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DEFORMATIONAL MECHANISM OF UPPER CENOZOIC SYSTEM IN NORTHERN FOSSA MAGNA, CENTRAL JAPAN

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Abstract Interacting with the gravity, a regional asymmetric upwarping brought a complicated deformation to the upper Cenozoic system in the northern Fossa Magna by means of antithetic faulting and gravity gliding. Such a rather simple mechanical model is reduced in this article through structural analysis.

Most prominent structure in the area is a large scale undulation of the NNE-SSW axial trend, which forms a pair of anticlinorium and synclinorium. The anticlinorium of sortheastward vergence is composed of culminations and depressions linked in the longitudinal direction. The Early Miocene volcanics intruded by quartz diorite stocks crops out extensively as cores of the culminations, and the Middle Miocene to Pliocene clastics of upward-coarsening tendency covers the volcanics in the depressions. Due to decollement between these two groups of sediment the covering strata is shrunk rather independently of the underlying one. The northwestern synclinorium is an association of the three subparallel synclines of curvilinear shape and the bounding anticlines of chevron shape which accompany with axial plane thrusts dipping to the northwest. The Middle Miocene to Early Pleistocene thick strata is concerned with such a complicated deformation.

Taking into consideration the modification by the assembling intrusion of quartz diorite stocks into some foci, the above structural features of the anticlinorium with some culminations appear to have been formed by an upwarping of southeastward vergence. The upwarping may have promoted also gravity gliding of the well-stratified covering strata, especially in its lowest horizon of monotonous black shale and mudstone. The convex direction of the rounded axial traces of detached folds on the northwestern slope of the anticlinorium confirms that the covering strata glided in the northwestern direction toward the synclionrium. In the synclionrium, the axial plane thrusts accompanied by the chevron-shaped anticlines seem to have turned from the antithetic faults in the pre-Neogene basement which were generated in an extensional stress field by the regional upwarping. Namely, gravity spreading of the hanging wall and rotation of the northwestern limb of the upwarp due to the advancement of upwarping can bend the upper parts of the surfaces of antithetic fault, resulting in transformation from normal faults in the basement into thrusts in the cover. Thereby the boundary faults which separate the three synclines in the synclinorium got cylindrical forms convex to the northwest. Furthermore, the northwestward gravity gliding of the covering strata on the northwestward slope extending from the anticlinorium to the synclinorium surely promoted the conspicuous folding in the synclinorium, as well as the shrinkage by axial plane thrusts of the chevron-shaped anticlines.

Thus, it is concluded that the complex structure of the late Cenozoic sedimentary basin in the target area was formed by the regional upwarping of southeastward vergence through the interaction with the gravity. The origin of the asymmetric upwarping can be traced back upto the begining of the Middle Miocene when the zone occupied by the anticlinorium at present turned from subsidence to embryonic uplift. Advancement of the upwarping during the Middle Miocene to the Pleistocene brought about the complicated tectonic deformation at last.

Introduction

This article presents a synthetic interpretation to the deformational mechanism of the upper Cenozoic system in the northern Central Japan.

The Neogene tectonics in the Japanese Islands was controlled largely by the Green Tuff Movement (IJIRI, 1958) which took place predominantly in the inner

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zone of island arc called the Green Tuff Region or the Green Tuff Basin (Fig. 1). FUJITA (1972a,b) clarified that the geohistorical developement of the movement was constructed of the following three stages. At the generative stage in the Early Miocene numerous polygonal collapse basins of ten and several kilometers across were formed as results of local doming, and then a violent initial volcanism started within the basins and was followed by regional subsidence. At the developing stage in the Middle to Late Miocene the zone of initial volcanism and subsidence turned to uplift and theredy the depocenter migrated toward the marginal sea intermittently until the Pliocene or the early Pleistocene. Contemporaneously acid plutonism proceeded in the uplifting zone and basic volcanism with intrusive episodes took place around the hinge between uplifting and subsiding zones. Remarkable deformation is characteristic of the vanishing stage in the Pliocene to Pleistocene. Thick sediment in the Green Tuff Basin was folded and faulted complicatedly.

The Central Japan, which includes the target area of this study, is the junction of the three island arcs, i.e., the Northeast Japan, the Izu-Ogasawara (the Bonin) and the Southwest Japan Arc. Although the Green Tuff Region ordinarily runs through the inner zones of island arc, it transects the Honshu Arc at the Central Japan to connect those of the three arcs with each other (Fig. 1). The transected part of the Honshu Arc forms a large scale graben-like structure named "Fossa Magna" by NAUMANN (1893). It is filled with the upper Cenozoic system between the eastern Kanto and Ashio and the western Hida Basement Mountains. The late Cenozoic tectonic movement in the Fossa Magna was extraordinarily intense in subsidence, magmatism and deformation compared with in the other areas of the Green Tuff Region. The target area of this study is situated in the nothern part of the Fossa Magna.

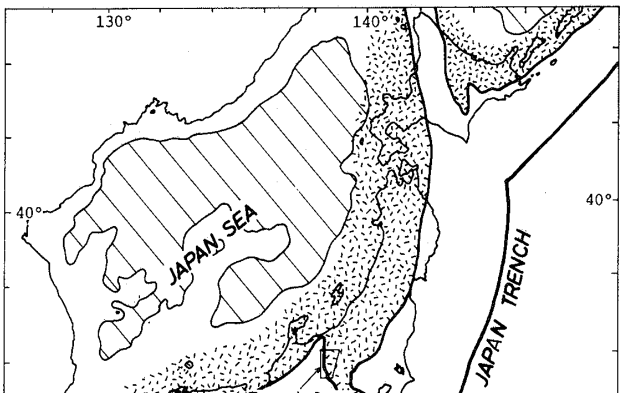

Fig. 1 Extent of the Green Tuff Region around the Japanese Islands.

In respect of direction in which a tectonic force acts to stratification of sediment, the following three types of model on deformation have been advanced within the target area ; (1) buckling models (e.g., KOMATSU, 1967 ; KATO, 1970 ; TAKEUCHI and SAKAMOTO, 1976), (2) bending models (e.g., SUZUKI and MITSUNASHI, 1974 ; UNION OF COLLABORATIVE RESEARCHES ON THE GREEN-TUFF OROGENY, 1977), (3) unified models of buckling and bending (e.g., UEMURA, 1976 ; TAKEUCHI, 1978 ; KATO, 1979). Such opinions on the folding mechanism do not come to an agreement even at present. A greatest obstacle to clarify the deformational mechanism uniquely seems to be absences of a thorough description of geologic structure and a recognition of orderliness of the structural framework in the Green Tuff Basin. Since YANO (1989) already described the precise structure in the target area, only its essential features are summed up in this artecle. The main purposes of this article are to elucidate the deformational mechanism and to extract its essential agent. These mechanism and agent may become most important clues to interpret the tectonic controller of the Green Tuff Movement, because they must be components of the tectonic controller together with other agents in the succeeding three stages of the movement.

Tectonic Division

The Green Tuff Basin in the northern Fossa Magna is subdivided into the four belts of NNE-SSW trend, i.e., the Chikuma, the Minochi, the Nishikubiki and the Nadachi Belt from south to north (Fig. 2). The Chikuma Belt was a zone of initial volcanism and subsidence in the generative stage of Green Tuff

Movement, and turned to uplift accompanying with acid plutonism in the developing stage. The Lower Miocene strata and the quartz diorite stocks, thereby, are exposed extensively in the belt at present. Incidentally the prevalent name "Central Uplift Zone" (IIJIMA, 1962) is replaced by the "Chikuma Belt" in this article, because the former is unsuitable and inconvenient to the belt which experienced not only uplift,

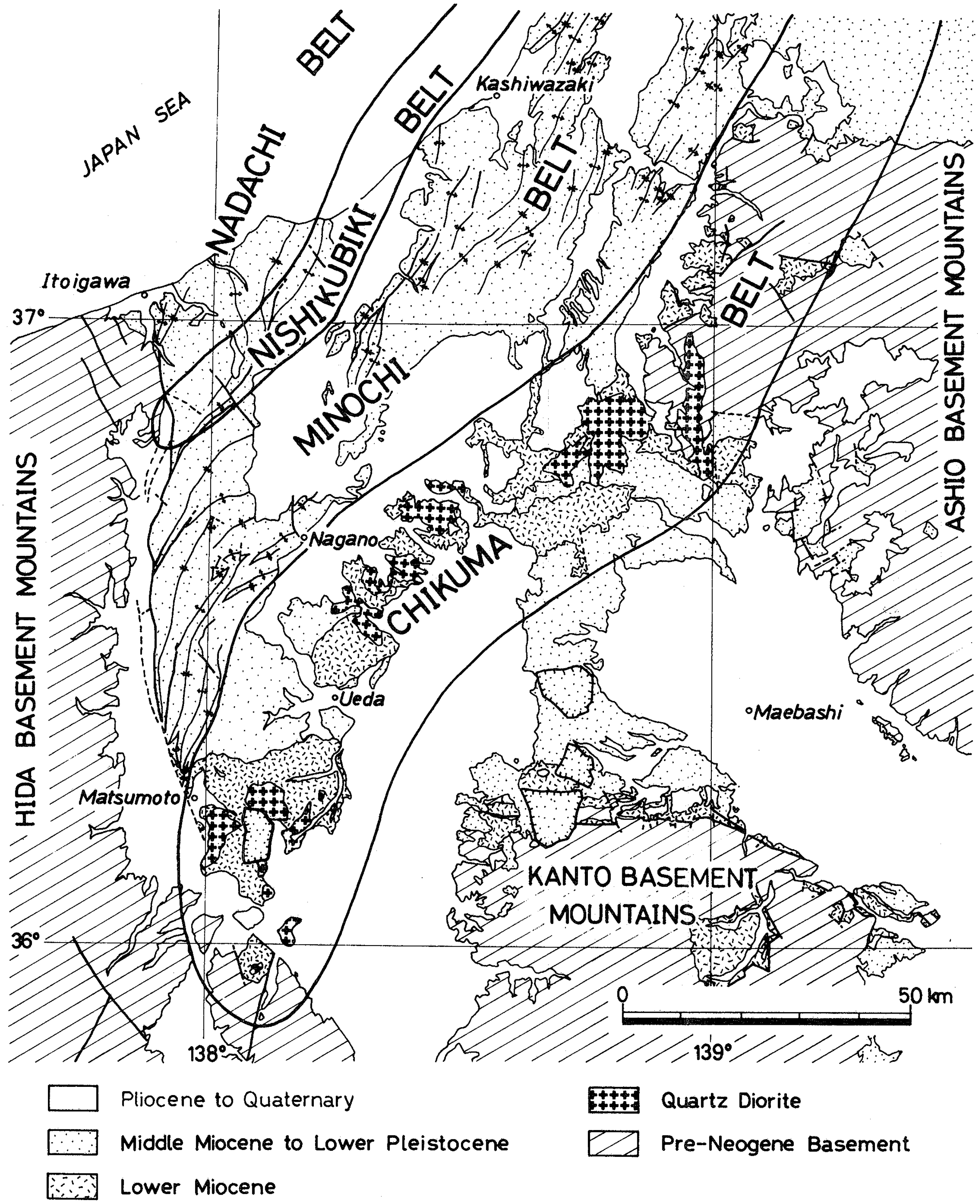

Fig. 2 Tectonic division of the northern Fossa Magna.

but also subsidence at the generative stage. The Minochi Belt was a belt of remarkable subsidence in the developing stage, being contrast to the contemporaneously uplifting Chikuma Belt, and then was complicatedly deformed in the vanishing stage. Thus a complex structure constructed of many folds and faults developed in fairly thick sediments in the belt. The Nishikubiki and Nadachi Belts are subordinate zones of uplift and subsidence respectively, which have differentiated since the developing stage of the Green Tuff Movement.

Among the above four belts this article deals with the southwestern parts of the Chikuma and Minochi Belts which are bounded by Matsumoto-Nagano Line (HIRABAYASHI, 1969). Although the line was defined as a tectonic line running through Matsumoto and Nagano Cities, it actually appears not to be a fault or a shear zone, but to be an apparent line assumed on the gradual boundary between the two belts of different properties as clarified afterward.

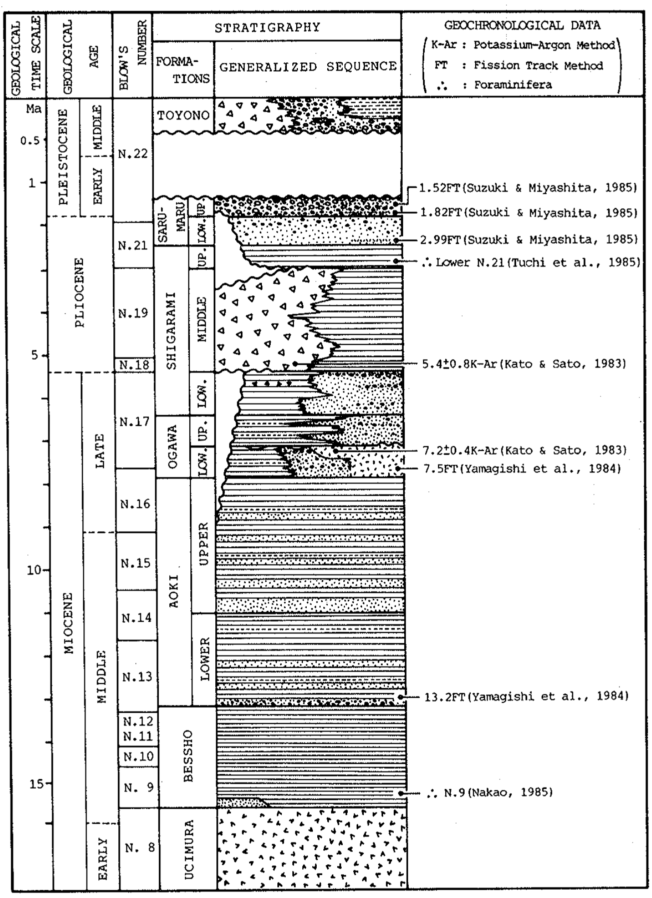

Fig. 3 Stratigraphy of the upper Cenozoic in the southwestern part of the northern Fossa Magna.

Stratigraphy

The upper Cenozoic system in the studied area consists largely of marine sediments and attains over 20,000 m in total maximum thickness. According to lithofacies change and stratigraphic discontinuity, the Miocene to Middle Pleistocene sequence is divided into the following seven formations in ascending order ; the Uchimura, the Bessho, the Aoki, the Ogawa, the Shigarami, the Sarumaru and the Toyono Formation (Fig. 3).

The Early Miocene Uchimura Formation over 4,900 m thick is exposed extensively in the Chikuma Belt and consists mostly of submarine basic to acid volcanics which is products of the initial volcanism of the Green Tuff Movement. Because the volcanics generally exhibits greenish color due to hydrothermal alteration, it is customarily called by the Japaneae geologists the "green tuff" from which the term "Green Tuff Movement" is also derived.

The Middle to early Late Miocene Bessho and Aoki Formations are distributed in the both Chikuma Minochi Belts and are predominant in fine-grained clastics. The Bessho Formation, 2,470 m thick in maximum, consists monotonously of black shale and mudstone, as like as "pre-flysch" facies. The Aoki Formation, over 3,480 m thick, is exclusively of sandstone-mudstone alternation of "flysch facies" and comprises two upward-fining cycles of which the upper cycle is more abundant in sandstone than the lower.

The middle Late Miocene to Pliocene Ogawa and Shigarami Formations are variable in facies and thickness, and are characterized by the appearanece of coarse-grained sediment of "molasse" facies. These formations are distributed extensively in the Minochi Belt and restrictedly in the Chikuma Belt. The Ogawa Formation, over 2,600 m thick, differentiates into the three subfacies of sandstone-mudstone alternation, sandstone-conglomerate and acid to intermediate pyroclastics. The latter two subfaies occupied the transitional zone from the uplifting Chikima Belt and to the subsiding Minochi Belt. The sandstone-conglomerate subfacies represents "molasse facies" in neritic to continental environment. A part of the

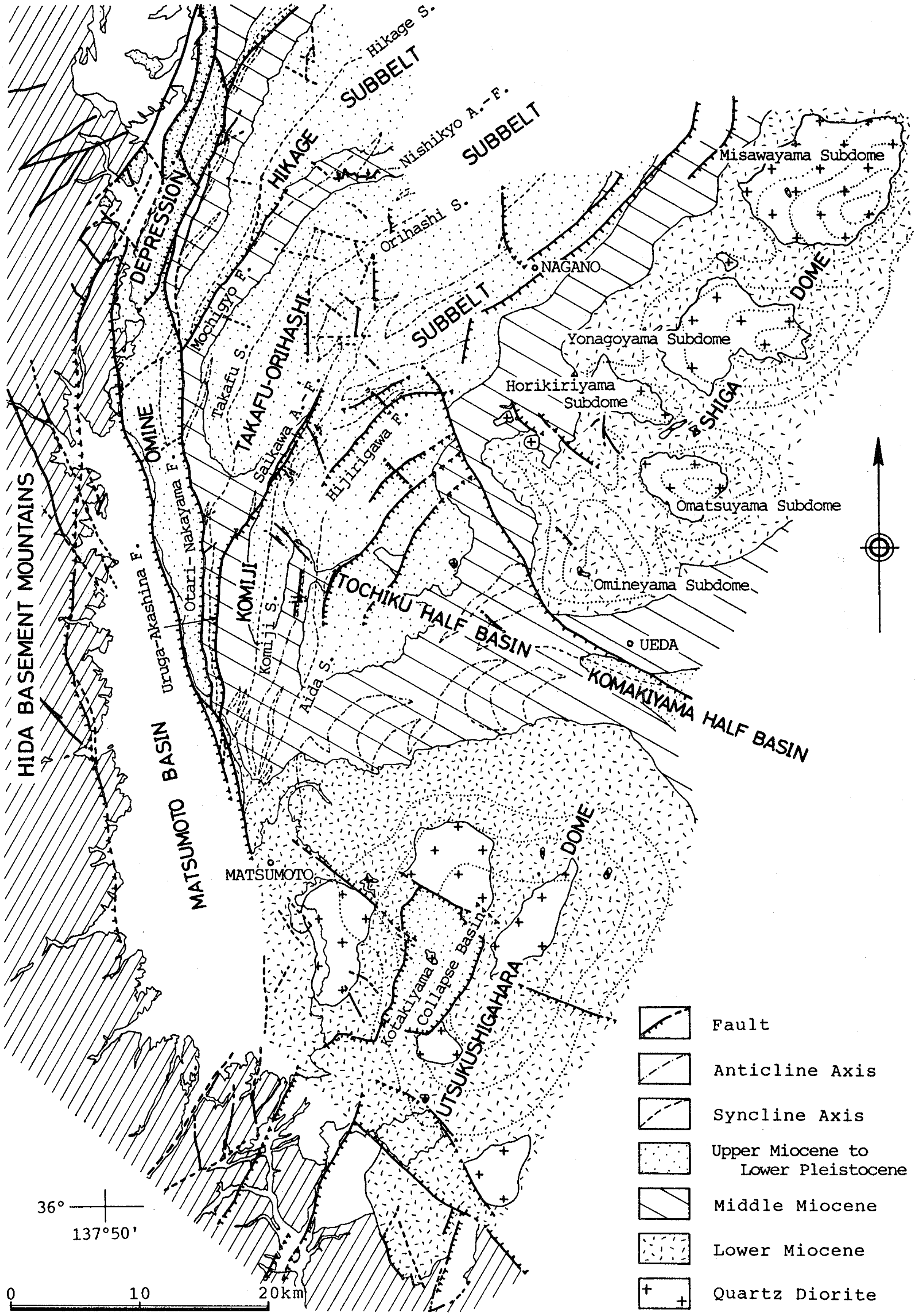

Fig. 4 Structural map in the southwestern part of the northern Fossa Magna.

pyroclastics subfacies fills a collapse basin formed at an apex of dome in the Chikuma Belt (Fig. 2). The Shigarami Formation, 5,500 m thick in maxmum, is a complicated association of monotonous mudstone, sandstone-conglomerate and andesitic volcanics, and is subdivied into three horizons by local unconformities which were formed by uplifting accompanied by the andesitic volcanism. The former two subfacies interfingering with each other in the lower Shigarami Formation are analyzed to show the sedimentary facies respectively of a bay and inflowing fan-deltas, sedimentary facies which reflect the further advancememt of regression.

The latest Pliocene to earliest Pleistocene Sarumaru Formation, over 1,600 m thick, is predominant in fairly coarse-grained sediment of upward-coarsening tendency, which situation indicats a prevalence of "molasse facies" in neritic to fluvial environment, in other words, a completion of regression. Intensifying uplift not only of the Chikuma Belt, but also of the Hida Basement Mountains contributed to supply coarse clasts into some differentiated small basins in the Minochi Belt. Contemporaneously the three volcano-tectonic depressions of the N-S and NW-SE trends, named the Omine, Komoro, Enrei Depressions, were superimposed across upon the stuctural framework of the Green Tuff Basins, as discussed later.

The Middle Miocene Toyono Formation, over 250 m thick, is continental sediment of volcanic, lacustrine and fluvial facies and covers the underlying formations with a marked clino-unconformity almost over the area.

The upper Cenozoic sequence in the target area, as a whole, appears being similar to that of "geosyncline" consisting of initial volcanics, pre-flysch, flysch and molasse facies in ascending order,

Geologic Structure

A most imporant issue to clarify the deformational mechanism in the northen Fossa Magna is the comprehensive understanding of substantial structure of the upper Cenozoic system, as stated in the foregoing lines. The essential features of geologic structure in the target area are described in this item (Fig. 4). The upper Cenozoic system is complicatedly deformed and constructs a pair of anticlinorium and synclinorium. The volcano-tectonic depressions in the Plio-Pleistocene disturbed some parts of such a tectonic framework of the Green Tuff Basin.

1. Geologic strucure of the Chikuma Belt

It has been considered that the Chikuma Belt was folded not so conspicuously, as represented by its another name "Non-folded District" (HONMA, 1931). The major structure of this belt, however, is characterized by a longitudinal linkage of large scale brachyanticlines (or elongated domes) of the NNE-SSW trend (Fig. 4). The Early Miocence Uchimura Formation and the quartz diorite stocks are exposed extensively as cores of the domes. Saddle-like structures are complementarily formed between the neithboring domes, and the Middle Miocene to Pliocene strata is rather extensively in them.

Of the dome structures in the Chikuma Belt the southwestern two are named the Utsukushigahara and the Shiga Dome (Fig. 4). Their southeastern flanks dip at an angle from 60° to 90° and are much steeper than their northwestern ones with an average dip angle of 30°, giving asymmetry of southeastward vergence to the domes. The Utsukushigahara Dome is a large scale doubly plunging antictine of 60 km in axial length and 30 km in half wavelength. Stocks of quartz diorite tend to concentrate into the central portion of the dome. At the apex of the dome the Late Miocene Kotakiyama Collapse Basin (UTSUKUSHIGAHARA COLLABORATIVE RESEARCH GROUP, 1977) was formed in unconformable contact with the surrounding Uchimura Formation and the quartz diorite. Superimposition of the Plio-Pleistocene Enrei and Komoro Volcano-tectonic Depressions fairly disturbed the southwestren half and eastern margin of the Utsukushigahara Dome. The Shiga Dome elongated in the NE-SW direction over 45 km long is an assemblage of five smaller scale subdomes of ten and several kilometers across. The quartz diorite crops out as cores of the four of the subdomes. Judging from structural concordance between the domes and the quartz diorite stocks, the minor reliefs of the Utsukushigahara and the Shiga Dome may be attributed respectively to the concentrative and the sporadic injection of the quartz diorite stocks.

The saddle structure between the Utsukushigahara and the Shiga Dome, which is named the Ueda Saddle, separates into the southeastern Komakiyama and the northwestern Tochiku Half Basin which open toward the southeast and the northwest respectively. Although the former half basin has a large cover of the younger sediments, the latter exhibits their own structural properties. In the Tochiku Half Basin and the Komiji Subbelt which is a southeastern one among the three longitudinal subbelts in the Minochi Belt, the Middle Miocene to Pliocene strata is shrunk by a number of fold.

Among these folds neighboring pairs of anticline and syncline tend to converge their axes with each other at their ends, resulting in disappearance of their fold forms. The disappearance surface of fold forms corresponds approximately with the interface between the Uchimura and the Bessho Formation, as clearly observed on the northwestern flank of the Utsukushigahara Dome. The disharmonic nature of these folds indicates that the formations overlying the interface were shortened independently of the underlying Uchimura Formation through detachment. The generation of such a detachment may depend on the large ductility contrast between the underlying Uchimura Formation and the overlying formations, especially the Bessho Formation just above.

Many detached folds of short axial- and wave-lengthes develope selectively in the Bessho and Aoki Formations. It is noteworthy that their axial traces are considerably rounded. Judging from the northwestward projection of rounded axial traces and the northwestward vergence of some folds, the gliding direction of the strata overlying the detachment zone is down to the northwest. Shrinkage of the overlying strata tends to increase monotonously toward the northwestern border of the Komiji Subbelt, and according to the classification by FLEUTY (1964), fold style also systematically changes from gentle folds in the southeastern part of the Tochiku Half Basin to tight or nearly isoclinal ones in the Komiji Subbelt. Therefore the Saikawa Anticline-Fault seems to define the northwestern border against the northwestward gliding of the strata upon the detachment zone in the Tochiku Half Basin and the Komiji Subbelt.

The step faults of the NE-SW trend are another structural feature of the Tochiku Half Basin, displacing the northwestward dipping strata in antithetic manner.

2. Geologic structure of the Minochi Belt

The Minochi Belt is complexly deformed by many folds and faults, as called "Folded District" by HONMA (1931). The Minochi Belt forms a synclinorium as a whole which is characterized by the subparallel arrangement of three broad synclines of curvilinear shape and two narrow anticlines of chevron shape. These two leading anticlines called the Saikawa and Nishikyo Anticlines subdivide the Minochi Belt into the three synclinal subbelts, i.e., the Komiji, the Takafu-Orihashi and the Hikage Subbelt which are named after the major synclines of the subbelts (Fig. 4). Most of the folds in the Minochi Subbelt shows, more or less, southeastward vergence. Especially the leading anticlines are overturned to the southeast and accompany with axial plane thrusts. Abrupt thickness changes of sediments beyond these anticlines indicates that these anticlinal zones played a role of boundaries of synsedimentary differential subsidence.

1) **Komiji Subbelt** The Komiji Subbelt is bounded on the southeast by the "Matsumoto-Nagano Line" and also on the northwest by the Saikawa Anticline-Fault. The "Matsumoto-Nagano Line" is tentatively supposed in this article from Matsumoto through traces of the Aida Syncline axis and the Hijirigawa Fault to Nagano. The upper Cenozoic strata in this subbelt is remarkably shrunk as mentioned in the foregoing lines.

In the southern portion of this subbelt many folds of short axial- and wave-lengthes are developed selectively in the Bessho and Aoki Formations, namely, in fine-grained and thin-bedded sediment. Three of them grow northward into large folds of relatively long axial- and wave-lengthes in the central portion of the subbelt. They, called the Komiji and Aida Synclines and the Noma Anticline in between, deform the Ogawa and Shigarami Formations, namely, coarse-grained and thick-bedded sediment. On the other hand, the folds of short axial-and wave-lengthes mentioned above disappear southward at the interface between the Uchimura and the Bessho

Formation through convergence of thier neighboring axes. Only one syncline survives into the Uchimura Formation through the detachment zone. Many folds composing the complex synclinal structure of the subbelt, thus, are bandled and transformed into the only one syncline of southeast vergence within the Uchimura Formation.

In proportion to the northeastward diminution of displacement of the Saikawa Anticline-Fault, the large shrinkage characteristic of the Komiji Subbelt tends to be destributed to the several open to closed folds of which neighboring axes tend to converge at their ends. Such a distribution of shrinkage seems to be attributable to release of the latelal obstraction by the Saikawa Anticline-Fault against the northwestward gliding of the strata upon the detachment zone in the Tochiku Half Basin and the Komiji Subbelt.

2) Takafu-Orihashi Subbelt The Takafu-Orihashi Subbelt is bounded on the southeast by the Saikawa Anticline-Fault and on the northwest by the Nishikyo Anticline-Fault. The doubly-plunging Takafu Syncline and the northeastward-plunging Orihashi Syncline, which construct the major part of geologic structure in the subbelt, are in oblique junction with each other in the central portion of the subbelt. The northwestern limbs of these synclines are steeper than the southeastern ones and partly overturned, resulted in their southeastward vergence. The core of synclinal structure in this subbelt consists of thick competent strata of sandstone-conglomerate and andesitic volcanics of the Shigarami Formation respectively in the southwestern and northeastern portions of the subbelt, and of incompetent mudstone of the same formation in the central portion, i.e., the juncture of the two major synclines. Large shrinkage in the central portion compared with in the other portions due to competency difference apperars to have been led to a result that the Takafu-Orihashi Subbelt differentiated into the two parts of doubly- and unidirectionally-plunging synclines. Incidentally, the boundary between this subbelt and the Komiji Subbelt becomes obscure in their most northeastern portions due to the disappearace of the Saikawa Anticline-Fault, and thereby these subbelts are united.

3) Hikage Subbelt The Hikage Subbelt is bounded on the southeast by the Nishikyo Anticline-Fault and on the northwest by the Buno Fault. The structure of this subbelt is rather simple and composed mostly of the Hikage Syncline plunging to the northeast. Its northwestern limb is steeper than its southeastern one in the central to northeastern portion of the subbelt, which situation brings southeastward vergence as well as in cases of the other folds in the Minochi Belt. As the thickness of competent strata such as andesitic volcanics and sandstone-conglomerate increases to the northeast, the Hikage Syncline decreases its tightness to transform into open shape at the northeastern end.

4) Western marginal zone of the Minochi Belt

The Otari-Nakayama Fault of N-S trend, which bounds the eastern margin of the Omine Depression and the Matsumoto Basin, obliquely truncates the Minochi and Chikuma Belts of the NNE-SSW trend. The Omine Depression is filled with the thick Plio-Pleistocene Omine Group consisting of coarse-grained clastics derived mostly from the Hida Basement Mountains and of dacitic and andesitic volcanics. The group forms several faullt blocks of homoclinal structures dipping to the east and of gentle- to open-shaped synclines of the N-S trend. Since the Middle Pleistocene the present Matsumoto Basin began to subside (MATSUMOTO BASIN COLLABORATIVE RESEARCH GROUP, 1972) by displacement of the Eastern Marginal Fault (HIRABAYASHI, 1971) of the basin.

Adjoining to the Omine Depression the western marginal zone the Minochi Belt with a width ranging from 2 to 5 km is largely modified with the following some exotic structures. (1) Shrinkage of strata increases within this peculiar zone and thus the Takafu and Hikage Synclines turn into sylindrical folds of closed to tight shape in their most southwestern portions. (2) Several pairs of anticline and syncline are formed in echelon fashion of left hand in this zone. The axial traces of the paired folds come in contact with the Otari-Nakayama Fault at their southwestern ends and converge to vanish fold form at their northeastern ends. (3) Some NNE-SSW trending faults in this zone, e.g., the Uruga-Akashina and Mochigyo Faults, branch off from the Otari-Nakayama Fault. Their fault planes are vertical or dip southeastward at high angles and their northwestern walls are steadily throw down. Their displacements abruptly decrease northeastward, resulting in disappearance of the faults. The fault traces of the Saikawa and Nishikyo Anticline-Faults continue to the traces of these faults at slightly oblique angles. Therefore, the anticline-faults appear to have been re-displaced in the reverse sence within the western margial zone, probably associated with generation of the Otari-Nakayama Fault since the Pliocene. Thus, the western marginal zone of the Minochi Belt is a zone which experienced the superimposed deformations of different trends and is characterized by relatively large shrinkage, left-lateral deformation and reverse displacement of pre-existing faults.

Deformational Mechanism

The fundermental geologic structure of the Green Tuff Basin in the northern Fossa Magna is a large scale undulation producing the uplift of Chikuma Belt and the subsidence of Minochi Belt. Furthermore this undulation is embellished by subordinate structures, such as folds, faults and collapse basin. Based on such structural features the deformational mechaism of the Green Tuff Basin are discussed in this item. Mesoscopically, bedding faults are frequently observed in layered rocks over the basin, especially in the Minochi Belt. Therefore the behavior of the folded materials seems to have been the "flexural slip" (DONATH, 1963) and partly accompanied by "flexural flow" (DONATH, 1963), as pionted out by UEMURA (1976).

1. Deformational mechanism in the Chikuma Belt

The fundamental structure of the Chikuma Belt is an longitudinal arrangment of domes and saddles, in other words, of culminations and depressions. These domes show conspicuous southeastward vergence and are intruded by the many stocks of quartz diorite. Decollement structure is characteristic of the covering strata upon the Uchimura Formation in the saddles.

The essential mechanism bringing such a structural features to the Chikuma Belt is inferred to be an upwarping of southeastward vergence in the gravity field (Fig. 5). In detail the upwarping had some foci which accompanied with assemble intrusion of quartz diorite stocks, resulting in the formation of the dome and saddle structure. Injecting pattern of the stocks appears to have decided minor relief of the domes, because the sporadic and concentrative injectionts correspond to dome morphologies respectively of an association of several smaller subdomes and of a unique large dome with a collapse basin at its apex.

In response to advancement of the asymmetric upwarping of the Chikuma Belt (1st and 2nd stages in Fig. 5), the tangential component of the gravity forced the Middle Miocene to Pliocene strata in the Ueda Saddle to glide down toward its dipping direction on the detachment layer which was appeared in the horizon of most conspicuous ductility contrast. Fissilities developing exclusively in shale of the Bessho Formation, which played a role of lubricant in the decollment, may be originated not only from diagenetic compaction but also from closely-spaced flexural slip in a stratified argillaceous sediments. Because the gravity gliding of the Bessho and Aoki Formations was not uniform in the Tochiku Half Basin, the strata hung down on the slope of the half basin into folds of which axes drew arcs convex to the northwest (Fig. 4). The differential amounts of gravity gliding seem to attain maxima at middles of the rounded axes. In the area ranging from the western margin of the Tochiku Half Basin to the Komiji Subbelt some major folds were formed in parallel with the Saikawa Anticline-Fault through interaction between the northwestward gravity gliding of the strata upon the detachment zone and the lateral obstraction by the antithetic basement fault. The basement fault grew in the extensional stress field due to the asymmetric upwarping and was compelled to turn into the axial plane thrust of the Saikawa Anticline-Fault at the shallower level by the gravity spreading of the northwestern elevating wall and by the counterclockwise rotation of the basement due to advancement of the upwarping (Fig. 5). Shrinkage of strata by the folding through such a mechanism tends to increase systematically northwestward as described in the previous item.

Additionally, acceleration of the asymmetric upwarping of the Chikuma Belt in the later stage may have generated the antithetic step faults of the NE-SW trend in the northwestern part of the Tochiku Half Basin (3rd stage in Fig. 5). Existence of these antithetic faults shows that the strata in the Tochiku Half Basin experienced not steady compression, but rather complex transitions between compression and extention through its deformational process.

The deformation in the Chikuma Belt, thus, is concluded to have been controlled wholly by the upwarping of southeastern vergence with some foci accompanying with the intrusion of quartz diorite.

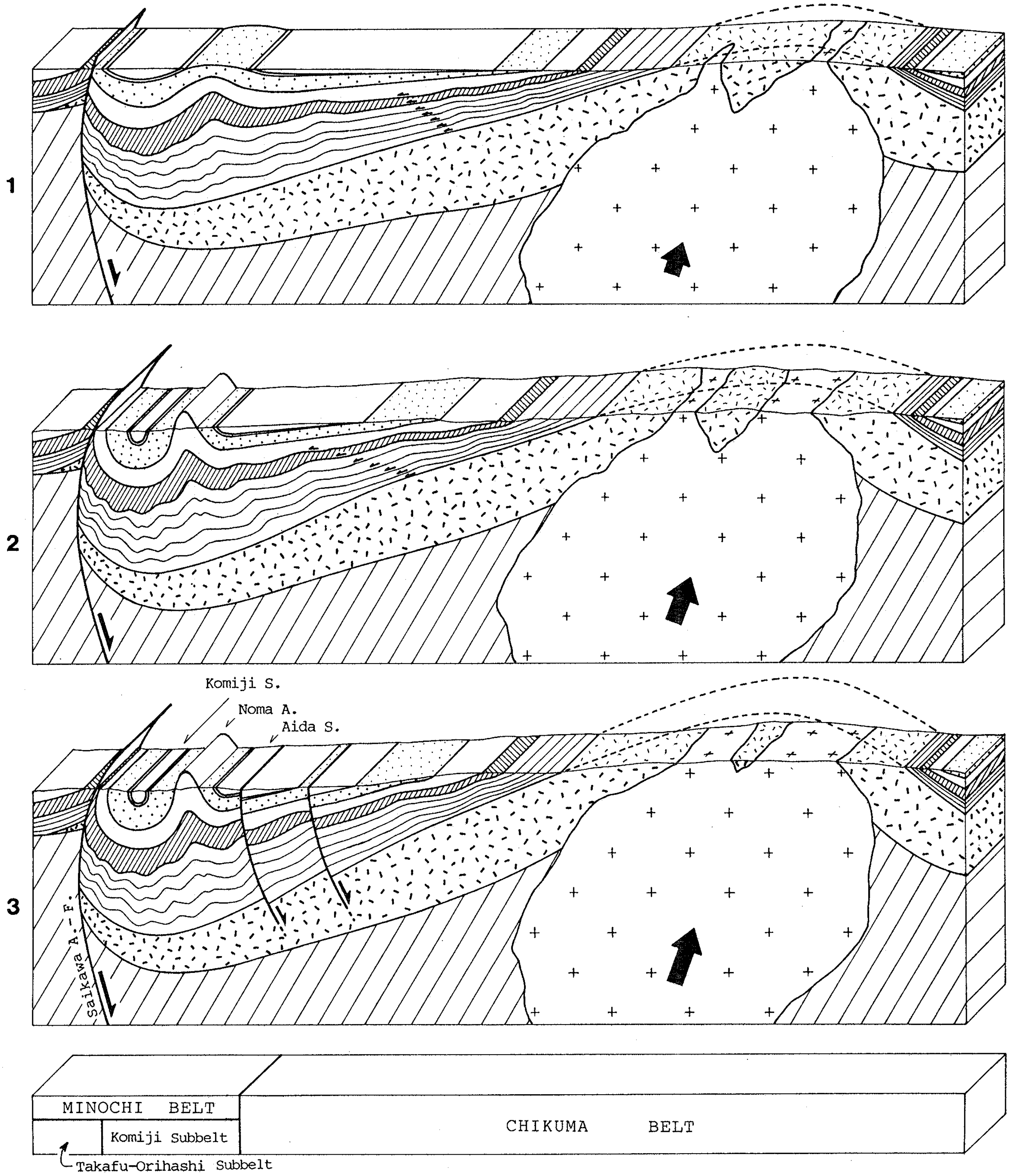

Fig. 5 Block diagrams showing the generalized deformational process in the Chikuma Belt and the Komiji Subbelt.

Furthermore the upwarping automatically brought about its derivative deformations such as gravity gliding of mobile strata, gravity faulting in antithetic manner, etc., through interaction with the gravity.

2. Deformational mechanism in the Minochi Belt

The fundamental structure of the Minochi Belt is the parallel arrangement of the three curvilinear synclines bounded by the chevron anticlines with axial plane thrusts. Most of these folds, especially anticlines show southeastward vergence. The axial plane thrusts of the anticlines elevate their northwestern walls in comparison with the southeastern ones. The western marginal zone of this belt is a zone which experienced the superimposed deformation derived from generation of the Omine Depression of the N–S trend.

The kinematic model by UEMURA (1976), which is composed mainly of northwestward tilting of basement blocks bounded by sylindrical faults, is quite suitable to the deformational process of the Minochi Belt. The deformational mechanism satisfying the

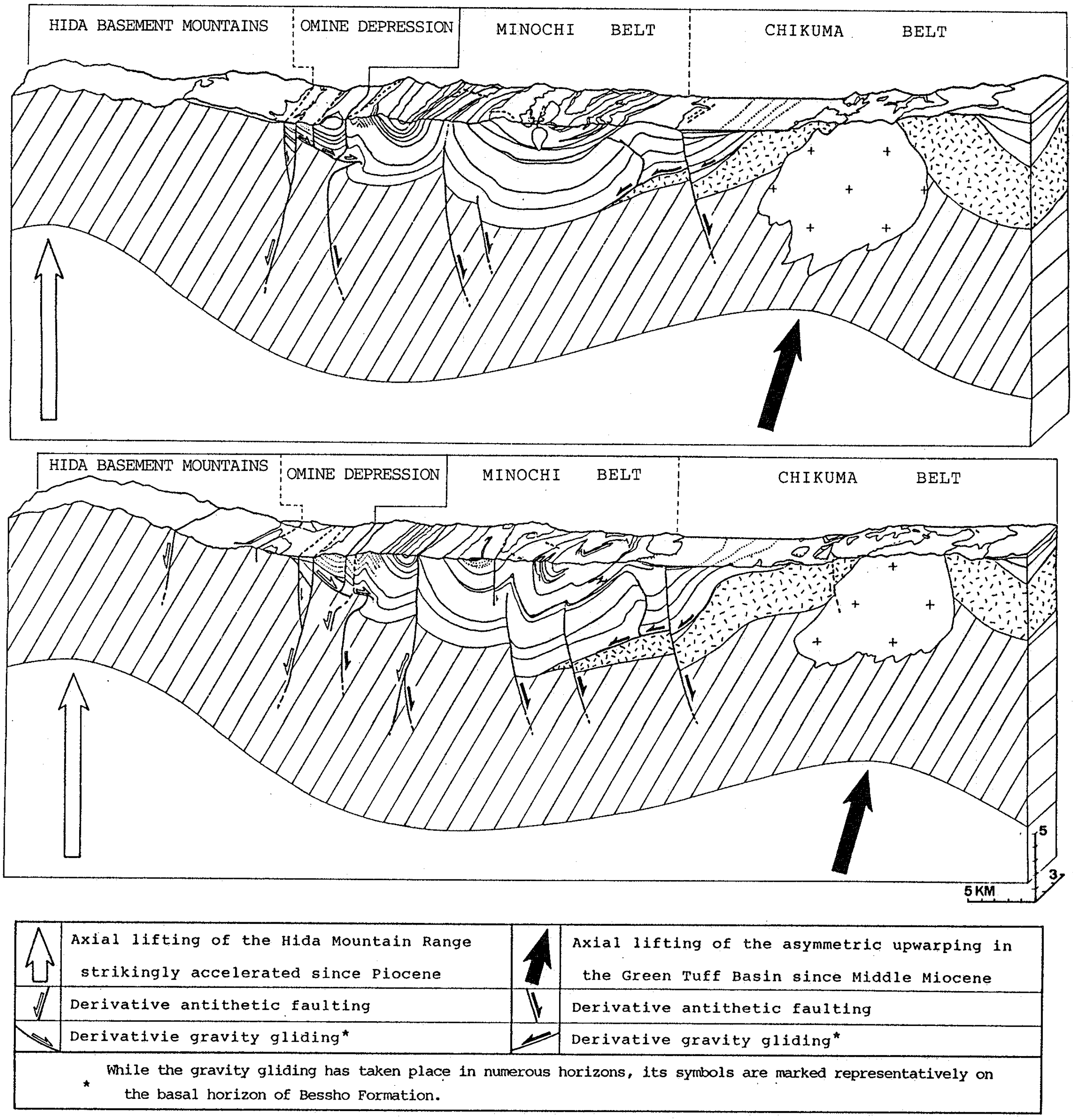

Fig. 6 Block diagrams showing the deformational mechanism in the northern Fossa Magna.

UEMURA's model seems to be the asymmetric upwarping of the whole Green Tuff Basin in the target area, as well as in the case of the Chikuma Belt (Fig. 6). The reason is that the UEMURA's model corresponds to a combination of the tilting of northwestern limb of the upwarp by its growth and of the antithetic faulting of the basement in the extentional stress field due to the upwarping. The antithetic faults appear to turn into thrusts at the shallower level due to gravity spreading of the elevated wall and rotation of basement blocks by advancement of the upwarping, resulting in formation of the cylindrical faults as a whole. Furthermore gravity gliding of the stratified sediments especially in mobile horizon must have promoted the folding, as pointed out also by UEMURA (1976). Thus the essential features of deformational mechanism in the Minochi Belt can be explained by the regional upwarping of the Green Tuff Basin in the gravity field.

The rapid uplifting of the Hida Basement Mountains of the N–S trend since the Pliocene, especially in the Quaternary, was confirmed by YANO (1989) through sedimentological analysis of conglomelates in the Minochi Belt. Contemporaneously with the uplifting of the Hida Basement Mountains, the Omine Depression and then the Matsumoto Basin generated on the eastern foot of the mountains as eastward-tilting basins bounded by antithetic faults on the east. These tilting basins and antithtic faults of the N–S trend seem to be brought about by the upwarping of the Hida Basement Mountains and its derivative gravity faulting. Although the basement faults in the Minochi Belt were oblique to the upwarping axis of the Hida Basement Mountains, their most southwestern portions were contemporaneously subjected to the antithetic faulting derived from the upwarping of the Hida Basement Mountasins due to their own fragility. As a result the Uruga-Akashina and Mochigyo Faults were formed through reverse displacement of the basement faults. Furthermore the eastward dipping strata in the Omine Depression seem to have glided to the east by tangential component of the gravity in response to advancement of the upwarping of the Hida Basement Mountains, and pushed the neithboring western margin of the Minochi Belt. Indeed, bedding faults are observed in the Omine Group, especially in argillace-

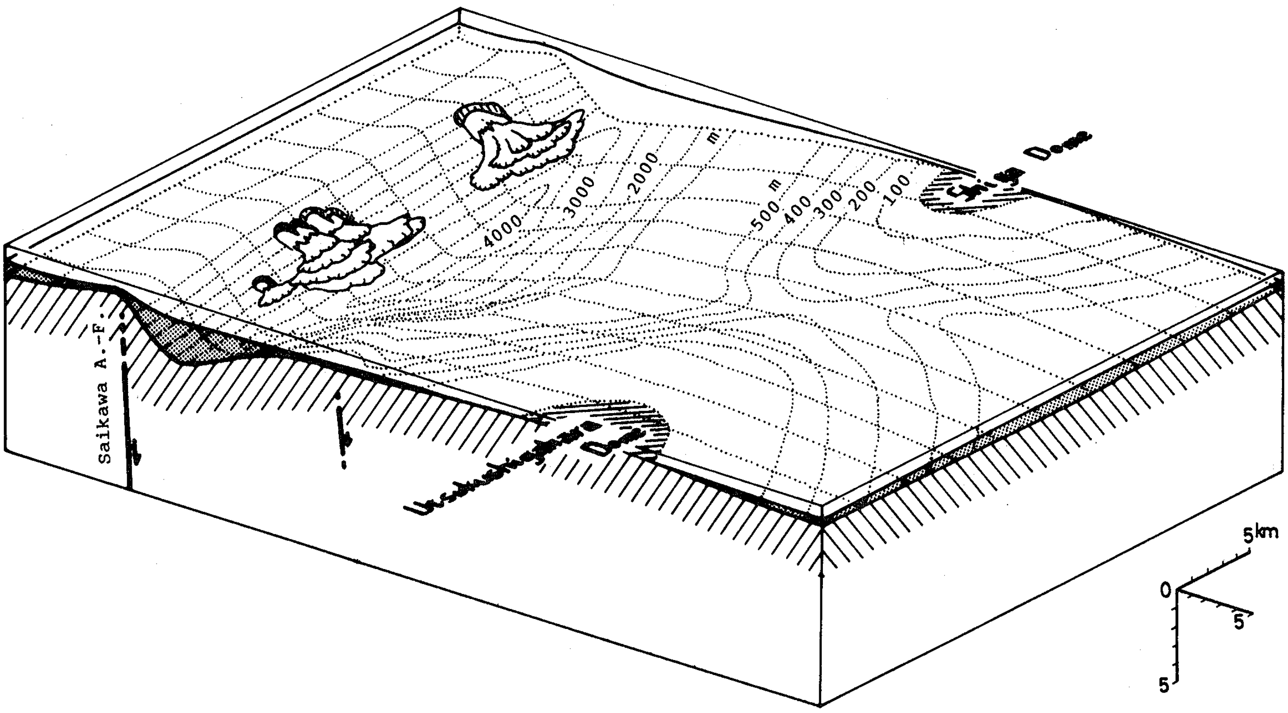

Fig. 7 Block diagram showing the structure of sedimentary basin in the Bessho stage, which is restored from the isopach map of the Bessho Formation in YANO (1989). Differential subsidence in the basin clearly reflects the embryonic uplifting of the Chikuma Belt with two foci.

ous intercalations. The western marginal zone of Minochi Belt of a width ranging from 2 to 5 km, thus, was extraordinarily shrunk. The Otari-Nakayama Fault, which bounds the eastern margin of the Omine Depression and the Matsumoto Basin, truncates the Minochi Belt in the N-S direction. As a result, the northwestward gravity gliding of the strata in the Minochi Belt brought about a left-lateral dislocation along the Otari-Nakayama Fault to form a group of echellon folds of left hand. In the Takafu-Orihashi Subbelt the axial trace of the Takafu Syncline of the NNE-SSW trend is bent into the N-S direction within the western marginal zone, probably due to a combination of the eastward gliding in the Omine Belt and the northwestward gliding in the Minochi Belt.

The whole geologic structure in the Minochi Belt, thus, appears to have been formed by the regional upwarping over the Green Tuff basin and its derivative antithetic faulting and gravity gliding. The uplifting of the Hida Basement Mountains superimposed the exotic structural features upon the western marginal zone of the Minochi Belt.

3. Deformational mechanism of the Green Tuff Basin

Most essential agent in the vanishing stage of the Green Tuff Movement in the northern Fossa Magna is concluded to be the regional upwarping of southeastward vergence in the gravity field (Figs. 5 and 6). Through the interaction with the gravity, the reginal upwarping automatically generated the antithetic faulting in the basement and the gravity gliding of mobile strata, both of which considerably embellished the deformational process to produce a complicated structure in the Green Tuff Basin. The N-S trending uplift of the Hida Basement Mountains in the Pliocene to Quaternary is a subordinate agent modifying the geologic structure in the western margin of the Green Tuff Basin through interaction with the gravity.

The origin of the regional upwarping of the Green Tuff Basin can be traced back upto the developing stage of Green Tuff Movement, develping stage which is characterized by uplifting of the Chikuma Belt and subsidence of the Minochi Belt. In detail, such a regional undulation seems to have started at the begining of the Bessho stage when the Chikuma Belt turned from subsidence to embryonic uplift with some foci (Fig. 7). Since that time the asymmetric upwarping continued to grow accompanying with the northwestward migration of depocenter and finally caused the tectonic deformation of the Green Tuff Basin. TAKEUCHI (1978) asserted the drastic change of regional stress state in the latest Miocene all over the northern Central Japan from extension in a subsidence mode of sedimentary basin to compression in a deformational mode. Such a change of regioal stress state, however, did not need for deformation of the Green Tuff Basin, because the tectonic deformation was, as mentioned above, caused by advancement of the asymmetric upwarping which continued to grow since the begining of the Middle Miocene. Thus, the geohistorical change in the tectonic mode of the Chikuma Belt from subsidence and initial volcanism to uplifting and plutonism looms up as the ultimate origin of the tectonic deformation in the Green Tuff Basin. In a reverse view point, the embryonic upwarping at the begining of the developing stage of the Green Tuff Basin, which had exceeded the foregoing subsidence at the generative stage, grew into a regional asymmetric upwarping and became the agent of tectonic deformation in the vanishing stage through interaction with the gravity.

Concluding Remarks

On the basis of the geologic structure of the upper Cenozoic system in the northern Fossa Magna and its orderliness, the deformational mechanism of the Green Tuff Basin was synthetically interpretated in this article. It is concluded that the regional asymmetric upwarping over the basin since the Middle Miocene and the rapid uplifting of the Hida Basement Mountains since the Pliocene have formed the complex stucture of this basin through the interaction with the gravity in manners of antithetic faulting and gravity gliding.

Such an interpretation should be refined through the feedback with field observations and the comparative researches with models reduced in different ways. According to the gravity survey in the northern Central Japan by KONO et al. (1982), the Bouguer anomaly contour of zero mgal runs in parallel with the

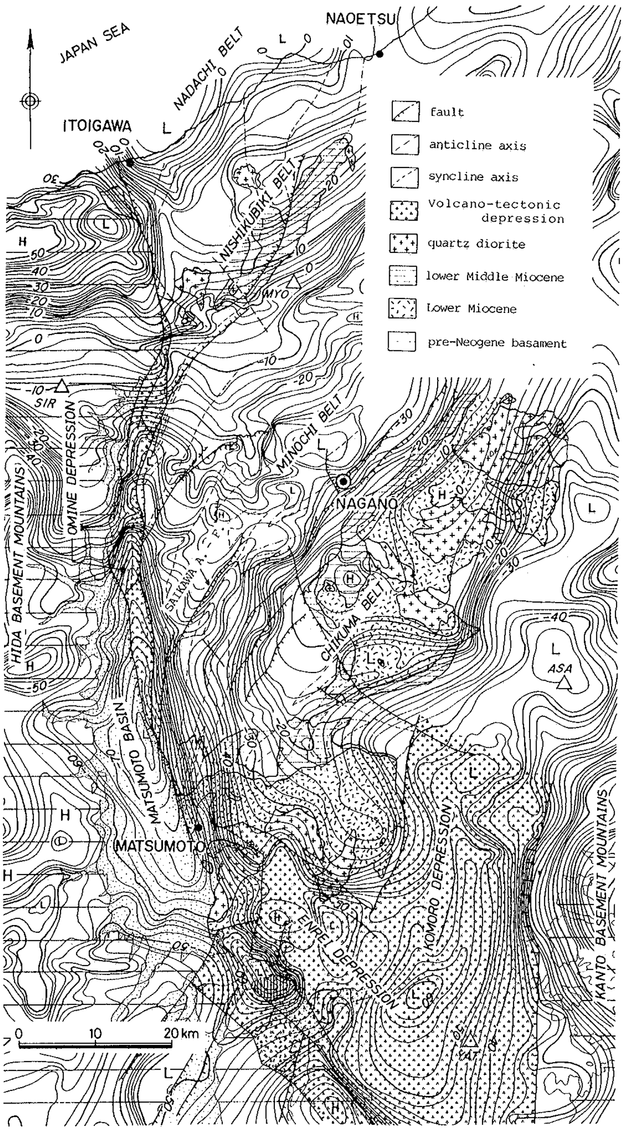

Fig. 8 Superimposition of the Bouguer anomaly (KONO et al., 1982) and the tectonic division around the northern Fossa Magna. Contour interval is 2 mgals.

coast line of the Japan Sea about 20 km inlandward and the negative anomaly occupies extensively to the south of the contour (Fig. 8). The anomalies of smaller wavelength fairly fit the structural features of the tectonic devisions around the northern Fossa Magna. The gravimetric highs are comparable with the Chikuma and Nishikubiki Belts in the Green Tuff Basin and the surrounding Hida and Kanto Basement Mountains. The gravimetric lows are also with the Minochi and Nadachi Belts in the Green Tuff Basin, the Plio-Pleistocene Enrei and Komoro Volcano-tectonic Depressions superimposing upon the south-western end and eastern margin of the Chikuma Belt, and the eastward-tilting Omine Depression and Matsumoto Basin on the eastern foot of the Hida Basement Mountains. In detail the linear step of the anomaly along the Saikawa Anticline-Fault in the Minochi Belt appears to reflect the antithetic displacement in the basement mentioned in the foregoing lines. On the other hand KOMATSU et al. (1985) pointed out that the gravimetric positive relief in the coastal zone is fairly affected by the deeply seated basic to ultrabasic rocks of the ENE-WSW trend supposed from the surrounding geological setting. Thus the gravimetric structure shown in the Bouguer anomaly of relatively small wavelength is conformable with the crustal structure supposed from the deformational mechanism reduced in this article.

The regional asymmetric upwarping of the Green Tuff Basin initiated as an embryonic upwarping of the Chikuma Belt (Fig. 7) at the begining of developing stage of the Green Tuff Movement. The embryonic upwarping, which turned from the preceding subsidence of the Chikuma Belt, succeedingly advanced through the developing stage, and brought the tectonic deformation to the Green Tuff Basin in the vanishing stage. The transition of the Chikuma Belt from subsidence to uplift, therefore, is considered to be the ultimate origin of the tectonic deformation of Green Tuff Basin, and must be one of the most epoch-making actions by the tectonic controller of the Green Tuff Movement, as well as the generation of the basin. Elucidation of the cause of this transition is the genetic issue for the study of the tectonic deformation of the basin. The important clues to the issue seem to be held in the plutonism accompanied by the upwarping and the preceding initial volcanism and subsidence.

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* : in Japanese with English abstract

** : in Japanese

地 名

Aida	会田	Kotakiyama	小滝山	Otari	小谷
Akashina	明科	Matsumoto	松本	Saikawa	犀川
Aoki	青木	Minochi	水内	Sarumaru	猿丸
Bessho	別所	Mochigyo	持京	Shiga	志賀
Buno	奉納	Nadachi	名立	Shigarami	柵
Chikuma	筑摩	Nagano	長野	Takafu	高府
Enrei	塩嶺	Nakayama	中山	Tochiku	東筑
Hida	飛驒	Nishikubiki	西頸城	Toyono	豊野
Hijirigawa	聖川	Nishikyo	西京	Uchimura	内村
Hikage	日影	Noma	野間	Ueda	上田
Komakiyama	小牧山	Ogawa	小川	Uruga	宇留賀
Komiji	込地	Omine	大峰	Utsukushigahara	美ヶ原
Komoro	小諸	Orihashi	折橋		

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北部フォッサマグナのグリーンタフ堆積盆地は，NNE-SSW 方向に伸長し，南東側の複背斜（筑摩帯）と北西側の複向斜（水内帯）に区分される．筑摩帯に軸をもつ南東フェルゲンツの広域的な曲隆運動によって盆地の伸長方向に連なるいくつかの大規模なドームが形成され，下部中新統のグリーンタフやそれに貫入した石英閃緑岩が広く露出した．グリーンタフと中部中新統の細粒砕屑岩との境界部を剝離層として，より上位の地層群は北西へ向かって重力滑動し，短波長の非調和褶曲群を形成した．水内帯では，曲隆にともなうアンチセチックな基盤断層運動と被覆層の北西への重力滑動との相互作用の結果，基盤断層群に沿う chevron 型の背斜—断層とそれらの間の幅広い curvilinear な向斜群とが交互に並走する複雑な複向斜構造が形成された．