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FOSSA MAGNA –A masked border region separating southwest and northeast Japan

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KATO, Hirokazu (1991) FOSSA MAGNA –A masked border region separating southwest and northeast Japan. *Bull. Geol. Surv. Japan*, vol. 43 (1/2), p. 1-30, 10 fig.

Abstract: The definition, sedimentation and tectonic events of Fossa Magna are reviewed. Fossa Magna as a border region separating southwest Japan and northeast Japan initiated during the late Early to early Middle Miocene opening of the Japan Sea. In middle Miocene, marine transgression was at a maximum and the whole area of Fossa Magna was submerged. The Fossa Magna sedimentary basin was a large half graben-like depression whose western margin was bordered with a major fault. Subsequently, the Central Upheval Zone emerged between the northern and southern Fossa Magna regions and the Kanto Syntaxis, the northward curvature of the basement rocks formed, by an increasing stress imparted from the collision with the Phillipine Sea Plate. Subsequent geologic development of the two regions became increasingly different. Hence it is oversimplification to treat the whole area of Fossa Magna as a single structural domain. The Itoigawa-Shizuoka Tectonic Line has been regarded as the western boundary of Fossa Magna, but is not the western boundary of the Miocene sedimentary basin of Fossa Magna. It is the Pliocene deformation boundary. During and after Pliocene the block on the western side of the tectonic line upheved with little strike-slip displacement.

1. Introduction

Fossa Magna region is a vaguely defined transition zone between southwest Japan (Seinan Nihon) and northeast Japan (Tohoku Nihon) micro continents. A lot of geological and geophysical data have been accumulated and interpretations of these data are eagerly debated because of the limitation of these data and their inherent nonuniqueness since Naumann proposed the Fossa Magna in 1885. The definition of Fossa Magna is also confused as the area developed as the result of several tectonic events. The deeper structural characteristics of the area were likely produced primarily during the opening of the Japan Sea, but subsequent tectonic events have complicated the structural and sedimentary history of the area. For example, Paleogene and early Miocene behavior of the Itoigawa-Shizuoka Tectonic Line (ISTL), western boundary of Fossa Magna is poorly understood partly because of the scarcity of deposits of those times, and partly because Quaternary deposits cover the ISTL especially in the northern Fossa Magna region. This paper reviews, the geology of Fossa Magna and argues unsolved tectonic problems concerning the structural history of Fossa Magna.

2. Geologic setting

2.1 Definition of Fossa Magna

One of the most important tectonic events in

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the Cenozoic geohistory of eastern Asia is the opening of Japan Sea during early to middle Miocene age. This event is directly related to the formation of Fossa Magna. Therefore, it should be distinguished from the geologic features which developed prior to and after the opening of the Japan Sea. In this paper the author mainly focuses on the post-opening stratigraphy and tectonics of the region. In the post-opening stage there is general agreement that the western margin of Fossa Magna coincides with the Itoigawa-Shizuoka Tectonic Line (the ISTL). In general the ISTL is the boundary between the westward pre-Tertiary rocks and the eastward Tertiary rocks. However, some Neogene rocks of Fossa Magna are distributed to the west of the ISTL, which implies that in some places, the ISTL was not the westernmost boundary of Fossa Magna basin during Neogene time. The ISTL was a major growth fault in the basement and had a significant influence on sedimentation. The ISTL as surface expression of the western boundary of deformed Fossa Magna has been after Pliocene. On the other hand the position of the eastern margin is less well defined and is the focus of considerable debate. In many ways, it is almost meaningless to debate the exact location of the eastern margin of Fossa Magna. Fossa Magna is thought to be a kind of complex half-graben and there is no firm evidence of major faulting in the eastern part during Neogene. There is, however, one exception ; Neogene deformation is observed along the NNE-SSW trending Shibata-Koide Tectonic Line (SKTL) along the northeastern margin of deformed Fossa Magna (See Figure 2). The distinction of tectonic events occurring in the southern and northern Fossa Magna are of generally considered more important to the development of the Fossa Magna region during middle Miocene.

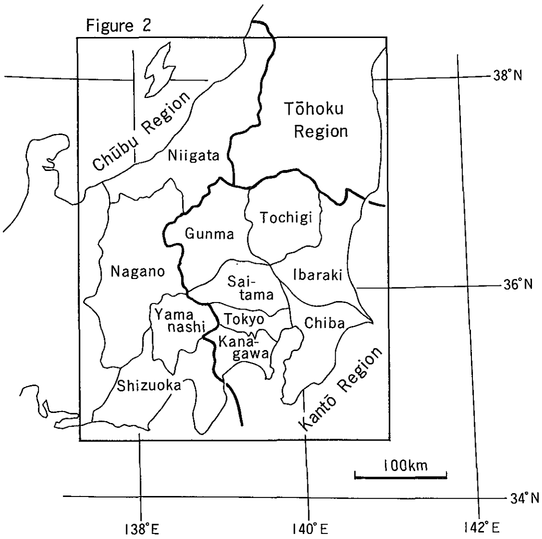

Figure 1 Index map.

The northern and southern parts of the Fossa Magna region are separated geologically by the concealed Median Tectonic Line. Many geologists regards the Suwa region of Nagano Prefecture to be regarded as the boundary zone between the northern and southern parts of Fossa Magna, since the characteristics of deformation along the ISTL in this region change significantly. This author prefers to emphasize that the Central Upheaval Zone, a major NE-SW trending horst block, which has actively developed since the middle Miocene, provides a Neogene age structural subdivision of Fossa Magna into northern and southern parts (Figure 2). In particular, the tectonic activity of southern Fossa Magna is controlled by the relatively dynamic processes of micro block collision and subduction of the Philippine Sea Plate. Divisions of Fossa Magna and surrounding regions discussed in this paper are shown in Figure 2.

2.2 Pre-Tertiary basement in Fossa Magna

In the Kanto Mountains of the southern Fossa Magna, the distribution of pre-Neogene tectonic belts is very similar to that found in the Outer Zone of southwest Japan. Tectonic belts found in both areas include the Sanbagawa Belt and the Chichibu Belt, which can be extended through the Fossa Magna region on the basis of geological data, volcanic xenoliths, deep-drilling data and geophysical data. As another example, the Ookitano-Iwamura Line (Fujimoto *et al.*, 1953) is interpreted to be the extension of the Median Tectonic Line (the

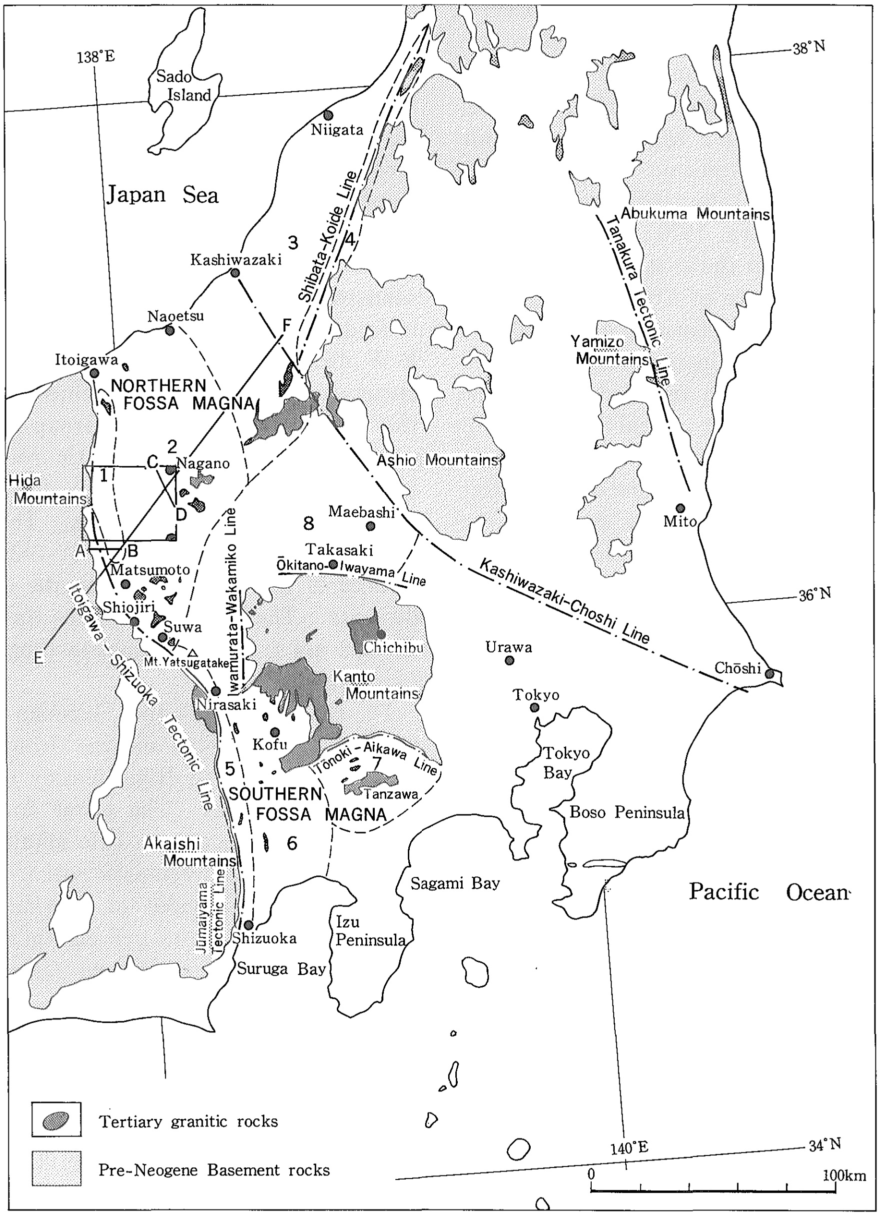

Figure 2 Index map of Fossa Magna.

MTL) across the northern margin of the Kanto Mountains. In addition, the pre–Tertiary basement rocks of the southern Fossa Magna show zonal arrangements towards the Pacific Ocean very similar to these of southwest Japan. For instance granitic rocks and metamorphic rocks belonging to the Ryoke Belt, one of tectonic belts of the Inner Zone, are scattered to the northern side of the MTL. So, the geology of pre–Tertiary basement rocks in the southern Fossa Magna is fundamentally the same as that of southwest Japan.

On the other hand, in the northern Fossa Magna the pre-Tertiary geology and structural framework is largely unknown since there are few pre-Tertiary basement rocks exposed at the surface. Rock fragments such as gabbro, diabase, clionopyroxenite, sandstone and shale are included in the volcanic ash and ejecta exposed from Yakeyaka volcano in 1974 (Komatsu and Chihara, 1976 ; Chihara, 1976). Deep drilling data to the east of Kashiwazaki City show the existence of Cretaceous granite, clionopyroxenite and serpentinite about 3,000 m deep from the surface (Inoma, 1971 ; Ishiwada and Igi, 1971). Xenolith included in Pliocene volcanic rocks contain hornblende-gabbro. These facts suggest that the zonal arrangements observed in the Inner Zone of southwest Japan extend beneath Tertiary rocks in the northern Fossa Magna. This structural characteristics is significantly different from that of northeast Japan which is to the Kashiwazaki-Choshi Line or the Tanakura Tectonic Line, there is not complete agreement concerning this. However, since the principal emphasis of this paper is on the Neogene tectonic subdivisions of the region, this is not addressed further.

2.3 Southern Fossa Magna

In the southern Fossa Magna thick Neogene formations consisting of volcanic rocks, conglomerate and alternating beds of sandstone and mudstone of marine origin are widely distributed. Formations at the base of the sequence such as the Nishiyatsushiro and Misaka Formations of middle Miocene age (Figure 3) form the Koma, Misaka and Tanzawa Mountains. Upper formations in the sequence such as the Fujikawa Formation of late Miocene to Pliocene age are distributed in the low land area along the River Fuji and Katsura.

In Pacific Coast side area of the southern Fossa Magna (Areas 5 and 6 in Figure 2) Neogene formations form several separate thrust sheets.

In the western marginal area between the Jumaiyama Tectonic Line and the ISTL, the Ryuso-Takakusayama volcanic rocks are distributed in a narrow belt (See Figures 1 and 2). These are mainly composed of dacite and alkali basalt of late Early Miocene age and are considered to be part of accretionary prisms formed in middle Early Miocene time. To the east of this thrust sheet the Shizuoka Group of late Miocene to Pliocene age is distributed between the ISTL and the west-dipping Tashiro-toge Thrust. The Shizuoka Group consists of sandstone and alternating beds of sandstone and mudstone of marine origin. It is folded and its strikes swings from a N-S to E-W direction forming a conscipious bending structure. To the east the Tashiro-toge Thrust, the Pliocene Hamaishidake Group is distributed. It is composed of clastic rocks with a small amount of andesite to dacite volcaniclastic rocks and is very thick. This group is deformed into N-S to NNW-SSE trending structures and is thrust over the Quaternary deposits. The Shizuoka and the Hamaishidake Groups are trench-fill deposits (Sugiyama and Shimokawa, 1990).

To the north of the Shizuoka area, the 2,000 m thick Nishiyatsushiro Group is distributed from the Fiji River Valley area to the Misaka Mountains. The lower formation is mainly composed of non-calc alkali basalt to andesite lava and pyroclastic rocks. The upper formation is composed of marine mudstone and andesite to dacite pyroclastic rocks (Matsuda, 1961). The Fujikawa Group of late Middle Miocene to Pliocene age conformably overlies the Nishiyatsushiro Group and lies in fault contact with the Koma Group in the northern part and with the Rhuso-Takakusayama volcanic rocks and the Shimanto Group in the western part along the ISTL. The lower part of this group is composed of alternating beds of sandstone, mudstone and fine conglomerate that varies in thickness from 600 to 3,000 m. The upper part is composed of conglomerate, conglomerate-rich sandstone alternating with andesite lava and pyroclastic rocks (Matsuda, 1961).

In the Koma Mountains area the Koma Group of late Early Miocene to Middle Miocene is divided into two subgroups, the lower subgroup is composed of basaltic pyroclastic

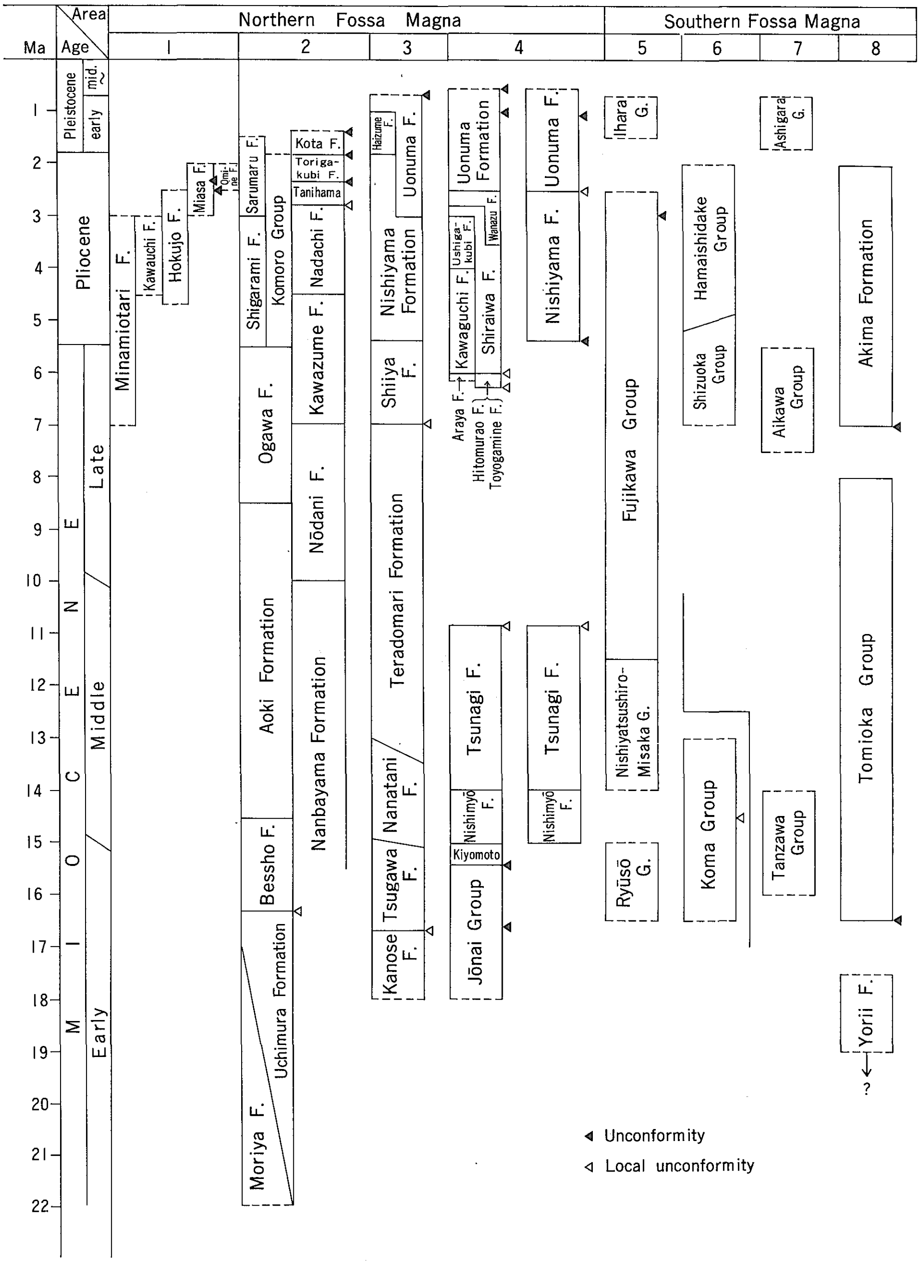

Figure 3 Stratigraphy in Fossa Magna. 1: Western marginal area of the northern Fossa Magna region (Omine Belt), 2: Western area of main part of the northern Fossa Magna region (mainly Nagano area), 3: Eastern area of main part of the northern Fossa Magna region (mainly Niigata area), 4: Eastern marginal area of the northern Fossa Magna region, 5: Western marginal area of the southern Fossa Magna region (mainly along River Fuji), 6: Western area of main part of the southern Fossa Magna region (mainly Shizuoka area), 7: Tanzawa area, 8: Northern area to the Kanto Mountains (mainly Gunma area).

rocks and the upper one is composed of coarse-grained marine clastic rocks (Kosaka and Tsunoda, 1969).

The Tanzawa Mountains area of the "Green Tuff" region is bordered by the Tonoki-Aikawa Line along its northern and eastern margins (Figure 4), and by the Kannawa Fault along its southern margin. The early to middle Miocene age Tanzawa Group of this area is composed mostly of andesite to basalt volcanic rocks interbedded with sedimentary rocks, whereas the upper part of late Miocene formation in this group are entirely clastic. The total thickness of the Tanzawa Group reaches 10,000m. The Tanzawa group in the central part of the mountains is intruded by a late Miocene to Pliocene large mass of quartz-diorite. To the south of this area the part of the Tanzawa Group is metamorphosed into crystalline schist. The Aikawa Group is a mollase-type sediment which developed during the uplifting of the Tanzawa sedimentary basin.

Niitsuma and Matsuda (1985) interpreted that the Tanzawa Mass collided with what and accreted from the south as a result of the subduction of the Philippine Plate.

In and around the Kanto Mountains, early to

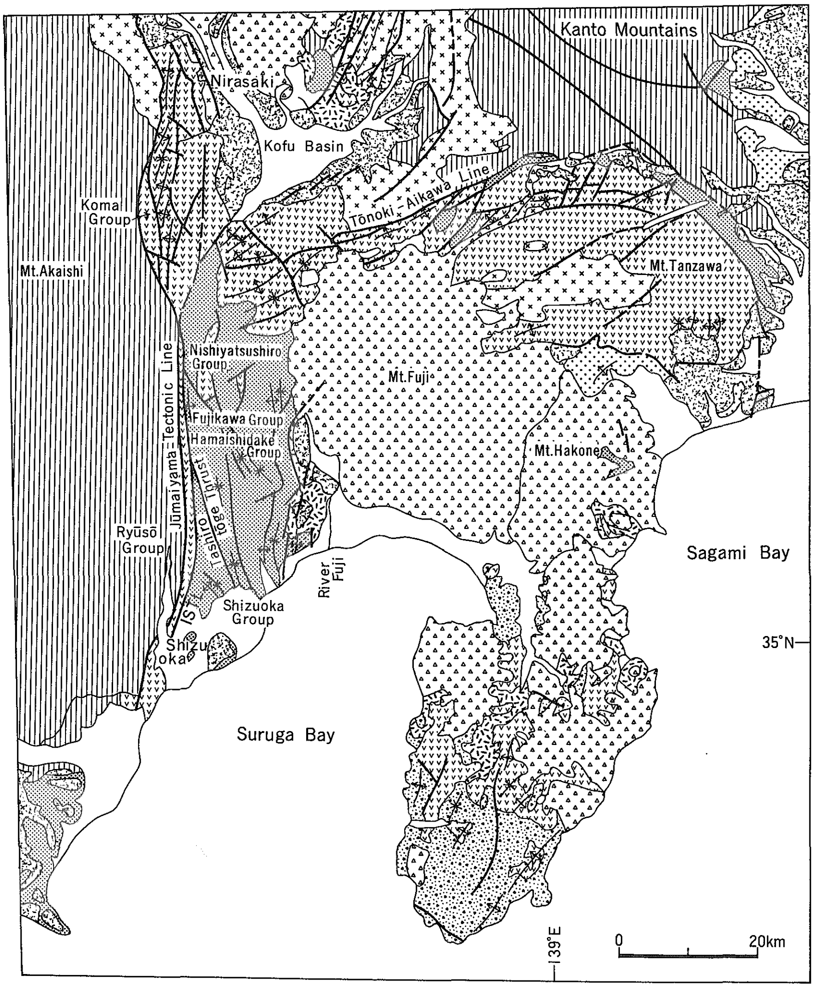

Figure 4 Geologic map of the southern Fossa Magna (After Kakimi *et al.*, 1982). Legend is shown in Figure 5.

middle Miocene clastic rocks, and late Miocene to Pliocene volcanic rocks are distributed. An early Miocene basal conglomerate overlies the Mesozoic unconformably in places. These formations are known as the "Green Tuff". Middle Miocene formations indicative of a warm environment also unconformably lie above pre–Tertiary basement and sometimes the lower Miocene. They are mainly composed of mudstone but in the uppermost part conglomerate is dominant and is partly made up of subaerial effusive rocks. This change in depositional environment marks the beginning of uplift at least along the northern margin of the Kanto mountains. Around the northeastern margin area of the Kanto Mountains, Miocene formations are distributed in several hills and are deformed by Pliocene faulting. The Yorii Formation, the lowest formation in this area, overlies the Sanbagawa metamorphic rocks unconformably. It consists of conglomerates including quartz–porphyry gravels and sandstone of marine origin. Most of middle to late Miocene formations consist mainly of clastic rocks. The uppermost Miocene formations include many gravels of Neogene clastic rocks, and therefore the underlying Miocene formations were widely eroded.

North of the Kanto Mountains the early to middle Miocene Tomioka Group is distributed. This group consists mainly of marine sandstone and mudstone. The overlying Akima Formation of late Miocene to Pliocene age is composed mainly of tuff breccia. Around the border area between the northern Gunma Prefecture and the southern Niigata Prefecture Neogene sedimentary rocks consisting mainly of "Green Tuff" with intermediate to acidic intrusive rocks are also widely distributed (Kubota, 1988). The geological situation is similar in general to the other areas in the southern Fossa Magna, that is, early Miocene rocks lie unconformably above the pre–Neogene basement rocks. Black shales of marine origin are found in middle Miocene formations. Some local unconformities developed in the middle and upper part of Miocene "Green Tuff." Pliocene formations consisting of dacite to andesite pyroclastic rocks lie unconformably above the Miocene formations which are succeeded unconformably by Quaternary andesite lava and lake deposits.

It is regarded that the Green Tuff region is situated along the Miocene volcanic arc. At this time that the Kanto Mountains formed a basement high in the Outer Belt, while the Neogene sediments in the Takasaki area formed an intra–arc basin fill deposits (Takahashi, 1990).

2.4 Northern Fossa Magna

The main part of the northern Fossa Magna consists fundamentally of a common sedimentary basin. The basin extends from northern Nagano Prefecture (western half) to Niigata Prefecture (eastern half including mainly Niigata Oil Field). This basin known as "the Shin–etsu sedimentary basin" has existed since at least the middle Miocene. The total thickness of the Neogene in this basin is about 5,000 m. This reflects the fact that subsidence was rapid and occurred on a regional scale. The western (Omine Belt) and eastern marginal areas were separated from the main part of the basin during their development.

The Neogene in northern Nagano Prefecture are divided into the Uchiyama, Moriya, Uchimura, Bessho, Aoki, Ogawa, Shigarami and Sarumaru formations. These formations are marked by NS or NNE–SSW trending zonal distributions. Deposits in the more northward part of the region are younger and intensely faulted and folded.

The lowest formation of the sequence in this region, the Moriya Formation of early (–middle) Miocene age is distributed to the west of the ISTL, just south of Lake Suwa. The lowest member is a basal conglomerate, composed of gravels of marine clastic rocks. The upper member consists of altered pyroclastic rocks, "Green Tuff" (Tanaka *et al.*, 1962).

The Uchimura Formation is composed of altered pyroclastic rocks known as the "Green Tuff" and is accompanied by marine black mudstone in the uppermost part. Its distribution is restristed to the areas east of the ISTL. This formation is often intruded by porphyrite or quartz-diorite bodies and dikes. Though the basal part of the Uchimura Formation is not exposed and therefore cannot be correlated precisely with the Moriya Formation, the upper part of the Moriya Formation is tentatively correlated with the lower part of the Uchimura Formation based on their lithologies (Yamagishi, 1964 ; Kato, 1980). This implies that early Miocene formations are distributed beyond the ISTL to the west. To the west of Itoigawa, a green tuff correlative with the early Miocene Tsugawa Formation (See Figure 3) is also distributed beyond the ISTL to the west (Yoshimura and Ishibashi, 1979).

The Bessho Formation and its correlatives of middle Miocene age which conformably lie above the "Green Tuff", are widely distributed not only in Nagano Prefecture but also along the Japan Sea Coast area of the Tohoku Region. The Bessho Formation consists mainly of black mudstone deposited in the subtropical environments and is often intruded by porphyrite or quartz-diorite bodies and dikes, as well. The total thickness reaches more than 1,000 m and thins toward the Central Upheaval Zone. Yamada *et al.* (1976) made an unverified report that a Vicarya fossil was collected at the unknown locality on the mountain slope of the northern Japan Alps, west of the ISTL. If their report can be verified, then the sedimentary basin within which the Bessho Formation was deposited extended to the west of the ISTL.

The Aoki Formation of middle Miocene age lies conformably above the Bessho Formation. It is composed mainly of flysh type alternating beds of sandstone and mudstone. It is noted that the basal conglomerate includes an andesitic-basaltic breccia brought from the Uchimura Formation, quartz-diorite and diorite distributed in the Uchimura region and black mudstone breccia from the Bessho Formation. This suggests that portions of the Central Upheaval Zone were undergoing erosion above sea level. Nishina (1991) insisted that granitic boulders of basal conglomerate were derived from 20–30 km west of the ISTL based on the comparison between granite bodies in the western mountain area and boulders. If his opinion was accepted, the sedimentary basin in which the Aoki Formation was deposited, also extended to the west of the ISTL.

The Ogawa Formation of late Miocene age is composed of coarse-grained clastic rocks which intercalate with a the remarkable rhyolitic tuff, known as the shallow-marine Susobana Tuff. The tuff erupted through the fault, Matsumato-Nagano Line which is the northwestern boundary of the Central Upheaval Zone.

The Shigarami Formation and its correlatives of Pliocene age conformably lie above the Miocene formations. This formation contains a wide variety of sedimentary facies including sandstone, mudstone, conglomerate and andesite pyroclastics. Extensive volcanic deposits of andesite and basalt reflect intense volcanic activity from earliest to middle Pliocene time. Local uplifting occurred in some places prior to the volcanic activity.

The Sarumaru Formation of late Pliocene to early Pleistocene age consists of sandstone and conglomerate with dacite to rhyolite tuff beds. This formation is partly of non-marine origin. The facies and thickness changes of the sequence occurred over short distances in this area during late Miocene to Pliocene time, reflecting the local tectonic movements. A most vigorous tectonic movement occurred in particular in the Nagano area of the northern Fossa Magna during the latest Pliocene to earliest

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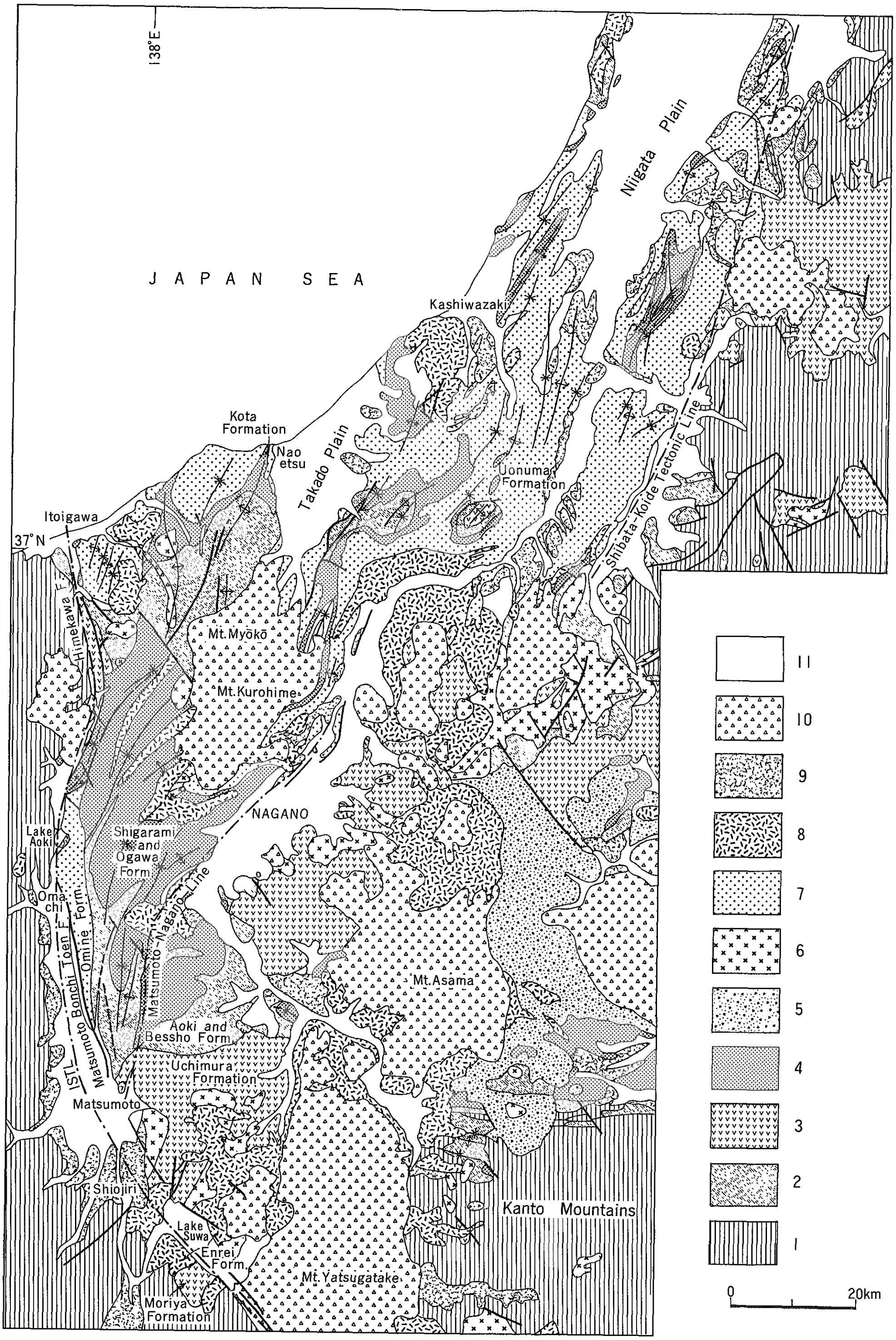
Figure 5 Geologic map of the northern Fossa Magna, compiled after Kato *et al.* (1984) and Kato and Sugiyama (1985). 1 : Pre-Tertiary rocks, 2 : Mainly sedimentary rocks of lower to middle Miocene age, 3 : Mainly volcanic rocks of lower to Middle Miocene age, 4 : Mainly sedimentary rocks of upper Miocene to Pliocene age, 5 : Mainly volcanic rocks of upper Miocene to Pliocene age, 6 : Neogene intrusive rocks, 7 : Mainly sedimentary rocks of Pliocene to lower Pleistocene age, 8 : Mainly volcanic rocks of Pliocene to lower Pleistocene age, 9 : Mainly sedimentary rocks of middle to late Pleistocene, 10 : Mainly volcanic rocks of middle to late Pleistocene, 11 : holocene sediments.


138°E
JAPAN SEA
Niigata Plain
Kashiwazaki
Kota Formation
Nao etsu
Takado Plain
Uonuma Formation
Shibata-Koide Tectonic Line
Itoigawa
37°N
Himekawa F.
Mt. Myōkō
Mt. Kurohime
NAGANO
Lake Aoki
Shigarami and Ogawa Form.
Oma chi
Omine Form.
Toen F.
Matsumoto Bonchi
ISTL
Matsumoto-Nagano Line
Mt. Asama
Aoki and Bessho Form.
Uchimura Formation
Matsumoto
Shiojiri
Lake Suwa
Enrei Form.
Mt. Yatsugatake
Moriya Formation
Kanto Mountains
11
10
9
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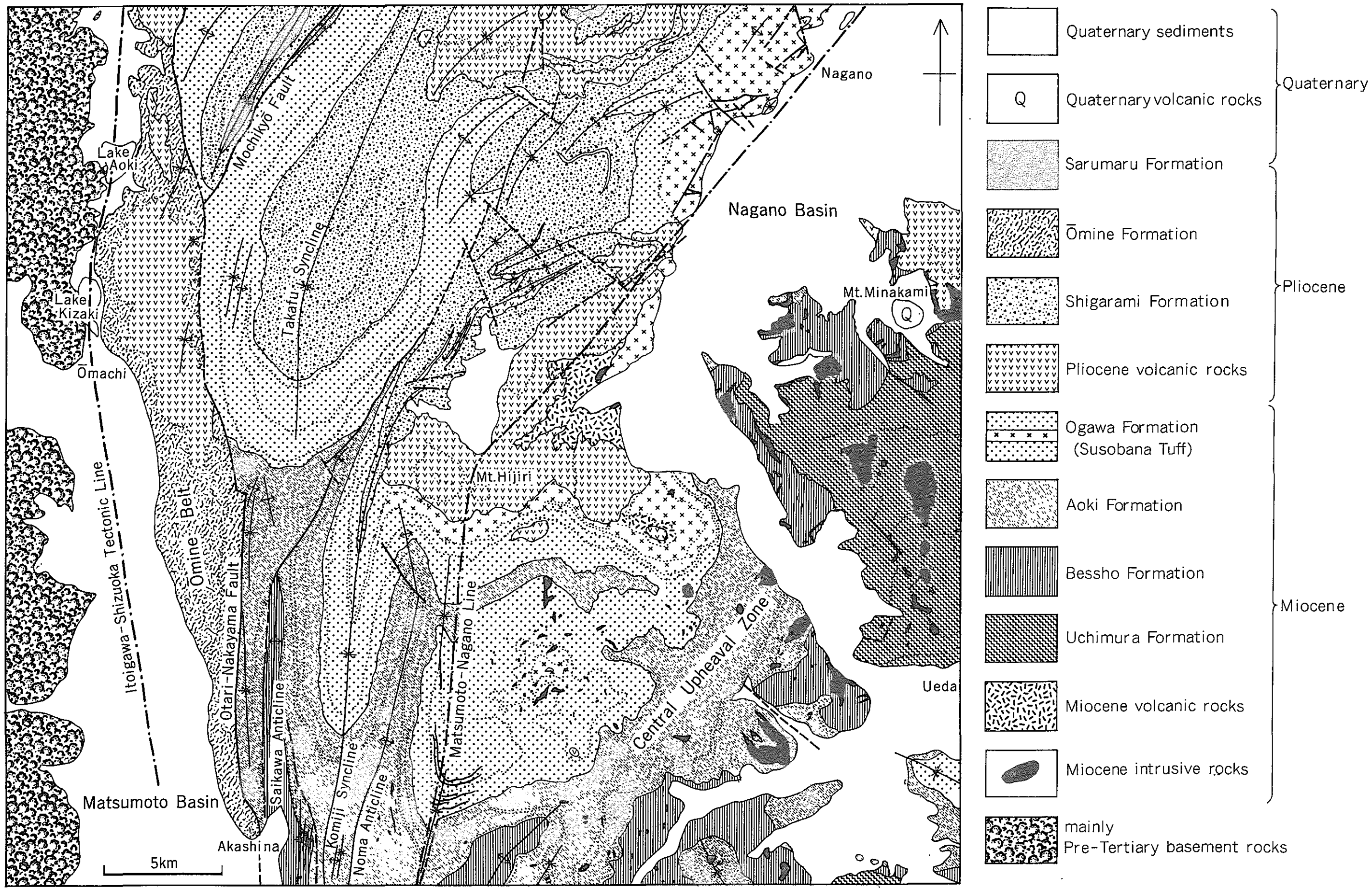

Figure 6 Detailed geologic map of the Nagano area.

Pleistocene age. This event is called the "Sarumaru phase movement". By this movement. A most Neogene formations in this area were intensely folded and faulted (Kato, 1980 ; Kato and Sato, 1983 ; Kato and Akahane, 1986 ; Kato *et al.*, 1989).

Along the western margin of the northern Fossa Magna, the area which is bounded by the N–S trending the ISTL and the Otari–Nakayama Fault (See Figures 5 and 6) is called the Omine Belt by Kosaka (1979). The geology of this area is different from the main part of the northern Fossa Magna. The Omine Belt is divided into five subareas by several oblique faults. The formations distributed here become younger to the south and are composed of coarse-grained clastics as well as volcanic rocks both of marine and terrestrial origin. The Minamiotari Formation, which is about 1,300 m thick, contains rocks in the lower part of the section that are uppermost Miocene in age (See Figure 3). Although marine clastics are dominant in the Minamiotari Formation, various kinds of non-marine pyroclastic rocks are dominant in other formations in the Omine Belt. For example, in the southern part of the basin latest Pliocene formations are distributed as follows. The Miasa Formation is composed of conglomerate, welded ash flow tuff and mudstone, and their alternations. The Taroyama Andesite consists mainly of andesite lava and N–S trending dikes intruding the Miasa Formation. The Omine Formation of latest Pliocene age consists of welded ash-flow deposits, conglomerate and sandstone, and intercalated tuff and silt beds deposited under deltaic environment. It overlies the Miasa Formation and its correlatives across a slight unconformity.

Hirabayashi (1953) reported the distribution of this Omine-type andesite and tuff on the mountain slope of Mt. Shirouma which is located to the west of the ISTL. This fact suggests that the Omine basin extended across the ISTL during the late Pliocene at least. The presence of weak local unconformities, rapid facies changes, and changes in the composition of conglomerate, in the formation that suggest upheaval and erosion from fault movements occurred several times since the early Pliocene (Kosaka, 1980, 1983 ; Kato *et al.*, 1989).

In particular, not only the formations of the Omine Belt but also those to the east of the Otari–Nakayama Fault are widely eroded at the sea level during the early Pleistocene. There are a few of these eroded surfaces and together they are called "the Oomine Surfaces" (Kobayashi *et al.*, 1955). These eroded surfaces presently lie between at 800 to 1,000 m above sea level. This implies that the Nagano region, the western half of the Shin-etsu sedimentary basin area, has been uplifted this distance since the early Pleistocene. In the Niigata area (Area 3 in Figure 2), early Miocene formations, for example the Kanose Formation consisting of marine clastic rocks are restricted to areas east of the Shibata–Koide Tectonic Line (SKTL) (Yamashita, 1970). Early to middle Miocene formations such as the Tsugawa Formation, which consists of basal conglomerate and green tuff, lies unconformably above the underlying rocks. This formation is widely distributed in the Niigata Oil Field although it is not exposed at the surface. The Nanatani Formation consists of mainly mudstone intercalated with tuff layers. The Teradomari Formation consists mainly of alternating beds of sandstone and mudstone deposited in a deep sea environment. During the deposition of this formation, volcanism of basalt, rhyolite and dacite composition took place. Although the Shiiya Formation is similar to the Teradomari Formation in lithofacies, it shows shallower sea environment than that of the Teradomari Formation. The thickness is variable. These facts imply that the abyssal sedimentary basin of the Teradomari Formation was uplifted regionally and separated into several smaller basins. The Pliocene Nishiyama Formation is composed mainly of massive mudstone at the type locality, however its lithofacies is very variable. Andesitic volcanism took place during Pliocene age. These geological situation of the Niigata area is similar to that of the Nagano area, however in the Niigata area the deposition of marine to non-marine sediments continued in Quaternary, such as the Uonuma Formation whose total thickness exceeds 2,000 m.

The eastern half of the northern Fossa Magna described above is tectonically bounded by the SKTL on its eastern side. The narrow area whose width ranges from a few kilometers to about ten kilometers west of the SKTL. This area is called the eastern marginal area of the northern Fossa Magna. The geology of this area is different from that of not only the main part of the northern Fossa Magna but also the western marginal area. The lowest stratigraphic unit of the Miocene formations in this area is the Jonai Group and its correlatives possessing the so-called green tuff facies. This group consists of andesite and basalt lavas and pyroclastic rocks and conglomerate. It gently dips to the west as a whole and terminates unconformably against the pre-Tertiary basement in the east. The middle Miocene formations of similar lithofacies are distributed in a scattered pattern in the border zone between Niigata and Gunma Prefectures and lie between a few hundred and one thousand meters above sea level. It is thought they were deposited in the same sedimentary basin during early middle Miocene age before the intrusion of Miocene quartz-diorite bodies and uplifts the mountains to the east, which consists of pre-Tertiary basement rocks. This sedimentary basin extends not only over SKTL to the east but into the deep part of the Niigata Oil fields to the west. Vigorous volcanic activity of basic magma during middle Miocene characterizes this marginal area. A conglomerate facies within the middle Miocene sequence indicates that the eastern basement area rapidly uplifted and that uplift and erosion extended into the eastern marginal area as well (Chihara, 1985). Whole unconformable distribution of the Pliocene Nishiyama Formation above these middle Miocene formations indicates that much of the area remained above sea level until Pliocene (Yanagisawa *et al.*, 1985, 1986). The stratigraphic record along this unconformity indicates that uplift continued during 7-6 Ma. This event is called Shiiya Event. Although subsidence continued in the central region of the Niigata Oil fields during the duration of the Shiiya Event, this event produced many lithofacies changes and local unconformities in the main part of the eastern half of the Fossa Magna region (Kobayashi and Watanabe, 1985). At the base of the Pliocene to Pleistocene formations, the Uonuma and Haizume Formations are found above local unconformities in this area. These unconformities are distributed narrowly in the eastern marginal area, and extend from 3 to 5 kilometers to the west of the SKTL. This suggests that the movements along the SKTL continued into the Pleistocene (Yamashita *et al.*, 1982).

3. Itoigawa-Shizuoka Tectonic Line (the ISTL)

3.1 General features of the ISTL

The ISTL is divided into three segments (See for example Yabe, 1918). In the southern segment the ISTL is clearly discernible as a fault trace which is smoothly curved and sometimes cut by small faults of variable, but generally NS trend. It passes through from Nirasaki, Yamanashi Prefecture to Shizuoka, Shizuoka Prefecture on the Pacific Ocean Coast. The length of this segment is about 75 km. In general it was a nearly vertical normal growth fault during Miocene (east side is down), however after Pliocene, motion along the fault is reverse (west side is up). The middle segment is about 55 km in length. It is NW-SE trending from near Shiojiri, Nagano Prefecture to near Nirasaki. This segment shows left lateral strike-slip movement since at least late Pliocene. Mostly it is active in Quaternary. The northern segment is nearly of 100 km in length. This segment extends from Shiojiri to Itoigawa, Niigata Prefecture, Japan Sea Coast and is largely unexposed. Physiographically it forms a narrow NS trending graben-like depression that separates the higher Northern Alps on the west side from the lower relief eastern mountains. Based on geophysical data and geologic interpretations mentioned later it is interpreted to have been a near vertical normal growth fault during Miocene (east side is down) and appears to have been inactive since the Pliocene. More recent activity has occurred along a subsidiary fault system parallel to the ISTL. The Matsumoto Bonchi Toen Fault, for example, is partly a high-angle reverse fault (west side up) that developed along the eastern margin of the Matsumoto Basin after Pliocene age.

3.1.1 Features of southern segment of the ISTL

In the lower reaches of the Fuji River, deposition of the Paleogene Setogawa Group is not controlled by the the ISTL. The Misaka Group of middle Miocene age and the Fujikawa Group of late Miocene to Pliocene age are distributed mostly to the east of the ISTL, though some of the deposits are also distributed to the west of the ISTL (Matsuda, 1961 ; Matsuda and Kuriyagawa, 1965). The distribution of the Setogawa, Misaka and the Fujikawa Groups implies that sedimentary basins migrated eastward from Paleogene to Pliocene and that growth of the the ISTL (west side up) controlled the western margin of those basins in Neogene. The ISTL primarily behaved as a steeply dipping to nearly vertical growth fault during Miocene. However, in late Pliocene the ISTL behaved primarily as a reverse fault dipping steeply but sometimes gently to the west.

From the middle reaches of the Fuji River to the southernmost part of the Koma Mountains, the ISTL is a complex structural zone rather than a single fault. Here, the N-S trending the ISTL is cut by NE-SW trending left lateral faults and by NW-SE trending right lateral faults. These faults are nearly vertical and are believed to result from reactivation of previously existing basement faults by differential uplifting. In this area, the NS trending the ISTL appears to be a high angle reverse fault. Associated faults are normal or reverse faults with strike-slip displacements and sometimes appear pivotal in nature. Displacements of those associated faults range from 300 m to more than 2,000 m. Most of them cut the Pliocene Fujikawa Group and therefore postdate formation of this group (Fujikawa Collaborative Research Group, 1976 ; Tsunoda *et al.*, 1977).

In the upper reaches of the Fuji River, the ISTL is a high angle reverse fault that trends NS, and dips to the west except at one locality. The general trend of the ISTL is slightly oblique to the general trend of both the Paleogene Setogawa Group distributed to the west of the ISTL, and the Neogene Koma and Fujikawa Groups to the east of the ISTL. The hanging wall, consisting of the Setogawa Group, is more intensely and widely fractured than the foot wall, which consists of the Neogene rocks. The ISTL is cut by some EW trending faults whose length and offset are smaller than the ISTL. Koyama (1984) concluded that faulting along the ISTL fault system occurred in two separate episodes based on structural and stereographic interrelationships observed in a shear zone exposed along the ISTL. The first stage occurred during deposition of the early to middle Miocene Koma Group. This episode involves left lateral strike-slip motion of unknown total displacement. The second episode of faulting occurred in the southern part of the ISTL along the Mogura Fault, a subparallel branch of the ISTL. The author interprets that the former (the Mogura Fault) controlled the basin margin during deposition and was a growth fault(east side down), while the latter (the ISTL), was a reverse fault which was active in the Pliocene.

Another important subsidiary fault in this area is the Akebono Thrust, which trends NE-SW. This fault plane dips 60 degrees to the west. The hanging wall is composed of pyroclastic rocks of the early Miocene Koma Group and the foot wall is composed of conglomerates of the late Pliocene pyroclastic rocks of the late Miocene to Pliocene Fujikawa Group (Koyama, 1984)

3.1.2 Features of middle segment of the ISTL

Middle segment of the ISTL runs from Shiojiri to Nirasaki and trends NW-SE. This trend differs from that of the northern and southern segments, which generally have a NS trend. This segment is composed of several smaller segments, which form an en echelon or parallel arrangement. Kaneko (1972) suggested the possibility of a pull-apart origin for the Lake Suwa area based on this en echelon arrangement. In general the segment shows remarkable left-lateral displacement accompanied by a vertical component(to be descried later) and has been periodically reactivated during Quaternary (e. g. Research Group for the Itoshizu Tectonic Line Active Faults, 1988).

Koyama (1988) surveyed the Shimotsutaki Thrust, a southeasternmost part of the middle segment of the ISTL and reported its several episodes of movement along the same faults. One occurred in or before late Miocene and offsets a cataclasite formed during an older episode of faulting that occurred before granite intrusion of late Miocene age. The most recent activity along the fault occurred in the late Quaternary age and it shows left-lateral slip component and a thrusting component (west side up).

3.1.3, Features of northern segment of the ISTL

In the northern Fossa Magna there are few exposures of the ISTL, however topographically the ISTL is associated with a series of valleys extending along its length. Because of this limited exposures, some refraction and reflection seismic surveys have been conducted to detect the ISTL. In the following discussion, the author adds a geological interpretation (Figure 7) to the velocity profiles derived from seismic refraction records published by Yamada (1968), Asano *et al.* (1969), and Ikami *et al.* (1986).

The first explosion seismic prospecting was made in the southern part of the Matsumoto Basin (Yamada 1968 ; Yamada *et al.*, 1976). The seismic profile revealed the presence of a five layer velocity structure across the ISTL. The 1st layer (1.2-1.5 km/s) correlates with Alluvial gravels and the 2nd layer (2.6 km/s) correlates with Pleistocene gravels and sand. The 3rd layer (3.0-3.4 km/s) on the east side of the ISTL correlates with late Pliocene sedimentary and pyroclastic rocks including welded tuff of the Omine Formation, while that on the west side has uncertain geological origins, but may be partly weathered pre-Tertiary basement rocks or Miocene rocks. The 4th layer actually has a duel velocity structure (3.8-4.2 km/s west, and 3.3 km/s on the east) the east side lager can be correlated to early-middle Miocene sedimentary rocks of the Uchimura, Bessho and Aoki Formations. The west side lager is correlated with Paleozoic sedimentary rocks and Cretaceous granite. The 5th layer (6.4 km/s) may be pre-Silurian (?) basement rocks.

The maximum thickness of the Quaternary gravels (the 1st and 2nd layers) is about 360 m. The smooth basal surface of the Quaternary is correlative with the Omine Surface which is the erosional surface formed during early Pleistocene discussed above and is widely distributed about 1,000 m above sea level to the east of the ISTL. The low velocity interval beneath the Quaternary gravels is associated with the ISTL. The width of this fault zone is about 600 m. The vertical displacement is unknown, with the east side down interpreted on the basis of Neogene rocks distribution on either side of the ISTL. Because the ISTL does not appear to displace the Omine Surface or cut the Omine Formation (about 2 Ma), this fault zone is assumed to have been inactive since earliest Pleistocene time. The Otari-Nakaya ma Fault, which runs nearly parallel with and east of the ISTL, has a similar record of movement, however, its west side is down. This means that the intervening Omine Belt, bounded by these two faults, was a narrow sedimentary NS trending depression during Pliocene time that evolved into a more graben-like structure during the earliest Pleistocene.

The south extent of the ISTL to the west of Matsumoto City is unclear according to the of gravity studies by Hagiwara *et al.* (1987). They emphasize the existence of high-angle reverse fault systems along the eastern margin of the basin. They pointed out that the fault system correlates with a fault system including the Otari-Nakayama Fault and that the total vertical displacement of 500 m occurred in combination with a deep-seated fault whose vertical displacement is more than 1,500 m. However they did not present gravity models to verify in support of their interpretation.

Okubo *et al.* (1990) also carried out a gravity survey in the northern part of the Matsumoto Basin and note the presence of a steep horizontal gravity gradient, which they suggest to in-

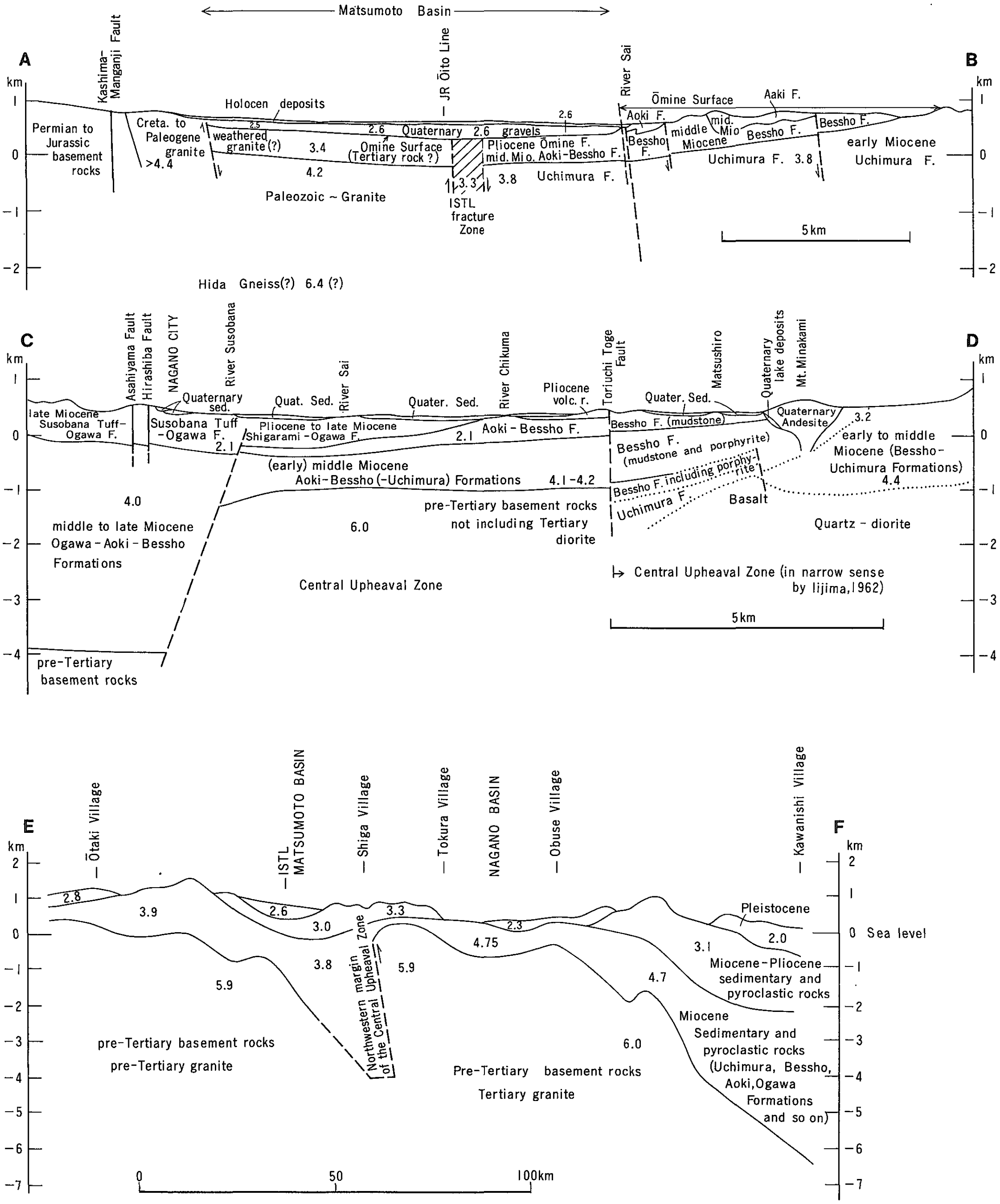

Figure 7 Cross sections of the ISTL and the Matsumoto-Nagano Line in the northern Fossa Magna. A–B (after Yamada, 1968), C–D (after Asano *et al.*, 1969) and E–F (after Ikami *et al.*, 1986) are shown in Figure 2.

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dicate that the steeply dipping (approximately 50 degrees) reverse fault, the Matsumoto Bonchi Toen Fault. Wilson and Kato (1991), however, present model studies showing that good agreement between calculated and observed gravity across the area can be achieved for a normal fault configuration.

At the eastern margin of the basin to the south of Omachi City, a small reverse fault (west side is 2.5 m down) is observed. This fault cuts the terrace deposits and the underlying Omine Formation of the latest Pliocene, and may be a surface branch of the Matsumoto Bonchi Toen Fault (Hirabayashi, 1971 ; Kato and Sato, 1983). Ikami *et al.* (1986) recorded 220 km-long seismic refraction profile trending NE-SW across southwestern Niigata and central Nagano Prefectures. Some important results are that there is an abrupt change of the basement depth by 4 km to the east of Matsumoto Basin, which is correlated with the Matsumoto-Nagano (Tsunan) Line, and that there is no distinctive seismic velocity features related to the ISTL. They also estimated that the MBTF is a high-angle reverse fault with a vertical displacement of about 4 km.

In the northern Matsumoto Basin Yokokura *et al.* (1987) conducted a seismic reflection survey. They concluded that a concealed fault under Alluvium gravels may be present 200 m west of the River Takase based on a velocity discontinuity. They suggest that this discontinuity maybe related to the ISTL, and that a faulted anticlinal structure in the Omine Formation may be present to the east of the fault. Based on their results, the fault plane is interpreted to be nearly vertical with the east side up. The total displacement along the fault is interpreted to be less than 20 m. This implies that the faulting occurred during the Quaternary (late Pleistocene to Holocene) and is related to the uplift of eastern mountains after the formation of Omine Surface. Therefore this fault is merely a reactivated subsidiary fault along the ISTL.

Tada and Hashimoto (1988) also suggest the presence of a fault in this area based on the 1918 Omachi earthquake ($M = 6.5$) which occurred near the ISTL. They proposed that the fault is a high angle reverse fault with a left lateral strike slip component based on the vertical crustal movement associated with the earthquake. Their fault correlates with the Matsumoto Bonchi Toen Fault.

Based on the proceeding interpretation, it is concluded that the ISTL exists as a discontinuity of velocity structure beneath the Matsumoto Basin. However, there is little evidence for the large displacement, activity along of the ISTL and the Otari-Nakayama Fault ceased by the end of Pliocene. The Matsumoto Bonchi Toen Fault bordering the eastern margin of the Matsumoto Basin appears to be a high angle reverse fault that was active during the Pleistocene development of the basin. In addition, the southwestern part of the Matsumoto-Nagano Line coincides with a high angle reverse fault whose displacement is a few kilometers at least. Since the Matsumoto Bonchi Toen Fault and the Matsumoto-Nagano Line appear to join near Matsumoto City, they may be parts of the same faults, however this relationship should be examined further.

To the north of the Matsumoto Basin three lakes of tectonic origin align on the ISTL. In particular the northernmost Lake Aoki has an asynmetrical and step-like topographical profile in an E-W cross section where the west side is steepest. This asynmetrical feature is the resulted of movement along the ISTL.

At the eastern margin of the Kamishiro Basin, north of Lake Aoki, active faults deform terrace surfaces. These active faults are related to the uplifting of Nishikubiki-Omine Block (N-O block, Figure 10) and not always to the movement of the ISTL.

To the north of Hakuba Town, the ISTL may pass through, along, or around the River Hime, but there is few exposure of the ISTL. None the less, though the Hime River Valley forms a distinct physiographic boundary between the eastern Hida Mountains area and western Nishi-Kubiki Mountains area of Fossa Magna. In this area the Himekawa Fault parallel to the ISTL eastwardly is one of the most important faults as same as the Otari-Nakayama Fault because they are related to the movement of the ISTL in Pliocene age. These NS trending

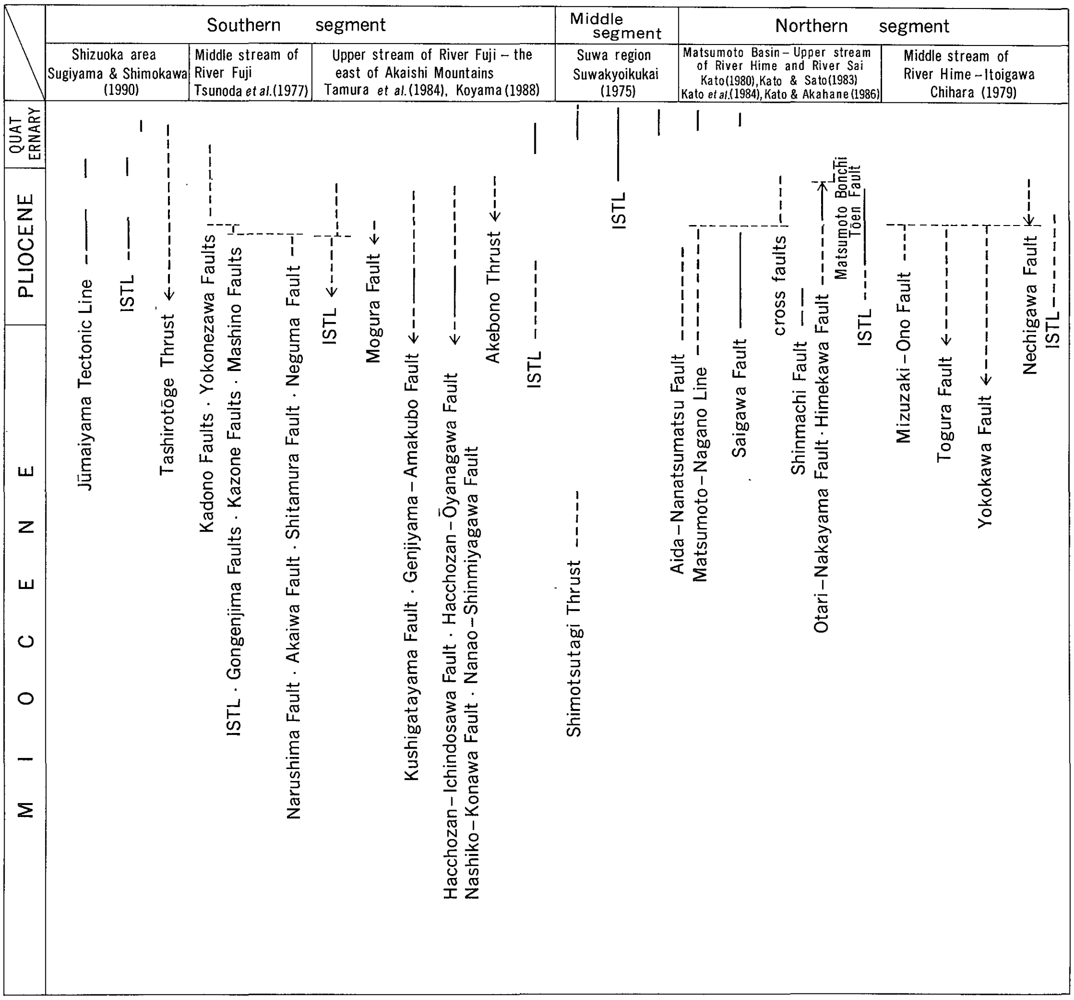

Figure 8 Faulting ages of the ISTL and associated faults.

faults are sometimes cut by smaller NW–SE trending strike–slip faults. The latter faults also divide the Omine Belt into several blocks. Saito (1978) reported that the Himekawa Fault is a reverse fault with the west side up. However he suggested that prior to late Miocene time the offsets were inverted and that the east side was up.

Saito *et al.* (1972) emphasized that Ishizaka Rhyolite of 58 Ma age, which is distributed narrowly along the Hime River Valley, represents the boundary between the eastern pre-Tertiary rocks and the eastern Neogene rocks. They suggest this marks the beginning of movement along the ISTL. But Yoshimura and Adachi (1976) and Sudo (1977) showed that the same kind of rhyolite are also found in the Niigata–Toyama Prefectures' boundary area to the west of the ISTL. Therefore the trend of this rhyolite is NW–SE and seems to be oblique to the ISTL as pointed by Yoshimura and Ishibashi (1979) and Chihara(1979). Yoshimura and Ishibashi (1979) also suggested that movement along the ISTL occurred from latest Miocene to Pliocene age because the ISTL cuts the early Miocene Tsugawa Formation and latest Miocene to Pliocene andesite which is distributed to the just west of the ISTL in the Itoigawa area.

At the mouth area of the River Hime, near Itoigawa, several faults with NS or NNW-SSE trends develop along the concealed the ISTL and cut Miocene and Pliocene formations. At Nechi along the River Nechi to the south of Itoigawa City, the ISTL is exposed as a crashed zone. This locality is the only one exposure of the ISTL which can be observed in the northern Fossa Magna. Around this crashed zone Paleozoic sandstone and metagabrro and Miocene pillow lava are sheared and brecciated. The crashed zone is nearly vertically and is composed of white fault clay whose width is a few meters.

3.2 Left-lateral movement of the ISTL

One of the most important questions concerning the ISTL is whether the ISTL has a large left-lateral displacement or not. Because during the Japan Sea opening, the Japanese Islands region was divided into two main parts, that is, northeast Japan and southwest Japan. If the boundary between them were the ISTL, it might have a large left-lateral displacement in middle Miocene time. Tokuyama (1972) and Tokuyama and Handa (1978) suggested that the Fossa Magna is a large meridional left lateral fault, holding of displacement of 100 km, and that such movement occurred since middle Pliocene and continues even into the present time. They analyzed the folded zones in the Akaishi Mountains to the south of the ISTL in the southern Fossa Magna and concluded that structural trends change from E-W to N-S near the ISTL as a result of left-lateral movement along the ISTL. They also pointed out that the Ryuso-Takakusayama volcanic rocks distributed in the Shizuoka area to the west of the ISTL is very similar to the Takahagi Basalt in the Yamanashi area to the east of the ISTL, therefore if these volcanic rocks have the same origin, their separation implies the left-lateral displacement along the ISTL. However, further study is needed to determine indeed their origin is if they are the same or not, and also to clarify the time when the arcuate trends of formations to the east of the ISTL developed. The author suspects this interpretation may be incorrect because the middle segment of the ISTL has only about 10 km of left-lateral displacement as discussed already, and because the northern segment shows little left-lateral offset and the Pliocene Omine Formation along the ISTL are only weakly deformed. It is difficult to estimate of 100 km order left-lateral displacement in the northern Fossa Magna. Koyama (1984) suggested that movement along the ISTL is left lateral based on drag-like changes of strike lines in the Koma Group near the ISTL in the southern Fossa Magna. Tamura *et al.* (1984) also suggested that the southern part of the Koma Mountains, in the western part of Yamanashi Prefecture, is divided into 10 fault blocks formed by the ISTL and its subsidiary faults. They emphasized NS trending fault traces and neglected EW (ENE-WSW or ESE-WNW) trending relatively shorter fault traces discussed by Kosaka and Tsunoda (1969) and Koyama (1984). They suggested that those blocks underwent left-lateral rotation caused by the drag along left-lateral strike-slip faults (possibly including the ISTL). Their interpretation is based on paleomagnetic measurements. Furthermore they estimated the total horizontal displacement at several tens to a hundred kilometers and pointed out that this displacement is reasonably consisted with that estimated from the relative movement between the Eurasian and Philippine Sea Plates (Niitsuma, 1982). Tamura *et al.* (1984) cited Koyama's result as supporting evidence, however their conclusion is unreasonable because drag features of strike lines are restricted to the Koma Group, which is early to middle Miocene in age and in addition, the structures in the Koma group weaken toward the upper member. This implies that left-lateral movement along the ISTL occurred during the sedimentation of the middle Miocene Koma Group and was finished by late Miocene. Tamura *et al.* (1984) suggest that left-lateral movement occurred along the ISTL during the Pliocene as the result of subduction of the Philippine Sea Plate (after 6 Ma). It is also difficult to estimate the amount of large strike-slip displacement only on the basis of drag features in strike lines. The author does not deny the possibility that a few kilometers of left-lateral displacement occurred along the ISTL in this region but finds the evidence for the huge displacement proposed by Tamura *et al.* (1984) to be unconvincing.

In the Matsumoto Basin area, Tada and Hashimoto (1988) found a high angle reverse fault with 62 cm of throw and a left lateral strike-slip component of 32 cm. This fault was produced by the 1918 Omachi earthquake. Okubo *et al.* (1990) assumed that the displacement of the Matsumoto Bonchi Toen Fault has 3 km-thrusting component and 1 km-right-lateral component, however, they did not present any detailed comparison of calculated and model data. In any case these lateral component of the Quaternary movement is negligible and not related to the main activity of the ISTL.

4. Eastern boundary of Fossa Magna

The structural trend of the Kanto Mountains in Fossa Magna is WNW-ESE direction, while that of the Ashio-Yamizo Mountains to the east of Fossa Magna is NNE-SSW direction. This remarkable difference is believed to be associated with rotational movement of northeast Japan. The large fault system separating these two areas is referred to as the Kanto Tectonic Line and the Tonegawa Tectonic Line. Yamashita (1970) also proposed the Kashiwazaki-Choshi Line of a discontinuity in the zonal arrangements of the basement rocks to the northeast and the southwest across this boundary line. These "faults" or at least portions of them are thought to represent the eastern boundary of Fossa Magna. However, the author considers it meaningless to attempt such precise definitions of the eastern boundary of Neogene Fossa Magna, in part because Fossa Magna is a kind of a half graben within which is contained several complex horst and graben structures and collapsed sedimentary basins. Hence, the eastern boundary of Fossa Magna was a broad structural transition zone rather than an abrupt fault during Neogene sedimentation. The Neogene stratigraphy of Fossa Magna is essentially the same as that of northeast Japan and there is little difference between the Neogene structures in these areas. Although the SKTL was intermittently active during the Neogene as mentioned above other eastern boundary faults such as the Kanto Tectonic Line have not been active since Neogene. These faults did not influence the Neogene sedimentary and structural development of the Neogene of Fossa magna and adjacent areas.

Hayama (1991) denied the existence of such major faults as the Kanto Tectonic Line and the Tonegawa Tectonic Line based on the distribution of the basement rocks of Jurassic sedimentary basins in the Inner Zone of southwest Japan. However, the northeastern boundary marked by the SKTL is a distinct fault boundary in the northern Fossa Magna. Although SKTL developed during the Neogene it is not the eastern boundary of the northern Fossa Magna Neogene sedimentary basin. As a matter of fact, based on the surface geology, the SKTL has tectonically masked features in the Fossa Magna, including the northern segment of the ISTL. The SKTL proposed by Yamashita (1970) passes through the eastern margin of the Niigata Plain and extends from near Shibata City, in the northern part of Niigata Prefecture to the town of Koide along the River Aburuma and generally lies along the northwestern margin of the Muikamachi Basin. Collaborative Research Group for the Sasagami Hills (1980) showed that the SKTL consists of several normal faults, namely a step-fault system that steps down to the west with the maximum vertical displacement of 4,000 m. They pointed out that the SKTL has been active probably since late Miocene or Pliocene at the eastern margin of the northern Niigata Plain. Maruyama *et al.* (1981) supported their conclusions on the basis of gravity survey covering the same area.

Yamashita *et al.* (1979) suggested that some unconformities at each base of the Nishiyama, Haizume and Uonuma Formation. So long the River Aburuma were formed in relation to the movements of the SKTL although the SKTL is not exposed in this area. They also suggest the existence of pre-Tertiary movement along the SKTL based on the preserved crushed granite of Cretaceous age in this area.

The northwest margin of the Muikamachi Basin represents the southwestern extent of the SKTL. Drilling data reveal that the upper surface of the Jonai Formation subsided rapidly to the west. This implies that the western Niigata Oil Field region lies in a structural depression bounded by the SKTL. However, the eastern part, that is the Muikamachi Basin area, is down by concealed vertical faults, and cut the Quaternary deposits along the basin margin, and pass through near SKTL. Some of them are active high-angle reverse faults initially developed in middle Middle Pleistocene age (0.3-0.4 Ma) (Kato and Yamazaki, 1979 ; Aoki *et al.*, 1978 ; Takano, 1989). This implies that tectonic invasion has taken place here as well as the Nagano Basin.

5. Tectonic setting of Fossa Magna

5.1 Some tectonic frameworks of Fossa Magna

5.1.1 The Kanto Syntaxis

The zonal arrangements of pre-Neogene formations in the Outer Belt of southwest Japan extend to the east of the ISTL, as recognized in the Kanto Mountains. However, the trend changes from ENE-WSW in the southwest, to nearly NS toward the ISTL. East of the ISTL the trend further changes to NW-SE. This large scale curvature of the pre-Neogene basement rocks called the Kanto Syntaxis and was produced by tectonic rotation of the Kanto Mountains. The timing development of the Kanto Syntaxis is debatable, 1) pre-Neogene time, 2) middle Miocene time or 3) early Pliocene time (5-6 Ma). 1) A pre-Neogene development is suggested on the basis of speculative interpretations of the geologic setting but there is little direct evidence in support of this hypothesis. 2) A middle Miocene development is based on paleomagnetic data (e. g. Hyodo and Niitsuma, 1986) ; the Kanto Mountains rotated almost 90 degrees since 16-15 Ma based on a geomagnetic survey of the Neogene formations in the Chichibu Basin in the Kanto Mountains. Takahashi and Nomura (1989) concluded that this bending structure of basement rocks had already formed in late Miocene age based on the paleomagnetic data of the late Miocene Chichibu quartz diorite. This episode coincides with the Niwaya Unconformity (Takahashi, 1990) formed as the result of a stress-orientation rotation from extensional to compressive in Fossa Magna. A clockwise rotation of southwest Japan occurred at this same time, as suggested from an analysis of minor deformed structures in the Neogene formations north of the Chichibu and Sanbagawa Zone of the Kanto Mountains (Takizawa and Kato, 1991). 3) A nearly Pliocene development is based on the plate tectonic model of the Philippine Sea Plate proposed by Seno (1977) and Minster and Jordon (1978, 1979). Niitsuma (1982) estimated a moving rate for the Philippine Sea Plate at 5 cm/year according to this model, and suggested that the Kanto Syntaxis was formed about 6 Ma. There is little direct geologic evidence in favor of this hypothesis. The Neogene formations of the southern Fossa Magna were shortened horizontally by about 30% and hence must have occupied an area 20 to 25 km wider before folding (Matsuda, 1980). The migration of the Izu Peninsula on the Philippine Sea Plate is therefore estimated to be less than 30 km, and the collision of the Izu Peninsula the deformed the Neogene formations but not the basement rocks.

5.1.2 The Central Upheaval Zone

The Central Upheaval Zone is one of the most important structures from the viewpoint of Neogene tectonics and paleogeography of Fossa Magna. It has been an uplifted zone since middle Miocene time. This zone in a narrow sense is the NS to NE-SW trending zone intruded by Miocene porphyrite to quartz diorite rocks (Iijima *et al.*, 1958 ; Iijima, 1962) (Figure 9). Kosaka (1984) similarly recognized the tectonic belt and called it as the "Takai-Utsukushigahara Zone".

The western margin of this zone extends from near Matsumoto, east of Mt. Hijiri and

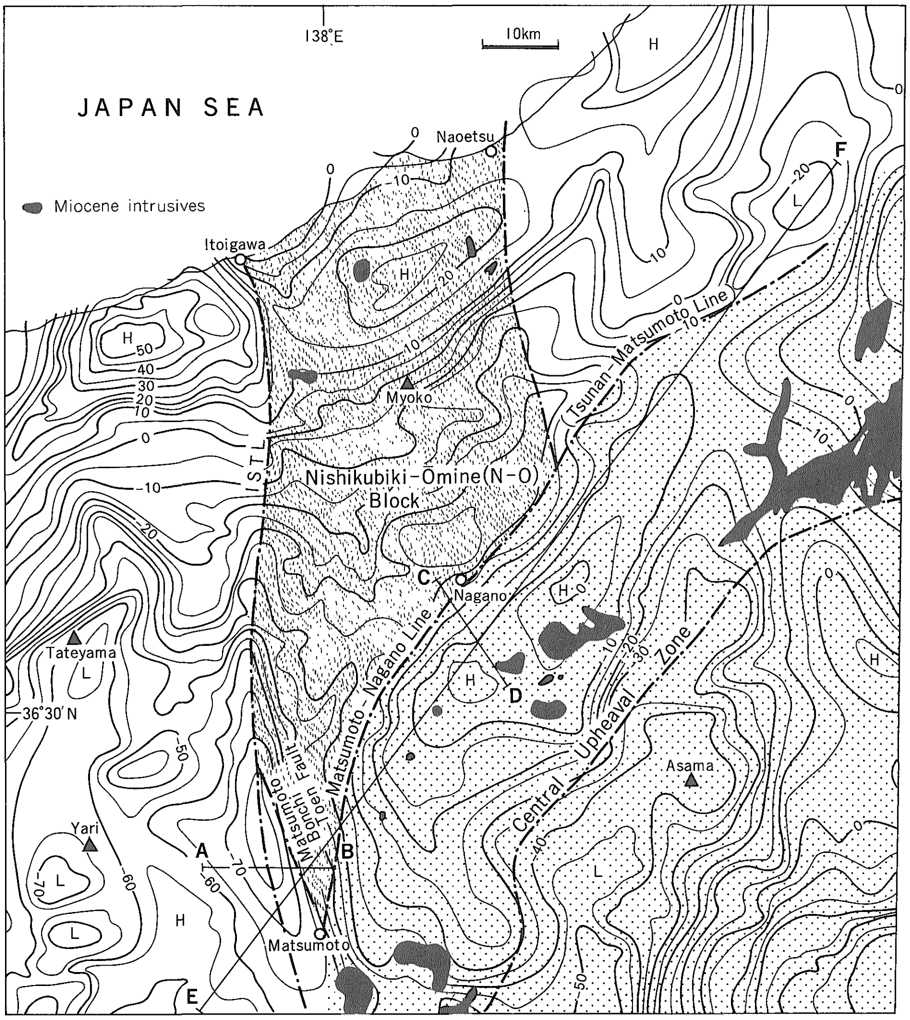

Figure 9 Gravity anomaly of the northern Fossa Magna region.

the southeastern margin of the Nagano Basin, to the northeast nearly along the River Chikuma (Iijima *et al.* 1958). The author defines it to extend from near Matsumoto west of Mt. Hijiri and the northwestern margin of the Nagano Basin, to the northeast nearly along the River Chikuma. The western boundary of this zone defined by the author, is called the Matsumoto–Nagano Line (Hirabayashi, 1969) or the Tsunan–Matsumoto Line (Kosaka, 1984).

The eastern margin of this zone in a narrow sense passes through Wada and Ueda and extends to the northeast around the border between Niigata and Gunma Prefectures. In a broad sense, uplifted areas in this eastern margin area are included in the Central Upheaval Zone because it uplifted in the middle Miocene but subsided again in the Pliocene as shown by the distribution of terrestrial sedimentary and pyroclastic rocks. In this paper the author uses this zone in the narrow sense as mentioned above.

This zone is recognized by a NE–SW trending relative high in the bouguer anomaly (Kono, 1990). Seya (1969) reported that many local high and low anomalies in the area are regularly spaced in this zone. He correlated these positive anomalies with the Tertiary sedimentary and underground intrusive rocks. He proposed "the Chikumagawa Tectonic Line" along the southeastern margin of the Nagano Basin suggesting that the gravity anomaly varies uniformly to the west of this line, that is the Nagano Basin area. However, on the contrary, a considerable change is present along the eastern part as described above (Seya, 1969). The correlation of these anomalies implies that intrusions of the Tertiary granite rocks are restricted to this zone. The fault along the southeastern margin of the Nagano Basin also correlates roughly with the geoelectrical discontinuity reported by Ono (1967) and with the extent of a geological fault inferred by Morimoto *et al.* (1966). This fault is not a single fault but consists of several parallel faults. They are called the Nagano Bonchi Toen faults (Kato and Akahane, 1986). One of these branches is the Toriitoge Fault. The northwestern side is down and its normal displacement is more than 150 m (Morimoto *et al.*, 1966). This fault cuts the Pliocene volcanic rocks. Though these rather small faults have displacements of a few hundreds meters, and are related to the uplifting of the Central Upheaval Zone, they are merely the shallow expression of a major fault beneath the area.

Asano *et al.* (1969) conducted an explosion seismic survey in the Matsushiro Earthquake Swarm area in Nagano Prefecture. A geological interpretation of their velocity model along the line B across the Nagano Basin and the Central Upheaval Zone is made in Figure 7. It is noted that the thickness of the 4.0 km/s velocity layer in the western area is three to four times as thick as that in the eastern area. This boundary is interpreted to be a fault and is called "Nagano Bonchi Seien Fault" (Akahane, 1981). This fault is a part of the Matsumoto-Nagano Line. The total displacement is more than 2,500 m. The 4.0 km/s velocity layer is inferred to represent Miocene formations. The fault had grew during Miocene time at least. Akahane (1981) suggested that the eruption of the Susobana Tuff occurred along this fault. Many faults of this system were active as high-angle reverse faults, during Quaternary where the northwestern side is up. Hence, a tectonic inversion occurred in early Pleistocene. The Central Upheaval Zone was further uplifted and tilted northwestward after Pliocene.

The 6.0 km/s velocity layer to the east of Chikumagawa Tectonic Line is mostly composed of quartz-diorite of Miocene age according to the drilling data (See Kato and Akahane, 1986). Sawamura *et al.* (1967) reported the presence of phyllite fragments in the Uchimura Formation, which may have been derived from the pre-Tertiary basement. Therefore part of the Uchimura Formation may consist of pre-Tertiary rocks. Geological and geophysical data suggest that this high velocity layer, west of Chikumagawa Tectonic Line, represents the pre-Tertiary basement, with the exception of local Miocene intrusive rocks.

Uplifting of the central Upheaval Zone began during the deposition of the Bessho Formation because the depocenters were separated by this zone and because porphyrite and quartz-diorite began to intrude since that time. This zone was eroded partly during deposition of the lowest member of the Aoki Formation, whose basal conglomerate includes breccia from the Bessho Formation and gravels of intrusive quartz-diorite. The area is composed of a series of block-like structures as inferred from the gravity studies of Seya (1969) and geologic mapping of Sawamura *et al.* (1969) and Kato (1979). Hence the area was uplifted along an intermittenly active fault system. The resulting differential uplift gently folded the surrounding Bessho Formation. This local tectonic event is called "the Bessho Phase movement" (Kobayashi, 1957) of middle Miocene time.

5.1.3 Nishikubiki-Omine Block (N-O block)

The northwestern part of the northern Fossa Magna is bounded by several faults, that is, by the ISTL and associated faults such as the Himekawa Fault along the western margin, the Matsumoto-Nagano Line along the southeastern margin and an unnamed NS trending fault along the eastern margin. This structural block is called "the Nishikubiki-Omine Block (N-O block)". Yamasaki (1928) originally named "The Nishikubiki Block" to this block and Nishina (1973) named "The Omine Block" to the similar structure. The presence of local unconformities of different ages indicates that the N-O block elevated at many different times from the Neogene to Quaternary. In particular the northwesternmost part is called "Kitaotari Uplifting Zone" by Hirabayashi (1969). This part began to uplift since middle Miocene as did the Central Upheaval Zone, and again rapidly uplifted during late Early Pleistocene to middle Pleistocene (Nishina, 1973). The southeastern part of this block area continued to subside with sediment filling during middle Miocene and Pliocene. In late Quaternary the southeastern part of this block was uplifted and the margin of the Nagano Basin, a part of the Matsumoto-Nagano Line, changed from a normal fault to a high-angle reverse fault.

On the contrary the northwestern end of this block in the Itoigawa area continually subsided. This subsidence was greater to the northwest than to the east as determined by the precise leveling (Yamasaki, 1928). Along the eastern margin of this block near the Naoetsu area, Japan Sea Coast, the Kota Formation, which is correlated with the Pliocene to Pleistocene Uonuma Formation, dips steeply or is overturned as the result of uplifting of this block. The western margin, the Himekawa Fault also changed its faulting sense from normal to reverse.

These facts imply that active tilting of this block began in late Quaternary and that the sense of tilting and uplifting inverted during Miocene to Pliocene. These block-like features in Fossa Magna consisting of a series of basins and structural highs or horsts and grabens developed since middle Miocene being controlled by NE-SW, NW-SE and NS trending faults.

5.2 Geologic history of Fossa Magna

Since Neogene tectonics of the southern Fossa Magna on the Pacific Ocean Coast side is discussed in detail by Sugiyama (1991, this volume), the author discusses mainly that of the northern Fossa Magna and the Kanto Mountains area.

General remarks of geologic history of Fossa Magna is summarized in Figure 10. In middle Early Miocene to early Middle Miocene age Fossa Magna was initiated to be a complex sedimentary basin composed of many horsts and (half) grabens. The sea invaded from Pacific Ocean through Fossa Magna and Paleo-Tsushima Straight north of Kyushu to the Japan Sea and even spread to the west of the ISTL. Otofuji *et al.* (1985) and others proposed a considerable clockwise rotation of southwest Japan and counterclockwise rotation of northeast Japan with theopening of the Japan Sea during a relatively short time period of 1 million years in early to middle Miocene. This interpretation is based on paleomagnetic data. Although the author has no evidence to examine their view, it is accepted that in a few million years during middle Early Miocene to early Middle Miocene age the Japan Sea opened and extended. In this time submarine volcanic activity was vigorous. This event is called "the Greentuff movement". In general remarkable transgression continued during Miocene but the sea area varied from region to region. In the middle Miocene the Central Upheaval Zone separated the northern Fossa Magna Sea and the southern one. The western half of the northern Fossa Magna Sea was separated into several smaller basins and some of them uplifted in the middle to late Miocene. Such sedimentary basins migrated northward except those in the Oomine Belt, the western margin of northern Fossa Magna. The eastern half of the northern Fossa Magna Sea continued to subside and accumulate sediments until early Pleistocene. The Kanto Mountains area began to regress in late Miocene and uplift continued until Quaternary.

Neogene structures in northern Fossa Magna reflect the presence of basement fault systems having three sets of orientations, that is NE-SW, NS and NW-SE. Among them, the ISTL and the Matsumoto-Nagano Line were active as growth faults during middle Miocene at least. In and around the northern Fossa

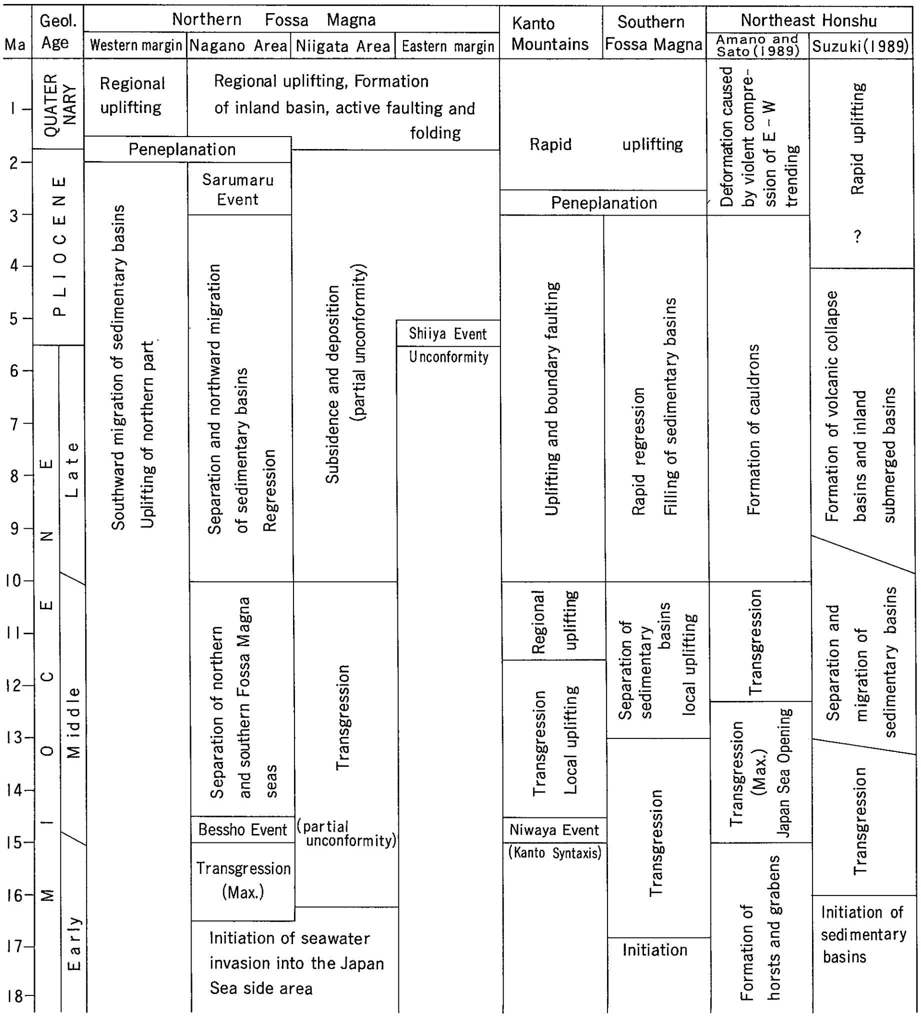

Figure 10 Simplified geologic history of Fossa Magna.

Magna one of the most remarkable tectonic events occurred in early Middle Miocene (about 15 Ma). It is the Niwaya Event (Takahashi, 1990) or the Bessho Event (Kobayashi, 1957) shown by a regional unconformity over this area and shown by a partial unconformity in Niigata Oil Field. This tectonic activity became more active to the south, therefore the Niwaya Event north of the Kanto Mountains area was most intense. Another remarkable tectonic event is the latest Pliocene to earliest Pleistocene Sarumaru Event in the Nagano Area, in the western half of the northern Fossa Magna. Most of the Miocene and Pliocene formations in this area were strongly folded and faulted during this event. After this event this region was eroded to the sea level. On the contrary the Niigata Area, the eastern half of the northern Fossa Magna continued to deform during Quaternary. Both areas underwent regional uplifting since middle Pleistocene. It is noted that movement along some faults such as the Matsumoto-Nagano Line has inverted, that is, the northwest side was down during Miocene and Pliocene but was up in Quaternary, representing a change from a normal fault to a high–angle reverse fault.

Tectonics in the southern Fossa Magna are different. Structural development of this region is controlled directly by major plate interactions. The Philippine Sea Plate possibly began to subduct beneath southwest Japan, and the Pacific Plate continues to subside beneath northeast Japan. The Izu-Ogasawara (Bonin) Arc began to collide with the southern Fossa Magna. This collision began in middle Middle Miocene. Multiple episodes of accretion have been proposed for the southern Fossa Magna, and will be discussed in a separate paper after data acquisition and analysis have been completed.

Finally the author emphasizes that there is little evidence that the ISTL and associated subsidiary faults were active during Miocene. Most of these deformed not only the Miocene but also Pliocene formations with exception of some growth faulting activities.

6. Conclusion

When the structural development of Fossa Magna is discussed, a clear distinction should be made between structural characteristics of the region which developed prior to the opening of the Japan Sea and those which developed afterward, to avoid confusion. The former set of structures is related to the pre–Tertiary geology and tectonics along the margin of the Asia continent. The latter set of structures is related mainly to geologic events associated with the opening of the Japan Sea, and major plate motion.

Although further consideration is necessary before we come to our final decision about the initiation of Fossa Magna, it is generally accepted that Fossa Magna initiated during late Early to early Middle Miocene (Kano *et al.* ed., 1991) related to the opening of the Japan Sea and the drift and rotation of southwest Japan and northeast Japan. In Fossa Magna, the sea began to invade from the Pacific Ocean to the Japan Sea, in early to middle Miocene. In middle Miocene, transgression was at a maximum and the whole Fossa Magna region is formed a common geologic province formed only during this time. The Fossa Magna sedimentary basin was a large scale half graben–like basin composed of many smaller grabens, collapse basins and horsts. After Early to early Middle Miocene time the Central Upheaval Zone divided the northern Fossa Magna Sea from the southern one. In the northern Fossa Magna, the western marginal area, western half, eastern half and the eastern marginal area are haracterized by distinct different sedimentary processes controlled by local block tectonics and inversion tectonics as described above. the ISTL is not the strict western boundary of the Fossa Magna sedimentary basin. It is the deformation boundary of the Fossa Magna mainly in Pliocene age. Evidence for a large amount of strike–slip movement along the ISTL seems to be negative. On the other hand the southern Fossa Magna has developed directly under the Plate Tectonics Paradime. The formation of the Kanto Syntaxis, the northward curvature of the basement rocks is suggested to have occurred during middle Miocene rather than Pliocene. The Neogene structures formed over the basement structures extending between northeast Japan and southwest Japan, and are remarkably different between the northern and southern Fossa Magna regions are remarkable, hence it is an oversimplification to treat the whole area of Fossa Magna in a single structural regime at least since the middle Miocene.

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フォッサ・マグナ—西南・東北日本を分ける隠された境界領域

加藤碵一

要旨

フォッサ・マグナの発生と発達に関する諸問題は，わが国地質学の黎明期より調査研究が進められ，膨大な資料が蓄積されてきたにもかかわらず未だに十分な総括が行われていないためその定義や論点が混乱したまま議論されているきらいがある．近年，日本海形成や日本列島の回転移動，南部フォッサ・マグナ地域における付加過程などについて新たな観点から地質学のみならず関連研究分野からの議論も盛んとなり，さらに諸外国の研究者の関心も集めているが，フォッサ・マグナの概念についての共通した認識や英文による総括的なレビューに乏しいため無用の齟齬が生じている．本論文では，上述した問題点の解決の一助とすべく，フォッサ・マグナの地質やテクトニクスなどについてレビューした．

その基本的観点は，フォッサ・マグナを定義域としてのフォッサ・マグナ，堆積域としてのフォッサ・マグナ，及び変形域としてのフォッサ・マグナに分けて論ずべきであるとするものである．

定義域としてのフォッサ・マグナとは，フォッサ・マグナとは何かを問うことである．従来のフォッサ・マグナの定義があいまいな理由は，(1)時代的なあいまいさ（古第三紀及び中新世最初期の地質学的データ不足による形成初期の議論のあいまいさや第四期のフォッサ・マグナとはどのような意味をもつのか），(2)領域的あいまいさ（漠然とした東西日本境界域としてのフォッサ・マグナ，糸魚川-静岡構造線の硬直した定義や糸魚川-静岡構造線すなわちフォッサ・マグナとする誤解やその東縁の不明瞭さ），(3)構造的位置付けの不十分さ（広域的テクトニクスにおける位置付けの実証的議論の不足）などによる．東アジアにおける日本列島形成に関する最大の地史的イベントの１つは日本海形成を伴う日本列島地域の大陸からの分離・移動である．したがって大陸縁辺時代の東西日本の古地理や構造境界としてのフォッサ・マグナ，日本海形成期の遷移時代における基盤の分離・回転・接合に伴うフォッサ・マグナの形成，及び島孤時代の堆積・変形域としてのフォッサ・マグナを明確に区分して論ずるべきである．

堆積域としてのフォッサ・マグナとは，おもに新第三紀におけるフォッサ・マグナ堆積盆の問題である．この時代のフォッサ・マグナ堆積域西縁は厳密には糸魚川-静岡構造線ではなく，堆積盆はその西側にも広がっており，糸魚川-静岡構造線は基盤中に発達する一種の成長断層としての性格が強い．フォッサ・マグナ全体は陥没盆地によって複雑化されているが全体としてはhalf grabenとみなすべきもので，この観点でフォッサ・マグナの東縁がどこか議論することは意味がない．

また，変形域境界としての糸魚川-静岡構造線及び近傍の断層活動はほとんどが後期鮮新世以降に限られること，従来提唱されていた糸魚川-静岡構造線の大規模左横ずれ運動は疑わしいこと，関東Syntaxisの形成時期は中期中新世ないしそれのやや前の時代の可能性が強いことなどをフォッサ・マグナ全域の地質・地史の総括とあわせて論じた．

（受付：1991年6月24日；受理：1991年7月24日）