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Sedimentary environments of the Jurassic-Cretaceous Tetori Group of Nagato River area, southern Toyama Prefecture

By

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with 19 figures

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ABSTRACT: Sedimentology and stratigraphy were studied for the Jurassic-Cretaceous Tetori Group in Nagato River area (southern Toyama Prefecture) in order to reconstruct the sedimentary environments and processes of an alluvial depositional system. The Tetori Group in the study area unconformably overlies the Hida metamorphic rocks, and is divided into the Nagatogawa and Atotsugawa Formations in the ascending order, which correspond to the Uppermost Jurassic to Lower Cretaceous Itoshiro and Akaiwa Subgroups, respectively. The Nagatogawa Formation is subdivided into the lower Ioridanitoge Conglomerate Member (about 250 meters thick) and the upper Inotani Sandstone-mudstone Member (about 150 meters thick). The Atotsugawa Formation is subdivided into the lower Minamimatadani Conglomerate Member (about 70 meters thick) and the upper Wasabu Sandstone-mudstone Member (about 700 meters thick). Fossil assemblage, consisting of plants, freshwater mollusks, tortoise shells, and ganoid scales, indicates that the four members were deposited in non-marine environments.

The sedimentary facies analysis defined five sedimentary facies (Facies A~E) from the Tetori Group in the study area. The conglomerate-dominant Facies A and Facies C were formed in alluvial fans, and in a proximal braided river, respectively. Facies B consists of the alternating beds of mudstone, sandstone and conglomerate, which were formed in the braidplain near a distal alluvial fan. Facies D is dominated by sandstone intercalating thin layers of conglomerate formed in a distal braided river environment. Facies E consists of alternating beds of sandstone and mudstone deposited in a meandering river environment.

Results of the facies analysis, together with paleocurrent and composition analysis of the coarse clastics, conducted four stages of the depositional history of the Tetori Group in the Nagatogawa River area. Stage 1 is characterized by the development of alluvial fans, proximal braided river and partially distal braided river, and this alluvial system deposited the Ioridanitoge Conglomerate Member. The current of the braided river generally directed from west to east, and delivered gravel of granitic and felsitic volcanic rocks originated from the Hida Terrane. Stage 2 was the period of the Inotani Sandstone-mudstone Member, which was deposited mainly in a meandering river flowing from north to south. In Stage 3, the Minamimatadani Conglomerate Member was deposited in the distal braided river with two current directions. One was from east to west, and carried the gravels of the siliceous sedimentary rocks. Another was from north to south, and delivered the rocks of the Hida Terrane. Stage 4 is characterized by the development of a meandering river, generally flowing from north to south. This meandering river system lasted for a long time and deposited thick alternating beds of the Wasabu Sandstone-mudstone Member.

I. Introduction

The Middle Jurassic-Lower Cretaceous Tetori Group, mainly distributed in Hokuriku District, was deposited in terrestrial-shallow marine environments on the Paleozoic-Mesozoic basement rocks including Hida, Hida Gaien, Unazuki, and Mino Belts. The group of the type section (Hakusan area, Fukui, Ishikawa and Gifu Prefectures) is devided into the Kuzuryu Subgroup mainly consisting of marine strata, the Itoshiro and Akaiwa Subgroups deposited in fluvial-fan environments, in the ascending order (Maeda, 1961). The group has been known by its well-preserved plant and molluscan fossils, and occurrence of dinosaurs bones and footprints was focused in recent researches (Toyama Dinosaur Research Group, 2002; Azuma et al., 2002).

Stratigraphic and paleontological researches on the Tetori Group have been carried out in different areas (e.g. Maeda, 1961). However, problems were left in age-determination and correlation among the stratigraphies of the different areas, due to the lateral facies change and lack of key beds and age-diagnostic fossils. In order to get an overview of depositional processes of the Tetori Group, facies analysis and sequence stratigraphy became current topics, which propose new interpretation on the depositional environments. For an instance of new findings, discoveries of marine fossils and results of facies analysis indicated the fact that marine environments was widely developed in the Itoshiro Subgroup of Fukui and Gifu Prefectures (Kumon et al., 1994; Umezawa, 1997; Fujita et al., 1998; Kumon and Umezawa, 2001). In the sense of the sequence stratigraphy, these marine strata indicate transgressive phases, which can be used for the regional correlation.

The Tetori Group is widely distributed in an area east of the Jinzu River (southern Toyama and northern Gifu Prefectures; Toyama Prefecture, 1970, 1992), but only a few sedimentological studies have been carried out in this area (Okamoto, 1985; Takeuchi and Takizawa, 1991; Takeuchi et al., 1991). Marine strata were never been found from the Itoshiro and Akaiwa Subgroup in this area, and this causes difficulty to correlate the stratigraphy of the other areas. This study subjects to the Tetori Group in the Nagato River area of southern Toyama Prefecture (Fig. 1), and deals with the facies change and stratigraphy by using methods of traditional sedimentology and facies analysis. With results of the analyses, sedimentary environments and depositional processes will be discussed.

II. Geological settings

The Tetori Group of the study area was deposited upon the Hida Metamorphic Rocks with an unconformable contact, and was used to be divided into the lower Nagatogawa Formation and the upper Atotsugawa Formation, each of which forms fining-upward sequence. It mainly consists of mudstone, sandstone, and conglomerate, but tuffaceous rocks are rarely interlayered. The Nagatogawa and Atotsugawa Formations were thought to be correlated to the Itoshiro and Akaiwa Subgroups of the type area, respectively (Fig. 2; Kawai and Nozawa, 1958). Strata corresponding to the Kuzuryu Subgroup are not developed in the study area.
Based on the lithofacies, the Nagatogawa Formation is subdivided into the lower Ioridanitoge Conglomerate Member and the upper Inotani Sandstone-mudstone

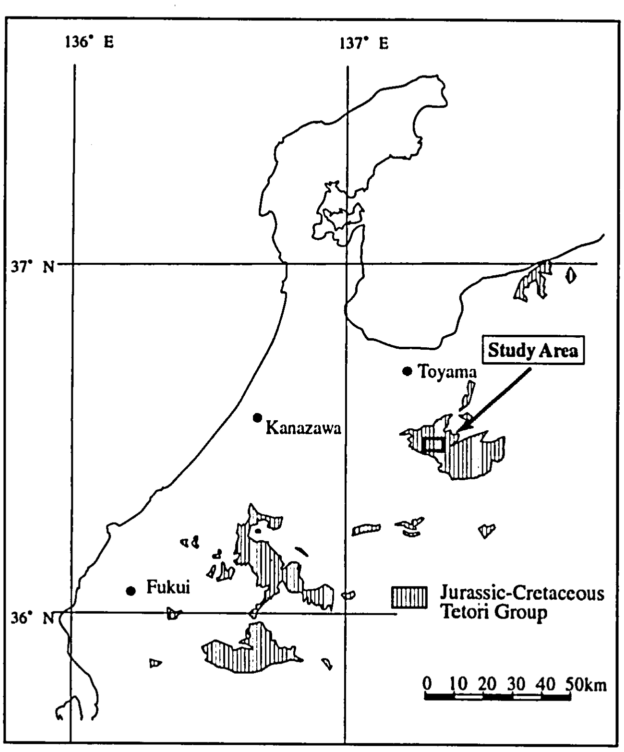

Fig. 1. Map showing the study area and distribution of the Jurassic - Cretaceous Tetori Group

Maeda and Takenami (1957)			Kawai and Nozawa (1958), This study			
Tetori Group	Itoshiro SG.	Yokodake Alternation	Akaiwa SG.	Atotsugawa Fm.	Wasabu Sandstone-mudstone Mb.	Study horizon
		Oritatetoge Conglomerate			Minamimatadani Conglomerate Mb.	
			Itoshiro SG.	Nagatogawa Fm.	Inotani Sandstone-mudstone Mb.	
					Ioridanitoge Conglomerate Mb.	
	Kuzuryu SG.	Arimine Shale	Kuzuryu SG.	Higashisakamori Fm.	Arimine Shale Mb.	
		Magawa Sandstone-conglomerate			Magawa Sandstone-conglomerate Mb.	

Fig. 2. Comperison of the stratigraphic divisions of the Tetori Group in the Nagato River area.

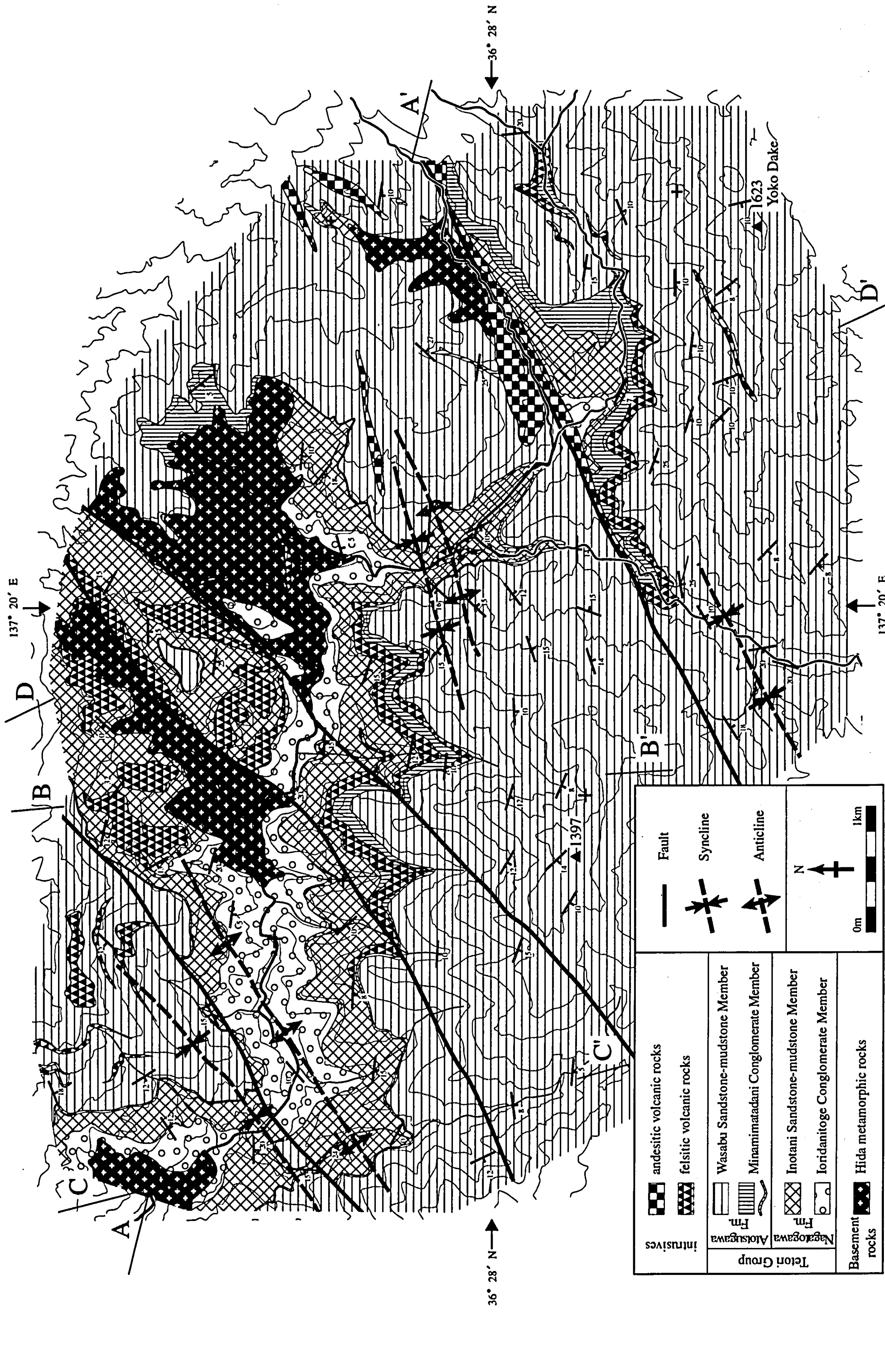

Fig. 3. Geological map of the study area. Location of geological sections (Fig. 4) are indicated.

Member. The Atotsugawa Formation is subdivided into the lower Minamimatadani Conglomerate Member and the upper Wasabu Sandstone-mudstone Member (Fig. 2). The four members yield plant fossils and the Wasabu Sandstone-Mudstone Member contains animal fossils. There are volcanic rocks intruding the Tetori Group and the basement rocks.

Along the unconformable contact, the strata covering the basement Hida Metamorphic Rocks commonly belong to the Nagatogawa Formation, but the Atotsugawa Formation directly rests on the basement in the eastern and northern parts of the study area. The strata generally strike E-W or NW-SE and dip 5~15 degrees to the south (Fig. 3). Intrusive rocks are common in the northern, central and southeastern parts. They are white-pale green felsic volcanic rocks and dark gray andesite. The felsic volcanic rocks occur as sills, few meters to 200 m in thickness, intruding parallel to bedding planes. Large bodies of the sills are distributed in north-central and southeastern parts. The andesite intruded mainly along a fault in the eastern part (Mozumi Fault) as dikes, up to 200 m in width. Agency of Metal Mineral and Coal Mining (1970) reported that the felsic volcanic rocks are truncated by the andesite.

III. Geological structure

Although general dip of the strata declines 5~15 degrees to the south, the strata near the folding axes dip to the north by 10-20 degrees. Other than the axes shown in the geological map (Fig. 3), smaller-scale folding structures occur and cause local disturbance of the strikes and dips. The five folding axes shown in Fig. 3 consists of two sets of an anticline and a syncline, and one syncline, all of which are directed from NE to SW. For the set of the northwestern part, the anticline and syncline, 1 km in distance and separated by a fault, are extended in parallel for more than 4 km. The less clear central set, about 500 m in width, can be extended for 2 km. The clearly defined southern syncline is extended for more than 2 km (Fig. 3).

There are four faults of a mappable size, and all directed from NE to SW parallel with the folding structures. Across the fault of the northwestern part, the SE side was uplifted

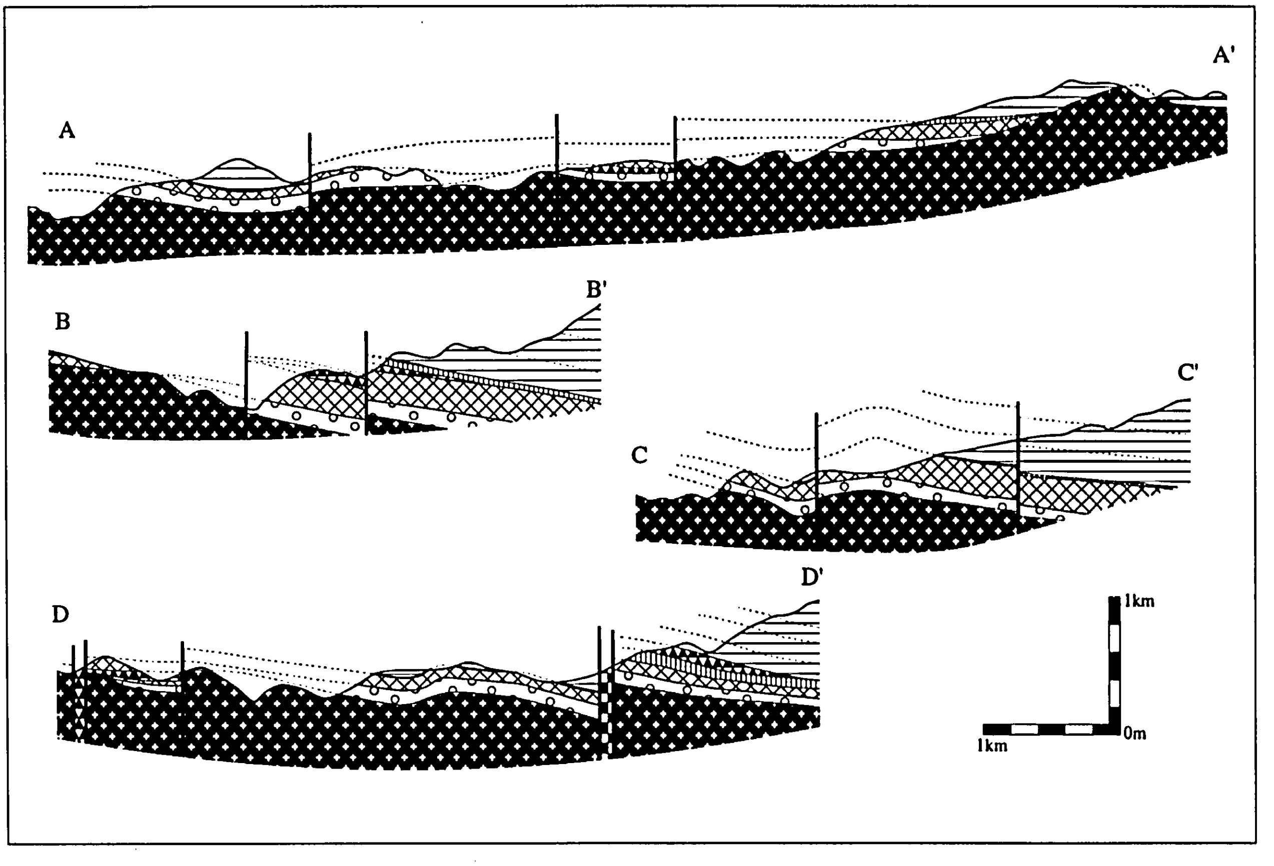

Fig. 4. Geological sections of the study area. Locations and legends are shown in Fig. 3.

relative to the NW side, and the estimated vertical dislocation is about 150 m (Fig. 4). The two faults in the central part are separated each other in 1 km distance, and the block between the two faults is subsided by 50-100 m to the NW and SE sides (Fig. 4). In the northern-central part, a felsic intrusion of 100-150 m wide occurs along the two faults. The fault located in the most SW part is called as Mozumi Fault, which is considered as an active fault (Toyama Prefecture, 1992). The SE side is uplifted to the NW side. Andesite dikes of 100-300 m wide occur along this fault in the eastern part of the study area (Figs. 3 and 4).

IV. General description of the Tetori Group

Stratigraphy and lithology of the Tetori Group of the study area are described with showing columnar sections (Fig. 5). Locations of the columnar sections are shown in Fig. 6.

A. Nagatogawa Formation

The Nagatogawa Formation (Kawai and Nozawa, 1958) is lithologically subdivided into lower Ioridanitoge Conglomerate Member and the upper Inotani Sandstone-mudstone Member.

1. Ioridanitoge Conglomerate Member

This member was proposed by Imamura (1933) and corresponds to the lower part of the Oritatetoge Conglomerate of Maeda and Takenami (1957). The type section is Ioridanitoge located west of the study area.

This member is mainly distributed as a belt of EW direction along the Nagatogawa River, and partly crops out in the southeastern part. Distribution of this member is extended to Ioridanitoge (type section) and NE side of Arimine Lake area (Kawai and Nozawa, 1958), which is located east of the study area. Thickness of the member reaches 250 m, but variable because the member onlaps an irregular topography of the basement (Fig. 5).

Constituents of this member are mainly conglomerates, and less commonly thin layers of sandstone. Mudstone is rare. The conglomerate is generally supported by rounded clasts of pebble-boulder size. Lithologies of the clasts are mainly granite and felsic volcanic rocks. However, the basal part of the member contains clasts of angular shape and limestone lithology. The middle part of the member is characteristic for containing red-colored granite clasts. The sandstone, thinly intercalated within the conglomerate, is medium-coarse grained feldspathic arenite. Tuffaceous layer was exposed on a floor of the Nagato River in the central part of the study area, but it cannot be traced for a distance.

Fossil wood was found in granules of the lowermost horizon. It was carbonaceous and black-colored, however preserved growth rings of a mm interval.

2. Inotani Sandstone-mudstone Member

This member was proposed by Kawai and Nozawa (1958) and corresponds to the middle part of the Oritatetoge Conglomerate of Maeda and Takenami (1957). The type section is Inotani located west of the study area. This member conformably overlies the Ioridanitoge Conglomerate Member, and rests on the basement with an unconformable contact in the northern part of the study area. Thickness of the member is up to 150 m in the eastern part, and decreases to about 100 m in the western part (Fig. 5).

This member is mainly composed of alternating beds of sandstone and mudstone, although the basal part commonly intercalates conglomerate layers. The base of this member is defined by the horizon where sandstone becomes dominant (Fig. 5). The sandstone is fine-coarse grained feldspathic arenite, exhibits white-light gray in the fresh specimens. The mudstone is black-dark gray in color, and commonly contains plant fragments. The sandstone-dominating lower part increases proportion of mudstone to the upward, and the alternation becomes consisting equally of sandstone and mudstone in the middle and upper parts. A tuffaceous bed of the uppermost member was exposed on a floor of the Nagato River in the central part of the study area, but it cannot be traced for a distance.

Common fossils of this member are plant fragments and roots in mudstone. They are not very well preserved. The sandstone yields fossil wood.

B. Atotsugawa Formation

The Atotsugawa Formation (Kawai and Nozawa, 1958) is subdivided into the lower Mimamimatadani Conglomerate Member and the upper Wasabu Sandstone-mudstone Member. This formation conformably overlies the Nagatogawa Formation.

1. Minamimatadani Conglomerate Member

This member was proposed by Kawai and Nozawa (1958) and corresponds to the upper part of the Oritatetoge Conglomerate of Maeda and Takenami (1957). The type section is Minamimatayama located SE of the study area. This member conformably overlies the Inotani Sandstone-mudstone Member, and rests on the basement with an unconformable contact in the northern part of the study

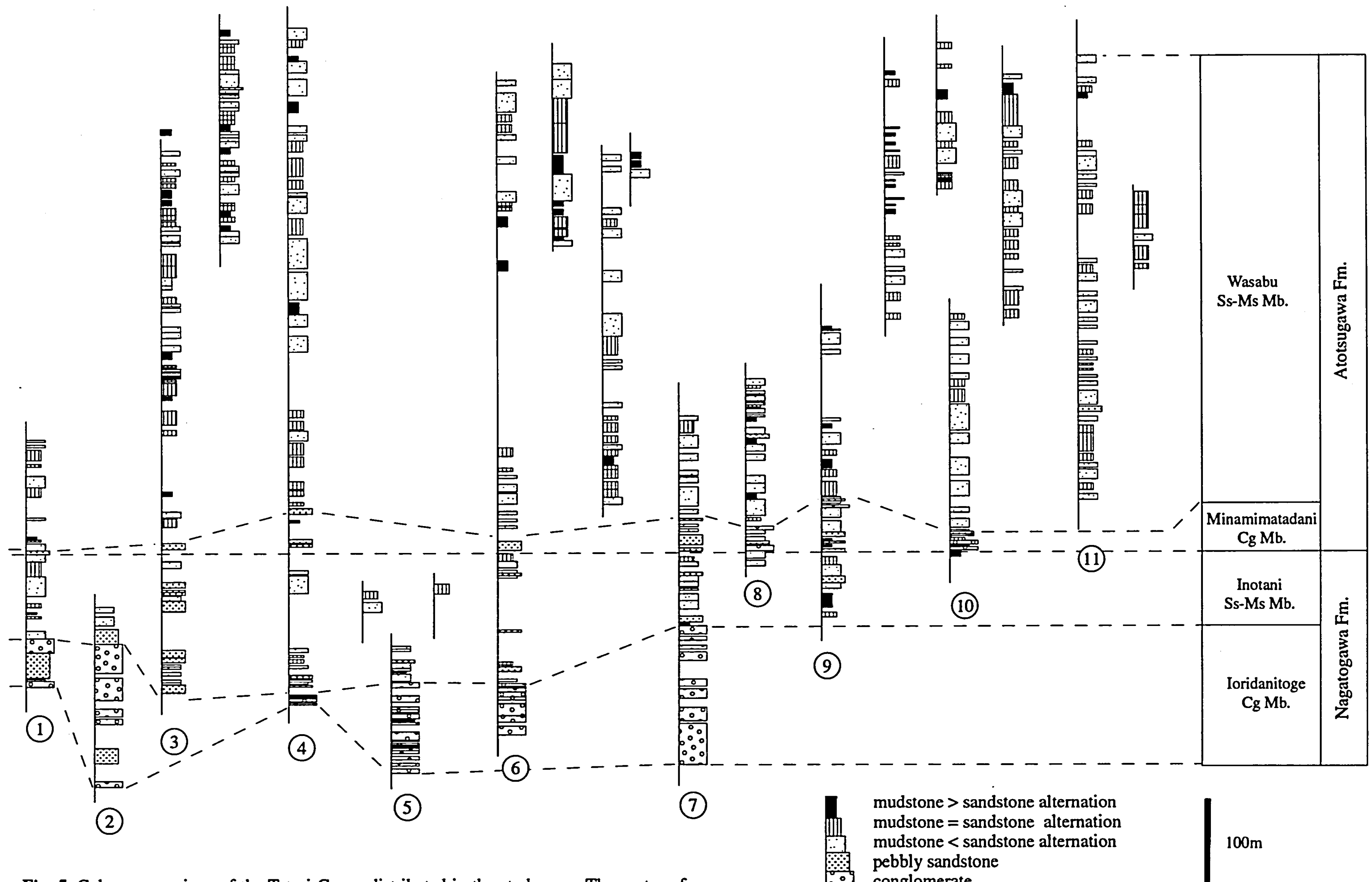

Fig. 5. Columnar sections of the Tetori Group distributed in the study area. The routes of the columnar sections are shown in Fig. 6.

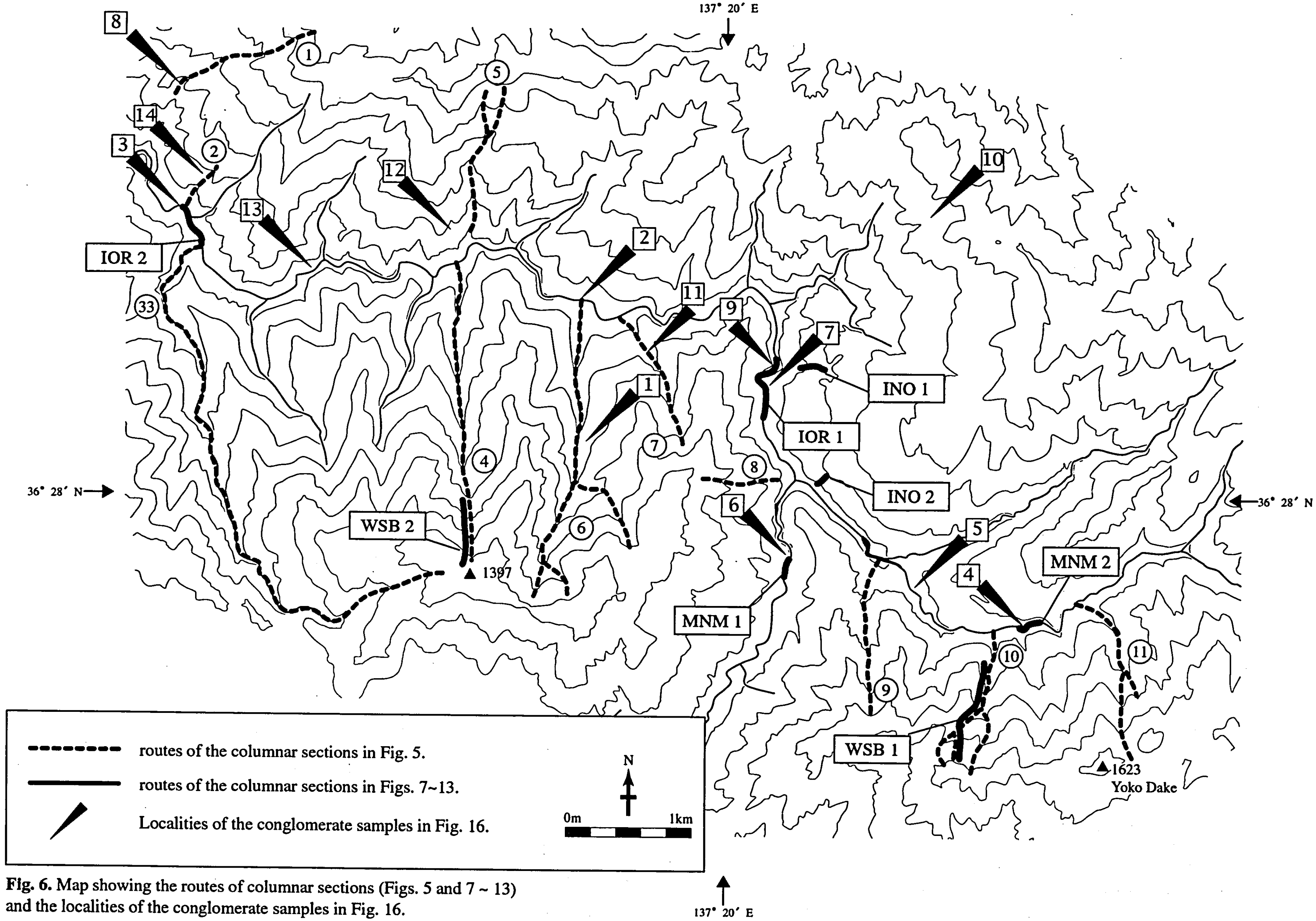

Fig. 6. Map showing the routes of columnar sections (Figs. 5 and 7 ~ 13) and the localities of the conglomerate samples in Fig. 16.

area. This member is largely exposed in the central and eastern parts of the study area. Thickness of the member is up to 70 m in the eastern part, and decreases to several meters in the western part (Fig. 5).

This member consists of conglomerate, sandstone and mudstone. The base of this member is defined by the horizon where conglomerate becomes common (Fig. 5). Size of the clasts ranges from pebble to cobble. Common lithologies of the clasts are granite and felsic volcanic rocks, but the conglomerate in the southeastern part contains siliceous mudstone and chert clasts. The conglomerate of this member differs from one in the Ioridanitoge Conglomerate Member, as to its smaller-sized clasts and lentic to thinly layered occurrence. The sandstone is fine to coarse-grained, white to light gray feldspathic arenite, Granule and pebble are normally scattered in the coarser-grained sandstone. The mudstone is normally black to dark gray, but in some cases it is reddish gray. The reddish gray mudstone often crops out along a path in the central part of the study area.

The most characteristic fossils are plant roots in the mudstone, as seen in a floor of the Nagato River in the central part of the study area. Other fossils are poorly preserved plant fragments and wood in sandstone and mudstone.

2. Wasabu Sandstone-mudstone Member

This member was proposed by Kawai and Nozawa (1958) and corresponds to the Yokodake Alternation of Shale and Sandstone of Maeda and Takenami (1957). The type section is Wasabu located south of the study area. This member conformably overlies the Minamimatadani Conglomerate Member, but rests on the basement with an unconformable contact in the northern part of the study area. This member is largely exposed in the southern half of the study area. The maximum thickness of the member is 700 m (Fig. 5).

This member consists mainly of alternating beds of sandstone and mudstone, and rarely intercalates tuffaceous layers. The base of this member is defined by the horizon where sandstone or mudstone becomes dominant (Fig. 5). The sandstone is white to light gray feldspathic arenite. It is fine to coarse-grained and often contains granule. Thickness of a single sandstone bed normally ranges from a few cm to one meter, however some beds reach 5 m in thickness. The mudstone normally exhibits black to dark gray in color, but in some cases it is reddish gray or greenish gray.

This member yields well-preserved fossils of plants, roots, and animals. The plant fossils were identified as *Onychiopsis elongata, Ginkgolites* sp., *Podozamites* sp., *Cladophlebis* sp., which are typical components of the Tetori Flora (Maeda, 1961). Animal fossils were found from boulders fallen from mudstone of this member. They are *Nakamuranaia* sp., *Pseudohyria* sp. (freshwater bivalves), tortoise shell, and ganoid scale.

V. Facies analysis

Strata of the Tetori Group basically represent three siliciclastic lithologies (conglomerate, sandstone, and mudstone), and the environmental reconstruction needs another scope than simple lithological description. Facies analysis is the potential method along this purpose. In terms of facies analysis applying for a siliciclastic depositional system, a facies is defined by lithological similarity, sedimentary structure, fossil contents, ichnofossils, configuration of a depositional body, and association of lithofacies. A well-defined facies ideally corresponds to a deposit which was formed under a certain environment and by certain processes. In order to reconstruct depositional environments of the Tetori Group, details in facies definition and description will be done here, based on the results of columnar sections of each member.

A. Definition of facies

For the Tetori Group of the study area, the following five sedimentary facies (Facies A~E) can be defined mainly due to association of lithofacies.

Facies A is mainly composed of brecchia, and accompanied with layers and lenses of sandstone and mudstone. Due to matrix lithology of brecchia, this facies is subdivided into Subfacies A1 (mud-matrix) and Subfacies A2 (sand-matrix).

Facies B consists of alternating beds of sandstone and mudstone with lenses of subangular clast-supported conglomerate. The conglomerate exhibits sandy matrix.

Facies C is mainly consists of subrounded-rounded clast-supported conglomerate, which intercalates thin lenses and layers of sandstone.

Facies D is bedded sandstone accompanied with thin lenses and layers of mudstone and conglomerate with rounded clasts.

Facies E consists of alternating beds of sandstone and mudstone, which represent repetition of fining-upward cycles.

B. Description of facies

1. Ioridanitoge Conglomerate Member

This member mainly consists of Facies C. The basal part includes Facies A and B, and Facie D is developed in the lower part. Details are described in following two columnar sections of this member (Figs. 7 and 8).

a. IOR 1 (Fig. 7)

This section is 60 m in thickness, and is exposed on a floor of the Nagato River in the northwestern part of the study area (Fig. 6). The base of the section is the unconformity with the Hida Metamorphic Rocks. Dominant facies changes from Facies A2 (lower-middle parts) through Facies D (middle-upper part) to Facies C (uppermost part).

Facies A of the basal part is poorly sorted brecchia containing clasts of granule to boulder size. Boulders more than 1 m in diameter occur just above the unconformity surface, and they represent an more abraded shape than the pebble and cobble occurring nearby. Lithologies of the clasts are mainly granite and felsic volcanic rocks. Fossil wood occurs in conglomerate in the lower section. The basal parts of the conglomerate beds often erode the underlying strata, and contain reworked clasts of mudstone up to 20 cm in diameter. The conglomerate beds may exhibit trough-type cross-lamination. The sandstone is commonly coarse-grained and pebbly, and exhibits parallel lamination and trough-type cross-lamination. The mudstone, which is thinly intercalated within the conglomerate and sandstone, contains sand~granule grains and lacks sedimentary structures. It is often eroded by the overlying bed.

In Facies D in the middle-upper section, the sandstone is commonly coarse-grained and contains granule and pebble. The sandstone beds may erode the underlying beds and contain reworked clasts of mudstone up to 50 cm in

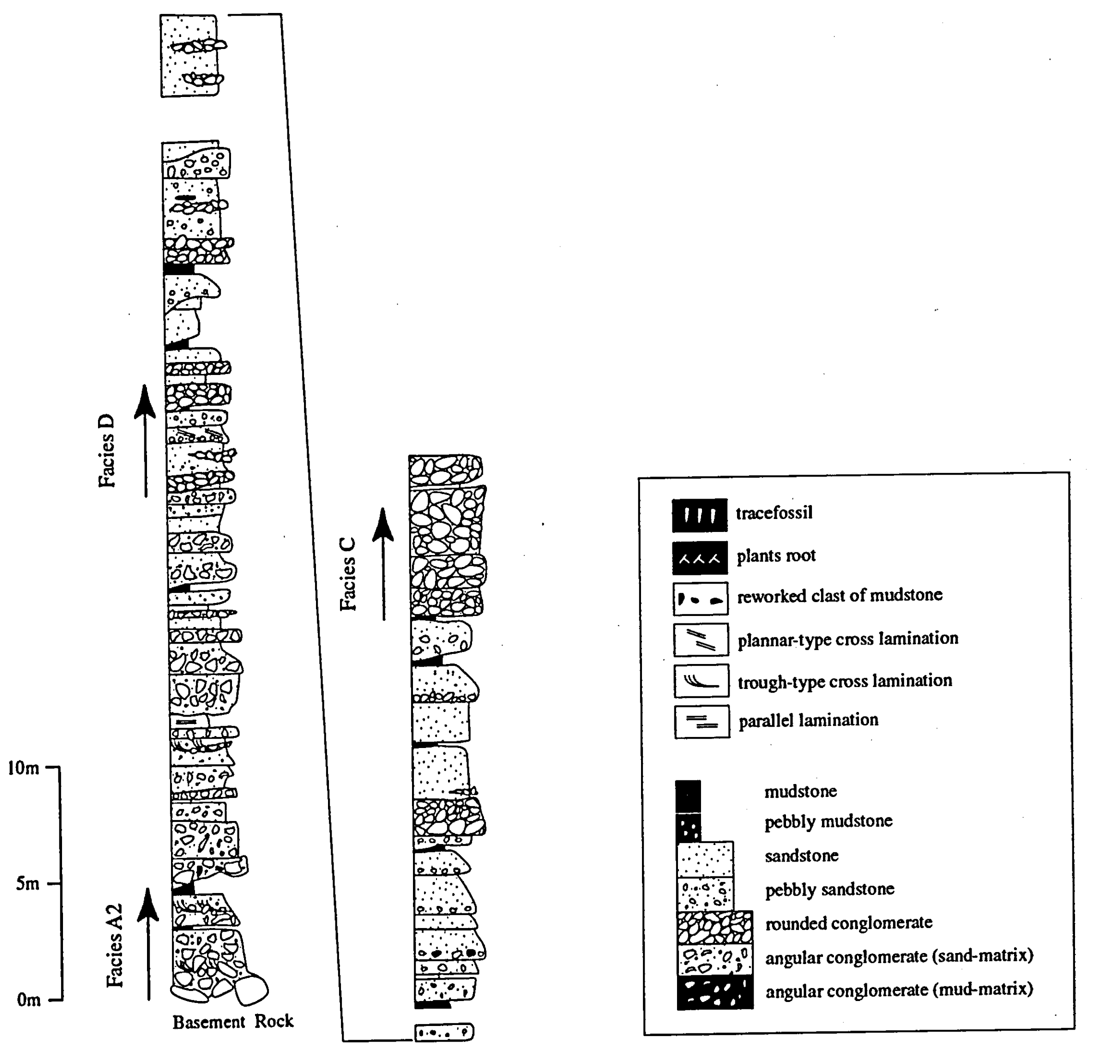

Fig. 7. Columnar section of IORl section in the lower part of the Ioridanitoge Conglomerate Member. The route of the columnar section is shown in Fig. 6.

diameter. The sandstone in the upper section shows grading and planner-type cross-lamination. The conglomerate consists of granule and pebble of subangular-subrounded shape. Lithologies of the clasts are mainly granite and felsic volcanic rocks, but limestone clasts also occur. The mudstone is gray in color and exhibits parallel lamination.

The uppermost 8 m is Facies C consisting mostly of conglomerate intercalating thin beds of sandstone. Clasts of the conglomerate are rounded, cobble-boulder in size, medium sorted, and shows weak imbrication. Lithologies of the clasts are mainly granite and felsic volcanic rocks. The conglomerate beds shows both of normal and reverse grading. The sandstone is coarse-grained and well sorted.

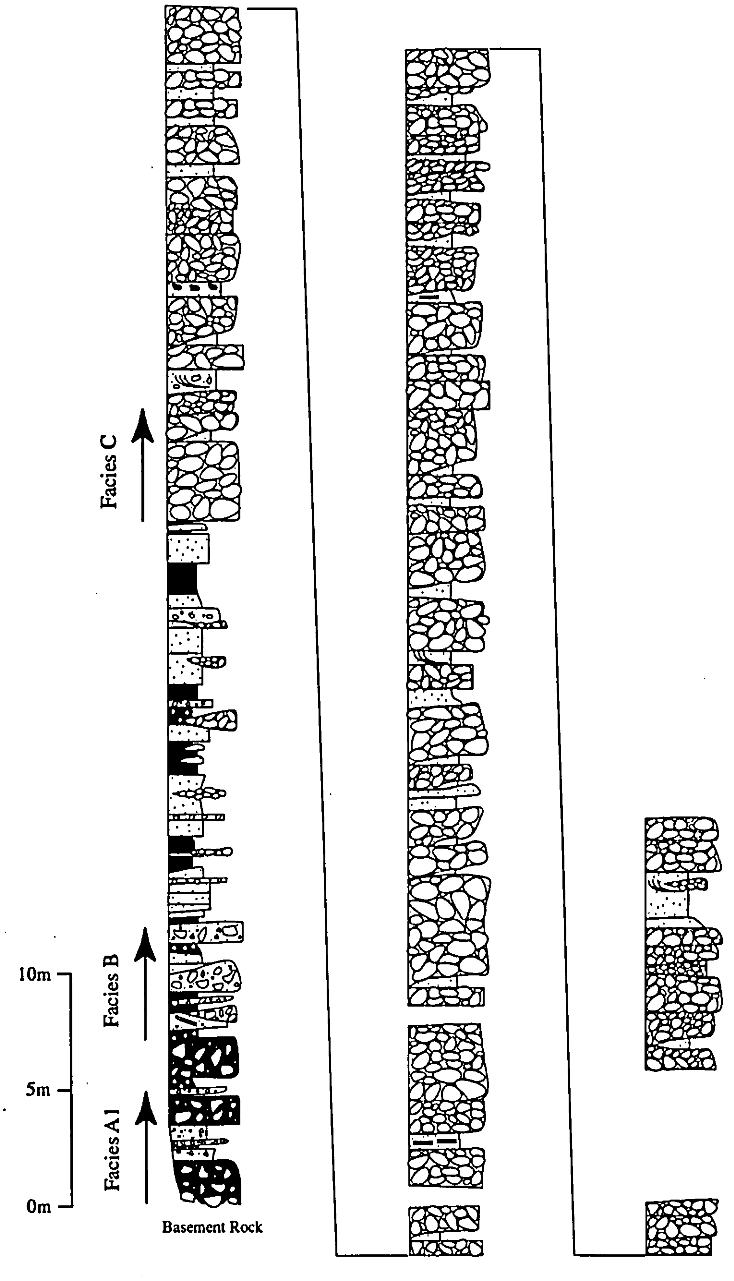

Fig. 8. Columnar section of IOR2 section in the Ioridanitoge Conglomerate Member. The route of the columnar section is shown in Fig. 6. Legend is the same as in Fig. 7

b. IOR 2 (Fig. 8)

This section is about 130 m in thickness, located on a floor of the Nagato River of the northwestern part of the study area (Fig. 6), and exposes the lower to upper parts of the Ioridanitoge Conglomerate Member. The lower section consists of Facies A1 and the thicker overlying Facies B, covering the basement with an unconformable contact. The middle and upper parts represent Facies C (Fig. 8).

Facies A1 of the lower section is brecchia with mud-matrix. The clasts are pebble to cobble in size, and are poorly sorted. Lithologies of the clasts are mainly granite gneiss and felsic volcanic rocks. Some brecchia beds are rich in limestone clasts. Matrix of the brecchia is dark gray-black mudstone containing sand grains. The sandstone is fine to coarse grained, poorly sorted and contains granule. It shows parallel lamination and trough-type cross-lamination. The mudstone is also poorly sorted and contains sand and granule grains. It is rich in organic matter and plant fragments.

In the overlying Facies B, the sandstone is fine to coarse grained and contains granule and pebble. Sedimentary structures are not conspicuous, but some sandstone beds exhibit parallel lamination. The mudstone is black-dark gray in color, preserves plant fragments, and may show parallel lamination. Some mudstone beds are pebbly. The conglomerate is clast-supported and sandy in the matrix. The conglomerate beds appear lenses with a concave-down configuration. The clasts are subangular-subrounded pebble and cobble. Sorting of the clasts is medium to poor. Lithologies of the clasts are mainly granite and felsic volcanic rocks. Limestone clasts were not found.

Facies C of the middle and upper parts is dominated by conglomerate, in which the clasts are moderately sorted, rounded cobble and boulder, which may shows weak imbrication. Lithologies of the clasts are mainly granite and felsic volcanic rocks, and in some beds, intermediate volcanic rocks are common. The conglomerate may show both normal and reverse grading. Thin beds of sandstone occurs within the conglomerate as lenses of a concave-down form, The sandstone is well sorted, medium to coarse grained, and exhibits various sedimentary structures including parallel lamination, trough-type and planner-type cross-lamination.

2. Inotani Sandstone-mudstone Member

This member mainly consists of Facies D and E, but in some parts represent Facies C. Two columnar sections were investigated in the central part of the study area.

a. INO 1 (Fig. 9)

The section located in the central part exposes strata of 60 m in thickness, which correspond to the lowermost to middle of the Inotani Sandstone-mudstone Member. The section is mainly composed of Facies E, but the middle part shows thin development of Facies C.

Facies E mainly consists of fine to coarse-grained sandstone, which is white-light gray feldspathic arenite. Planner cross-lamination and normal grading are the common sedimentary structures in the sandstone. Thick sandstone beds in the lower and middle parts often contain granule. The mudstone is well sorted and dark gray-gray in color. It may shows parallel lamination. The mudstone yields plant fragments, root fossils, and sand pipes.

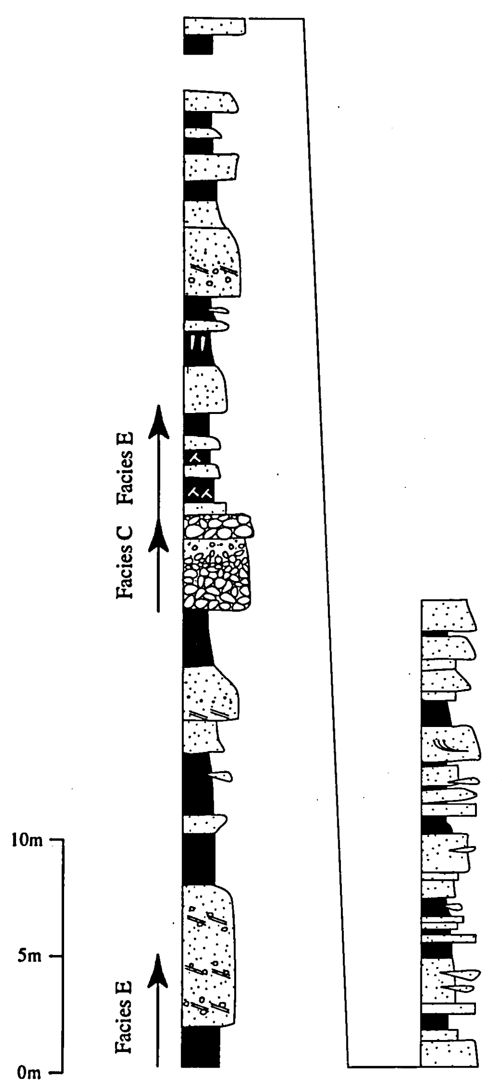

Fig. 9. Columnar section of INO1 section in the lower part of the Inotani Sandstone-mudstone Member. The route of the columnar section is shown in Fig. 6. Legend is the same as in Fig. 7.

Thickness of the mudstone is 1~2 m in the lower section, and less than 50 cm in the upper section.

Facies D of 5 m thick is developed in the middle of the section. It consists of rounded conglomerate showing weak normal grading. The clasts are mainly pebble size and relatively well sorted. Lithologies of the clasts are mainly granite and felsic volcanic rocks.

b. INO 2 (Fig. 10)

This section is located along a stream in the central part of the study area, and exposes the middle and upper parts of the Inotani Sandstone-mudstone Member (Fig. 6). The section is 60 m in thickness and composed of Facies E.

In Facies E of INO 2, the sandstone is coarse-grained feldspathic arenite. It is generally well sorted, and exhibits planner-type cross-lamination and both of normal and reverse grading. The base of the sandstone bed often erodes the underlying strata. Thickness of a single sandstone bed is less than 1 m in the lower section, but in the upper part it generally ranges from 3 to 5 m. The dark gray-gray mudstone contains plant fragments and root fossils, and it is often burrowed by sand pipes. The mudstone may show parallel lamination.

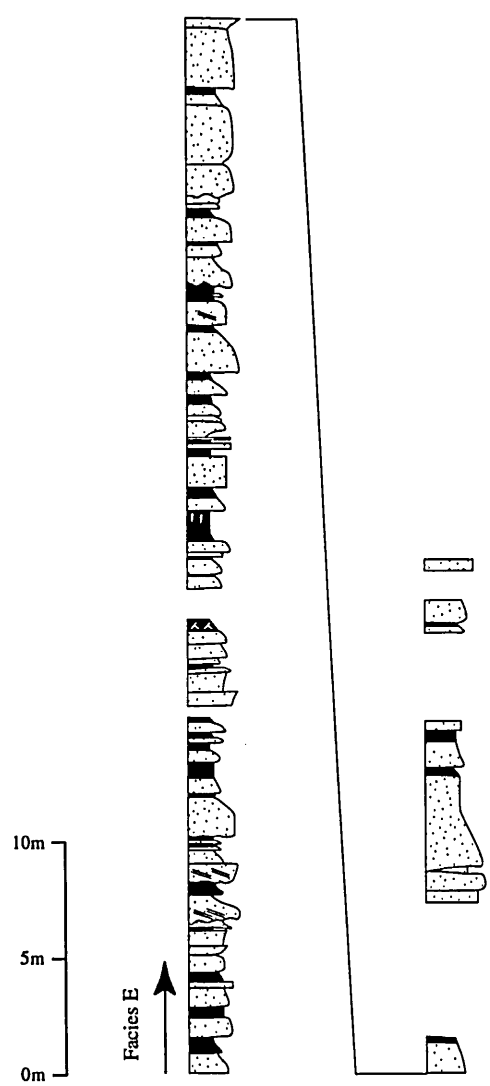

Fig. 10. Columnar section of INO2 section in the upper part of the Inotani Sandstone-mudstone Member. The route of the columnar section is shown in Fig. 6. Legend is the same as in Fig. 7.

3. Minamimatadani Conglomerate Member

This member mainly consists of Facies D intercalating Facies C and E. Two sections were investigated in the central and southeastern parts of the study area (Fig. 6).

a. MNM 1 (Fig. 11)

This section is about 40 m in thickness, located on a floor of the Nagato River of the central part of the study area (Fig. 6), and exposes the lower to middle parts of the Minamimatadani Conglomerate Member. The section consists of Facies D.

The sandstone is medium-coarse grained, and contains pebble, cobble, and reworked clasts of mudstone. Planner-type cross-lamination is the common sedimentary structure of the sandstone. The conglomerate occurs as thin lenses and layers intercalated with sandstone. The clasts are well-moderate sorted and pebble to cobble in size. Lithologies of the clasts are mainly granite and felsic volcanic rocks. The conglomerate beds in the upper section show weak normal grading. The gray-reddish gray mudstone is interlayered within the sandstone. The mudstone in the middle section contains granule. Root fossils were found in the lower section.

b. MNM 2 (Fig. 11)

This section is about 45 m in thickness, located on a floor of the Nagato River of the southeastern part of the study area (Fig. 6), and exposes the middle to upper parts of the Minamimatadani Conglomerate Member. The upper and lower parts of section consist of Facies D and the middle section shows Facies C and E.

In Facies D, the sandstone is generally medium-coarse grained, and includes granule and pebble. It commonly shows normal grading, trough-type and planner-type cross-lamination. The conglomerate is composed of pebble and cobble of granite and felsic volcanic rocks in lithology. Lenses of the conglomerate show a concave-down geometry. The gray-reddish gray mudstone often shows parallel lamination, and yields plant fragments, root fossils, and sand pipes.

In Facies C of the middle section, the conglomerate consists of moderate to poorly sorted cobble and boulder. Lithologies of the clasts are felsic volcanic rocks, granite, siliceous mudstone, and chert. The felsic volcanic rock and granite clasts are generally subrounded in shape, and siliceous mudstone and chert clasts are subangular. The conglomerate beds show weak normal grading. The sandstone is medium-coarse grained and contains granule.

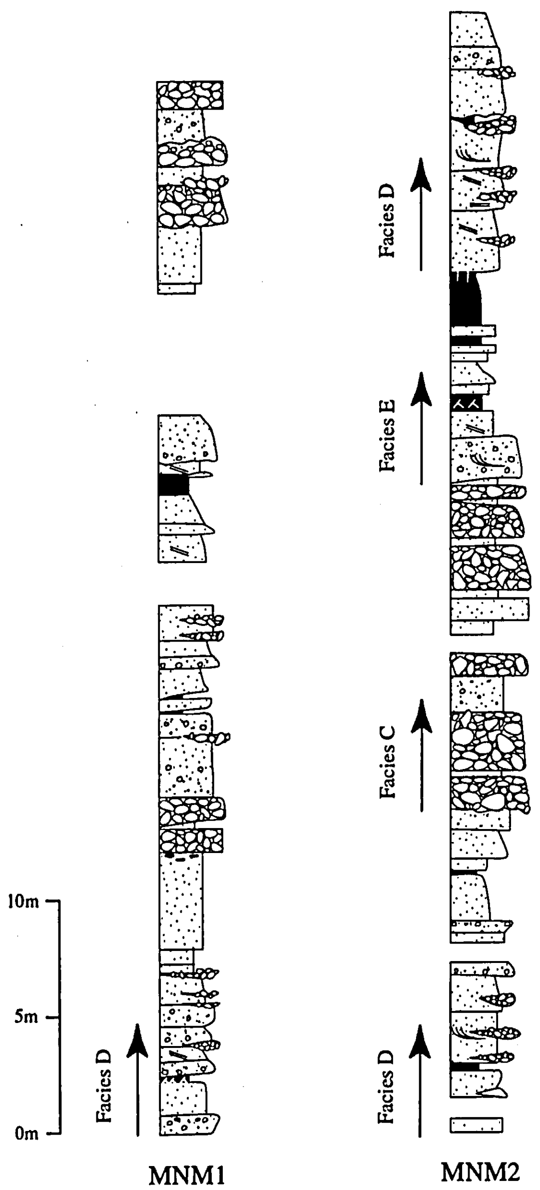

Fig.11. Columnar section of MNM1 and MNM2 section showing the Minamimatadani Conglomerate Member. The routes of the columnar sections are shown in Fig. 6. Legend is the same as in Fig. 7.

Thick beds of sandstone exhibits trough-type cross-lamination.

In Facies E, the sandstone is well sorted and coarse-medium grained. The beds of sandstone are generally less then 50 cm in thickness, and may exhibit trough-type and planner-type cross-lamination. The mudstone is gray-dark gray and contains plant fragments.

4. Wasabu Sandstone-mudstone Member

This member consists of Facies E. Two sections were investigated in the central and southwestern parts of the study area (Fig. 6).

a. WSB 1 (Fig. 12)

This section is about 320 m in thickness, located along a stream of the southeastern part of the study area, and exposes the lower and middle parts of the Wasabu Sandstone-mudstone Member. The section is fully Facies E.

The sandstone is coarse-fine grained feldspathic arenite commonly showing normal grading, but occasionally reverse grading occurs. The sandstone exhibits various sedimentary structures, parallel lamination, planar-type and trough-type cross-lamination. Thickness of a sandstone bed normally ranges from several tens cm to 2 m. However, thick beds more than 5 m are developed in the middle and upper parts of the section. Fossil wood was often found. The mudstone normally gray-dark gray and exhibits parallel lamination. It is well sorted, but some beds contain sand grains. Well-preserved fossil root and plants were found, especially from the middle to upper parts. Thickness of the mudstone normally ranges from several tens of cm to 1 m.

b. WSB 2 (Fig. 13)

This section is about 300 m in thickness, located along a stream in the central part of the study area, and exposes the middle and upper parts of the Wasabu Sandstone-mudstone Member. The section all consists of Facies E.

This section is similar to WSB 1 section in terms of lithological characters of the sandstone and mudstone. However, there is a tendency that the lower part of this section is more dominated by sandstone than the upper part. The thickness of the sandstone beds exceeds 5 m in the lower part, which corresponds to the middle to upper parts of WSB 1 section. The mudstone became developed in the upper part of this section, and it increases thickness of the beds (up to 5 m in thickness) and proportion relative to the sandstone.

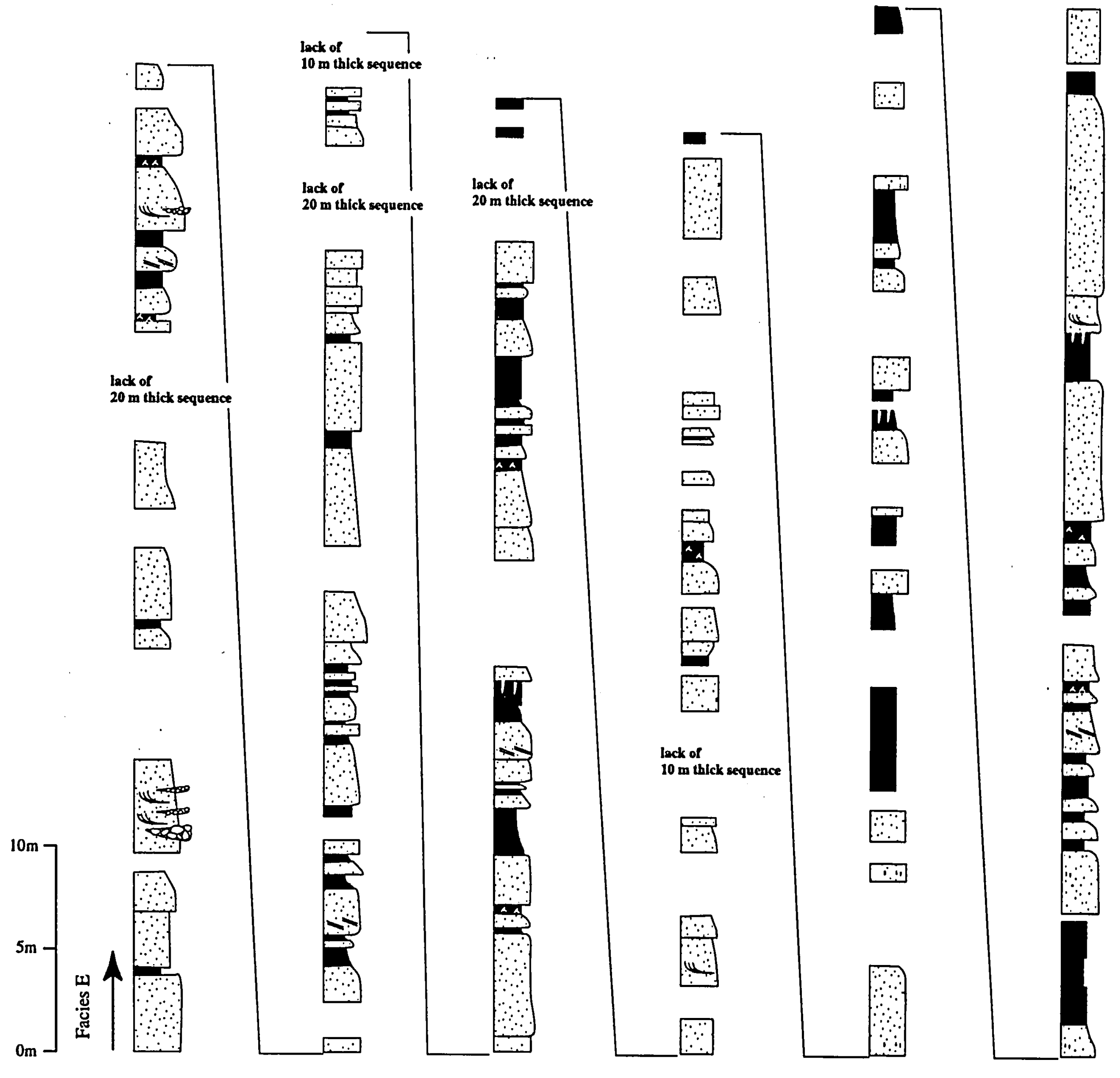

Fig.12. Columnar section of WSB1 section showing the lower part of the Wasabu Sandstone- mudstone Member. The route of the columnar section is shown in Fig. 6. Legend is the same as in Fig. 7.

C. Spatial trend of facies distribution

Vertical change in the sedimentary facies in the Tetori Group of the study area is summarized as follows. Facies of the Ioridanitoge Conglomerate Member changes from the basal Facies A, through Facies D or B, and to the upper Facies C. This facies shifts to Facies D in the lower Inotani Sandstone-mudstone Member, and changes into Facies E in the middle and upper of this member. From the base of the Minamimatadani Conglomerate Member, the sedimentary facies starts from Facies C or D, and changes into Facies E of the Wasabu Sandstone-mudstone Member.

Lateral variation of the facies distribution was also recognized in the study area. In terms of facies change in the Ioridanitoge Conglomerate Member, the facies changes from A through D to C in the northwestern part, but the facies changes from A through B to C in the central part of the study area. Focusing to thickness of Facies D of the lower Inotani Sandstone-mudstone Member, it is clearly thicker in the northwestern parts than in the other parts of the study area. In contrast, the southeastern part is characterized by thin development of Facies C in the Minamimatadani Conglomerate Member (Fig. 14).

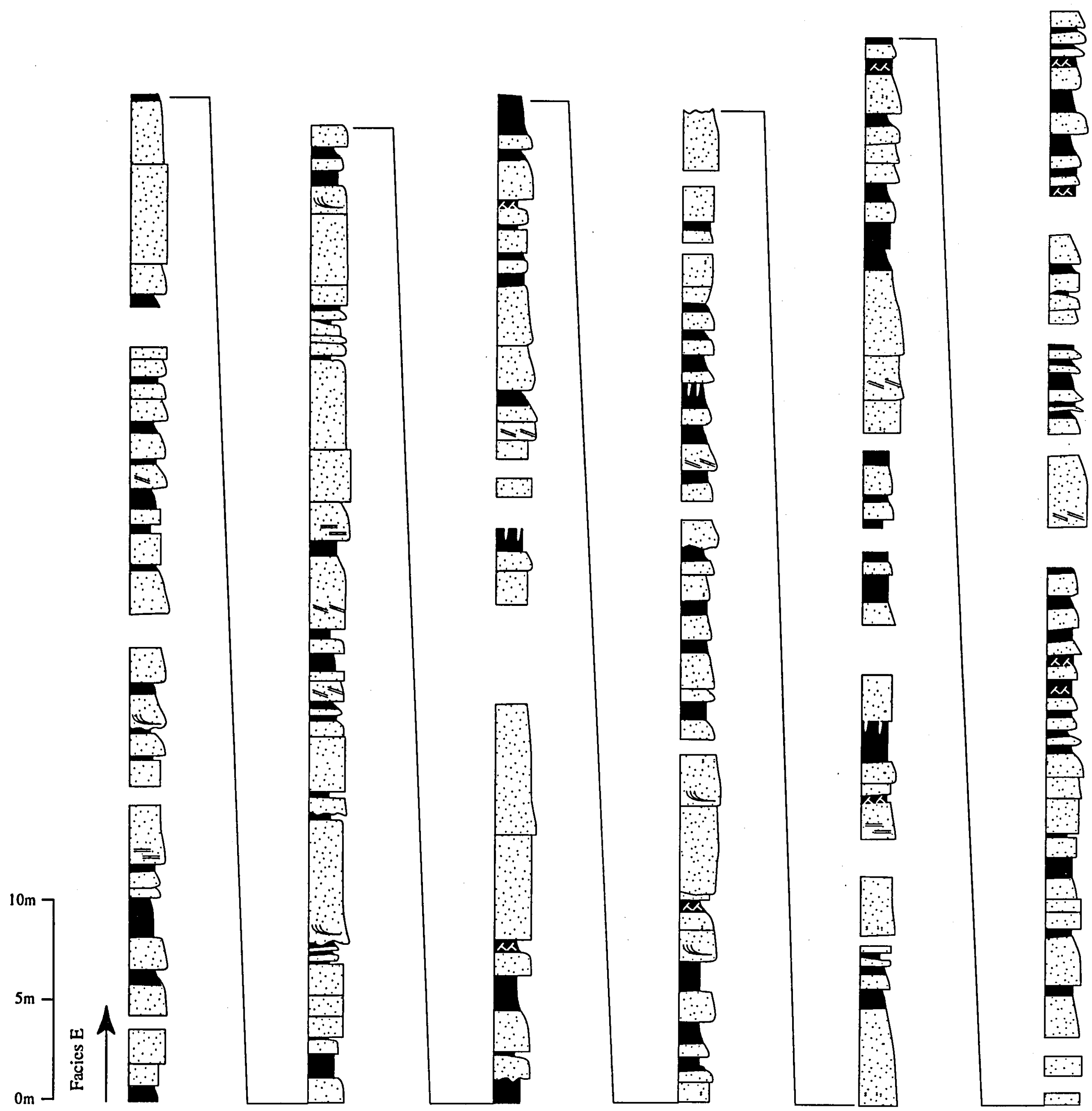

Fig.13. Columnar section of WSB2 section showing the upper part of the Wasabu Sandstone- mudstone Member. The route of the columnar section is shown in Fig. 6. Legend as same as in Fig. 7.

VI. Depositional properties of the Tetori Group

A. Paleocurrent

Paleocurrent was estimated from trough-type cross-lamination, planner-type cross-lamination, and imbrication of clasts. Results indicate difference in directions among the members (Fig. 15).

23 directions were estimated from imbrication in conglomerate beds of the Ioridanitoge Conglomerate Member. In the beds used for the paleocurrent analysis, size of the clasts ranges from cobble to boulder, and the longer-axes of the clasts are relatively well arranged. The direction has a wider range from NNE to SE (in the present direction), however average direction is 82.6° that means the direction from west to east.

Nine data were measured from cross-lamination of coarse-grained sandstone beds. The average value is 169.9° in the present direction, however bimodal distributions are

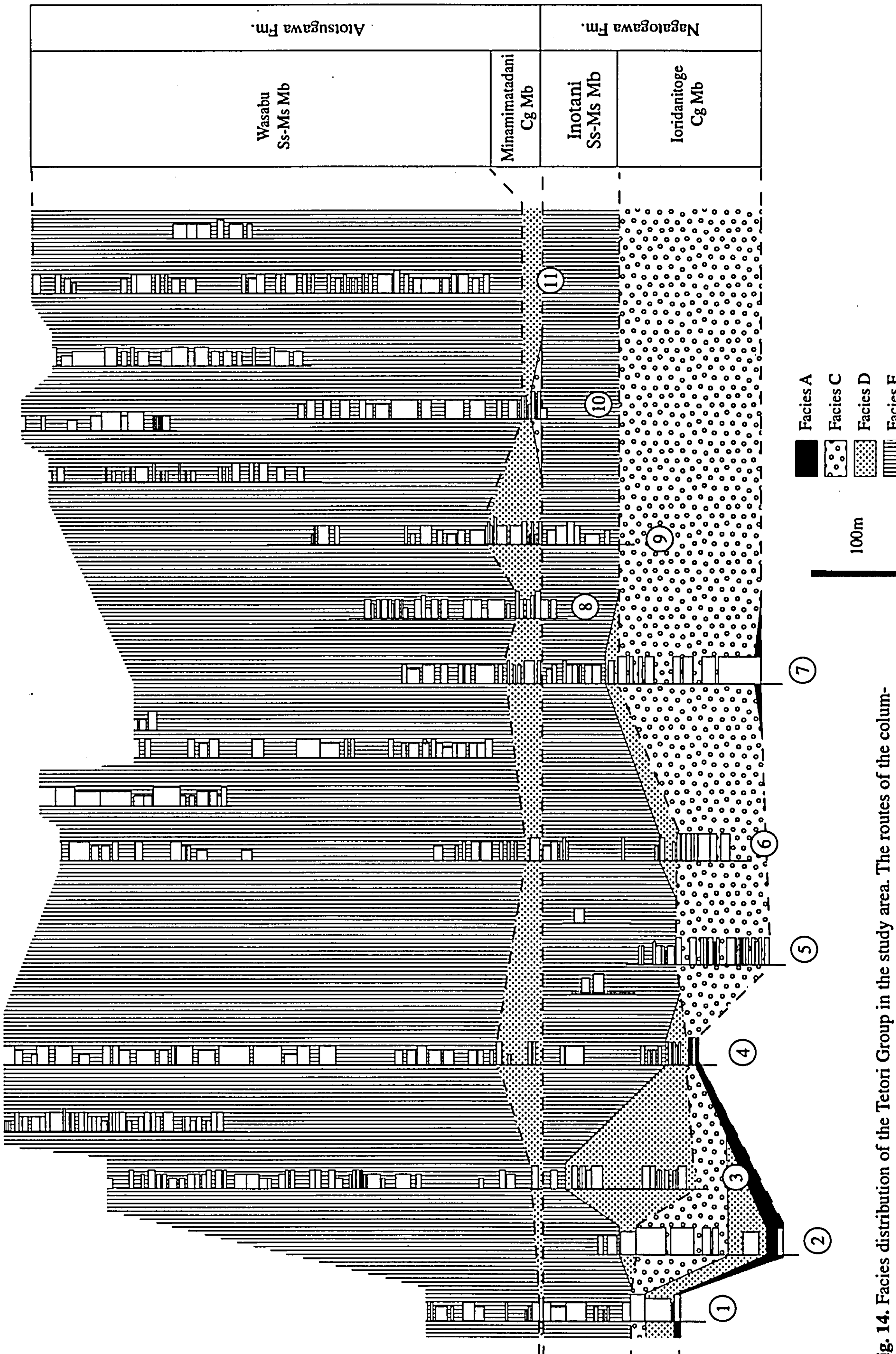

Fig. 14. Facies distribution of the Tetori Group in the study area. The routes of the columnar sections are shown in Fig. 6.

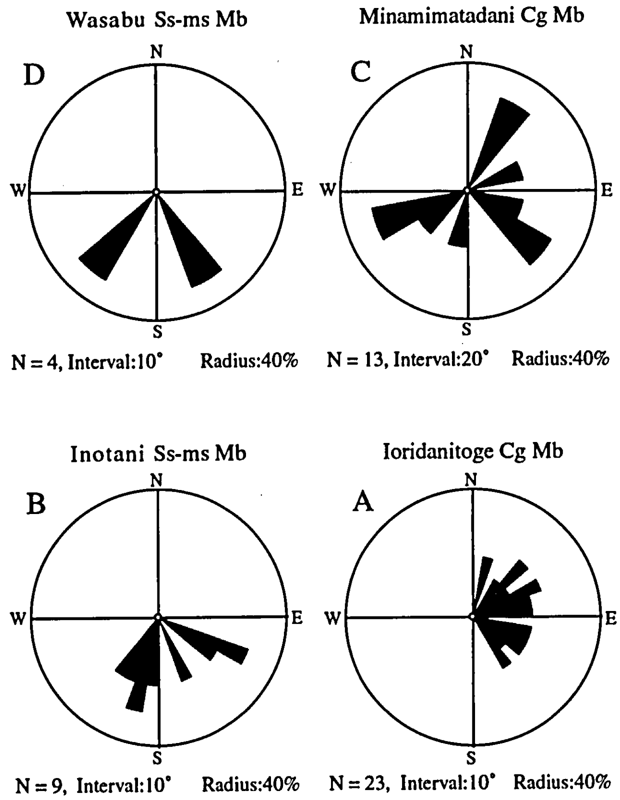

Fig. 15. Paleocurrents of the four members of the Tetori Group in the Nagato River area.
A: Ioridanitoge Cg Mb, B: Inotani Ss-ms Mb, C: Minamimatadani Cg Mb, D: Wasabu Ss-ms Mb.
The radius is 40% in frequency. The interval of data assemblage is 20° for Fig. 15-c and 10° for other figures.
N means the number of the data.

found (Fig. 15). One is from NNE to SSW, and another is from WNW to ESE.

For Minamimatadani Conglomerate Member, 13 data were collected from imbrication of conglomerate beds and cross-lamination of coarse-grained sandstone. The results seem to be dispersed, but indicates three directions, SW to NE, NW to SE, and ENE to WSW. Average direction is 138° (in the present direction).

Four directions were reconstructed from cross-lamination of the Wasabu Sandstone-mudstone Member. Although number of the data is small, the data set may indicate two directions, one is from NW to SE, and another is from NE to SW. The average is 189° (in the present direction; Fig. 15).

B. Gravel composition of conglomerate beds

Lithology of the gravels was investigated for 14 conglomerate beds. Ten beds are from the Ioridanitoge Conglomerate Member, and four are from Minamimatadani Conglomerate Member. For each beds, more than 50 gravels were collected and the lithology was determined in field and in thin section. The two conglomerate members show a difference in lithologic composition of the gravels (Fig. 16).

The most dominant clast lithologies in the Ioridanitoge Conglomerate Member are granite and felsic volcanic rocks, and they are contained in a high proportion throughout the member. Intermediate volcanic rocks and metamorphic rocks (including gneiss and crystalline schist) are common in the middle and upper parts of this member. Clasts of poly quartz rocks were found in the lower and upper parts, but not in the middle part of this member.

Results of the Minamimatadani Conglomerate Member reveal two types of gravel composition. One is dominated by granite (about 80% in proportion) and subordinated by aplite. This type of conglomerate is characterized by rounded shape of the clasts. Another type shows diverse gravel composition including granite, felsic volcanic rock, siliceous mudstone, sandstone, and chert. The felsic volcanic rock and granite clasts are generally subrounded in shape, and clasts of other lithologies are subangular. Distribution of this type of conglomerate is restricted in southeastern part of the study area.

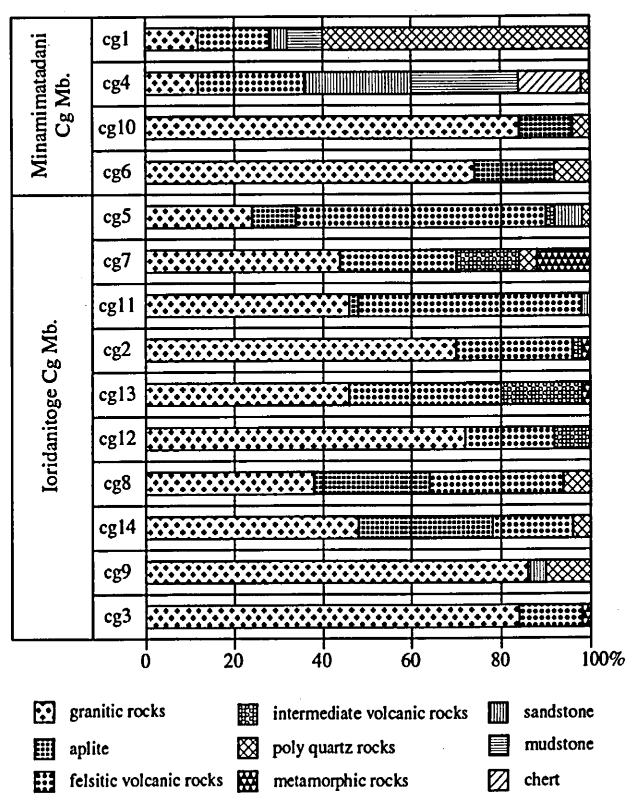

Fig. 16. Gravel composition of the Tetori Group. Localities of the samples are shown in Fig. 6.

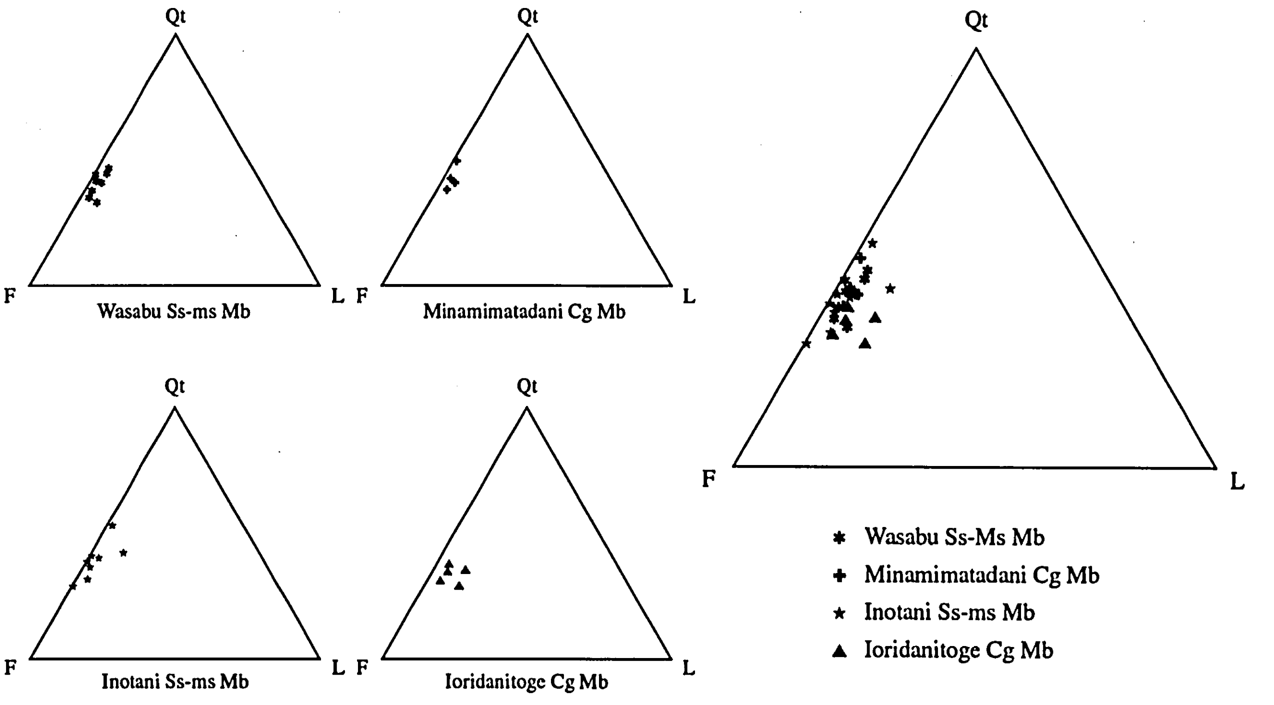

Fig.17. Qt-F-L diagram of sandstones from the four members of the Tetori Group in the Nagato River area.
Qt: total quartz, F: feldspar, L: lithic fragment.

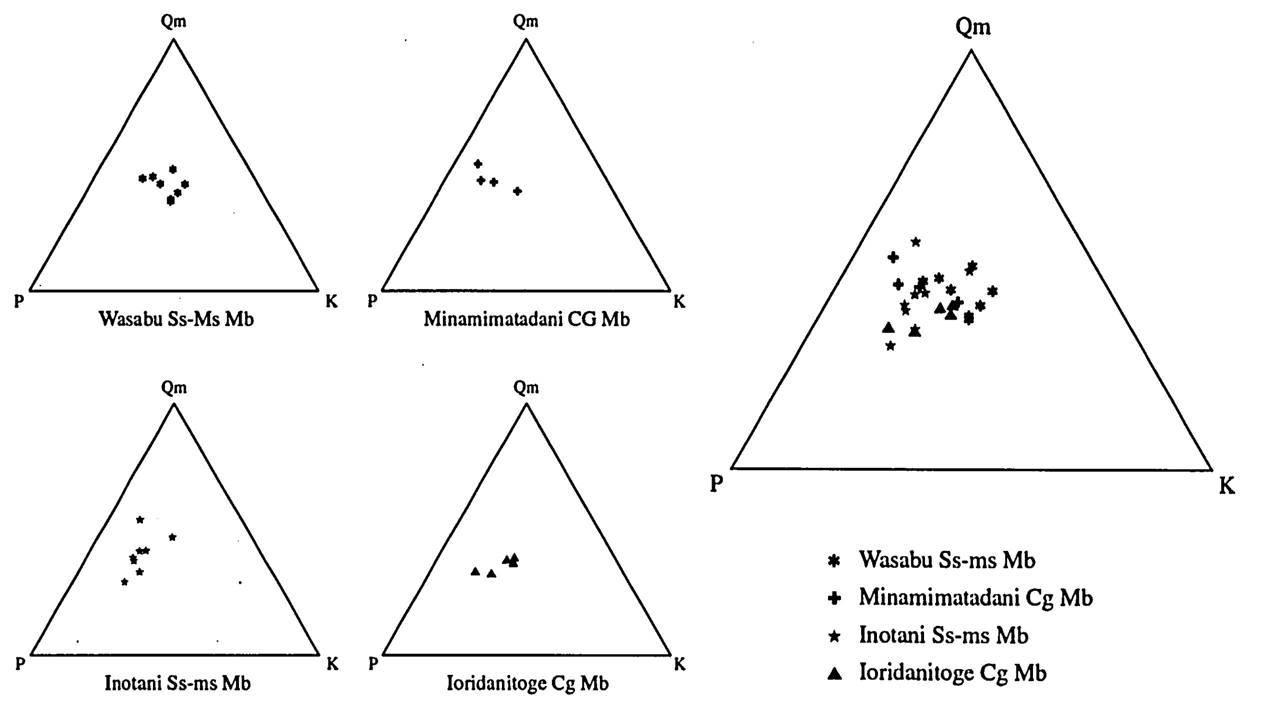

Fig. 18. Qm-P-K diagram of sandstones from the four members of the Tetori Group in the Nagato River area.
Qm: monocrystaline quartz, P: plagioclase, K: potassium feldspar.

C. Grain composition of sandstone

Grain composition of 25 sandstone specimens of the Tetori Group was quantified by point-counting method under a microscope (Figs. 17 and 18).

Results of the analysis indicate that the all specimens are feldspathic arenites and shear poor contents (less than several %) of lithic fractions. There is no clear difference in grain composition of the sandstone specimens among the four members (Figs. 17 and 18). However, the sandstone of the Atotsugawa Formation tends to increase the proportion of monocrystalline quartz. Proportion of plagioclase is low in Wasabu Sandstone-mudstone Member, and K-feldspar is low in Inotani Sandstone-mudstone and Minamimatadani Conglomerate Members (Fig. 18). Lithic fractions of the sandstone specimens were identified as felsic to intermediate volcanic rocks, and more rarely chert. The Ioridanitoge Conglomerate Member records a slightly larger proportion of lithic fractions than the other members (Fig. 17).

VII. Discussion

A. Interpretation of depositional environments of the facies

The Tetori Group of the study area yields relatively well-preserved plant fossils, fossil root, and non-marine animals, but it lacks marine fauna. This fossil occurrence suggests that the Nagatogawa and Atotsugawa Formations in the study area was deposited in non-marine environments. In order to interpret the depositional environment of the Tetori Group, well-established models of non-marine depositional systems (Miall, 1977; Einsale, 1992; Blair and McPherson, 1994; Collinson, 1996) are applied to the five sedimentary facies defined in this study.

1. Facies A

Poorly sorted angular clasts indicate that transported distance of the clasts is shorter in this facies in comparison with conglomerates of Facies C and D. This is supported by occurrence of limestone clasts, which is normally abraded out by a long-distance transportation. Mud gravity flow may be the accurate interpretation for the brecchia of Facies A1, which is poorly sorted and mud-supported. The brecchia with sandy matrix of Facies A2 is very similar to a deposit by sheet flood (Mlair and McPhaerson, 1994). A fan is the most reasonable environment, which is characterized by gravity flow and sheet flood (Blair and McPhaerson, 1994). Probably, A1 was deposited in a environment dominated by gravity flow, and A2 was under the domination of sheet flood.

2. Facies B

Altemating beds of Facies B were deposited under the repetition of increase and decrease of water flow energy. This facies tends to be deposited as thin layer on the fan deposits (Facies A) and overlain by Facies D (braided river deposits). This stratigraphic tendency indicates that the environment of this facies is braidplain aside the braided river currents, located near a distal part of a fan. The braidplane was probably developed in topographic depression and was periodically submerged.

3. Facies C

This facies is very similar to the vertical sequence of Scott-type braided river of Maill (1977). Weakly stratified conglomerate was formed and accreted by a longitudinal bar under strong water energy. Thin sandstone layers within the conglomerate were formed by deposition of bed load in a small current system when the flow energy decreased. Rounded shape of the clasts indicates relatively long-distance transportation.

4. Facies D

This facies is very similar to the vertical sequence of Platte-type braided river of Maill (1977). Intercalation of conglomerate suggests strong water flow, but the intercalation is less frequent than in Facies C. Because the flood events were rare, deposited mud was preserved against erosion. Under this environment, the dominant sedimentary structure is planner-type cross-lamination that formed in a bar condition.

5. Facies E

Fining-upward depositional cycles characterizing Facies E are similar to the deposits found in a meandering river system consisting of point bar, chute bar and crevasse splay. The mudstone with fossil root is the deposit on a flood plane of the river (Einsale, 1992; Collinson, 1996).

B. Depositional processes of the Tetori Group

Depositional processes of the Tetori Group of the study area are reconstructed by the results of stratigraphy, facies, paleocurrent, and sediment composition. The depositional history consists of the following four stages, which corresponds to the four stratigraphic members.

1. Stage 1

This stage is the depositional period of the Ioridanitoge Conglomerate Member. The conglomerate was deposited in braided rivers and small-scale fans developed on the basement with irregular topography (Fig. 19). A

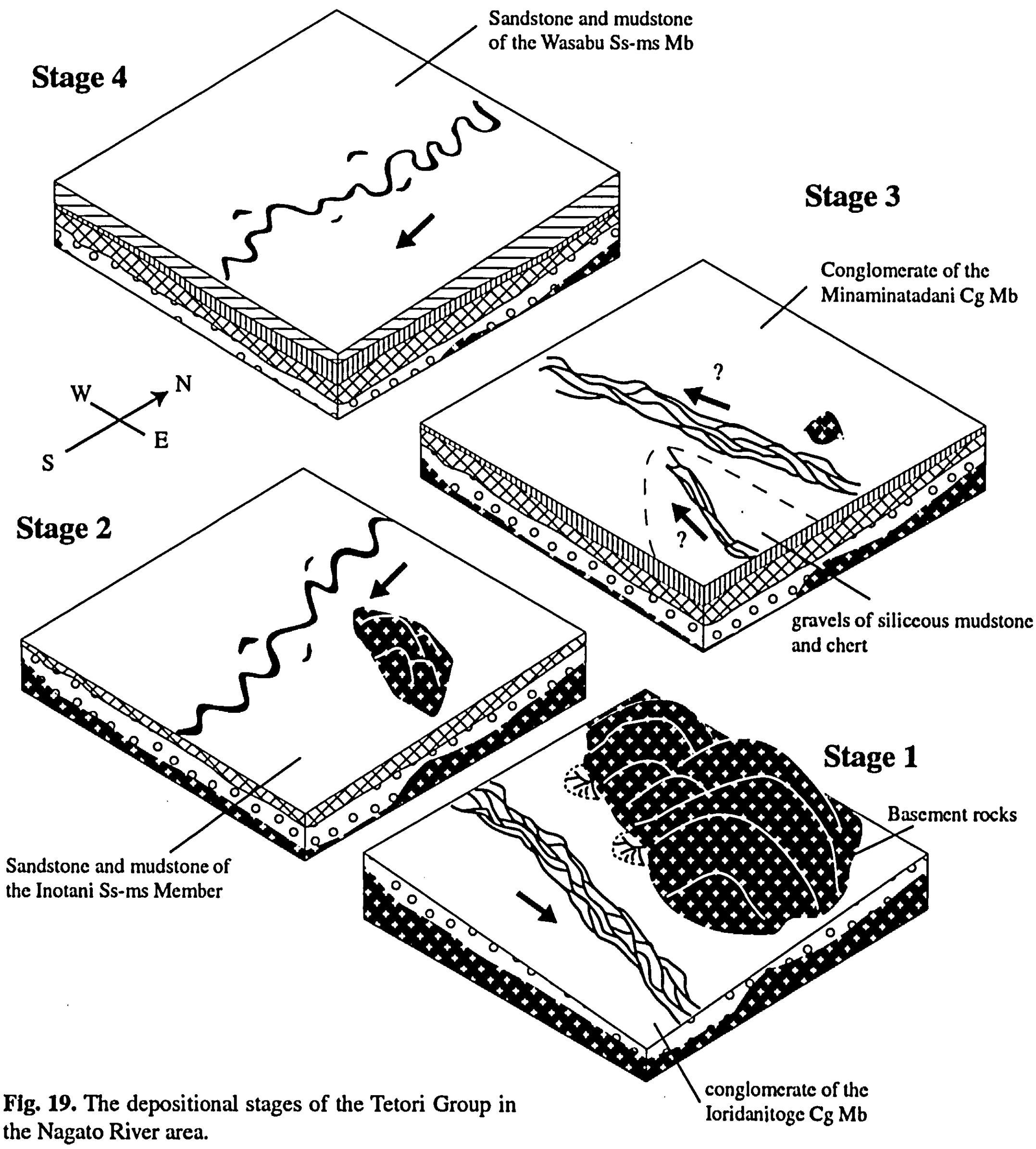

Fig. 19. The depositional stages of the Tetori Group in the Nagato River area.

topographic high was located in the NE study area, and was a place of erosion rather than deposition. The depositional system of the study area started from a fan environment developed near the mountain area. Sediments were transported in a short-distance and supplied from the Hida Metamorphic Rocks. Then, braided rivers were developed in the central part of the basin and deposited Facies C. Distance of the sediment transportation became longer. Facies D was deposited in the NW study area, where was located far from river passages and escaped from strong influence of flood events.

2. Stage 2

Beginning of this stage is marked by shift of the depositional system from braided rivers to a meandering river, which generally flow from north to south. The meandering system deposited the Inotani Sandstone-mudstone Member consisting mostly of Facies E. Thin development of Facies D was formed by declining of the braided rivers. The topographic high was still partly exposed in this stage.

3. Stage 3

The meandering river was again shifted to braided rivers, and the Minamimatadani Conglomerate Member was deposited. The limited distribution of siliceous mudstone and chert clasts in the southern study area indicates that the braided river directed E-W. These clasts are relatively angular, and were probably supplied form a short distance. Granite and felsic volcanic rock clasts are more common in the eastern part than in the central part, and this tendency indicates that these clasts were transported by a river flowing from east to west, or by a river extending N-S direction.

4. Stage 4

A meandering river flowing from north to south was developed in this stage and deposited the Wasabu Sandstone-mudstone Member. The basement, which used to have been exposed in northern and eastern parts, was covered by thick sedimentation (or completely eroded; Fig. 19). The meandering river system had been stable for a long periods and accumulated thick (about 700 m) sequence of sandstone and mudstone.

VIII. Conclusions

Following results and discussions are concluded in this study dealing with sedimentology of the Tetori Group distributed in the Nagato River area, southern Toyama Prefecture.

(1) The Tetori Group in the Nagato River area is divided into the Nagatogawa and Atotsugawa Formation, which corresponds to the Akaiwa and Itoshiro Subgroup of the type area, respectively. Based on lithology, the Nagatogawa Formation was further subdivided into the lower Ioridanitoge Conglomerate Member and the upper Inotani Sandstone-mudstone Member. The Atotsugawa Formation was subdivided into the Minamimatadani Conglomerate Member and the Wasabu Sandstone-mudstone Member. All members yield plant fossils, and the animal fossils were found from the Wasabu Sandstone-mudstone Member.

(2) Five sedimentary facies were recognized in the Tetori Group. They are Facies A (fan), Facies B (distal fan and braided river plane), Facies C (Scott-type braided river), Facies D (Platt-type braided river), and Facies E (meandering river).

(3) The four members show no clear difference in grain composition of sandstone. The sandstone beds are all feldspathic arenite.

(4) The two conglomerate members differ in the lithologic composition of the clasts. Granite and felsic volcanic rock clasts dominate the deposits of the Ioridanitoge Conglomerate Member, but the conglomerate bed of the middle and upper parts contains clasts of intermediate volcanic rocks. Two types of gravel composition were recognized in the conglomerate beds of the Minamimatadani Conglomerate Member. One is dominated by granite and aplite. Another type shows diverse composition including siliceous mudstone and chert and occurs in southeastern part of the study area.

(5) Imbrication and cross-lamination indicate the paleocurrent was from east to west for the Ioridanitoge Conglomerate Member, from north to south for the Inotani Sandstone-mudstone Member and the Wasabu Sandstone-mudstone Member. Three directions, E to W, NW to SE, and SW to NE, were recognized for the Minamimatadani Conglomerate Member.

(6) The depositional history of the Tetori Group of the Nagato River area consists of four stages, which corresponds to the four stratigraphic members. Stage 1 was development of fans and braided rivers in a basin in a mountainous area. Stage 2 was development of a meandering river system. Stage 3 was development of at least two braided river systems. One extended east to west and transported gravels of chert and siliceous mudstone in the SE study area. Stage 4 is stable condition of a meandering river system, which accumulated thick sandstone and mudstone and buried the basement topography.

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