exist two first-order basins in the surveyed area, i.e., the basin of the Central Upheaval Zone in the east and that of the Subsidence Zone in the west. Both basins have a common character in having approximately 15 km wide and 50 km long and thick accumulation of a sequences of about 3,000–6,000 m in thickness. The basin of the Subsidence Zone can be divided into several second-order ones, but details of the basin of the Central Upheaval Zone are uncertain.

1. Sedimentary Cycles

As shown in Fig. 10, three coarsening upward megasequences can be recognized

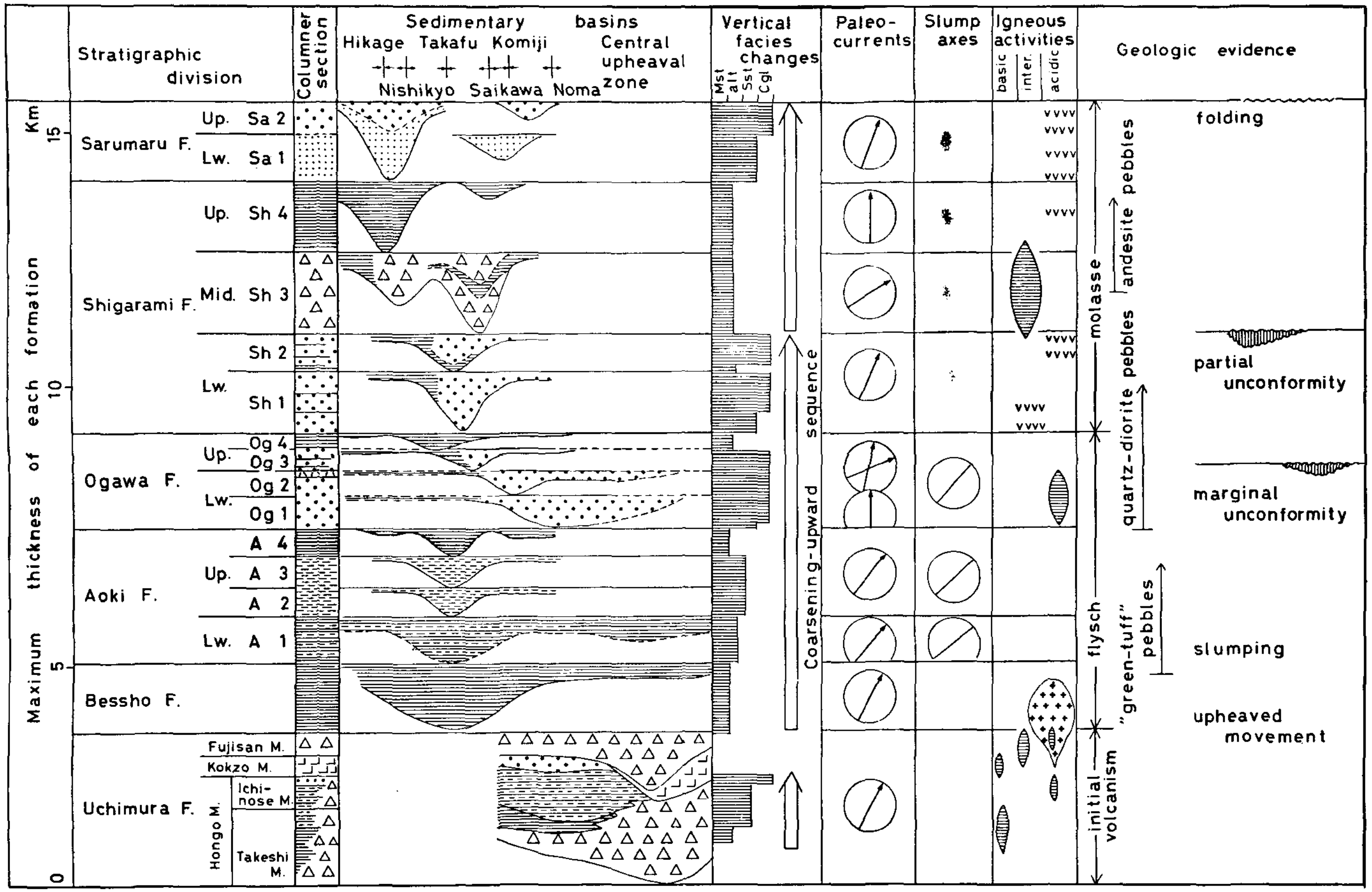

Fig. 13. Schematic relations of vertical facies changes, paleocurrents, slump axes and igenous activities of the Neogene sedimentary basins.

in the Neogene formations. These are:

A. The sequence from Member H-1 to Member H-4 in the Uchimura Formation
B. The sequence from the Bessho Formation to the Lower Shigarami Formation
C. The sequence from the Middle Shigarami Formation to the Sarumaru Formation

The relation among these sequences, migration of sedimentary basins, paleocurrents and volcanic activities are schematically shown in Fig. 13. Each sedimentary sequence composed of several formations begins with mudstone or muddy flysch, and ends with massive and/or thick-bedded sandstone and conglomerate through sandy flysch. The total thickness usually attains to 1,000 to 3,000 m. Several fining upward sequences are found in these formations. Compared with the coarsening upward megasequence these are less in thickness, constituting minor unit of the former. These coarsening upward megasequences are considered to reflect the development of the sedimentary basins. The first megasequence in the Uchimura Formation indicates the extinction of the initial volcanic basin and second one corresponds to the progress from flysch to molasse stage, reflecting gradual filling-up of the southern half of the molasse basin. The third one corresponds to the extinction of the molasse basin.

2. Migration of the Flysch-Molasse Basins

The reconstructions of the sedimentary basins were made on the basis of thickness variation of each formation-order. These were already shown in Fig. 8. However, the second-order thickness variation cannot be neglected. Such second-order thickness variation was clarified by means of several traceable units or marker beds in the flysch-molasse basins. These are shown also in Figs. 12 and 13. Although the depocenter in the flysch basins remained stable during each stage of flysch sedimentation, that in the molasse basins had much mobility. For instance, the depocenter was situated in the eastern wing of Komiji syncline in Og-1 stage, while it was shifted to the western wing of the Komiji syncline in Og-2 stage. In the next stage (Og-3) the basin was abruptly migrated northward and depocenter was shifted to the eastern wing of the Takafu suncline. Thereafter, the depocenter was located in the eastern wing of the Takafu syncline in Sh-1 and Sh-2 stage. Since Sh-3 stage two depocenters can be recognized, each is located in the central part of the Hikage synclinal area and Orihashi synclinal area, respectively. Each basin has a different size as tabulated below, of which size was measured on the basis of 500 m isopach line.

	width (km)	length (km)
Sa-2	(2)	(8)
Sa-1	(4)	(17)
Sh-4	6	20
Sh-3	7—8	15
Sh-1 and Sh-2	15	30
Og-4	4	12
Og-3	6	17
Og-2	4	12
Og-1	2—3	7

( ), measured by 300 m isopach line

The basins from Og-1 to Sh-4 are assigned as second-order basins, and Sa-1 and Sa-2 basins are third-order ones. Migration of flysch-molasse basins is schematically shown in Fig. 14. Throughout the flysch stage the depocenter remained in the same position. On the contrary, the depocenter in the molasse stage was considerably changed. Successive northward migration of the second-order basins was inferred in the early half of the molasse stage. It is noticeable that the migration of the second-order basins is oblique to the general trend of the Ogawa Formation. In the later half of the molasse stage third-order basins were born in the northern part, and these migrated northeastward successively. This migration trend is parallel to the Shigarami and Sarumaru Formations. It is interesting that oppositional

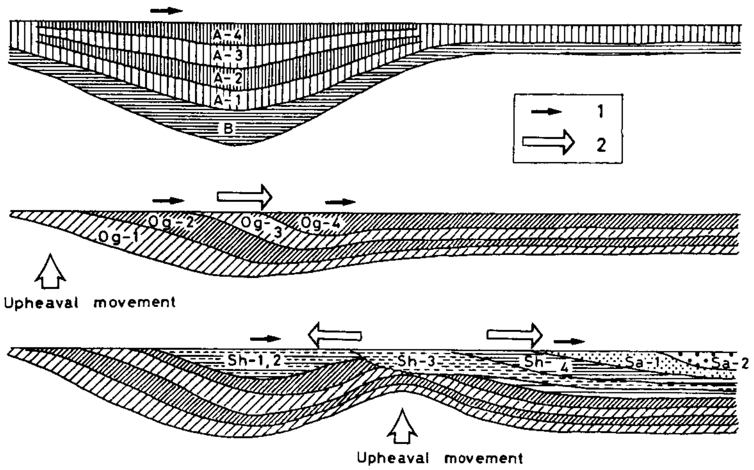

Fig. 14. Schematic figures (longitudinal section) showing the relation between the migration of sedimentary basin and sedimentation.
Legend: 1. direction of transportation 2. migration of sedimentary basins.

migration of the basins is observed in Sh-1 and Sh-2 stage. These may be related to the upheaval movement within the molasse basins. This upheaval movement resulted in the formation of a barrier, and terrigenous materials transported from the southern provenance brought about dam up with coarsening upward sequence from Og-4 to Sh-2 Members.

3. The Geologic Development of the Northern Fossa Magna Region and its Bearing in the Shin'etsu Geosyncline

The Neogene Shin'etsu geosyncline in the Green Tuff region is one of the most productive oil-fields in Japan. The surveyed area is located in the southern part of the Shin'etsu geosyncline, which surrounded by Pre-Neogene basement rocks. The geosyncline has a size of 90 km in width and 300 km in length and the sedimentary sequence attains 6,000 m in total thickness. A lot of geologic data have been accumulated by the exploration of the oil fields. Regional isopach map of the Miocene and lower Pliocene was compiled by the association of oil companies (PROFESSIONAL EXPLORATION COMMITTEE, 1969). Echelon arrangement of sedimentary basins is clearly shown on this map. SUZUKI and MITSUNASHI (1974) discussed the origin of the fold system in central and northern parts of the Shin'etsu geosyncline and concluded that folds have been formed with close relation to the development of the sedimentary basins and that the depocenters migrated westward from the eastern upheaval zone. Westward migration in the northern part of the Shin'etsu geosyncline was also inferred by IKEBE et al. (1978), which is clearly indicated in their schematic profile between Sado Island and Shinunji near Murakami.

As shown already, the westward migration of depocenters is clarified also in the Northern Fossa Magna region by the present writer. The Neogene sedimentary basins and their migration in the whole Shin'etsu geosyncline can be illustrated as shown in Fig. 15. The writer's studied area is situated in the southernmost part. Each basin shown by isopach line of 2,000 m is 10 to 20 km in width, and 30 to 50 km in length. As already mentioned, three developmental stages i.e., the initial volcanic, the second flysch, and the third molasse stage, can be recognized throughout the Shin'etsu geosyncline. Three stages can be roughly correlated to the generative, developing, and geanticlinal stages of the Green Tuff orogeny by FUJITA (1960, 1972).

In the surveyed area, the Central Upheaval Zone was the main depositional site of volcanicalstic materials. Generally speaking, a non-marine environment had predominated at the beginning of this stage in the Green Tuff region. However, volcaniclastic rocks in the surveyed area were formed under marine environment. In the next flysch stage, the site of thick geosynclinal deposition migrated westward from the Central Upheaval Zone to the Subsidence Zone, and thick flysch sediments

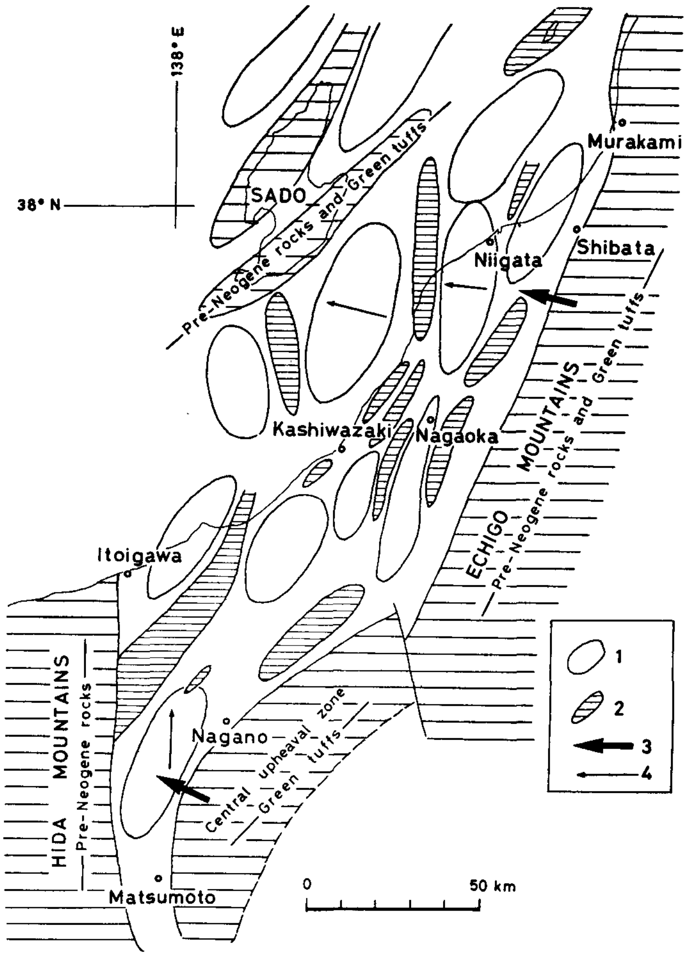

Fig. 15. Structure of the Shin'etsu mega-sedimentary basin. The southernmost sedimentary basin is a surveyed area.
Legend: 1. First-order sedimentary basin 2. upheaval zone 3. direction of first-order migration and 4. second-order migration

were deposited in this newly formed basin. This is assigned as the first-order migration in the Shin'etsu geosyncline. In the surveyed area, migration is nearly perpendicular to the general trend of the geologic structures. It is worth to mention here that this migration was caused by the upheaval movement of the Central Upheaval Zone, and that the Upheaval movements were closely related to the activity of quartz diorite which took place in the Central Upheaval Zone at the beginning of the flysch stage (Bessho stage). The migration of the sedimentary basins during the last molasse stage and their successive filling by coarse terrigenous sediments were characteristic phenomena and the second-order migration and the third-order migration are distinguishable in the surveyed area. Northward migration occurred in early half of the stage was the second-order oblique to the general trend of the geologic structures, while northeastward migration occurred in the later half of the stage was the third-order parallel to the general structures.

It is generally accepted among Japanese geologists that the Green Tuff geosyncline, of which the Shin'etsu geosyncline is a part, started with extensive subaerial and submarine volcanism at the dawn of the Neogene after prolonged subaerial denudation throughout the Paleogene Period. These were followed by extensive marine invasion at middle Miocene, and several sedimentary basins in the inner side of Japan, especially along the Japanese Sea coast were formed. To the Akita basin, a type area of the Japanese Neogene stratigraphy, many paleontologic and geochronologic studies have devoted until now. The standard division in Akita is as Monzen, Daijima, Nishikurosawa, Onnagawa, Tentokuji, Kitaura, and Wakimoto Formations in ascending order, and TAKAYASU and MATOBA (1978) summarized Neogene geohistory of the coastal region of Sea of Japan briefly as follows.

The Green Tuff of the Monzen stage consists chiefly of altered andesite volcanics with intercalations of plant beds of the cool-temperate Aniai-type flora. The first marine transgression into Japan Sea region from Pacific side started in this stage, but was restricted to the east of the backbone range area of northern Honshu. During the Daijima stage, the Green Tuff was characterized by acidic volcanics including basaltic and andesitic in part with intercalation of the warm-temperate Daijima plant beds. The marine invasion became to cover almost all of the Green Tuff region during the Nishikurosawa stage, and was characterized by inhabitation of warm-sea organism such as *Miogypsina*, *Operculina*, *Vicarya* and *Vicaryella*. At the end of the Nishikurosawa stage, because of uplift of the backbone ranges of Honshu, the sea was separated from the Pacific Ocean. This condition continued from the Onnagawa up to the Funakawa stage, and the deposition of "hard shale" and "black shale" were characterized in the basin. It is interesting that as for the migration of the sedimentary basin, concept of first-order migration by the present writer is also referable in the above area. Biostratigraphic zonation of Neogene strata is well established in Akita district. However, it should be noted that the zonation in the Shin'etsu geosyncline is insufficient owing to the lack of index fossils, especially of planktonic foraminifers. Therefore, the correlation of Neogene strata between the Akita and Shin'etsu districts has not been fully settled yet. In this paper, the writer follows a correlation proposed by IKEBE (1978) and TSUCHI et al. (1979). According to this correlation below, the development of Neogene sedimentary basins in the Inner Side of the Northern Japan may be summarized as follows.

	Akita region	Niigata region	Northern Fossa Magna region
Pleistocene	Shibikawa	Uonuma	Sarumaru
Pliocene	Wakimoto	Haizume	Shigarami
	Kitaura	Nishiyama	
Late Miocene	Funakawa	Shiiya	Ogawa
		Teradomari	Aoki
Middle Miocene	Onnagawa		Bessho
	Nishikurosawa	Nanatani	
Early Miocene	Daijima	Iwafune	Uchimura
	Monzen	Aikawa	Moriya
basement	granite Paleozoic	granite Paleozoic	Paleozoic?

In the early to middle Miocene intensive volcanic activity accompanied with marine transgression took place along the Inner Side of Northern Japan, and initial sedimentary basins were formed there. Then, basins migrated to the inner side (first-order migration), that is, westward in Akita and Shin'etsu districts, and northward in Hokuriku district of West Japan at the Onnagawa stage. Accordingly, the first-order migration to the Sea of Japan side can be recognized as a general pattern of the Neogene development of the Inner Side of Japan arc. It is related to the uplift of the backbone ranges of Honshu. Furthermore, it should be mentioned here the relation between the Northern Fossa Magna region and Southern Fossa Magna region. These areas, collectively called Fossa Magna, have often been regarded as a single geologic province during the Neogene time because of the extensive distribution of similar volcanic rocks in both areas. But from the viewpoint of basin migration, there exists an important difference between the Northern and Southern Fossa Magna. That is, the migration of the Neogene basin in the Southern Fossa Magna region, which is inferred from the data of FUJIGAWA COLLABORATIVE RESEARCH GROUP (1976), is principally southward. Sedimentologic studies have rarely been done in the southern Fossa Magna region. However, several paleocurrents reported in Yamanashi Prefecture (MATSUDA, 1958) suggest southward longitudinal currents in the Fujigawa district. The present writer also confirmed the existence of southward longitudinal currents in the Shimobe district. Recently KAWACHI (1979) reported that the basement rocks underlying the Yatsugatake volcanoes, which locates around the boundary between the two regions, belong to the extension of the Shimanto Supergroup which is distributed along the Pacific coast. From the above-mentioned facts it is better to say that the Northern Fossa Magna and Southern Fossa Magna regions belong to the different geologic provinces respectively, although they were connected by seaway in the early and middle Miocene.

Concerning to the second-order migration in the Shin'etsu geosyncline (Niigata-Northern Fossa Magna region), it is well analysed in the central part by SUZUKI and MITSUNASHI (1974) and in the southern part by the present study. In the late Miocene Funakawa stage, the mega-sedimentary basin of flysch stage, formed by the first-order migration at the Nishikurosawa-Onnagawa stage, has been differentiated into smaller basins which are assigned as second-order basins according to the writer's definition. An upheaval zone formed at the boundaries between the first-order basins. Then, the direction of the migration reflects the local upheaval movement, which was formed within the Shin'etsu mega-sedimentary basin. That is, the migration is westward in the Niigata region, while it is northward in the Northern Fossa Magna region. In the former, the amount of upheaval movement is rather small to be compared with that of the backbone range (Echigo Mountains). On the other hand, in the surveyed area in the southernmost part of the Shin'etsu basin, upheaval movement of Hida Mountains to the west and the south of the basin is more conspicuous than the Central and Otari Upheaval Zones. Consequently, the sediments were supplied mostly from south and southwest, and the basins were migrated to the north obliquely to the general trend of geologic structures.

Recently the subsurface geologic survey along the Japan Sea coast and submarine survey of the continental shelves have been greatly advanced indebted to oil and gas exploration. These data were summarized by SUZUKI (1979), and thick Neogene strata underlying has been ascertained. Consequently, it is definite that there are several basins, and each is as the Shin'etsu basin. This may support the writer's idea that the basins migrated to the Japan Sea side.

VII. Summary

For the Neogene sequence in the central part of the Northern Fossa Magna region, the sedimentary facies and facies variation, sedimentary structures, paleocurrents and thickness variations were described. The basin analysis and the reconstruction were carried out. Furthermore, the relation between the migration of the basins and sedimentaty processes were discussed. The results are summarized as follows.

1. The geosynclinal sediments can be divided into three major sequences, which reflect the three stages of geologic development, that is, initial volcanism stage (Uchimura Formation), flysch sedimentation stage (Bessho and Aoki Formations) and molasse sedimentation stage (Ogawa, Shigarami and Sarumaru Formations). These Formations show a considerable lithofacies variation as shown in

Figs. 8 and 10. In the initial volcanism stage, thick pyroclastic materials accumulated in the main part of the basin. Terrigenous sediments were deposited only in the southern part of the basin. In the flysch stage, especially the Aoki stage the sedimentary piles are rich in sandstones in the northwestern part of the Basin, while muddy alternations and mudstones are predominant in the southeastern part. In the molasse stage a large amount of conglomerates and sandstones with large-scale cross-bedding were deposited in the southern part of the basin, while thick massive mudstones in the northern part. Based on the sedimentary analysis of sandstones and alternations, it is considered that turbidity currents were a main trasnportation mechanism during the flysch stage.

2. As shown in Fig. 10, three coarsening-upward sequences can be recognized in the Neogene formations.

These are;

a) The sequence from Member H-1 to Member H-4 in the Uchimura Formation

b) The sequence from the Bessho Formation to the Lower Shigarami Formation

c) The sequence from the Middle Shigarami Formation to the Sarumaru Formation

The relation among these sequences, migration of sedimentary basins, paleocurrents and volcanic activities are collectively shown in Fig. 13. These coarsening-upward sequences are considered to reflect the development and migration of sedimentary basins.

3. Paleocurrent directions indicated by sole markings and cross-bedding are summarized in Fig. 9. Generally speaking, paleocurrent directions are from SSW to NNE in each stage. But in the molasse stage directions of the maximum dip of the cross-bedding are variable indicating the paleocurrent from south, east and west.

4. The thickness variations of each formation are shown in isopach maps (Fig. 8). More detailed thickness variations are shown in Figs. 12 and 13. As shown in the isopach maps depocenters of the flysch Aoki stage are stable, while the shifting of depocenters is conspicuous in the molasse Ogawa, Shigarami and Sarumaru stages.

5. Reconstruction of basins of the Uchimura, Aoki, Ogawa and Shigarami stages are shown in Fig. 11.

6. Concerning the migration of sedimentary basins in the Northern Fossa Magna region, it can be summarized as follows;

a) Northwestward migration from the site of initial volcanism to that of flysch and molasse sedimentation, which is perpendicular to the general trend of geologic structure (first-order migration).

b) Northward migration in the early half of the molasse stage, which is oblique to the general trend of geologic structure (second-order migration).

c) Northeastward migration in the later half of the molasse stage, which is parallel to the general trend of geologic structure (third-order migration).

The schematic profile of the movements is shown in Fig. 14.

7. Relation among the basins, lithofacies, sedimentary cycles, paleocurrents, slump and igenous activities is schematically summarized in Fig. 13.

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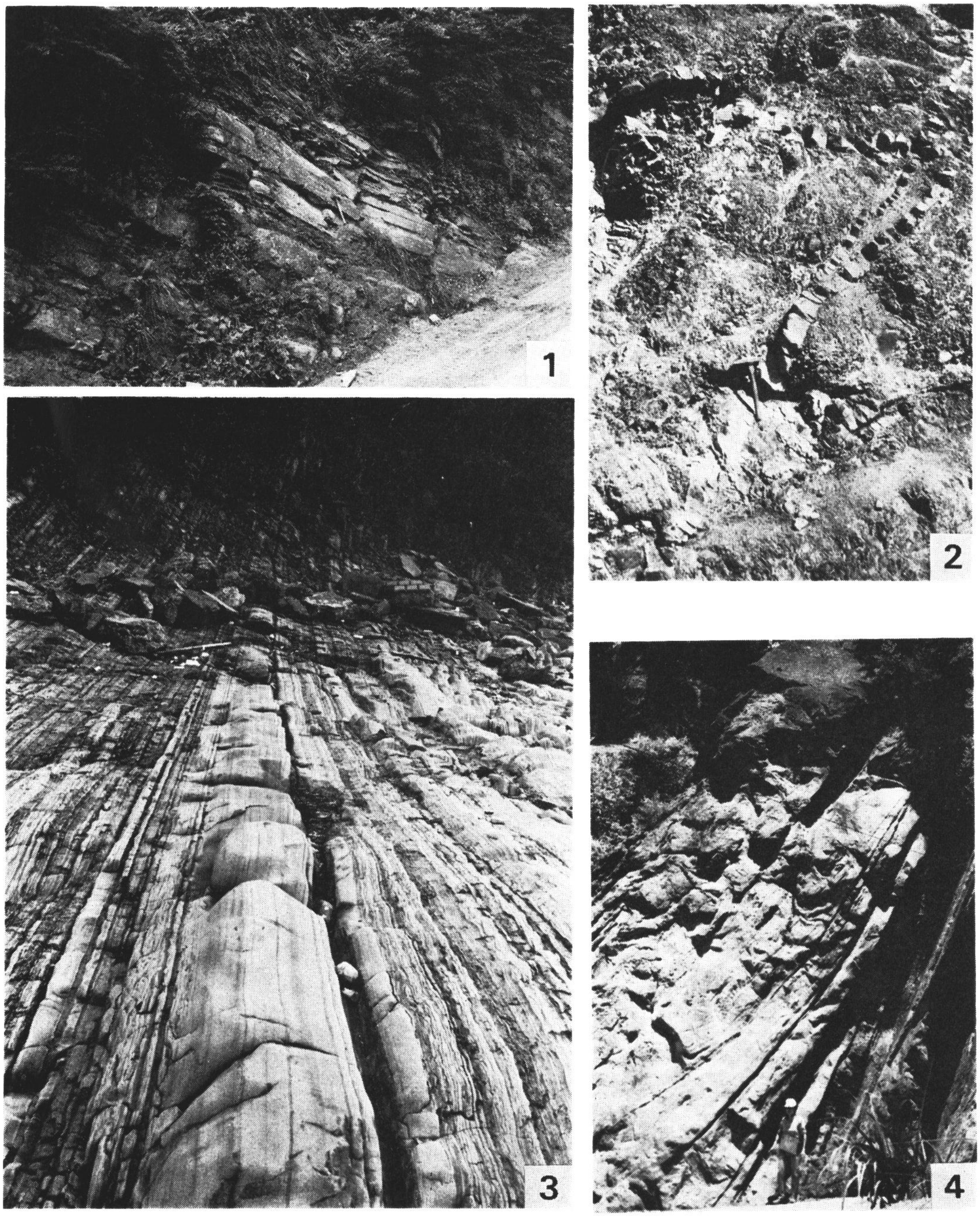
Place Names

Aoki	青木	Bessho	別所	Takeshi	武石
Hikage	日影	Hongo	本郷	Fujisan	富士山
Itoigawa	糸魚川	Jinda	神田	Ichinose	一之瀬
L. Kizaki	木崎湖	Matsumoto	松本	Kokuzo	虚空蔵
Moriya	守屋	Murakami	村上	Mochikyo	持京
Nakayama	中山	Naniai	七二会	Nagano	長野
Nishikyo	西京	Noma	野間	Naoetsu	直江津
Ogawa	小川	Omachi	大町	Odagiri	小田切
Otari	小谷	Saigawa (R. Sai)	犀川	Orihashi	折橋
Sarumaru	猿丸			Shiunji	紫雲寺
Takafu	高府	Shigarami	柵	Ueda	上田

Explanation of Plate 1

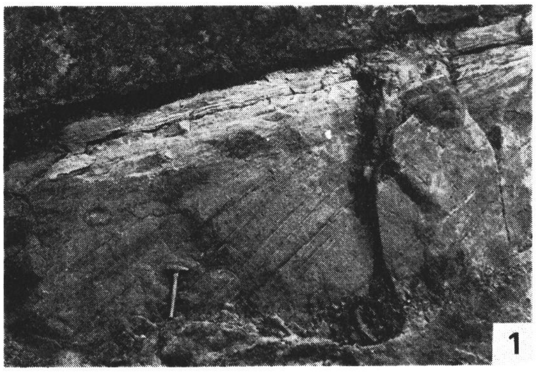
1. Sandy alternation of the Uchimura Formation (H-2).
2. Slump structure of the Bessho Formation.
3. Sandy alternation of the Aoki Formation (A-2).
4. Cross-laminated sandstone of the Ogawa Formation (Og-1).

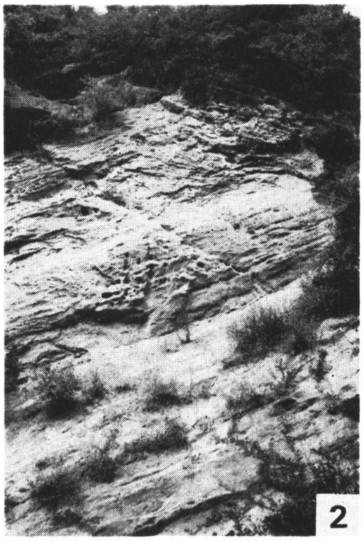


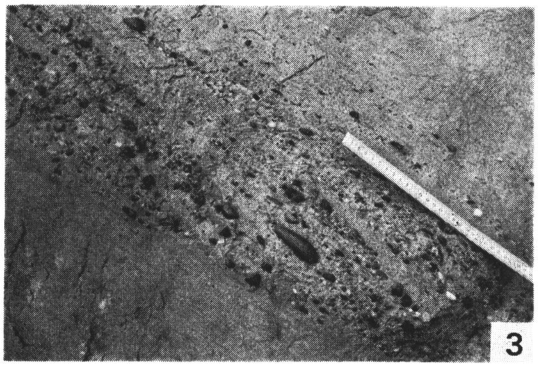
SUZUKI: Sedimentological Analysis of the Neogene Basins

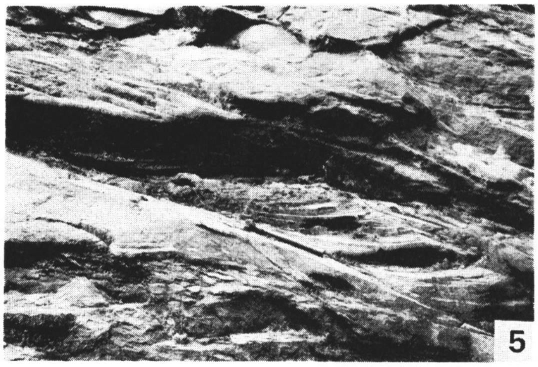
Explanation of Plate 2

1. Cross-laminated sandstone of the Ogawa Formation (Og-3).
2. Massive sandstone of the Shigarami Formation (Sh-1).
3. Cross-laminated sandstone of the Shigarami Formation (Sh-2).
4. Muddy alternation of the Shigarami Formation (Sh-4).
5. Cross-laminated sandstone of the Sarumaru Formation (Sa-1).









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