Late Cenozoic Geohistory in the Northern Fossa Magna Region, Central Japan

By

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with 4 Tables and 35 Text-figures

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ABSTRACT

In the northern Fossa Magna region situated at a junction of the Honshu Arc and the Izu-Ogasawara Arc, an extremely thick series of Upper Cenozoic strata is extensively developed. In this paper, the stratigraphy is described in detail, and the sedimentary and tectonic history is reconstructed on the basis of the analyses of sedimentary environment and geologic structure.

The Upper Cenozoic system in this region is divided into seven formations; namely, the Uchimura, Bessho, Aoki, Ogawa, Shigarami, Sarumaru and Toyono Formations in ascending order. They are moderately deformed by folds and faults. Six types of fold and six systems of fault are discriminated. The subsidence pattern and sedimentary environment are analyzed through examining the change in thickness and litho- and bio-facies, as well as paleocurrents.

The Late Cenozoic geohistory in the northern Fossa Magna region is divided into two stages, though they overlap each other in their transitional period. The first stage during Miocene to Early Pleistocene is characterized by a series of movements including initial volcanism and subsequent subsidence, plutonism and folding. The sedimentation of pre-flysch, flysch and molasse facies have taken place. The history in this stage may be comparable with that of " geosyncline". The development of sedimentary basin with a polarity toward back-arc side and the folding of strata have essentially resulted from the growth of regional asymmetric upwarping of NE-SW trend under the influence of gravity. The second stage during Pliocene to Quaternary is characterized by block faulting associated with uplifting of island arc. Volcanic chains and volcano-tectonic depressions of N-S and partly NW-SE trends were superimposed upon the structural framework constructed in the first stage. The migration of depocenters of sedimentary basins newly generated in this stage is oblique to that in the first stage, and seems to have continued until the present.

It is considered that the Late Cenozoic geohistory in the northern Fossa Magna region has been tectonically controlled by superposition of the block-faulting with a trend parallel to the Izu-Ogasawara Arc upon the asymmetric upwarping with an axis parallel to the Northeast Japan Arc.

CONTENTS

I. INTRODUCTION

Central Japan is situated at a junction of three island arcs, namely, the Northeast Japan, the Izu-Ogasawara (Bonin) and the Southwest Japan Arc. This junction is characterized by a syntaxis in the zonal arrangement of the pre-Neogene basements (Fossa Magna Syntaxis; Hara, 1979), and by a large-scale "Graben" filled with the thick Neogene sediments (Fossa Magna; Naumann, 1893), as well as by the remarkable uplifting during Quaternary time generating the most mountainous highland in Japan (Fig. 1).

On the geology of the northern part of the Fossa Magna region, many contributions have been made since the 1920's. The epoch-making studies were produced by Homma (1931) and Kobayashi (1957). Homma (1931) established the standard of stratigraphy, clarified the framework of geologic structure, and discussed the origin of sedimentary basins and the mechanism of folding. After the last war, Kobayshi (1957) interpreted the Late Cenozoic geohistory of this region in view of the geosynclinal orogenesis theory based on the advancements of stratigraphical study.

The recent progresses of research in many branches of geology (e.g., sedimentology, structural geology, paleontology, geochronology and petrology) have made it one of the most important themes to restore the Late Cenozoic geohistory of the northern Fossa Magna based upon a precise reexamination on the stratigraphy and geologic structure. The tectonic controllers of the Neogene and Quaternary Systems, furthermore, may be extracted from the detailed geohistory.

The author has studied mainly the stratigraphy and geologic structure of the thick Upper Cenozoic strata in the central part of the northern Fossa Magna region. In this paper, the stratigraphy and geologic structure are described at first with an outline of geology, and subsequently the transition of sedimentary basins and the formative process of structural systems are analyzed. In conclusion, geohistory is restored from which the tectonic agents driving the growing process of the Late Cenozoic sedimentary basin in the region are induced.

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II. OUTLINE OF GEOLOGY

A. GENERAL REMARKS

Among the above-mentioned three tectonic characters of Central Japan, the latter two are considered to be originated from the Green Tuff Movement (Ijiri, 1958) and the Island Arc Disturbance (Fujita, 1970), respectively.

Fujita (1972a, b) summarized the geohistorical process of the Green Tuff Movement which had taken place in the inner zone of island arc (called "Green Tuff Region") as follows: At the generative stage of the movement in Early Miocene time many polygonal collapse basins, being ten and several kilometers across, were formed as a result of local doming-up, and then the violent initial volcanism started in the basins followed by a regional subsidence. At the developing stage in Middle to Late Miocene, the zone of initial volcanism and subsidence began to turn into uplifting zone. The latest Early to early Middle Miocene transgression ("Nishikurosawa Transgression") advanced rapidly, and the depocenter has migrated intermittently toward the marginal sea until Pliocene time. The acid to intermediate plutonism proceeded in the uplift zone, and the basic volcanism accompanied with intrusive episode took place along

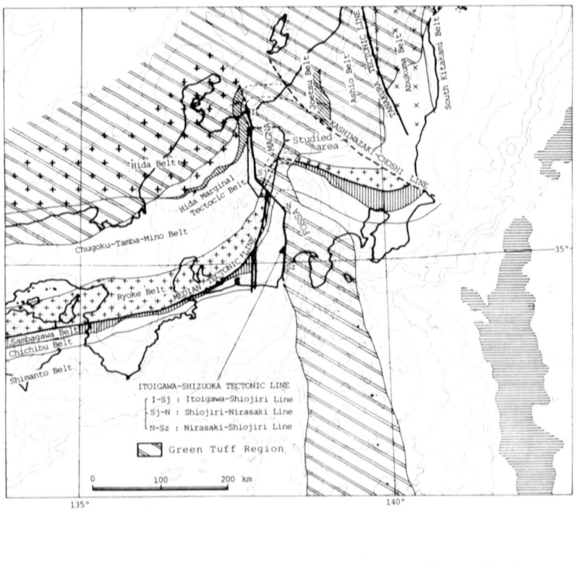


FIG. 1. Tectonic division of Central Japan (compiled from Minato *et al.*, 1956 ; Geol. Surv. Japan, 1977 ; Huzita, 1980 ; Chihara and Komatsu, 1982).

the hinge between the uplifting and subsiding zones. The marked deformation was characteristic of the vanishing stage, and the thick strata were folded and faulted at last.

The Green Tuff Movement in Fossa Magna displays two peculiarities. Although the Green Tuff Region runs through the inner zone of island arc in general, in Fossa Magna it transects the Honshu Arc in N-S direction and connects the Green Tuff Basin of the Northeast Japan Arc with that of the Izu-Ogasawara Arc (Fig. 1). Also, the crustal movement in Fossa Magna is fairly more intense in subsidence, magmatism and deformation than in other regions.

Concerning the arrangement of the sedimentary basins generated by the Green Tuff Movement (" Green Tuff Basin" for short) in Fossa Magna, Fujita *et al.* (1968) pointed out that the collapse basins at the generative stage tend to concentrate into the several zones elongating in NE-SW direction, 80 to 100 km long, and arranged in en échelon fashion of left-hand. The structural pattern of the Fossa Magna region is illustrated in Fig. 2 (Yano, 1982a). The distinctive features of the pattern loomed up as a confrontation between the subsiding zones and the uplifting zones in the developing stage of the Green Tuff Movement. The wavelength of such a large-scale undulation is estimated to be 40 to 50 km.

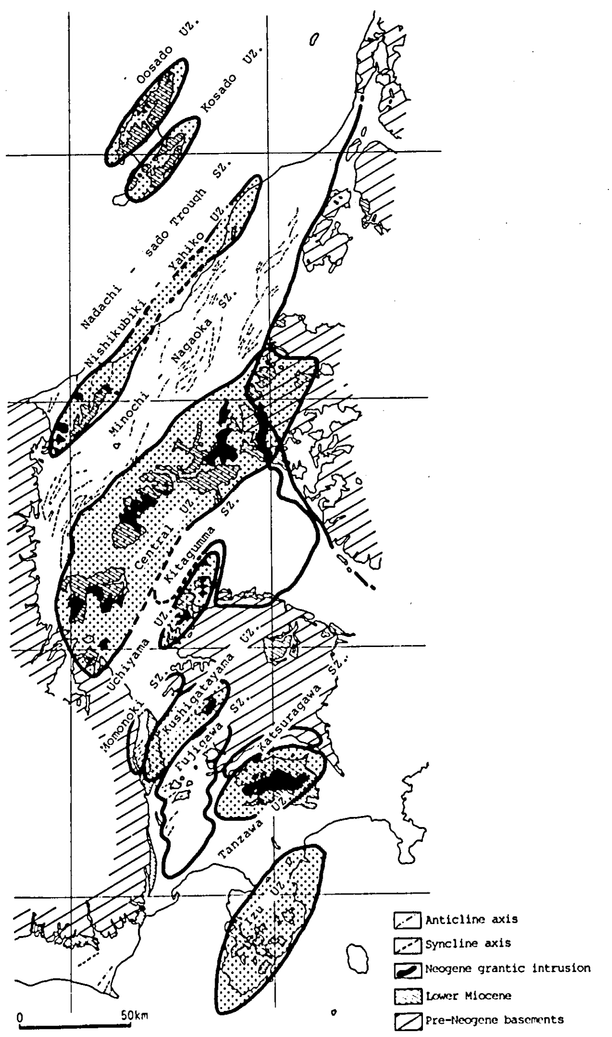


FIG. 2. Structural pattern of the Green Tuff Basin in the Fossa Magna.

UZ: Uplift Zone, SZ: Subsidence Zone.

Among such subparallel geological units the author has surveyed the southwestern Minochi-Nagaoka Subsidence Zone and a part of the Central Uplift Zone (Fig. 3). This paper subjects the Green Tuff Basin in the southwestern half of these two zones to investigation based on the author's reexamination in addition to previous works.

On the other hand, the Island Arc Disturbance since Pliocene or Middle Pleistocene time has produced the today's arc-trench system. It is characterized by the violent uplifting of island arc in a manner of large-scale block movement, the arc volcanism and the intermediate to deep earthquakes along the Wadachi-Benioff Zone (Fujita, 1970). For instance, the Itoigawa-Shizuoka Tectonic Line bordering the western margin of Fossa Magna at present is clarified to be a result of block faulting in this stage (Fujita, 1973b). In this paper the representation of the Island Arc Disturbance and its relationship to the Green Tuff Movement in the Fossa Magna region will be discussed briefly.

B. Geological Subdivision of Northern Fossa Magna

The structural elements of the Green Tuff Basin in the northern Fossa Magna trend in NNE-SSW direction. In detail, the general trend turns from N-S direction in the southwestern area to NE-SW direction in the northeastern area, and as a whole delineates somewhat convex curve to the northwest.

The Green Tuff Basin of the northern Fossa Magna is divided into the Central Uplift Zone and the Minochi Subsidence Zone by the Matsumoto-Nagano Line (Hirabayashi, 1969) as shown in Fig. 4.

In the Central Uplift Zone, the lower sequence of the Upper Cenozoic Group is exposed extensively, accompanied partly with the middle to upper sequence. The geological structure of the zone is represented by two large-scale domes elongated in NNE-SSW to NE-SW direction with the concentration of plutonic rocks, and by a half basin occupying the western half of the saddle between the two domes. According to such structural features, the Central Uplift Zone is subdivided into the three portions named the Utsukushigahara Dome, the Shiga Dome and the Tochiku Half Basin.

In the Minochi Subsidence Zone, the middle to upper sequence was accumulated very thickly, and was complicatedly deformed by numerous folds and faults. Two leading anticlines subdivide the zone into three longitudinal subzones of differential subsidence, i.e., the Komiji, Takafu-Orihashi and Hikage Subzones.

The fracturing and volcanism in N-S and NW-SE directions in Pliocene to Early Pleistocene time have produced several volcano-tectonic depressions. Namely, the Komoro Depression on the eastern side, the Shigarami Volcanics Chain in the central belt, the Omine Depression (" Omine Belt"; Kosaka, 1979) on the western margin and the Enrei Depression on the southern border are superimposed on the Green Tuff Basin obliquely and transversely (Fig. 4).

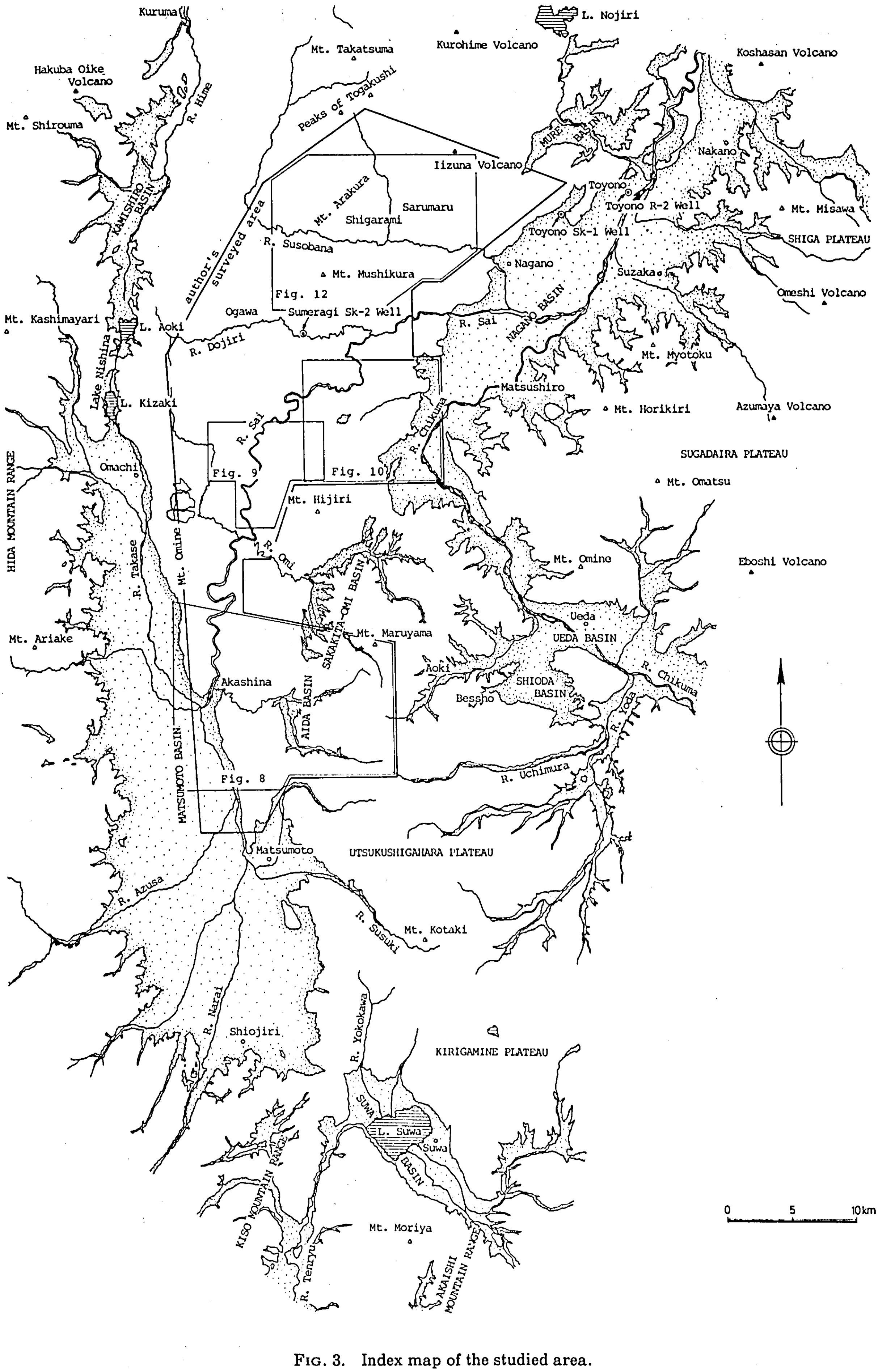


FIG. 3. Index map of the studied area.

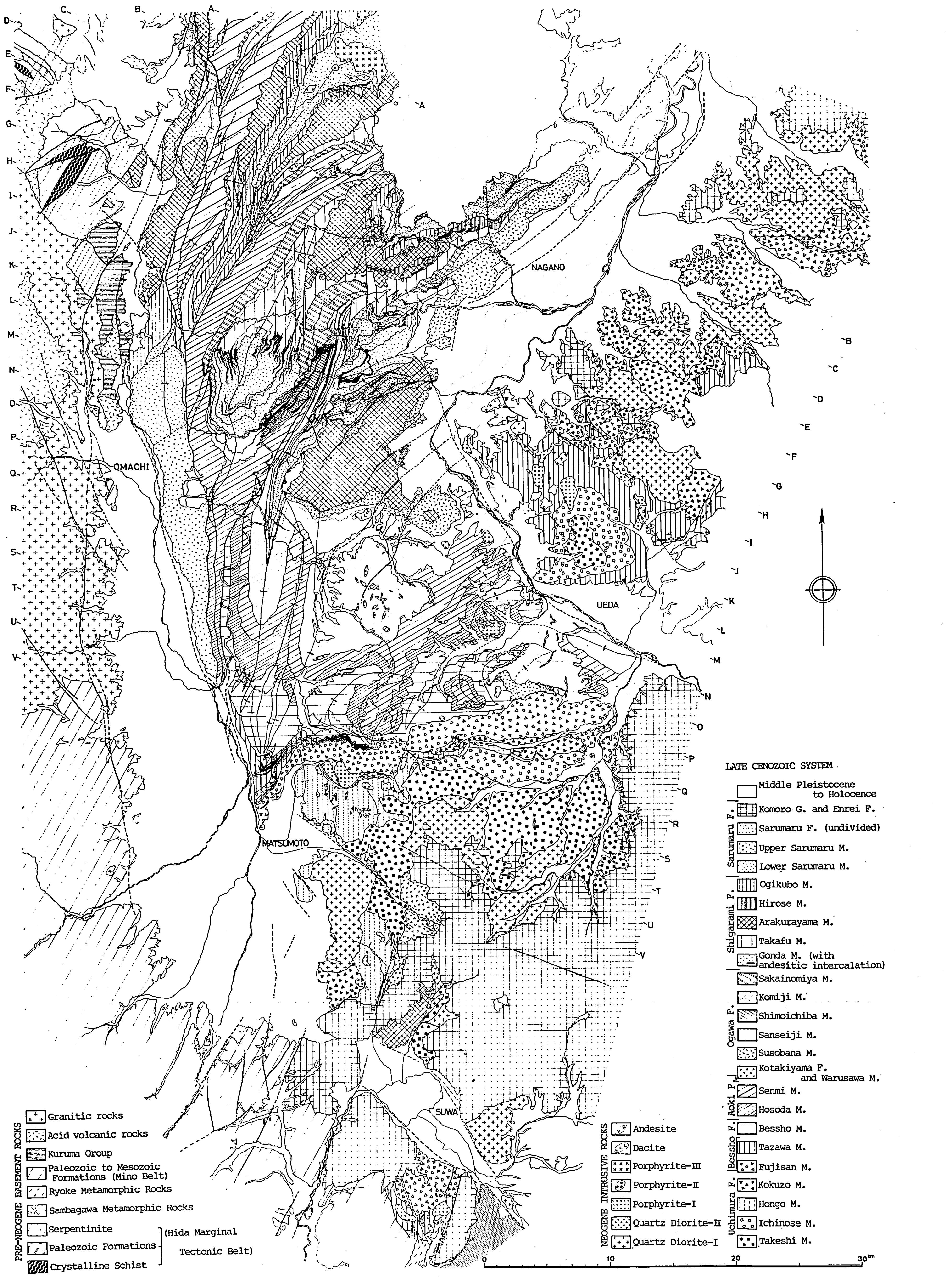


FIG. 5. Geological map of the northern Fossa Magna region (compiled from Ota and Katada, 1955; Inaba, 1959; Geological Association of Nagano Prefecture, 1962; Yamagishi, 1964; Ishii, 1976; Mizuno, 1976; Shibata *et al.*, 1976; Utsukushigahara C. R. G., 1977; Akahane, 1979; Kawachi and Aramaki, 1979; Kato, 1980; Saito and Akahane, 1980; Ishizawa, 1982; Yoshino, 1982; Kato and Sato, 1983; Kosaka, 1983; Shimodaira, 1983; in addition to the authors survey).

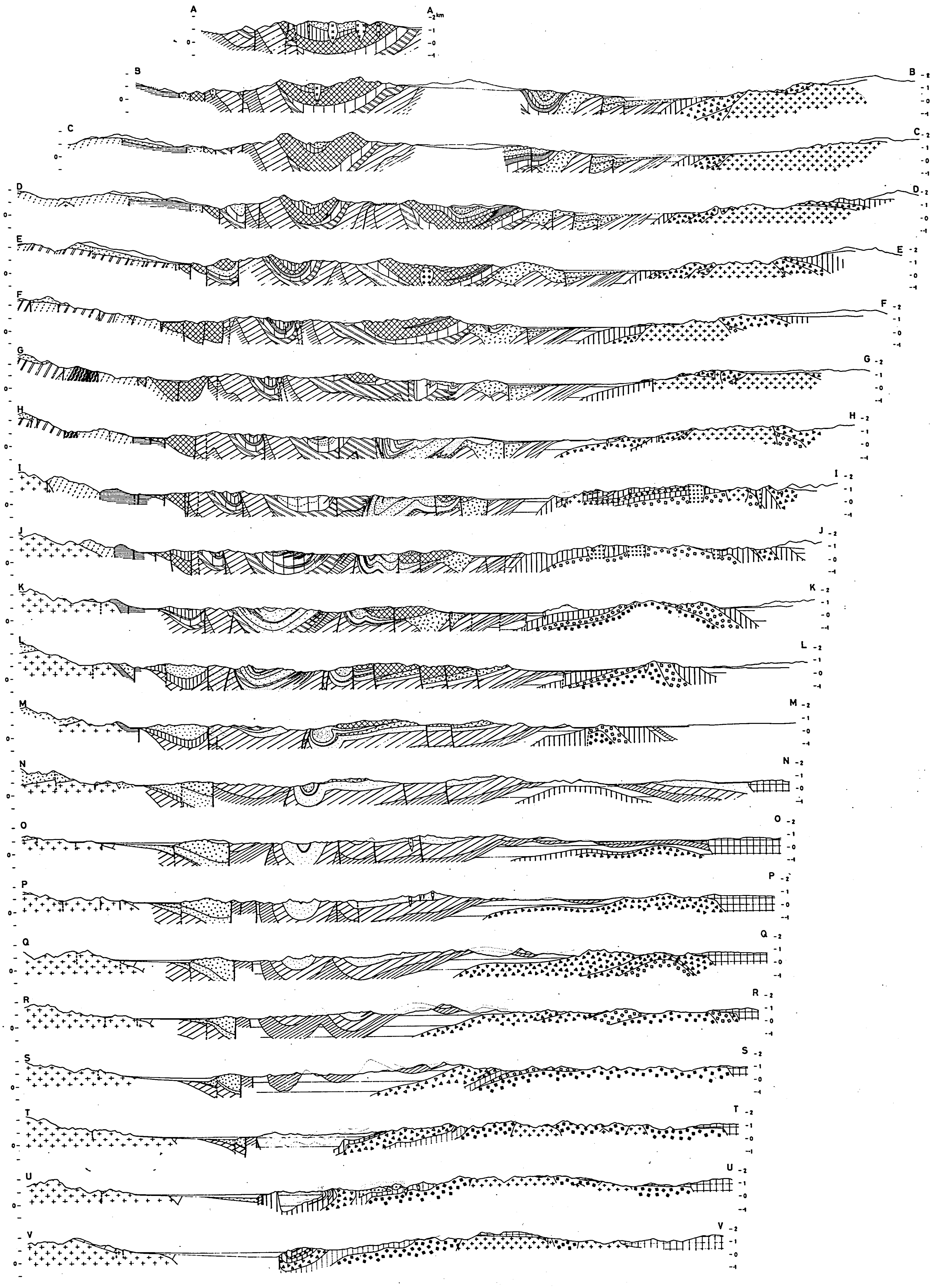


Fig. 6. Geological profiles of the northern Fossa Magna region. See the legend of Fig. 5.

III. Stratigraphy

The pre-Neogene basements are exposed extensively in the Hida and Kiso Mountain Ranges on the western and southwestern sides of the Itoigawa-Shizuoka Tectonic Line (Figs. 5, 6). The following rocks are arranged from north to south; the crystalline schist, serpentinite and Paleozoic formations of the Hida Marginal Tectonic Belt accompanied with the Lower Jurassic Kuruma Group, the Paleozoic to Mesozoic formations of the Mino Belt, the complex of gneiss and granite of the Ryoke Belt and the crystalline schist of the Sambagawa Belt. Also, the volcano-plutonic complex of Late Cretaceous to Paleogene age is extensively emplaced into the middle part of the Hida Mountain Range. On the other hand, the basement rocks cannot be found in the northern Fossa Magna region itself except the Yokokawagawa Metamorphic Rocks (an equivalent of the Sambagawa Metamorphic Rocks; Kawachi *et al.*, 1966) which crops out along a fault on the north of Lake Suwa.

Conversely, the Neogene to Quaternary sediments extend widely over the northern Fossa Magna, and beyond the Itoigawa-Shizuoka Tectonic Line a small part of them is preserved upon the basement rocks. The sediments accumulated in and around the northern Fossa Magna during Miocene to Middle Pleistocene attain more than 20800m in total maximum thickness, and are subdivided into seven formations, i.e., the Uchimura, Bessho, Aoki, Ogawa, Shigarami, Sarumaru and Toyono Formations in ascending order (Fig. 7). The lowest formation crops out in the large-scale domes of the Central Uplift Zone, and the next three formations are exposed in the Tochiku Half Basin and extensively in the Minochi Subsidence Zone. The further next Shigarami and Sarumaru Formations are distributed in the Minochi Subsidence Zone, and also in the Shigarami Volcanics Chain and the Omine, Komoro, Enrei Depressions. The uppermost Toyono Formation covers the underlying formations with a marked unconformity almost over the region.

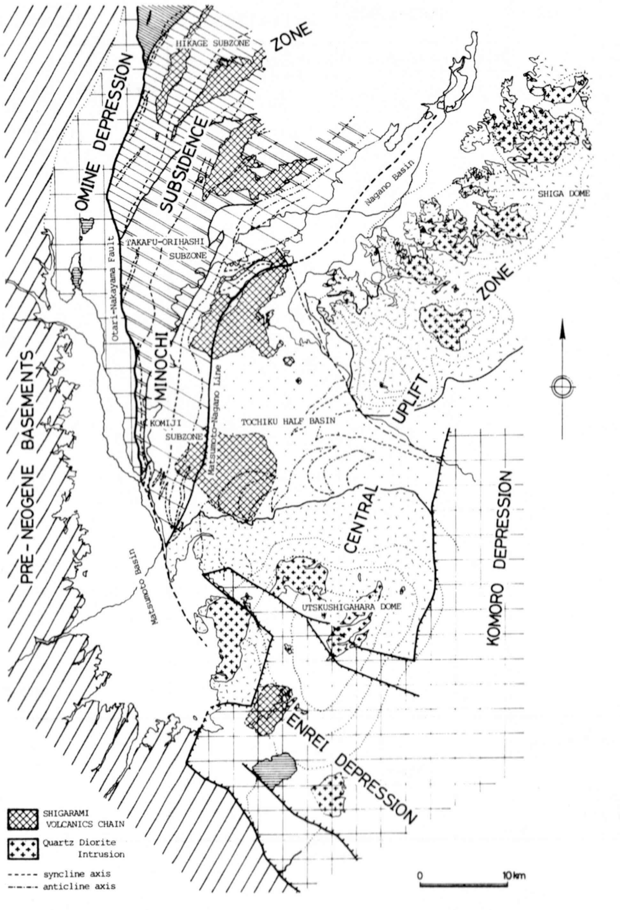


FIG. 4. Simplified structural map of the northern Fossa Magna region.

1. Uchimura Formation

The Uchimura Formation is exposed extensively as cores of the Utsukushigahara and Shiga Domes. Its lower limit and total thickness are unknown because of shallow erosional level and plutonic intrusion.

According to Uchimura Collaborative Research Group (hereafter symbolized " C. R. G.") (1953), Ota and Katada (1955), Inaba (1959), Yamagishi (1964), and Yoshino (1976, 1982), the characteristics of this formation are summerized as follows: The formation, being more than 4900 m in sum of maximum thickness of the exposed succession, consists of lava flows and pyroclastic rocks accompanied with clastic rocks, and is stratigraphically divided into the lower and upper parts.

a) Lower Uchimura Formation

The Lower Uchimura Formation is subdivided into three members, i.e., the Takeshi, Ichinose and Hongo Members. The former two are represented by volcanic facies. Due to marked hydrothermal alteration such as chloritization, epidotization, silicification, sericitization and pyritization, the volcanic rocks exhibit greenish color, and therefore are called the "Green Tuff" by the Japanese geologists customarily. The Takeshi Member consists of basaltic to dacitic volcanics with a thickness of 1500 m in exposed succession, and is accompanied with a large amount of black shale in the Shiga Dome. The Ichinose Member, 0 to 1300m thick, consists of dacitic to rhyolitic volcanics and overlies conformably the Takeshi Member. On the other hand, the clastic facies called the Hongo Member is distributed in the western marginal part of the Utsukushigahara Dome. This member, 0 to 1600 m thick, is composed of mudstone, sandstone and conglomerate, and tends to thin and fine toward the east. The volcanic and the clastic facies of the Lower Uchimura Formation interfinger mutually on the western flank of the Utsukushigahara Dome.

b) Upper Uchimura Formation

The Upper Uchimura Formation consists also of the volcanic and the clastic facies which interfinger with each other on the north of Matsumoto and complicatedly in the Shiga Dome. The volcanic facies is subdivided into the Kokuzo Member in the basal part and the Fujisan Member occupying the main part. The former is made up of moderately altered basalt with a thickness of 0 to 600m which exhibits partially pillow structure, and the latter of weakly altered glassy andesite to dacite with a thickness of 400 to 1500m. The clastic facies called the Tazawa Member, more than 1550m thick, consists mainly of black mudstone, occasionally containing volcanic materials on

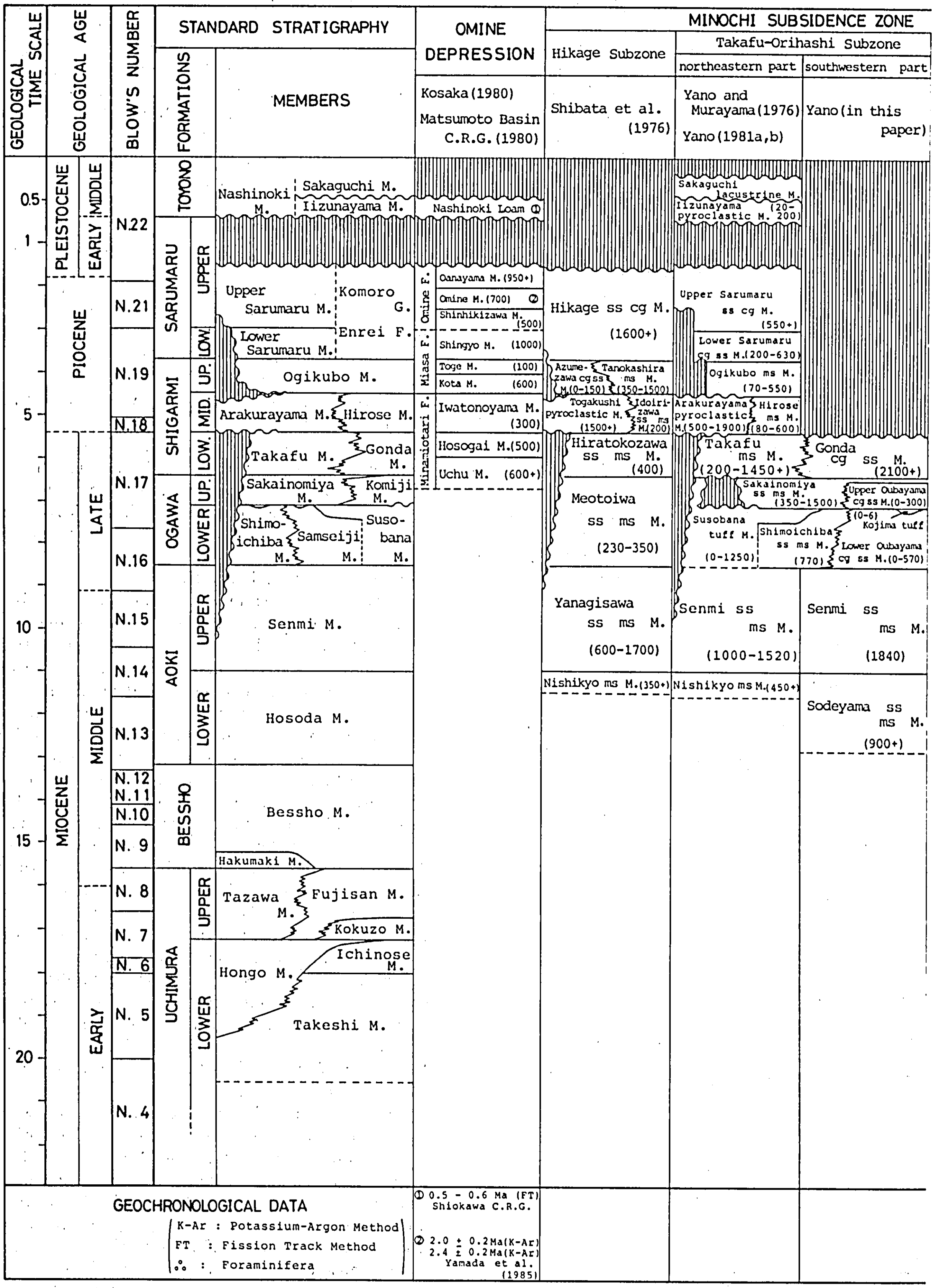
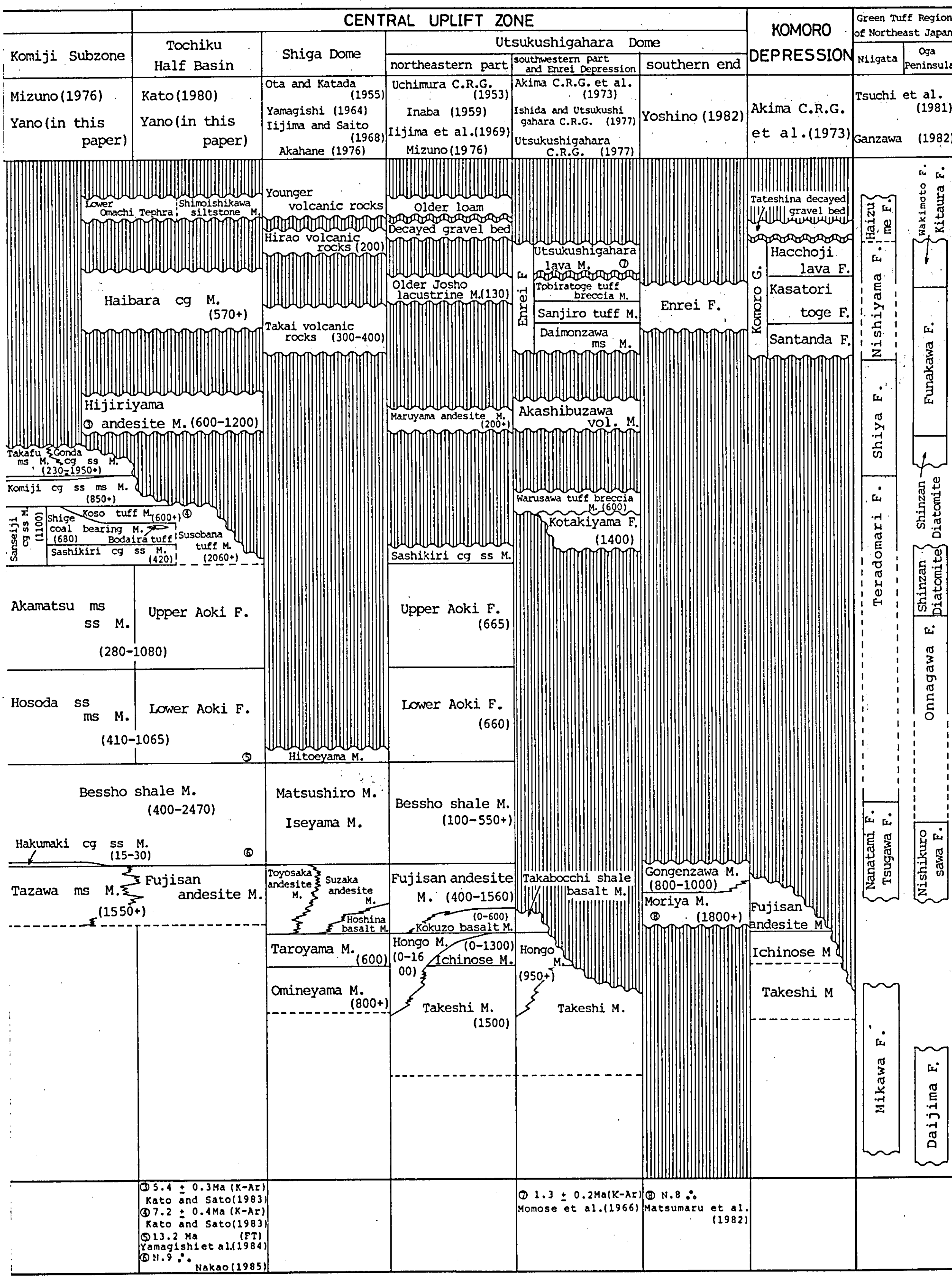


FIG. 7. Stratigraphy and correlation of the Upper Cenozoic System in the northern Fossa Magna region.


CENTRAL UPLIFT ZONE
KOMORO DEPRESSION
Green Tuff Region of Northeast Japan
Komiji Subzone
Tochiku Half Basin
Shiga Dome
Utsukushigahara Dome
northeastern part
southwestern part and Enrei Depression
southern end
Niigata
Oga Peninsula
Mizuno (1976)
Yano (in this paper)
Kato (1980)
Yano (in this paper)
Ota and Katada (1955)
Yamagishi (1964)
Iijima and Saito (1968)
Akahane (1976)
Uchimura C.R.G. (1953)
Inaba (1959)
Iijima et al. (1969)
Mizuno (1976)
Akima C.R.G. et al. (1973)
Ishida and Utsukushigahara C.R.G. (1977)
Utsukushigahara C.R.G. (1977)
Yoshino (1982)
Akima C.R.G. et al. (1973)
Tsuchi et al. (1981)
Ganzawa (1982)
Lower Omachi Tephra
Shimoishikawa siltstone M.
Younger volcanic rocks
Older loam
Decayed gravel bed
Hirao volcanic rocks (200)
Tateshina decayed gravel bed
Haizume F.
Wakimoto F.
Kitaura F.
Utsukushigahara lava M. ⑦
Tobiratoge tuff breccia M.
Sanjiro tuff M.
Daimonzawa ms M.
Enrei F.
Komoro G.
Hacchoji lava F.
Kasatori toge F.
Santanda F.
Nishiyama F.
Haibara cg M. (570+)
Older Josho lacustrine M. (130)
Takai volcanic rocks (300-400)
Funakawa F.
Hijiriyama ③ andesite M. (600-1200)
Maruyama andesite M. (200+)
Akashibuzawa vol. M.
Shiya F.
Takafu ms M.
Gonda cg ss M. (230-1950+)
Komiji cg ss ms M. (850+)
Warusawa tuff breccia M. (600)
Kotakiyama F. (1400)
Shinzan Diatomite
Sanseiji cg ss M. (1100)
Shige coal bearing M. (680)
Koso tuff M. (600+) ④
Bodaira tuff
Susobana tuff M. (2060+)
Sashikiri cg ss M. (420)
Sashikiri cg ss M.
Teradomari F.
Akamatsu ms ss M. (280-1080)
Upper Aoki F.
Upper Aoki F. (665)
Onnagawa F.
Hosoda ss ms M. (410-1065)
Lower Aoki F.
Lower Aoki F. (660)
⑤
Hitoeyama M.
Bessho shale M. (400-2470)
Matsushiro M.
Iseyama M.
Bessho shale M. (100-550+)
Hakumaki cg ss M. (15-30)
⑥
Nanatani F.
Tsugawa F.
Nishikurosawa F.
Tazawa ms M. (1550+)
Fujisan andesite M.
Toyosaka andesite M.
Suzaka andesite M.
Hoshina basalt M.
Fujisan andesite M. (400-1560)
Kokuzo basalt M. (0-600)
Takabocchi shale basalt M.
Gongenzawa M. (800-1000)
Moriya M. ⑧ (1800+)
Fujisan andesite M
Taroyama M. (600)
Hongo M. (0-1600)
Ichinose M. (0-1300)
Hongo M. (950+)
Ichinose M
Omineyama M. (800+)
Takeshi M. (1500)
Takeshi M.
Takeshi M
Mikawa F.
Daijima F.
③ 5.4 ± 0.3Ma (K-Ar) Kato and Sato (1983)
④ 7.2 ± 0.4Ma (K-Ar) Kato and Sato (1983)
⑤ 13.2 Ma (FT) Yamagishi et al. (1984)
⑥ N.9 Nakao (1985)
⑦ 1.3 ± 0.2Ma (K-Ar) Momose et al. (1966)
⑧ N.8 Matsumaru et al. (1982)

the north of Matsumoto, and frequently intercalating layers of sandstone and conglomerate around Mt. Moriya, southernmost part of the Utsukushigahara Dome. In the Shiga Dome, this member comprises so much amount of andesite that it is designated as the Toyosaka Andesite Member (Fig. 7).

Thus, the Uchimura Formation is characterized by the enormous volcanic rocks of two cycles (each from basic to acid), and by the peculiar hydrothermal alteration called the "Green Tuff Alteration".

2. *Bessho Formation*

The Bessho Formation is characterized by the predominance of monotonous black shale and mudstone, being in conformable contact with the Uchimura Formation. It attains a maximum thickness of 2470 m on the north of Matsumoto, but thins gradually toward the east and abruptly toward the west (Figs. 8, 9). The formation is subdivided into the Hakumaki and the Bessho Member.

The Hakumaki Member, 15 to 30 m thick, is composed of fine- to medium-grained sandstone, accompanied with dacitic tuff at the base. This tuff is a bottom marker which separates the Bessho Formation from the underlying Tazawa Member of the Uchimura Formation.

The Bessho Member occupying the majority of the formation consists of black shale and mudstone, accompanied with a minor amount of mudstone-

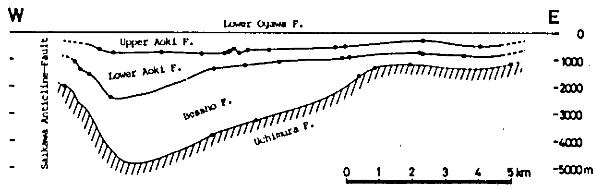


FIG. 9. Stratigraphic profile of the Uchimura to Aoki Formation in the area to the north of Matsumoto.

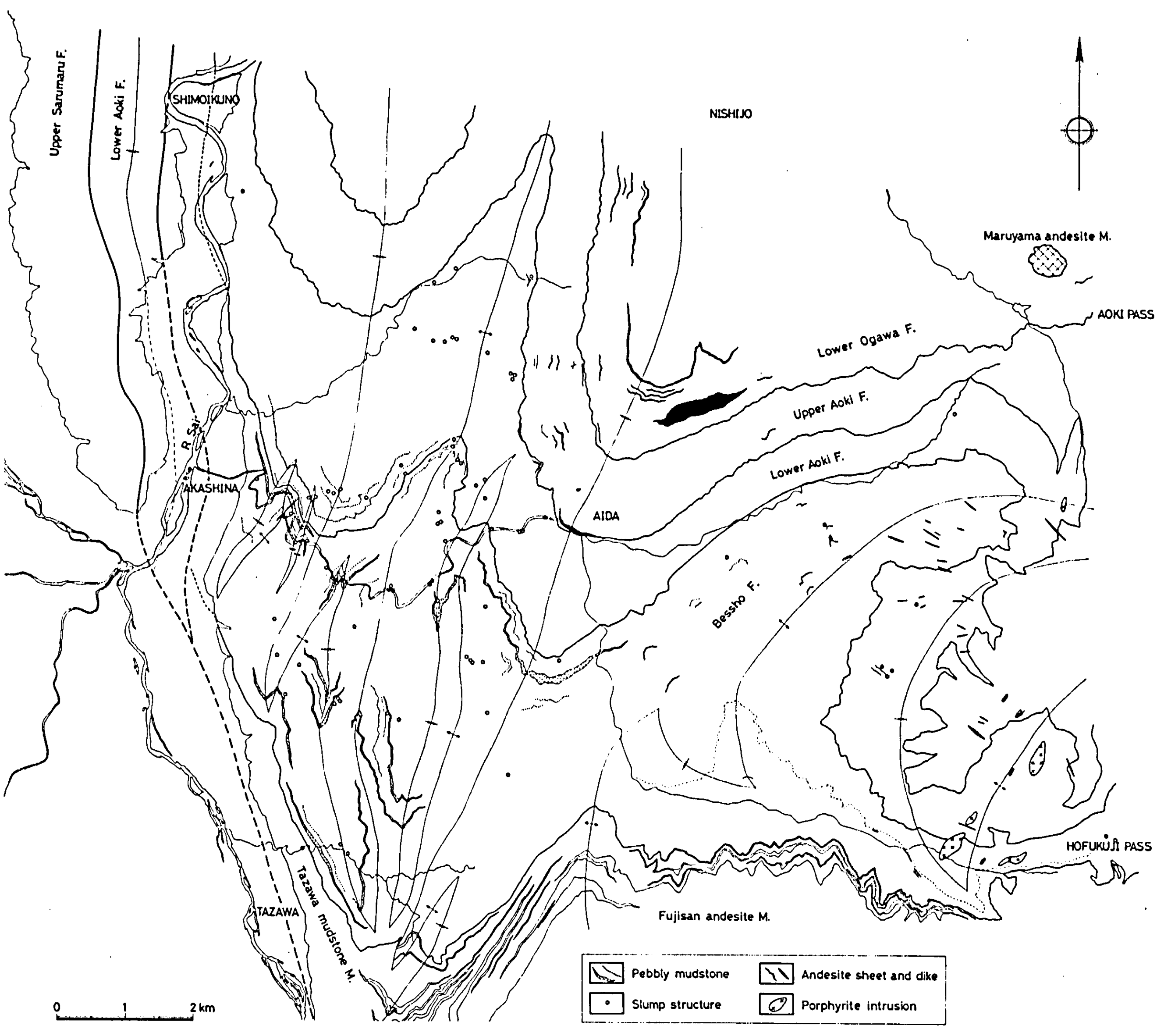


FIG. 8. Geological map of the area to the north of Matsumoto.

dominant sandstone-mudstone alternation. Seams of glauconitic sandstone are intercalated near the basal horizon, and a small amount of volcanic materials is contained on the north of Matsumoto. Disturbed structures such as slump fold and slump ball together with pebbly mudstone occur locally (Fig. 8).

Thus, the Bessho Formation plays a role of key formation over the region because of its remarkable monotonous facies. It is also noticed that the thickness tends to increase from the axial part to the flank of dome in the Central Uplift Zone.

3. Aoki Formation

The Aoki Formation consists exclusively of sandstone-mudstone alternation exhibiting a flysch appearance, and comprises two upward-fining cycles of which the upper cycle is more abundant in sandstone than the lower. Such a facies is very stable over its extensive distribution.

a) Lower Aoki Formation

The Lower Aoki Formation overlies conformably the Bessho Formation and is represented by the Hosoda Sandstone Mudstone Member. It consists mainly of massive mudstone, mudstone laminated with very fine-grained sandstone and mudstone-dominant alternation, accompanied with a minor amount of bedded sandstone and conglomerate. The base is marked by conglomerate and sandstone with a thickness of 10 to 65 m which are traced clearly over the region. The lithofacies tends to fine upward and to coarsen slightly southwestward. Disturbed structures such as slump fold and slump ball as well as pebbly mudstone develop in many places, especially at the uppermost horizon on the east-southeast of Omachi. The member has a maximum thickness of 1650 m on the north of Matsumoto, but thins gradually toward the east and abruptly toward the west (Fig. 9). In the Takafu-Orihashi and Hikage Subzones, the thickness is unknown because the bottom is not exposed.

b) Upper Aoki Formation

The Upper Aoki Formation is represented by the Senmi Sandstone Mudstone Member. It consists mainly of mudstone, sandstone-mudstone alternation, and bedded sandstone accompanied with conglomerate. The layers of fine-to medium-grained sandstone frequently with muddy seams, about 10 to 200m thick, are intercalated at many horizons. The sandstone-mudstone alternation shows distinct graded bedding, parallel lamination and ripple-cross lamination. The lithofacies tends to fine upward and to coarsen toward the east of Omachi. Structures showing penecontemporaneous erosion are observed occasionally in the upper part of the member on the eastern margin of southern Komiji Subzone and on the western margin of the southern Takafu-Orihashi Subzone. The thickness changes abruptly beyond the Saikawa and the Nishikyo Anticline, and a maximum (more than 1840 m) is in the southwestern part of the Takafu-Orihashi Subzone.

Thus, the Aoki Formation exhibits a flysch-like facies and forms two upward-fining cycles. The abrupt change of thickness beyond the leading anticlines in the Minochi Subsidence Zone is also a characteristic of this formation.

4. Ogawa Formation

The Ogawa Formation displays a remarkable differentiation of sedimentary facies in lateral direction. Stratigraphically, it is divided into the Lower Ogawa and the Upper Ogawa Formation, each of which is subdivided further into two or three members of different facies. Besides, the Kotakiyama Facies is developed isolatedly.

a) Kotakiyama Facies

According to Utsukushigahara C. R. G. (1977), the Kotakiyama Facies distributing in the central part of the Utsukushigahara Dome is characterized by lava flows and pyroclastics of hornblende andesite, and is composed of the Kotakiyama Formation and the Warusawa Tuff Breccia Member. The Kotakiyama Formation, about 1500m thick, rests unconformably upon the pre-Neogene Yokokawagawa Metamorphic Rocks, the Takeshi Member of the Uchimura Formation and the Quartz Diorite intruding into the Takeshi Member. The basal conglomerate is ill-sorted, comprizing subangular to angular cobbles and boulders (2 m in maximum diameter) derived directly from the surrounding basement rocks. It is confirmed that the lower and middle parts of the Kotakiyama Formation intercalate layers of mudstone occasionally containing plant fragments, and abut to the basements along the western margin. The Warusawa Tuff Breccia Member, about 600m thick, consists of pyroclastics of hornblende andesite with arenaceous mudstone seams, covering the Kotakiyama Formation with an unconformity.

The Kotakiyama Formation is intruded by diorite with an extent of 1 × 0.5 km.

b) Lower Ogawa Formation

The Lower Ogawa Formation is composed of contemporaneous three members, i.e., the Susobana, Sanseiji and Shimoichiba Members. The latter two overlay conformably the Senmi Member of Aoki Formation, but the relationship between the Susobana Member and the underlying strata is unknown for the most part.

Susobana Member

The Susobana Member is represented by lava flows and pyroclastics of rhyolite to dacite. Of this member, the exposures along the northwestern fringe of the Nagano Basin and along the southern foot of Mt. Hijiri are called the Susobana and the Koso Tuff Member, respectively.

The base of the Susobana Tuff Member is not exposed except the Asakawa Mudstone Member in the north of Nagano. The Susobana Tuff Member, more than 2060m thick, is subdivided into five units at least, i.e., S1 to S5 Unit in assending order at the southwestern end of the Nagano Basin (Fig. 10). Main constituent rocks are as follows; S1 Unit (more than 130m thick), dacitic pumice tuff; S2 Unit (more than 590 m thick), compact crystal tuff, abundant in large high-quartz crystals and locally welded; S3 Unit (about 320 m thick), plagiorhyolitic lava; S4 Unit (150 to 220m thick), porphyritic plagiorhyolite lava, turning into pealite lava at the northeastern end; S5 Unit (more than 800m thick), massive dacitic crystal tuff, containing abundant large high-quartz crystals besides pumice. The rocks underwent hydrothermal alteration along the Hijirigawa Fault and especially along the

Sanogawa Fault.

On the other hand, along the southern foot of Mt. Hijiri the Bodaira Tuff (Morishita *et al.*,1957) consisting of pumiceous acid tuff of about 10 to 30m in thickness, is intermittently intercalated in the upper part of the Sanseiji Member to be described below. It is inferred to be an extension of a part of the Susobana Tuff Member. The Koso Tuff Member resting upon the Sanseiji Member with a conformity is about 600m thick in the east (Kato,1980) and thins out finally in the western margin of the Komiji Subzone. This member consists mainly of massive dacitic crystal tuff, containing abundant large high-quartz crystals in addition to pumice and partly welded. Judging from the lithofacies, the Koso Tuff Member is an equivalent of the S5 Unit of Susobana Tuff Member.

Recently, the northwestern extension of the Susobana Member has been confirmed in the Takafu-Orihashi Subzone. The Kojima Tuff found at the middle horizon of the Oubayama Sandstone in the southern part of the subzone consists of massive dacitic pumiceous crystal tuff (6m in maximum thickness) abundant in large high-quartz crystals (Yano,1983a). Based on the resemblance in lithofacies and the composition of heavy minerals (Fig. 11), the Kojima Tuff is a correlative with the Koso Tuff Member and also with the S5 Unit of Susobana Tuff Member. The Sumeragi SK-2 well boring for the exploitation of natural oil and gass on the south of Mt. Mushikura (Fig. 3) has also cored a dacitic crystal tuff of about 45m in thickness at a depth of 2000m under the ground (Mining Society of Natural Gass and Japanese Association for Petroleum Exploitation in Continental Shelf, 1982), which remarkably resembles to the dacitic tuff of S5 Unit of the Susobana Tuff Member. Thus, it became possible to trace the top horizon of the Susobana Member into the Takafu-Orihashi Subzone, and it was clarified that only the S5 Unit displayed an exceptionally extensive distribution among the five units of Susobana Member.

Sanseiji Member

The Sanseiji Member conformably overlies the Senmi Member of the Aoki Formation, but the change in lithofacies between the two members is abrupt. It consists mostly of massive or thick-bedded fine- to coarse-grained sandstone, conglomeratic sandstone and pebble conglomerate, with occasional intercalation of arenaceous mudstone seams. The sandstone is white-colored and arkosic. The lower half of this member extends from the Tochiku Half Basin to the southern Takafu-Orihashi Subzone with an uniform lithofacies mostly of shallow marine environment, but the upper half shows a considerable facies-variation from non-marine to shallow marine condition. A greenish-colored carbonaceous mudstone with coal seams is frequently intercalated in non-marine sediments. Some of the coal seams were mined before. In the north-east Komiji Subzone and the middle Takafu-Orihashi Subzone, the Sanseiji Member as a whole consists of fine-grained bedded sandstone and sandstone-dominant sandstone-mudstone alternation, and interfingers northward with the Shimoichiba Member.

Shimoichiba Member

The Shimoichiba Member crops out only along

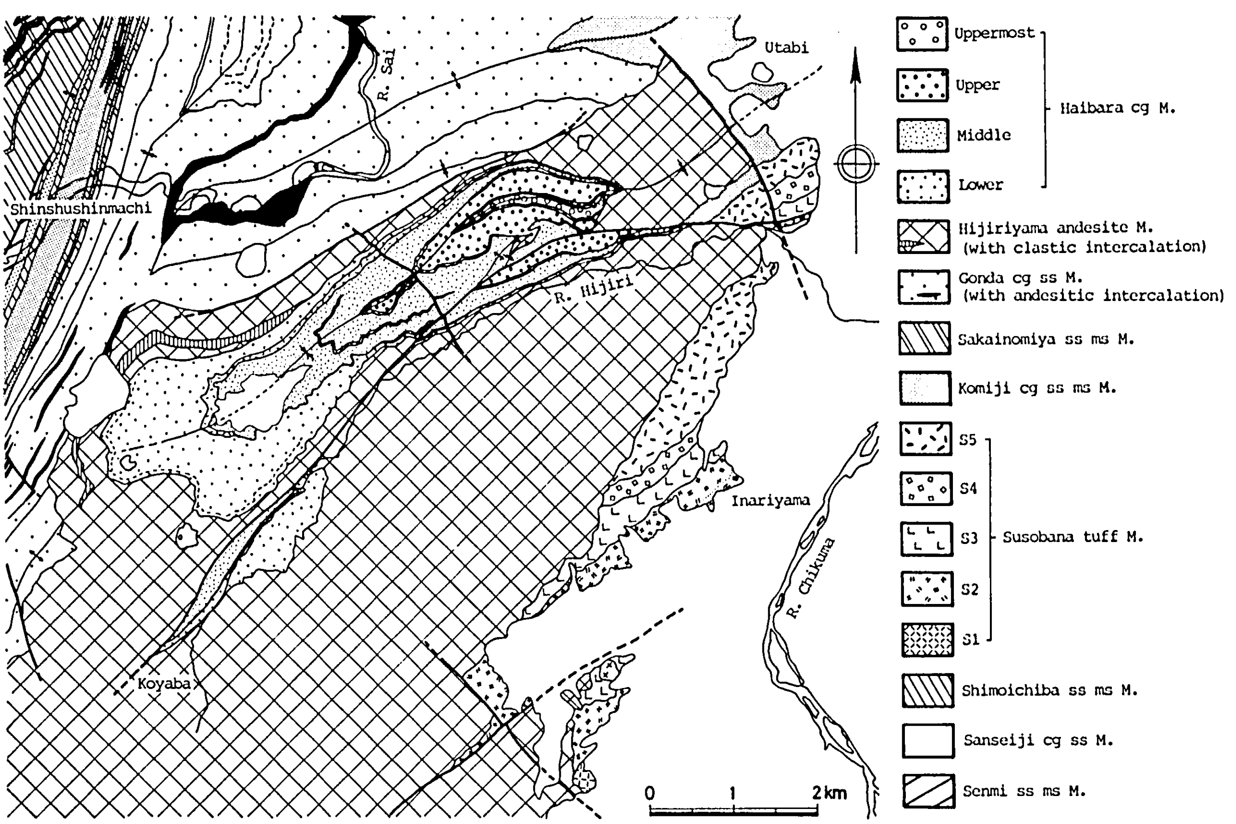


FIG. 10. Geological map of the southwestern part of Nagano Basin.

the middle stream of the Sai River as a core of the Saikawa Anticline, and consists of mudstone and sandstone-mudstone alternation.In the Sumeragi SK-2 well, this member is about 400m thick (from 2000 to 2430 m in depth), overlain by the top maker (S5 Unit) of the Susobana Tuff Member (Mining Society of Natural Gass and Japanese Association for Petroleum Exploitation in Continental Shelf, 1982).

The total thickness of the Sanseiji-Shimoichiba Member is 1100m in maximum at the southern Komiji Subzone, but decreases gradually toward the east and abruptly toward the west. Also, it is 770m at the eastern margin of the middle Takafu-Orihashi Subzone, decreasing monotonously toward the west.

c) Upper Ogawa Formation

The Upper Ogawa Formation is composed of the Komiji and Sakainomiya Members, which are interfingering with each other. The formation is exposed within the Monochi Subsidence Zone and limitedly at the southern foot of Mt. Hijiri in the Central Uplift Zone. The maximum thickness is about 1500m at Sumeragi on the south of Mt. Mushikura.

Komiji Member

The Komiji Member is characterized by the predominance of coarse-grained sediments. It exposed separately in the following three areas with different facies. On the southwest of Nagano, the member covers unconformably the Susobana Tuff Member with a basal conglomerate containing cobbles and boulders derived from the Susobana Member, and consists chiefly of medium- to coarse-grained, white quartzose sandstone.Such a lithofacies tends to fine toward the northeast and changes into that of the Sakainomiya Member. In the southern Komiji Subzone, the present member comprises a number of upward-fining cycles, each of which is 10 to 25 m in thickness and is composed of conglomerate, sandstone and greenish-colored mudstone with coal seams. In the southern Takafu-Orihashi Subzone, the member consists of massive or thick-bedded fine- to coarse-grained sandstone, conglomeratic sandstone and conglomerate accompanied with arenaceous mudstone seams. The Komiji Member in the latter two areas conformably overlies the Koso and Sanseiji Members, and interfingers northward with the Sakainomiya Member.

Sakainomiya Member

The Sakainomiya Member consists mostly of mudstone and mudstone-dominant sandstone-mudstone alternation, accompanied with bedded sandstone. It is exposed in the northern part of the Minochi

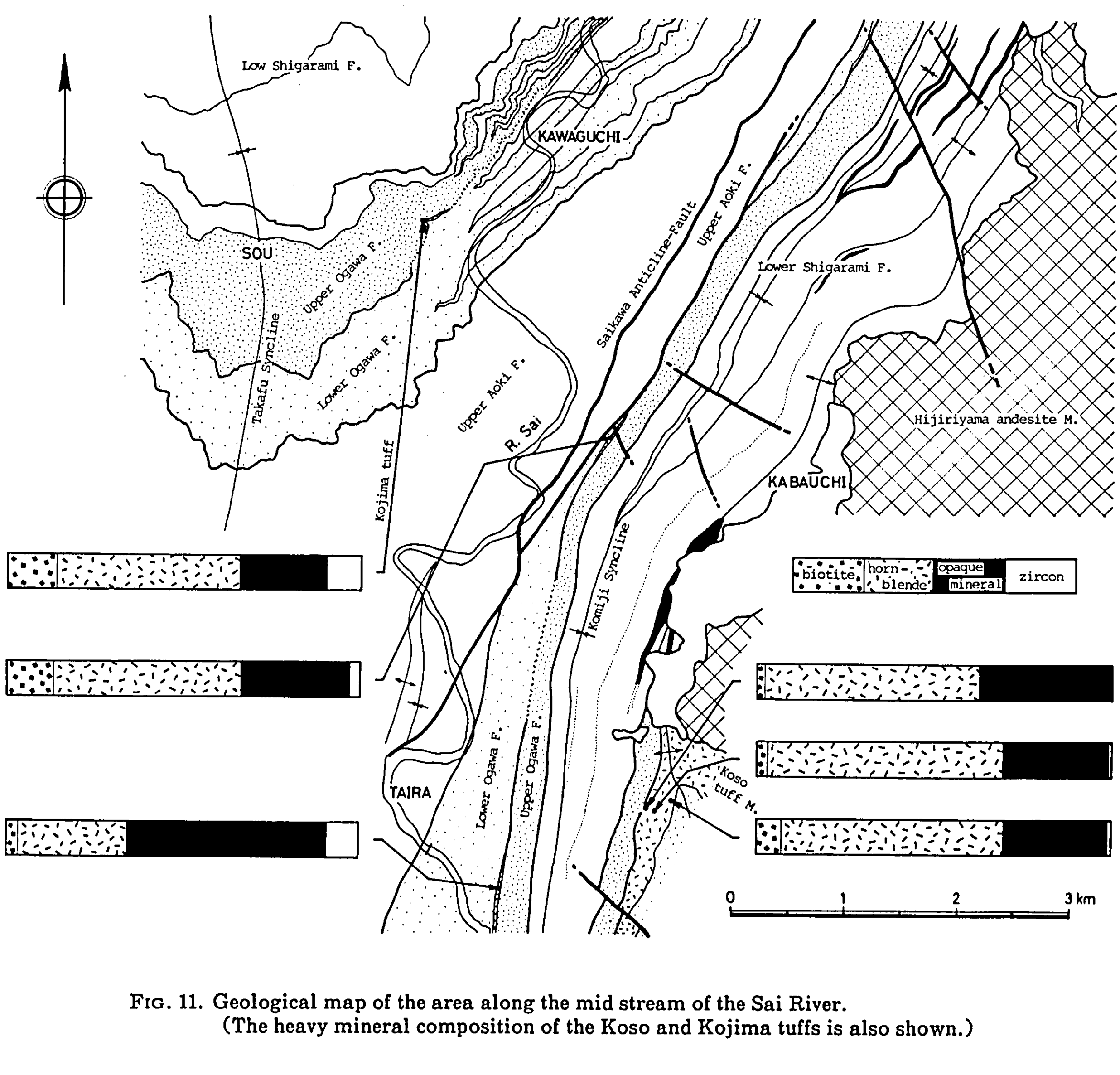


FIG. 11. Geological map of the area along the mid stream of the Sai River. (The heavy mineral composition of the Koso and Kojima tuffs is also shown.)

Subsidence Zone repeatedly by folds. It unconformably overlies the Susobana Tuff Member on the west of Nagano (Yano, 1981b), and conformably the Shimoichiba Member along the middle stream of the Sai River.

As a whole, the following four facies are recognized in the Ogawa Formation. The intermediate volcanic facies with succeeding plutonic intrusion in the collapse basin at the apex of dome in the Central Uplift Zone (Kotakiyama Facies), the acid volcanic facies on the flank of the zone (Susobana Facies, represented by the Susobana Member), the molasse-like coarse clastic facies in the frontal area of the zone (Tochiku Facies,represented by the Sanseiji and Komiji Members) and the muddy flysch-like clastic facies far off the zone (Minochi Facies, represented by the Shimoichiba and Sakainomiya Members).

5. Shigarami Formation

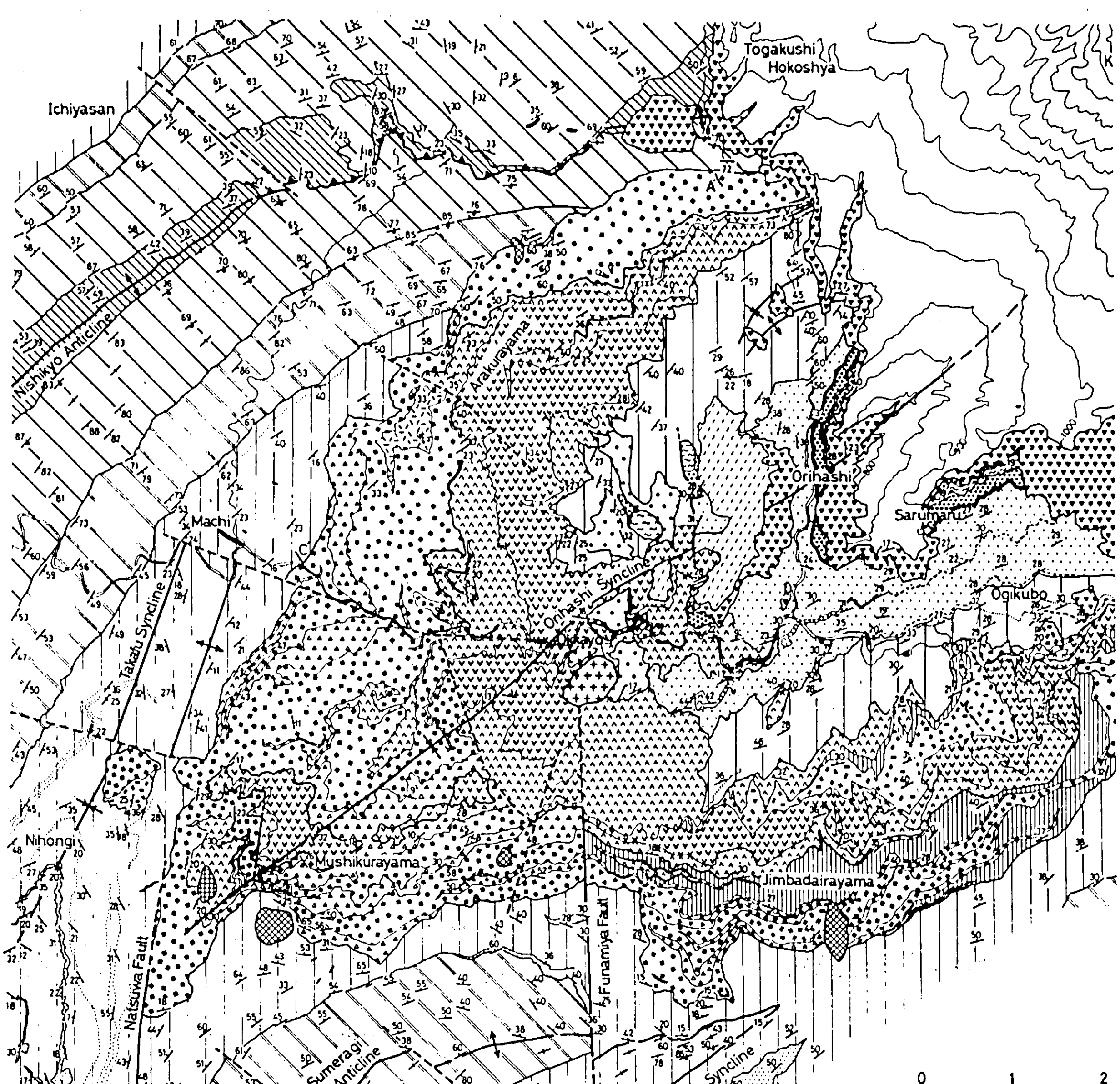
The Shigarami Formation is distributed largely in the central and northwestern Minochi Subsidence Zone, and consists of mudstone, sandstone and conglomerate, accompanied with a thick series of andesitic lava and pyroclastics. The formation exhibits a complicated facies-change in lateral direction, and is stratigraphically divided into the lower, middle and upper parts by partical unconfomities.

a) Lower Shigarami Formation

The Lower Shigarami Formation conformably overlies the Upper Ogawa Formation and overlaps the Susobana Tuff Member of the Lower Ogawa Formation on the northwest of Nagano (Yano, 1981b). It is composed of the Gonda and the Takafu Member, which interfinger with each other on a large scale in the central Minochi Subsidence Zone. The thickness is markedly variable and attains a maximum of more than 2400 m in the eastern part of the middle Takafu-Orihashi Subzone.

Gonda Member

The Gonda Member consists mostly of coarse-



grained clastics such as sandstone, conglomeratic sandstone and conglomerate. The sandstone is black-colored and dirty in appearance, containing a large amount of volcanogenic clasts especially at the middle horizon. The present member displays a lateral facies-change as follows: In the southern to middle Komiji Subzone, the member comprises a number of upward-fining cycles (each being 10 to 45 m in thickness) resembling those of the underlying Komiji Member; lenses of andesitic lavas and pyroclastics are included there. The main part of the Gonda Member distributed in the northeastern Komiji Subzone and the middle Takafu-Orihashi Subzone, consists mostly of massive or thick-bedded fine- to coarse-grained sandstone, conglomeratic sandstone and pebble to cobble conglomerate, intercalated occasionally with seams of arenaceous mudstone and pyroclastics. Such a lithofacies grades northward into argillaceous very fine-grained sandstone, and thus the Gonda Member interfingers with the Takafu Member. On the southwest of Mt. Mushikura, a part of the Gonda Member which consists of fine- to coarse-grained sandstone and pebble to cobble conglomerate, occurs as lenticular bodies (each being 15 to 45 m in thickness) in the Takafu Member.

Takafu Member

The Takafu Member is characterized by monotonous dark grey mudstone, accompanied in the Hikage Subzone with a minor amount of mudstone-dominant sandstone-mudstone alternation. Thin layers of andesitic and partly dacitic pyroclastics are intercalated, which tend to coarsen and thicken toward Mt. Mushikura in the central Takafu-Orihashi Subzone.

b) Middle Shigarami Formation

The middle Shigarami Formation is composed of the Arakurayama and the Hirose Member. The former is characterized by a thick series of andesitic lavas and pyroclastics, whereas the latter by a mudstone-dominant facies. They interfinger with each other in the Hikage, Takafu-Orihashi Subzones and a part of the Komiji Subzone.

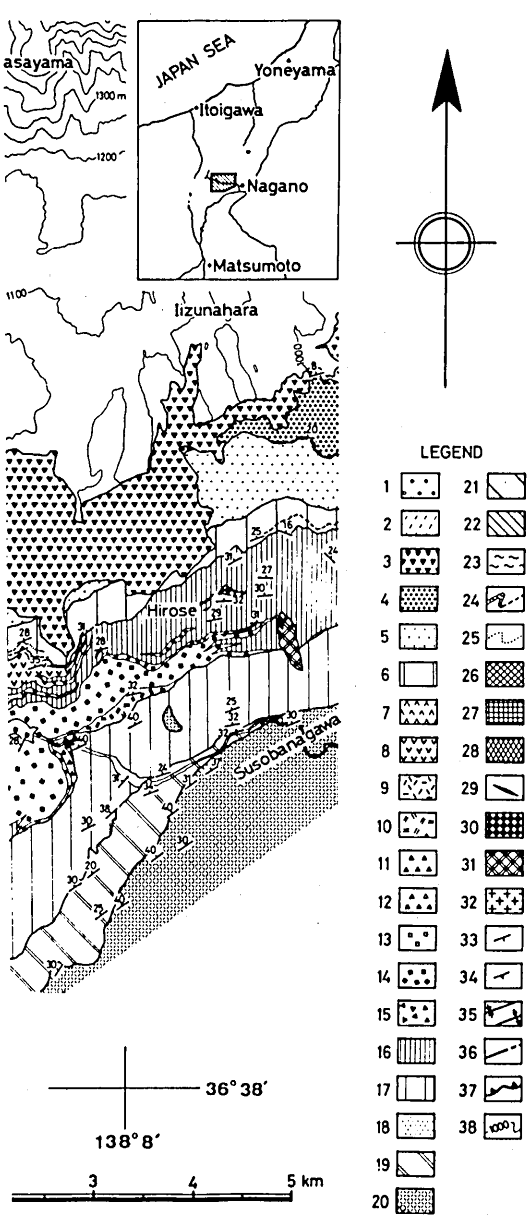


FIG. 12. Geological map of the Shigarami area (after Yano, 1981b).
1: Tanokashira gravel bed, 2: Shimizu sand and silt bed, 3: Iizunayama pyroclastic Member, 4: Upper Sarumaru sandstone and conglomerate Member, 5: Lower Sarumaru conglomerate and sandstone Member, 6: Ogikubo sandstone and mudstone Member, 7–15: Arakurayama pyroclastic Member, 7: hornblende-hypersthene-augite andesite, 8: hypersthene-augite andesite, 9: hornblende andesite, 10: augite-hornblende andesite, 11: hypersthene-augite-hornblende andesite, 12: hypersthene-hornblende-augite andesite, 13: hypersthene-bearing augite andesite, 14: augite andesite and olivine-augite andesite, 15: accessory tuff breccia, 16: Hirose mudstone Member, 17: Takafu mudstone Member, 18: Gonda conglomerate and sandstone Member, 19: Sakainomiya sandstone and mudstone Member, 20: Susobana tuff Member, 21: Senmi sandstone and mudstone Member, 22: Nishikyo mudstone Member, 23: welded tuff, 24: acid tuff, 25: andesitic pyroclastics, 26–32: intrusive rocks, 26: hornblende andesite, 27: hypersthene- or augite-bearing hornblende andesite, 28: hypersthene-augite-hornblende andesite, 29: olivine-augite andesite and hypersthene-augite andesite, 30 : augite andesite, 31: hypersthene-augite andesite, 32: hornblende-hypersthene-augite porphyrite, 33: strike and dip of bedding plane, 34: strike and dip of platy joint, 35: fold axis, 36: fault, 37: over-thrust, 38: geonorphological contour line.

Arakurayama Member

The volcanic bodies of the Arakurayama Member are distributed not only in the Minochi Subsidence Zone, but also in the Central Uplift Zone, forming the Shigarami Volcanics Chain in N-S direction oblique to the general trend of the Green Tuff Basin in the northern Fossa Magna region (Fig. 4). Each of the volcanic bodies is named from north to south the Togakushi Pyroclastic, the Arakurayama Pyroclastic, the Hijiriyama Andesite, the Maruyama Andesite and the Akashibuzawa Volcanic Member (Yagi and Yagi, 1958; Takeshita *et al.*, 1960; Morishita *et al.*, 1957; Mizuno, 1976; Ishida and Utsukushigahara C. R. G., 1977). The whole of the Togakushi Member, the lower half and the marginal part of the upper half of the Arakurayama Member consist of submarine volcanic products, and also the northwestern margin of the Hijiriyama Member exhibits subaqueous nature. All of the remainings, i.e., the central part of upper half of the Arakurayama Member, the most part of the Hijiriyama Member, and the Maruyama and Akashibuzawa Members, are characterized by volcanics of subaerial facies.

A partial unconformity is recognized at the base of the volcanic bodies. The denudation of sediments during the period represented by this unconformity tends to become more serious from north to south. The Togakushi Member covers the strata from Lower Shigarami to Upper Aoki Formation on its northwestern margin with an unconformity, but in other areas it covers the Lower Shigarami Formation with a conformity. The Arakurayama Member unconformably overlies the Lower Shigarami to Upper Aoki Formation in its central to northwestern part, but a conformable relationship is presumed in the eastern part (Fig. 12). The thickness of eroded strata is estimated to attain a maximum of more than 1800m at the northern end. The Hijiriyama Member covers the Lower Shigarami to Lower Ogawa Formation entirely with an unconformity, cutting off the fairly tilted pyroclastic units of the Susobana Tuff Member on its eastern margin (Fig. 10). The Maruyama Member rests unconformably upon the Lower Ogawa Formation and the Akashibuzawa Member also upon the Ogawa and Uchimura Formations and the quartz diorite.

Hirose Member

The Hirose Member consists of mudstone and mudstone-dominant sandstone-mudstone alternation in the Hikage Subzone, monotonous mudstone in the Takafu-Orihashi Subzone, mudstone, sandstone and conglomerate in the Komiji Subzone. Thin lenses of pyroclastic rock are contained near the Arakurayama Member.

The Middle Shigarami Formation tends to thicken toward the centers of volcanic bodies in the Hikage and Takafu-Orihashi Subzones; the muximum thickness is more than 1900 m in the northeast of Mt. Mushikura.

c) Upper Shigarami Formation

The Upper Shigarami Formation is represented by the Ogikubo Mudstone Member, and is distributed in the northeastern Takafu-Orihashi Subzone and the Hikage Subzone. It consists mostly of arenaceous mudstone and partly of contemporaneous coarse-grained clastics such as conglomerate and sandstone. Seams of andesitic pyroclastics and pumice tuff are occasionally intercalated. The formation overlies the Middle Shigarami Formation with a conformity for the most part, but an unconformity is observed near the centers of volcanic bodies of the Arakurayama Member. The Togakushi Pyroclastic Member on the northwestern slope of Peaks of Togakushi and the major part of the Arakurayama Pyroclastic Member are unconformably overlain by the coarse-grained clastics of the Upper Shigarami Formation (Shibata *et al.*, 1976; Yano and Murayama, 1976; Yano, 1981a). The basal conglomerate contains abundant subangular to rounded boulders and cobbles of andesite (7 m in maximum diameter) derived from the underlying volcanic bodies.

The Upper Shigarami Formation attains 1500 m in maximum thickness at the northwestern end of Hikage Subzone. In each subzone, it tends to thicken northwestward and conversely to thin southeastward, pinching out at the northeastern ends.

The Shigarami Formation is, as a whole, characterized by the predominance of mudstone, though a large amount of sandstone and conglomerate develops in the lower part of the southern area. The several large andesitic volcanic bodies arranged in N-S direction in the middle part are also characteristic of the formation.

6. Sarumaru Formation

The Sarumaru Formation in a wide sense is composed of coarse-grained clastic facies and volcanic one. The former is represented by the Sarumaru Formation in a narrow sense and the latter by the Komoro Group and the Enrei Formation.

a) Sarumaru Formation (s.s.)

The Sarumaru Formation (s.s.) consists mainly of sandstone and conglomerate, accompanied with greenish-colored mudstone in the upper part. Layers of acid tuff are also intercalated.

In the northeastern part of the Takafu-Orihashi Subzone, this formation overlies conformably the Ogikubo Member of the Shigarami Formation, and exceptionally overlaps the Arakurayama Pyroclastic Member on the northeast of Mt. Mushikura as well as the Susobana Tuff Member at the northeastern end of the subzone. It is subdivided into two conformable members of the Lower Sarumaru Conglomerate Sandstone Member and the Upper Sarumaru Sandstone Conglomerate Member. The Lower Sarumaru Member consists of fine- to coarse-grained sandstone, conglomeratic sandstone and pebble conglomerate, accompanied with mudstone and acid tuff, tending to coarsen upward. The Upper Sarumaru Member exhibits a very coarse lithofacies, consisting mainly of pebble to cobble conglomerate, accompanied with fine- to coarse-grained sandstone, greenish-colored mudstone and acid tuff (partially welded). Seams of lignite are intercalated in the both members.

In the Hikage Subzone the formation displays a little finer lithofacies than in the Takafu-Orihashi Subzone, and conformably overlies the Ogikubo Member, though a local overlapping relationship to the Togakushi Pyroclastic Member is observed at the northeastern end.

In the Komiji Subzone the formation covers the Hijiriyama Andesite Member with an unconformity, and consists of pebble to cobble (occasionally boulder) conglomerate, accompanied with fine-to coarse-grained sandstone, greenish-colored mudstone and acid tuff (rarely welded). It is noticeable that conglomerate in the upper part of this formation exhibits an appearance of decayed gravel bed. On the northeast of Nagano, incidentally, the present formation is buried under the Nagano Basin, and in the Toyono SK-1 and R-2 exploitative wells it rests directly upon the Susobana Tuff Member (Ijima, 1960).

Around and under the Shioda Basin to the southwest of Ueda, the formation overlies unconformably the Uchimura, Bessho and Aoki Formations, and consists of conglomerate, mudstone and sandstone, intercalated with layers of pumice tuff and peat (Iijima *et al.*, 1969). It froms a basinal structure with a dip angle gentler than 15° , which is concordant with the configuration of the Shioda Basin.

The thickness of the Sarumaru Formation (s.s.) attains a maximum of more than 1600m in the northeastern part of the Hikage Subzone, and tends to decrease toward the south-southeast, being only 130 m under the Shioda Basin.

b) Komoro Group, Enrei Formation

The Komoro Group and the Enrei Formation, representing the volcanic facies of the Sarumaru Formation (s.l.), are distributed in the Komoro and Enrei Volcano-Tectonic Depressions on the eastern and southwestern sides of the Utsukushigahara Dome, respectively.

According to Northern Fossa Magna R. G. and Chikumagawa C. R. G. (1976), both of the Komoro Group and the Enrei Formation exhibit a similar stratigraphic succession, consisting of fine- to coarse-grained clastics, basic to intermediate pyroclastics partly of subaqueous origin and "Flat Lava" (subaerial andesitic lava flows spreaded out over a depositional surface of underlying strata or a primary peneplain) in ascending order. The Komoro Group rests unconformably upon and partly abuts westward to the Uchimura Formation, whereas the Enrei Formation covers the Uchimura Formation, the quartz diorite and the Kotakiyama Facies of Ogawa Formation with an obvious unconformity. The thickness is estimated to be more than 610m (Iijima, 1962) in the Komoro Group and 850m (Momose *et al.*, 1959) in the Enrei Formation.

In the Shiga Dome area, are distributed the Takai and the Hirao volcanic rocks, the latter being unconformably underlain by the former and both covering the Uchimura and Bessho Formations and the quartz diorite with a distinct unconformity (Akahane, 1976). The Takai Volcanic Rocks, 300 to 400m thick, consist mostly of glassy andesite lava showing a nature of "Flat Lava" . Prismatic joints develop well in the lava, and the rocks have been partly subjected to a remarkable hydrothermal alteration. The Hirao Volcanic Rocks, about 200m thick, consist of alternation of lava and pyroclastics of fresh andesite. Platy joints develop in the lava.

In the northern part of the Komoro Depression, incidentally, the Tateshina Decayed Gravel Bed covers the Komoro Group with an unconformity, and the equivalent gravel bed overlies unconformably the Older Josho Lacustrine Member in the Shioda Basin. It is noteworthy that the depositional surface of these gravel beds has been preserved without a severe disturbance until the present.

On the whole, the Sarumaru Formation is composed of coarse-grained sediments comparable to the top conglomerate of the Miocene to Early Pleistocene sequence in the Minochi Subsidence Zone, and of volcanics erupted mostly in the volcano-tectonic depressions superimposed obliquely and transversely upon the Central Uplift Zone.

7. Omine Group

The equivalent of the Shigarami and Sarumaru Formations distributed in the Omine Depression are provisionally named the Omine Group in this paper. According to Kosaka (1980) and Kosaka and Arai (1982), the group is divided into three formations, i.e., the Minamiotari, the Miasa and the Omine Formation in ascending order. These formations are arranged from north to south, and are party in fault contact with each other.

The Minamiotari Formation is composed of the lower mudstone and sandstone, the middle conglomerate and the upper thick andesite member. The Miasa Formation is made up of mudstone and conglomerate in the lower and middle parts and acid tuff (partly welded) in the upper part. The Omine Formation consists of ill-sorted cobble to boulder conglomerate and acid tuff (mostly welded).

The total thickness is estimated to be over 6250 m. The base is not exposed except on the eastern foot of the Hida Mountain Range, where the small remnants of the group rest unconformably upon the surpentinite and the Late Cretaceous to Paleogene acid volcanics.

8. Toyono Formation

The Toyono Formation is divided into the Iizunayama Pyroclastic Member, the Sakaguchi Lacustrine Member, and the Nashinoki Loam or the Lower Omachi Tephra. Key beds of crystal ash named C1, C2 and C3 are intercalated in the loam or the tephra (Matsumoto Basin C. R. G., 1977). The detailed correlation among these strata has not yet been clarified.

The formation rests upon the underlying folded strata in the Central Uplift Zone, the Minochi Subsidence Zone and the Omine Depression with a marked clino-unconformity, and upon the nearly flat strata in the Komoro Depression with a parallel unconformity. In the Nagano basin, however, it conformably overlies the uppermost horizon of the Sarumaru Formation, and is remarkably deformed by the Tago, Kaesa and Nagaoka Faults on the northwestern margin of the basin (Toyono C. R. G., 1977).

9. Intrusive Rocks

The thick strata in the northern Fossa Magna are subjected to the multi-phased intrusions of quartz diorite, porphyrite and volcanic rocks. The features of these intrusive rocks are summerized as follows.

a) Quartz Diorite

The exposures of quartz diorite are restricted within the Central Uplift Zone. Furthermore, all the plutonic bodies except a small one on the northeastern margin of the Tochiku Half Basin occur in the Utsukushigahara and Shiga Domes. As stated in the preceding paragraph, the Kotakiyama Facies of the Ogawa

Formation covers the underlying quartz diorite with an unconformity and is intruded by the younger quartz diorite on the southeast of Matsumoto. Consequently, the intrusion of quartz diorite is classified into the two stages, i.e., pre- and post-Kotakiyama stages.

Quartz Diorite - I : This is represented by the quartz diorite body covered unconformably by the Kotakiyama Facies of the Ogawa Formation. Although there are many other bodies whose relationship with the Ogawa Formation is unknown, they are tentatively included in Quartz Diorite-I because of the similarity in occurence and lithology. They tend to occur as stocks (the largest being about 12km across), and to be emplaced into the Lower Uchimura Formation concentratedly in the central part of the Utsukushigahara Dome and into the Uchimura to Bessho Formation as cores of several subdomes in the Shiga Dome area. According to Utada (1973), the facies of Quartz Diorite - I is variable even within a body. It changes from quartz diorite to granite, accompanied with porphyrite, andesite, rhyolite, occasionally dolerite and basalt as a marginal facies, and rarely with aplite and pegmatite in the central portion. The contact-metamorphic effect around the bodies attains to amphibolite facies especially on their southeastern side with several to several ten meters in width, and displays an unique nature to change into diagenesis or burial metamorphism with out a clear boundary.

Quartz Diorite - II : This is represented by two small bodies intruding into the Ogawa Formation on the southeast of Matsumoto and the northeastern margin of the Tochiku Half Basin. It consists of diorite to quartz diorite with marginal facies of porphyrite and diabase, and has a contact metamorphic effect on the country rocks (Utsukushigahara C. R. G., 1977; Kato, 1980).

b) Porphyrite

Porphyrite intrusions are classified into three stages according to the stratigraphic situation of country rocks.

Porphyrite - I: Porphyrite - I intrudes as dikes, sheets and phacoliths into the Uchimura to Lower Ogawa Formations in the western part of the Central Uplift Zone, especially in the Tochiku Half Basin. It may possibly show a malti-phased intrusion because of the variation in lithology, but no available data is obtained. Porphyrite-I is occasionally subjected to hydrothermal alteration such as silicification, chloritization and pyritization.

Porphyrite - II : Porphyrite - II is represented by two or three small bodies intruding into the central portion of the Arakurayama Pyroclastic Mmeber in the Takafu-Orihashi Subzone. It exerts a hydrothermal alteration on the country rocks and even on part of the Ogikubo Mudstone Member which overlies the Arakurayama Member with an unconformity (Yano, 1981a).

Porphyrite - III : Around Mt. Takatsuma at the northeastern end of the Hikage Subzone, the Middle Shigarami to Sarumaru Formations are intruded by sheets, dikes and stocks (the largest being 6km across) of Porphyrite-III. The surrounding rocks are subjected to contact metamorphism (Shibata *et al.*, 1976).

c) Volcanic rocks

The volcanic rocks occur as dikes and sheets in various areas, and are classified into the following three or four groups.

Basalt and Dolerite: In the Utsukushigahara and Shiga Domes, dikes and sheets of basalt, dolerite and locally diabase intrude into the Kokuzo Member of the Uchimura Formation. The rocks are subjected to hydrothermal alteration (Uchimura C. R. G., 1953; Ota and Katada, 1955; Inaba, 1959; Yamagishi, 1964).

Dacite: At the southern foot of Mt. Hijiri, laccolith-like dacite is exposed with an extent of 1.8 × 0.9 km, intruding into the Sanseiji Member of the Lower Ogawa Formation (Kato, 1980).

Andesite: Dikes and sheets of andesite intrude into the volcanic bodies of the Middle Shigarami Formation and the surrounding strata. Especially at the southwestern end of the Tochiku Half Basin, non-altered andesite similar in lithology to the Maruyama Andesite Member intrudes into the Bessho to Lower Ogawa Formation as dikes orientated in NW- SE and WNW- ESE directions and as sheets (Fig. 8). On the other hand, the volcanic facies of the Sarumaru Formation (s.l.) is intruded by andesitic dike swarm of NW- SE direction extensively in the southern Komoro and the Enrei Depression (Northern Fossa Magna R. G. and Chikumagawa C. R. G., 1976).

IV. GEOLOGICAL STRUCTURE

The upper Cenozoic systems in the Green Tuff Basin of the northern Fossa Magna are complicatedly deformed and moderately shrank. On the whole, the strata construct an anticlinorium in the Central Uplift Zone and a synclinorium in the Minochi Subsidence Zone, both being partly destroyed by block-faulting which was responsible for the formation of volcano-tectonic depressions. Such structural features of the northern Fossa Magna are produced by an association of the following structural elements (Fig. 13).

A. FOLDS

Folds of thick strata in the northern Fossa Magna region are markedly complex, but are classified into the six types, Type-A to Type-F (Table 1) according to their structural properties.

1. Type-A

The two large-scale domes (strictly speaking, doubly plunging anticlines), Utsukushigahara and Shiga Domes, belong to the Type-A fold. They construct the major structure of the Central Uplift Zone, being arranged longitudinally but somewhat in en échelon fashion of left-hand.

The Utsukushigahara Dome is a large-scale doubly plunging fold of 60km in axial length and 30km in half wavelength, though some short-axis folds develop in the clastic sediments of the Uchimura Formation on its northwestern flank. The axial direction is NNE-SSW. The strata on the flank have the average dip-angle of ca. 30°. But they are more steeply dipping on the eastern margin than on the western one, giving the dome an asymmetry. The stocks of Quartz Diorite-I tend to assemble in the central portion of the dome. At the apex of the dome, the Kotakiyama Collapse Basin is formed in unconformable contact with the underlying Quartz Diorite-I, Lower Uchimura For-

Fig. 13. Structural map of the northern Fossa Magna region.

TABLE 1. CLASSIFICATION OF FOLDS IN THE NORTHERN FOSSA MAGNA REGION.

Type	Subzone	Fold	
Type-A		Utsukushigahara	Dome
		Shiga	Dome
		Omineyama	Subdome
		Omatsuyama	Subdome
		Horikiriyama	Subdome
		Yonagoyama	Subdome
		Misawayama	Subdome
Type-B		Uwadaira	A.
		Kurumizawa	S.
		Mitsugashirayama	A.
		Komakiyama	S.
		Maeyama	S.
		Nogura	A.
		Ogamidake	S.
		Naramoto	A.
		Seaigawa	S.
		Kutejizawa	A.
		Kinokoyadani	S.
		Nishikibe	A.
		Akanuta	S.
		Inakura	A.
Type-C		Saikawa	A.
		Nishikyo	A.
		Yamada	S.
		Mitsuishi	A.
		Aida	S.
		Gojo	A.
		Gojo	S.
		Noma	A.
Type-D	Komiji Subzone	Hakumaki	S.
		Shimizu	A.
		Komiji	S.
		Oashi	A.
		Oashi	S.
		Tocchu	A.
		Tocchu	S.
		Haibara	S.
		Yoshiwara	S.
		Jinda	A.
		Naniai	S.
		Odagiri	A.
	Takafu-Orihashi Subzone	Takafu	S.
		Suguji	A.
		Orihashi	S.
		Kitago	S.
	Hikage Subzone	Hikage	S.
Type-E		Ishidatami	A. and S.
		Magario	A. and S.
		Kumanoiri	A. and S.
		Sugesawa	A. and S.
		Himichizawa	A. and S.
		Kamikusukawa	A. and S.
		Tanokashira	S. and A.
		Nodaira	S. and A.
		Sugeyachi S. and Hodai A.	
Type-F		Marukirizawa	S.
		Iwatoyama	S.

A.: Anticline, S.: Syncline

mation and Yokokawagawa Metamorphic Rocks (Utsukushigahara C. R. G., 1977). The collapse basin shapes a quadrangle elongated in the NNE-SSW direction, and is 6 × 12km in extent, more than 1.3km in depth. The southwestern half and eastern margin of the Utsukushigahara Dome are fairly disturbed by the superposition of the volcano-tectonic depressions, Enrei and Komoro Depressions generated in later stage.

The Shiga Dome trending in the NE-SW direction over 45km in length is a culmination consisting of five smaller-scale subdomes which are of ten and several kilometers in axial length. The strata on the flank of the dome have the dip-angle ranging from 20 to 40°, steeply dipping to 50° or 65° on the southeastern margin and hence giving its an asymmetry. The four stocks of Quartz Diorite- I are exposed extensively as the cores of subdomes. A few of the transverse faults, represented by the Chikumagawa Fault, disturb and truncate the southwestern end of the Shiga Dome.

The western half of the saddle-like depression between the above-mentioned culminations, Utsukushi gahara and Shiga Domes, corresponds to the Tochiku Half Basin plunging gently towards the west-northwest. The half basin is modified by the development of the Type-B folds and the faults of System L-1b mentioned later.

2. Type-B

The Type-B folds are of gentle to open form and develop in the Bessho and Aoki Fomations and also in a part of the Uchimura and Ogawa Formations in the Tochiku Half Basin. Their axial lengthes are commonly relatively short, being about 2 to 14km long. Although the axial trends are NE-SW on the whole, they tend to be markedly curved being convex to the west-northwest. The half wavelengthes are 2 or 3km. For the neighboring pairs of anticlines and synclines, the fold axes contact with each other at their ends, resulting in disappearance of fold form. On the northwestern flank of the Utsukushigahara Dome, such disappearance surface of fold forms corresponds approximately with the interface between the Uchimura and the Bessho Formation. While the Type-B folds are generally of upright type, the two anticlines, i.e., the southwestern half of Nishikibe Anticline and the Inakura Anticline situated near the southwestern end of the Tochiku Half Basin exhibit northwestward vergence. The Inakura Anticline exceptionally involves the Uchimura Formation.

Thus, it is pointed out that the Type-B folds are characterized by the curvilinear axes convex to the northwest, the upright axial surfaces though rarely steeply to moderately inclined toward the southeast, and the development of detachment zone placed near the boundary surface between the Bessho and the Uchimura Formation.

3. Type-C

The Type-C folds comprise two large-scale anticlines, Saikawa and Nishikyo Anticlines, which develop as such leading structures that subdivide the Minochi Subsidence Zone into three subzones, Komiji, Takafu-Orihashi and Hikage Subzones. The anticlines are of close form and are asymmetric folds with axial surfaces inclined to the northwest in the angles ranging from 50 to 80°. Their axial zones change into the thrust faults of System L-la. The dip separations along such thrusts are generally estimated to be less than 1 km. An exceptionally large value, attaining to 5.5km in maximum, is measured along the overthrust changed from the mortheastern part of the Nishikyo Anticline. Although the southwestern extensions of Saikawa and Nishikyo Anticlines are cut off by the faults of System L-2, their axial lengthes are estimated to have been initially more than 50km and 22km, respectively.

It is noticeable that the thickness of the strata involved in the Minochi Subsidence Zone abruptly changes beyond the axial surfaces of Type-C folds. As discussed later, such phenomena may indicate for the Type-C folds to have appeared as septa between the sedimentary basins with differential subsidences during sedimentation.

4. Type-D

Most of folds in the three subzones of Minochi Subsidence Zone are grouped into the Type-D, except for subsidiary Type-E folds. The styles and sizes of the folds of this type are fairly variable. They are of open to tight form, and change from upright type to moderately inclined type with axial surfaces dipping to the northwest. The axial lengthes are ranging from 1.5 to 40km.

The Type-D folds are complicatedly arranged in the Minochi Subsidence Zone. In the Komiji Subzone, many folds of this type run parallel or subparallel to each other. But the axes often converge with the neiboring ones at their ends. The three large-scale folds (Komiji Syncline, Noma Anticline and Aida Syncline) and the associated smaller-scale folds developed with in the Bessho and Lower Aoki Formations are bundled into only one syncline at the southern end of this subzone. Most of Type-D folds in the Komiji Subzone exhibit the closed to tight forms, showing that the strata in this subzone have been shortened to a fairly extent. In the middle part of the Komiji Subzone, the Hijiriyama Andesite Member shows exceptionally a nearly flat-lying structure. The strata on the western side of the Hijiriyama Member, however, have been strikingly shrank, forming the overturned Noma Anticline and the fan-shaped Komiji Syncline. Consequently, through this subzone the whole shrinkage of strata is not much different but settled in an extent of 25 to 30%. It is noticeable that the overturned Noma Anticline on the westernside of Hijiriyama Andesite Member has northwestward vergence, which is only one exceptional attitude of axial surfaces of the Type-D folds (commonly vertical or with southeastward vergence).

The three Synclines in the Takafu-Orihashi Subzone (Takafu, Orihashi, Kitago Synclines) are arranged in en échelon-like fashion of right-hand. They commonly are of open form except for close one in the southernmost part of Takafu Syncline. The attitudes of their axial surface are dominantly vertical and partly inclined to the northwest.

The Type-D of the Hikage Subzone is the Hikage Syncline which is its major fold. It is of open form in the northern and middle parts and of close one in the southern.

It can be said that the Type-D folds are a group of folds which forms the synclinorium or major syncline of individual subzone of the Minochi Subsidence Zone, and are their parastic folds. Their morphological features are characterized by uprightness to northwestward inclination of axial surfaces and by a tendency for complexity of structural arrangement and asymmetry to decrease northwestwards. It is noticeable that the strata in the Komiji Subzone are especially strongly folded.

5. Type-E

The Type-E folds are nine pairs of syncline and anticline of small-scale in Minochi Subsidence Zone. Five pairs of them are formed on the northwestern limbs of the major synclines of the Takafu-Orihashi and Hikage Subzones, arranging in en échelon fashion of left-hand along the Otari-Nakayama Fault. One pair develops on the northwestern limb of the Orihashi Syncline. The remaining three pairs are formed on the southeastern limbs of the major synclines of the three subzones, being closely connected with the crooking parts of the faults of System L-1 mentioned later. The axes of Type-E folds commomly trend in NNE-SSW to NE-SW. The paired folds converge either at one axial end or at both axial ends.

6. Type-F

Two synclines in the Omine Depression are classified as the Type-F folds. They are of open form. Their axes trend in N-S oblique to the general trend of Green Tuff Basin, and plunge nealy to the south.

B. Faults

Many faults of various attitudes and sizes are formed in the northern Fossa Magna region. They are classified into three types, longitudinal, transverse and oblique faults, on the basis of their orientations relative to the general trend of Green Tuff Basin (Table 2).

TABLE 2. CALSSIFICATION OF FAULTS IN THE NORTHRN FOSSA MAGNA REGION.

System L	System L-1	L-1a	Saikawa F.
			Nishikyo F.
		L-1b	Onota F.
			Ichinokawa F.
			Sanogawa F.
			Hijirigawa F.
			Kaesa F.
			Tago F.
			Nagaoka F.
	System L-2		Uruga-Akashina F.
			Mochigyo F.
			Buno F.
System T	System T-1		Kirisawa F.
			Noma F.
			Wadaira F.
			Buppu F.
			Onazori F.
			Otsuki F.
			Nakahara F.
			Kamanashiyama F.
			Southern Marginal F. of Lake Suwa
	System T-2		Kamisuwa F.
			Sugenosawa F.
			Takayama F.
			Gofukuji F.
			Susukigawa F.
			Chausuyama F.
			Jingasaka F.
			Fudodaki F.
			Chikumagawa F.
			Aooni F.
System O	System O-1		Dojirigawa F.
			Kaminagai F.
	System O-2		Himekawa F.
			Eastern Marginal F. of Kamishiro Basin
			Tsukiyodana F.
			Ichinokura F.
			Otari-Nakayama F.
			Eastern Marginal F. of Matsumoto Basin
			Natsuwa F.
			Funamiya F.
			Komatsubara F.
			Kadosawa F.

F.: Fault

1. Longitudinal faults

The longitudinal faults, whose strikes are parallel with the general trend of Green Tuff Basin, are subdivided into the two systems according to their senses of displacement. The one group of faults along which the northwestern walls upheave in comparison with the southeastern ones is named System L-1, while the other group with the converse sense of displacement is System L-2.

a) System L-1

The faults of System L-1 develop in the Minochi Subsidence Zone and the Tochiku Half Basin, and on the northwestern margin of Nagano Basin. They are furthermore divided into System L-1a and System L-1b with reference to mode of occourence.

System L-1a : The System L-1a faults correspond to the two thrusts, Saikawa and Nishikyo Faults, along the axial surfaces of the Type-C folds in the Minochi Subsidence Zone which have been described in the preceding section. The generation of System L-1a faults appears to be closely connected with the growing process of the Type-C folds. The distributive thrust fault branching off from the middle part of the Saikawa Fault is also classified into this system.

System L-1b : The faults of System L-1b are formed in the northwestern part of the Tochiku Half Basin and on the northwestern margin of Nagano Basin, independent of the Type-C folds. They are step faults loosely spaced at about 2 to 3km intervals as a whole, and arranged in an 'antithetic' attitude (in the wide sense after Mackin (1960) that, regardless the direction of the dip of the faults, their throws tend to be opposite to, and to counteract the effect of, the dip of the faulted strata) against the northwestward-dipping structures of Tochiku Half Basin and the Shiga Dome. It has been clarified by Toyono C. R. G. (1977) and Kobayashi and Saito (1982) that, on the northwestern margin of Nagano Basin, the faults of this system had cut even the Middle Pleistocene Toyono Formation with marked fault drags.

b) System L-2

The System L-2 comprises three faults branching off from the Otari-Nakayama Fault in the N-S to NNE-SSW direction. Their fault planes are vertical or dip southeastward at high angle. The displacements along them tend to decrease abruptly to the north or northeast, resulting in extinctions of them. The faults of this system run subparallel to the Type-C anticlines and the thrusts of System L-1a, and trancate obliquely their southwestward extension.

2. Transeverse faults

The transeverse faults, which trend nearly perpendicular to the general trend of Green Tuff Basin, are subdivided into the two types based on displacement manners. The one series of faults with the obvious horizontal displacements is named System T-1, while the other series is System T-2.

a) System T-1

The faults of System T-1 are formed on the western side of nearly flat structure of the Hijiriyama Andesite Member in the Komiji Subzone, and just to the south of the Arakurayama Pyroclastic Member. The faults in the former area are short in trace lengthes, and transect the axial traces of folds and the nearly vertical strata of Komiji Syncline with horizontal separations. They are grouped into the two sets consisting of several left-lateral faults of NNW-SSE to NW-SE trend and one right-lateral fault of WNW-ESE trend, probably forming a conjugate fault system. In the latter area the axial trace of Sumeragi Anticline is transposed right-laterally by the two faults of this system trending in the NW-SE direction.

b) System T-2

The System T-2 faults, i.e., the transverse faults of dip-slip type and of group undetermined slip-direction, are developed all over the region. The prominent faults of this system are the Chikumagawa Fault bounding the Tochiku Half Basin from the Shiga Dome, and the parallel faults along the Shiojiri-Nirasaki Line which corresponds to the middle part of the Itoigawa-Shizuoka Tectonic Line (Fig. 1). The many displacements striking in the NW-SE direction are presumed also in and around the Enrei Depression.

3. Oblique faults

The oblique faults, whose strikes are oblique to the general trend of Green Tuff Basin, comprise the two systems different in strike, E-W trending faults classified as System O-1, and N-S trending faults as System O-2.

a) System O-1

The two faults of System O-1 are situated at the northeastern end of the Saikawa Anticline, bringing apparently left-lateral separations to the nearly vertical strata. They coincide approximately with the line of abrupt change of thickness in the Upper Ogawa and Lower Shigarami Formations.

b) System O-2

Many faults running in the N-S direction have been generated in and around the Omine Depression and the Matsumoto Basin developed along the Itoigawa-Shiojiri Line, the northern part of Itoigawa-Shizuoka Tectonic Line (Fig. 1). The representative faults among them are the Otari-Nakayama Fault separating the Omine Depression from the Minochi Subsidence Zone, the Eastern Marginal Fault of Matsumoto Basin bounding the Matsumoto Basin from the Omine Depression and the Kashima-Manganji Fault linking the many kern kols. Three faults of middle-scale formed in the northeastern part of the Takafu-Orihashi Subzone belong also to this fault system. The western and eastern margins of the Komoro Depression are also controled by the N-S trending faults of this type (Northern Fossa Magna R. G. and Chikumagawa C. R. G., 1976).

V. ANALYSIS OF SEDIMENTARY BASINS

The analysis of sedimentary basins in the northern Fossa Magna region is relatively easy, because the strata are repeatedly exposed by several major folds and the lateral change in facies and thickness can be examined not only in longitudinal direction but also in transverse one. However, the intermittence of exposure in transverse direction due to erosion of strata in the anticlinal area and to concealing by overlying strata in the synclinal area prevents continuous observation.

In this chapter, features of subsidence pattern and sedimentary environment in each stage are analized on the basis of available data on thickness, lithofacies, biofacies and paleocurrent. Thickness of the formations in many successions is shown collectively in Fig. 14.

A. UCHIMURA STAGE

1. Subsidence pattern

There are few precise data on subsidence pattern in the Uchimura stage. Only one typical stratigraphic profile (Fig. 15) is restored across the northern part of the Utsukushigahara Dome in E-W direction (Inaba, 1959). Although the whole thickness of the Lower Uchimura Formation is unknown, the thicknesses of the Ichinose Member and the Upper Uchimura Formation attain maximums in the eastern area. Therefore, the depocenter is inferred to have been be situated in the eastern part of the dome (Utashiro *et al.*,1958). A fairly large thickness of the Upper Uchimura Formation to the north of Matsumoto may indicate that one more depocenter is generated on the western flank of the dome in the later stage.

2. Sedimentary environment

a) Lithofacies

A large amount of volcanic products reflects the violent initial volcanism of the Green Tuff Basin in this stage. Judging from the intercalation of clastic sediments (rarely yielding marine fossils) and the presence of pillow structures in basalt lavas, the volcanism is inferred to have taken place mainly in submarine condition. In the Utsukushigahara Dome area, the eastward extension of clastic facies in the middle horizon suggests that the eastern area relatively subsided in an intermission of volcanism between the two volcanic cycles, and received an inflow of clastic materials from the west.

b) Palecurrent

Sole markings on flysch-like beds in the Hongo Member of the Lower Uchimura Formation indicate mainly longitudinal currents from south-southwest

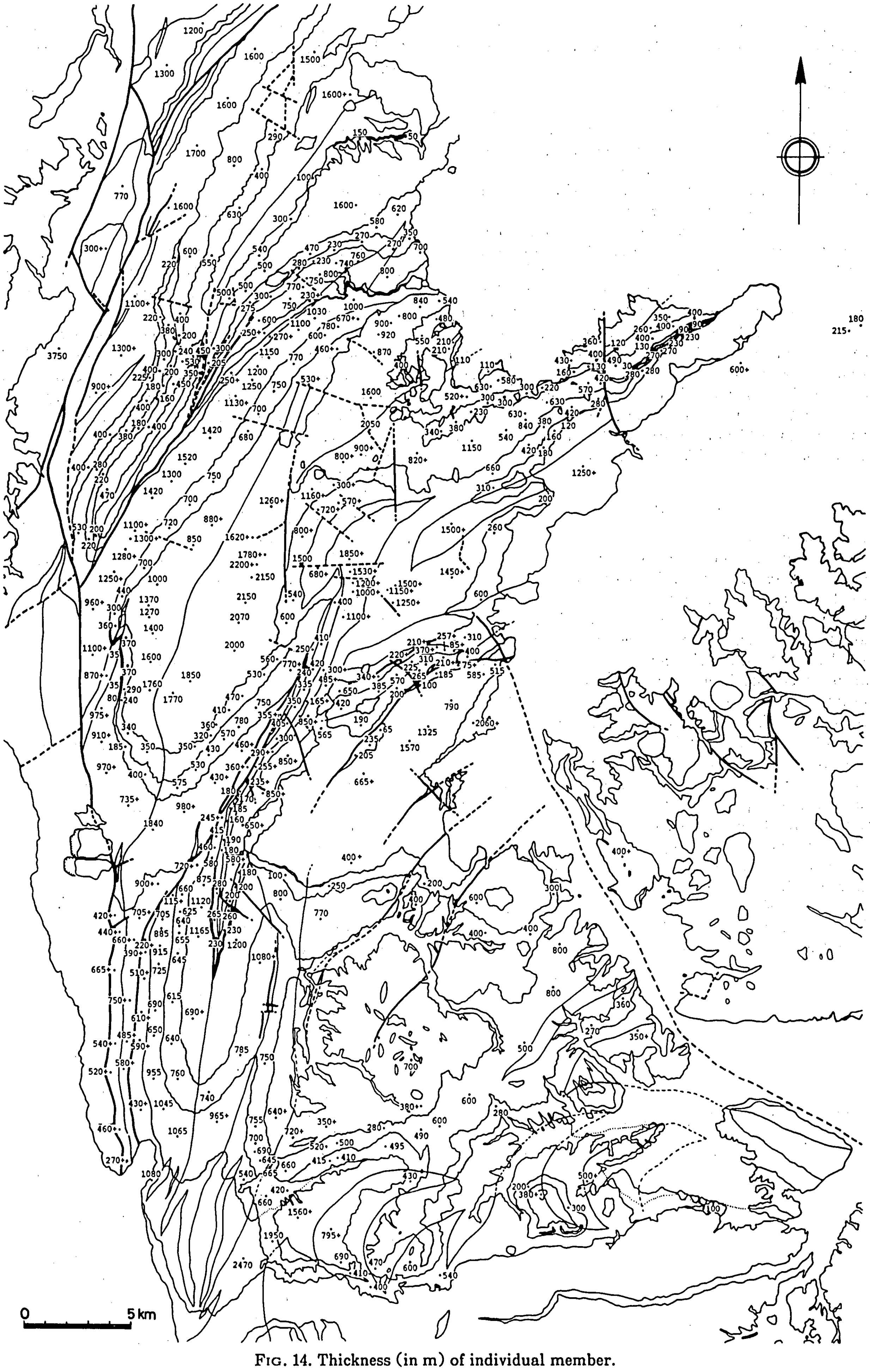


FIG. 14. Thickness (in m) of individual member.

to north-northeast, accompanied with several lateral currents toward the west (Tanaka *et al.*, 1973; Suzuki, 1982).

c) Biofacies

Molluscan fossils found in the Hongo Member are mostly of neritic environment, represented by *Acila (Acila) divaricata, Anadara makiyamai, Callista brevisiphonata, Nassarius nakamurai*, etc. Around Mt. Moriya, the Tazawa Member of the Upper Uchimura Formation yields neritic molluscs such as *Anadara moriyensis, Dosinia fujimotoi, Cyclina japonica* and *Turritella chichibuensis* (Tanaka, 1973), and foraminifers of N.8 zone such as *Miogypsina (Miogypsina) kotoi* (Matsumaru *et al.*, 1982). The Tazawa Member overlaps the pre-Neogene basement rocks beyond the Itoigawa-Shizuoka Tectonic Line. This fact may indicate the initiation of the"Nishikurosawa Transgersion"in the northern Fossa Magna region. A cephalopod fossil, *Aturia* sp. obtained near the boundary between the Uchimura and Bessho Formations in the Shiga Dome area (Omori *et al.*, 1973) probably reflects the advancement of this transgression.

B. BESSHO STAGE

1. Subsidence pattern

The isopach map shown in Fig.16 reveals a part of the subsidence pattern in the Bessho stage. From the tendency of thickness change, the depocenter is inferred to be situated in the southern Komiji Subzone and the thickness at the depocenter to attain ca. 4000 m. The westward deflection of depoaxis suggests an asymmetric subsidence pattern with a fairly steeper gradient on the western wing. The gentle gradient ascending to the southeast indicates that the central part of the sedimentary basin of the Uchimura Formation ceased to subside and began to upheave in this stage, as pointed out by Kobayashi (1957). As a whole, the subsidence pattern in the Bessho stage may fit the saddle-like structure formed between the embryonic Utsukushigahara and Shiga Domes. The asymmetric downwarping of crust, causing such a subsidence pattern, is inferred to be propelled complementally by the doming-up of the Central Uplift Zone in two foci and by the flexuring along the Saikawa Anticline-Fault elevating its western side.

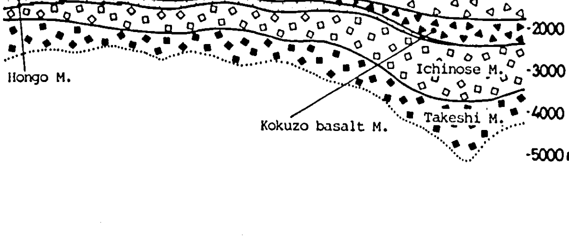


FIG. 15. Stratigraphic profile of the Uchimura to Bessho Formation across the northerm part of Utsukushigahara Dome.

Although no available data are obtained, the Bessho Formation presumably lies under the younger strata in the Takafu-Orihashi and Hikage Subzones, because the northern Fossa Magna region was extensively submerged by the transgression in this stage as mentioned just later.

2. Sedimentary environment

a) Lithofacies

The monotonous lithofacies of black shale and mudstone indicates that a low-energy environment dominated throughout the Bessho stage. No marginal facies is observable in the formation. Therefore, the sea probably invaded very extensively into the northern Fossa Magna region.

The occurence of disturbed beds concentrated on the western wing of the depoaxis (Fig. 8) is attributed to an instability of paleo-submarine slope. Such an unstable paleoslope corresponds to the steep gradient of thickness change mentioned above, and is ultimately inferred to be originated from a differential subsidence on the eastern limb of the embryonic Saikawa Anticline-Fault.

b) Paleocurrent

As usual in muddy facies, sole markings are rather rare in the Bsssho Formation. Several flute casts on sandy intercalations display a longitudinal current from south to north or from southwest to northeast (Tanaka *et al.*, 1973; Suzuki, 1982).

c) Biofacies

The Bessho Formation yields various kinds of fossils (foraminifera, molluscs, fish bones and scales, plants, etc.).

Calcareous foraminifera such as *Uvigerina* sp., *Epistominella* sp. and *Cassidulina* sp. are found in the eastern part (Masatani and Ichimura, 1970). According to Kitazato (1983), they are grouped into his C-Assemblage, which is comparable to a recent foraminiferal assemblage on middle continental slope ranging from 1000 to 2500m in depth.

The molluscan fauna is characterized by *Adulomya uchimuraensis, Yoldia landabilis, Portlandia lischkei, Modiolus akanutaensis, Palliolum (Delectopecten) peckhami, Conchocele nipponica, Buccinum koyamai* and *Neverita fissuratus*, and indicates a neritic to upperbathyal open-sea condition (Tanaka, 1973). Recently, some fossils of Cephalopoda such as *Argonata tokunagai* are obtained from the middle horizon (Kosaka and Taguchi, 1983).

According to the study on the fish bones by Ueno (1979), some species of certainly deep-sea environment classified as order Myctophiformes and family Macrouridae are found in addition to inhabitants of surface, middle and bottom layers.

The Kurumizawa Flora obtained from the middle horizon is represented by *Quercus* (Evergreen Oaks), *Cinnamomum, Machilus, Laurus, Ilex, Berchemia*, etc., and is considered to have been a plant community in subtropical coastal region (Matsuo, 1979).

As a whole, the biofacies of the Bessho Formation indicates a neritic to upperbathyal open-sea environment in subtropical climate. Such a relatively deep marine condition in this stage is probatly a manifestation of the maximum phase of the "Nishikurosawa Transgression" in the northern Fossa Magna region.

C. Aoki Stage

1. Subsidence pattern

a) Early Aoki stage

The isopach map of the Lower Aoki Formation is shown in Fig. 17. From the tendency of thickness change, the depocenter is inferred to be situated in the southern to middle Komiji Subzone, where the thickness attains ca. 1300 m. The westward deflection of depoaxis brings about a remarkable asymmetry in the subsidence pattern with a fairly steep gradient on the western margin. The gentle slope on the southeastern wing is not so smooth as in the case of the Bessho stage, but slightly undulates with NE-SW trending axes. On the whole, the asymmetric downwarping of sedimentary basin in this stage is complementary to

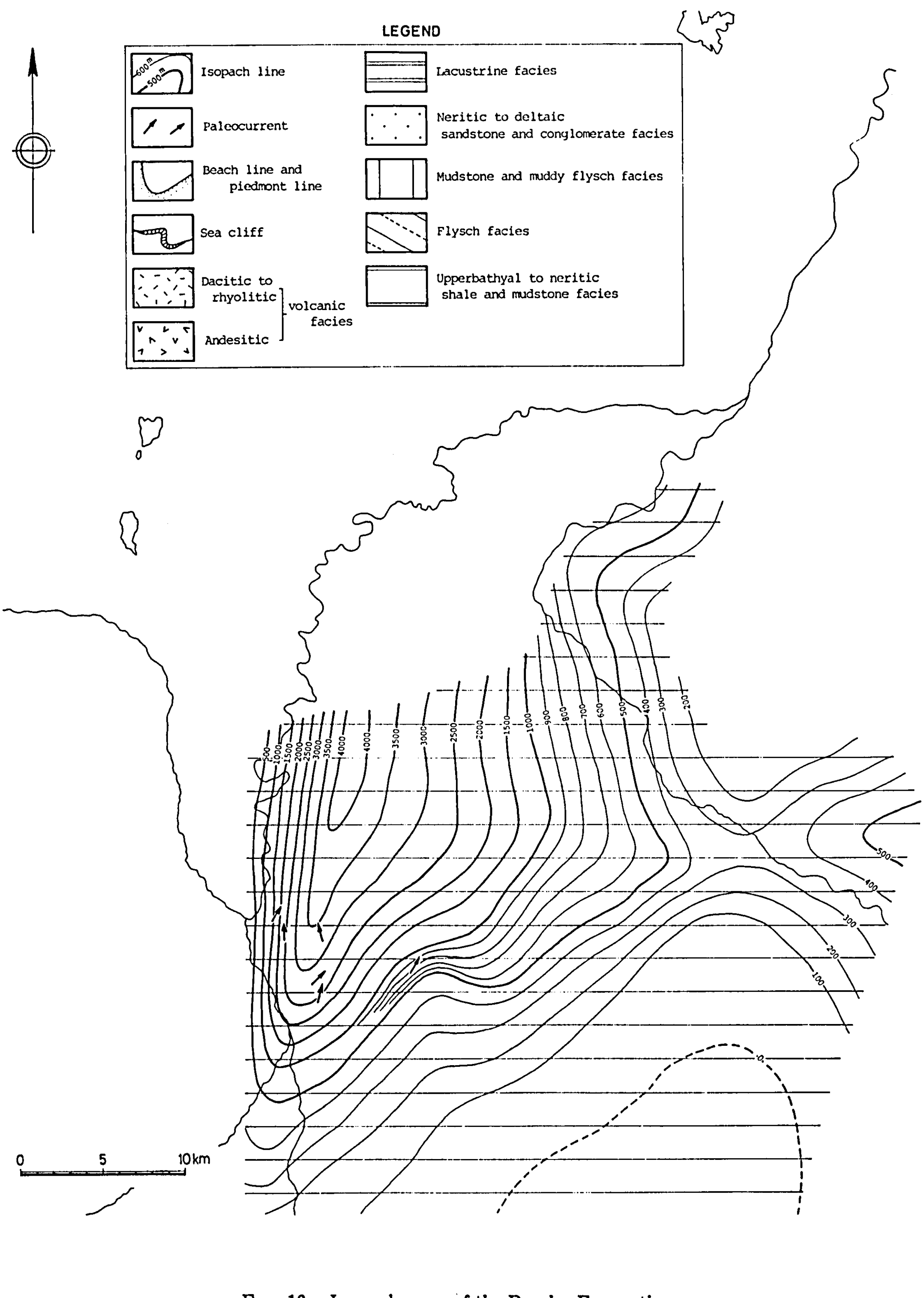


Fig. 16. Isopach map of the Bessho Formation.

the doming-up of the Central Uplift Zone and to the flexuring along the Saikawa Anticline-Fault, as in the Bessho stage. However the contrast between down warping and upwarping is not so striking. The subordinate undulation on the southeastern wing may suggest the embryonic deformation of some of the Type-B and -D folds, because the undulation is harmonious with these folds.

The sedimentary basin of the Lower Aoki Formation has certainly extended over the Takafu-Orihashi and Hikage Subzones, since the formation is exposed along the Nishikyo Anticline-Fault and the Buno Fault.

b) Late Aoki stage

The isopach map of the Upper Aoki Formation is shown in Fig. 18. The fundamental feature of subsidence pattern in this stage is the presence of three basins separated by the two rows of structural-high which are later to grow into the principal anticlines (Type C-folds).

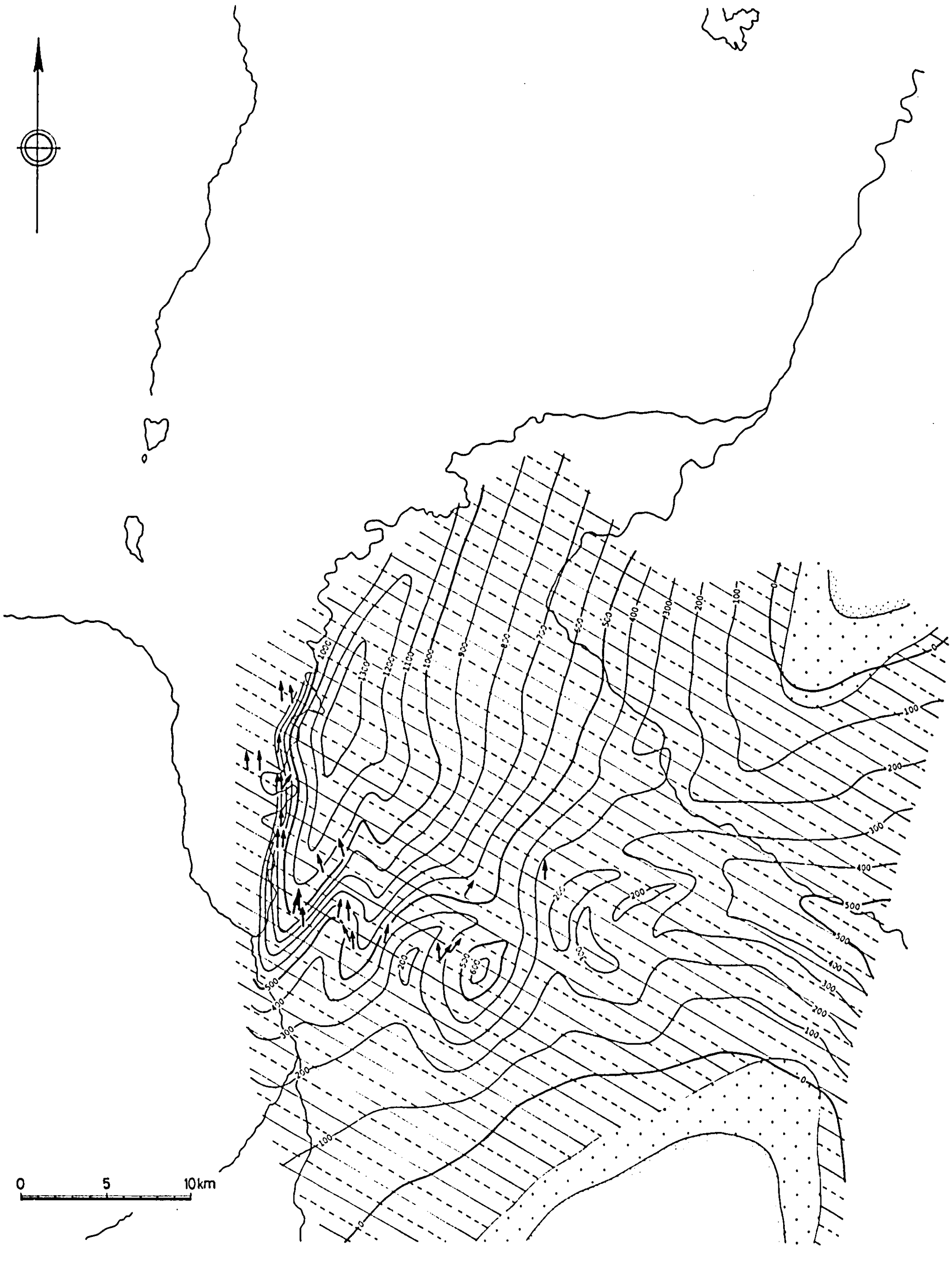


FIG. 17. Isopach map of the Lower Aoki Formation. See the legend of Fig. 16.

The structural-high along the Saikawa Anticline-Fault exhibits a somewhat complex style. The Upper Aoki Formation on the western side of the structural-high is more than twice as thick as that on the eastern side, and the formation tends to thin toward the axis of the high. Such an abrupt change of thickness presumably results from the block movement along the Saikawa Anticline-Fault, as pointed out at first by Takeuchi and Sakamoto (1976). Another structural-high along the Nishikyo Anticline-Fault exhibits an asymmetric anticlinal-shape with an axial surface inclined to the northwest.

Among the three basins separated by rows of structural-high, the southeastern one named the Tochiku-Komiji Sedimentary Basin shows a subsidence pattern similar to that in the Early Aoki stage. The depocenter is probably situated in the middle Komiji Subzone, where the thickness attains ca. 1400m. The

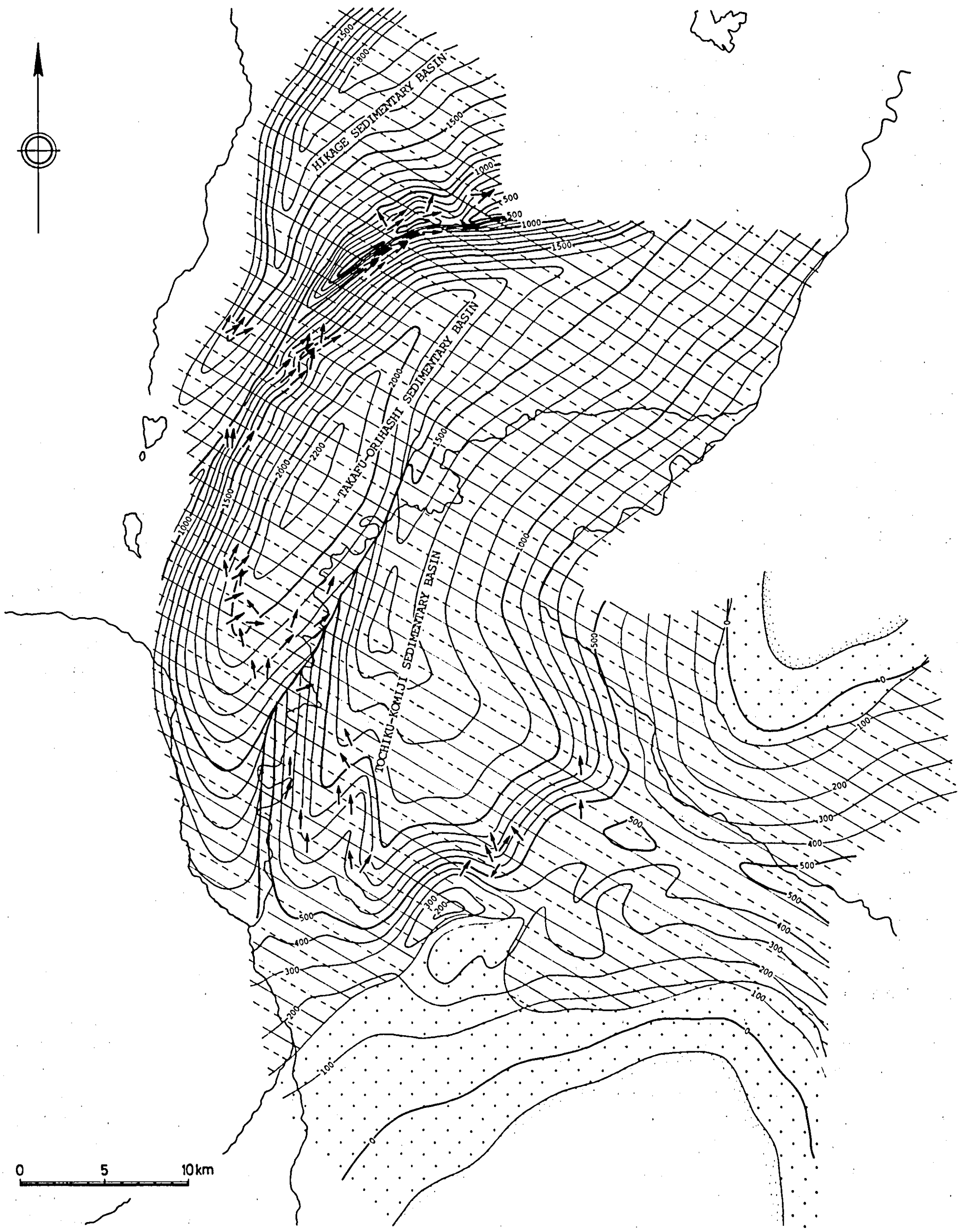


FIG. 18. Isopach map of the Upper Aoki Formation.
See the legend of Fig. 16.

middle basin named the Takafu-Orihashi Sedimentary Basin shows a trough-like shape with fairly steep gradient on both the southeastern and northwestern margins. The estimated thickness at the depocenter is 2200m. As a result of disappearance of the Saikawa Anticline-Fault in the northern area, this trough-shaped basin is presumably turned into asymmetric basin with a very steep northwestern wing and a gentle southeastern wing ascending directly toward the Shiga Dome. The subsidence pattern of the northwestern basin, the Hikage Sedimentary Basin, is also asymmetric, with a depoaxis deflected northwestward. The thickness at the depocenter attains ca. 1900m.

As stated above, the subsidence pattern in the Late Aoki stage is characterized by three asymmetric sedimentary basins with depoaxes generally deflected northwestward, and also by two rows of structural-high separating the basins. As a whole, the asymmetric downwarping in this stage was controlled complementally by the doming-up of Central Uplift Zone in two foci and by the growth of Type-C folds in the Minochi Subsidence zone. Incidentally, the subsidence pattern of the southeastern Tochiku-Komiji Sedimentary Basin was modified by the growth of some of the Type-B and -D folds, as in the Early Aoki stage.

2. Lithofacies

The Aoki Formation is characterized by the predominance of flysch facies, consisting of two upward-fining cycles. From the lithofacies, it may be suggested that the intermittent input of sand- and rarely pebble-sized clastic materials was repeated extensively over the sedimentary basins throughout this stage. Based on the lithofacies change, the supply of coarse-grained clastics tends to increase southwestward, and is more abundant in the late stage than in the early stage.

According to Hirabayashi (1970a, b), the conglomerate of the Aoki Formation consists mostly of gravels derived from pre-Neogene basement rocks such as chert, sandstone, slate and acid volcanic rock, and additionally of those from the Uchimura Formation such as altered rhyolite to dacite, andesite and basalt. The content of gravels from the Uchimura Formation tends to increase eastward. These facts indicate that the apex of the growing domes in the Central Uplift Zone emerged and the coarse-grained clasts began to be supplied from the Uchimura Formation as well as from the basement rocks.

b) Paleocurrent

Sole markings, such as flute and groove casts, are well developed in the Aoki Formation. According to the restoration of paleocurrent by Tanaka *et al.* (1973) and Suzuki (1982), a longitudinal current from south to north or from southwest to northeast is predominant over the region (Figs. 17, 18). In the Late Aoki stage, the lateral currents from west-southwest to east-northeast joined the longitudinal current pattern. Coarsest facies of the Upper Aoki Formation occurs in such a joining area of the paleocurrents to the northeast of Omachi, and therefore one of the main outwash gates of clastic materials might exist probably in the westward of the area (Suzuki, 1982).

c) Biofacies

According to the study on foraminifera by Masatani and Ichimura (1970), the Aoki Formation is subdivided into the lower *Dorothia* sp. -*Haplophragmoides* sp. zonule and the upper *Cribrostomoides* sp. -*Trochamina* sp. zonule. It is considered that the foraminifera of the latter zonule indicate shallower bathymetry than that of the former.

The molluscan fauna is characterized by *Acila divaricata, Yoldia uranoi, Portlandia watasei, P. yotsukurensis, Anadara amicula tazawaensis, A. setoensis, Lucinoma acutilineata, Laevicardium angustum, Mercenaria y-iizukai, Dosinia (Kaneharaia) kaneharai, Macoma tokyoensis, Tectonatica janthostomoides* and *Nassarius nakamurai*, associated with a few boreal species such as *Peronidia venulosa* and *Neptunea* sp. (Tanaka, 1962). A predominance of shallow marine species accompanied with cool elements is characteristic of this fauna (Tanaka, 1973).

D. OGAWA STAGE

Subsidence pattern and sedimentary environment of the Ogawa Formation are fairly defferent between the early and the late stage.

D-1. EARLY OGAWA STAGE

1. Subsidence pattern

Subsidence pattern in the Early Ogawa stage is characterized by the three basins separated by structural-highs, and by the Kotakiyama Collapse Basin at the apex of Utsukushigahara Dome (Fig. 19).

Among the three basins, the Tochiku-Komiji Sedimentary Basin shows an asymmetric subsidence pattern as in the previous stages, though the northeastern margin is closed by an upheaval bounding the Susobana Sedinontary Basin mentioned later. The depoaxis is deflected extremely to the west, and the thickness at the depocenter attains ca. 1300 m. The Takafu-Orihashi Sedimentary Basin exhibits also a remarkably asymmetric subsidence pattern with a very steep eastern margin (being an eastward-tilted basin). The maximum thickness attains ca. 800 m. There are no definite data on the Susobana Sedimentary Basin in which the Susobana Tuff Member is accumulated. However, it may be considered that the basin is a westward-tilted one bounded by a growth fault on its western to southern margin, with a maximum thickness exceeding 2000m.

The structural-high along the Saikawa Anticline-Fault shows a ridge-like shape. The Lower Ogawa Formation tends to thin toward the axis of the ridge from its both sides. The other structural-high separating the Susobana Sedimentary Basin from the Tochiku-Komiji and Takafu-Orihashi Sedimentary Basins may correspond to an edge of tilted block.

As a whole, the sedimentary basin in this stage are contracted to a certain extent by an advancement of upheaval movements in surrounding area. The subsidence pattern is inferred to be controlled by the following six factors: doming-up of the Central Uplift Zone in two foci, collapsing at an apex of the dome, antithetic faulting on the western to southern margin of the Susobana Sedimentary Basin, growth of some of the Type-B and -D folds in the Tochiku-Komiji Sedimentary Basin, southeastward-tilted subsidence of the Takafu-Orihashi Sedimentary Basin (presumably originated from the uplifting of the Hida Mountain Range as mentioned later), and growth of the Saikawa Anticline-Fault.

2. Sedimentary environment

a) Lithofacies

The Lower Ogawa Formation is characterized by a remarkable differentiation of lithofacies in lateral direction, and by an appearance of molasse and volcanic facies.

The volcanic facies is classified into the Kotakiyama and the Susobana Facies, both of which are products of volcanism closely connected with doming-up of the Central Uplift Zone. Most of the Kotakiyama Facies is of subaqueous, probably lacustrine origin on the ground of intercalation of clastic layers in many horizons without marine fossils. Subaerial nature of the Susobana Facies in the southwestern part of the Susobana Sedimentary Basin turns into subaqueous one in the middle to northeastern part, where clastic layers are intercalated and various types of lamina-

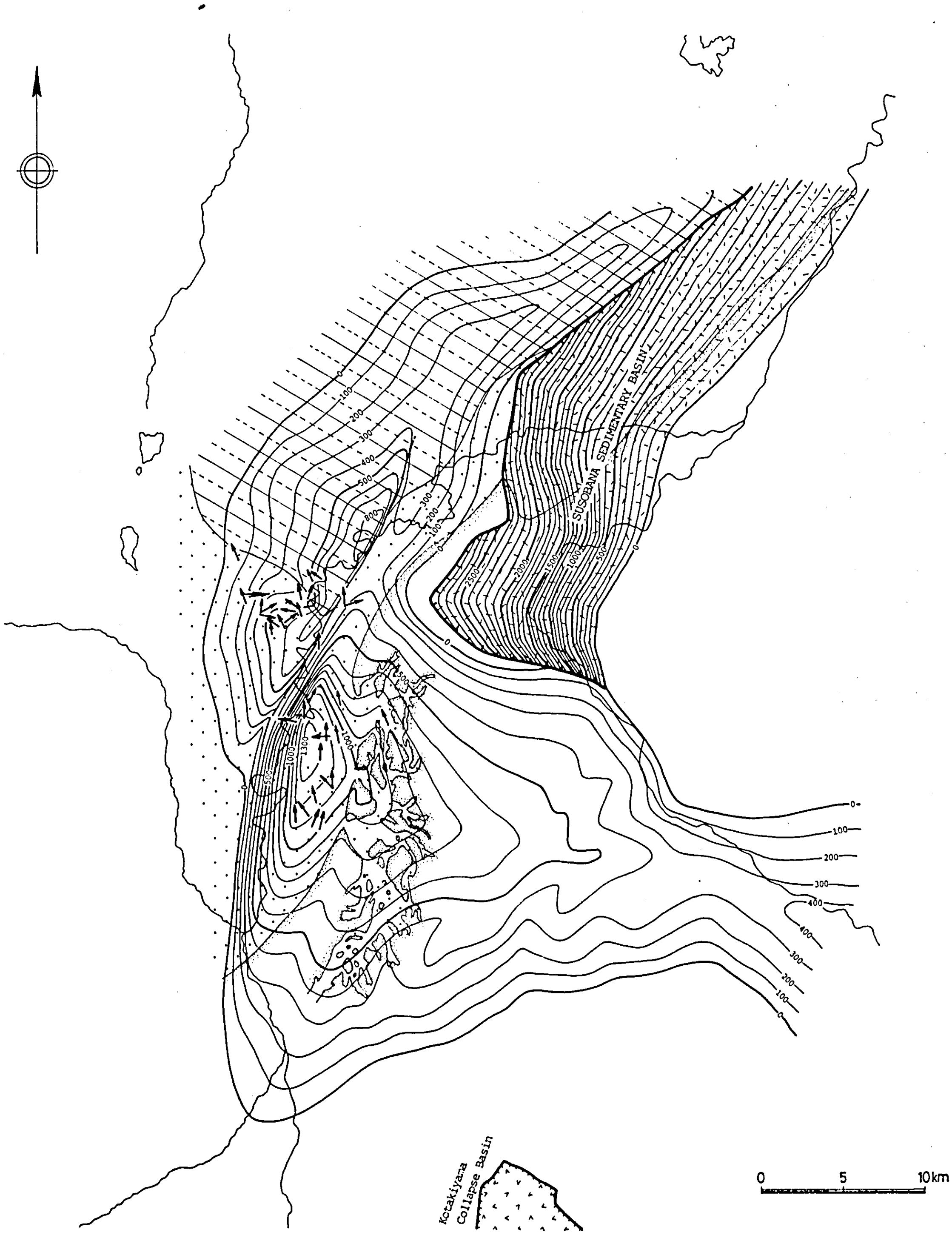


Fig. 19. Isopach map of the Lower Ogawa Formation. See the legend of Fig. 16.

tion are observed.

The clastic facies is composed of molasse and flysch facies. The abrupt appearance of molasse facies in the Tochiku-Komiji and southwestern Takafu-Orihashi Sedimentary Basins is due to a rapid shallowing of sedimentary basins at the beginning of this stage. The upper part of the molasse facies becomes to contain a large amount of coal in the Tochiku-Komiji Sedimentary Basin. Especially, the eastern part of the basin is occupied by frequent alternation of coarse-grained clastics and greenish-colored carbonaceous mudstone containing coal seams. Such sediments may show a repetition of high-energy condition and stagnant one under a fluvial environment. Besides, the arkosic nature of sandstone in the molasse facies may reflect an upheaval of the middle part of the Hida Mountain Range where granitic rocks are widely exposed. On the other hand, the flysch facies is developed in the northwestward frontal area of the molasse facies, where rather low-energy condition has been prevailing since the Aoki stage.

b) Paleocurrent

Paleocurrents in the Early Ogawa stage are restored from cross laminations in molasse facies, and from sole markings in flysch facies. According to Suzuki (1982) and author's data, longitudinal current is more predominant than lateral one. The longitudinal current in the northwestern Tochiku-Komiji Sedimentary Basin runs into the Takafu-Orihashi Sedimentary Basin across the structural-high along Saikawa Anticline-Fault. In the southwestern part of the latter basin, lateral currents toward the east are also observed.

c) Biofacies

Foraminifera, molluscs, plants, etc. are obtained from the Lower Ogawa Formation.

The lower part of molasse facies yields neritic molluscs such as *Glycymeris crassa*, *G. k-suzukii*, *Lucinoma actilineata*, *Laevicardium angustum*, *Mercenaria y-iizukai and Dosinia* (*Kaneharaia*) *kaneharai*, accompanied increasingly with cool-water elements such as *Peronidia venulosa*, *Astarte borealis*, *Mactra sulcataria*, *Spisula voyei* and *S. sachalinensis* (Tanaka, 1962, 1973). The upper part of molasse facies is poor in molluscan fossils except *Crassostrea* sp. which forms numerous fossil beds in the Tochiku-Komiji Sedimentary Basin. Moreover, *Anodonta* sp. and tree stumps in growth position are obtained in the eastern part of the basin (Morishita *et al.*, 1957), where the strata exhibit fluvial-like lithofacies as mentioned above.

The Omi Flora (Imaizumi, 1931) from the molasse facies is characterized by *Sequoia*, *Glyptostrobus*, *Fagus*, *Castanea*, *Quercus* (Deciduous Oaks), *Betula*, *Carpinus*, *Acer*, etc., inferred to be a plant community in the temperate to warm-temperate zone.

As to the foraminiferal fossils, remarks are given in the next section. Thus, the biofacies in the Early Ogawa stage shows that under the temperate to warm-temperate climate the sedimentary environment of molasse facies in the Tochiku-Komiji Sedimentary Basin turned from a neritic condition to a brackish, or locally fresh-water to subaerial condition.

D-2. LATE OGAWA STAGE

1. Subsidence pattern

The isopach map of the Upper Ogawa Formation (Fig. 20) reveals a vanishing of the sedimantary basin almost over the Central Uplift Zone. Subsidence pattern in this stage is rather simple, characterized an échelon arrangement of three asymmetric basins separated by the structural-highs. Each of the basins shows northwestward-tilted subsidence with a depoaxis deflected to the northwest. The Type-C folds grow to the asymmetric structural-highs whose axial planes incline toward the northwest. It is noticeable that another small depocenter with a maximum thickness of 1500m exists near the northeastern end of the Saikawa Anticline-Fault. Two faults of System O-2 are generated just in a steep gradient zone on the southern side of this depocenter.

As a whole, the subsidence pattern is controlled by the advancement of upwarping of the Central Uplift Zone, and by the growth of Type-C folds in antithetic manner against the upwarping.

2. Sedimentary environment

a) Lithofacies

The lithofacies of the Upper Ogawa Formation is characterized by a combination of southeastern molasse and northwestern flysch.

The molasse facies in the southern part of the Tochiku-Komiji Sedimentary Basin is characterized by a frequent repetition of upward-fining cycles. A greenish-colored mudstone containing coal-seams occurs at the top of each cycles. As supported by the occurrence of fresh-water molluscs, such conspicuous cyclic sediments are inferred to be accumulated under a fluvial environment. The structural-high along the Saikawa Anticline-Fault may protect such a fluvial environment from the adjacent marine condition. In the northeastern part of the Tochiku-Komiji Sedimentary Basin, coarse-grained clasts are supplied from a hinterland composed mainly of the Susobana Tuff Member.

The northwestern part of the Minochi Subsidence Zone is still occpied by muddy flysch facies.

b) Paleocurrent

A longitudinal current toward the north to northeast prevails also in this stage, accompanied with lateral currents into the southern part of the Takafu-Orihashi Sedimentary Basin from the west and from the Tochiku- Komiji Sedimentary Basin.

c) Biofacies

The Upper Ogawa Formation yields foraminifera, molluscs, echinoderms, plants, etc.

From the molasse facies in the Tochiku-Komiji Sedimentary Basin, fresh-water molluscs such as *Anodonta* sp., *Margaritefera* sp., *Cristaria* ? sp., *Corbicula* cf. *sakaensis* and *Viviparus* sp. are reported by Kobayashi and Isomi (1950), Tomizawa (1962), Tanaka and Teradaira (1964) and Saikawa C. R. G. (1966). Additionally, fossil beds of *Crassostrea gigas* are intercalated in the northwestern part of the basin. On the other hand, the flysch facies yields neritic and rarely upperbathyal species, such as *Conchocele disjuncta*, *Clinocardium shinjiense*, *Laevicardium angustum*, *Dosinia* (*Kaneharaia*) *kaneharai*, *Spisula sachalinensis*, *Serripes makiyamai*, *Mya donaciformis*. *Bucci-*

num shinanoense, *Ancistrolepis fragilis* and *Nassarius nakamurai* (Kanno and Tomizawa, 1959; Yano and Murayama, 1976). It is noteworthy that this fauna, represented by the Zenkoji Spa Fauna, is a relatively cool-type mixed-fauna composed of cold water elements (*Spisula sachalinensis*, *Serripes makiyamai*) and warm water elements (*Dosinia* (*Kaneharaia*) *kaneharai*).

The Chausuyama Flora (Endo, 1948) obtained from the northeastern end of the Tochiku-Komiji Sedimentary Basin is characterized by warm-temperate elements such as *Acer*, *Fagus*, *Ficus*, *Glyptostrobus*, *Onodea*, *Poplus*, *Pterocarya and Sequoia*, with subordinate cool-temperate ones such as *Betula*, *Alnus* and *Ulnus*.

According to the study on foraminifera by Masatani and Ichimura (1970), the whole of the Ogawa Formation is represented by *Cribrostomoides-Trochamina* zonule. The paleobathymetry is inferred to be largest on the north-western margin of the Hikage

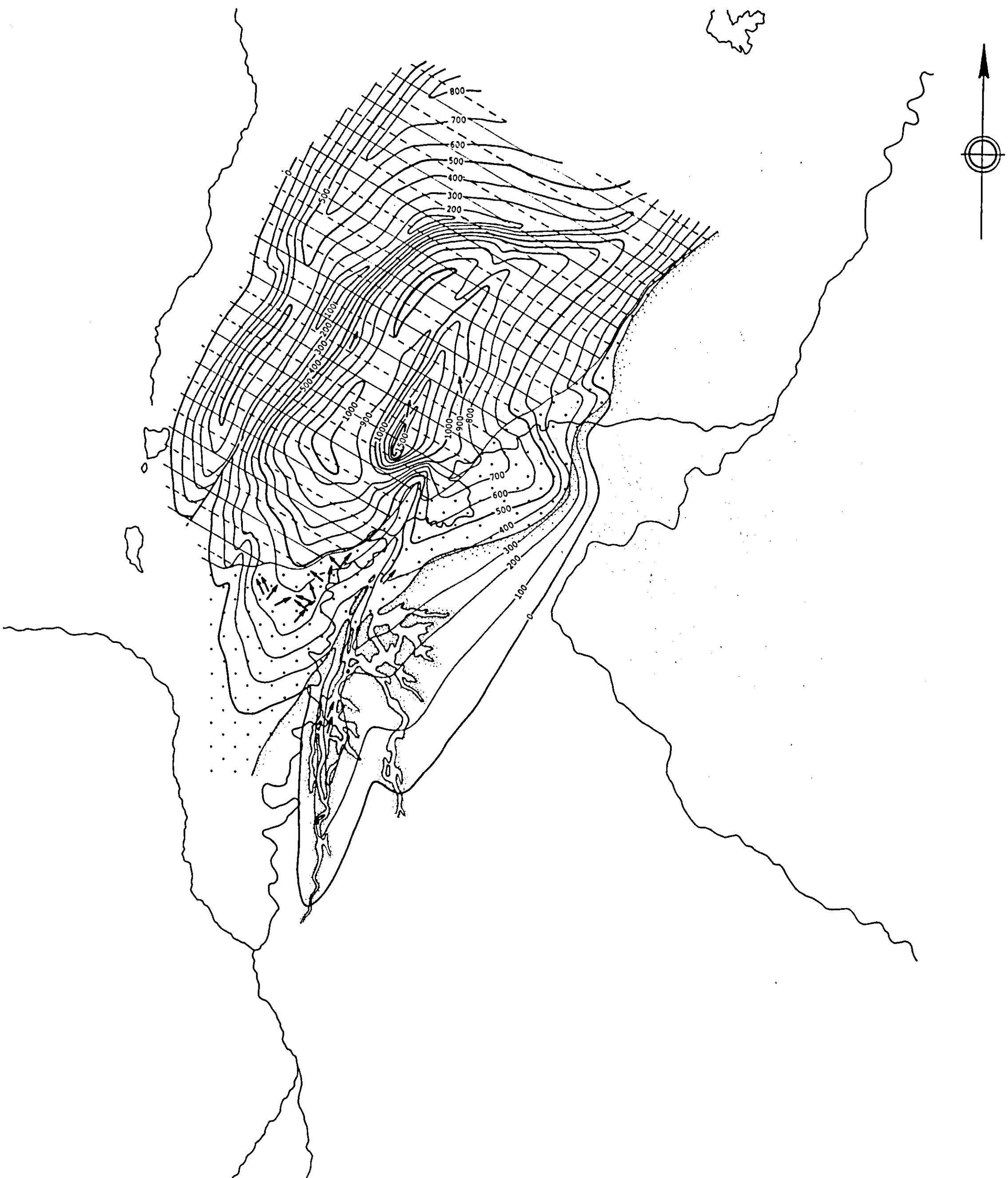


FIG. 20. Isopach map of the Upper Ogawa Formation. See the legend of Fig. 16.

Sedimentary Basin, and to decrease abruptly toward the northwest and gradually toward the southeast. Poverty in calcareous foraminifera over the region (except the northwestern side of Buno Fault) and barrenness in planctonic ones suggest an environment of embayment from the "Paleo-Japan Sea" and an influence of fresh-water from the surrounding land area.

Thus, it may be concluded that in the Late Ogawa stage a large-scale bay opens toward the north or northeast and is margined with an alluvial plain along the southeastern coast. Moreover, the temperate to warm-temperate climate in the previous stage seemes to become a little cooler.

E. SHIGARAMI STAGE

During the Shigarami stage, features of sedimentary basin largely change through the two episodes of local uplifting and denudation.

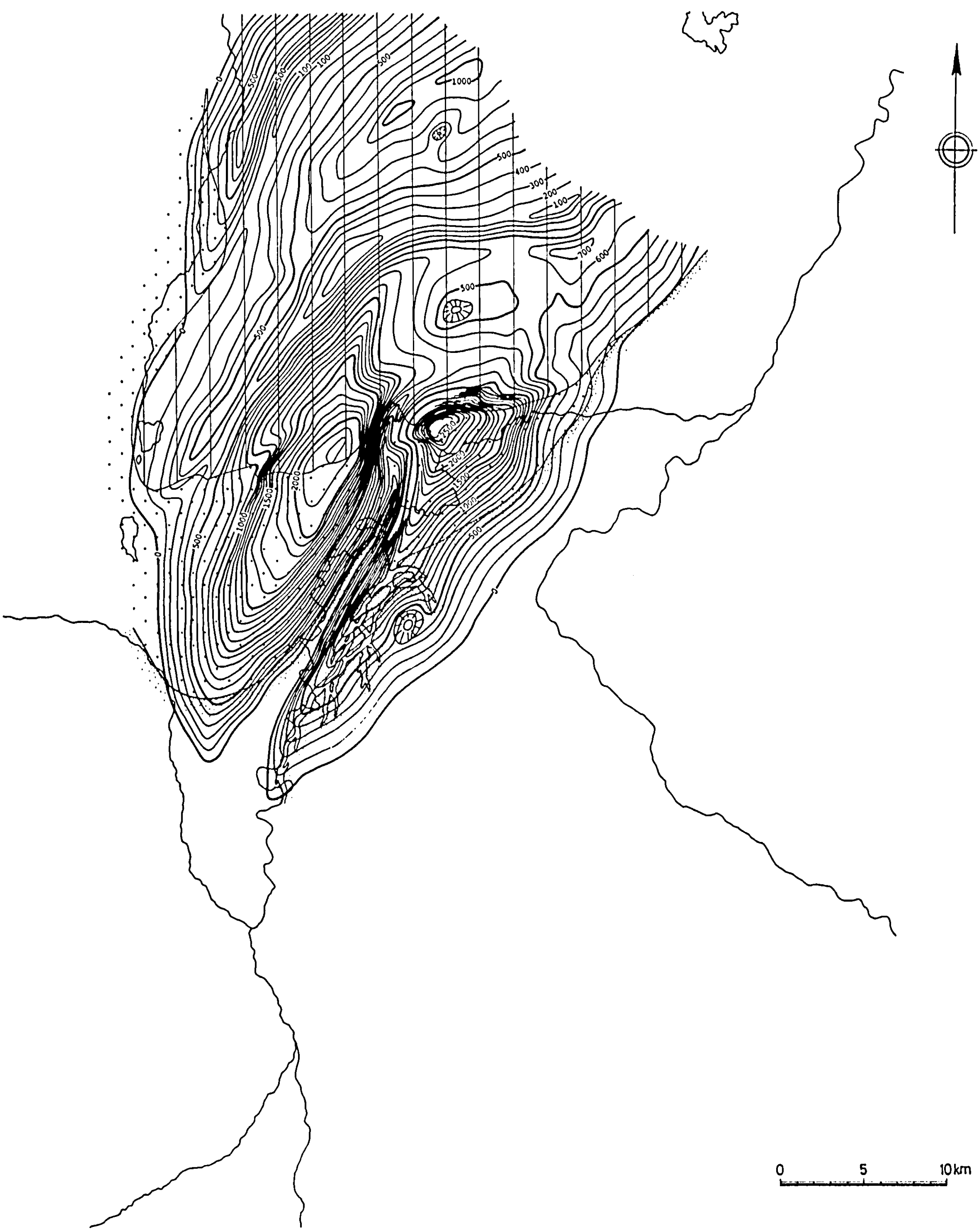


FIG. 21. Isopach map of the Lower Shigarami Formation.
See the legend of Fig. 16.

E-1. Early Shigarami Stage

1. Subsidence pattern

A large-scale subsidence and a complex arrangement of three or four sedimentary basins are distinctive features of subsidence pattern in the Early Shigarami stage (Fig. 21).

The Tochiku-Komiji Sedimentary Basin exhibits a markedly asymmetric subsidence pattern (a northwestward-tilted basin) with a depocenter in the northern end, where a thickness attains ca. 2500m. A basinal subsidence elongated in NNE-SSW direction is characteristic of the Takafu-Orihashi Sedimentary Basin, whose depoaxis is deflected to the southeast. The maximum thickness in this basin is ca. 2200m. The Hikage Sedimentary Basin may open northeastward, though the thickness change is not clear.

The structural highs separating these basins are produced by the anticlinal growth of Type-C folds.

The subsidence pattern in this stage is controlled by the upwarping of Central Uplift Zone and the growth of Type-C folds, and partly by the upheaval of the Hida Mountain Range as stated later.

2. Sedimentary environment

a) Lithofacies

The Lower Shigarami Formation is composed of two facies of southeastern molasse and northwestern monotonous mudstone, accompanied with a small amount of volcanic products.

The molasse facies expands northwestward especially in the Takafu-Orihashi Sedimentary Basin, as compared with the Ogawa stage, reflecting presumably an upheaval of the Hida Mountain Range. In the

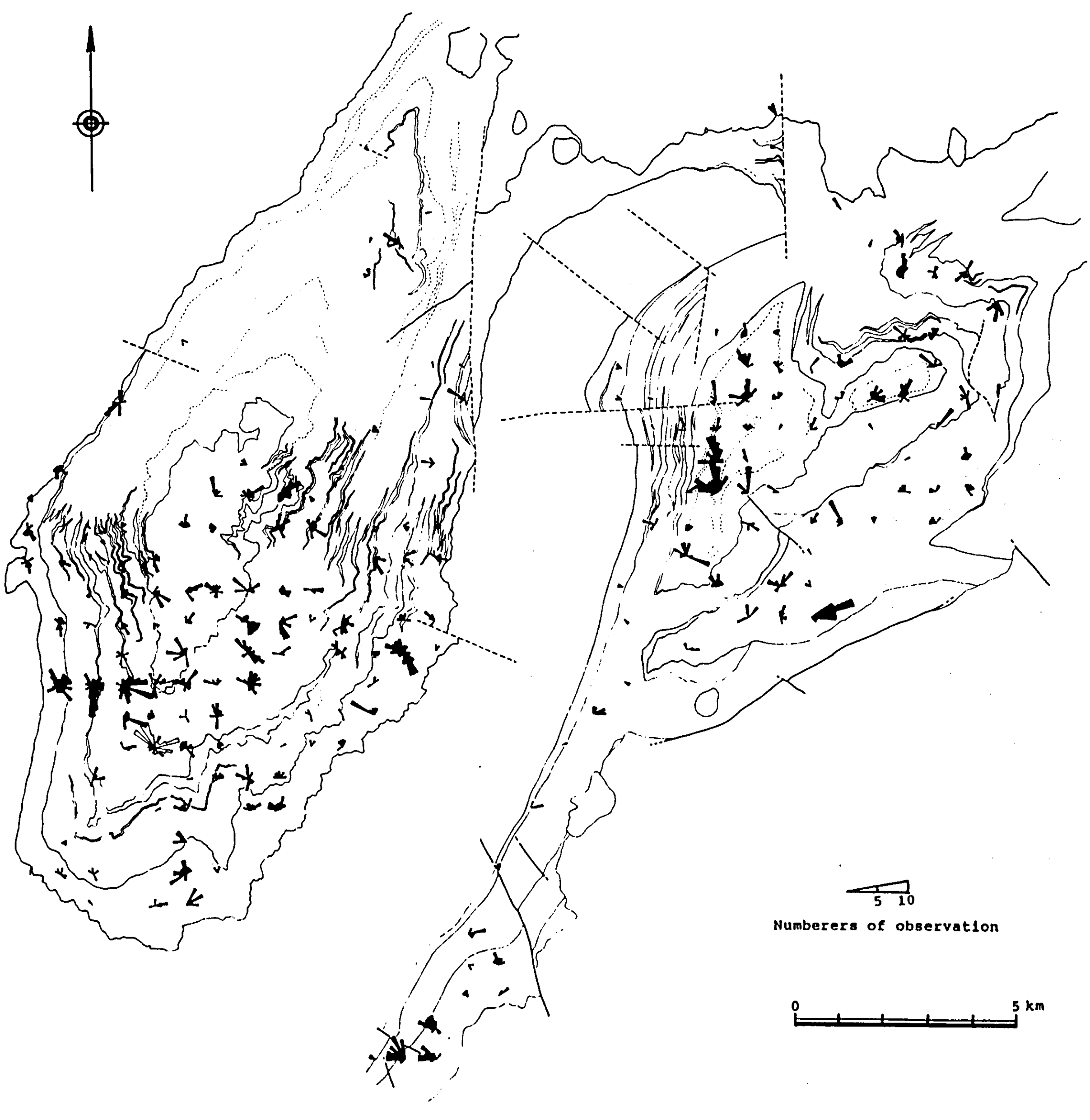


FIG. 22. Cross-lamination in the Lower Shigarami Formation.
Current roses summarize paleocurrent for each 0.5km square.

southern part of Tochiku-Komiji Sedimentary Basin, the molasse facies is characterized by a frequent repetition of upward-fining cycles as in the Late Ogawa stage, being inferred to be deposited under a fluvial environment bordered by the structural-high along the Saikawa Anticline-Fault. Whereas the main part of this facies is composed of fairly well-sorted coarse-grained sediments with cross lamination, the northern marginal part is made up of very fine-grained argillaceous sandstone, which at last turns into mudstone. The sorting drops abruptly on the nortern margin.

The monotonus mudstone facies occupies the northwestern area extensively, accompanied with a small amount of flysch facies in the Hikage Basin. A low-energy to stagnant condition seems to predominate in the frontal area of molasse facies.

The small-scale volcanism supplying andesitic to rarely dacitic lavas and pyroclastics into the three main basins is probably a forerunner of violent volcanism in the Middle Shigarami stage, because of a similarity in petrographic properties. In the Takafu-Orihashi Sedimentary Basin, pyroclastic intercalations tend to thicken and coarsen toward Mt. Mushikura where the Arakurayama Pyroclastic Member of Middle Shigarami Formation is developed.

Additionally, the advancement of uplifting of the Hida Mountain Range in this stage is suggested by a larger average diameter of gravels derived from the pre-Neogene basements and by a content of granite

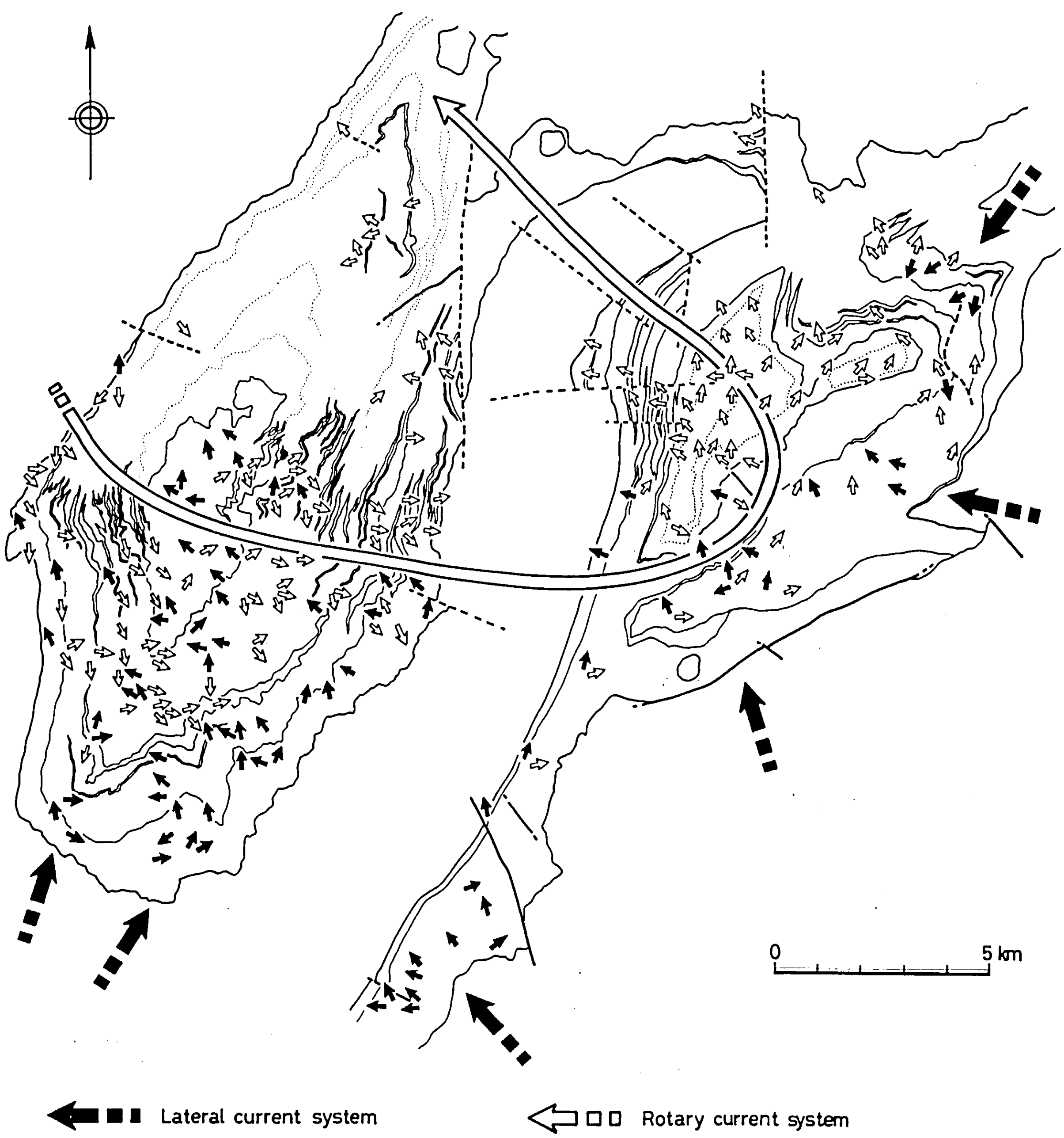


FIG. 23. Paleocurrent system restored from cross-lamination in the Lower Shigarami Formation.

pebbles attaining sometimes several per cent in the southwestern Takafu-Orihashi Sedimentary Basin (Hirabayashi, 1970a, b). On the contrary, the content of gravels derived from the Uchimura Formation and the Susobana Tuff Member tends to increase southeastward, due to the fluvial systems started in the Central Uplift Zone.

b) Paleocurrent

Paleocurrents restored mainly from cross lamination display a rather scattered pattern (Fig. 22). However, they may be grouped into two systems, i.e., an anticlockwise rotary current system and some lateral current systems from southeast to northwest and from southwest to northeast (Fig. 23).

c) Biofacies

The biofacies of the Lower Shigarami Formation has already been examined by Yano *et al.* (1983) in the Takafu-Orihashi and the northeastern Tochiku-Komiji Sedimentary Basin.

Molluscan fossils occur in more or less allochthonous mode, though *Mya* and *Conchocele* show in some cases an autochthonous occourence. They are grouped into five assemblages based on their association and dominancy, i.e., the *Corbicula, Crassostrea, Clementia, Anadara-Dosinia, Conchocele* Assemblages (Table 3). The vertical change in arrangement of faunal assemblages is illustrated in Figs. 24 and 25. Conspicuous features through the Early Shigarami stage are a zonal arrangement of faunal assemblages (from south-southeast to north-northwest, *Clementia, Corbicula* or *Crassostrea* Assemblage-*Anadara-Dosinia* Assemblage-*Conchocele* Assemblage), and also a considerable prosperity of the *Crassostrea* Assemblage in the late to latest Early Shigarami stage.

Trace fossils are grouped into sand-pipe type and *Cylindrichnus* type, both of which tend to occur complementarily with each other (Fig. 26). *Cylindrichnus* sp. occurs selectively on the border between molasse facies and mudstone facies, namely in fine-to very fine-grained argillaceous sandstone. On the other hand, the sand-pipe type spreads over the southeastern part of the area of coarse-grained sediments, and disappears in the southernmost fluvial facies. According to the paleobathymetric study of trace fossils by Chamberlain (1978), inhabitants in *Cylindrichnus* are inferred to dwell in nearshore.

As a whole, the zonal arrangement of sedimentary facies changing continuously from fluvial to neritic one may indicate a fan-deltaic environment. Judging from the bathymetry of *Cylindrichnus*, the border line between the biotopes of *Anadara-Dosinia* and *Conchocele* Assemblages corresponds roughly to the wave base, and lithologically to the boundary between molasse and mudstone facies ("mud line "). The sedimentary environment in this stage is divisible into the following three components from south-southeast to north-northwest; a fluvial plain along the southeastern coast bordered by a structural-high, a delta occupying the estuary and nearshore, and an extensive frontal basin. According to the study of foraminifera by Masatani and Ichimura (1970), muddy sediments in this frontal basin are represented by *Epistominella pulchella-Cribrostomoides* cf. *subglobosum* zonule, being inferred to be accumulated under a fairly deep condition. The exclusive prosperity of *Crassostrea* in the late to latest Early Shigarami stage is attributed to a decline of salinity by an intensification of embayment condition, presumably originated from a upheaving in the frontal basin associated with the forerunning volcanism around Mt. Mushikura.

TABLE 3. MOLLUSCAN ASSEMBLAGES FROM THE LOWER SHIGARAMI FORMATION.

CORBICULA ASSEMBLAGE
Corbicula sp.
OSTREA ASSEMBLAGE
Ostrea (Crassostrea) gravitesta
Tectonatica janthostomoides
Macoma calcarea
CLEMENTIA ASSEMBLAGE
Clementia sp.
Mercenaria cf. *yokoyamai*
ANADARA - DOSINIA ASSEMBLAGE
Amadara amicula
Dosinia (kaneharaia) kaneharai
Lucinoma acutilineatum
Mya japonica
Glycymeris minochiensis
Tectonatica janthostomoides
Neverita fissuratus
Mercenaria shigaramiensis
Patinopecten tryblium
P. yamasakii
Cardium shinjiense
Clinocardium angustum
Spisula (Mactromeris) voyei
Thracia kamayashikiensis
CONCHOCELE ASSEMBLAGE
Conchocele bisectoides
Buccinum shinanoense

Additionally, an increace of cool-water molluscs such as *Mactra sachalinensis, Supisula* cf. *voyei, Patinopecten (Kotorapecten) triblium* and *Buccinum koyamai* is worthy to note.

E-2. MIDDLE SHIGARAMI STAGE

1. Subsidence pattern

Subsidence pattern in this stage is characterized by emergence almost over the Tochiku-Komiji Sedimentary Basin and by basinal subsidences centering on volcanic bodies of the N-S trending Shigarami Volcanics Chain (Fig. 27). The maximum thickness attains ca. 2100m in such volcanic basins. Another thick volcanic pile is distributed in the northern Omine Depression along the Otari-Nakayama Fault.

2. Sedimentary environment

a) Lithofacies

The lithofacies of the Middle Shigarami Formation is characterized by a combination of volcanic and clastic facies. In the volcanic facies subaerial products

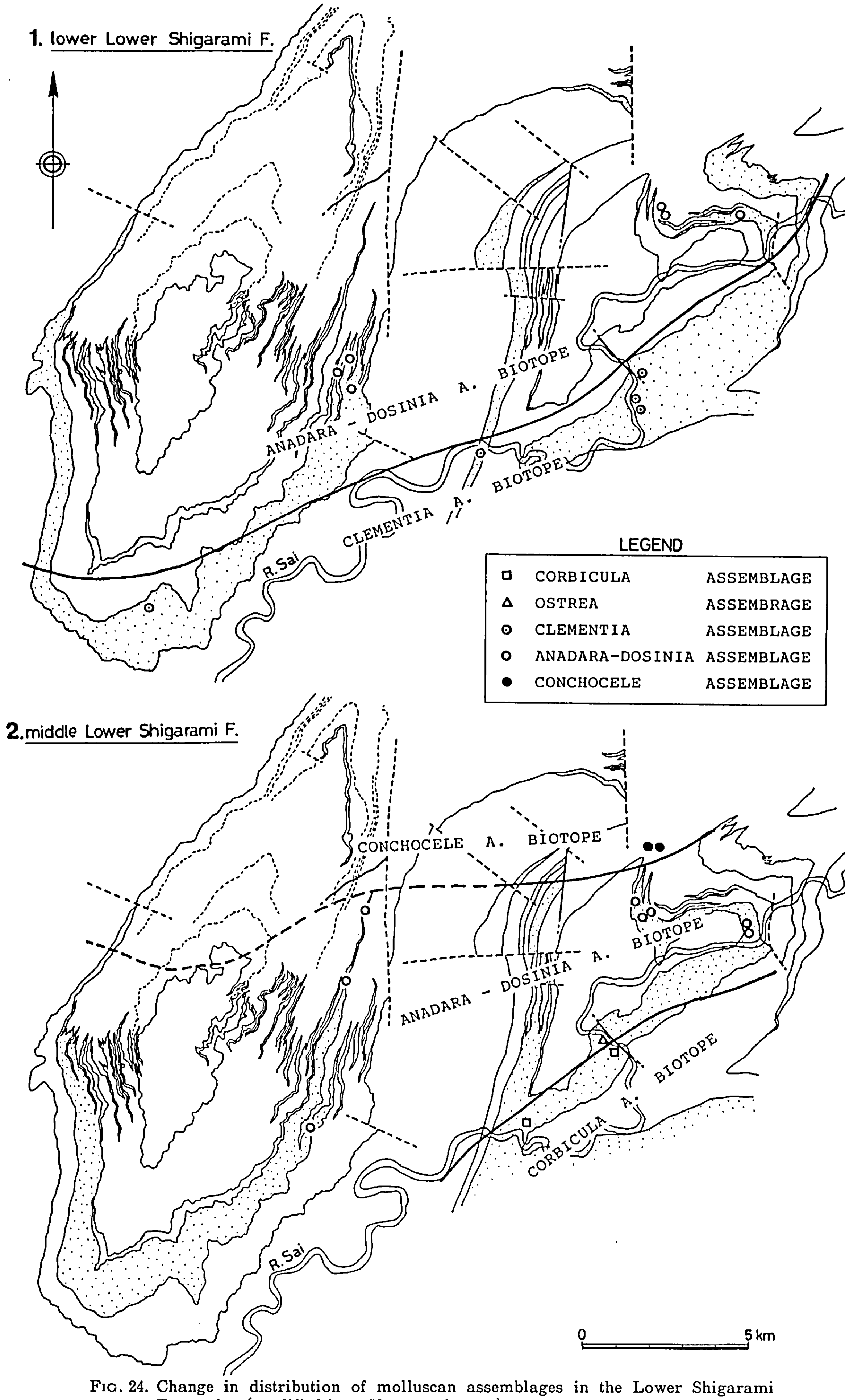


FIG. 24. Change in distribution of molluscan assemblages in the Lower Shigarami Formation (modified from Yano *et al.*, 1983).

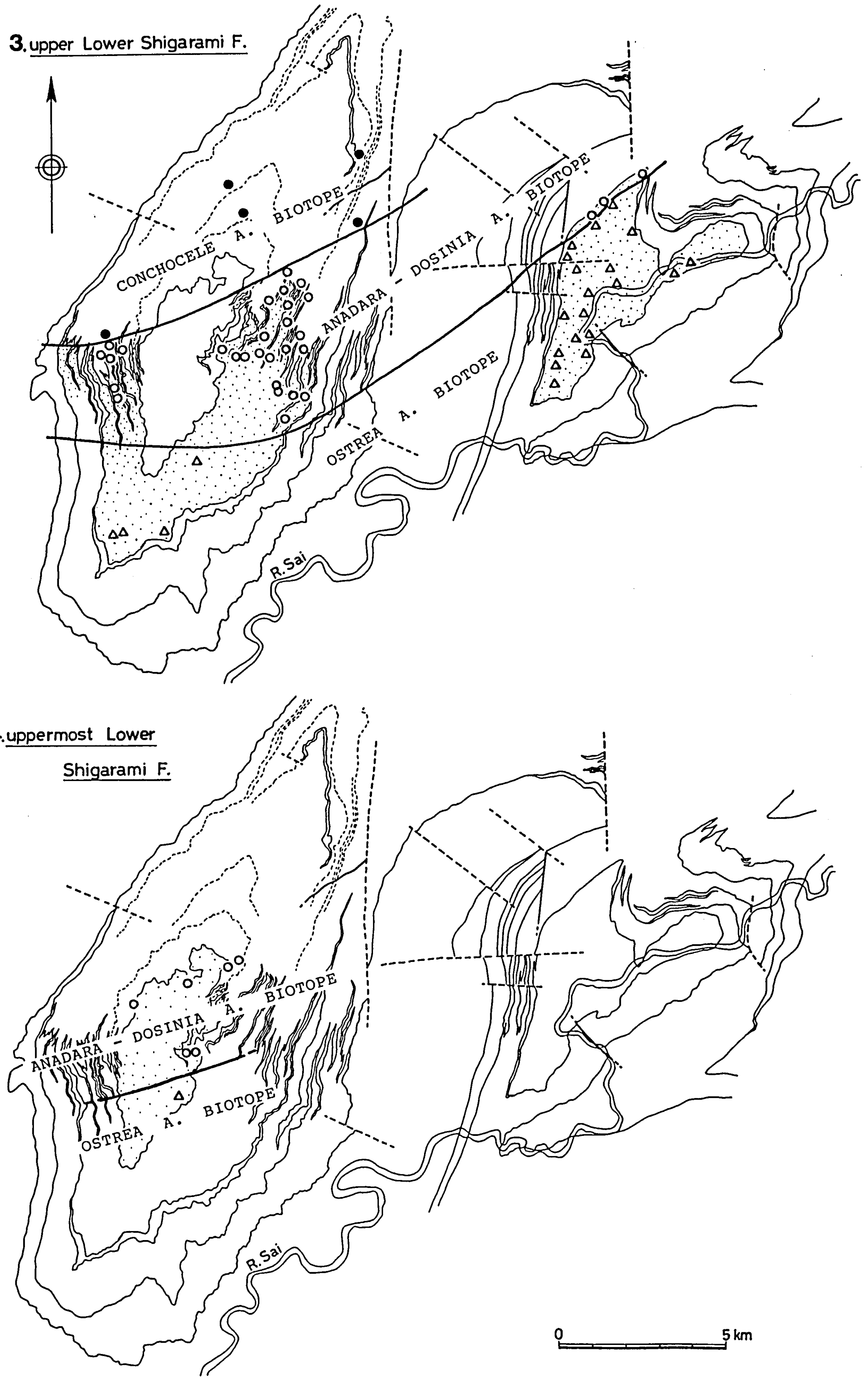


FIG. 24. (Continued)

become predominant from north to south. This may reflect a differential movement between the Minochi Subsidence Zone and the Central Uplift Zone. The Arakurayama volcanic body is inferred to be formed as a volcanic cone by central eruption, because the depocenter coincides with the distribution center of lava flows (Fig. 28), where the intrusion of Porphyrite-II occurs. The volcanic activity changes from an explosive submarine volcanism mainly of (olivine-) augite andesite in the earlier time to a mostly subaerial volcanism of (hornblende-) hypersthene-augite andesite in the later time (Fig. 29).

The clastic facies is characterized by the predominamce of mudstone, accompanied with muddy flysch in the Hikage Sedimentary Basin and with coarse-grained sediments on the southeastern coastal margin. As a whole, a low-energy submarine condition is prevailing over the sedimentary basins except around the volcanic areas.

b) Paleocurrents

There are no available data on paleocurrents, because of the predominance in volcanic and muddy facies.

c) Biofacies

The Middle Shigarami Formation yields molluscs, cirripedia, bryozoa, etc. Fossils reported from the Tokafu-Orihashi Sedimentary Basin are represented by neritic species such as *Anadara amicula*, *Glycymeris* cf. *yamasakii*, *Lucinoma annulata*, *Mercenaria chitaniana* and *Callista chinensis* (Yano, 1981b). Sessile species such as *Haliotis* sp., *Monia* sp. and *Balanus* sp. are also obtained. Thus, the biofacies indicates a shallow marine environment with rock reefs in the volcanic area.

E-3. Late Shigarami Stage

1. Subsidence pattern

A northwestward restriction of sedimentary basin in the Minochi Subsidence Zone, and a southward shifting of depocenter in the Omine Depression are characteristic of the subsidence pattern (Fig. 30).

An asymmetric structural high along the northeastern Nishikyo Anticline-Fault separates the sedimentary basin of the Minochi Subsidence Zone into two portions. In the Takafu-Orihashi Sedimentary Basin, the subsiding area is restricted within its northeastern part. A depoaxis deflected northwestward and a small peninsula (about 3km long) extending from the southwest are characteristic of this basin. The peninsular upheaval succeeding to an upwarping of the whole volcanic body of Arakurayama Pyroclastic Member is considered to have been caused by the rising Porphyrite-II under the ground (Fig. 31), because both the zone of intrusion of Porphyrite-II and the zone of hydrothermal alteration coincide with the peninsula (Fig. 32), and because the intrusion is still active in this stage. On the other hand, the Hikage Sedimentary Basin is characterized by a trough-like subsidence in the southern to middle part and an asymmeteic large subsidence (a northwestward-tilted basin) in the northern part. The maximum thickness in the latter basin is ca. 1500m.

In the Omine depression, the depocenter is inferred to be situated to the east of Lake Nishina (Kosaka, 1980). The N-S trending depoaxis is presumably

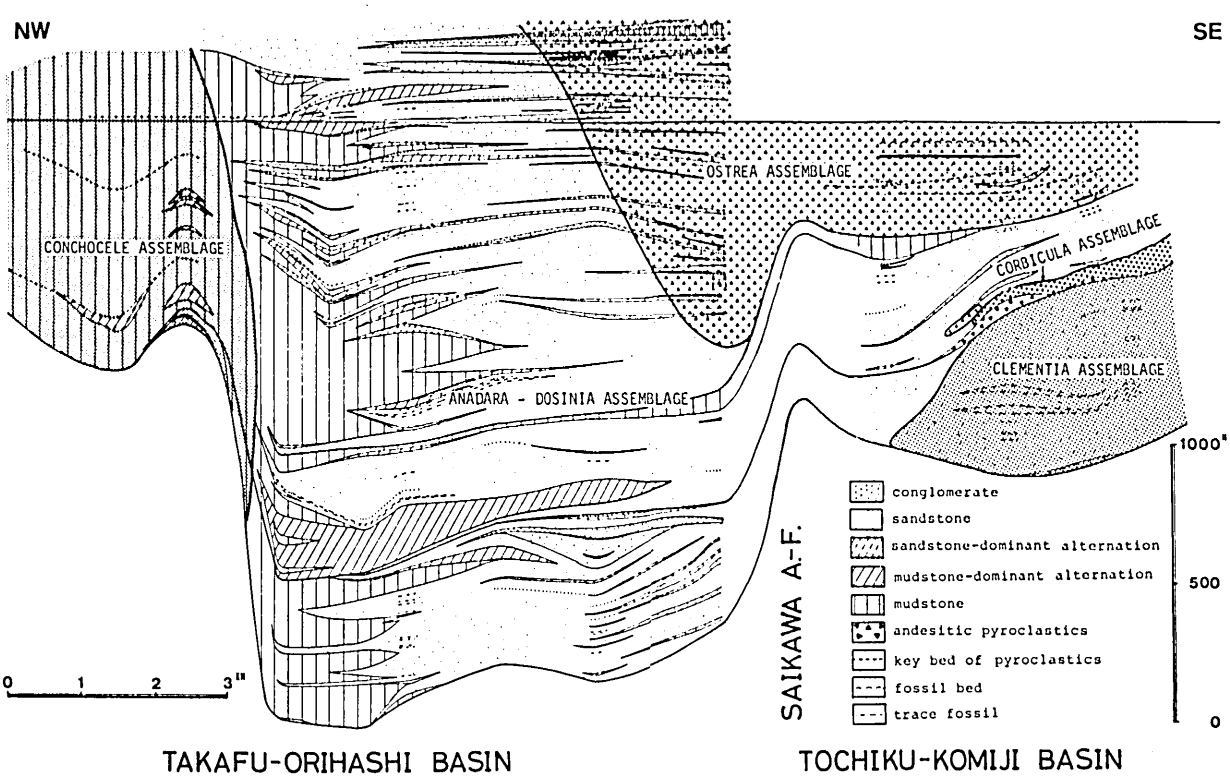


FIG. 25. Stratigraphic distribution of molluscan assemblages in the Lower Shigarami Formation (modified from Yano *et al.*, 1983).

deflected eastward, due to the upheaval of the Hida Mountain Range.

2. Sedimentary environment

a) Lithofacies

Arenaceous mudstone is predominant over the sedementary basins, accompanied with basal and peripheral conglomrates in the Minochi Subsidence Zone, and also with frequent intercalations of conglomerate in the Omine Depression. Besides, acid tuff is characteristic especially in the Omine Depression.

The basal and peripheral conglomerates in the Minochi Subsidence Zone consist of clasts ranging from sand to large boulder derived entirely from the Arakurayama Member. In the Takafu-Orihashi Sedimentary Basin, debrises are sometimes supplied from sea cliffs around the aforesaid peninsula through this stage (Fig. 31). In most of the basins except the basal and marginal areas, ill-sorted muddy sediments are accumulated under stagnant condition. Additionally, a remnant activity of the violent volcanism in the Middle Shigarami stage supplys a small amount of andesitic pyroclastics.

In the Omine Depression, the conglometate consists of clasts derived mostly from the pre-Neogene basement rocks in the Hida Mountain Range, and also from the Neogene strata in the Minochi Subsidence Zone and the northern Omine Depression (Kosaka, 1980). This fact suggests an upheaving tendency of the surrounding area, especially of the Hida Mountain Range.

b) Paleocurrent

Based on the restoration from fabrics of conglomerate on the northeastern margin of the Omine Depression, a paleocurrent of N-S to NE-SW direction is prevalent (Kosaka, 1983).

c) Biofacies

The Upper Shigarami Formation yields abundant fossils of molluscs, brachiopods, cirripeds, bryozoans, echinoderms, etc. They are grouped under the name of the Shimonireki Fauna by Tomizawa (1958). Fossils

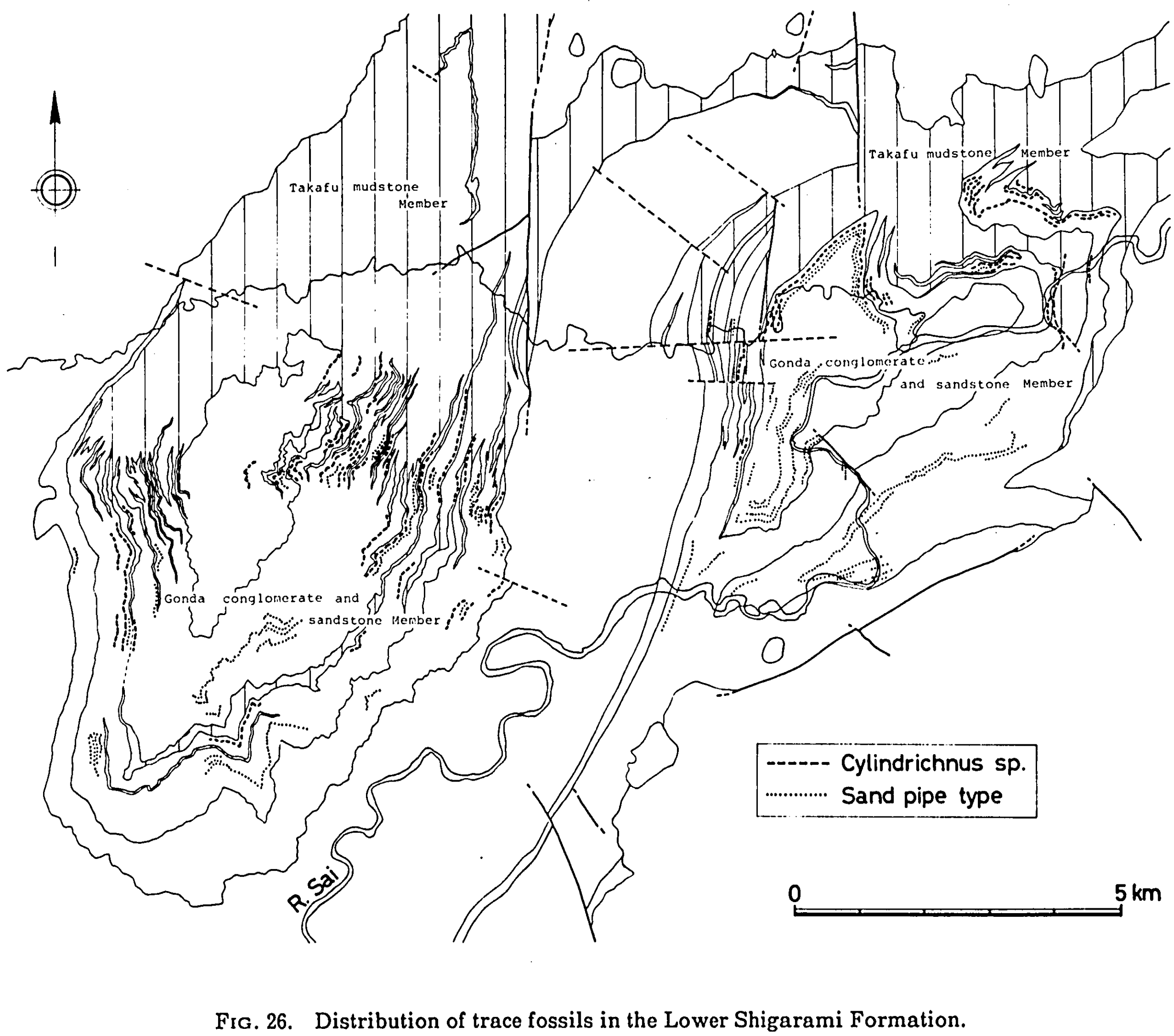


FIG. 26. Distribution of trace fossils in the Lower Shigarami Formation.

reported by Yano (1981a) are listed in Table 4.

The Shimonireki Fauna is characterized by abundant neritic species including sessile ones such as *Haliotis, Littorina, Serpulorbis, Hydroides, Modiolus, Anonia, Monia, Coptothyris, Terebratella* and *Balanus*. The sessile species are represented by inhabitants on rock coast. This fauna is also characterized by a comparative abundance in cool-water elements such as *Chlamys* (s.s.) cf. *sendaiensis* and *Placopecten* (s.s.) cf. *setanaensis*. According to Masuda and Ogasawara (1981), the Shimonireki Fauna may be a little older than the Omma-Manganzi Fauna, one of the representative cool-water faunas in Japan.

F. SARUMARU STAGE

1. Subsidence pattern

The Minochi Subsidence zone and the Omine Depression show a subsidence pattern similar to that in the Late Shigarami stage. In the Central Uplift Zone,

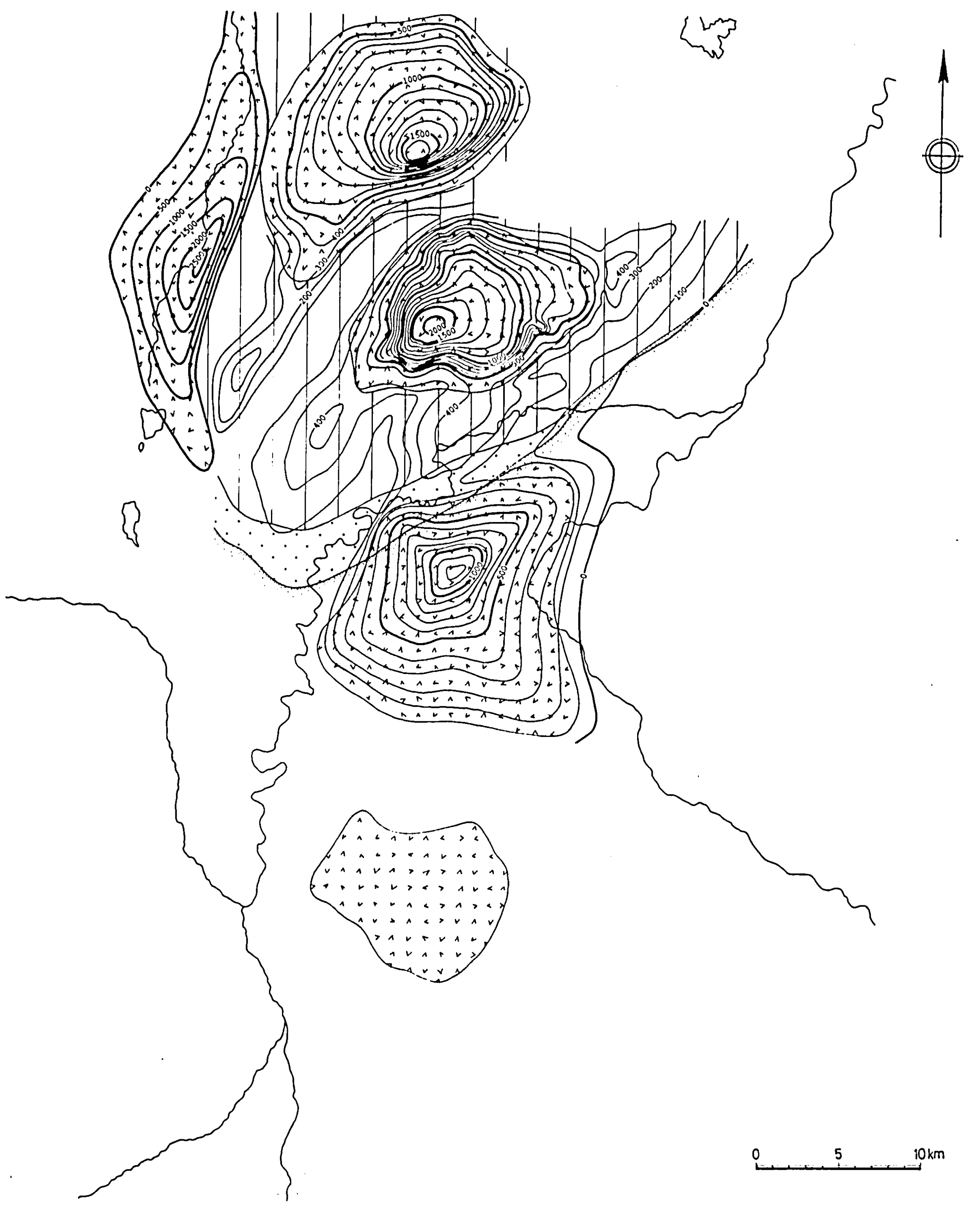


FIG. 27. Isopach map of the Middle Shigarami Formation.
See the legend of Fig. 16.

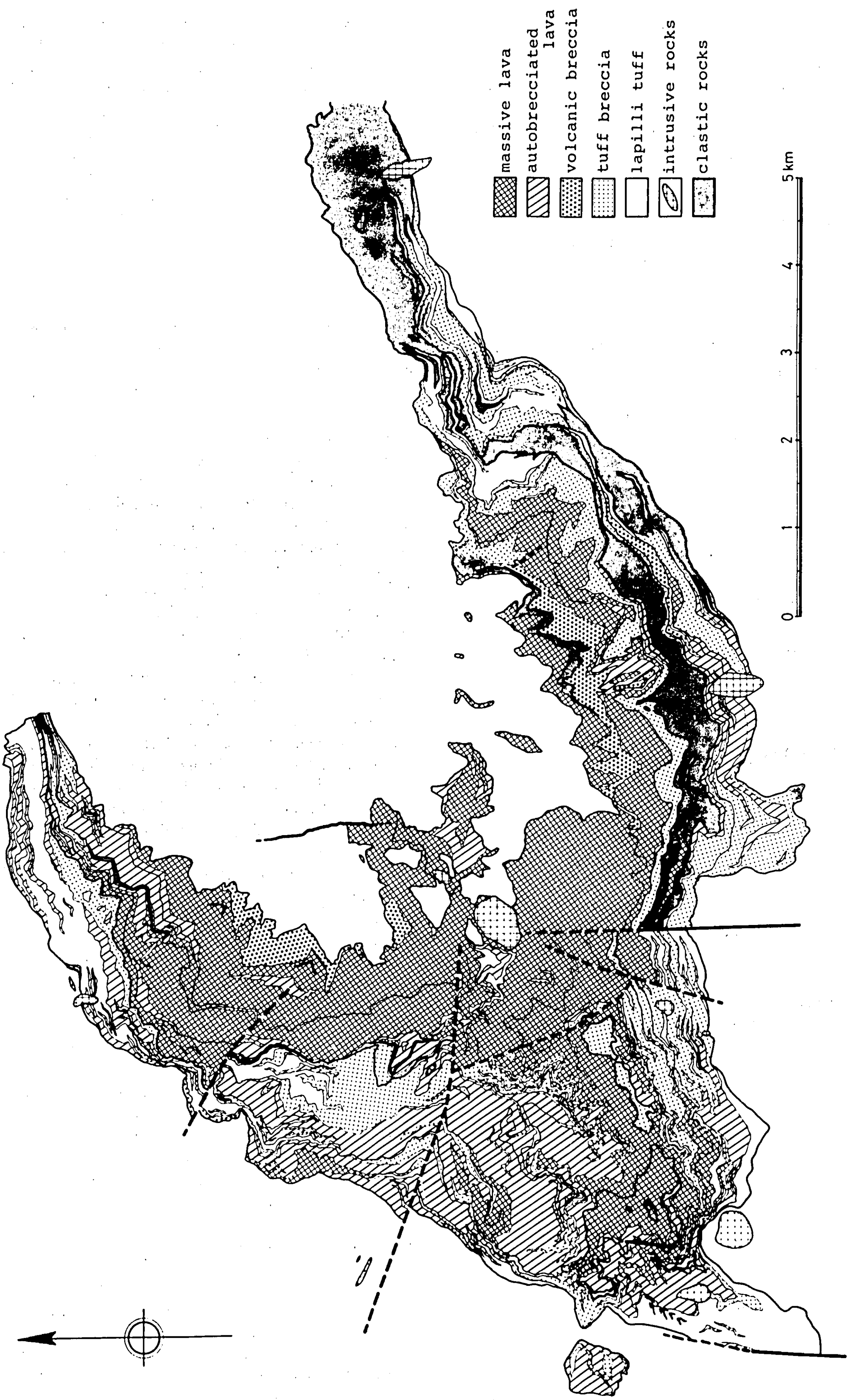


FIG. 28. Lithofacies map of the Middle Shigarami Formation in the Takafu-Orihashi Sedimentary Basin (after Yano, 1981b).

however, new sedimentary basins appear in this stage.

a) Early Sarumaru stage

In the Minochi Subsidence Zone, both the depoaxes and the depocenters shift to the southeast or to the east (Fig. 33), as compared with the Late Shigarami stage. Conesquently, the asymmetry of subsidence pattern becomes remarkably weak. The depocenter of the Omine Depression also migrates southward (Kosaka, 1980).

In the Central Uplift Zone, the Komoro and the Enrei Depression are formed by faulting of N-S and NW-SE directions, superimposed on the eastern and southwestern sides of the Utsukushigahara Dome, respectively.

b) Late Sarumaru stage

The depocenter of the Takafu-Orihashi Sedimentary Basin shifts to the northeast, and that of the Omine Depression to the south. In the Komoro and the Enrei Depression, lavas and pyroclastic flows partly run over the margin of depression (Fig. 34).

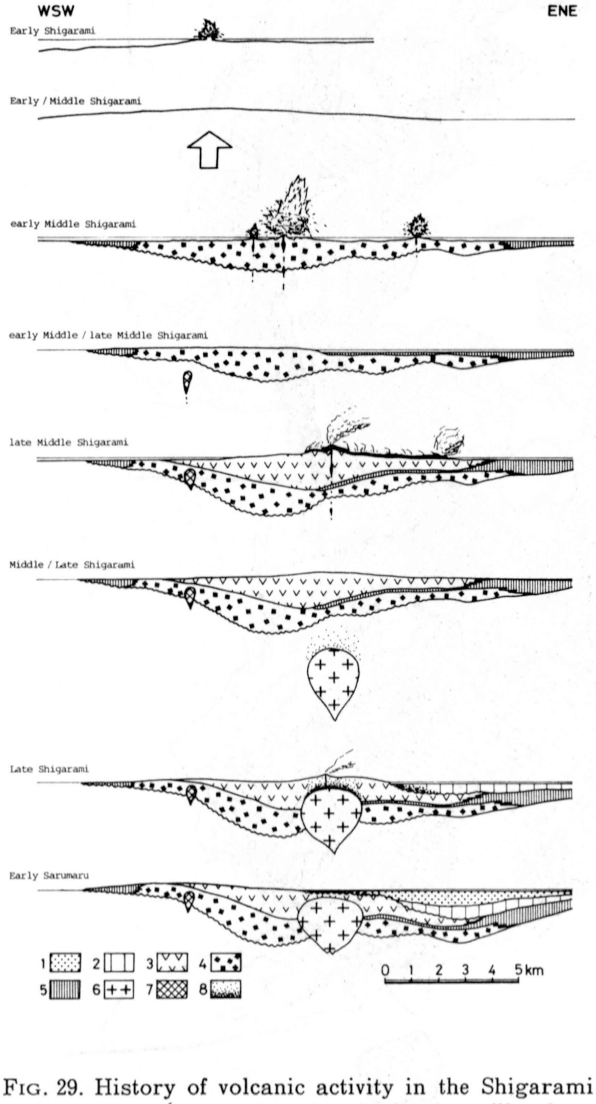


FIG. 29. History of volcanic activity in the Shigarami stage (shown as a longitudinal profile along the axis of Orihashi Syncline in the Takafu-Orihashi Sedimentary Basin).

New sedimentary basins are generated in the area from Nagano Basin to northern foot of Mt. Hijiri and in the vicinity of Shioda Basin. The sedimentary basin in the Nagano area shows a northwestward-tilted subsidence with an extremely deflected depoaxis and two depocenters, where the thickness attains ca. 600m. The northwestern margin of this basin is bounded by flexures along the Tago and Samizu Faults of System L-1b. The small sedimentary basin in the Shioda area has a complicated outline. The thickness there is less than 130m.

2. *Sedimentary environment*

a) Lithofacies

Conspicuous features on lithofacies are a coarseness of clastic sediments over the whole region and a wide expansion of volcanic rocks.

The coarseness of clastic sediments in the Early Sarumaru stage reflects a rapid uplifting of provenance areas and a simultaneous appearance of high-energy condition over the depositional sites. In the Late Sarumaru stage, clastics become further coarser and the conglomerate contains abundantly cobbles and in some places boulders. Intercalations of greenish-colored mudstone and lignite are also characteristic. Layers of welded acid tuff are observed locally in the Takafu-Orihashi Sedimentary Basin and frequently in the Omine Depression. This fact indicates that subaerial condition occupies a part of the sedimentary basins, even if temporarily.

The composition and average diameter of conglomerate in the Takafu-Orihashi Sedimentary Basin are shown in Fig. 35. In the Early Sarumaru stage, gravels derived from the pre-Neogene basement rocks of the Hida Mountain Range are prevalent in the western area, while those from the Neogene strata (Uchimura and Bessho Formations, Susobana Tuff Member, Takai Volcanic Rocks) are predominant in the eastern area. Such a variation in composition is undoubtedly attributed to a difference in provenance. In the Late Sarumaru stage, the average diameter of conglomerate becomes larger, and gravels from the pre-Neogene basement rocks increase over the whole area; gravels from the Uchimura and Bessho Formations and the Susobana Tuff Member decrease comparatively. These changes reflect an upheaval of provenance areas, especially of the Hida Mountain Range. According to Kosaka (1980), the conglomerate in the Omine Depression consists of clasts derived largely from the pre-Neogene basement rocks, and additionally from volcanic and clastic rocks of the Neogene strata, together with acid (welded) tuff in the Omine Depression. Besides, it is noticeable that clasts of semiconsolidated sandstone from the adjacent Minochi Subsidence Zone is contained abundantly in the later half of the Late Sarumaru stage. These facts indicate an advancement of uplifting in the Hida Mountain Range and a marked denudation in the Minochi Subsidence Zone.

Judging from the standard stratigraphic succession of volcanic rocks described in Chapter III, the environment of Komoro and Enrei Depressions changes from subaqeous condition to subaerial one, and the mode of volcanism turns from explosive activity to effusion of "Flat Lava". Volcanic activities in the Shiga Dome area erupt "Flat Lava " and pyroclastics exclusively under a subaerial condition. The widespread nature of "Flat Lava" is attributed to an abnormally low viscosity for andesitic magma and a flatness of bottom surface.

b) Paleocurrent

Paleocurrents are locally restored from cross lamination in the Takafu-Orihashi Sedimentary Basin. Lateral currents from southeast to northwest are predominant in the Early Sarumaru stage.

c) Biofacies

Early Sarumaru stage

Molluscan fossils reported from the Takafu-Orihashi Sedimentary Basin are characterized by neritic and brackish-water species such as *Glycymeris yamasakii, Crassostrea gigas, Macoma incongrua, Callista brevisiphonata, Cyclina orientalis, Mercenaria shigaramiensis* and *Mya japonica* (Tomizawa, 1962). In the

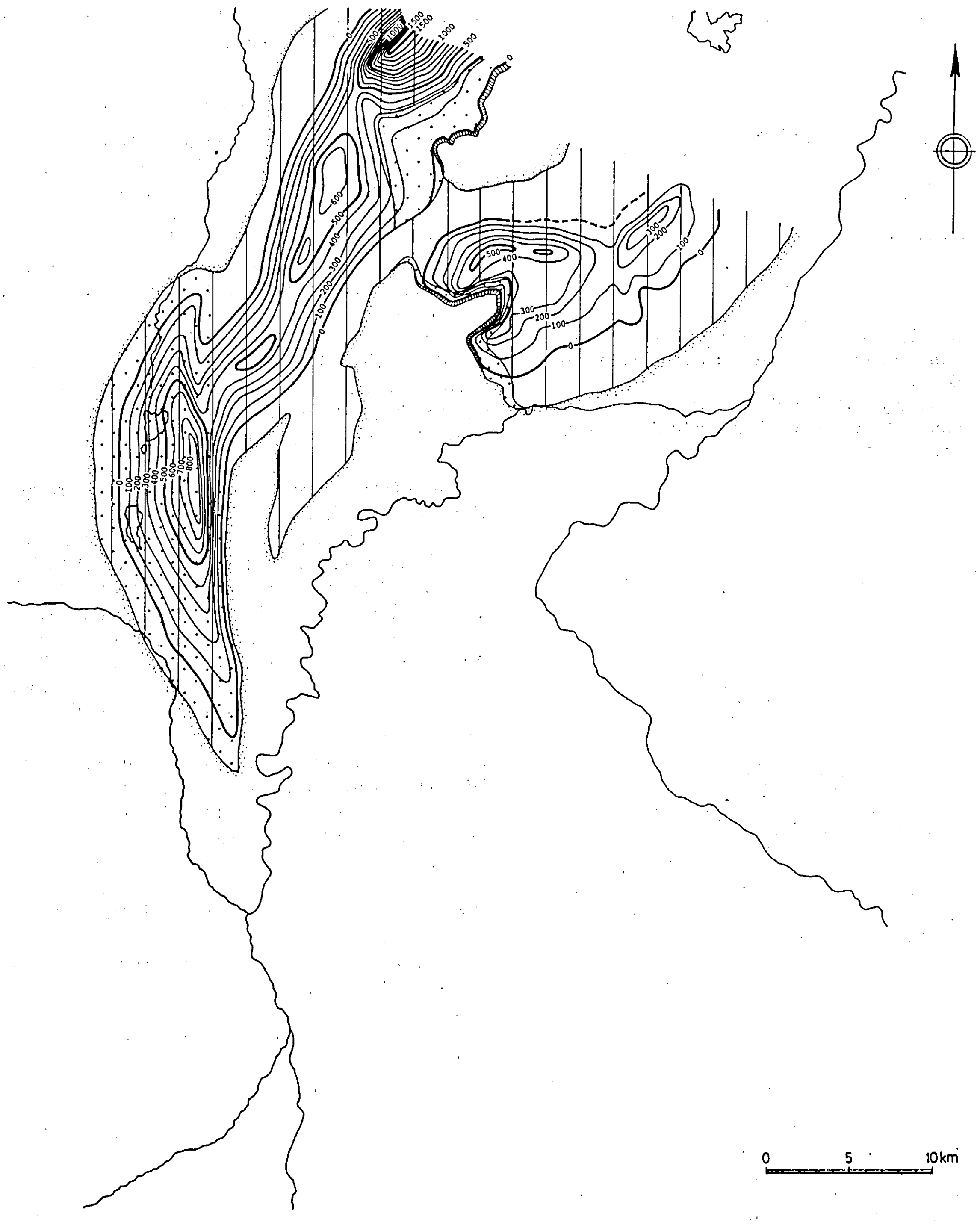


Fig. 30. Isopach map of the Upper Shigarami Formation.
See the legend of Fig. 16.

Omine Depression, *Anodonta* sp., *Crassostrea* sp. and *Glycymeris yamasakii* are obtained, which indicate a fresh- to brackish-water condition on the one hand and a neritic condition on the other (Himekawa C. R. G., 1958).

As to plant remains, *Metasequoia disticha* is found in the northeastern part of the Takafu-Orihashi Sedimentary Basin (Saito *et al.*, 1960). Fossil diatoms obtained from the lowest part of the Komoro Group are of lacustrine environment (Kubota *et al.*, 1976).

Late Sarumaru stage

According to Toyono C. R. G. (1972), fresh-water diatoms occur in the Takafu-Orihashi Sedimentary Basin. The pollen analysis of lignites shows that the content of *Picea, Pinus* and *Alnus* attains 35 to 40% in the lower horizon of the Upper Sarumaru Formation and that of *Picea* to ca. 65% in the middle horizon, where *Metasequoia* disappears. The increase of these elements may suggest the advent of cool climate in early Quaternary time.

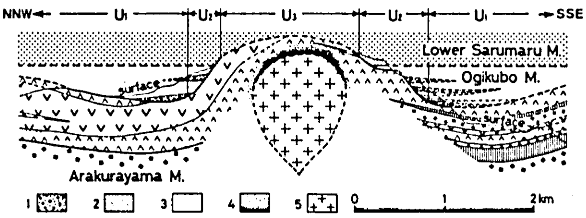


FIG. 31. Stratigraphic profile across the peninsular upheaval in the Takafu-Orihashi Sedimentary Basin.
1: poorly-sorted boulder conglomerate, 2: sandstone, 3: mudstone, 4: alteration envelope, 5: prophyrite.

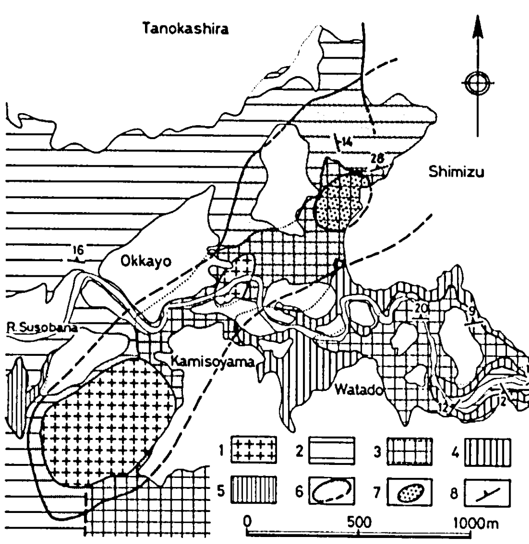


FIG. 32. Geological map of the area around Porphyrite-II.
1: Porphyrite-II (hornblende-hypersthene-augite porphyrite), 2-5: Arakurayama Pyroclastic Member, 2: hypersthene-augite andesite, 3-5: hornblende-hypersthene-augite andesite (3: massive lava, 4: autobrecciated lava, 5: tuff), 6-7: alteration envelope, 6: chlorite-montmorillonite zone, 7: chlorite-montmorillonite-mica / montmorillonite-mixed layer mineral-biotite-kaolinite zone, 8: strike and dip of platy joint.

VI. STRUCTURAL ANALYSIS

The geological structure of the northern Fossa Magna is characterized by a superimposition of the Green Tuff Basin and the Pliocene to Early Pleistocene volcano-tectonic depressions.

A. STRUCTURAL ANALYSIS OF GREEN TUFF BASIN

The fundamental geological structure of the Green Tuff Basin is a large-scale undulation producing the Central Uplift and Minochi Subsidence Zones. And this undulation is embellished by several types of smaller-scale folds and faults, and by a collapse basin. In this item, formative processes of each embellishing structures are examined on the basis of morphological analysis. Mesoscopically, bedding faults are frequently observed in layered rocks over the region, especially in the Minochi Subsidence Zone. Therefore it is considered that the behavior of folded materials was the flexural slip type and partly might be the flexural flow type, as pointed out by Uemura (1976).

1. Formative processes of geological structure of the Central Uplift Zone

The geological structure of the Central Uplift Zone is composed of two culminations (Utsukushigahara and Shiga Domes = Type-A folds) and an associated depression (Tochiku Half Basin) which is embellished by Type-B folds and System L-1b faults. As clarified in the previous chapter, the Type-A folds were initiated by a doming-up in the central part of sedimentary basin of the Uchimura Formation at the beginning of the Bessho stage, and grew into large-scale culuminations (elongated in NNE-SSW to NE-SW direction) during late Cenozoic time. The Shiga Dome consists of several subdomes with stocks of Quartz Diorite-I and saddles among them. In the central part of Utsukushigahara Dome also develop the stocks of Quartz Diorite-I concentratedly. Because of a structural concordance between the dome (and subdomes) and the stocks, it may be said that such morphological features of the Shiga and Utsukushigahara Domes are attributed to the sporadic injection and to the concentrative injection of the stocks of Quartz Diorite-I, respectively. The Kotakiyama Collapse Basin may be referred to a gravitational collapse generated under an extensional stress field which appeared by doming-up of the Utsukushigahara Dome. On the other hand, the Tochiku Half Basin was formed as a depressional area by a complementary down-warping which occurred between the two foci of large-scale doming-up in the Central Uplift Zone. Furthermore, the strata in this half basin have been deformed by both the Type-B folds and the System L-1b faults.

The Type-B folds are developed mostly in the

Bessho and Aoki Formations. The disharmonic morphology of Type-B folds at a detachment zone between the Uchimura and Bessho Formations may indicate that the overlying Bessho and Aoki Formations were shortened rather independently of the underlying Uchimura Formation. The fissility which develops predominantly in shale of the Bessho Formation may ascribe to such a deformational process. Judging from their northwestward vergence, the overlying folded strata are inferred to have moved relatively to the northwest. The magnitude of the displacement resulted from this folding appears to have been not uniform but of the largest in the middle parts of curved fold-axes convex to the northwest, vanishing at their ends. The type-B folds may have started to grow in the Early Aoki stage as shown by the analysis of sedimentary basin, and have been presumably accelerated by the advancement of upwarping. Dip of the

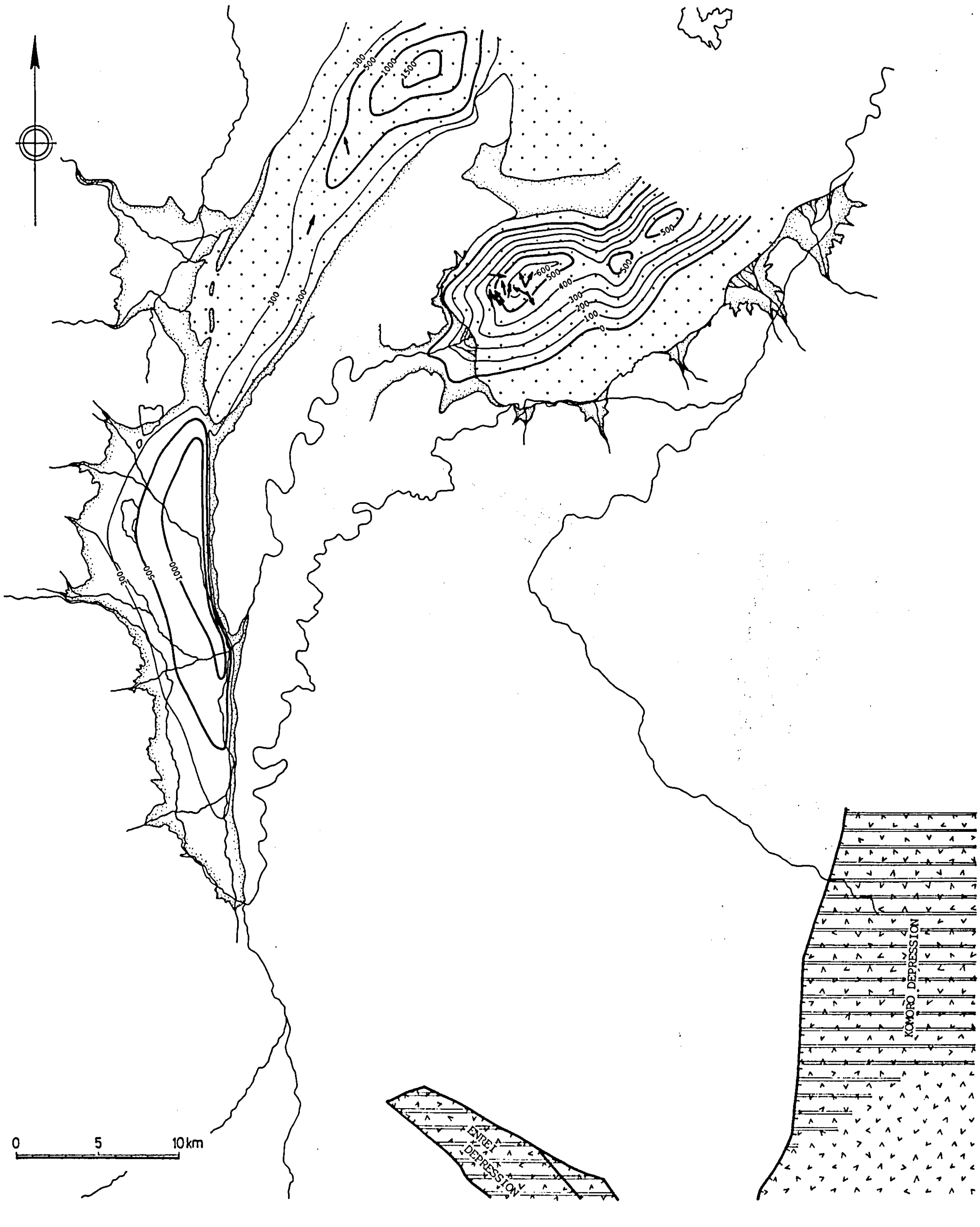


FIG. 33. Isopach map of the Lower Sarumaru Formation.
In the Hikage Sedimentary Basin, the whole thickness of Sarumaru Formation is shown.
See the legened of Fig. 16.

interface between the Uchimura and Bessho Formations on the north-western flank of Utsukushigahara Dome is estimated to have already attained about 9°, 17° and 19° at the beginnings of the Early Aoki, Late Aoki and Ogawa stages, respectively (Fig. 9). They were probably enough values of dip for soft to semiconsolidated sediments to slip down only by the tangential component of gravity. Thus, it may be pointed out that during the upwarping of Central Uplift Zone, the Type-B folds were formed by an inhomogeneous gravity gliding of the mobile strata (= Bessho and Aoki Formations) over the northwestward-dipping stable surface of the Uchimura Formation.

The System L-1b faults of the Tochiku Half Basin are regarded as a group of antithetic faults formed under an extensional stress field due to the upwarping of Central Uplift Zone. They displace the Upper Sarumaru Formation, as well as the underlying strata,

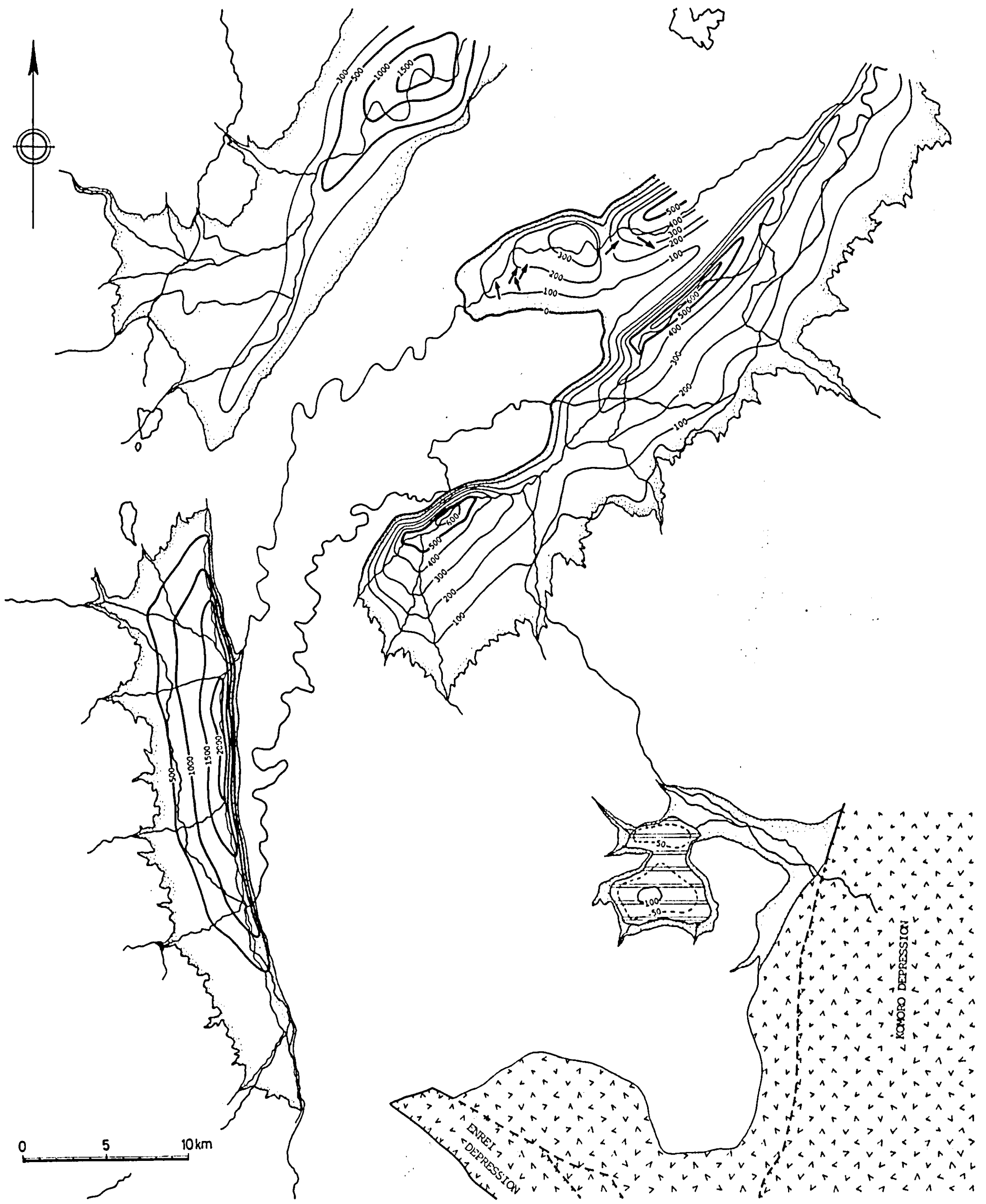


FIG. 34. Isopach map of the Upper Sarumaru Formation.
In the Hikage Sedimentary Basin, the whole thickness of Sarumaru Formation is shown.
See the legend of Fig. 15.

and also locally the Toyono Formation. These facts indicate that the System L-1b faults were generated in the fairly younger stage.

Thus, it may be concluded that the formative processes of the geological structure of the Central Uplift Zone were wholly controlled by its upwarping in two foci which was associated with the intrusion of Quartz Diorite-I stocks, and embellished by gravity gliding of the mobile strata and by gravity faulting which were induced also by the upwarping.

2. Formative processes of geological structure of the Minochi subsidence Zone

The geological structure of the Minochi Subsidence Zone is characterized by the three synclinal subzones, Komiji, Takafu-Orihashi and Hikage Subzones, separated by the two anticlines (Type-C folds).

As clarified by the analysis of sedimentary ba-

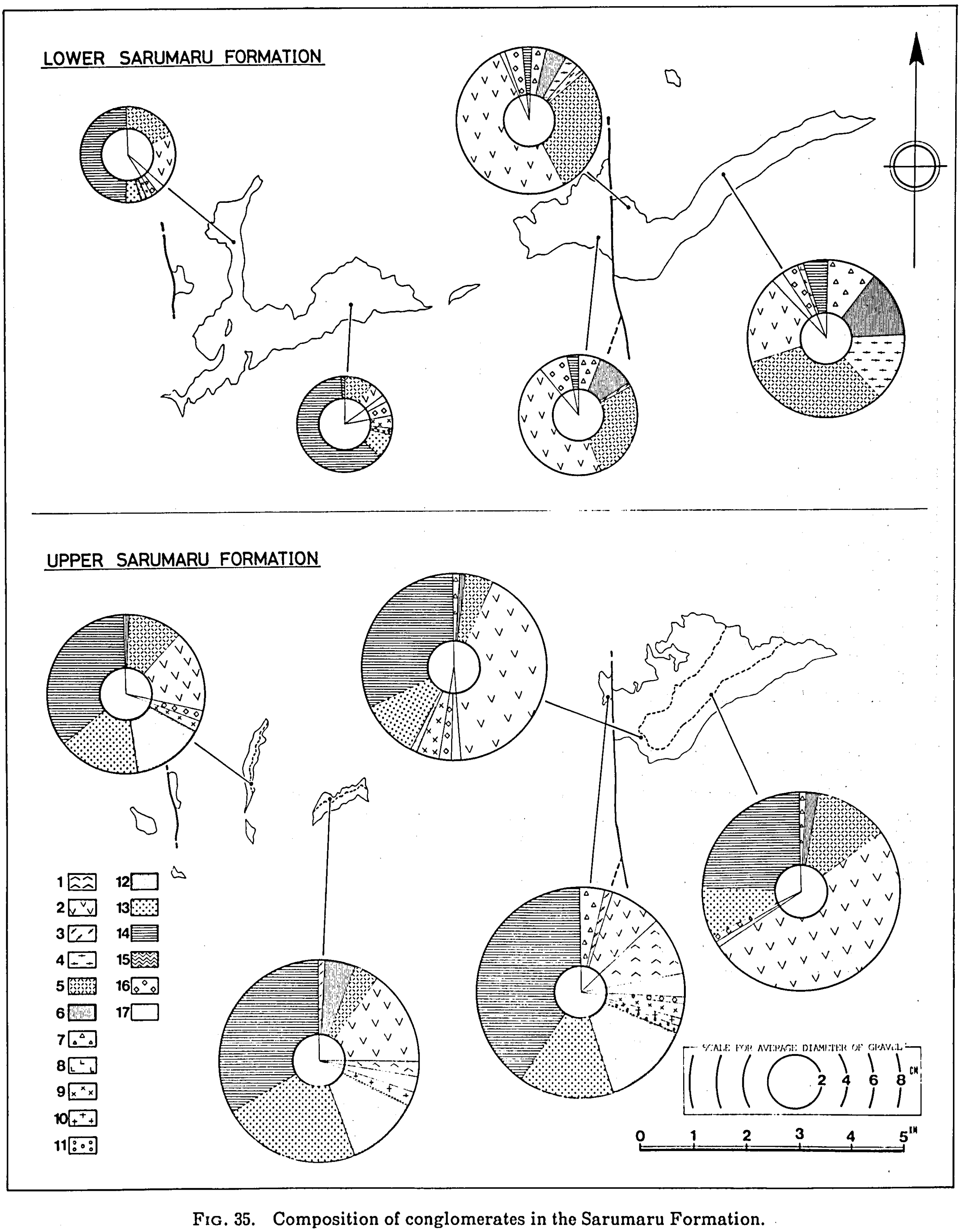


FIG. 35. Composition of conglomerates in the Sarumaru Formation.

TABLE 4. FAUNAL LIST OF THE UPPER SHIGARAMI FORMATION IN THE SHIGARAMI AREA.

Gastropoda
Haliotis aff. *varia* (Linné)
H. sp.
Puncturella (s.s) *noblis* A. Adams
P. sp.
Notoacmaea sp.
Calliostoma sp.
Enida japonica A. Adams
Homalopoma sangarensis (Schrenck)
Littorina (Littorivaga) cf. *brevicula* (Phillipi)
Turritella saishuensis Yokoyama
Serpulorbis shinanoensis (Yokoyama)
Hydroides defrenatus (Yokoyama)
H. sp.
Bittium sp.
Cryptonatica janthostomoides (Kuroda & Habe)
Ancistrolepis trochoides Dall
Neptunea (Barbitonia) cf. *arthritica* (Bernardi)
Neverita sp.
Siphonaria sp.
Tectura cf. *asimiformis* (Yokoyama)
Pelecypoda
Nucula ? sp.
Anadara amicula (Yokoyama)
Pseudogrammatodon dalli (Smith)
Glycymeris yamasakii (Yokoyama)
G. cf. *yamasakii* (Yokoyama)
Modiolus difficilis (Kuroda & Habe)
Crenella ? sp.
Chlamys (s.s) *jousseaumei* Bavay
C. (s.s) cf. *Jousseaumei* Bavay
C. (s.s) cf. *nipponensis* Kuroda
C. (s.s) cf. *sendaiensis* Masuda
C. (s.s) *tamurus* Masuda & Sawada
C. (s.s) *tanakai* Akiyama
C. (s.s) cf. *tanakai* Akiyama
C. *(Mimachlamys) nobilis* (Reeve)
C. sp.
Placopecten (s.s) cf. *setanaensis* (Kubota)
Patinopecten (Kotorapecten) yamasakii yamasakii (Yokoyama)
P. *(K.)* cf. *yamasakii yamasakii* (Yokoyama)
P. sp.
Anomia cytaeum Gray
Monia cf. *macrochisma* (Deshayes)
M. *umbonata* (Gould)
M. sp.
Ostrea (Crassostrea) gravitesta Yokoyama
Lucinoma aff. *acutilineata* (Conrad)
L. *annulata* (Reeve)
L. cf. *annulata* (Reeve)
L. sp.
Conchocele bisectoides Kuroda
Cycladichama ? *cumingi* (Hanley)
Montacuta sp.
Venericardia sp.
Cardium sp.
Laevicardium angustum (Yokoyama)
Clinocardium cf. *ciliatum* (Fabricius)
Mactromeris sp.
Peronidia venulosa (Schrenck)
Macoma praetexta (v. Martens)
Heteromacoma irus (Hanley)
Saletellina minoensis (Yokoyama)
S. *(Nuttallia) petri commoda* (Yokoyama)
Solen grandis Dunker
S. sp.
Trapezium sp.
Mercenaria cf. *chitaniana* (Yokoyama)
M. cf. *yokoyamai* (Makiyama)
M. sp.
Paphia sp.
Dosinia (Phacosoma) japonica Reeve
Callista chinensis (Holten)
Cyclina (s.s) *sinensis* Gmelin
Mya (Arenomya) grewingki var. *elongata* Nagao & Inoue
M. *japonica* Jay
Panope japonica A. Adams
Pandora ? sp.
Thracia hitosaoensis Nomura
T. *kamayashikiensis* Hatai
T. sp.
Brachiopoda
Coptothyris grayi (Davidson)
C. cf. *grayi* (Davidson)
C. ? *grayi* (Davidson)
C. sp.
Terebratella sp.
Cirripedia
Balanus cf. *amphitrite communis* Darwin
B. cf. *rostratus* Hoek
Bryozoa
Echinoidea

sin, the Type-C anticlines, whose axical surfaces dip to the northwest, accompanied locally with thrusts along the axial surfaces, are supratenuous folds grown as structural-highs separating the sedimentary basins since the Bessho stage. Although their growing processes are fairly complicated, the fundamental tendency of the northwestern limbs to have been elevated as compared with the southeastern, associated with the northwestward-tilted subsidence of sedimentary basins, may indicate that the Type-C folds were originated from antithetic faulting of basements against the regional upwarping centered on the Central Uplift Zone. It seems to be probable that these antithetic faults tends to curve their surfaces in the upper level and to change into thrust faults near the ground surface (System L-1b faults) due to the gravity spreading of the northwestern blocks and the rotational movement of basement blocks associated with the regional upwarping. If so, the growth of structural-highs along the Type-C folds reflects probably the increasing displacement of antithetic block-faulting in the basements since the Bessho stage. In addition, the uplift of the Hida Mountain Range has also affected the growing process of structural-high along the Saikawa Anticline-Fault occasionally, as pointed out in the previous chapter. Furthermore, in the later stages, it has generated the tilted subsidences (Kodama and Yano, 1985) of Omine Depression and Matsumoto Basin, and the antithetic displacements of System L-2 faults and some of System O-2 faults represented by the Otari-Nakayama Fault, in the western marginal zone of the northern Fossa Magna.

The formation of the Type-D folds, a group of folds forming the major synclinal structures of individual sedimentary basins of the Minochi Subsidence Zone, appears to have been induced by the asymmetric growth of the Type-C anticlines since the Bessho stage. Consequently, the axial surfaces of this type folds sometimes incline toward the northwest like in the case of those of Type-C folds. In the Takafu-Orihashi and Hikage Subzones, the shrinkage of strata attains at least to 20-35%. The Type-C and Type-D folds of these subzones are considered to have been also compressed by the gravity gliding (especially in the Bessho horizon) due to the regional upwarping centered on the Central Uplift Zone and to the upheaving of Hida Mountain Range which has been accelerated especially in Pliocene to Quaternary time. On the other hand, the markedly large shrinkage of strata and the complicated arrangement of structural elements in the Komiji Subzone may be ascribed to a combined motion of the growth of Saikawa Anticline-Fault with southeastward vergence and the northwestward gravity gliding of strata in the Tochiku Half Basin mentioned above. The northwestward vergence of the middle part of Noma Anticline, which is only one exceptional vergence in the Minochi Subsidence Zone, may be attributed to a gravity gliding overloaded by the Hijiriyama Andesite Member, because such an abnormal vergence is restricted within the western area of this volcanic body of higher dencity. The strata in this area are strongly folded forming both the fairly overturned Noma Anticline and the fan-shaped Komiji Syncline, attaining a maximum shrinkage in terms of flexural slip. These folds have been furthermore flattened by the conjugate strike-slip faulting of System T-1.

In addition, the subsidiary folds (Type-E) comprising nine pairs of small-scale syncline and anticline have been formed in the two styles. Some folds were formed selectively on the western limbs of major syncline in the Takafu-Orihashi and Hikage Subzones, especially along the Otari-Nakayama Fault in en échelon fashion of left hand. They may be resulted from the stress concentration in these areas owing to the asymmetric growth of Type-C folds, and from the northwestward gravity gliding bordered by the Otari-Nakayama Fault which has brought about compressive and left-lateral displacing components. The other Type-E folds connected with crooks in the traces of System L-1 thrusts were probably produced by the interfelence between the crooked hanging walls which were thrust up in convergent directions to each other.

The geological structure in the Minochi Subsidence Zone as a whole appears to have been formed by the regional upwarpings under the gravity field and by the consequent antithetic faulting of the basements and gravity gliding in the mobile strata (especially in the Bessho Formation). As to the mechanism of folding in this zone, the three types of model have been already proposed, i.e., buckling models (Komatsu, 1967; Kato, 1970; Takeuchi and Sakamoto, 1976), bending models (Suzuki and Mitsunashi, 1974; Union of the Collaborative Researches on the Green Tuff Orogeny, 1977) and a unified model of buckling and bending (Uemura, 1976). The above-mentioned formative process supports the last model composed of tilting blocks of basement rocks bounded by cylindrical faults.

3. Structural controllers of Green Tuff Basin

In conclusion, the formative processes of geological structure of the Green Tuff Basin were controlled by the growth of large-scale undulation from the Central Uplift Zone to the Minochi Subsidence Zone under the influence of gravity and partly by the upheaving of the Hida Mountain Range especially in Pliocene to Quaternary time. The derivative deformations such as gravitational collapse, gravitational faulting in antithetic manner and gravity gliding were automatically generated in this structural setting under the influence of gravity.

Ultimately, the origin of such a large-scale undulation becomes to loom up as an essential problem for the tectonic control of the Green Tuff Basin. However, this problem is left for the future study because the author have now no definitive bases to interpret it. It is, however, noticeable that the undulation does not show a simple sinus curve, but the upwarping of Central Uplift Zone shows asymmetric style with a steeper southeastern flank and the downwarping axis, i.e., depoaxis in the Minochi Subsidence Zone tends to migrate toward the northwest or north as mentioned later.

B. Structural analysis of volcano-tectonic depressions

The volcano-tectonic depressions were generated in Pliocene to Early Pleistocene time, associated with a regional fracturing in N-S and NW-SE directions. These two directional fractures (System T-2 and O-2) as a whole are arranged in parallel to subparallel with the Itoigawa-Shiojiri and Shiojiri-Nirasaki Lines, parts of the Itoigawa-Shizuoka Tectonic Line (Fig. 1).

The Omine Depression bounded by the Otari-Nakayama Fault is characterized by the initial andesitic and the subsequent dacitic to rhyolitic volcanisms, and also by a large amount of coarse-grained clastics mainly from the Hida Mountain Range. The depocenter of this basin tend to shift toward the south, as pointed out by Nishina (1973) and Kosaka (1979). According to the data by Matsumoto Basin C. R. G. (1977), such movement of the Omine Depression is followed by the eastward-tilted subsidence in the Matsumoto Basin in middle to late Quaternary time, whose eastern margin is bounded by the southern extension of Otari-Nakayama Fault and the Eastern Marginal Fault of Matsumoto Basin. Thus, it may be said that the subsidence of the Omine Depression and Matsumoto Basin has been controlled by the eastward tilting and gravity gliding associated with upheaval of the Hida Mountain Range and by the antithetic displacements represented by the Otari-Nakayama Fault. The folding of Type-F in N-S trend may attribute to an interaction between such eastward gravity gliding and antithetic faulting. As mentioned above, the upheaval of the Hida Mountain Range is affecting also to the Minochi Subsidence Zone. That is, the strata in this zone have been compressed by the eastward gravity gliding and re-faulted along the southwestern parts of pre-existing deep fractures of the Type-C folds and System L-1a faults in NNE-SSW direction, resulting in the generation of System L-2 faults (Fig. 13). The Komoro and Enrei Depressions were generated by the faulting in this stage, being filled with a large amount of subaqeous (lacustrine) volcanic products and subaerial "Flat Lava". In the Komoro Depression on the eastern side of the Utsukushigahara Dome, it is noticeable that the leveled bottom surface of "Flat Lava" and also the depositional surface of the Tateshina Decayed Gravel Bed are well preserved without a severe disturbance until the present. On the other hand, the Enrei Depression superimposed on the southwestern half of the Utsukushigahara Dome is fairly disturbed, as shown by difference in elevation of the bottom surface of "Flat Lava" over 1000 m from the flank of dome to the top. Such a contrast of the attitude of "Flat Lava" between the Komoro and the Enrei Depression may be caused by the marked upwarping of Central Uplift Zone in the latest Sarumaru stage when the final folding in the Green Tuff Basin took place and the regional unconformity was formed (Fig. 7).

The two directional faulting in Pliocene to Early Pleistocene time, which has produced the volcano-tectonic depressions, seems to be associated with a large-scale block faulting represented by the generation of Itoigawa-Shizuoka Tectonic Line. Some fractures may have reached to a considerable depth concerning with magma geneses. It is noticeable that in Pliocene to Early Pleistocene time, the regional faulting and the associated volcanisms were proceeding contemporaneously with the structural movements of Green Tuff Basin.

Inicidentally, the structural importance of the Shigarami Volcanics Chain in N-S direction will be discussed in the following chapter.

VII. LATE CENOZOIC GEOHISTORY

A. SUMMARY OF THE LATE CENOZOIC GEOHISTORY

The geologic development of the northern Fossa Magna region during the Late Cenozoic is summarized as follows.

The subsidence process and the deformational process in the Green Tuff Basin are essentially cognate, controlled by the growth of large-scale asymmetric undulation in gravity field and partly modified by the upheaval of Hida Mountain Range. In Pliocene to Pleistocene time, the regional block-faulting and the volcanism trending in N-S and NW-SE directions were superimposed on the Green Tuff Basin.

The geohistory during the Uchimura to Ogawa (or Early Shigarami) stage can be comparable with that of "geosyncline", represented by initial volcanism, sedimentation of pre-flysch, flysch and molasse facies and plutonism. In the Shigarami and Sarumaru stages, however, the regional uniformity of lithofacies might have been produced by unified sedimentary environment and structural movement over the region.

The igneous activity was restricted within the Central Uplift Zone during the Uchimura to Ogawa stage. In the Shigarami and Sarumaru stages, however, such a structural control was released, and the igneous activity became to be controlled by faulting parallel with the Itoigawa-Shizuoka Tectonic Line.

As to the sedimentary environment, upperbathyal condition in the Bessho stage owing to the maximum phase of "Nishikurosawa Transgression" and the subsequent shallowing tendency during the Aoki to Sarumaru stage are worthy to note. Concerning the paleocurrent, the longitudinal system prevailed in the earlier stages, whereas the lateral one became to contribute in the later. The paleoclimate changed from subtropical condition in the Bessho stage, through warm-temperate to temperate in the Ogawa, to cool-temperate to subfrigid in the Late Sarumaru.

B. MIGRATION OF DEPOCENTERS

Through the development of sedimentary basins, the depocenters shifted complicatedly. There are, however, two different patterns in migration.

The first is a tendency of northwestward or northward migration, though sometimes the depocenter stays in same place for a few stages or returns backward. This tendency started subsequently to the initial volcanism and subsidence in the Uchimura stage, and continued until the Sarumaru stage. It is considered that such a systematic migration was controlled by the growth of large-scale asymmetric undulation in the Green Tuff Basin and by the consequent northwestward shifting of the largest displacement among antithetic faults in the basements.

The second is a tendency of the northeastward and the southward (Nishina, 1973; Kosaka, 1979) migration. This tendency started subsequently to the andesitic volcanism in the Middle Shigarami stage which produced the Shigarami Volcanics Chain of N-S direction (Fig. 4). It continues probably until the present, because the recent basins such as Mure, Nagano, Ueda and Matsumoto Basins (Fig. 3) are formed in the forward position of the migration of this pattern.

The next problem is the interrelation between these two migration patterns. They are different from each other not only in migrating direction and duration, but also in relation with the axis of sedimentary basin (the first type being transverse or oblique and the second type being longitudinal to the axis). Moreover, the Shigarami Volcanics Chain, which was produced by the volcanism marking the initiation of second type migration, extends in N-S direction over 110 km long from the north of Lake Suwa to the coast of Japan Sea. This volcanics chain obviously cuts the general trend of Green Tuff Basin obliquely. It runs in parallel with the Middle Pleistocene to Holocene Myoko Volcanic Chain (composed of three volcanic cones) to the north of Nagano, and also with the N-S trending regional fault system generated since Pliocene time. These facts indicate that the second type migration of depocenters has an exotic nature against the first type which is characteristic of the Green Tuff Basin. Therefore, it may be controlled by an another structural movement than that of the first type migration in Green Tuff Basin. If so, the genealogy of recent intramountain basins can be traced back to Pliocene time, not to Miocene time.

Generally, the geologic structure of sedimentary basin formed by a unidirectional shifting of depocenters is called the "sedimentary imbricate structure" (Fujita, 1958). According to this definition, it can be said that the development of sedimentary basin in the northern Fossa Magna region is represented by the two types of sedimentary imbricate structure.

According to Yano (1982b), the development of Late Cenozoic sedimentary basins in the Japanese Islands is generally represented also by two types of sedimentary imbricate structure. The first type is toward the marginal sea and have advanced subsequently to the initial volcanism of Green Tuff Movement in Early Miocene time. The northwestward to northward sedimentary imbricate structure characteristic of the Green Tuff Basin in the northern Fossa Magna region belongs to this type. Only in the southern Fossa Magna region, the polarity is in disorder. The second type, started in Pliocene and locally in latest Miocene time, has controlled the migration of Pliocene to Pleistocene sedimentary basins in a manner peculiar to each island arc. This migration continues probably until the present, because the recent sedimentary basins, such as intra-mountain basins, lake basins, coastal plains, embayments and deep sea terraces, are formed to the fore of migration.

Judging from the differnces in direction and duration of migration, these two types of sedementary imbricate structure are inferred to be independent to each other, even if partly overlapped in space and time. The first type is peculiar to the Green Tuff Movement, especially to its developing stage, as pointed out by Fujita (1972a). The second type is presumably one of the components of the Island Arc Disturbance which has produced the geomorphological framework of arc-trench system. By reason of the regularity of migration ("the law of sedimentary imbricate structure " by Fujita, 1958), it may be possible to forecast the direction toward which the recent sedimentary basins will shift in future.

C. Tectonic Controllers of Late Cenozoic Geohistory

The Green Tuff Movement and the Pliocence to Pleistocene block movement have produced the structural framework of the northern Fossa Magna region. Judging from the structural trend and mechanical process, these two crustal movements may be of different nature.

As to the Green Tuff Basin in Japanese islands, the zone of initial volcanism and subsidence runs on the inner side of island arc. In the junctions of island arc, i.e., Hokkaido, Central Japan (Fossa Magna) and Kyushu, many smaller-scale zones of initial volcanism and subsidence parallel with the Honshu Arc are arranged in en échelon fashion in directions of the joining Curil, Izu-Ogasawara and Ryuku Arcs. As the result, the Green Tuff Region transects the Honshu Arc in these three junctions. Although such a peculiarity exists in the junctions, the development of Green Tuff Basin is fundamentally similler over the region (Minato *et al.*, 1956; Fujita, 1972a, 1973a; Tanaka, 1979; Aiba, 1982). If so, the Green Tuff Movement may be controlled uniformly by the asymmetric undulation with the Pacific-ward vergence, which has shifted the depoaxis toward the marginal sea as shown by the sedimentary imbricate structure.

On the other hand, the Pliocene to Pleistocene block movement in the northern Fossa Magna region, producing the volcano-tectonic depressions, is considered to be an important component of the Island Arc Disturbance since Pliocene time, because this disturbance is charachterized by the regional block faulting originated from the slant uplift of island arc along the Wadachi-Benioff Zone (Fujita, 1982). Based on the attitude of fault blocks, Yano (1983b) and Yano and Yamasaki (1985) proposed an uplifting mechanism of the Japanese Islands in the following four manners ; 1) asymmetric arching of island arc with an axial surface slightly declined toward the back-arc side, 2) antithetic block faulting mainly on the back-arc side in an extensional stress field originated from asymmetric arching under the influence of gravity, 3) overthrusting at the toe of continental slope on the fore-arc side (Nagumo, 1980), 4) tilted subsidence of trench due to the loading of overthrusted arc-front (Nagumo, 1982).

The asymmetric archings of Honshu Arc and Izu-Ogasawara Arc may intersect each other in the junction of them (Yano, 1985). The change in elevation of all of the geomorphological elements in Central Japan, such as the arching axis of Southwest Japan Arc, the bottom surface of sedimentary basins and peneplain remnants in Plio-Pleistocene time, the fill-top surface of fore-arc basin, and the Southwest Japan Trench and its eastern extension (Suruga and Sagami Troughs), are in concordance with the profile of Izu-Ogasawara Arc joining to the Central Japan from the south. It is considered that the most mountainous highland, which is one of the most prominent characters in Central Japan as mentioned in the introduction, was produced by a superimposition of the N-S trending arching of Izu-Ogasawara Arc upon the arching of Honshu Arc. The antithetic block faulting originated from the arching of the fomer arc, which is represented by a large displacement along the middle to southern part of Itoigawa-Shizuoka Tectonic Line, has spreaded over the Central Japan. The regional block faulting in the northern Fossa Magna region since Pliocene time, trending in parallel with the Itoigawa-Shizuoka Tectonic Line, might have been originated also from the upwarping of the Izu-Ogasawara Arc. The Shigarami Volcanics Chain of N-S trend, which marks the initiation of sedimentary imbricate structures formed by the Island Arc Disturbance, probably represents a forerunning volcanism of such block faulting in this region.

In conclusion, tectonic controllers of the Late Cenozoic geohistory in the northern Fossa Magna region are the asymmetric undulation with the Pacific-ward vergence by the Green Tuff Movement during Miocene to Early Pleistocene, the regional block faulting associated with the asymmetric arching of island arc by the Island Arc Disturbance since Pliocene, and the peculiar tectonic condition in the intersecting junction of island arcs (Fig. 1).

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