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Stratigraphical Study of the Miocene Series in the Eastern Part of Tottori Prefecture, Southwest Japan

By

Toshio MATSUMOTO

With 9 Tables, 17 Text-figures and 1 Plate

(Received, January 23, 1986)

ABSTRACT

In this paper, the stratigraphy of the Miocene series distributed in the eastern part of Tottori Prefecture is described in detail, with some considerations on correlation and geologic history. The results obtained are summarized as follows.

The eastern part of Tottori Prefecture occupies a part of the so-called Green Tuff region, and is characterized by the development of a thick series of Miocene volcanic and clastic rocks formed by strong volcanism and subsequent subsidence. The Miocene series is called the Tottori Group, and is divided into two formations, i. e., the lower Yazu and the upper Iwami Formation. The Yazu Formation is subdivided into the Koge Conglomerate Member below and the Kawabara Volcanic Member above, which are conformable with each other. The Koge Member is the basal conglomerate member of the Tottori Group. The Kawabara Member consists mainly of thick piles of volcanic rocks such as andesite lavas and andesitic to dacitic pyroclastics, with intercalation of layers of clastic sediments. The Iwami Formation has an unconformable relationship with the Yazu Formation, and is lithologically subdivided into the Entsuji Conglomerate and Sandstone, Moroga Conglomerate, Fuganji Mudstone, Oda Andesite, Aragane Pyroclastic and Shichiyama Sandstone and Mudstone Members. The first two members are interfingered with the lower part of the Fuganji Member, while the last three with the upper part of the Fuganji. The Entsuji and Moroga Members are composed mainly of alternating beds of conglomerate and sandstone. The Fuganji Member is made up of well-stratified mudstone, accompanied with parallel-laminated, fissile one in the lower part. The Oda and Aragane Members consist largely of thick accumulations of volcanic rocks such as andesite lavas and dacitic pyroclastics. The Shichiyama Member is represented by fine- to medium-grained sandstone, accompanied with mudstone and dacitic pyroclastic rocks.

Two molluscan assemblages of relatively deep sea type, namely, the *Acesta* assemblage below and the *Propeamussium-Delectopecten* assemblage above, are recognized in the main part of the Fuganji Member. Judging from the faunal and floral assemblages, as well as from the lithofacies, it is inferred that the sedimentary environment of the Iwami Formation changed from fresh-water condition to brackish-water or shallow marine one and further to the deeper sea. The main part of the Fuganji Member represents deposits of maximum transgression at Middle Miocene time.

The northward tilting of the basement blocks controlled by the uplifting of the island arc has been revealed through the analysis of stratigraphic relationship, geologic structure and lateral change in lithofacies. The uplifting and tilting may be closely related not only to the migration of depocenters of the Miocene and Pliocene sedimentary basins toward the Sea of Japan but also to the longitudinal gravity faulting in horizontally tensional stress field. The initiative uplifting may have begun at Early Miocene time.

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I. INTRODUCTION

During Miocene time, the so-called Green Tuff movement characterized by the violent volcanic activity and the subsequent subsidence and folding took place regionally in the Japanese Islands. KITAMURA (1959) and IKEBE (1962) explained the movement of the Green Tuff regions in Northeast Honshu based upon the idea that those regions had been subjected to geosynclinal subsidence and geanticlinal upheaval in Miocene time. FUJITA (1972, 1973a, b, c, 1982a) and FUJITA *et al.* (1981) have emphasized that the Green Tuff movement was regulated by a series of events, namely, the generation of magma in the depth, ascent of the magma, partial upheaval at the surface, collapse, volcanic activity and subsidence. The analogous claims have been put forward by SAN-IN GREEN TUFF RESEARCH GROUP (1973, 1979), YOSHITANI(1974), YOSHITANI and YAMAUCHI (1981) and many others. From the standpoint of the plate-tectonics theory, NAKAMURA (1969) has hypothesized that the horizontal extension caused the collapse movement and the volcanism of Miocene age. To date, it seems that the view that the magmatic collapse movement was followed by the volcanism and the subsidence in the Green Tuff sedimentary basins has been accepted by relatively many scholars.

Meanwhile, clarifying the movement of the basement rocks in the Green Tuff sedimentary basins is exceedingly important, for the movement of the basements is closely related to the formation and progress of the sedimentary basins. With the recent studies of petroleum geology and the increasing data of geophysical prospecting and drilling, our knowledge has expanded rapidly. Particularly in the Sea of Japan, the presence of a thick series of Neogene deposits and the imbricate structure formed by the shifting of the depocenter of sedimentary basins emerged (MINAMI, 1979; SUZUKI, 1979; TANAKA, 1979). TANAKA and OGUSA (1981) have interpreted that the migration of the central part of the sedimentation was due to the subsidence and uplift of the basement blocks. The analogous interpretations have been given by MITSUNASHI (1973), SUZUKI and MITSUNASHI (1974), SUZUKI *et al.* (1971, 1974) and YOSHITANI and YAMAUCHI (1981). In order to explain a primary factor of the development of sedimentary basins, it may be necessary to investigate practically the character of the movement of the basement rocks throughout the formative to progressive processes of the Green Tuff sedimentary basins. Because the Miocene series is well-exposed in the eastern part of Tottori Prefecture and the accumulated data on its equivalent strata in the Sea of Japan are abundant, the present area is pertinent to a discussion about the relationship between sedimentation and tectonics.

The Miocene Tottori Group (MURAYAMA *et al.*, 1963; TOTTORI PREFECTURE, 1966; UEMURA *et al.*, 1979; MATSUMOTO, 1986), which is the object of this study, is the strata deposited in the western part of the Miocene Eastern San-in Sedimentary Basin (UEMURA *et al.*, 1979) belonging to the Hokutan subprovince (ICHIKAWA and KITAMURA, 1978). IMAMURA *et al.* (1962), MURAYAMA *et al.* (1963), TOTTORI PREFECTURE (1966), UEMURA *et al.* (1979) and MATSUMOTO (1986) have carried out the stratigraphic reseaches of the Tottori Group, yet there is some diversity of opinion as to the stratigraphic division and correlation (Table 2). SAWAI *et al.* (1973), YOSHITANI (1974), YOSHITANI *et al.* (1975) and YOSHITANI and TOTTORI GREEN TUFF RESEACH GROUP (1983, 1984) have explained that the sedimentary basins were formed by the collapse movement. There are also many studies concerned with fossils. Plant fossils have been reported by YAMANA (1968) and HOJO (1973), and animal fossils by OZAKI and YAMANA (1972), YAMANA (1962, 1972, 1977, 1979), DEWAKI (1984) and others.

In this paper, the author intends to elucidate the stratigraphy and geologic structure of the Miocene Tottori Group exposed in the eastern part of Tottori Prefecture by means of detailed geologic mapping, and to review the geologic history including volcanism, sedimentary environment and tectonic movement. The data obtained from the Sea of Japan are appended in order to discuss the movement of the basement blocks.

Acknowledgements

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II. Outline of Geology

The Miocene Tottori Group exposed in the eastern part of Tottori Prefecture (Fig. 1) is represented by thick piles of clastic sediments, accompanied with a large amount of volcanic rocks which are subjected to remarkable alteration. It unconformably covers or abuts on the basement rocks, or is partly in fault contact with them. The basement rocks are composed of the Sangun Metamorphic Rocks (Shitani Formation), the ultramafic to mafic rocks, the non-metamorphic Paleozoic to Mesozoic strata (Tsunotani Formation) and the Late Cretaceous to Early Paleogene igneous rocks. Furthermore, the group under consideration is intruded by intermediate to felsic stocks, dykes and sheets (rarely by basic sheets), and is unconformably overlain by the Latest Miocene to Pleistocene volcanic rocks.

The Tottori Group is stratigraphically divided into two formations of the lower Yazu and the upper Iwami. The relationship between them is unconformable (Table 1). The stratigraphy is summarized as follows.

Yazu Formation

This formation is subdivided into the Koge Conglomerate Member below and the Kawabara Volcanic Member above. They are conformable with each other.

The Koge Member represents a basal conglomerate of the Tottori Group. It is composed mainly of conglomerate containing subangular to subrounded pebbles and cobbles derived from the basement rocks. An ill-sorted breccia occurs locally. The Kawabara Member consists largely of andesite lavas and andesitic to dacitic pyroclastic rocks, with subordinate rhyolite lavas and clastic rocks.

Iwami Formation

This formation is subdivided into the Entsuji Conglomerate and Sandstone, Moroga Conglomerate, Fuganji Mudstone, Oda Andesite, Aragane Pyroclastic and Shichiyama Sandstone and Mudstone Members. The Entsuji and Moroga Members are contemporaneous but heteropic with the lower part of the Fuganji Member, while the Oda, Aragane and Shichiyama Members are with the upper part of the Fuganji Member.

The Entsuji Member consists of irregularly alternating beds of conglomerate and sandstone. It becomes thinner and finer-grained toward the east to northeast, and pinches out in the Fuganji Member. The Moroga Member is composed of alternating beds of conglomerate and sandstone. It also becomes thinner and finer-grained northward. The Fuganji Member is made up largely of well-stratified gray to black

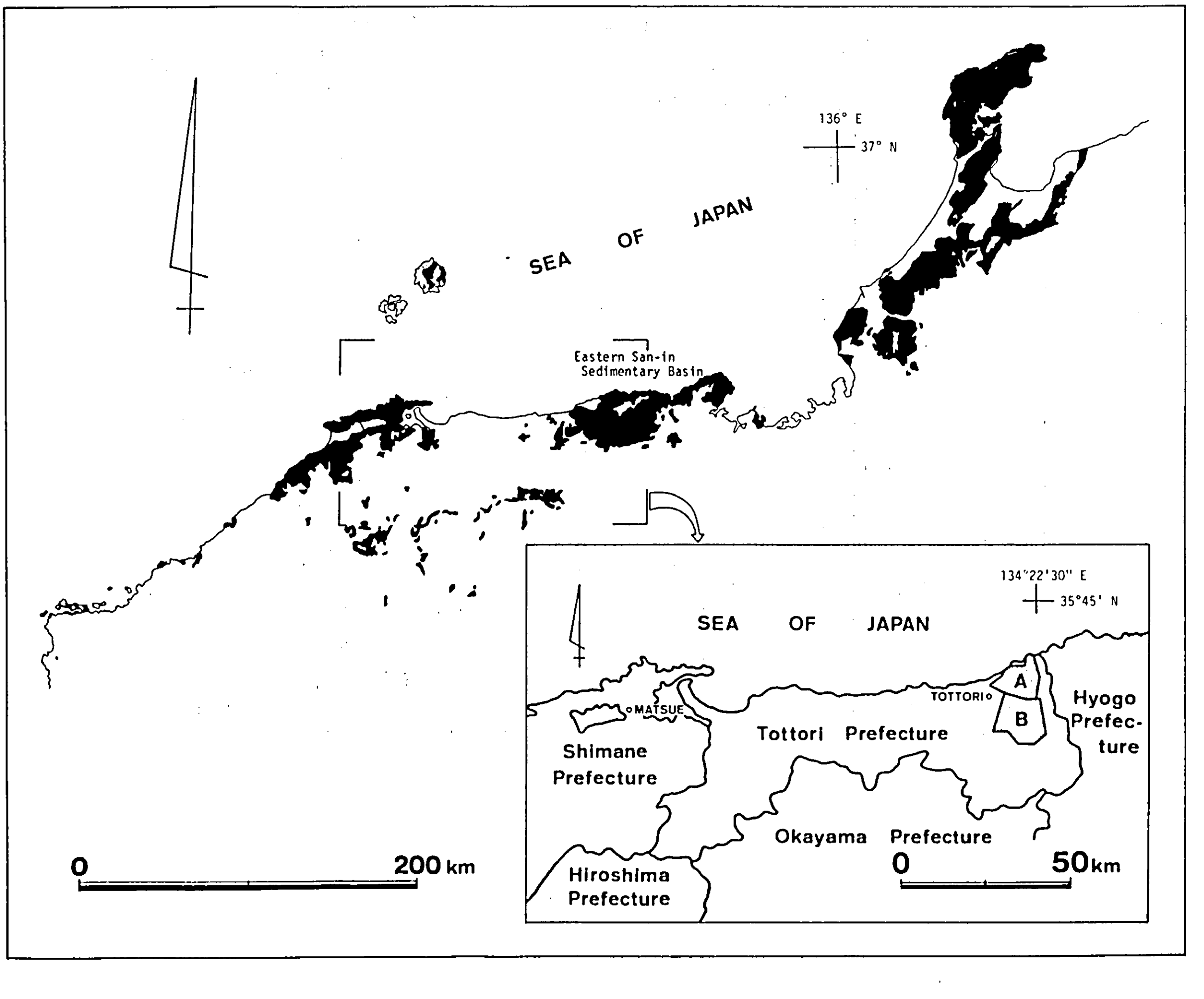
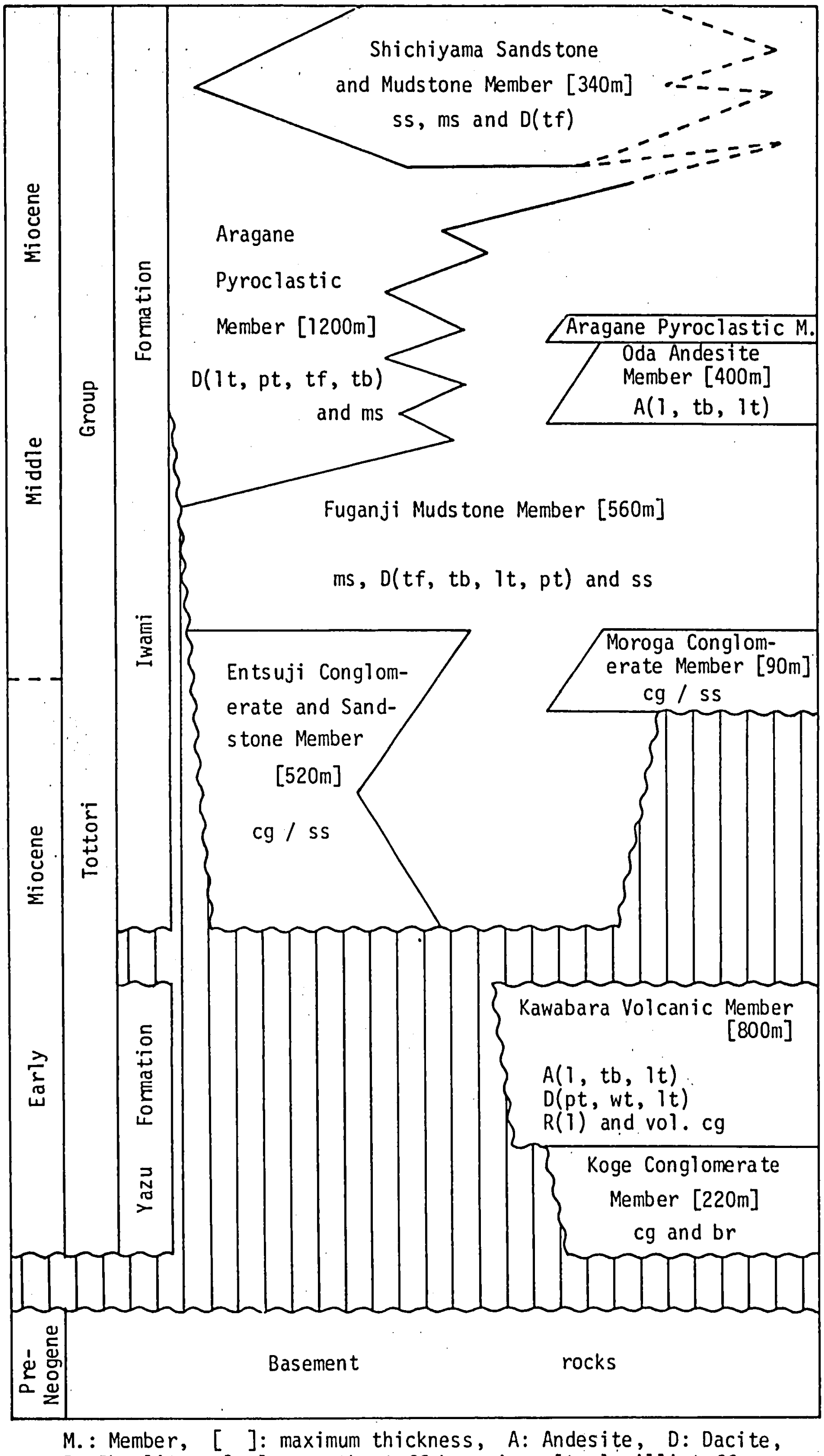


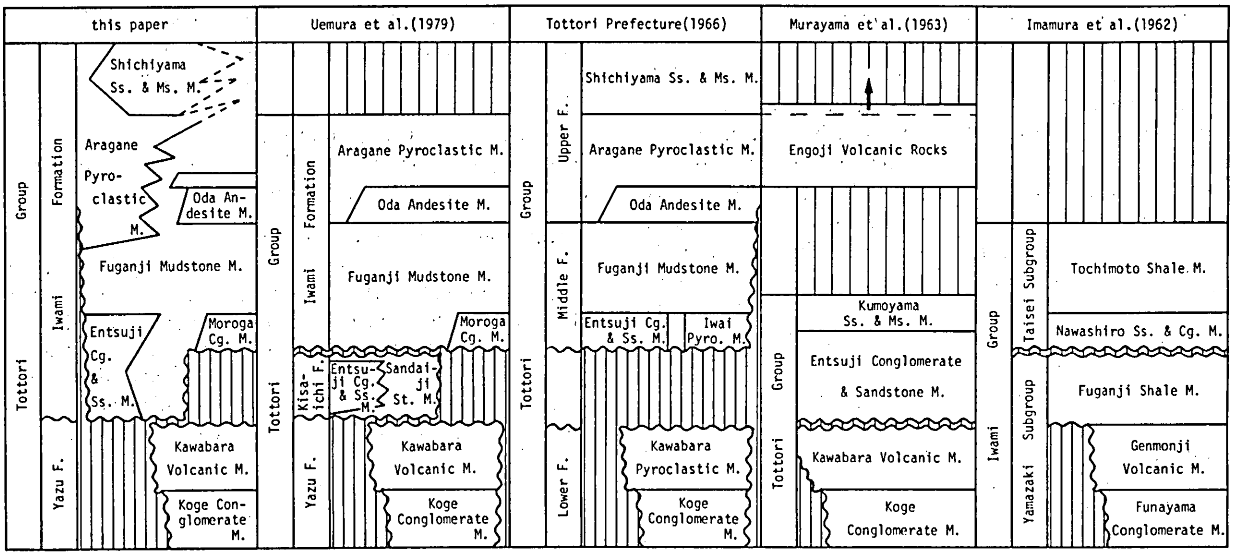
Fig. 1. Map showing the distribution of the Miocene series in the innermost side of Southwest Japan and the location of the investigated area (A: the northeastern part of the Tottori area, B: the southeastern part of the Tottori area).

TABLE 1. GENERALIZED STRATIGRAPHY OF THE TOTTORI GROUP IN THE EASTERN PART OF TOTTORI PREFECTURE.



M.: Member, [ ]: maximum thickness, A: Andesite, D: Dacite, R: Rhyolite, l: lava, tb: tuff breccia, lt: lapilli tuff, pt: pumice tuff, wt: welded tuff, tf: tuff, br: breccia, cg: conglomerate, vol. cg: volcanic conglomerate, ss: sandstone, ms: mudstone.

TABLE 2. CORRELATION OF THE STRATIGRAPHIC DIVISION OF THE TOTTORI GROUP IN THE EASTERN PART OF TOTTORI PREFECTURE.



F.: Formation, M.: Member, Cg.: Conglomerate, Ss.: Sandstone, St.: Siltstone, Ms.: Mudstone, Pyro.: Pyroclastic.

mudstone, with parallel-laminated, fissile one in the lower part. The Oda Member consists of andesite lavas grading locally into hyaloclastite and andesitic pyroclastic rocks, and laterally thins out in the Fuganji Member. The Aragane Member is composed of thick accumulations of dacitic pyroclastic rocks, and interfingers with the upper part of the Fuganji Member. The Shichiyama Member is composed of fine- to medium-grained sandstone, accompanied with mudstone and dacitic pyroclastic rocks. It interfingers with a part of the Aragane Member and probably with the uppermost part of the Fuganji Member.

Table 2 shows the correlation of the author's stratigraphic division with the previous ones. Some remarks are given below.

The Genmonji Volcanic Member of IMAMURA *et al.* (1962), the Kawabara Volcanic Member of MURAYAMA *et al.* (1963) and UEMURA *et al.* (1979) and the Kawabara Pyroclastic Member of TOTTORI PREFECTURE (1966) are equivalent to the author's Kawabara Volcanic Member. IMAMURA *et al.* (1962) interpreted that the Genmonji Volcanic Member is conformably overlain by the Fuganji Shale Member, which is in turn unconformably covered by the Nawashiro Sandstone and Conglomerate Member. The Fuganji Shale is almost equivalent to the lower part of the author's Fuganji Mudstone, while the Nawashiro Sandstone and Conglomerate to the Moroga Conglomerate and the Entsuji Conglomerate and Sandstone. They are interfingering with one another. Moreover, an unconformity is present at the base of the Entsuji-Moroga-Fuganji. The Tochimoto Shale Member of IMAMURA *et al.* (1962) corresponds to the main part of the Fuganji Mudstone.

UEMURA *et al.* (1979) claimed that the Iwami Formation rests unconformably upon the underlying Kisaichi Formation. But, this relationship is conformable and the Kisaichi Formation is included in the lower part of the author's Iwami Formation.

The Iwai Pyroclastic Member (TOTTORI PREFECTURE, 1966), which was considered to be heteropic with the Entsuji Conglomerate and Sandstone and was separated from the Fuganji Mudstone, is included in the author's Fuganji Mudstone.

The Kumoyama Sandstone and Mudstone Member (MURAYAMA *et al.*, 1963) is lithologically divided into the Entsuji Conglomerate and Sandstone and Fuganji Mudstone.

According to TOTTORI PREFECTURE (1966) and UEMURA *et al.* (1979), the Fuganji Mudstone Member is conformably overlain by the Oda Andesite Member, which is in turn covered by the Aragane Pyroclastic Member. It is, however, considered that they are partly interfingering with one another.

The Engoji Volcanic Rocks of MURAYAMA *et al.* (1963) comprizes the author's Aragane Pyroclastic Member and the Latest Miocene to Pleistocene volcanic rocks, together with intrusive rocks.

III. STRATIGRAPHY

A. BASEMENT ROCKS

The basement rocks of the Tottori Group are classified into the Sangun Metamorphic Rocks, the ultramafic to mafic rocks, the non-metamorphic Paleozoic to Mesozoic strata and the Late Cretaceous to Early Paleogene igneous rocks (Figs. 2, 7 and 11).

The Shitani Formation (UEMURA *et al.*, 1979), namely the Sangun Metamorphic Rocks, is exposed in the southeastern margin of the mapped area. It is composed mainly of pelitic schist, accompanied with basic schist, siliceous schist and psammitic schist. The estimated thickness is about 500 meters. The eastern and western blocks separated by the fault of N-S direction are characterized by syncline-like and homocline structures, respectively. The K-Ar ages of muscovite in pelitic schist are 292 ± 7 Ma and 281 ± 9 Ma, and the Rb-Sr ages are 288 ± 13 Ma and 279 ± 10 Ma (SHIBATA and NISHIMURA, 1984).

The ultramafic to mafic rocks (MATSUMOTO, 1986) are distributed in the southeastern margin of the investigated area, and are in fault contact with the Shitani Formation. They are made up mostly of dunite and olivine clinopyroxenite, with subordinate hornblendite and hornblende gabbro. The ultramafic rocks are largely serpentinized.

The Tsunotani Formation (UEMURA *et al.*, 1979), namely the non-metamorphic Paleozoic to Mesozoic strata, widely crops out in the southern part of the area, and is in fault contact with the Shitani Formation along the eastern margin. It is composed mainly of pebbly mudstone including fusiform to angular fragments of sandstone, with subordinate amounts of chert and greenstone. The total thickness is about 1000 meters. The strata trend northwest and dip northeast. Early Jurassic radiolarians have been obtained from the bedded chert (HAYASAKA and HARA, 1982).

The Late Cretaceous to Early Paleogene igneous rocks (UEMURA *et al.*, 1979) are classified into the Yadagawa Group, the Hanabara Complex, the Tottori Granite and the Kyushozan Granite.

The Yadagawa Group (WADATSUMI and MATSUMOTO, 1958) is sporadically distributed in the mapped area. It is composed mostly of rhyolitic welded tuff, accompanied with tuff, lapilli tuff and rhyolite and andesite lavas. Although the welded tuff trends northwest or northeast and dips southward, the geologic structure is as a whole not clear, because the pyroclastic rocks are almost massive and restricted in distribution.

The Hanabara Complex (UEMURA *et al.*, 1979) is exposed in the southern part of the area. It extends west-northwestward with a width of 200 to 500 meters, and intrudes into the Tsunotani Formation, the Yadagawa Group and the Shitani Formation. It is composed of biotite-hornblende diorite-porphyrite, granite porphyry, granophyre and felsite.

The Tottori Granite (TOTTORI PREFECTURE, 1966) crops out in the northeastern and southern parts of the investigated area, and intrudes into the Tsunotani Formation, the Yadagawa Group, the Hanabara Complex and the Shitani Formation. It is represented by coarse-grained, light-colored biotite granite, associated with aplite in frequent.

The Kyushozan Granite (UEMURA *et al.*, 1979) is locally distributed in the western part of the area, and intrudes into the Yadagawa Group. It is represented by fine-grained, porphyritic biotite granite.

B. TOTTORI GROUP

1. *Tottori Group in the southeastern part of the Tottori area*

Because the stratigraphy of the Tottori Group distributed in the southeastern part of the Tottori area has been described in detail by MATSUMOTO (1986), an outline is given below.

Yazu Formation

Koge Conglomerate Member

This member is composed mainly of conglomerate. It is estimated to be 220 meters thick at Sasanami, but becomes thinner southeastward (Figs. 2 and 4).

The conglomerate is massive and not stratified in the lower part, but shows stratification in the upper, containing subangular to subrounded cobbles and pebbles of granite, granite porphyry, felsic pyroclastic rocks, andesite etc. Upward, cobbles and pebbles become smaller, and those of andesite come to be abundant. An exceedingly ill-sorted breccia occurs locally, which consists of rock-fragments derived from the adjacent basements.

The Koge Conglomerate Member covers unconformably the basement rocks, but partly abuts on or is in fault contact with them.

Kawabara Volcanic Member

This member is represented by thick piles of altered volcanic rocks. It is about 800 meters in maximum thickness at the central to northern part of the distributed area, but thins northwestward and southeastward (Figs. 2 and 4). It is subdivided into nine stratigraphic units, that is, the k_1 to k_9 units based upon their succession and lithofacies (Table 3, Fig. 2).

The Kawabara Volcanic Member conformably overlies the Koge Member and sometimes unconformably covers or abuts on the basement rocks. Locally, it is in fault contact with the basements.

k_1: Composed mostly of andesitic lapilli tuff and tuff breccia, interbedded with layers of tuff. The thickness is about 120 meters at Fukuchi. The lateral change in thickness is poor. The pyroclastic rocks are ill-sorted and massive in the western part of the distributed area, but become finer-grained and stratified southward to southeastward.

k_2: Made up of lavas of orthopyroxene-bearing augite andesite. The thickness is about 80 meters. The lavas are massive and compact in general, but flow structures and platy joints are partly recognizable.

k_3: Characterized by andesitic lapilli tuff and tuff breccia. The estimated thickness is 50 meters. The pyroclastic rocks partly show stratification. The lateral change in lithology is poor.

k_4: Composed mainly of dacitic welded tuff (k_{4-1}), with subordinate dacitic lapilli tuff (k_{4-2}). The thickness is approximately 220 meters at Genmonji, but laterally decreases rapidly. The welded tuff is rich in crystal fragments and rather uniform in lithology. It grades into the lapilli tuff near the northwestern end of the distributed area (Figs. 2, 4 and 6).

k_5: Represented by lavas of hypersthene-augite andesite. The thickness reaches 110 meters at Arafune, but laterally decreases step by step (Fig. 4). The lavas are generally massive and rich in phenocrysts, showing locally autobrecciated structure.

k_6: Composed of volcanic conglomerate. The maximum thickness is 160 meters at Arafune-Kango. The volcanic conglomerate contains rounded cobbles of andesite and welded tuff at least partly derived from the underlying units. Matrix is made up of ill-sorted volcanic sand. The change in lithofacies is poor, though cobbles in the conglomerate become smaller horizontally. A stratification is partially observed.

k_7: Represented by lavas of rhyolite. The thickness is approximately 200 meters at the center of the distributed area, but decreases rapidly toward the margin. The lavas show commonly flow structure and are partly autobrecciated, containing spherulites.

k_8: Made up of dacitic pumice tuff (k_{8-1}) and welded tuff (k_{8-2}). The thickness attains 180 meters at the area south of Fuganji, but gradully decreases

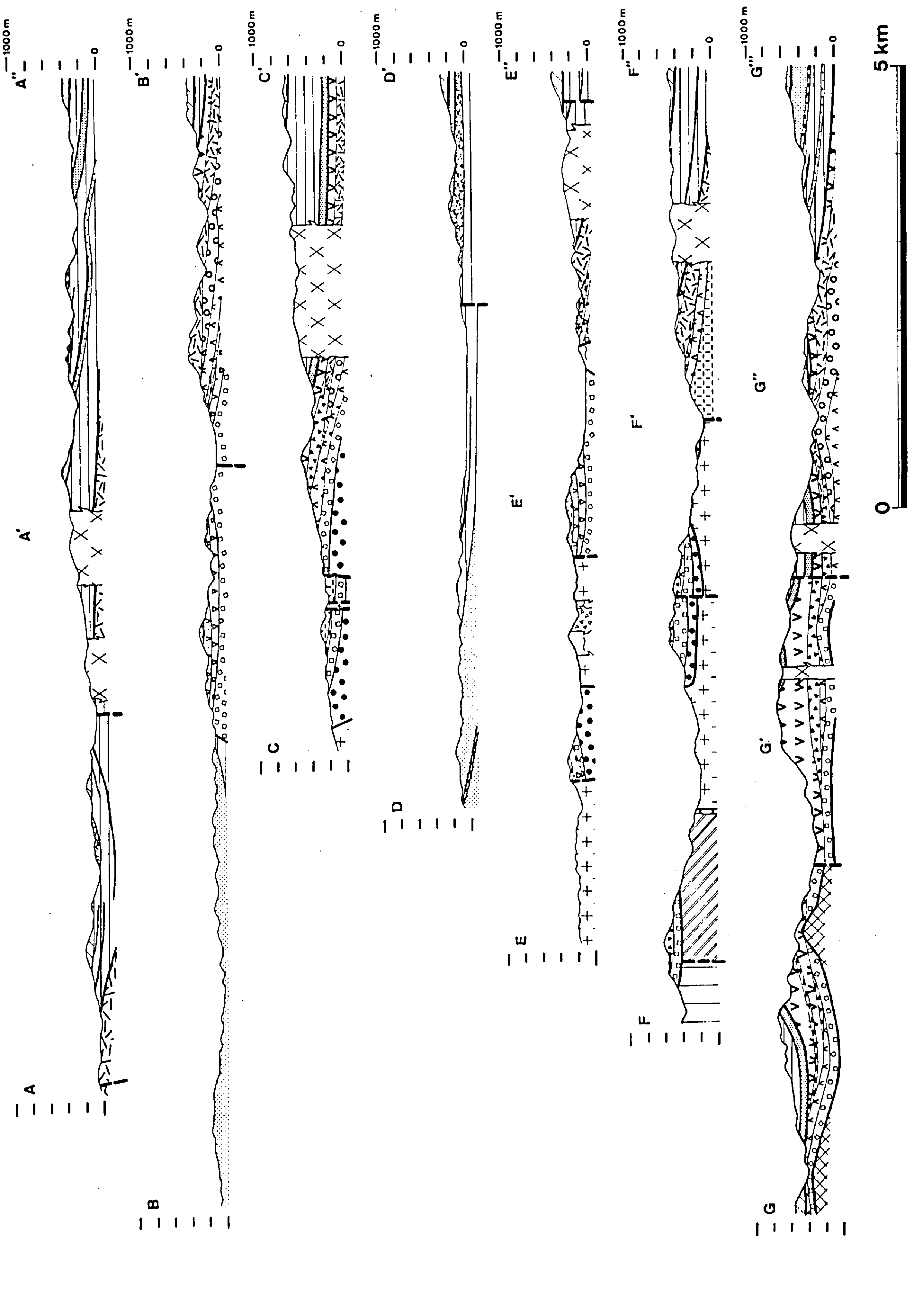
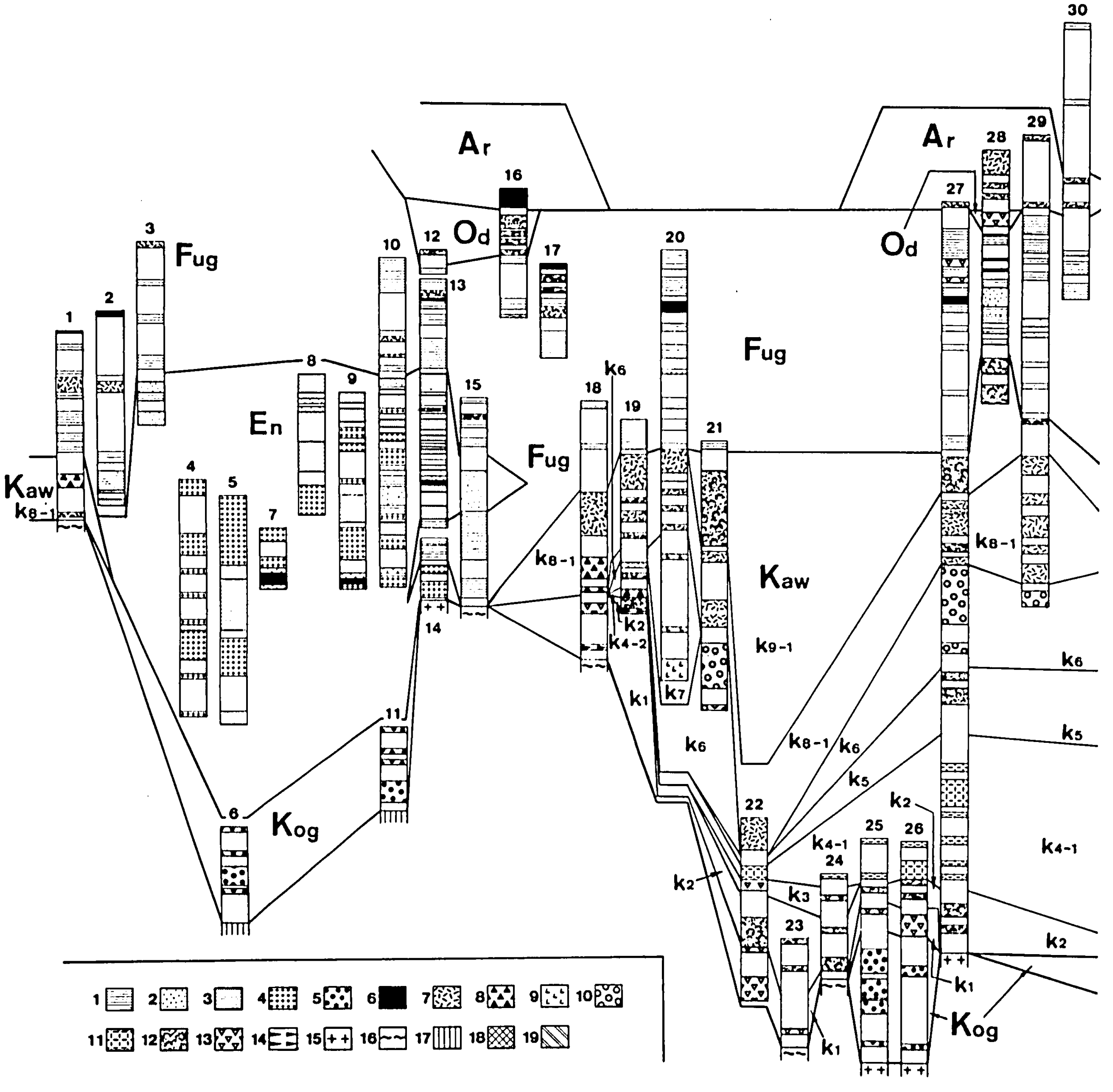


FIG. 3. Geologic profiles of the southeastern part of the Tottori area. See the legend of Fig. 2.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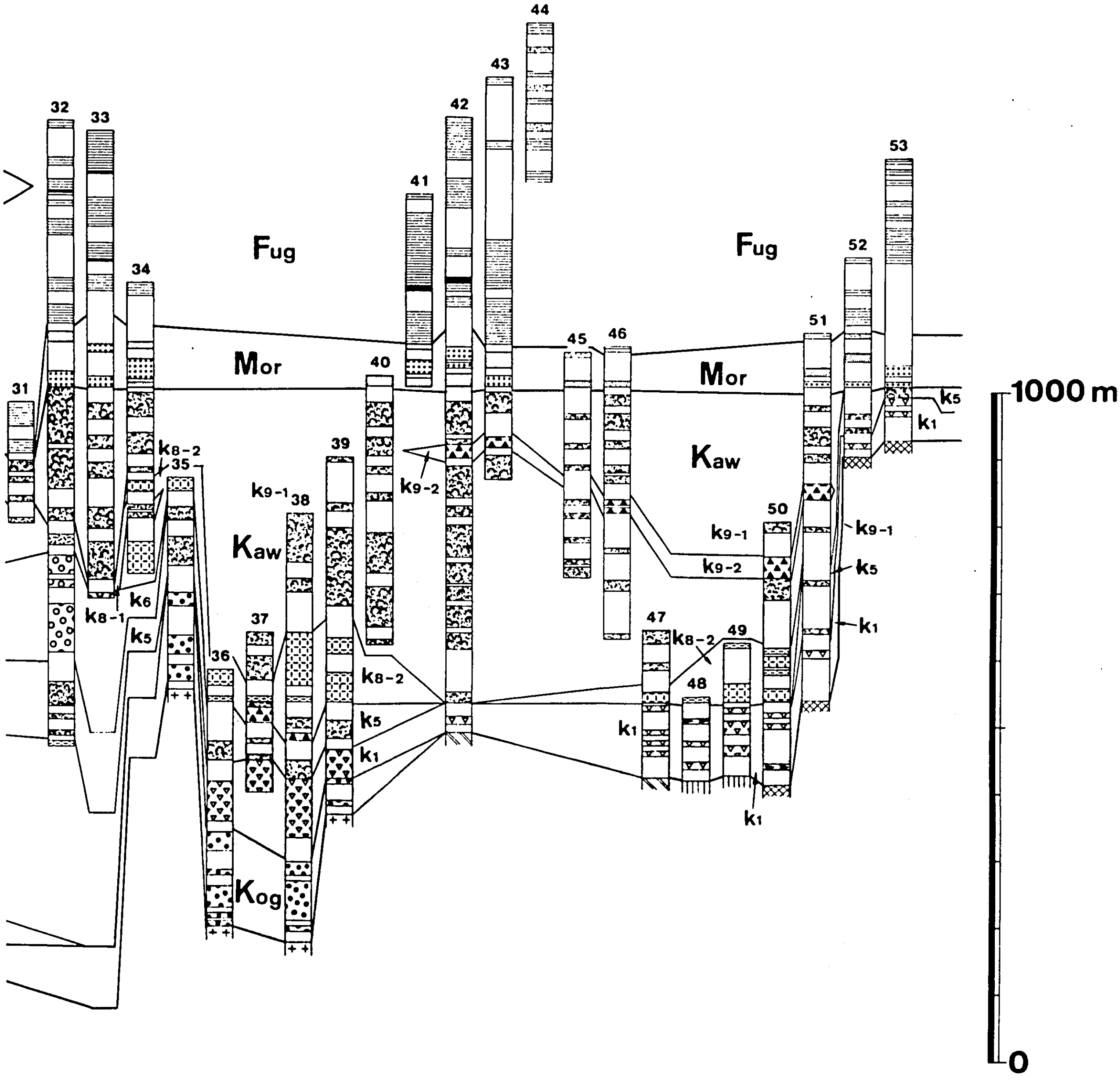


FIG. 4. Columnar sections of the Tottori Group in the southeastern part of the Tottori area. Ar: Aragane Pyroclastic Member, Od: Oda Andesite Member, Fug: Fuganji Mudstone Member, Mor: Moroga Conglomerate Member, En: Entsuji Conglomerate and Sandstone Member, Kaw: Kawabara Volcanic Member, Kog: Koge Conglomerate Member. 1-14: Tottori Group [1: mudstone, 2: sandstone, 3: alter-nating beds of sandstone and conglomerate (sandstone-dominated), 4: alter-nating beds of conglomerate and sandstone (conglomerate-dominated), 5: conglomerate, 6: dacitic tuff, 7: dacitic pumice tuff, 8: dacitic lapilli tuff, 9: rhyolite lava, 10: volcanic conglomerate, 11: dacitic welded tuff, 12: andesite lava, 13: andesitic lapilli tuff to tuff breccia, 14: andesitic tuff]. 15-19: Basement rocks (15: Tottori Granite, 16: Yadagawa Group, 17: Tsunotani Formation, 18: Ultramafic to mafic rocks, 19: Shitani Formation). k_1—k_{9-2}: unit name of the Kawabara Volcanic Member.

laterally. The pumice tuff complicatedly changes in lithology vertically. Furthermore, the size and content of pumice and lithic fragment tend to decrease slightly southward. The welded tuff is rather uniform in lithology. Layers of lapilli tuff are intercalated near the lowermost part. The pumice tuff grades into the welded tuff at the center of the distributed area (Figs. 2, 4 and 6).

k_9: Consisting mainly of lavas of orthopyroxene-bearing augite andesite (k_{9-1}), with intercalated dacitic lapilli tuff (k_{9-2}). The estimated thickness is 450 meters at Ochiiwa, but decreases laterally by degrees (Figs. 2 and 4). The andesite lavas are rich in phenocrysts, showing partly autobrecciated structure. Thin layers of tuffaceous sandstone and welded tuff are intercalated in the northern part of the distributed area. In the southern part the lavas are massive and uniform in lithology. Locally, columnar joints are observable. The lapilli tuff changes partially into welded tuff, and rarely intercalates thin layers of sandstone.

Iwami Formation

Entsuji Conglomerate and Sandstone Member

This member is composed of a thick series of irregularly alternating conglomerate and sandstone. It is about 520 meters in maximum thickness in the western part of the exposed area, but thins eastward to northeastward, and finally pinches out in the lower part of the Fuganji Mudstone Member (Figs. 2 and 4).

The conglomerate and sandstone in alternating beds vary in individual thickness from dozens of centimeters to several meters, and the sandstone becomes slightly dominant upward. The conglomerate in the lower part is ill-sorted, consisting predominantly of subangular to subrounded pebbles and cobbles of andesite at least partly derived from the k_2 unit of the Kawabara Volcanic Member. Pebbles and cobbles derived from the basement rocks, such as quartz schist, pelitic schist, chert, granite, granite porphyry, felsic pyroclastic rocks are also common. Upward, pebbles and cobbles become smaller, and those from the basement rocks come to be abundant instead of rare occurrence of andesite pebbles.

The sandstone is medium- to coarse-grained and often pebbly. Cross-bedding is locally observed. As a whole, the present member has a tendency to become finer-grained eastward to northeastward.

The Entsuji Member unconformably overlies and abuts on the Yazu Formation. It also directly covers or is partially in fault contact with the basement rocks.

Moroga Conglomerate Member

This member is made up of alternating beds of conglomerate and sandstone. It ranges in thickness from 50 to 90 meters, becoming slightly thinner northward (Fig. 4).

The conglomerate contains predominantly subangular to subrounded pebbles derived from the basement rocks (quartz schist, pelitic schist, chert, granite, felsic pyroclastic rocks etc.), and rarely those from the Kawabara Volcanic Member. The matrix is made up of medium- to coarse-grained sand. The composi-

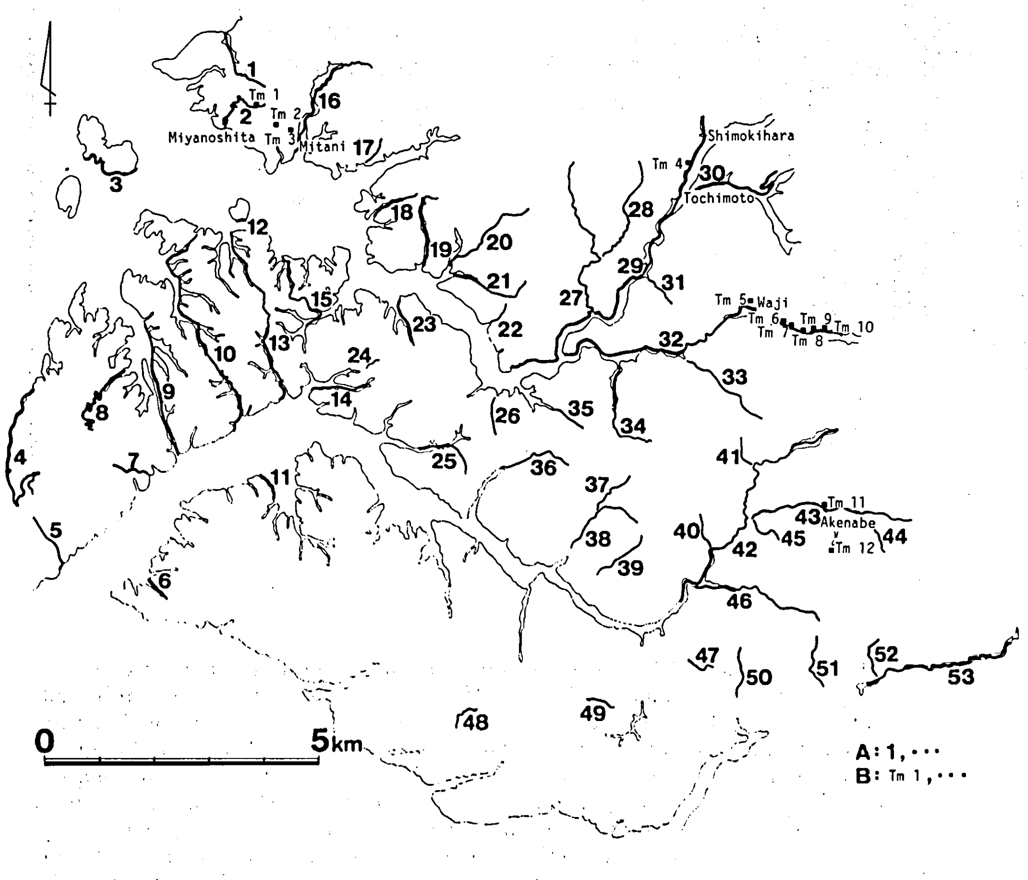


FIG. 5. Index map showing the routes along which the columnar sections were obtained and fossil localities.
A: route number of columnar section, B: fossil localities.

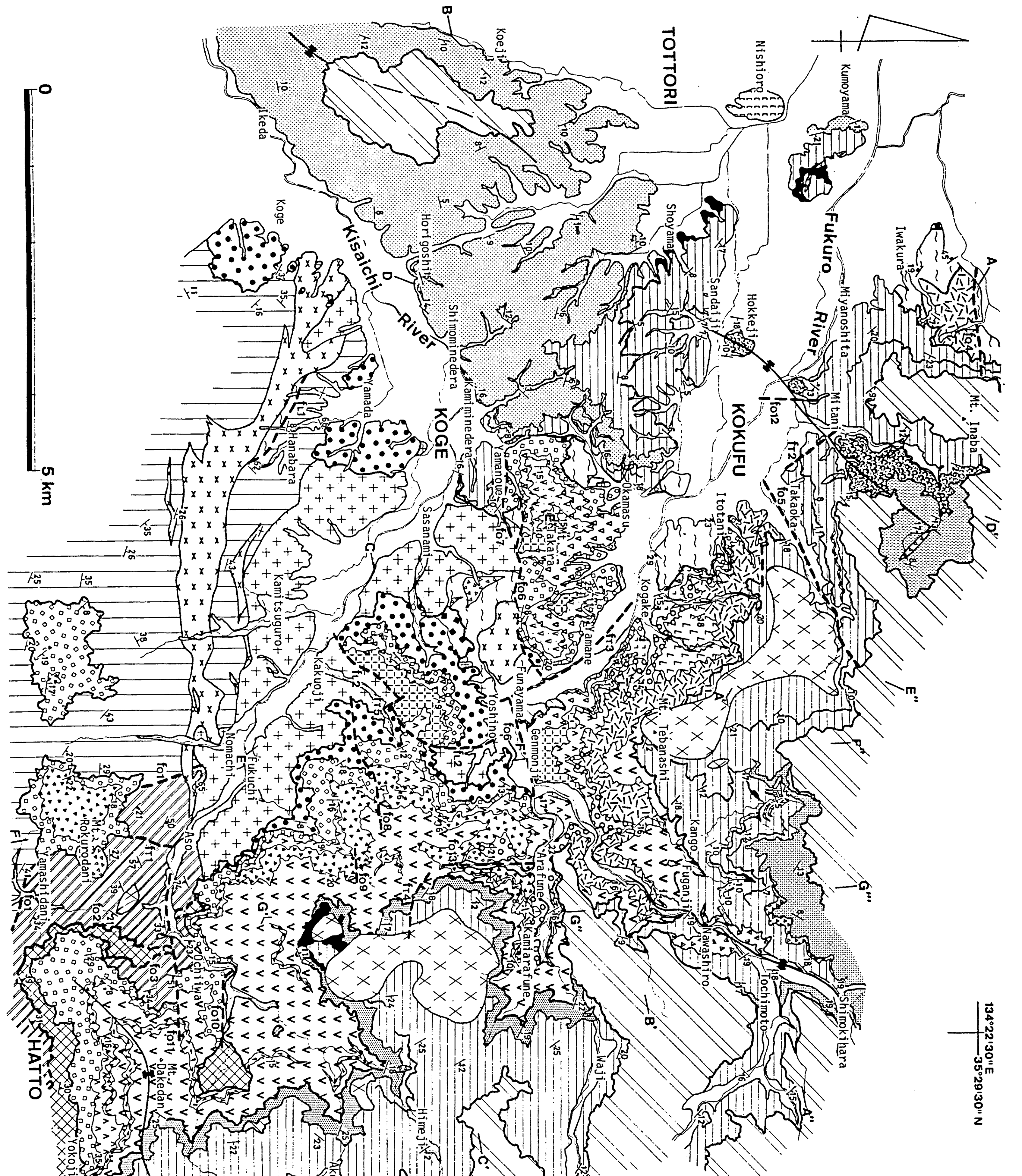


FIG. 2. Geologic map of the southeastern part of the Tottori area. 1: Latest Miocene to Pleistocene volcanic rocks. 2–5: Intrusive rocks (2: Fuchimi Diorite, 3: dolerite, 4: andesite, 5: rhyolite). 6–28: Tottori Group [6–7: Aragane Pyroclastic Member (6: dacitic pumice tuff, 7: dacitic tuff), 8–9: Oda Andesite Member (8: andesitic lapilli tuff, 9: augite andesite lava), 10–14: Fuganji Mudstone Member (10: andesitic lapilli tuff, 11: augite andesite lava, 12: dacitic pyroclastic rocks, 13: sandstone, 14: mudstone), 15: Moroga Conglomerate Member, 16–17: Entsuji Conglomerate and Sandstone Member (16: dacitic pyroclastic rocks, 17: alternating beds of conglomerate and sandstone), 18–26: Kawabara Volcanic Member (18: left, dacitic lapilli tuff (k_{9-2}), right, orthopyroxene-bearing augite andesite lava (k_{9-1}), 19: left, dacitic welded tuff (k_{8-2}), right, dacitic pumice tuff (k_{8-1}), 20: rhyolite lava (k_7), 21: volcanic conglomerate (k_6), 22: hypersthene-augite andesite lava (k_5), 23: left, dacitic lapilli tuff (k_{4-2}), right, dacitic welded tuff (k_{4-1}), 24: andesitic lapilli tuff and tuff breccia (k_3), 25: orthopyroxene-bearing augite andesite lava (k_2), 26: andesitic lapilli tuff and tuff breccia (k_1), 27–28: Koge Conglomerate Member (27: conglomerate, 28: breccia)]. 29–34: Basement rocks (29: Tottori Granite, 30: Hanabara Complex, 31: Yadagawa Group, 32: Tsunotani Formation, 33: ultramafic to mafic rocks, 34: Shitani Formation). 35: Strike and dip of bedding planes. 36: Strike and dip of welding. 37: Strike and dip of flow structure of lava. 38: Strike and dip of schistosity. 39: Fold axis. 40: Fault. 41: Line of profile.

TABLE 3. PETROGRAPHY OF MAIN VOLCANIC ROCKS OF THE KAWABARA VOLCANIC MEMBER.

UNIT NAME	MAXIMUM THICKNESS	VOLCANICS	PHENOCRYSTS	GROUNDMASS	LITHIC FRAGMENTS
k9	450m	opx-bearing augite andesite (k9-1) [massive, partly autobrecciated. columnar joints] intercalated dacitic lapilli tuff (k9-2) grading locally into welded tuff	k9-1 pl, (opx)*, aug, opaq*	hyalopilitic-pilotaxitic	k9-2 and, gp etc.
k8	180m	dacitic pumice tuff (k8-1) intercalating thin layers of tuffaceous ss, ms and cg dacitic welded tuff (k8-2) [weakly welded]	pl, qz*, (hb)*, opaq* pl, qz*, hb*, opaq*	cryptocrystalline eutaxitic	and, gp, fel etc. and, gr, etc.
k7	200m	rhyolite [massive lava with flow structure. partly autobrecciated, spherulitic]	pl, (mf)*, opaq*	cryptocrystalline	———
k6	160m	volcanic conglomerate intercalating thin layers of pebbly ss and ss	———	———	———
k5	110m	hyp-aug andesite [massive, partly autobrecciated]	pl, hyp, aug, opaq*	pilotaxitic-hyalopilitic	———
k4	220m	dacitic welded tuff (k4-1) [weakly welded] grading locally into lapilli tuff (k4-2)	k4-1 pl, qz*, (hb)*, opaq*	eutaxitic	and, gr, dp etc.
k3	50m	andesitic lapilli tuff and tuff breccia [massive, partly stratified]	pl, (mf)*, opaq*	microcrystalline-cryptocrystalline	and, dp etc.
k2	80m	opx-bearing augite andesite [massive lava with flow structure. platy joints]	pl, (opx)*, aug, opaq*	pilotaxitic	———
k1	120m	andesitic tuff breccia, lapilli tuff and tuff [massive, partly stratified]	pl, (mf)*, opaq*	microcrystalline-cryptocrystalline	and, gr, dp etc.

cg: conglomerate, ss: sandstone, ms: mudstone, pl: plagioclase, qz: quartz, opx: orthopyroxene, aug: augite, hb: hornblende, opaq: opaque minerals, ( ): pseudomorph, (mf): altered mafic minerals, *: a small amount, and: andesite, gr: granite, gp: granite porphyry, dp: diorite porphyrite, fel: felsite.

tion of the conglomerate is uniform throughout the member.

The sandstone is medium- to coarse-grained and often pebbly. Upward and northward, the present member tends to become finer-grained, and the intercalation of sandstone and mudstone increases.

The Moroga Member rests unconformably on the Yazu Formation.

Fuganji Mudstone Member

This member consists largely of well-stratified, gray to black mudstone, interbedded with thin layers of felsic tuff at many stratigraphic horizons. The thickness ranges from 400 to 500 meters in the eastern part of the distributed area, but decreases toward the west to northwest (Figs. 2 and 4).

There are two types of mudstone; the one is parallel-laminated, fissile mudstone (type I) developed in the lower part of this member and the other is homogeneous, compact, hard one (type II) in the middle to upper part. The type I tends to be exposed in the western part of the distributed area, where it intercalates very thin layers of conglomerate, sandstone and siltstone. Parallel lamination and fissility are most conspicuous in the lowermost part. The type II is widely distributed in the eastern part, where thin layers of conglomerate, sandstone, andesite lava and andesitic lapilli tuff are partly intercalated. The type I grades upward into and passes rapidly eastward into the type II.

Marine fossils indicating a relatively cold deep sea environment have been obtained from the type II mudstone (Table 8, Figs. 5 and 10).

The Fuganji Member unconformably overlies the Yazu Formation. It also directly covers or abuts on the basement rocks. Locally, it is in fault contact with the basements.

Oda Andesite Member

This member is composed of lavas of andesite and andesitic lapilli tuff. It attains about 70 meters in maximum thickness, but laterally thins out in the upper part of the Fuganji Mudstone Member (Figs. 2 and 4).

The andesite lavas usually exhibit conspicuous autobrecciated structure, and are subjected to remarkable alteration. Angular to subangular fragments of mudstone are partly contained in them. The andesitic lapilli tuff is usually massive, and becomes slightly finer-grained upward.

Aragane Pyroclastic Member

This member is made up of dacitic tuff and pumice tuff. It reaches abuot 110 meters in thickness at Shimokihara, but becomes thinner horizontally, interfingering with the upper part of the Fuganji Mudstone Member (Figs. 2 and 4).

The tuff is mostly fine-grained, hard, compact and well-stratified, intercalating occasionally thin layers of mudstone and medium- to coarse-grained tuff. The pumice tuff is massive, partly hard, compact, stratified, and rarely greasily lustrous. It has a tendency to become in some degree finer-grained upward.

2. *Tottori Group in the northeastern part of the Tottori area*

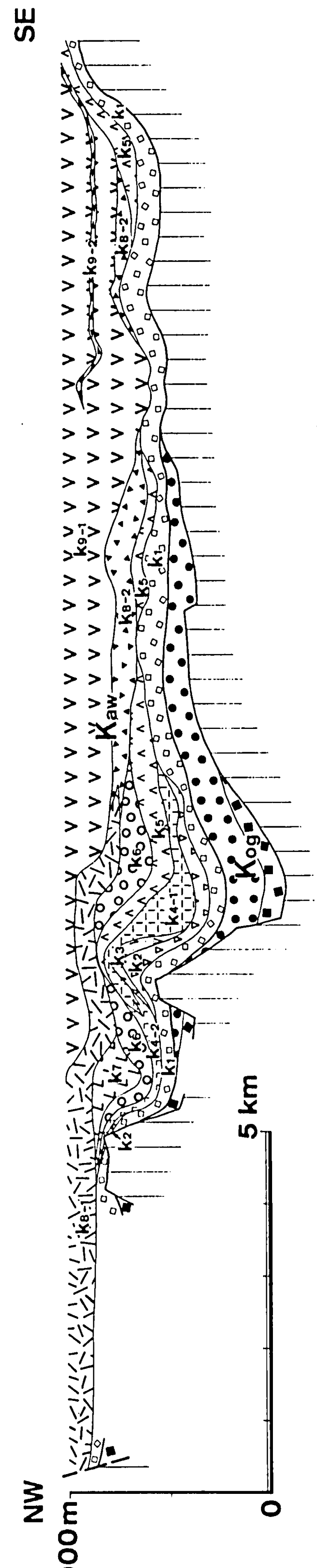


FIG. 6. Stratigraphic profile of the Yazu Formation in the southeastern part of the Tottori area.
Kaw: Kawabara Volcanic Member, Kog: Koge Conglomerate Member, k_1—k_{9-2}: unit name of the Kawabara Volcanic Member.

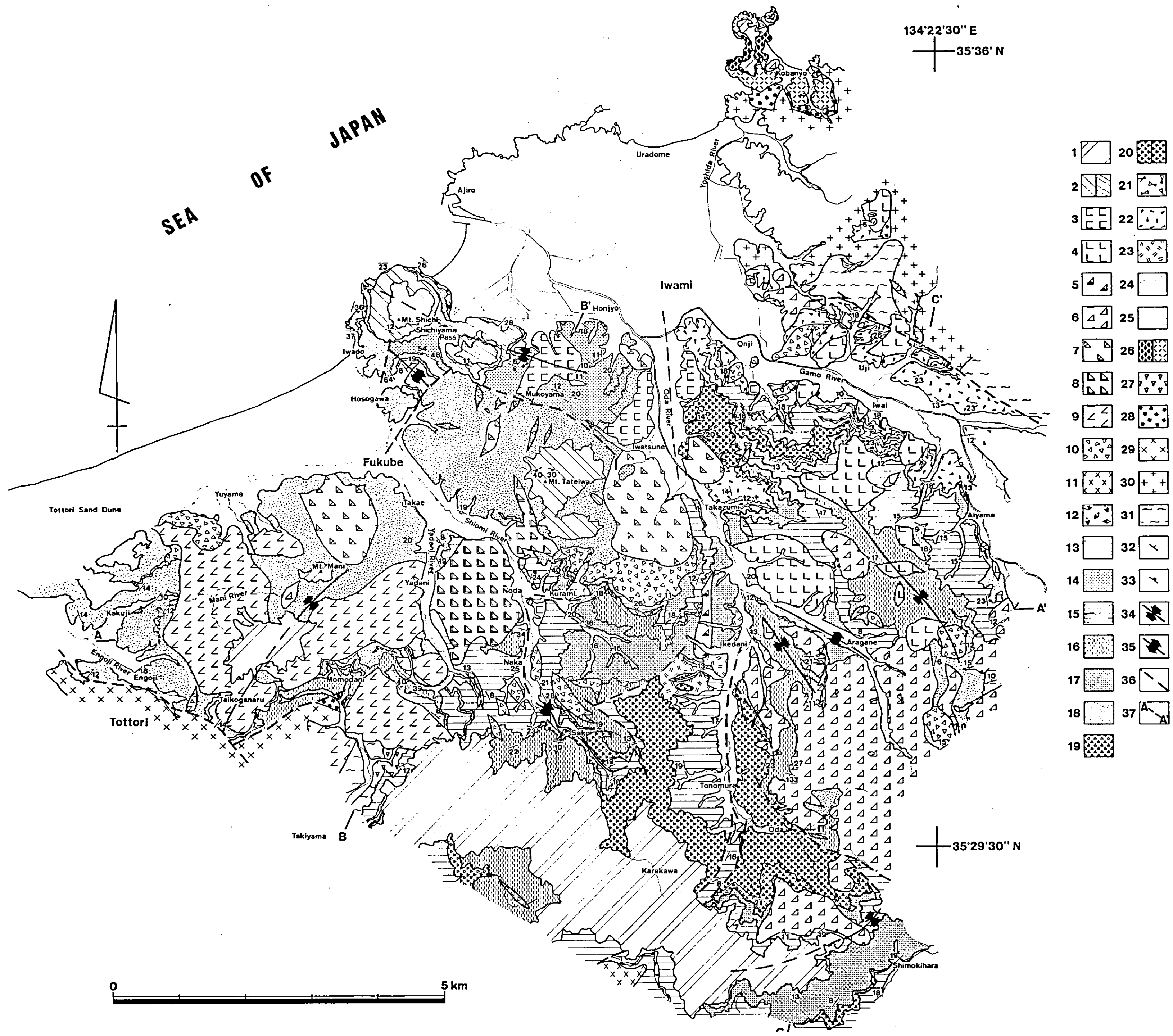


FIG. 7. Geologic map of the northeastern part of the Tottori area.

1–2: Latest Miocene to Pleistocene volcanic rocks (1: andesite and basalt lavas, 2: left, hypersthene-augite dacite lava, right, dacitic welded tuff). 3–11: Intrusive rocks (3: quartz porphyry, 4: rhyolite, 5: augite dacite, 6: altered dacite, 7: hypersthene-augite dacite and augite dacite, 8: orthopyroxene-dacite, 9: clinopyroxene dacite and orthopyroxene-clinopyroxene dacite, 10: andesite, 11: Fuchimi Diorite). 12–28: Tottori Group [12–14: Shichiyama Sandstone and Mudstone Member (12: dacitic pyroclastic rocks, 13: mudstone, 14: sandstone), 15–18: Aragane Pyroclastic Member (15: mudstone, 16: dacitic tuff, 17: dacitic pumice tuff, 18: dacitic lapilli tuff), 19–20: Oda Andesite Member (19: andesitic pyroclastic rocks, 20: left, augite andesite lava, right, hypersthene-augite andesite lava), 21–25: Fuganji Mudstone Member (21: andesite lava, 22: dacitic tuff, 23: dacitic lapilli tuff and tuff breccia, 24: sandstone, 25: mudstone), 26–27: Kawabara Volcanic Member (26: left, conglomerate to pebbly sandstone, right, dacitic lapilli tuff and tuff breccia, 27: orthopyroxene-bearing augite andesite lava), 28: Koge Conglomerate Member]. 29–31: Basement rocks (29: Kyushozan Granite, 30: Tottori Granite, 31: Yadagawa Group). 32: Strike and dip of bedding planes. 33: Strike and dip of welding. 34: Synclinal axis. 35: Anticlinal axis. 36: Fault. 37: Line of profile.

In the following, the stratigraphy of the Tottori Group distributed in the northeastern part of the Tottori area is described.

Yazu Formation

This is almost equivalent to the Yazu Formation defined by UEMURA *et al.* (1979).

Koge Conglomerate Member

This is nearly equal to the Koge Conglomerate Member of MURAYAMA *et al.* (1963). It is narrowly distributed along the boundary between the Tottori Group and the basement rocks in the southwestern and northeastern parts of the investigated area, and abuts on or is in fault contact with the basement rocks.

This member consists exclusively of breccia. The thickness is about 60 meters (Figs. 7 and 9). The breccia is as a whole massive, not stratified and ill-sorted, containing angular to subangular blocks and fragments of basement rocks (mostly granite) ranging in size from a few centimeters to 2 meters. The change in lithofacies is poor throughout the member. No fossils have been obtained.

Kawabara Volcanic Member

This corresponds to the Kawabara Volcanic Member of MURAYAMA *et al.* (1963). It is locally exposed in the southwestern and northeastern parts of the mapped area. It covers conformably the Koge Conglomerate Member, but sometimes abuts on the basement rocks.

This member is made up chiefly of lavas of orthopyroxene-bearing augite andesite, together with dacitic pyroclastic rocks. The estimated thickness is 60 and 240 meters at Momodani and Kobanyo, respectively (Figs. 7 and 9).

The andesite lavas crop out near Momodani, and are probably correlative with the k_2 unit of the present member exposed on the southeast of Tottori City. They are massive and compact, showing occasionally flow structure. Under the microscope, phenocrysts are composed of a small amount of plagioclase, augite, orthopyroxene and opaque minerals, groundmass being pilotaxitic. Chlorite, saponite etc. are seen as alteration products.

The dacitic pyroclastic rocks crop out in the vicinity of Kobanyo, and are represented by light green lapilli tuff and tuff breccia. They are generally massive, not stratified and rather uniform in lithology, containing lithic fragments of andesite, rhyolite, diorite-porphyrite etc. Layers of conglomerate to pebbly sandstone are intercalated in the pyroclastic rocks. The conglomerate is massive and ill-sorted, containing subangular to angular boulders, cobbles and pebbles (a few centimeters to 2 meters in size) mostly of granite and subordinately of aplite and rhyolite. The size and content of clasts tend to decrease slightly upward.

Chlamys sp. has been reported by YAMANA (1977, 1979).

Iwami Formation

This comprises the Iwami Formation of MATSUMOTO (1986) and the Shichiyama Sandstone and Mudstone Member of TOTTORI PREFECTURE (1966). In the northeastern part of the Tottori area, this formation is represented by four members of the Fuganji Mudstone, Oda Andesite, Aragane Pyroclastic and Shichi-

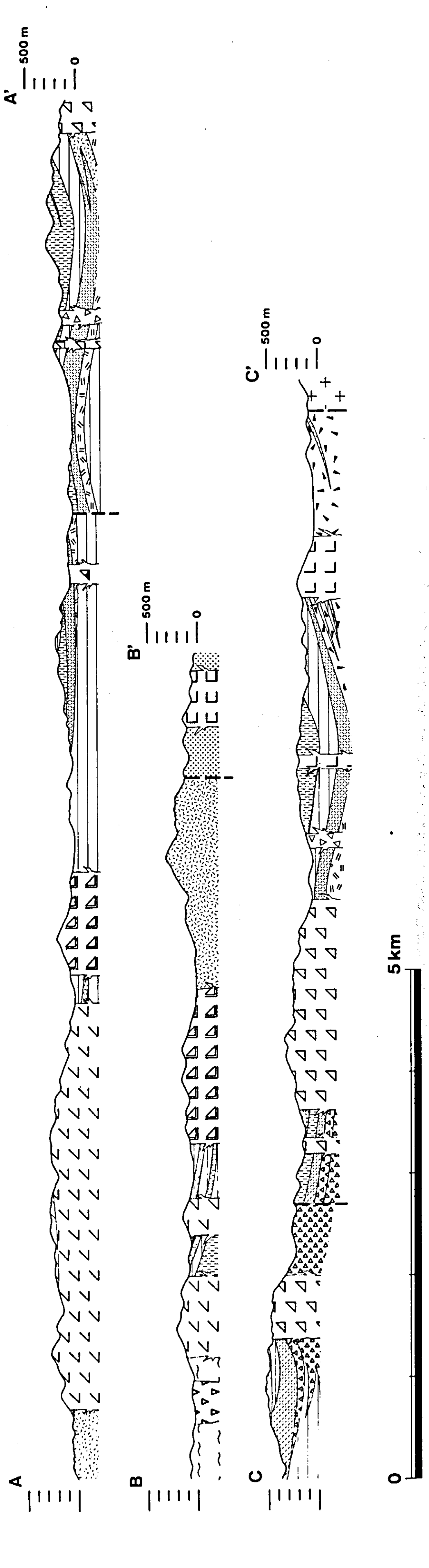
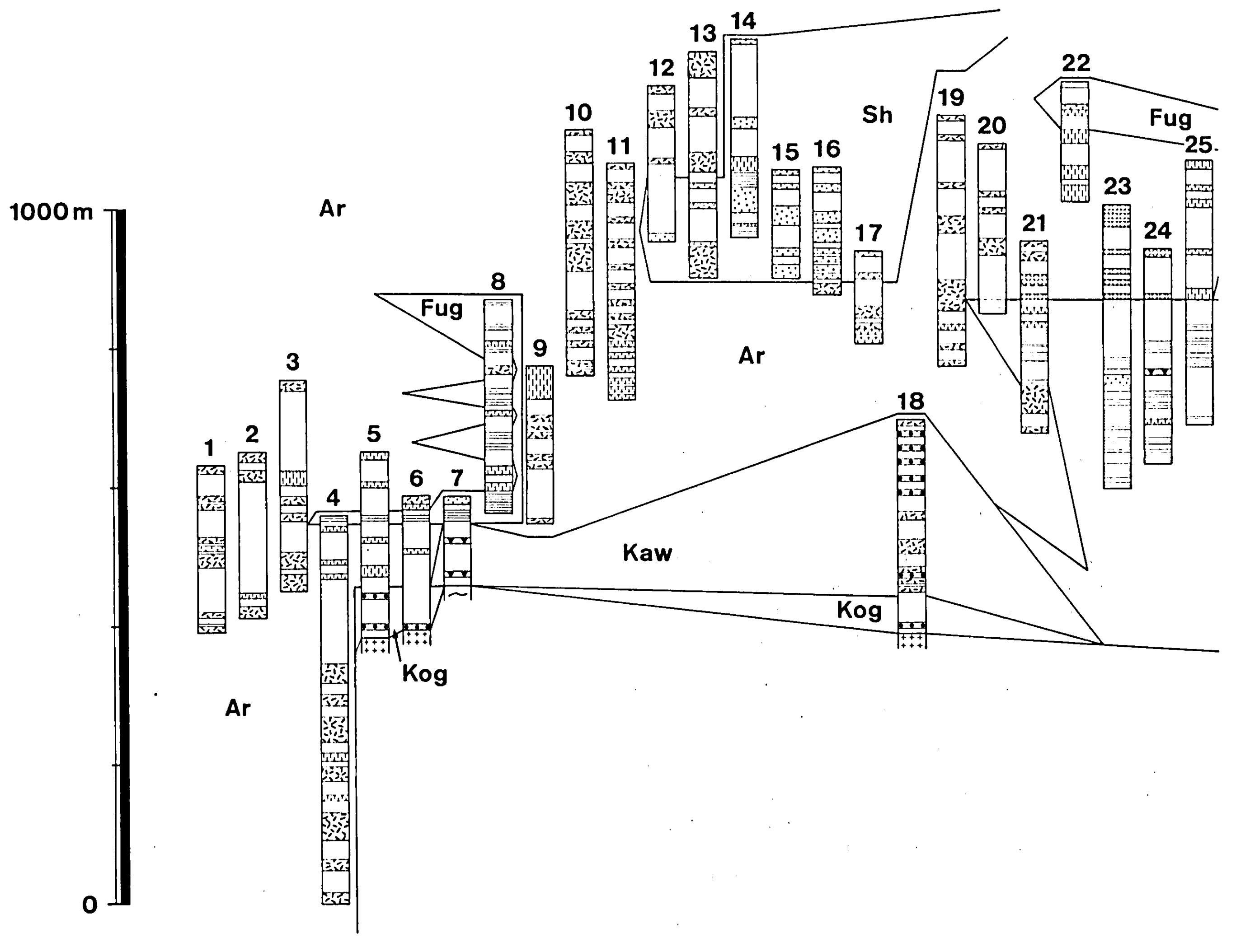


FIG. 8. Geologic profiles of the northeastern part of the Tottori area. See the legend of Fig. 7.



yama Sandstone and Mudstone, the Entsuji Conglomerate and Sandstone and Moroga Conglomerate Members being not exposed.

Fuganji Mudstonne Member

This is comparable with the Fuganji Mudstone Member redefined by MATSUMOTO (1986). It is widely exposed in the investigated area, and unconformably covers the Kawabara Volcanic Member, or partially abuts on the Koge Conglomerate Member as well as on the basement rocks. A fault contact with the basements is also observable.

This member is made up of stratified, gray to black mudstone, accompanied with dacitic pyroclastic rocks and tuffaceous sandstone. The thickness attains 560 meters at Uji, but decreases gradually westward (Figs. 7 and 9). The mudstone is similar to the type II mudstone typically exposed in the southeastern part of the Tottori area. The pyroclastic rocks are represented by tuff, tuff breccia, lapilli tuff and pumice tuff. The Iwai Pyroclastic Member of TOTTORI PREFECTURE (1966) corresponds to the tuff developed in the lower part of the author's Fuganji Mudstone Member.

Some marine fossils, such as *Solemya (Acharax)* cf. *tokunagai*, *Propeamussium tateiwai*, *Delectopecten peckhami* and echinoids are obtained.

Oda Andesite Member

This corresponds nearly to the Oda Andesite Member redefined by MATSUMOTO (1986). It crops out in the vicinity of Iwatsune, Sako and Oda, resting con-

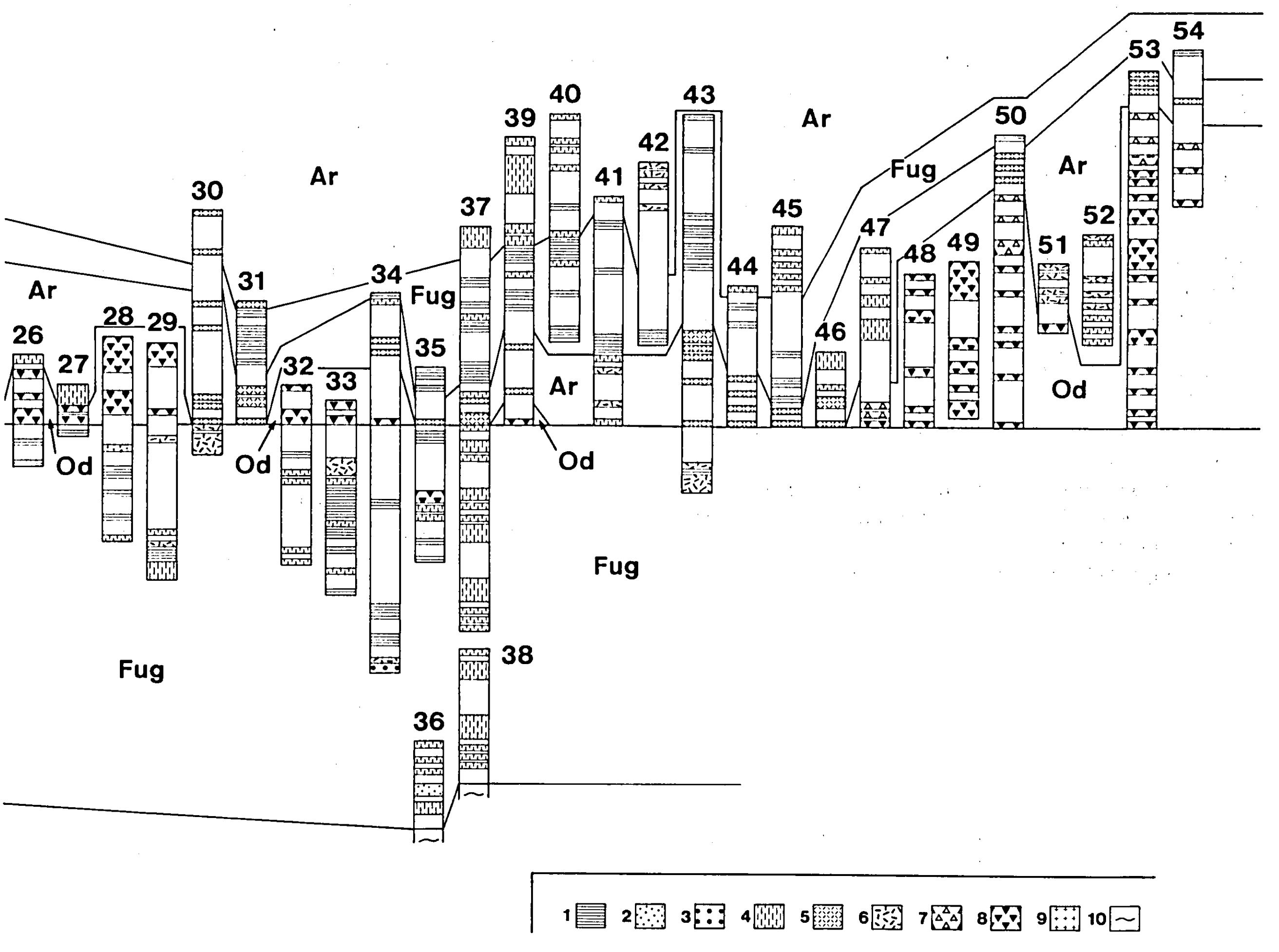


FIG. 9. Columnar sections of the Tottori Group in the northeastern part of the Tottori area.
Sh: Shichiyama Sandstone and Mudstone Member, Ar: Aragane Pyroclastic Member, Od: Oda Andesite Member, Fug: Fuganji Mudstone Member, Kaw: Kawabara Volcanic Member, Kog: Koge Conglomerate Member. 1-8: Tottori Group (1: mudstone, 2: sandstone, 3: conglomerate, 4: dacitic tuff, 5: dacitic pumice tuff, 6: dacitic lapilli tuff, 7: andesitic lapilli tuff to tuff breccia, 8: andesite lava). 9-10: Basement rocks (9: granite, 10: rhyolitic pyroclastic rocks).

formably on the Fuganji Mudstone Member.

This member is composed of lavas of augite andesite and hypersthene-augite andesite, together with andesitic pyroclastic rocks (Table 4). It has a maximum thickness of 400 meters at Oda (Figs. 7 and 9), but rapidly thins out in the upper part of the Fuganji Mudstone Member.

The lavas of augite andesite are dark to grayish green in color, showing entirely conspicuous autobrecciated structure and locally grading into hyaloclastite. Fragments of mudstone ranging in size from several millimeters to a few centimeters are occasionally included. Microscopically, phenocrysts are composed of a small amount of plagioclase, augite and opaque minerals, groundmass being hyalopilitic. Alteration minerals are zeolite, calcite and so on. The interstices between broken pieces of the autobrecciated lavas are filled with devitrified glass and a minor amount of fragmental plagioclase and quartz.

The lavas of hypersthene-augite andesite are dark green in color, commonly massive and rich in phenocrysts. Autobrecciated structure and columnar joints are partially observable. Microscopically, phenocrysts are made up of plagioclase, augite, hypersthene and opaque minerals, glomeroporphyritic texture being rarely recognizable. Groundmass is hyalopilitic-pilotaxitic. Chlorite, saponite, calcite etc. are found as alteration products. The hypersthene-augite andesite appears to pass laterally into the augite andesite.

The andesitic pyroclastic rocks are represented by lapilli tuff and tuff breccia. They are green to grayish green in color, and usually rather uniform in lithology, though fine-grained parts indicate occasionally stratification. Lithic fragments of andesite ranging in size from several millimeters to 20 centimeters are contained abundantly. An indeterminable broken piece of molluscan fossil has been obtained from the lapilli tuff.

Aragane Pyroclastic Member

This is nearly equivalent to the Aragane Pyroclastic Member redefined by MATSUMOTO (1986). It is extensively distributed in the mapped area, interfingering largely with the upper part of the Fuganji Mudstone Member and partly with the Oda Andesite and Shichiyama Sandstone and Mudstone Members. In some cases, it abuts on or is presumably in fault contact with the basement rocks.

This member is made up largely of dacitic lapilli tuff, pumice tuff and tuff (Table 4), interbedded with tuff breccia and clastic rocks. The thickness attains

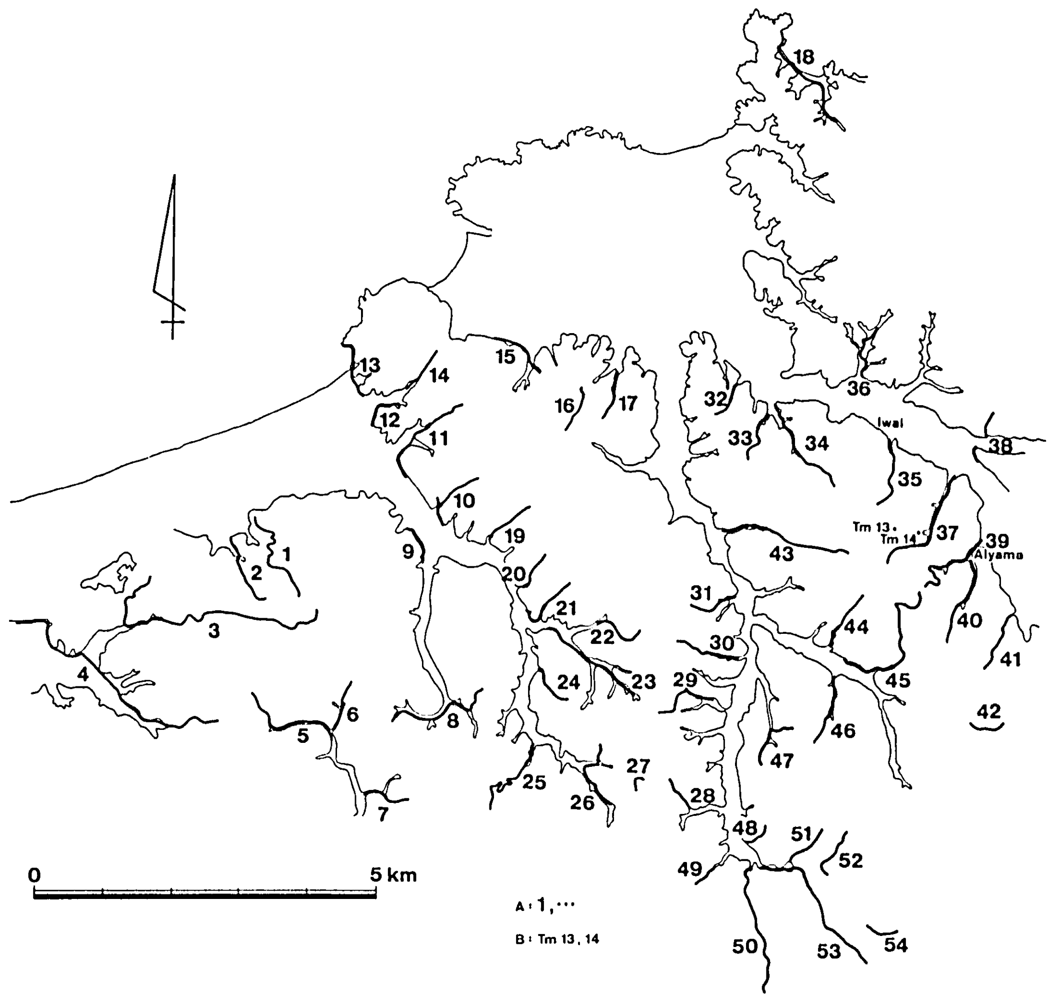
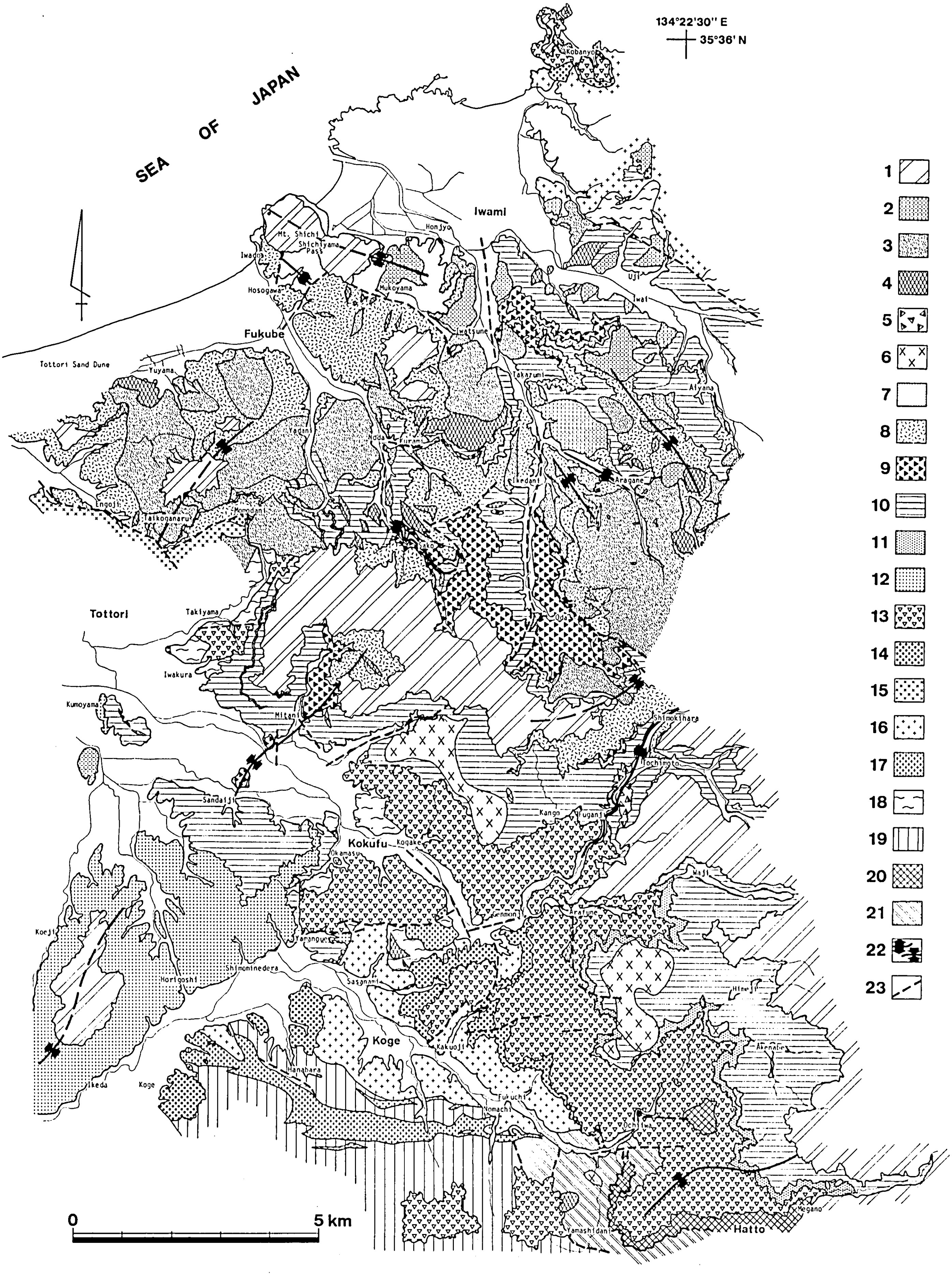


FIG. 10. Index map showing the routes along which the columnar sections were obtained and fossil localities.
A: route number of columnar section, B: fossil localities.

TABLE 4. PETROGRAPHY OF MAIN VOLCANIC ROCKS OF THE ODA ANDESITE AND ARAGANE PYROCLASTIC MEMBERS.

	VOLCANICS	MAXIMUM THICKNESS	PHENOCRYSTS	GROUNDMASS	LITHIC FRAGMENTS
Aragane Pyro. M.	dacitic tuff [well-stratified]	200m	pl*, qz*, (mf)*, opaq*	microcrystalline-cryptocrystalline	——
	dacitic pumice tuff [massive, partly stratified]	220m	pl, qz*, (mf)*, opaq*	vitric-cryptocrystalline	and, rhy, dp, fp etc.
	dacitic lapilli tuff and tuff breccia [massive, partly stratified]	900m	pl, qz*, aug*, hb*, opaq*	cryptocrystalline-vitric	and, rhy, dp, gr, ms etc.
Oda Andesite Member	andesitic lapilli tuff and tuff breccia [massive, partly stratified]	80m	pl, (mf)*, opaq*	microcrystalline-cryptocrystalline	and, dp etc.
	aug andesite [conspicuously autobrecciated]	70m	pl*, aug*, opaq*	hyalopilitic	——
	hyp-aug andesite [massive, partly autobrecciated. columnar joints]	340m	pl, hyp, aug, opaq*	hyalopilitic-pilotaxitic	——

Pyro.: Pyroclastic, M.: Member, pl: plagioclase, qz: quartz, hyp: hypersthene, aug: augite, hb: hornblende, opaq: opaque minerals, (mf): altered mafic minerals, *: a small amount, and: andesite, rhy: rhyolite, fp: felsic pyroclastic rock, gr: granite, dp: diorite porphyrite, ms: mudstone.



134°22'30" E
35°36' N
SEA OF JAPAN
Iwami
Honjyo
Mt. Shichi
Shichiyama Pass
Iwado
Hosogawa
Mukoyama
Kobanyo
Uji
Iwai
Iwatsune
Fukube
Tottori Sand Dune
Yuyama
Takazumi
Aiyama
Furami
Aragane
Ikedani
Engoji
Taikoganaru
Momodani
Tottori
Takiyama
Oda
Iwakura
Kumoyama
Mitani
Shimokihara
Tochimoto
Sandaiji
Kango
Yugani
Kokufu
Kogake
Okamasu
Waji
Koeji
Yamanoue
Genkoji
Shimominedera
Horigoshi
Sasanami
Koge
Kakuoji
Hanabara
Ikeda
Koge
Fukuchi
Nomachi
Ochi
Yamashidani
Hatto
Megano
0
5 km
1
2
3
4
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6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

FIG. 11.

about 1200 meters in the central to western part of the distributed area, but decreases eastward (Figs. 7 and 9).

The lapilli tuff is mainly exposed in the western part of the investigated area. It is massive and grayish green to green in color, showing stratification in the lower part. Fragments of andesite, rhyolite, diorite-porphyrite, granite, chert, mudstone etc., ranging in size from 1 to 5 centimeters (rarely about 3 meters), are contained. Pumices, 1 centimeter or less in size and light green to green in color, are also relatively abundantly included. The lapilli tuff tends to intercalate layers of tuff breccia in the northwestern part of its distributed area. It passes rapidly into the pumice tuff and tuff at Kurami and in the northeast of Momodani.

The pumice tuff is exposed in the central to eastern part of the investigated area. It is massive, partly stratified, light green to green in color, and rarely greasily lustrous. Besides a large quantity of irregularly shaped pumices, ranging in size from several millimeters to 2 centimeters, a small amount of lithic fragments of 1 or 2 centimeters (rarely about 60 centimeters) are included. Fragments of andesite, rhyolite, diorite-porphyrite, granite, felsic pyroclastic rocks and mudstone are quite common. The size of pumices and lithic fragments tends to decrease slightly southward.

The tuff is mainly exposed in the eastern part of the investigated area. It is fine- to medium-grained, well-stratified, grayish white in color, and contains occasionally accretionary lapilli. The vertical change in lithology is poor. Fossils have not yet been found.

Shichiyama Sandstone and Mudstone Member

This corresponds roughly to the Shichiyama Sandstone and Mudstone Member of TOTTORI PREFECTURE (1966). It is exposed in the northern part of the mapped area, interfingering with a part of the Aragane Pyroclastic and Fuganji Mudstone Members. In most cases, however, it is in fault contact with the Aragane.

The present member consists mainly of sandstone, with interbedded layers of mudstone and dacitic pyroclastic rocks. It is about 340 meters in maximum thickness at the Shichiyama Pass, but slightly thins eastward (Figs. 7 and 9).

The sandstone is fine- to medium-grained, usually stratified and yellowish brown in color, intercalating dacitic pyroclastic rocks in the lower part. The interbedded mudstone is stratified, partly parallel-laminated and gray to black in color, ranging in individual thickness from several centimeters to several meters. It intercalates thin layers of dacitic tuff. Indeterminable broken pieces of echinoids were collected from the mudstone.

C. INTRUSIVE ROCKS

The rocks intruding into the Tottori Group are roughly classified into the Fuchimi Diorite, dolerite, andesite, dacite and rhyolite (Figs. 2, 7 and 11).

Fuchimi Diorite (TOTTORI PREFECTURE, 1966)

The Fuchimi Diorite occurs as stocks and dykes. It intrudes into the Kawabara Volcanic, Moroga Conglomerate, Fuganji Mudstone and Aragane Pyroclastic Members. It is represented mainly by hypersthene-augite porphyrite to diorite-porphyrite and augite-biotite-hornblende quartz-diorite-porphyrite, the latter of which locally grades into augite-hornblende quartz-diorite, biotite-augite-hornblende quartz-diorite, hornblende-augite quartz-diorite and hornblende-augite quartz-diorite-porphyrite (MATSUMOTO, 1986).

Dolerite

Dolerite occurs as sheet, intruding into the Fuganji Mudstone Member. Microscopically, coarse-grained crystals of plagioclase and pyroxene are observed in doleritic or intergranular groundmass.

Andesite

Andesite occurs in places as small-scale dykes and sheets. Main rock-facies are hypersthene-augite andesite, augite andesite and aphyric andesite.

Dacite

Stocks and dykes of dacite are found here and there. Most of them had formerly been included in the Fuchimi Diorite.

The rock bodies exposed near Yuyama-Taikoganaru-Momodani-Yadani consist of light green clinopyroxene dacite, with subordinate orthopyroxene-clinopyroxene dacite. Microscopically, phenocrysts are composed of plagioclase, quartz, orthopyroxene, clinopyroxene and opaque minerals. They are partly grouped together to form glomeroporphyritic aggregates, and are embedded usually in a cryptocrystalline groundmass (rarely in a fine-textured one with flow structure). Chlorite, saponite, calcite etc. are seen as alteration products. The surrounding rocks are affected by weak contact metamorphism.

The rock body found in the vicinity of Noda consists predominantly of highly altered light green porphyritic orthopyroxene-augite dacite. Microscopically, phenocrysts of plagioclase, orthopyroxene, augite and opaque minerals are observed. Common alteration minerals are tridymite, zeolite, epidote, calcite etc..

The masses cropping out to the east of Yuyama and in the vicinity of Iwatsune are round to somewhat

FIG. 11. Geologic map of the eastern part of Tottori Prefecture (compiled from Figs. 2 and 7).
1: Latest Miocene to Pleistocene volcanic rocks, 2–6: Intrusive rocks (2: rhyolite, 3: dacite, 4: andesite, 5: dolerite, 6: Fuchimi Diorite). 7–14: Tottori Group (7: Shichiyama Sandstone and Mudstone Member, 8: Aragane Pyroclastic Member, 9: Oda Andesite Member, 10: Fuganji Mudstone Member, 11: Moroga Conglomerate Member, 12: Entsuji Conglomerate and Sandstone Member, 13: Kawabara Volcanic Member, 14: Koge Conglomerate Member). 15–21: Basement rocks (15: Kyushozan Granite, 16: Tottori Granite, 17: Hanabara Complex, 18: Yadagawa Group, 19: Tsunotani Formation, 20: ultramafic to mafic rocks, 21: Shitani Formation). 22: Fold axis, 23: Fault.

elongated in shape with a length of about 1.5 to 2 kilometers. They are composed mainly of light green to green porphyritic hypersthene-augite dacite which locally grades into augite dacite. Microscopically, phenocrysts and microphenocrysts of plagioclase, quartz, augite, hypersthene and opaque minerals are commonly present in a microcrystalline groundmass. Zeolite, saponite, epidote, calcite etc. are found as alteration products. The country rocks are affected by weak contact metamorphism.

The masses exposed to the south of Aragane and Oda are composed mainly of highly altered light green porphyritic dacite. Microscopically, phenocrysts of plagioclase, alkali feldspar, clinopyroxene? and opaque minerals are embedded usually in a fine-textured groundmass with flow structure (rarely in a cryptocrystalline one). Secondary minerals are sericite, saponite, calcite and so on. The country rocks show weak signs of contact metamorphism.

The rock body found to the west of Ikedani is composed of augite dacite. Microscopically, plagioclase, quartz, augite and opaque minerals are present as phenocrysts. Groundmass is vitreous, with perlitic cracks. Zeolite, saponite etc. are seen as secondary minerals. Contact metamorphic effect is partly observed on surrounding rocks.

Rhyolite

The rhyolite, occurring as stocks or dykes, is roughly divided into the following two rock types.

The rock bodies found scatteringly in the northeastern part of the investigated area intrude into the Fuganji Mudstone, Oda Andesite and Aragane Pyroclastic Members. Generally, the rocks are subjected to conspicuous alteration. Flow structure is partly observed, and spherulites are included. Microscopically, plagioclase, quartz, alkali feldspar, biotite (pseudomorph) and opaque minerals are present as phenocrysts. Groundmass is cryptocrystalline or microfelsitic. Alteration minerals are sericite, saponite etc..

The rock bodies exposed in the vicinity of Mukoyama, Iwatsune and Kurami consist wholly of gray to grayish white quartz porphyry. Microscopically, phenocrysts are made up of plagioclase, quartz, alkali feldspar, biotite (pseudomorph) and opaque minerals. Groundmass is cryptocrystalline or microfelsitic. Sericite, saponite, epidote etc. are observed as alteration products. The country rocks are affected by weak contact metamorphism.

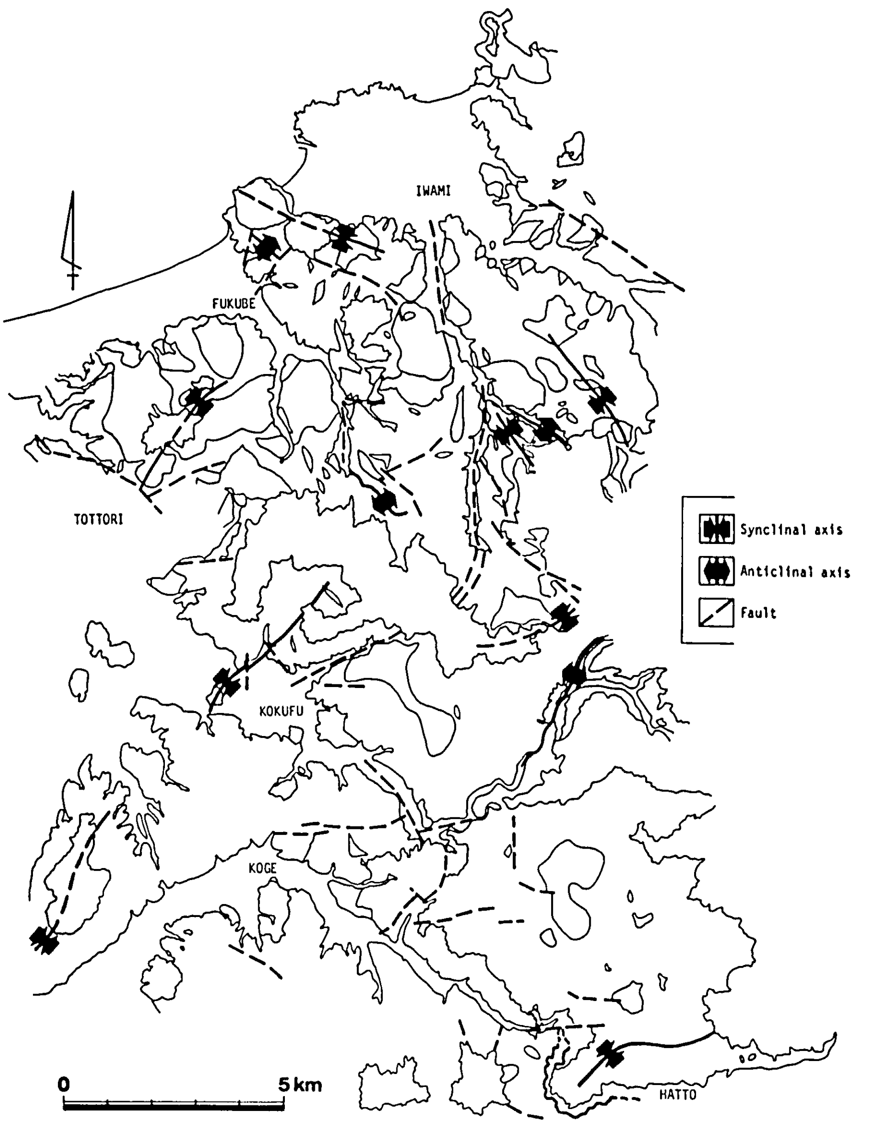


FIG. 12. Structural outline of the eastern part of Tottori Prefecture.

D. Latest Miocene to Pleistocene Volcanic Rocks

The Latest Miocene to Pleistocene volcanic rocks (Matsumoto, 1986) are widely distributed in the central to eastern part of the investigated area, and are also found scatteringly in the northern part (Fig. 11). They unconformably cover the Tottori Group, and are composed of lavas of basalt, andesite and dacite as well as andesitic and dacitic pyroclastic rocks. The thickness exceeds 150 meters. As already described by Tottori Prefecture (1966), lavas of olivine basalt, augite-olivine basalt, olivine andesite, hypersthene-augite andesite and hornblende andesite and also andesitic pyroclastics are recognizable as basaltic to andesitic rocks. In addition, dacitic rocks such as lavas of hypersthene-augite dacite and dacitic welded tuff are distributed in the vicinity of Mt. Shichi and to the north of Kurami.

The hypersthene-augite dacite is light brown in color, showing flow structure. It intrudes locally into the Shichiyama Sandstone and Mudstone Member in the vicinity of the Shichiyama Pass. Microscopically, phenocrysts of plagioclase, augite, hypersthene and opaque minerals are embedded in a cryptocrystalline groundmass.

The dacitic welded tuff is fine-grained, hard, compact and dark brown in color. It is densely welded. Microscopically, fragments of crystals of plagioclase, quartz, augite, hypersthene and opaque minerals, as well as lithic fragments of andesite, dacite, felsic tuff, granitic rocks etc. are embedded in a eutaxitic, glassy matrix.

IV. Geologic Structure

The features of faults and folds found in the Tottori Group and its basement rocks are as follows (Figs. 2, 7, 11 and 12).

Basement rocks

Faults

Three faults of N-S, NW-SE and N-S to NW-SE trends are presumable in the southern part of the mapped area (Figs. 2 and 11). Structurally, it is considered that the eastern to northeastern blocks of these faults are upheaved against the western to southwestern ones. There are observed two low-angle faults of NW-SE trend to the south of Ochiiwa. The block bounded on its both sides by these low-angle faults is relatively upheaved against the adjacent blocks. Some of the faults have horizontal slip component in greater or less degree.

Tottori Group

Faults

The faults of NE-SW, NW-SE, NNW-SSE, E-W to ENE-WSW, and N-S to NNE-SSW trends are presumed at many places. Judging from structural and stratigraphical evidences, it is inferred that the southeastern blocks of NE-SW faults, the southwestern blocks of NW-SE faults and the southern blocks of E-W to ENE-WSW faults are upheaved against the opposite blocks, though there are a few exceptions. These faults tend to form step faults. In the case of NNW-SSE and N-S to NNE-SSW faults, the eastern or western blocks are upheaved against the opposite ones. Several faults of NW-SE trend cut the faults of ENE-WSW and NE-SW trends and the fold axes striking NE-SW. There is also a fault of N-S to NNE-SSW direction cutting a fold axis of NE-SW one. Some of the faults have horizontal slip component more or less.

Folds

synclines

The synclines with axes running in NNE-SSW, NW-SE, NE-SW, NE-SW to ENE-WSW and E-W to NE-SW trends are present at some places. The axis of syncline located to the east of Koeji runs in NNE-SSW trend, and plunges gently NNE in the south and SSW in the north. The axes of synclines running in NW-SE trend plunge NW, and those running in NE-SW, NE-SW to ENE-WSW and E-W to NE-SW trends plunge NE to ENE at a low angle. These axes extend only for a distance of 2 to 4 kilometers. The intensity of folds is usually very gentle.

anticlines

There are anticlines with axes running in NNE-SSW and NW-SE trends at some places. The anticlinal axis at Tochimoto plunges gently NNE. These anticlinal axes continue only for a distance of 1 to 4 kilometers. In general, strata on both wings dip with a low angle.

V. Fossils

The Yazu Formation of the Tottori Group scarcely yields fossils. On the contrary, abundant animal as well as plant fossils have been reported from the Iwami Formation.

Yamana (1977, 1979) has reported *Chlamys* sp. from a block of tuff derived from the Kawabara Volcanic Member. The block is, however, considered to be derived in reality from the Moroga Conglomerate Member.

The Moroga Conglomerate Member yields molluscan fossils such as *Vicarya* and *Geloina*, which indicate mostly brackish, mangrove swampy environment of subtropical to tropical water (Yabe and Hatai, 1938; Nishiwaki and Imamura, 1956; Wadatsumi and Matsumoto, 1958; Imamura *et al.*, 1962; Tottori Prefecture, 1966; Ozaki and Yamana, 1972; Sawai *et al.*, 1973; Yamana, 1962, 1977, 1979; Uemura *et al.*, 1979; see Table 5).

Relatively well-preserved plant fossils are contained in the lowermost part of the Fuganji Mudstone Member (Table 6). This fossil flora including *Liquidambar, Cinnamomum, Castanea* etc. closely resembles the Daijima-type flora (Yamana, 1968; Hojo, 1973).

Abundant marine fossils have been reported from the main part of the Fuganji Mudstone Member by Tai (1959), Tottori Prefecture (1966), Sawai *et al.* (1973), Yamana (1962, 1972, 1977, 1979), Uemura *et al.* (1979) and Dewaki (1984). Tai (1959) has pointed out that two faunules of smaller foraminifers, namely, *Martinottiella-Sigmoilina-Lagenonodosaria* faunule below and *Cyclammina* faunule above are recognized in the Fuganji Member. He has mentioned that the *Martinottiella-Sigmoilina-Lagenonodosaria* faunule corresponds to the upper part of *Lagenonodosaria scalaris-Uvigerina crassicostata* zone and the *Cyclammina* faunule to the lower part of *Cyclammina orbicularis-Martinottiella communis* zone (Table 7).

TABLE 5. LIST OF MOLLUSCAN FOSSILS FROM THE MOROGA CONGLOMERATE MEMBER (AFTER NISHIWAKI AND IMAMURA, 1956; WADATSUMI AND MATSUMOTO, 1958; IMAMURA *et al.*, 1962; TOTTORI PREFECTURE, 1966; OZAKI AND YAMANA, 1972; YAMANA, 1962, 1977, 1979).

Anadara (*Hataiarca*) *daitokudoensis* Makiyama
Striarca uetsukiensis (Hatai et Nishiyama)
Mytilus sp.
Chlamys nisataiensis Otuka
C. notoensis (Yokoyama)
C. sp.
Patinopecten cf. *kimurai* (Yokoyama)
P. cf. *kagamianus nimaensis* Masuda
P. cf. *nakajimai* Masuda
Aequipecten yanagawaensis (Nomura et Zinbo)
Mizuhopecten sp.
Masudapecten cf. *iwasakiensis* (Nomura)
Crassostrea sp.
Conchocele sp.
Ctena sp.
Geloina sp.
Dosinia nomurai Otuka
Tapes (*Siratoria*) *siratoriensis* Otuka
Cyclina sp.
Cultellus izumoensis Yokoyama
Panope sp.
Pholadomya cf. *turunagai* Tan
Turbo cf. *ozawai* Otuka
Turritella sp.
Cerithidea sp.
Batillaria (*Tateiwaia*) *yamanarii* Makiyama
Vicarya callosa japonica Yabe et Hatai
Vicaryella ishiiana (yokoyama)
Bittium sp.
Natica sp.
Chicoreus tiganouranus (Nomura)
Riuguhdrillia sp.

TABLE 6. LIST OF PLANT FOSSILS FROM THE FUGANJI MUDSTONE MEMBER (AFTER TOTTORI PREFECTURE, 1966; YAMANA, 1968; HOJO, 1973).

Pinus sp.
Glyptostrobus europaeus (Brongniart)
Metasequoia occidentalis (Newberry)
Salix sp.
Comptonia naumanni (Nathorst)
Carya sp.
Juglans japonica Tanai
J. sp.
Pterocarya asymmetrosa Konno
Alnus sp.
Betula cf. *nipponica* Tanai
Carpinus miocenica Tanai
C. cf. *stenophylla* Nathorst
C. subcordata Nathorst
C. sp.
Castanea ungeri Heer
Quercus sinomiocenicum Hu et Chaney
Q. sp.
Ulmus protojaponica Tanai et Onoe
Zelkova ungeri (Ettingshausen)
Cinnamomum lanceolatum (Unger)
Lindera sp.
Machilus ugoana Huzioka
Neolitsea sp.
Hydrangea sp.
Liquidambar miocenica Hu et Chaney
Entada cf. *mioformorsana* Tanai
Wistaria sp.
Acer protojaponicum Tanai et Onoe
Tilia sp.
Alangium aequalifolium (Goeppert)

TABLE 7. LIST OF FORAMINIFERS FROM THE FUGANJI MUDSTONE MEMBER (AFTER TAI, 1959).

Species \ Zones	*Ls-Uc* Z				*Co-Mc* Z		
Fauns.	*M-S-F*				*C-F*		
Locs.	1	2	3	4	5	6	7
Bathysiphon sp.		+					
Haplophragmoides cf. *trullissatum* (Brady)			+				
H. sp.	+						
Cribrostomoides cf. *kyushuense* Asano			+				
C. sp.			+				
Cyclammina cf. *incisa* (Stache)	+	+					+
C. pusilla Brady	+						
C. sp.							+
Plectina nipponica Asano			+				
Martinottiella communis (d'Orbigny)		+	+	+	+	+	
Sigmoilina imamurai Tai		+	+				
S. cf. *schlumbergeri* Silvestri			+				
S. sp.							
Miliolinella cf. *circularis* (Bornemann)	+						
Pyrgo sp.	+						
Trochammina cf. *nobensis* Asano	+						
T. sp.	+		+	+			
Robulus sp.	+						
Dentalina sp.	+		+				
Lagenonodosaria scalaris sagamiensis Asano		+				+	
L. sp.		+				+	
Lagena sulcata spicata Cushman and McCulloch		+					
Oolina cf. *hexagona* (Williamson)						+	
Uvigerina crassicostata Schwager	+						
Gyroidina orbicularis d'Orbigny	+						
Rotalia takanabensis (Ishizaki)	+						
Cassidulina laevigata carinata Cushman	+						
C. cf. *margareta* Karrer	+						
Cibicides lobatulus (Walker and Jacob)	+						
Globigerina bulloides d'Orbigny	+			+			

Ls-Uc Z: *Lagenonodosaria scalaris-Uvigerina crassicostata* Zone, *Co-Mc* Z: *Cyclammina orbicularis-Martinottiella communis* Zone, *M-S-F*: *Martinottiella-Sigmoilina-Lagenonodosaria* Faunule, *C-F*: *Cyclammina* Faunule.

The former zone defines the middle to upper Miyoshian stage, while the latter the Iwami-Otan stage. YAMANA (1977) has stated that the molluscan fossils from the Fuganji Member are characterized by acestid together with the constituents of the Higashibessho fauna of KASENO (1964).

Marine macrofossils collected by the author from the Fuganji Mudstone Member are listed in Table 8. Two molluscan assemblages, i.e., *Acesta* assemblage and *Propeamussium-Delectopecten* assemblage are recognized in the middle to upper part of the Fuganji Member. The horizon of the *Acesta* assemblage is slightly lower than that of the *Propeamussium-Delectopecten* assemblage.

Acesta assemblage (Loc. Tm 8)
Chief elements: *Acesta* (*Acesta*) *goliath*, *Acesta* (*Acesta*) cf. *goliath*
Accessory elements: *Gloripallium izurensis*, *Acesta* (*Plicacesta*) *watanabei*, *Limatula* (*Limatula*) cf. *vladivostokensis*, etc.

The present assemblage occurs in black mudstone. Shell remains are crowded and the great majority of them are disarticulated. They are, however, hardly broken. Judging from the mode of occurrence and the state of preservation, this assemblage is considered to be para-autochthonous.

Propeamussium-Delectopecten assemblage (Loc. Tm 6, Tm 10)
Chief elements: *Propeamussium* sp. (n. sp.), *Delectopecten peckhami*, *Linthia* sp.
Accessory elements: *Solemya* (*Acharax*) cf. *tokunagai*, *Propeamussium tateiwai*, *Lucinoma* sp., etc.

The present assemblage is also obtained from black mudstone. Fossils are usually found sporadically, but valves of *Delectopecten* occur sometimes in layer. They are mostly disarticulated, but not damaged. The mode of occurrence and the state of preservation indicate autochthonous to para-autochthonous origin.

It is considered that the *Acesta* and *Propeamussium-Delectopecten* assemblages inhabited the lower part of outer sublittoral zone to bathyal zone with muddy bottom. Therefore, the middle to upper part of the Fuganji Mudstone Member might have been deposited under relatively deep sea condition.

Judging from both the litho- and bio-facies, the sedimentary environments of the Iwami Formation of the Tottori Group may be briefly summed up as follows (see also Chapter VI). The lowermost part of the Entsuji Conglomerate and Sandstone and Fuganji Mudstone Members is considered to have accumulated under fresh-water condition (MATSUMOTO, 1986). Subsequently the regional transgression took place, and the Moroga Conglomerate Member as well as the upper part of the Entsuji Conglomerate and Sandstone Member were deposited under brackish to shallow sea environment. The sea became deeper, and the middle to upper part of the Fuganji Mudstone Member including the *Acesta* and *Propeamussium-Delectopecten* assemblages was deposited at the time of maximum transgression of Middle Miocene age.

VI. CONSIDERATIONS ON THE GEOLOGIC HISTORY

A. CORRELATION

The correlation among the Miocene series of various areas in Japan is summarized in Table 9. For this purpose, fossil evidences and stratigraphic records such as sequence of strata and lithofacies, together with the volcanism, are taken into consideration. Some remarks are given below.

The Yazu Formation is characterized by a dominance of remarkably altered volcanic rocks of andesite to dacite origin. It is correlated with the Hata Formation in the San-in Province based on the stratigraphic position and lithologic characters. As the volcanic rocks are predominant in the Yazu Formation and its equivalents, it is impossible to conclude the precise geological age. However, the radiometric age determination by fission track and K-Ar methods for the volcanic rocks from various areas reveals that the lower part was formed at about 20.9-23.7 Ma and the upper part at about 15.2-16.4 Ma (SHIBATA, 1973; MATSUDA, 1979; SUZUKI, 1980; TSUCHI and IGCP-114 NATIONAL WORKING GROUP OF JAPAN, 1981; TSUCHI *et al.*, 1981; GANZAWA, 1983; KANO and YOSHIDA, 1984; WADATSUMI, 1984 and others).

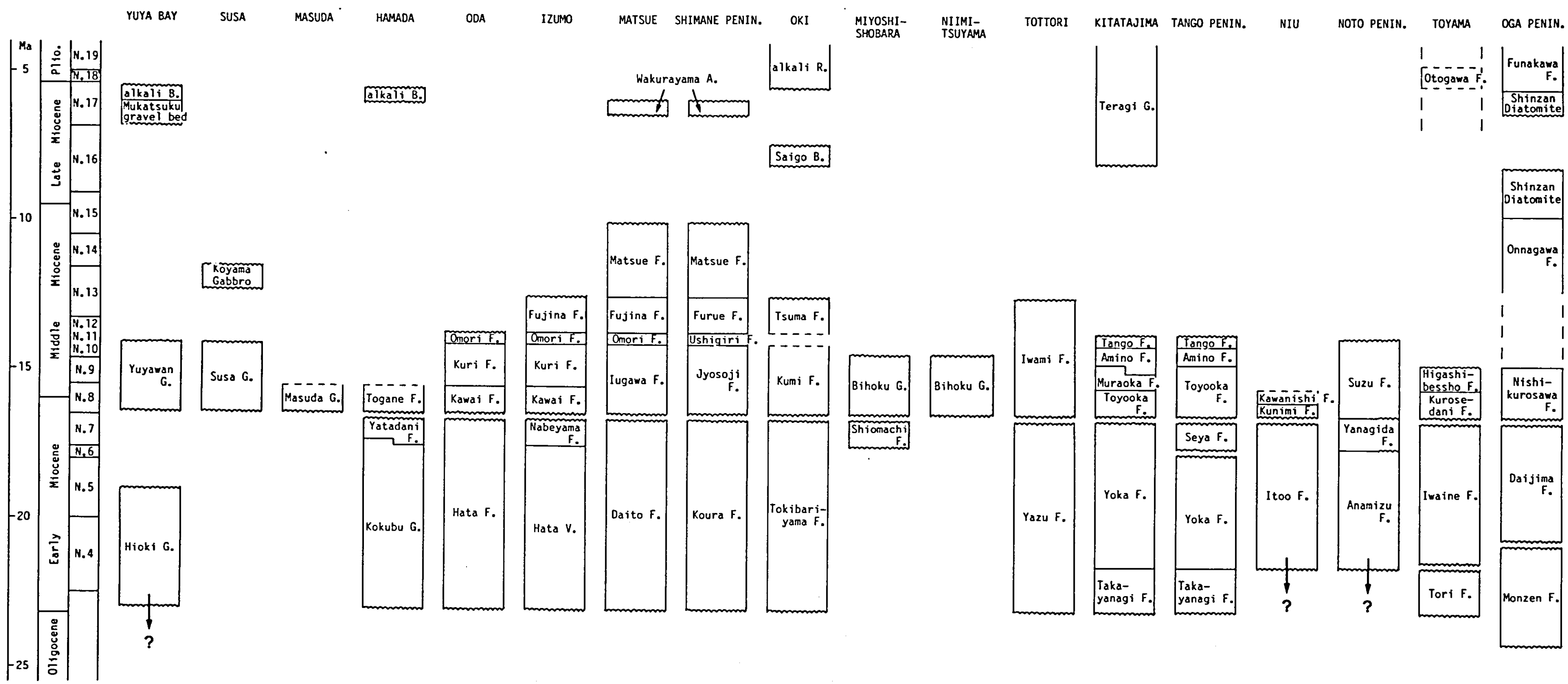
The Iwami Formation is composed of a thick series of clastic sediments and volcanic rocks, and is characterized by the occurrence of abundant animal fossils. It is correlated with the Kawai-Kuri-Omori-Fujina Formation in the San-in Province on the basis

TABLE 8. LIST OF MARINE FOSSILS FROM THE FUGANJI MUDSTONE MEMBER. (FOSSIL LOCALITIES ARE SHOWN IN FIGS. 5 AND 10).

Specific Name \ Fossil Localities	Tm 1	Tm 2	Tm 3	Tm 4	Tm 5	Tm 6	Tm 7	Tm 8	Tm 9	Tm 10	Tm 11	Tm 12	Tm 13	Tm 14
Solemya (*Acharax*) cf. *tokunagai* (Yokoyama)									+					+
Acila (*Truncacila*) sp.				+										
Acila sp.		+												
Saccella sp.			+											
Propeamussium tateiwai Kanehara					+	+				+	+			+
P. cf. *tateiwai* Kanehara	+		+								+			
P. sp. (n. sp.)					++++			+	++++					
P. ? sp.					+				+					
Delectopecten peckhami (Gabb)					+	+	+		++++	+	+		+	
Chlamys nisataiensis Otuka												+		
C. sp.												+		
C. ? sp.												+		
Gloripallium izurensis Masuda							+							
G. cf. *izurensis* Masuda							+							
G. sp.							+							
G. ? sp.							+							
Acesta (*Acesta*) *goliath* (Sowerby)							+++							
A. (*A.*) cf. *goliath* (Sowerby)							++++							
A. (*Plicacesta*) *watanabei* Nakano et Okamoto							+							
A. (*P.*) sp.						+	+							
Lima ? sp.							+							
Limatula (*Limatula*) cf. *vladivostokensis* Scarlato							+				+			
Lucinoma sp.				+	+	+	+							
Lucinoma ? sp.						+								
Dosinia (*Phacosoma*) *nomurai* Otuka												+		
Oxyperas osawanoensis Tsuda												+		
Panomya sp.					+									
Periploma sp.							+							
Gastropoda gen. et sp. indet.							+				+			
Fissidentalium sp.	+		+			++					+			
Brachiopoda gen. et sp. indet.							+++							
Linthia sp.					++				+++					
Carcharhinus sp.				+										

number of individuals : + (<5), ++ (5-9), +++ (10-19), ++++ (≧20)

TABLE 9. CORRELATION OF THE NEOGENE STRATA IN VARIOUS AREAS IN JAPAN. (ADAPTED FROM TSUCHI AND IGCP-114 NATIONAL WORKING GROUP OF JAPAN, 1981; KANO AND NAKANO, 1985 AND OTHERS).



G: Group, F: Formation, V: Volcanics, B: Basalt, A: Andesite, R: Rhyolite.

of stratigraphic position and lithofacies as well as of fossil evidences. As the Moroga Conglomerate Member is composed mainly of medium- to coarse-grained clastic sediments and yields important molluscan fossils such as *Vicarya* and *Geloina* (YABE and HATAI, 1938; SAWAI *et al.*, 1973; YAMANA, 1977 and others), it is roughly correlated with the Kawai Formation. Generally, the *Vicarya-Geloina-Telescopium* assemblage characterizing the Kadonosawa and Kurosedani faunas occurs in the horizon of *Miogypsina* and *Operculina* (TSUCHI, 1981, 1983). According to the biostratigraphic examination of planktonic foraminifers coexisting with larger foraminifers, the *Miogypsina-Operculina* horizon corresponds commonly to the N.8 of BLOW (1969) and rarely to the base of the N.9 (IBARAKI, 1981). The Fuganji Mudstone Member consists of a thick series of mudstone with intercalated felsic pyroclastic rocks, and yields abundant molluscan fossils of deep sea type such as *Acharax, Acesta, Propeamussium* and *Delectopecten* (SAWAI *et al.*, 1973; YAMANA, 1977; MATSUMOTO, 1986 and others). Furthermore, according to the study of benthonic foraminifers by TAI (1959), the Foram. Sharp Line (TAI, 1963), which corresponds nearly to the boundary between Blow's N.9 and N.10 (TAI and KATO, 1979; MAIYA and INOUE, 1981; TAI, 1982), is drawn in this member. From the evidence of fossils, the Fuganji Member is almost correlative with the Kuri Formation. The Oda Andesite and Aragane Pyroclastic Members are characterized by the development of volcanic rocks, and are probably correlated with the Omori Formation, judging from the stratigraphic position and lithofacies. The molluscan assemblage closely related to the Kadonosawa fauna has been obtained from the upper part of the Omori Formation (OKAMOTO and IMAMURA, 1971; OGASAWARA and NOMURA, 1980). The Shichiyama Sandstone and Mudstone Member consists mainly of clastic rocks with accompanied pyroclastics. It is presumably compared with the Fujina, Furue and Tsuma Formations, all in the San-in Province, though lacking in available fossils. From the Fujina and Tsuma Formations, the constituents of the Shiobara and Yama faunas have been obtained (SUEHIRO, 1979; OGASAWARA and NOMURA, 1980; OKAMOTO. 1981a, b; OKUBO, 1981). Moreover, the foraminifers from the Fujina, Furue and Tsuma Formations show Middle Miocene in age (TAI and KATO, 1980; NOMURA, 1984).

B. VOLCANISM

With regard to the volcanic activity during the deposition of the Tottori Group, two stages of Yazu and Iwami are distinguishable on the basis of the stratigraphic position and lithology of volcanic rocks, together with the scale of volcanism. The characteristics of the volcanic activity in each stage are summarized as follows.

Yazu stage

The volcanic activity of the Yazu stage is represented by the Kawabara Volcanic Member. However, the pioneering volcanism might have taken place during the deposition of the Koge Conglomerate Member, because pebbles and cobbles of andesite similar in lithology to lavas (pyroxene andesite) of the Kawabara Volcanic Member are contained in the upper part of the Koge. The Kawabara Member is characterized by a thick series of andesite lavas and andesitic to dacitic pyroclastic rocks. From the stratigraphic succession, it is considered that relatively quiet outpourings of lavas and violent explosions of pyroclastic fragments were alternated with each other. Furthermore, the thick accumulations of lavas and pyroclastics near the center of distributional area suggests that these extrusive rocks might have mostly been ejected and deposited in situ by central eruption.

Because the andesitic lapilli tuff and tuff breccia of the k_1 and k_3 units of the Kawabara Volcanic Member commonly exhibit stratification, they were presumably deposited under aquatic environment. Afterwards, the sedimentary basin was gradually filled up, and the welded tuff of k_{4-1} accumulated on dry land in the southern to southeastern part of the area. The volcanic conglomerate of k_6 unit is restricted in distribution within the central to northern part (Fig. 6). Moreover, cobbles of andesite and welded tuff partly derived from the underlying units (k_{4-1}, k_5) are included in the conglomerate. The k_8 unit is characterized by welded tuff (k_{8-2}) in the southern to southeastern part and by pumice tuff showing partly stratification (k_{8-1}) in the central to northwestern part. So far as the k_4, k_6 and k_8 units are concerned, there is a tendendy that these units accumulated under aquatic environment in the central to northwestern part and on dry land in the southern part (Fig. 16). On the other hand, it is generally difficult to find out such tendency with regard to the lava flows of k_2, k_5 and k_7. The andesite lavas of k_{9-1} partly indicate autobrecciated structure. Locally, columnar joints are also observable. Thin layers of dacitic lapilli tuff and tuffaceous sandstone are intercalated, and the lapilli tuff changes laterally into welded tuff. These features may indicate that the k_9 unit was deposited mainly on land, and partly under aquatic environment.

Iwami stage

The volcanic activity of the Iwami stage is represented by the Oda Andesite and Aragane Pyroclastic Members. The former is characterized by andesitic lavas and pyroclastics, while the latter by a dominance of dacitic pyroclastic rocks. Judging from the lithology of these eruptive rocks, it is considered that relatively quiet outpourings of lava flows and explosive extrusions of a large amount of fragmental volcanic materials took place during the Iwami time.

The Aragane Pyroclastic Member is composed mainly of lapilli tuff, pumice tuff and tuff. The lapilli tuff is mostly exposed in the western part of the distributed area, where it attains a maximum thickness. The lapilli tuff intercalates thin layers of tuff breccia in the northwestern part. On the other hand, it changes rapidly into pumice tuff and tuff toward the east and the south, where such coarse-grained rocks as tuff breccia cannot be observed. Moreover, the size of fragments in pumice tuff decreases slightly southward. These features suggest that the pyroclastic rocks of the Aragane Member were erupted through vents probably located in the northwestern part of the mapped area or to the farther northwest. Layers of tuff of the Aragane Member are traceable to thin intercalations in the Fuganji Mudstone Member, as far as the southeastern part of the Tottori area (Fig. 11). This fact may support the author's previous assumption (MATSUMOTO, 1986) that constituents of tuff beds in the Fuganji Member distributed in the southeastern Tottori area were probably brought from the farther northwestern part of the investigated area. On the other hand, the lava flows of the Oda Andesite Member are exposed discontinuously, and it is considered that they were welled out through several vents. From the distribution, it is clear that the northward shifting of eruptive center took place from the Yazu to the Iwami stage.

Secondly, we shall consider the environment under which the volcanic rocks were deposited. The Oda Andesite Member laterally thins out in the upper part of the Fuganji Mudstone Member which contains marine fossils. It is composed of lava flows and pyroclastics of andesite. The lava flows indicate autobrecciated structure in part and grade into hyaloclastite, while the pyroclastic rocks show stratification in finer-grained part and yield a broken piece of molluscan fossil. These facts may suggest that the extrusive rocks of the Oda Member were deposited under aquatic (probably marine) environment. The Aragane Pyroclastic Member is interfingering with the upper part of the Fuganji Member. The lapilli tuff exposed in the western part is commonly massive, but it is stratified and intercalates mudstone beds in the lower part. Therefore, this part of the Aragane Member was probably deposited under marine environment. Afterwards, the sedimentary basin was gradually filled up by volcanic materials, and the upper part might have at least partly accumulated on dry land. Meanwhile, the pumice tuff and tuff cropping out in the eastern and southern parts exhibit usually stratification, and are interbedded with mudstone, from which *Acharax*, *Propeamussium* and *Delectopecten* have been obtained. Therefore, these pumice tuff and tuff are considered to have been deposited under relatively deep sea condition.

C. SEDIMENTARY ENVIRONMENT IN THE IWAMI STAGE

The Iwami Formation of the Tottori Group is characterized by thick piles of various kinds of clastic and volcanic rocks. Marine fossils occur widely from the clastic rocks, and plant remains are also found locally. In this chapter, sedimentary environments of the three members of the Iwami Formation, i. e., the Entsuji Conglomerate and Sandstone, Moroga Conglomerate and Fuganji Mudstone Members are discussed. Some remarks on sedimentary environments of the Yazu Formation and the Shichiyama Sandstone and Mudstone Member are also added.

The sedimentary environment of the Iwami Formation shows some local variation. Molluscan fossils indicating brackish-water to shallow sea condition in subtropical to tropical climate have been reported from the Moroga Conglomerate Member distributed in the eastern part of the surveyed area (NISHIWAKI and IMAMURA, 1956; OZAKI and YAMANA, 1972 and others). The conformably overlying middle to upper part of the Fuganji Mudstone Member yields abundant molluscan fossils of deep sea type, such as *Acesta*, *Propeamussium* and *Delectopecten* (Table 8). Judging from both the lithofacies and the faunal assemblages, the sedimentary environment might have rapidly changed from brackish-water or shallow sea to deeper sea (lower part of outer sublittoral zone to bathyal zone) during the Iwami time.

In the western part of the area, no molluscan fossils indicating the definite environment are obtained from the lower part of the Iwami Formation. However, the type I mudstone developed in the lower part of the author's Fuganji Member yields plant fossils belonging to the Daijima-type flora (Table 6). From the mode of occurrence of fossils and from the lithofacies, this mudstone is possibly of non-marine origin (IMAMURA *et al.*, 1962; UEMURA *et al.*, 1979). In particular, the lowermost part exposed in the vicinity of Okamasu and Yamanoue is characterized by parallel-laminated, remarkably fissile mudstone containing numerous well-preserved plants, and therefore it was presumably deposited under fresh-water condition. As has been pointed out by UEMURA *et al.* (1979), there might have been effects of influx of river water from the south during the deposition of the Entsuji Member, which is interfingering with the lower part of the Fuganji Member. The main part of the type I mudstone might have probably accumulated in a basin like lagoon connected with sea and also influenced by fresh-water. Afterwards, the sea rapidly deepened, and the middle to upper part of the Fuganji Member represented by the type II mudstone was deposited under rather deep sea condition.

YAMANA (1977, 1979) has stated that *Chlamys* sp. has been obtained from a block of tuff derived from the author's Kawabara Volcanic Member of the Yazu Formation, and that at least the upper part of the member is of marine origin. But, the fossiliferous block may be derived in reality from the Moroga Conglomerate Member. Thus, the exact depositional environment of the Yazu Formation is unknown. There are no available data concerning the sedimentary environment of the Shichiyama Sandstone and Mudstone Member, except for the occurrence of ill-preserved specimens of echinoids from mudstone.

D. DEVELOPMENT OF SEDIMENTARY BASINS AND THE UPLIFTING OF SOUTHWEST JAPAN ARC

As a result of the recent progress of petroleum geology and the increasing data of geophysical prospecting and drilling, our knowledge on the development of sedimentary basins in the Green Tuff regions has expanded rapidly. In this chapter, the migration of sedimentary basins and the tilting of basements are discussed through the data obtained from the onshore and offshore Tottori area. Some remarks on the uplifting of Southwest Japan Arc are also added.

1. *Migration of sedimentary basins*

Firstly, we shall examine into the change of thickness of the Neogene strata distributed in the eastern part of Tottori Prefecture. As shown on the stratigraphic profile in NW-SE direction (Fig. 13), the depocenter of the Yazu Formation is located in the central part of its distributional area. The formation is about 1000 meters in maximum thickness, and becomes gradually thinner southeastward. Toward the northwest, it also tends to thin step by step. The thickest part of the overlying Iwami Formation on land is located to the north of the depocenter of the Yazu Formation. The estimated thickness is 1200 meters there.

The recent data obtained by sonic prospecting reveals that the thick accumulation of the equivalent of Iwami Formation, together with the Middle to Upper Miocene and Pliocene strata, is found in the offshore Tottori basin and Oki trough (Figs. 14 and 15). In the offshore Tottori basin, the correlative of Iwami Formation and the Middle to Upper Miocene strata are about 1900 and 1800 meters in maximum thickness, respectively. The depocenter of the latter is situated to the north of that of the former. These strata become gradually thinner southward and also northward. The depocenter of the Pliocene strata is in the Oki trough further to the north. The thickness attains a maximum of about 5200 meters, but decreases gradually toward the south.

Thus, the depocenter clearly shifts toward the north from land to the Sea of Japan. Moreover, the strata in the Sea of Japan are thicker than those on land (Figs. 15 and 17). YANO (1980) has already stated that the depocenters of the Green Tuff sedimentary basins migrate from the island arc to the marginal sea both in Northeast Japan and in the Inner Zone of Southwest Japan without exception. The sedimentary imbricate structures produced by the migration of depocenters in the onshore and offshore Tottori area belong to the IA type of YANO (1980, 1982a, b), judging from the stratigraphic profiles and the relationship between the elongation of basins (or the direction of fold axes) and the direction of migration (Figs. 14, 15 and 17).

2. *Tilting of basements*

As shown on the stratigraphic profile (Fig. 13), the Yazu Formation commonly overlies the basements in the central to southeastern part, but it probably abuts on them in the central to northwestern part. Similarly, the Iwami Formation unconformably covers the Yazu Formation and in some cases the basement rocks, but it locally abuts on them in the northern part (MATSUMOTO, 1986). In the Sea of Japan (the offshore Tottori basin, Fig. 15), the correlative of Iwami Formation extensively covers the acoustic basements. It is, however, locally in fault contact with the offshore San-in ridge, the hanging wall of the fault being dragged up. In the same manner, the Middle to Upper Miocene strata commonly overlie the underlying rocks such as the correlative of Iwami Formation and the acoustic basements, but are in fault contact with the offshore San-in ridge with an upward dragging. Furthermore, the Pliocene strata generally cover the Middle to Upper Miocene strata and the acoustic basements, and are in fault contact with the Oki ridge further to the north with an upward dragging.

As mentioned above, each formation generally conformably or unconformably covers the underlying rocks, but abuts on or is in fault contact with the pre-Neogene rocks (on land) or the acoustic basements (in the Sea of Japan) at the northern margin. The faults are considered to be growth faults, judging from the upward dragging and a considerable difference in thickness of the Middle to Upper Miocene strata on both sides of the fault (Fig. 15). Furthermore, each formation tends to thicken northward, attaining a maximum thickness near the margin. These facts may

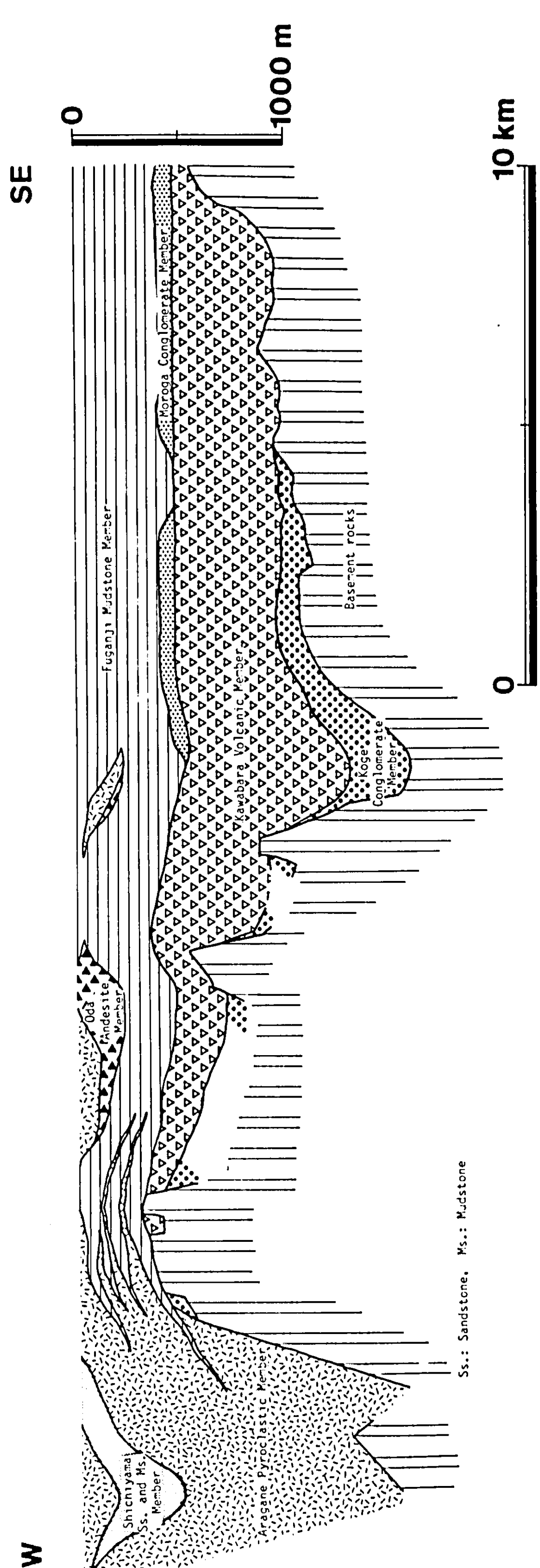


FIG. 13. Stratigraphic profile of the Tottori Group in the eastern part of Tottori Prefecture.

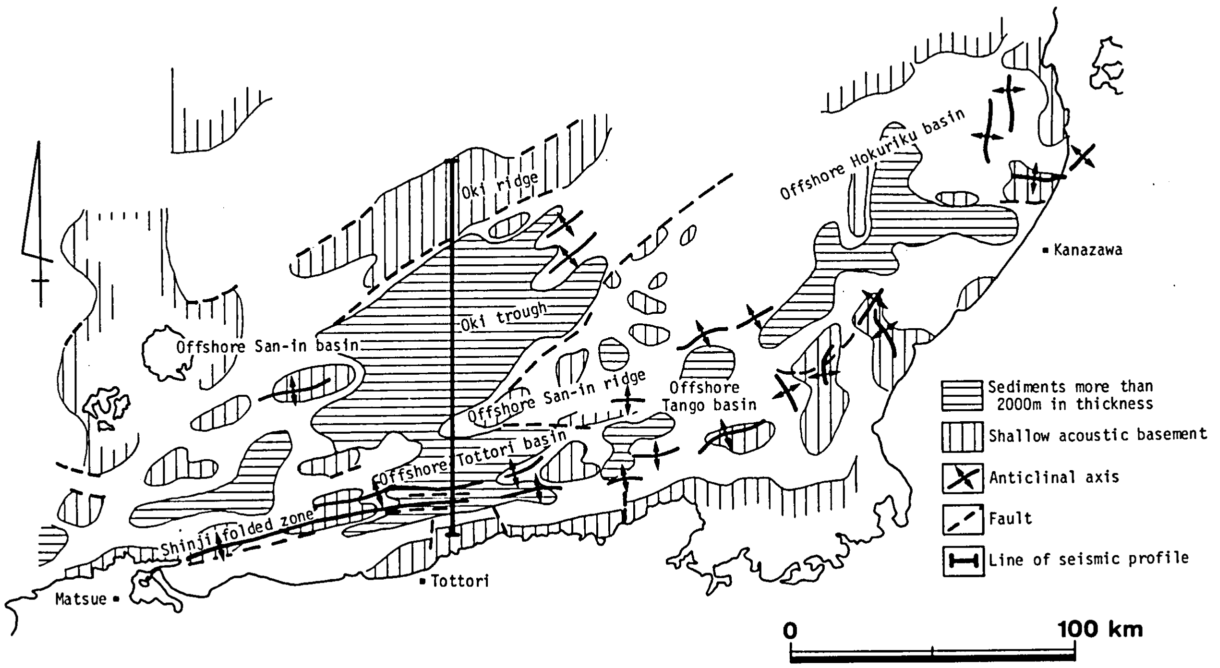


FIG. 14. Map showing the tectonic framework in the offshore San-in-Hokuriku region (adapted from TANAKA and OGUSA, 1981).

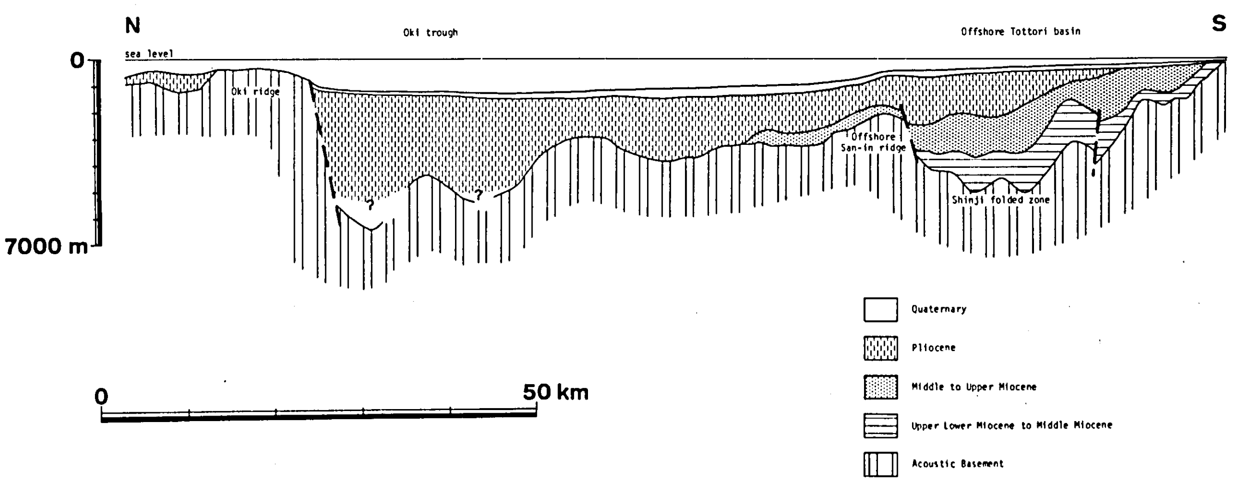


FIG. 15. Depth section based upon the seismic profile in the offshore San-in basin (after TANAKA and OGUSA, 1981).

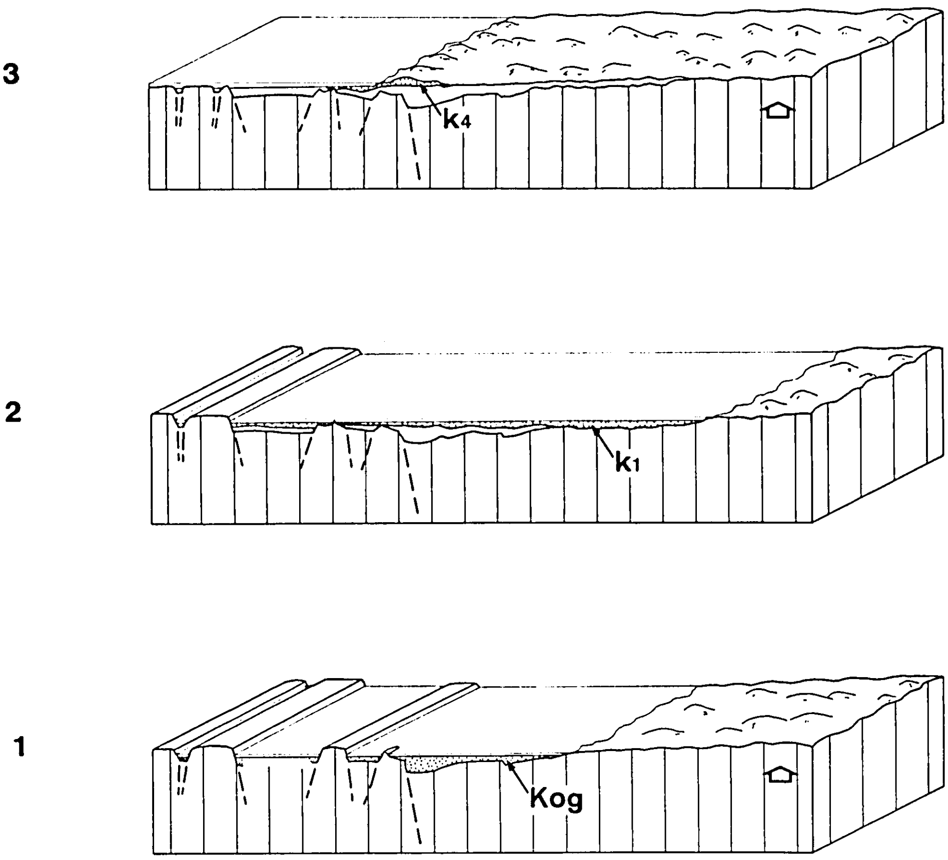


FIG. 16. Block diagram showing the sedimentary and tectonic history during Miocene time in the eastern part of Tottori Prefecture.
Kog: Koge Conglomerate Member, k_1, k_4, k_6 and k_8: unite name of the Kawabara Volcanic Member, Mor: Moroga Conglomerate Member, Iw: Iwami Formation.

indicate the tilting of basements accompanied with a group of longitudinal faults. At the same time, the following characters are recognizable concerning the geologic structure. (1) Each block tilts to the north with few exceptions. (2) The boundary faults are gravity faults in which the southern hanging walls have moved downward relative to the northern foot walls (Figs. 15, 16 and 17).

The k_4 and k_8 units of the Kawabara Volcanic Member of the Yazu Formation are composed of welded tuff in the southern to southeastern part of the distributed area, which passes into non-welded pyroclastic rocks toward the north to northwest (Figs. 2, 4, 6 and 16). The distribution of the volcanic conglomerate of k_6 unit is restricted within the central to northern part. Moreover, the conglomerate partly contains cobbles of andesite and welded tuff derived from the underlying units (k_5, k_{4-1}) (MATSUMOTO, 1986). Such a lateral change of lithofacies may indicate that the Kawabara Member was deposited under aquatic environment in the northern to northwestern part and on dry land in the southern to southeastern part.

The conglomerate of the lower part of the Entsuji Member contains abundant pebbles and cobbles of andesite derived from the Kawabara Volcanic Member and those of quartz schist and pelitic schist from the Sangun Metamorphic Rocks. On the other hand, the conglomerate of the upper part of the Entsuji Member and the Moroga Member is characterized by the dominance of pebbles and cobbles from the basement rocks, andesite pebbles being rare. The intercalated sandstone and conglomerate in the Fuganji Mudstone Member contain many rock fragments and pebbles derived from the Sangun Metamorphic Rocks, with minor amount of those from the Kawabara Volcanic Member (MATSUMOTO, 1986). The change of composi-

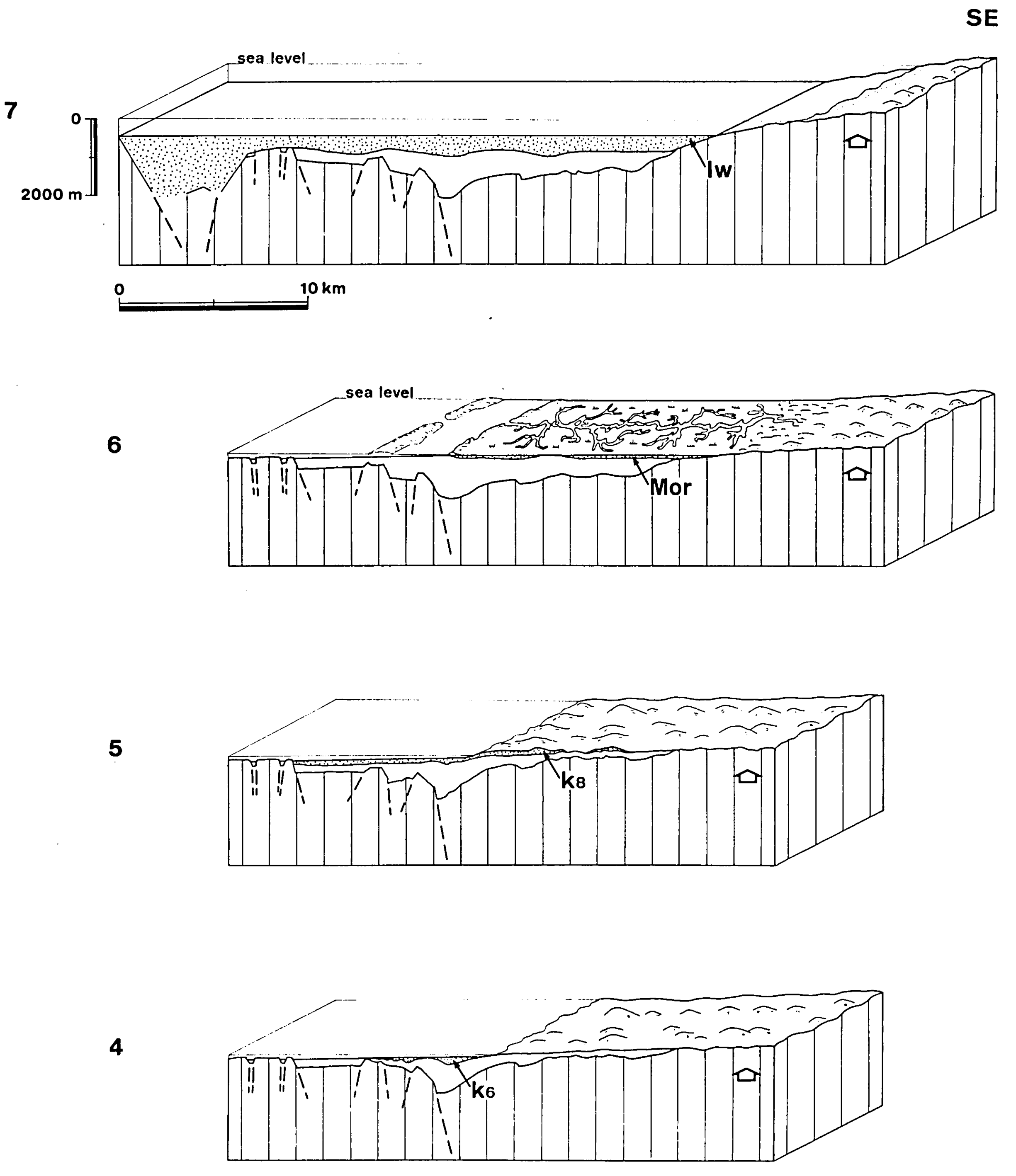


FIG. 16. (Continued).

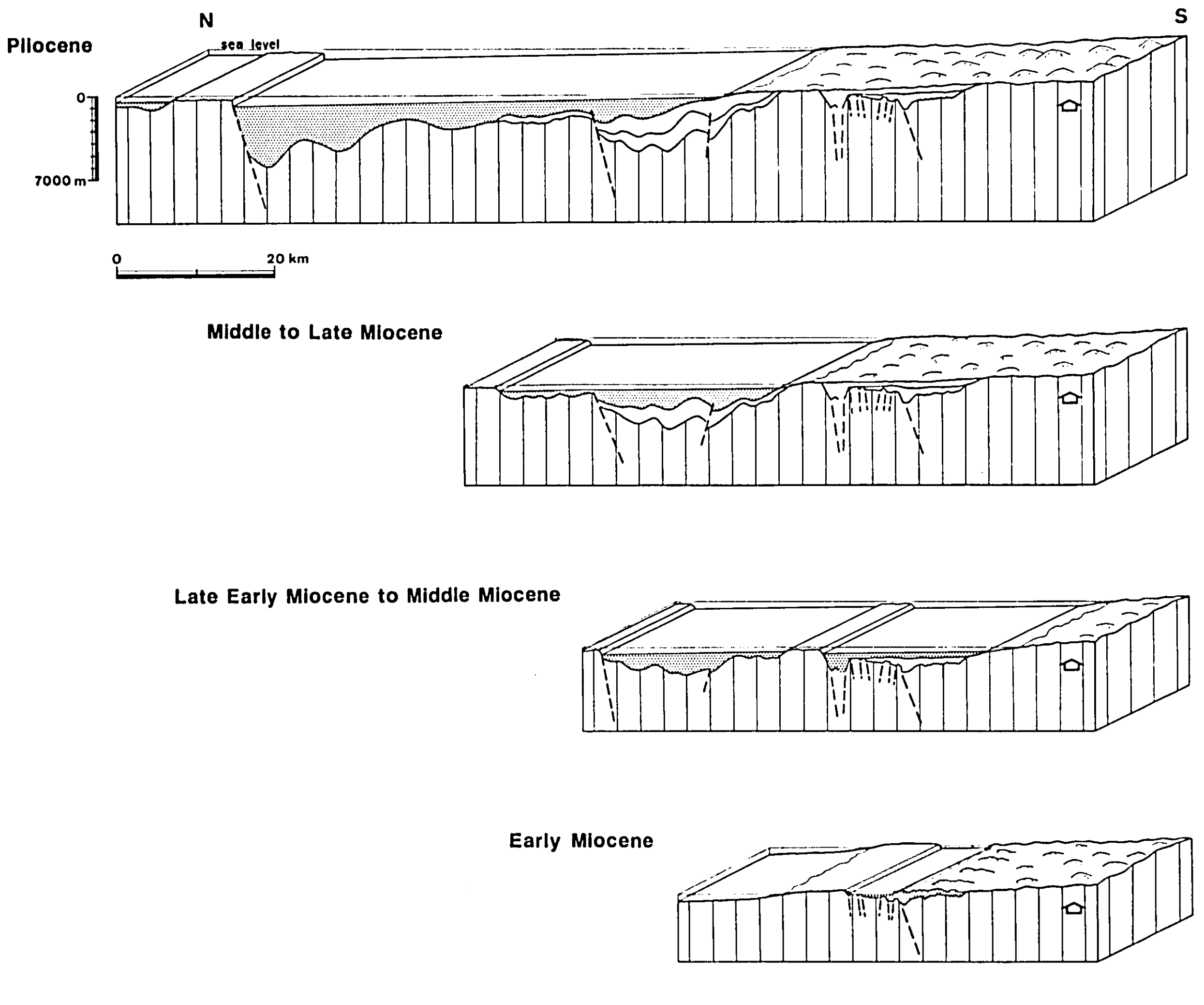


FIG. 17. Block diagram showing the sedimentary and tectonic history during Miocene to Pliocene time in the onshore and offshore Tottori area.

tion of conglomerate of the Entsuji, Moroga and Fuganji Members indicate a progressing upheaval of the Sangun Metamorphic Rocks exposed to the south.

Thus, the northward tilting of basement rocks is also supported by the lateral change of lithofacies. The migration of depocenters and the formation of sedimentary imbricate structures may be closely related to this tilting.

3. *Uplifting of Southwest Japan Arc*

As already stated, the deformation imposed on the basements of the Miocene to Pliocene series is characterized by the following two structural elements. One is the systematic northward tilting of the basement rocks, and the other is a group of longitudinal gravity faults accompanying the tilting (Figs. 16 and 17). It is inferred that with the advancement of the uplifting of the southern part, the basement rocks were subdivided into many blocks by the longitudinal gravity faults (antithetic sense) formed in horizontally tensional stress field. The tilted block structure was promoted by the complementary advancement of the uplifting. The analogous interpretation for the process of uplifting and block-faulting of the Southwest Japan Arc during post-Miocene time has been put forward by YANO (1983) and YANO and YAMASAKI (1985). The characteristics of the geologic structure in the onshore and offshore Tottori area formed by the tectonic movement during Miocene time are, however, similar to those of the geologic structure built up by the post-Miocene uplifting and block-faulting. This fact may indicate a resemblance between the Green Tuff movement and the post-Miocene crustal movement (Island-arc disturbance), as has been suggested by FUJITA (1979, 1980, 1981, 1982b) and FUJITA and GANZAWA (1982). It is generally said that major reliefs of the present island-arc trench system in Japan have been generated during the latest Cenozoic time (FUJITA, 1970, 1982b; KIZAKI and TAKAYASU, 1976; OKUDA *et al.*, 1976; HUZITA, 1978; INOUCHI *et al.*, 1978; VON HUENE *et al.*, 1980). Nevertheless, the initiative uplifting might have begun at Early Miocene.

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EXPLANATION OF PLATE

Fig. 1. Sandstone intercalating layers of parallel-laminated mudstone of the Shichiyama Sandstone and Mudstone Member.
Mukoyama, Iwami-cho. The hammer (about 33cm long) gives scale.

Fig. 2. Well-stratified mudstone (type II) of the Fuganji Mudstone Member.
Megano, Hatto-cho. The hammer gives scale.

Fig. 3. Parallel-laminated mudstone (type I) of the Fuganji Mudstone Member.
Kamiminedera, Koge-cho. The pencil is about 14cm long.

Fig. 4. Massive sandstone of the Moroga Conglomerate Member.
Akenabe, Koge-cho. The scale is 1m long.

Fig. 5. Conglomerate of the Entsuji Conglomerate and Sandstone Member.
Horigoshi, Koge-cho. The scale is 1m long.

Fig. 6. Volcanic conglomerate (k_6) of the Kawabara Volcanic Member.
Kango, Kokufu-cho. The hammer gives scale.

Fig. 7. Andesitic lapilli tuff (k_1) of the Kawabara Volcanic Member.
Fukuchi, Koge-cho. The hammer gives scale.

Fig. 8. Conglomerate of the Koge Conglomerate Member.
Sasanami, Koge-cho. The hammer gives scale.

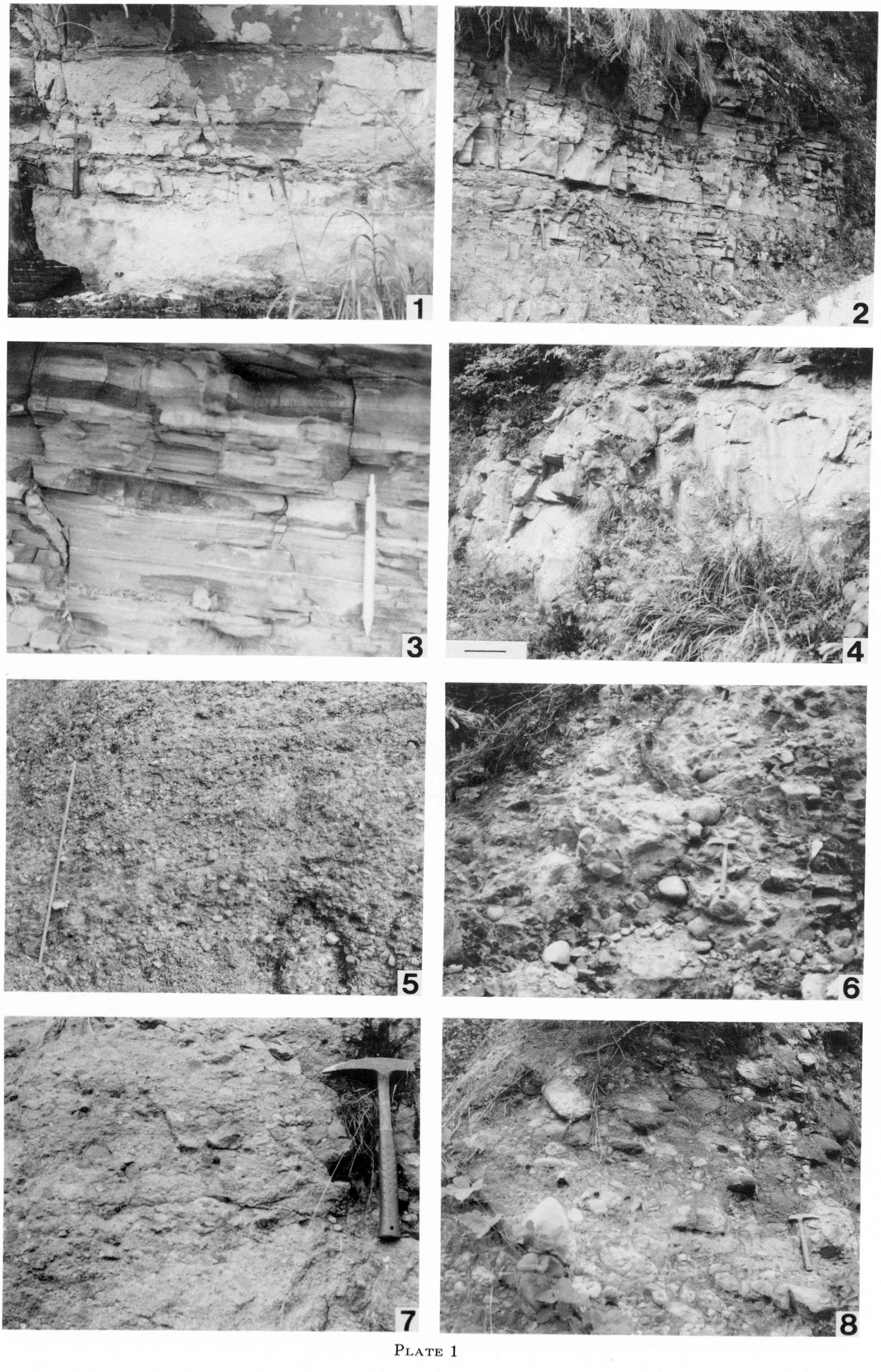

PLATE 1