Bulletin of the Geological Survey of Japan, vol.57 (1/2), p. 29- 50 , 2006

Stratigraphy and structure of the Jurassic accretionary complex in the Daigo district, northern Ibaraki and eastern Tochigi Prefectures, central Japan

Satoshi Nakae[1]

Satoshi Nakae (2006) Stratigraphy and structure of the Jurassic accretionary complex in the Daigo district, northern Ibaraki and eastern Tochigi Prefectures, central Japan. *Bull. Geol. Surv. Japan*, vol. 57 (1/2), 29-50, 21 figs, 3 tables.

Abstract: The Daigo district covers nearly 420 km^2 in the northern Ibaraki and eastern Tochigi Prefectures, central Japan, about 150 km NNE of Tokyo. The district is topographically distinguished into three areas: in the northeast the Abukuma Mountains, in the central area the dissected lowland and hills, and in the west the Yamizo Mountains. The Abukuma Mountains are separated from the central lowland and hills by the Tanagura tectonic line (TTL). East of the tectonic line, the Abukuma Mountains are mainly underlain by Cretaceous metamorphic and granitic rocks of the Abukuma belt. To the west, accretionary complexes of the Ashio belt ranging from Triassic to probably earliest Cretaceous in age and unconformably overlying Miocene sedimentary and volcanic rocks are respectively exposed in the west and central areas. The mapped area is located in the Yamizo Mountains.

The Yamizo Mountains are mainly underlain by a disrupted and dismembered accretionary complex of various depositional environments ranging from pelagic to terrigenous. The accretionary complex, called the Ashio Terrane, is thought to have been formed along a convergent margin where the Izanagi plate was subducting beneath the ancient Asian continent during the Jurassic period. The Ashio Terrane in this district is tectonostratigraphically subdivided into the Kasama and Takatori Complexes; their lithologic features are almost similar, but the variety and/or abundance of their component rocks, age of deposition and tectonic contact with the complexes can provide the basis for classification.

The Kasama Complex is mainly composed of clastic rocks such as massive to stratified sandstone, laminated mudstone, silty mudstone and pelagic chert. Among these rocks, massive sandstone and laminated mudstone are most dominant, and chert is rarely included in the complex. Pelitic mixed rock, which consists of foliated black mudstone with pebbles or lenticular small blocks of sandstone and chert, is also observed. The Takatori Complex is almost similar to the Kasama Complex in lithology as a whole, however the sequence of laterally extending cherts and overlying clastic rocks of mudstone and sandstone is repeatedly exposed at least three times in this complex. The thickness of each complex is thought to be about 4,000 m.

The Kasama Complex is inferred to be in fault contact with the overlying Takatori Complex. These complexes gently to moderately dip westward. Post-Jurassic folding is represented by the strike obviously swinging from NE-SW to NW-SE. Furthermore numerous subvertical faults, NNW-SSE and NE-SW trending, transect the complexes.

Keywords: accretionary complex, Ashio Terrane, Kasama Complex, Takatori Complex, regional geology, geologic map, 1:50,000, Daigo, Ibaraki, Tochigi, Yamizo Mountains, Jurassic

1. Introduction

The Daigo district lies in a mountainous area between the northern Ibaraki and eastern Tochigi Prefectures, covering an area of 18.5 km x 22.3 km, and is about 150 km NNE of Tokyo (Fig. 1A). The district extends west from the foothills of the Abukuma Mountains to the Yamizo Mountains. It is divided into three distinct topographic areas (Fig. 2A): in the northeast the Abukuma Mountains, in the central area the dissected lowland and hills with the Kuji-gawa River and in the west the Yamizo Mountains with a summit over 1,000 m. The Abukuma Mountains are separated from the central lowland and hills by the Tanagura tectonic line (TTL). East of the tectonic line, especially the Tanagura eastern fault (TEF), the Abukuma Mountains are mainly underlain by the Takanuki and the Gosaisho metamorphic rocks and the Abukuma granite in the

[1] Geological Survey of Japan, AIST

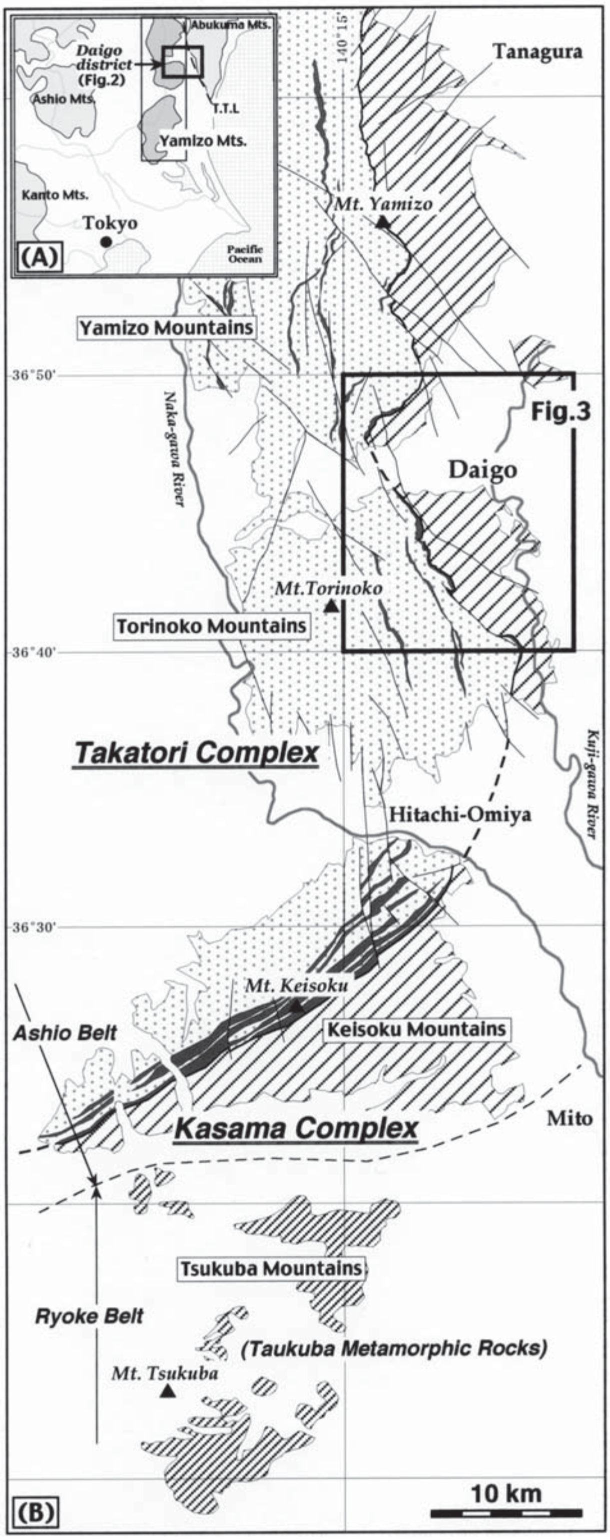

Fig. 1 Index map showing the location of the Yamizo Mountains and Daigo district (A), and geological setting of the Yamizo Mountains with the location of the mapped area (B). Laterally elongated slabs of remarkable chert are accentuated by dark grey zones. The Yamizo Mountains in a wide sense are generally divided into the Yamizo, Torinoko, Keisoku and Tsukuba mountains.

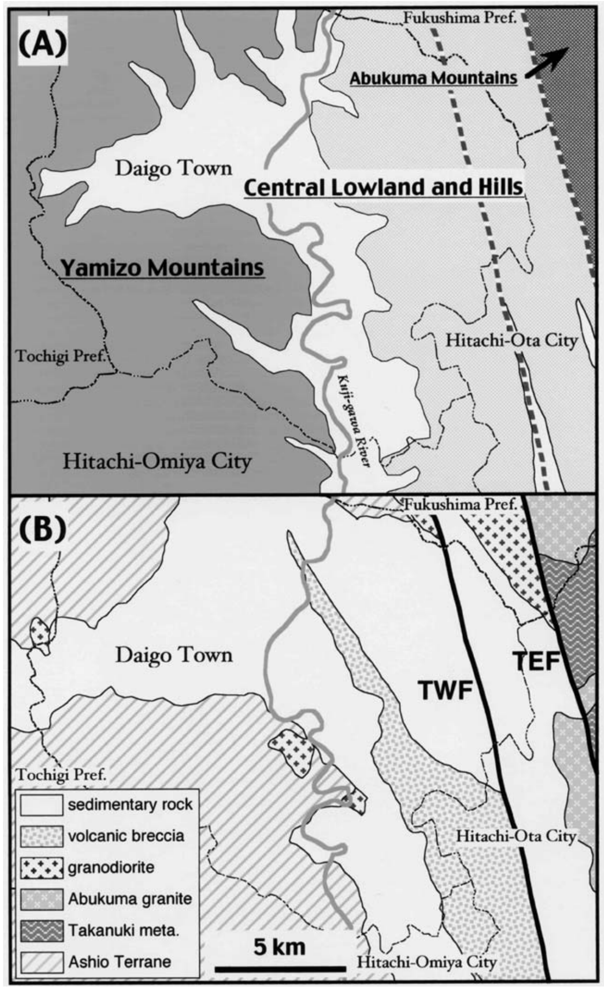

Fig. 2 Topographical setting and geological framework of the Daigo district. TEF: Tanagura eastern fault, TWF: Tanagura western fault. (A): The Daigo district is topographically divided into the Abukuma Mountains (dark gray) in the northeast, dissected lowland and hills in the central area, and Yamizo Mountains (gray) in the west. (B): Each area is underlain by its own specific geologic units. Accretionary complex of the Ashio Terrane widely outcrops in the southwestern and northwestern areas and is observed in the north area with a small distribution.

Abukuma belt (Fig. 2B). The high P/T Takanuki metamorphic rocks, whose protolith is unknown in age, consist mainly of Cretaceous pelitic gneiss (*e.g.*, Kano, 1979). The low P/T Gosaisho metamorphic rocks once originated as a Jurassic accretionary complex and were metamorphosed in the Cretaceous period (Hiroi *et al.*, 1987). To the west including the west and central areas is an accretionary complex of Triassic to Jurassic age and overlying Miocene sedimentary and volcanic rocks. The mapped area is located in the Yamizo Mountains (Fig. 1B).

The Yamizo Mountains consist of Mts. Yamizo,

Table 1 Correlation of stratigraphic divisions. Gr: Group, Fm: Formation

<table>
<tr><td colspan="3">(a)</td><td colspan="3">(b)</td><td>(c)</td><td>(d)</td><td colspan="2">(e)</td><td colspan="2">(f)</td><td colspan="2">(g)</td><td colspan="2">(h)</td><td>(i)</td></tr>
<tr><th colspan="3">Kawada (1953)</th><th colspan="3">Kanomata (1961)</th><th>Oyama and Kasai (1974)</th><th>Sato (1974)</th><th colspan="2">Kasai (1978)</th><th colspan="2">ANRE (1986)</th><th></th><th>Sashida et al. (1993)</th><th colspan="2">Hori and Sashida (1998) Sashida and Hori (2000)</th><th>This report</th></tr>
<tr><td rowspan="7">Triassic to Jurassic</td><td colspan="2" rowspan="7">Yamizo Gr/ Torinoko Gr</td><td rowspan="10">Mesozoic</td><td rowspan="10">Yamizo Gr</td><td>Karasuyama Fm</td><td rowspan="2">Upper Fm</td><td>Triassic to Jurassic</td><td rowspan="2">Upper Jurassic</td><td rowspan="2">Mashiko Gr</td><td rowspan="11">Yamizo Gr</td><td rowspan="3">Ayuta Fm</td><td rowspan="11">Upper Jurassic</td><td>- - ? - -</td><td rowspan="3">Ayuta Unit</td><td rowspan="6">Takatori Unit</td><td rowspan="6">Takatori Complex</td></tr>
<tr><td rowspan="2">Torinokosan Fm</td><td rowspan="2">Jurassic</td><td rowspan="5">Unit 3</td></tr>
<tr><td rowspan="2">Middle Fm</td><td rowspan="9">Triassic</td><td rowspan="9">Yamizo Gr</td></tr>
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<tr><td rowspan="2">Lower Fm</td></tr>
<tr><td rowspan="2">Keisokusan Fm</td></tr>
<tr><td rowspan="2">Upper Fm</td><td rowspan="5">Permian</td><td rowspan="4">Kunimi-yama Fm</td><td rowspan="3">Unit 2</td><td rowspan="4">Kunimi-yama Unit</td><td rowspan="5">Kasama Unit</td><td rowspan="5">Kasama Complex</td></tr>
<tr><td rowspan="4">Upper Paleozoic</td><td rowspan="4">Keisoku Gr</td><td rowspan="3">Keisokusan Fm
Isehata Fm
Nanakai Fm</td><td rowspan="3">Kunimiyama Fm</td></tr>
<tr><td rowspan="2">Middle Fm</td></tr>
<tr><td rowspan="2">Unit 1
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<tr><td>Kasama Fm</td><td>Paleozoic</td><td colspan="2">Kasama Gr</td><td>Lower Fm</td><td>Kasama Fm</td><td>Kasama Unit</td></tr>
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conformity fault

Torinoko, Keisoku and Tsukuba from north to south. From a geologic viewpoint, the mountains are divided into the Ashio and Ryoke belts (Fig. 1B); the northern three mountains belong to the Ashio belt and the southern most one is included in the Ryoke belt. Although both belts are underlain by an accretionary complex of Triassic to Middle Jurassic cherts and Middle to Late Jurassic, probably reaching to earliest Cretaceous, clastic rocks (= Jurassic accretionary complex of the Ashio Terrane), the rocks in the Ryoke belt have been metamorphosed (= Tsukuba Metamorphic Rocks) and intruded by granitic rocks through a low P/T condition in the Cretaceous period (*e.g.*, Miyazaki *et al.*, 1992). The Ashio Terrane is regarded to have been formed along the convergent margin where the Izanagi plate was subducting beneath the ancient Asian continent during the Jurassic period.

The mapping of the Daigo district has been carried out since 1993 under a mapping project of the Geological Survey of Japan, AIST, and the full text of 'Geology of the Daigo district' with a 1:50,000 geological map (quadrangle series) will be published in the near future. This report particularly concentrates on the Jurassic accretionary complex of the Ashio Terrane, oldest basement rock in the district, and its stratigraphy, lithology, age and structure will be described later.

2. Previous works

2.1 Yamizo Mountains

On the accretionary complex distributing the Yamizo Mountains, the 1:20,000 geological maps of 'Mito' (Yamada, 1887), 'Kitsuregawa' (Otsuka, 1889) and 'Shirakawa' (Otsuka, 1892) took the lead in studying regional geology during the late Meiji Period (1880s-1910s). Based on the maps, the accretionary complexes in the Yamizo Mountains have commonly been expected to be Paleozoic in age in spite of no fossil evidence and were divided into the older and younger Paleozoic systems in 'Mito' or into the Kobotoke and Chichibu Paleozoic systems in 'Kitsuregawa' and 'Shirakawa'. Compared with the systems, the older and younger Paleozoic systems might be identical with the Kobotoke and Chichibu Paleozoic systems, respectively. Their type localities are in the Kanto Mountains, ca.150 km southwest of the Yamizo Mountains (see Fig. 1A) so the names of the Paleozoic systems become meaningless.

The first report on fossil from the accretionary complex in the Yamizo Mountains was released in the early Showa Period (1920s-1940s) by Prof. Haruyoshi Huzimoto, who was a pioneer in the research on the mountains. He found radiolarian fossils from pale green silty mudstone, originally described as 'dark green sandy shale', at Odaira and Nokura, Daigo Town that is situated at the northeastern foot of Mt. Torinoko and inferred that these radiolarians were of Mesozoic (Huzimoto, 1932). Research by Kawada (1953) and Kanomata (1961) gave the same result as Huzimoto (1932); radiolarian fossils from pale green silty mudstone at three outcrops in the Yamizo Mountains were considered to be Mesozoic in age. However, they were quite different than the previously expected age and have never been acceptable at that time and until the 1980s.

Huzimoto and Hatakeyama (1938) detected late Carboniferous fusulinids. Later Prof. H. Igo pointed out that these fusulinids are of Permian age (Sato, 1981) and Permian foraminifers from limestones are included in the Kobotoke Paleozoic system of Otsuka (1889).

Regional and comprehensive investigation on stratigraphy and geologic structure of the accretionary complex in the mountains began from the 1950s. Kawada (1953) nominated the upper Paleozoic Keisoku Group and Mesozoic Yamizo and Torinoko Groups for each accretionary complex in Mt. Keisoku and Mts. Yamizo and Torinoko, respectively (Table 1-a), and regarded that these groups homoclinally incline westward. Kanomata (1961) also represented the similar structure to that of Kawada (1953), but repealed Kawada's division and proposed a revised division, the upper Paleozoic Kasama Group and the Mesozoic, probably Jurassic Yamizo Group in ascending order (Table 1-b), because of the uniform lithostratigraphy recognized in each mountain.

Oyama and Kasai (1974), Sato (1974), Kasai (1978) and Agency for Natural Resources and Energy (ANRE) (1986) showed their own stratigraphic divisions, which are different from those of Kawada (1953) and Kanomata (1961). Oyama and Kasai (1974) divided the accretionary complex into lower, middle and upper formations and considered that these formations are duplicated and exposed twice by a thrust (Table 1-c). On the contrary, Sato (1974) denied the above Oyama and Kasai's division and regarded the accretionary complex as Permian to Jurassic, which was classified into four formations (Table 1-d). Kasai (1978) redefined the Karasuyama Formation which is the uppermost part of the Yamizo Group of Kanomata (1961) as the Mashiko Group due to obviously different lithology of the intercalated conglomerate from other formations (Table 1-e). This conglomerate has been designated as the Sarukubo Conglomerate (Kano, 1960). In addition, Kasai (1978) mentioned about the geologic structure; the accretionary complex in the Yamizo Mountains is partially overturned because of thrust-related folding.

During 1985, the exploration on rare metallic resources has been carried out around the Takatoriyama Mine near Mt. Keisoku by ANRE, Ministry of International Trade and Industry. ANRE (1986) named the accretionary complex in Mt. Keisoku as the Yamizo Group and divided it into the Kasama, Kunimiyama, Takatori and Ayuta Formations in ascending order (Table 1-f). Radiolarian fossils ranging in age from latest Jurassic to earliest Cretaceous were extracted from mudstone of the Kasama Formation (Wakita *et al.*, 1989).

Since the 1970s due to the increase in the number of reports on the occurrence of Mesozoic fossils, a more precise age of the accretionary complex became known; for example, Triassic conodonts from cherts (Igo, 1972; Yoshida *et al.*, 1976), Jurassic plant fossils from silty mudstones (Oyama and Kasai, 1974), a Late Jurassic ammonite from laminated mudstone (Suzuki and Sato, 1972), and Jurassic radiolarians from mudstones (Sashida *et al.*, 1982, 1993; Wakita, *et al.*, 1989; Hori, 1998, 1999, 2001; Nakae and Takizawa, 1998; Nakae, 2000a; *etc.*). As a result of the above reports, Paleozoic, which has formerly been inferred (*e.g.*, Yamada, 1887), is unacceptable and Jurassic is the most suitable age for the accretionary complex from a viewpoint of the accretionary process.

Recently, stratigraphic redivision and redefinition of the accretionary complex in the Yamizo Mountains has been done on the basis of a tectonostratigraphic concept together with a sense of subduction-accretion tectonics. Hori and Sashida (1998) revised the formations of ANRE (1986) as the Kasama, Kunimiyama, Takatori and Ayuta Units (Table 1-h). Although the unit names conform to those of ANRE (1986), Hori and Sashida (1998) considered that the units are thrust-bounded to each other. Just after Hori and Sashida (1998), they released the revised version of their former division again; the Kasama and Takatori Units (Table 1-h; Sashida and Hori, 2000).

2.2 Daigo district

In the Daigo district, Mesozoic radiolarian biochronology established during the 1980s has been making rapid progress in detailed field investigation on stratigraphy and geologic structure of the accretionary complex since the 1990s. As already stated, it has been well known that Mesozoic radiolarian fossils were found from pale green silty mudstone in the district (Huzimoto, 1932). Afterwards, Sashida *et al.* (1993) studied the northeastern foot of Mt. Torinoko within the Daigo district and clarified that the pale green silty mudstone is late Late Jurassic in age. They also divided the accretionary complex into three units (Table 1-g). Nakae (1997) distinguished a successive sequence consisting of lower chert and upper mudstone from the accretionary complex and further determined the sequence to be Middle Triassic to Upper Jurassic. In addition, Nakae and Takizawa (1998) detected latest Jurassic (Tithonian) radiolarian fossils from silty mudstone intercalated with sandstone, and Nakae (2000a) divided the accretionary complex in the district into Complexes I, II and III. On the other hand, Hori (1998) confirmed the age of the pale green silty mudstone to be within Tithonian by a detailed radiolarian biostratigraphic study. Hori and Sashida (1999) and Hori (2001) distinguished the Karasuyama Unit from the Takatori Unit of Sashida and Hori (2000). And a radiolarian biostratigraphic study of Hori (2001) ratified the result of Nakae (1997).

3. Outline of Geology

The mapped area in the Daigo district lies at the northeastern foot of Mt. Torinoko and southeastern foot of Mt. Yamizo, and a greater part of the mapped area belongs to southwestern Daigo Town and northeastern Hitachi-Omiya City, Ibaraki Prefecture and eastern Kurobane and Bato Towns, Tochigi Prefecture (Figs. 1B and 2). In this area, the oldest basement rock, into which Early Cretaceous granodiorites intrude and on which Miocene sedimentary rocks unconformably lie, consists of an accretionary complex. It is mainly composed of predominant sandstone and mudstone with a minor amount of siliceous mudstone and chert. Each rock has its specific age; *i.e.*, chert ranges from Middle Triassic to Early or Middle Jurassic, siliceous mud-

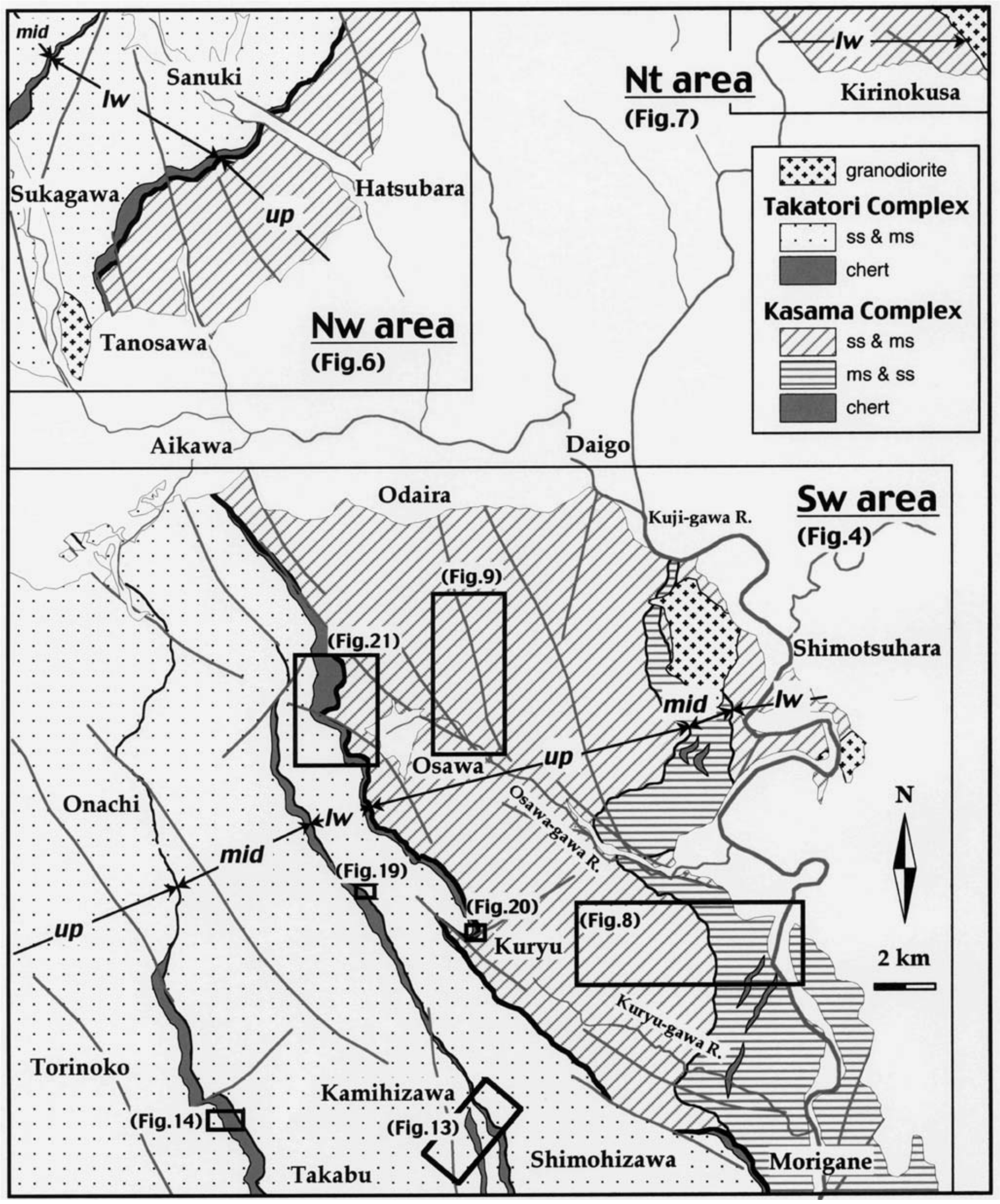

Fig. 3 Brief geologic map in the western Daigo district. Mapped area is shown in Fig. 1B. lw: lower part, mid: middle part, up: upper part, ms: mudstone, ss: sandstone. Thick lines with A - N are routes of columnar sections shown in Figs. 10 and 15.

stone is Middle to Late Jurassic and mudstone is Late Jurassic. These component rocks are records of the subduction-accretion process, which had been occurred by the interaction between the Izanagi plate and ancient Asian continental plate during the Middle to Late Jurassic period.

Two stratigraphic units, Kasama and Takatori, are distinguished in the Daigo district (Fig. 3), and the Kasama Complex is in fault contact with the overlying Takatori Complex. These complexes gently to moderately dip westward. Post-Jurassic folding is represented by the strike obviously swinging from NE-SW to NW-SE. Furthermore numerous subvertical faults, NNW-SSE and NE-SW trending, transect the complexes.

The accretionary complex widely outcrops in the southwestern and northwestern areas and is observed in northern area with a small distribution (Fig. 2B). Each area will be called the Sw, Nw and Nt areas for short, hereafter (Fig. 3).

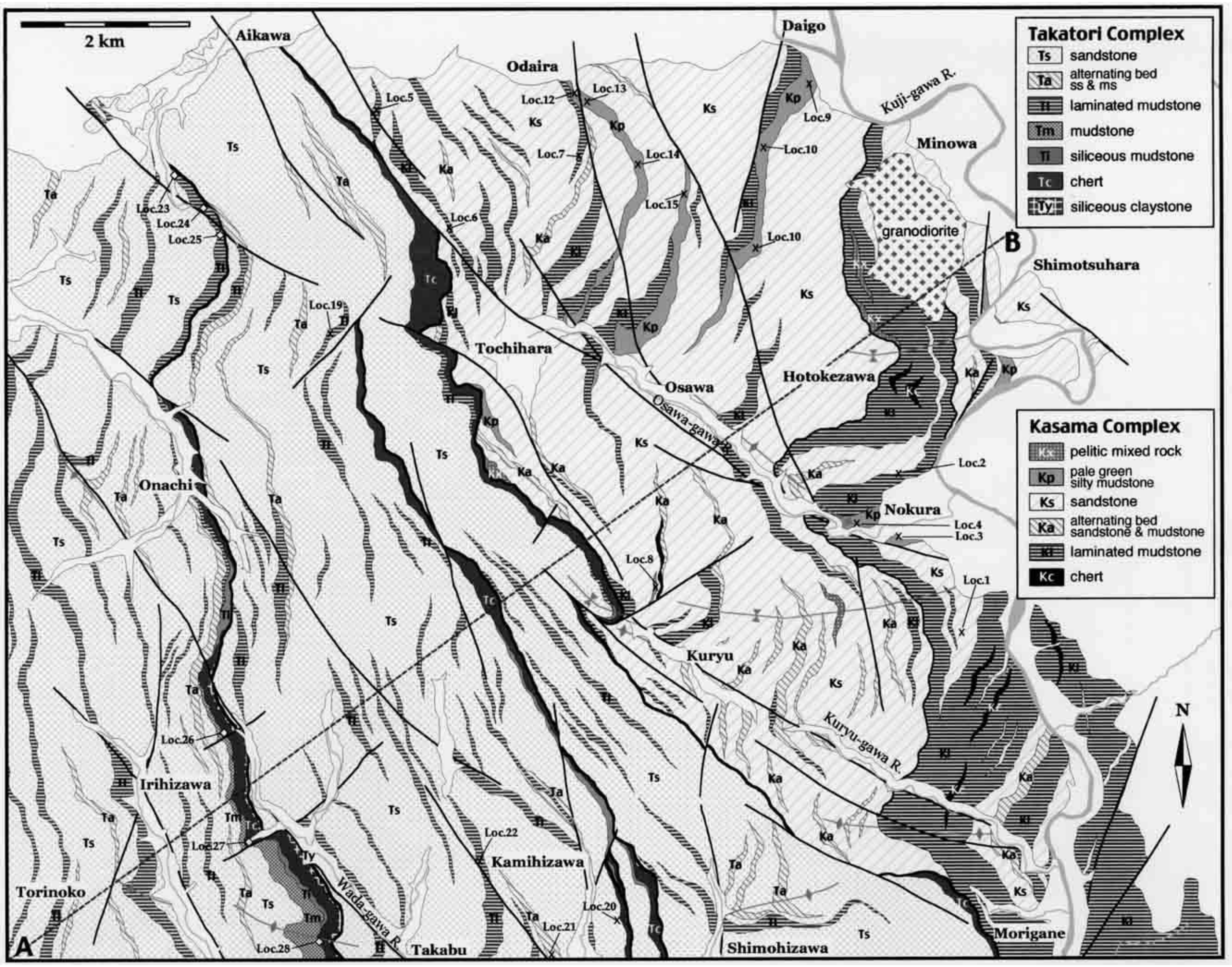

Fig. 4 Geologic map in the Sw area of the Daigo district with radiolarian fossil localities (Loc). Each locality number is shown in Tables 2 and 3.

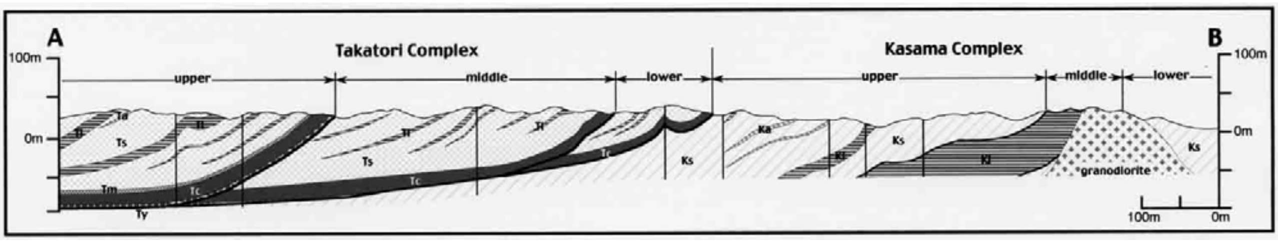

Fig. 5 Geologic profile of the complexes in the Sw area of the Daigo district. Lithologies with abbreviations are the same as those in Fig. 4. Cross section A-B is also shown in Fig. 4.

4. Stratigraphic Division

The Ashio Terrane, formed originally as an accretionary complex during the Jurassic period, was deformed by an accretionary and post-accretionary process. Consequently, the original succession of cherts and clastic rocks was somewhat disrupted and sliced. Stratigraphical analysis on the accretionary complex is generally difficult because of the heterogeneous nature of its lithology and lack of stratal continuity to aid correlation and mapping in the area of structural complexity. However, a tectonostratigraphic concept and framework (Nakae, 2000b) can provide a possibility to dividing the Ashio Terrane in the Daigo district into two stratigraphic units, Kasama Complex and Takatori Complex (Table 1-i).

Detailed geological maps of the Sw, Nw and Nt areas are shown in Figs. 4, 6 and 7, respectively. Gen-

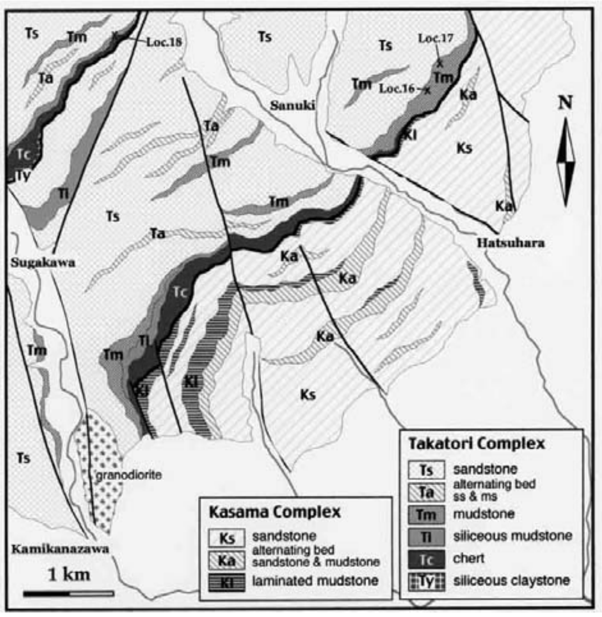

Fig. 6 Geologic map in the Nw area of the Daigo district with radiolarian fossil localities (Loc). Each locality number is shown in Table 3.

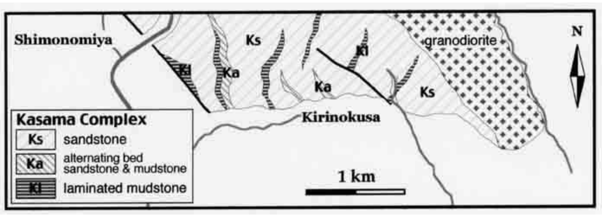

Fig. 7 Geologic map in the Nt area of the Daigo district.

eral profile of the complexes in the Sw area is also illustrated by Fig. 5.

4.1 Kasama Complex (Kc, Kl, Ka, Ks, Kp, Kx)

(Previously Kasama Formation, Kawada, 1953)

Designation

The originally defined Kasama Formation (Kawada, 1953) was once renamed as the Kasama Group by Kanomata (1961) or the Kasama Unit by Hori and Sashida (1998). Later Sashida and Hori (2000) incorporated the overlying Kunimiyama Unit with the Kasama Unit and redefined them as the revised Kasama Unit. The unit will be renamed hereafter as the Kasama Complex (Table 1-i).

Type locality

Exposed succession along the ‘Kasama-Mito road’ and a riverbed of the Hinuma-gawa River in Kasama City (Kawada, 1953). In the Daigo district, this complex typically outcrops along the Osawa-gawa River between Nokura and Tochihara, Daigo Town (Fig. 4).

Distribution and stratigraphical relations

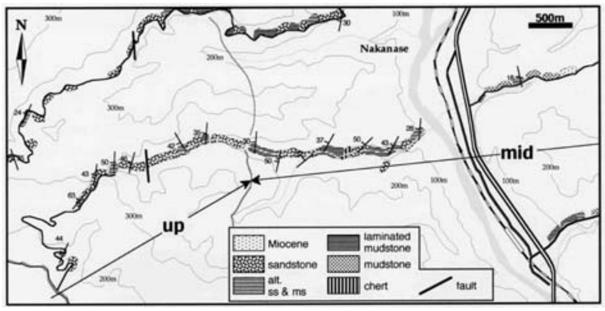

Fig. 8 Route map showing the Kasama Complex around Nakanase, west of the Kuji-gawa River. Mudstone and laminated mudstone are dominant in the middle part (mid) and sandstone is widely exposed in the upper part (up).

The Kasama Complex outcrops in the Sw, Nw and Nt areas of the district (Figs. 4, 6 and 7). To the lower boundary of the complex is unclear due to Miocene sedimentary rocks unconformably covering it. The complex is in fault contact with the overlying Takatori Complex (see Figs. 20 and 21). Early Cretaceous granodiorites intrude into the Kasama Complex at several locations.

Content and thickness

The complex is mainly composed of clastic rocks such as massive to stratified sandstone, alternating bed of sandstone and mudstone, laminated mudstone, silty mudstone and chert. The thickness of the complex is thought to be more than 4,500 m (see Fig. 10). Among these rocks, massive sandstone and laminated mudstone are the most dominant components in the complex, and the massive sandstone dominates over the laminated mudstone. Chert is rarely included. Pelitic mixed rock, which consists of foliated black mudstone as the matrix and pebbles or lenticular small blocks of sandstone and chert, is observed at a few localities. A lithologic feature is that chert is rarer and mudstone is more abundant in comparison with the Takatori Complex. In the Kasama Complex, stratal continuity is somewhat broken or disrupted on the outcrop scale, but the complex displays coherent facies as a whole at a 1:50,000 map scale.

Chert together with siliceous claystone and/or siliceous mudstone tends to appear at the middle of the complex as small-sized slabs, 10 to 100 m thick, which intercalate into laminated mudstone (Fig. 8). This laminated mudstone is about 400 m thick and laterally extends for more than 5 km. Laminated mudstones crop out in the following two manners; one is that it is intercalated with chert slabs as above-mentioned, the other is that it is accompanied by pale green silty mudstone as described below; at the lower and upper of the complex, the laminated mudstone generally overlies the pale green silty mudstone and laterally

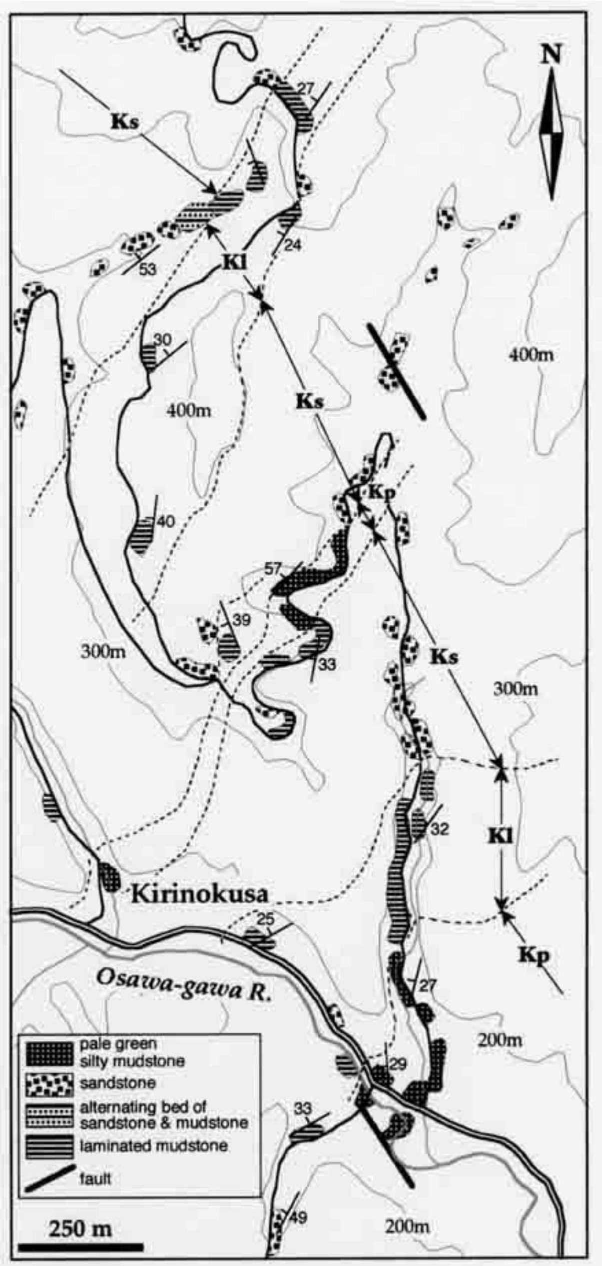

Fig. 9 Route map showing the upper part of the Kasama Complex around Kirinokusa, north of the Osawa-gawa River. Laminated mudstone (Kl), sandstone (Ks) and pale green silty mudstone (Kp), arranged in this order, are exposed at least three times.

elongates for 2 to 5 km with several tens of meters to 200 m thick (Fig. 9).

Alternating beds of sandstone and mudstone including its broken facies does not occur much wider than laminated and silty mudstones, being 20 to 100 m thick and 100 m to 3 km long. Sandstone, massive or thick-bedded, is dominant at the lower and upper of the complex whereas it rarely occurs in predominant laminated mudstone in the middle.

Stratigraphy

As stated above, the Kasama Complex is subdivided into the lower, middle and upper parts on the basis of the state of the lithologic assemblage (Fig. 10). However, it is impossible to determine their boundaries.

Lower part : Distributing around Shimotsuhara, Daigo Town in the eastern end of the Sw area (Fig. 4). Sandstone and mudstone exposed in the Nt area (Fig. 7) probably belong to the lower part, although the stratigraphic relation between the Nt and other areas has not been confirmed. Although the lower boundary of this part is still unclear due to Miocene sedimentary rocks unconformably covering it, the thickness might be more than 1,200 m (Fig. 10). This part consists mainly of predominant sandstone and subordinate alternating bed of sandstone and mudstone, laminated mudstone and pale green silty mudstone.

Middle part : Distributing along the Kuji-gawa River from Morigane, Hitachi-Omiya City through Nakanase and Nokura to Minowa, Daigo Town in the Sw area (Fig. 4). Thickness of this part is 500 to 1,000 m (Fig. 10). Around Morigane and Nakanase, slaty mudstone is present east of the Kuji-gawa River and laminated mudstone of more than 400 m thick outcrops west of the river (Fig. 8). Moving up to around Hotokezawa and Shimotsuhara west of the Kuji-gawa River, massive sandstone and alternating bed of sandstone and mudstone of 100 to 200 m thick and chert slabs of 50 to 100 m thick intercalate into laminated mudstone, and pelitic mixed rock including chert clasts of several tens of meters in diameter is rarely observed at the uppermost of this part.

Upper part : Dominating over the Kasama Complex and distributing along the Osawa-gawa and Kuryu-gawa Rivers in the Sw area (Fig. 4) and southeastern margin of the Nw area (Fig. 6). This part is about 2,500 m in thickness (Fig. 10). Massive to stratified sandstone is predominant and intercalated with laminated mudstone and pale green silty mudstone of several tens of meters to 200 m. In addition, minor amounts of alternating bed of sandstone and mudstone of 20 to 100 m thick are involved in sandstone. The successive sequence consisting of the above rocks; laminated mudstone, massive to stratified sandstone and pale green silty mudstone in ascending order, is repeatedly exposed in this part (Figs. 9 and 10).

Lithology

Siliceous Claystone : It is overlain by chert and rarely present at Hotokezawa, north of Nokura, Daigo Town. It is included in chert on the geologic map (Fig. 4). The siliceous claystone is weakly to intensely foliated, gray to greenish gray (Fig. 11-a), and mainly composed of very fine-grained claystone. Under the microscope, phyllosilicates and cryptocrystalline quartzes are observed and any clastic grain bigger than silt is invisible.

Chert (Kc) : In most cases, it appeared as bedded chert that consists of siliceous beds of 1 to 3 cm thick

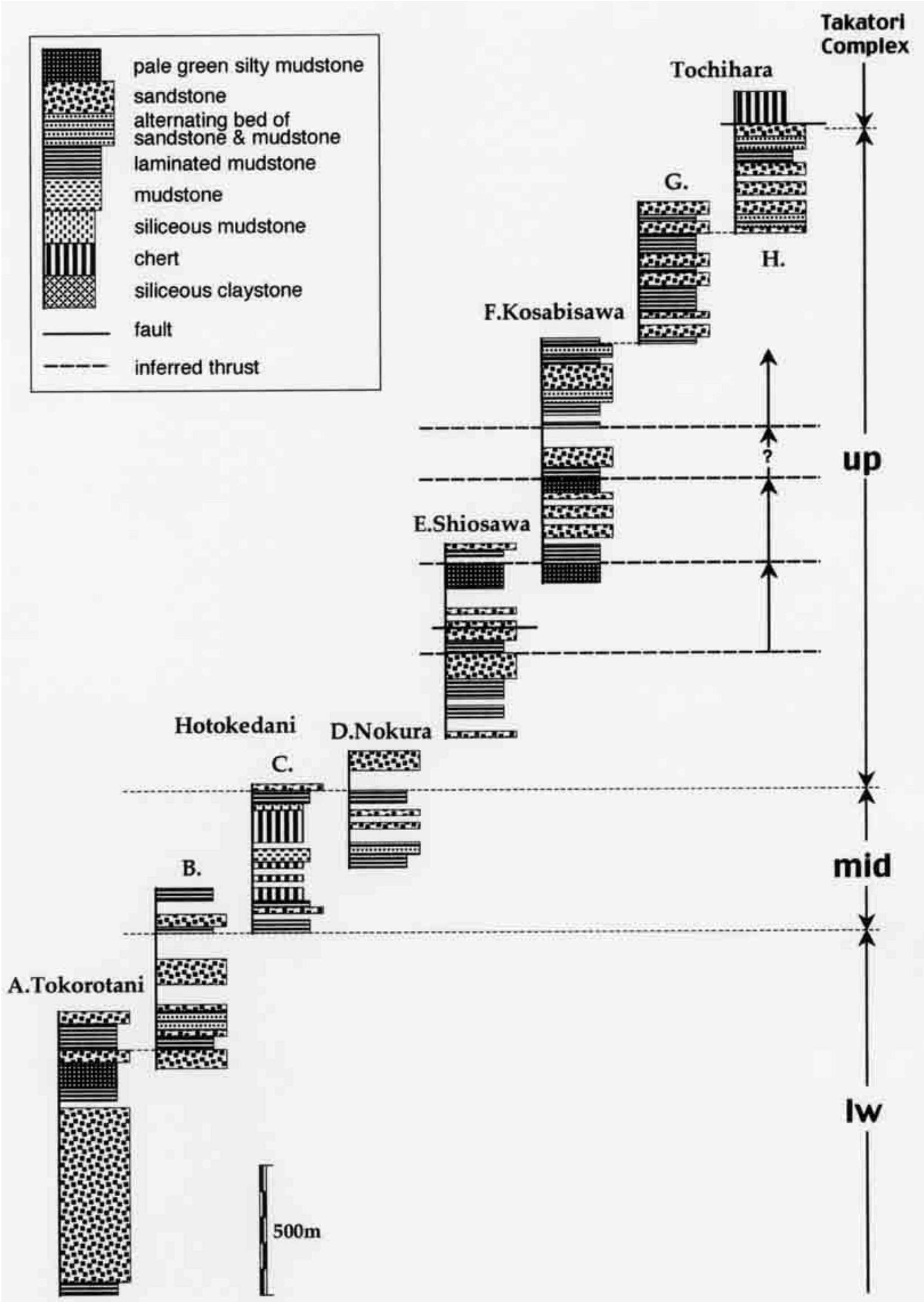

Fig. 10 Columnar sections of the Kasama Complex. Arrows in the upper part indicate repetition of the successive sequence composed of laminated mudstone, sandstone and pale green silty mudstone in ascending order. Each locality of the sections is shown in Fig. 3. lw: lower part, mid: middle part, up: upper part.

and interbedded black muddy beds less than 1 mm thick (Fig. 11-b). The chert, dark gray to black, is composed of cryptocrystalline quartz and any clastic grain is excluded. Most cherts of the Kasama Complex are somewhat sheared and recrystallized.

Siliceous mudstone : Dark to light gray, commonly homogenous and structureless although slaty cleavage is weakly developed at some localities. Gradual lithological change from chert to siliceous mudstone is observed at several localities including Hotokezawa,

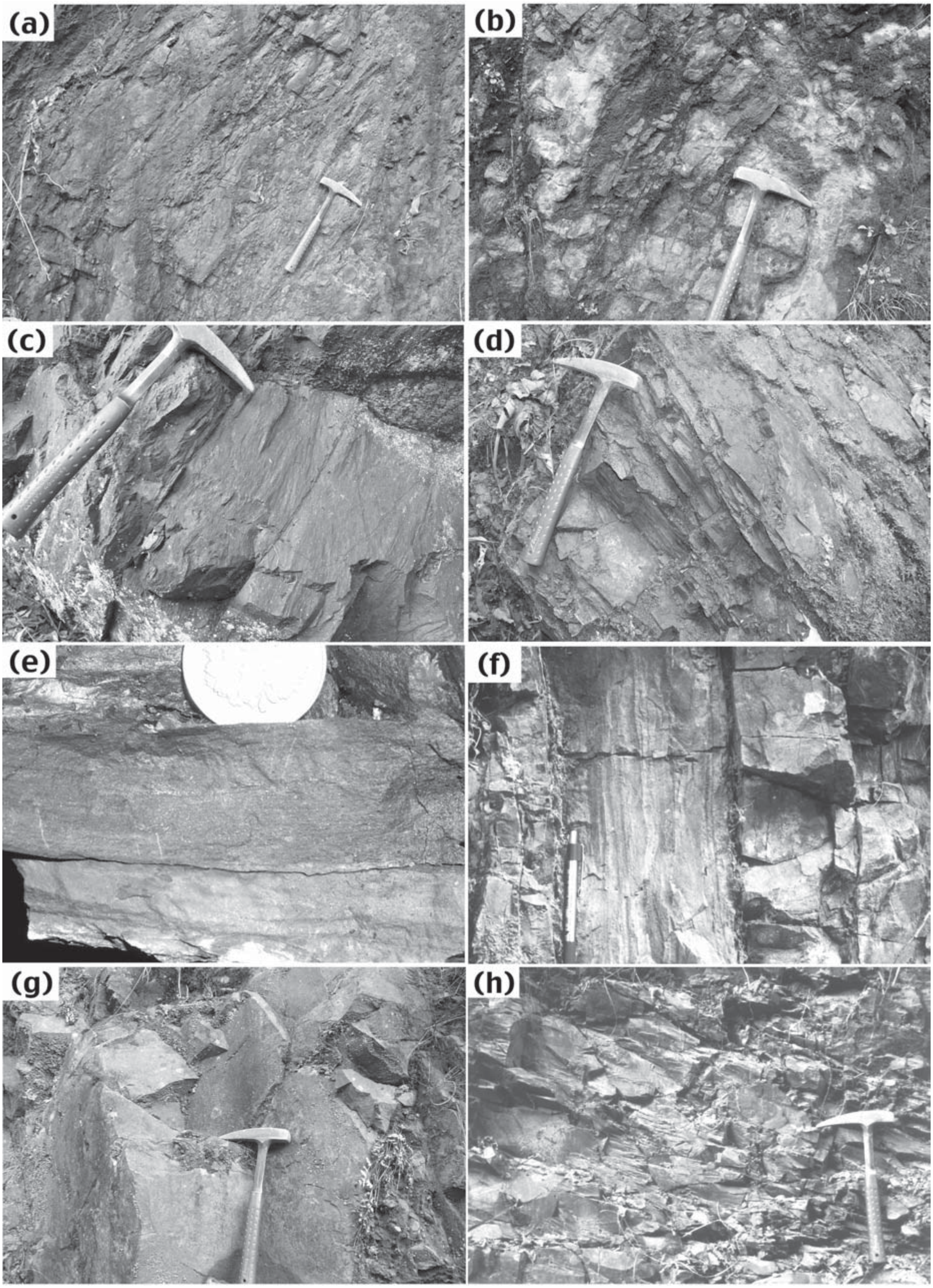

Fig. 11 Field lithologies of the Kasama Complex. (a) Siliceous claystone of the middle part at Hotokezawa, (b) chert of the middle part at Hotokezawa, (c) mudstone of the middle part at Shuku, (d)-(e) laminated mudstone of the upper part at Tochihara-Honda, (f) alternating bed of sandstone and mudstone of the upper part at Kuryu, (g) massive sandstone of the middle part at Hotokezawa and (h) pale green silty mudstone of the upper part at Kosabizawa.

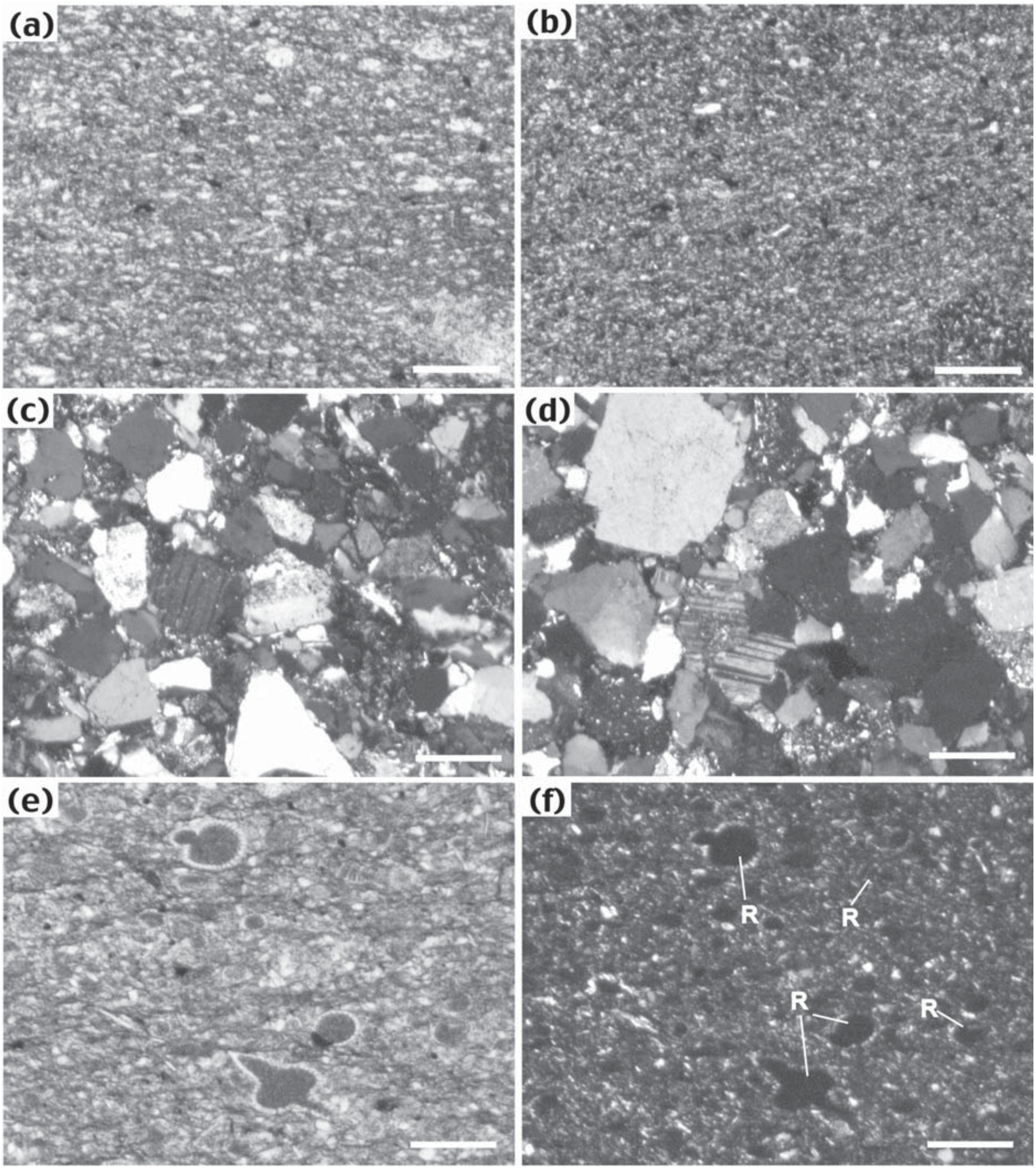

Fig. 12 Microphotographs of each lithology of the Kasama Complex. (a)-(b) Mudstone of the middle part at Kitatomita, (c) sandstone of the upper part at Tochihara-Honda, (d) sandstone of the middle part at Morigane, and (e)-(f) pale green silty mudstone of the upper part at Kosabizawa. Many radiolarian remains indicated by white bars with R are observed in (e) and (f). (a) and (e): open nicol, (b)-(d) and (f) are crossed nicols. All scale bars are 0.2 mm.

north of Nokura, Daigo Town. On the geologic map (Fig. 4), the siliceous mudstone is not drawn and is included in chert because it has a small area of distribution.

Mudstone : Dark gray to black (Fig. 11-c). Neither clastic grain coarser than silt nor silty lamina is contained so that the mudstone is much finer than the laminated mudstone described below. Under the microscope, clastic grains smaller than silt such as quartz, plagioclase and opaque minerals are observed in the matrix of phyllosilicate and cryptocrystalline quartz (Fig. 12-a, b). Generally, not foliation, nor well-developed cleavage, is observed, but the bluish dark gray mudstone outcropping along the Kuji-gawa River at the middle part of the complex is cloven. Slaty cleavage of this mudstone has originated from the preferred orientation, which is formed by the parallel arrangement of black seams with clay minerals. Furthermore, aggregations of biotites, individually ca.0.1 mm in diameter, are spotted on the surface of the cloven mudstone. It is impossible to draw mudstone, consequently it is included in laminated mudstone on the geologic map (Fig. 4) by the same reason as siliceous mudstone.

Laminated mudstone (Kl) : Dark gray mudstone universally intercalated with laminae and thin beds of silt to fine-grained sand (Fig. 11-d,e). Mudstone including a great amount of coarser grains is regarded as siltstone. Weak fissility parallel to the lamination is partially developed. Clastic grains of less than 0.02 mm in diameter, mostly quartz, are scattered in the matrix of clay minerals in the muddy parts, and clastic grains of 0.1 to 0.3 mm in diameter such as quartz, plagioclase, potassium feldspar, mica, opaque mineral and rock fragment are accumulated in the laminated parts.

Alternating bed of sandstone and mudstone (Ka) : Subdivided into sandstone-predominant and mudstone-predominant types according to the ratio of sandstone and mudstone, or into thick-bedded and thin-bedded types in terms of the thickness of sandstone. Thick-bedded alternating bed consists of sandstone of several tens of meters to 1m thick and mudstone of 10 to 50 cm thick. In some cases, a few beds of sandstone are amalgamated, forming massive and structureless sandstone of thicker than 5 m, which will be called stratified sandstone as below. Thin-bedded alternating beds are composed of sandstone of 2 to 20 cm thick and mudstone of 5 to 30 cm (Fig. 11-f). In both mudstone-predominant and thin-bedded types of alternating bed, some sandstone beds are disrupted and consequently display a pinch-and-swell structure or form rhombic lenses as a result of ductile deformation.

Massive to stratified sandstone (Ks) : Mostly massive (Fig.11-g), but frequently bedded with mudstone is called stratified sandstone. Sandstone is gray in color and is composed of medium to coarse clastic grains such as predominant quartz and subordinate plagioclase, mica, rock fragment, and the matrix of finer grains (Fig. 12-c,d). Most sandstones are classified into arenite. Clastic grains are angular to subangular in shape and are well sorted. Graded bedding and thin layers of mudstone to siltstone are recognized in the stratified sandstone.

Pale green silty mudstone (Kp) : Greenish gray to pale green in color and homogenous, weak cleavage is partially developed, in appearance (Fig. 11-h). Under the microscope, clastic grains less than silt in size such as quartz, plagioclase, mica and other minerals are observed scattering in the matrix of very fine-grained clay minerals (Fig. 12-e, f) so that the clastic grains do not form lamination or bedding. On the contrary, clay minerals partially indicate indistinctive preferred orientation. Numerous and well-preserved radiolarian remains are also observed. This pale green silty mudstone is thought to correlate with 'the dark green sandy shale' which was originally described at Odaira and Nokura, Daigo Town by Huzimoto (1932), and later was described as greenish gray mudstone by Nakae (2000a).

Table 2 List of radiolarian localities in the Kasama Complex. Ms: mudstone, L: laminated mudstone, Pgs: pale green silty mudstone, J: Jurassic, NT: Nakae and Takizawa (1998) and H: Hori (1998).

	Middle part				Upper part										
Locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sample No.	d 23	DC30-03	DG31-02	DG32-03	DG19-08	DG21-05	DG19-01	d238c	KK-1	SK-2	SO-1	OD-1	OD-2	KS-1	YTZ
Lithology	Ms	L	Pgs		Laminated ms			Pale green silty mudstone							
Age	Late J		late Late Jurassic												
Reference	NT	Nakae (2000a)							Sashida *et al* .(1993)						H

Pelitic mixed rock (Kx) : Composed of mudstone as the matrix chaotically enveloping clasts of sandstone and chert. The mudstone is black and slightly coarse. The clasts generally range from 1 to 50 cm in size and vary from rounded to rhombic.

Age

Age data are insufficient to identify the whole Kasama Complex, particularly where the rocks belonging to the lower part is unknown in age because of slightly metamorphosed lithology. Age of cherts also has not been determined. However, age determination for clastic rocks such as mudstone, silty laminated mudstone and pale green silty mudstone of the middle and upper parts was already done by Sashida *et al.* (1993), Hori (1998, 1999), Nakae and Takizawa (1998) and Nakae (2000a) on the basis of radiolarians (Fig. 4 and Table 2).

In the middle part, Late Jurassic radiolarian faunas were extracted from mudstone at locality (Loc.) 1 (Nakae and Takizawa, 1998) and silty laminated mudstone at Loc. 2 (Nakae, 2000a), and late Late Jurassic radiolarian faunas were obtained from pale green silty mudstone at Locs. 3 and 4 (Nakae, 2000a). Sashida *et al.* (1993) also reported similar faunas from pale green silty mudstone adjacent to Locs. 3 and 4. On the upper part, silty laminated mudstones at Locs. 5 to 7 (Nakae, 2000a) and pale green silty mudstones at Loc. 8 (Nakae, 2000a) and Locs. 9 to 14 (Sashida *et al.*, 1993) yielded late Late Jurassic radiolarians. Hori (1998, 1999) examined the faunal composition of radiolarians from pale green silty mudstones at Loc. 15 to determine its age in detail and revealed that this pale green silty mudstone is late Tithonian (latest Jurassic) in age and younger than silty laminated mudstones of the middle and upper part.

4.2 Takatori Complex (Ty, Tc, Ti, Tm, Tl, Ta, Ts)

(Previously Takatori Formation, ANRE, 1986)

Designation

Originally defined as the Takatori Formation by ANRE (1986) in Mt. Keisoku. Hori and Sashida (1998) once renamed it the Takatori Unit, but later Sashida and Hori (2000) redefined it as the revised Takatori Unit into which the Takatori and the overlying Ayuta Units were integrated. The unit will be renamed hereafter as the Takatori Complex (Table 1-i).

Type locality

Typical succession is exposed from Aikawa through Bukkokuji and Takatoriyama to Shioko, Hitachi-Omiya City, northeast of Mt. Keisoku (ANRE, 1986). In the Daigo district, this complex typically outcrops around the area from Kuryu through Takabu to Torinoko, Hitachi-Omiya City (Fig. 4).

Distribution and stratigraphical relations

The Takatori complex widely distributes in the Sw and Nw areas of the district (Figs. 4 and 6). At the lower boundary, it is in fault contact with the underlying Kasama Complex. The upper boundary of the complex is unknown because it extends westward out of the district. Early Cretaceous granodiorites intrude into the Takatori Complex at a few locations.

Content and thickness

The complex is mainly composed of clastic rocks such as massive to stratified sandstone, alternating bed of sandstone and mudstone, laminated mudstone, siliceous mudstone and chert. Thickness of the complex is thought to be more than 3,800 m (see Fig. 15). Among these rocks, massive sandstone is the most dominate component in the complex. Chert is rarely included, but is commonly observed; being accompanied by siliceous claystone at its base and overlying siliceous mudstone. It generally ranges from 50 to 100 m in thickness, extends for more than 5 to 10 km and is broken through the whole district. Alternating bed of sandstone and mudstone together with laminated mudstone is not dominant, but has a wide distribution with several tens of meters to 100 m in thickness and 500 to 3,000 m in lateral extension.

Compared with the Kasama Complex, lithologic differences that chert is much abundant and mudstone is scarce are raised for the Takatori Complex. In this complex, stratal continuity is less or not broken so that the complex displays coherent facies as a whole on a 1:50,000 map scale.

Stratigraphy

The Takatori Complex consists mainly of laterally extending cherts and overlying clastic rocks of mudstone and sandstone. Such a sequence is regarded to be one type of the ‘chert-clastics sequence’ (CCS) documented by Matsuoka (1984), which is a typical example of oceanic plate stratigraphy. This sequence generally begins with siliceous claystone and is conformably overlain by chert, siliceous mudstone, mudstone and coarser clastic rocks such as sandstone or alternating bed of sandstone and mudstone (*e.g.*, Matsuoka, 1984; Otsuka, 1985). In the Daigo district, the typical sequence is observed at several localities.

On the geologic map (Figs. 4 and 6), a successive sequence composed of the CCS is exposed at least three times. Then, the Takatori Complex can be subdivided into three parts; lower, middle and upper parts according to this stratigraphic triplication (Fig. 15). Focusing attention on outcrop examples, duplicate and/or triplicate CCS on a smaller scale is recognized as illustrated in Figs. 13 and 14. The boundary thrusts among each CCS are situated at the base of cherts or underlying siliceous claystone (Fig. 13).

Lower part : Distributing around Sanuki, Daigo Town in the Nw area and from Shimohizawa, Hitachi-Omiya City to Aikawa, Daigo Town in the Sw area. The thickness is 750 to 1,700 m.

Middle part : Distributing north of Sugakawa, Kurobane Town in the Nw area and from Kamihizawa and Takabu, Hitachi-Omiya City to Aikawa, Daigo Town in the Sw area. Thickness of this part is about 1,200 m. On the route map shown in Fig. 13, siliceous and laminated mudstones of the lower part are exposed to the northeast, and the duplicated CCS of the middle part crops out to the southwest. Within the sequence, siliceous claystone, chert, mudstone, laminated mudstone and sandstone are exposed in ascending order. The boundary between the lower and middle parts is not confirmed.

Upper part : Distributing from Torinoko, Hitachi-Omiya City to Onachi, Bato Town in the Sw area. The thickness is more than 1,200 m. Around Irihizawa, Hitachi-Omiya City, the CCS, which is composed of siliceous claystone, chert, siliceous mudstone and mudstone in ascending order, is typically observed (Fig. 14).

Lithology

Siliceous Claystone (Ty) : Gray to light pale gray and massive to weakly foliated. Siliceous claystone is mainly composed of very fine-grained claystone and partially intercalated with thin beds of black carbonaceous claystone (Fig. 16-a). It is closely accompanied by chert and gradually changes in lithology to overlying chert. Under the microscope, phyllosilicates and cryptocrystalline quartz are observed and any clastic grain coarser than silt is invisible (Fig. 17-a, b). Some opaque minerals, probably pyrites, are also recognized.

Chert (Tc) : In most cases, appearing as rhythmically bedded chert that consists of siliceous beds of 1

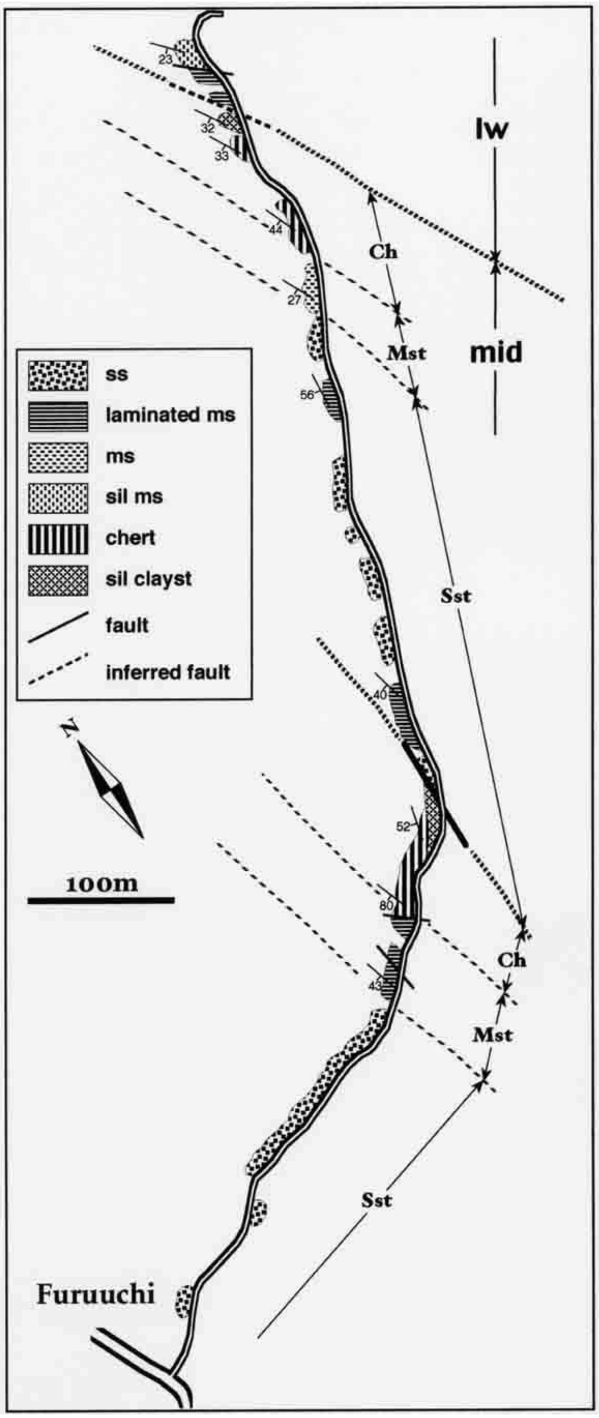

Fig. 13 Route map showing the middle part of the Takatori Complex at Furuuchi, east of Kamihizawa. Chert-clastics sequence composed of chert, mudstone and sandstone is duplicated. lw: lower part, mid: middle part, clayst: claystone, sil: siliceous, ms: mudstone, ss: sandstone. Ch, Mst and Sst are dominated by chert with siliceous claystone, mudstone and laminated mudstone, and sandstone, respectively.

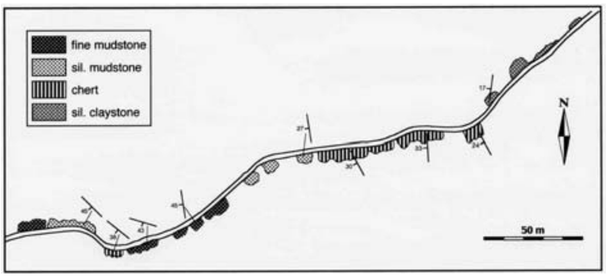

Fig. 14 Route map of the upper part of the Takatori Complex, east of Torinoko. Chert-clastics sequence composed of siliceous claystone and/or chert, siliceous mudstone and mudstone is duplicated. sil: siliceous.

to 5 cm thick and interbedded black muddy beds of 3 mm to 1 cm thick (Fig. 16-b,c). The chert, commonly gray to dark gray or black but rarely light gray to white, is composed of cryptocrystalline quartz and any clastic grain coarser than silt is included.

Siliceous mudstone (Ti) : Dark to light gray, commonly homogenous and structureless (Fig. 16-d). Slaty cleavage is weakly developed at some localities. Under the microscope, it is clear that siliceous mudstone is composed of phyllosilicate and cryptocrystalline quartz and subordinate clastic grains of silt size such as quartz, plagioclase and opaque minerals. Radiolarian remains are also visible (Fig. 17-c,d).

Mudstone (Tm) : Dark gray to black and mostly characterized by slaty cleavage (Fig. 16-e). This mudstone is much finer than the mudstone interbedded with sandstone. Clastic grains are invisible to the naked eye because the clastic grain coarser than silt and no silty lamina is contained. This mudstone has been called 'fine-grained mudstone' by Nakae (2000a). Under the microscope, preferred orientation, which is formed by the parallel arrangement of black seams with clay minerals, is observed (Fig. 17-e,f). Recrystallized radiolarian remains are flattened and arranged parallel to slaty cleavages by a pressure solution (Fig. 17-e). Slaty cleavage of the mudstone has originated from the parallel arrangement.

Laminated mudstone (Tl) : Dark gray to black mudstone universally intercalated with laminae and thin beds of silt to fine-grained sandstone (Fig. 16-f). Partially fissility parallel to the lamination is weakly developed. Under the microscope, the difference between laminated and muddy parts is recognized. Clastic grains coarser than silt such as quartz, plagioclase, potassium feldspar, mica, opaque mineral and rock fragment are aggregated in the laminated parts, whereas finer clastic grains mostly of quartz and plagioclase are scattered in the matrix of clay minerals in the muddy parts. Preferred orientation, which is formed by the parallel arrangement of clay minerals, is also observed

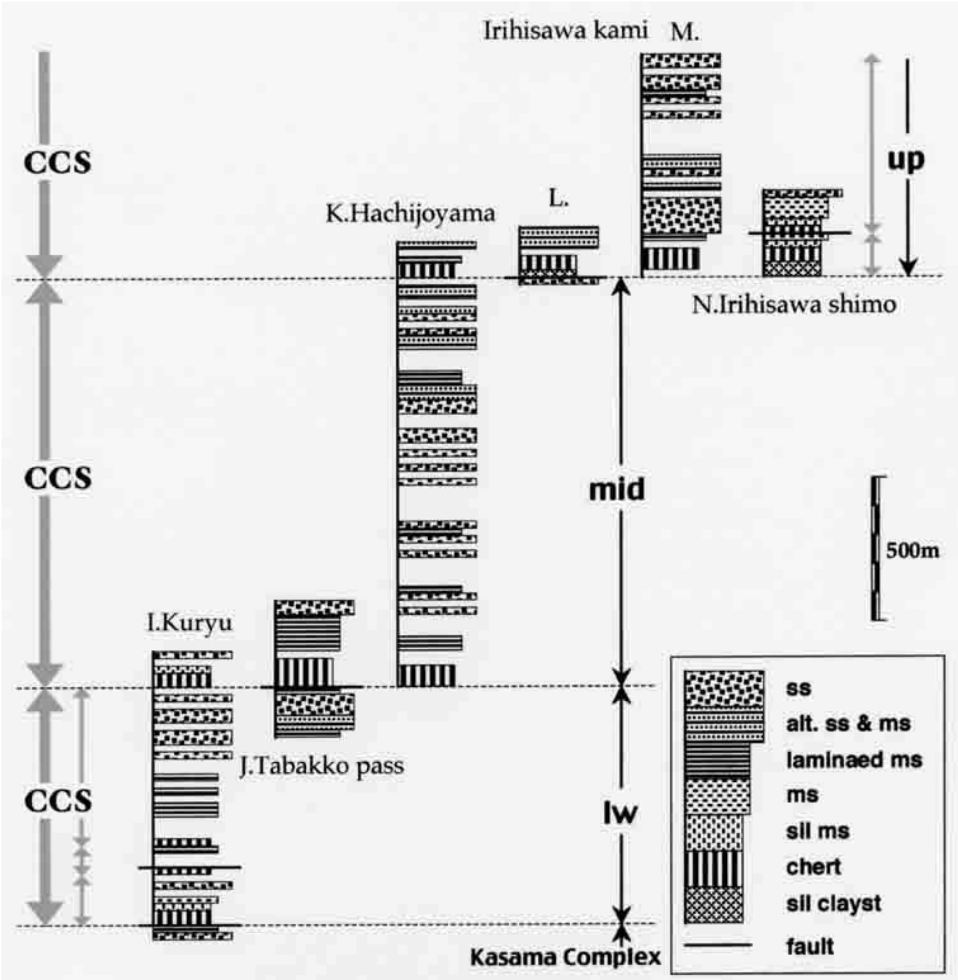

Fig. 15 Columnar sections of the Takatori Complex. Each part consists of chert-clastics sequence as indicated by arrows. Smaller scale duplications and/or triplication of CCS are also recognized. Each locality of the sections is shown in Fig. 3. lw: lower part, mid: middle part, up: upper part, sil: siliceous, clayst: claystone, ms: mudstone, alt: alternating bed, ss: sandstone, CCS: chert-clastics sequence.

in the muddy part.

Alternating bed of sandstone and mudstone (Ta) : Subdivided into sandstone-predominant and mudstone-predominant types by the same criteria as the case of the Kasama Complex. The thick, alternating bed consists of sandstone of several tens of meters to 1m thick and mudstone of 10 to 50 cm thick. Thin alternating beds are composed of sandstone of 2 to 20 cm thick and mudstone of 5 to 30 cm. For both mudstone-predominant and thin-bedded types of the alternating bed, some sandstone beds are disrupted and display a pinch-and-swell structure or form rhombic lenses as a result (Fig. 16-g).

Massive to stratified sandstone (Ts) : Mostly massive, but frequently bedded with mudstone called stratified sandstone. Sandstone is dark gray and arkosic to subarkosic arenite (Fig. 16-h). It is composed of medium to coarse clastic grains such as predominant quartz and subordinate plagioclase, mica, rock fragment, and a matrix of finer grains (Fig. 17-g,h). Graded bedding and thin layers of mudstone to siltstone are recognized in the stratified sandstone.

Age

Radiolarians provide an excellent age control throughout the Takatori Complex, ranging from Middle Triassic to Late Jurassic. Age determination based on radiolarians was already done by Nakae (1997, 2000a), Nakae and Takizawa (1998) and Hori (2001) for the Takatori Complex (Figs. 4,5 and Table 3).

Mudstones of the lower part at Locs. 16 and 17 (Fig. 6) yielded some radiolarians ranging from middle Middle to early Late Jurassic in age (Nakae, 2000a). In the middle part, radiolarians indicating an age probably Middle or Late Jurassic, and Jurassic were obtained from mudstone at Loc. 18 (Fig. 6) and laminated mudstone at Loc. 19, respectively (Fig. 4; Nakae, 2000a). Latest Jurassic radiolarians were also detected from silty mudstones of the middle part at Locs. 20 to

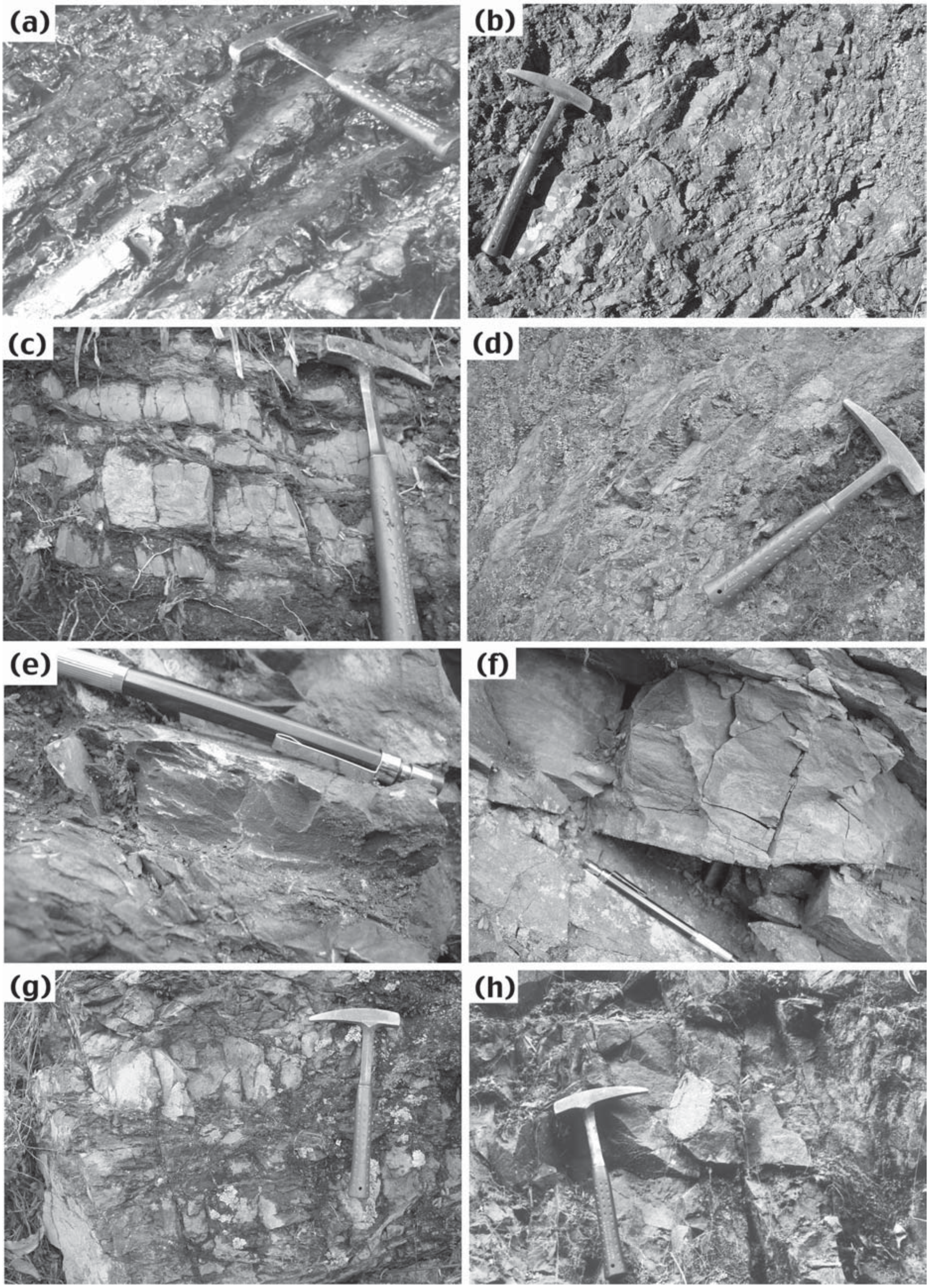

Fig. 16 Field lithologies of the Takatori Complex. (a) Siliceous claystone of the middle part at Furuuchi, (b) chert of the middle part at Tabakko pass, (c) chert of the upper part at Onachi, (d) siliceous mudstone of the middle part at Tabakko pass, (e) mudstone of the upper part at Onachi, (f) laminated mudstone of the upper part at Onachi, (g) broken facies of alternating beds of sandstone and mudstone of the upper part at Yanokusa, and (h) massive sandstone of the middle part at Tabakko pass.

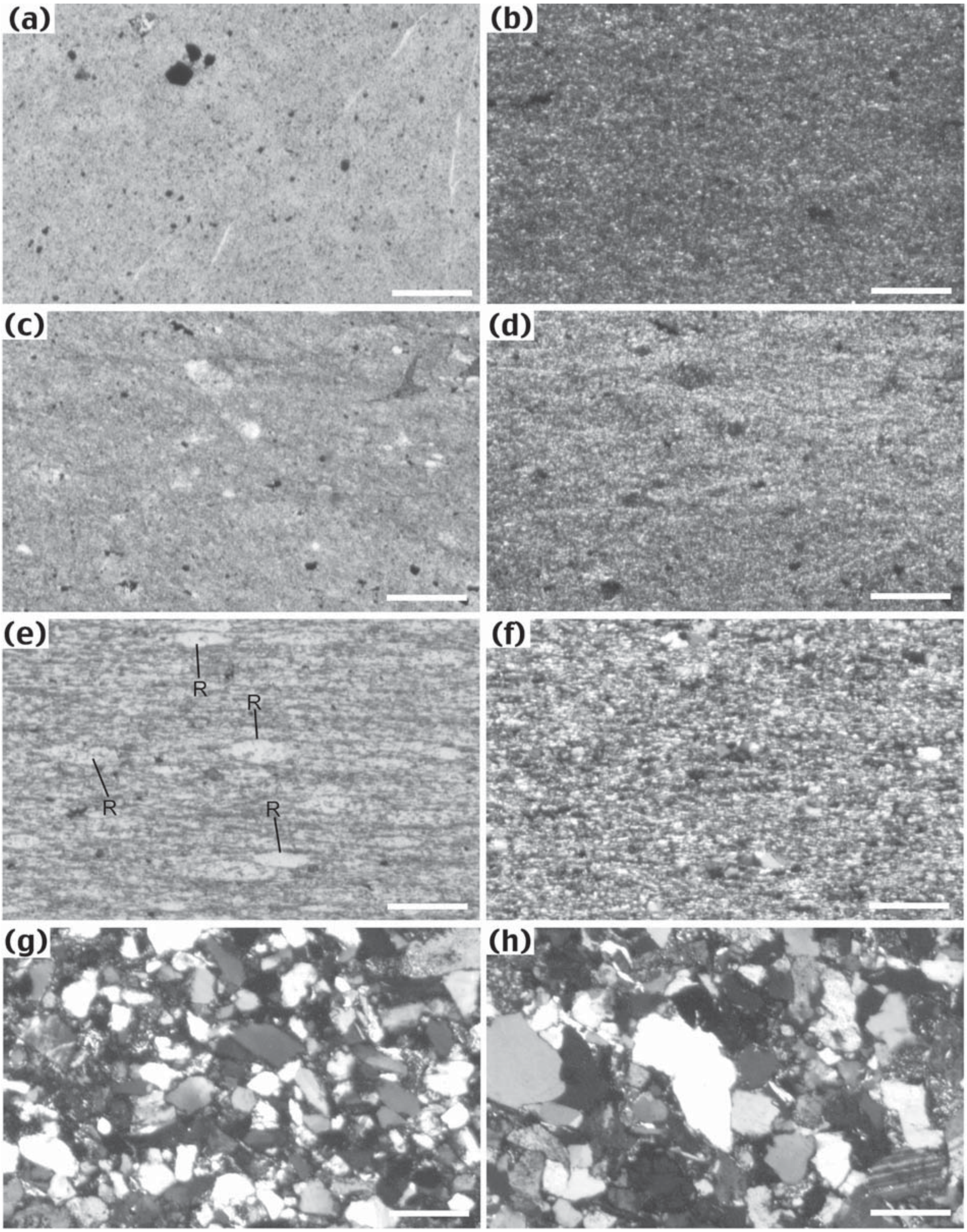

Fig. 17 Microphotographs of each lithology of the Takatori Complex. (a) Siliceous claystone of the upper part at Irihizawa, (b) siliceous claystone of the middle part at Furuuchi, (c)-(d) siliceous mudstone of the lower part at Omichizawa, (e)-(f) mudstone of the middle part at Kakinokusa, (g) sandstone of the lower part at Furuuchi and (f) sandstone of the middle part at Furuuchi. (a), (c) and (e) are open nicol and (b), (d), (f)-(h) are crossed nicols. Black bars with R indicate radiolarian remains. All scale bars are 0.2 mm.

22 (Fig. 4; Nakae and Takizawa, 1998). On the other hand, Nakae (1997) preliminarily reported Middle Triassic to Late Jurassic radiolarians from several successions of the CCS in the upper part. Later Hori (2001) examined the detailed age of these CCS (Locs. 23 to 28 in Fig. 4) and identified their age as follows; chert is Middle Triassic to early Early Jurassic, siliceous mudstone is early Middle to early Late Jurassic, mudstone is middle Late Jurassic and silty laminated mudstone is late Late Jurassic in age.

5. Structure

The mapped area lies in the Yamizo Mountains in the western area of the Daigo district. In this area, the Ashio Terrane composed of the Kasama and Takatori Complexes is separated from the central lowland and hills by the distribution of Miocene sedimentary rocks and volcanic breccias (Fig. 2). Detailed structural development of the Ashio Terrane around this district has never been explained, in so far as it relates to the formation and deformation of the terrane. The Ashio Terrane is extensively deformed by mappable large-scale thrusts, folds and faults. On these deformation structures, the structural history of this terrane can be simplified into three board periods, each of which is characterized by a dominant tectonic regime.

5.1 Structural history

Initial deformation is recognized throughout the complexes and occurred during a post-depositional stage, probably late Jurassic to earliest Cretaceous period, with the formation of intra- and inter-complex thrusts. A compressive tectonic regime involving these thrusts was probably controlled by the subduction of the Izanagi plate. Folding is displayed by the swing of the complexes, and the folds are classified into two types based on their scale and morphology. The last stage of deformation is characterized by subvertical faults, which intersect the complexes and folds.

The simplified deformation structures are illustrated in Fig. 18, and the following sections focus particularly on mappable large-scale deformation structures of the Ashio Terrane.

5.2 Intra-complex thrust

Case in the Kasama Complex

The Kasama Complex is divided into the lower, middle and upper parts on the basis of the state of the lithologic assemblage (Fig. 10). Although the boundaries are not clearly observed, each of them is thought to be a thrust (Fig. 18). Particularly in the upper part, pale green silty mudstone has a specific stratigraphic relationship with the surrounding laminated mudstone and sandstone, *i.e.*, litho-stratigraphic sequence composed of laminated mudstone, sandstone and pale green

Table 3 List of radiolarian localities in the Takatori Complex. CCS: chert-clastics sequence, e: early, m: middle, M: Middle, L: Late, J: Jurassic, NT: Nakae and Takizawa (1998).

	Lower		Middle part					Upper part					
Locality	16	17	18	19	20	21	22	23	24	25	26	27	28
Sample No.	DG11-02	DG13-02	DG31-02	DG18-01	DG49-36	d128a,b	DG50-01	YNKS section	TDCH section	TDCH-12 section	IHZW section	IGZA section	IHZS section
Lithology	Mudstone			Silty/laminated ms				CCS					
Age	mM-eLJ		M-L J?	J	late Late J			Middle Triassic-Late Jurassic					
Reference	Nakae (2000a)				NT			Hori (2001)					

silty mudstone in this order is exposed at least three times north of Osawa-gawa River, Daigo Town (Figs. 4 and 9). The similar strike (NE-SW striking) and dip (westward dipping at 20° to 45°) of these rocks demonstrates that the complex is not folded, but homoclinic. For the age of these rocks, pale green silty and laminated mudstones of each litho-stratigraphic sequence yield Tithonian (latest Jurassic) radiolarian fossils (Table 2; Sashida *et al.*, 1993; Nakae, 2000a), indicating that the whole sequence is the same age. From these stratigraphical and structural features, it is reasonable that the triplication of the sequence was caused not by folding, but by thrusting (Fig. 18). Sashida *et al.* (1993) have also illustrated a similar structure in their figure. However, any field evidence on the intra-complex thrusts has unfortunately not been recognized.

Case in the Takatori Complex

As described before, the Takatori Complex is divided into the lower, middle and upper parts (Fig. 18), which consist of almost the same lithologic sequence, called 'chert-clastics sequence' (Fig. 15). On the boundaries, only a fault between the lower and middle parts is recognized west of Tabakko pass. Sandstone of the lower part is overlain by chert of the middle part through the fault whose plane strikes N13°W and dips westward at 60°(Fig. 19).

5.3 Inter-complex thrust

Any inter-complex thrust has never been found, except only one locality as described as follows. Around the inter-complex thrust observed at Kuryu (Fig. 20), mudstone of the footwall is laminated with very thin layers of sandstone and intensely cloven, but chert of the hanging wall is not as sheared, except just above the thrust fault plane. Although the mudstone and chert dip westward at a similar angle (20° to 30°), their strikes are obviously oblique. The dip and strike of the thrust fault plane is discordant from those of the mudstone and chert.

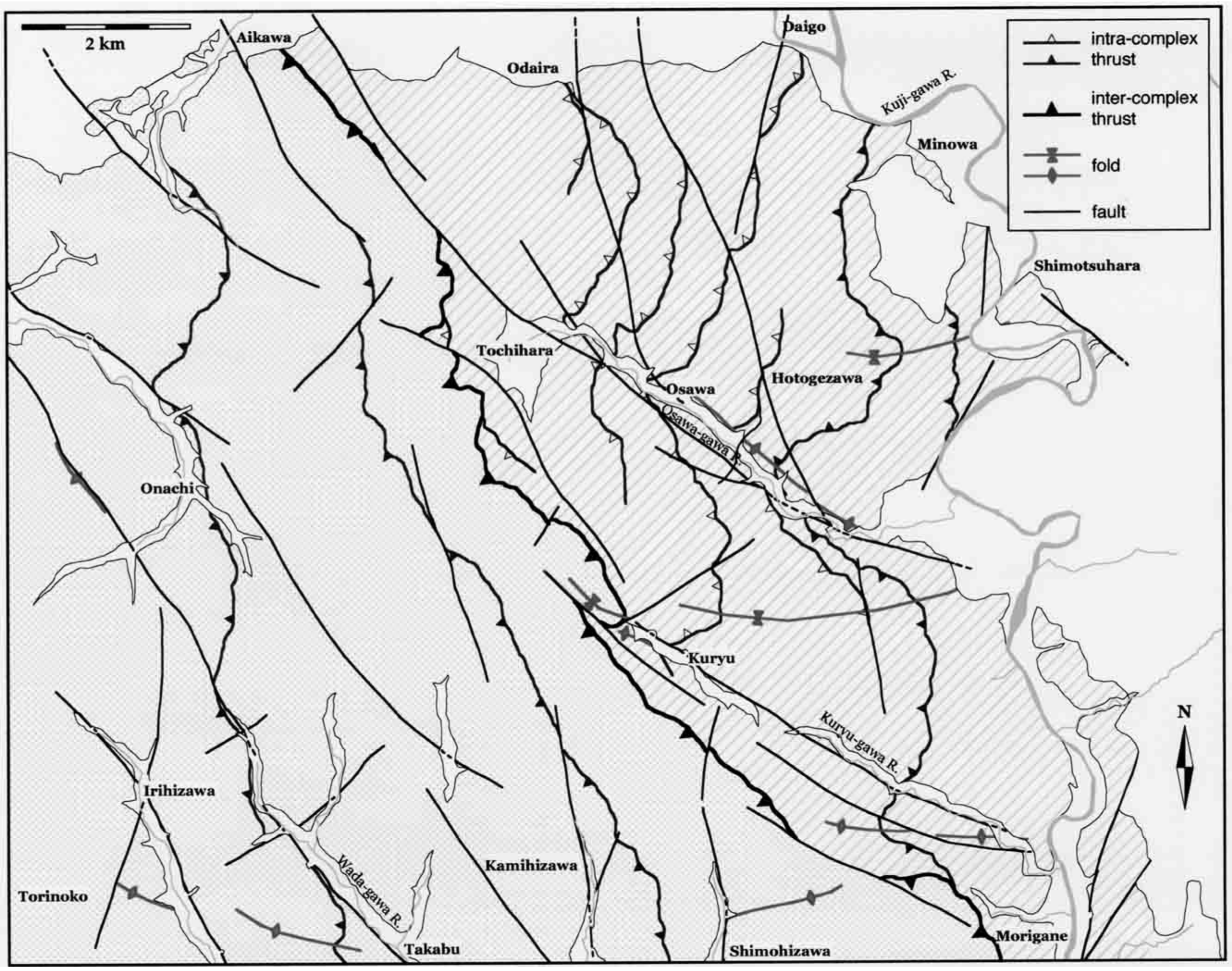

Fig. 18 Surface structures in the mapped area of the Daigo district. Intra- and inter-complex thrusts are recognized in the Daigo district, and an additional two types of the former thrust are distinguished; thrusts with open triangles in the upper part of the Kasama Complex and thrusts with solid triangles dividing each complex into the lower, middle and upper parts.

On the other hand, existence of thrusts can be inferred on the basis of the different strikes and dips and/or distribution mode of the rocks around the boundaries. For example, west of Tochihara (Fig. 21), clastic rocks such as sandstone and mudstone of the Kasama Complex crop out along streams and strike NW-SE. On the contrary, cherts of the Takatori Complex are exposed at an elevated area and extended NE-SW. Therefore, it is quite reasonable that a low angle fault, probably a thrust, exists between the complexes.

5.4 Folds

Kawada (1953) and Kanomata (1961) previously mentioned that the complexes in the Yamizo Mountains homoclinally incline westward. The Kasama and Takatori Complexes in this district also gently to moderately dip westward as a whole (Fig. 5). However, the complexes swing slightly or intensely from NW-SE through NE-SW to NW-SE. This swing is probably attributable to post-Jurassic folding.

Two types of folds are distinguished on the basis of their scale and morphology: E-W trending open folds and NW-SE trending tight folds (Fig. 18). Most of the open folds are recognized in the Kasama Complex and their half-wavelength is 1-2 km. The tight folds are asymmetric in the length of the limb, much smaller and less extensive than the open folds. Their half-wavelength is 250-400 m.

5.5 Subvertical Faults

Numerous subvertical faults, NNW-SSE and NE-SW trending, transect the complexes. The NNW-SSE trending faults are dominant and generally extend more than 5 km. An apparent offset along some of these faults can be seen on the surface indicating a sinistral slip, but dip-slip displacements are still unsolved. Most remarkable faults are exposed along the Osawa-gawa, Kuryu-gawa and Wada-gawa Rivers. The NE-SW

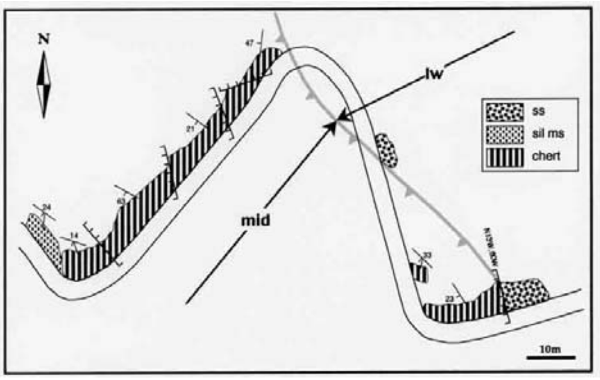

Fig. 19 Route map showing an intra-complex thrust in the Takatori Complex west of Tabakko pass. Sandstone of the lower part and chert of the middle part are bounded by a westward-dipping fault. lw: lower part, mid: middle part, sil ms: siliceous mudstone, ss: sandstone.

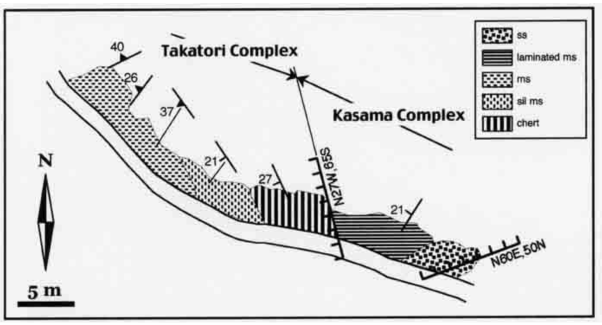

Fig. 20 Route map showing an inter-complex thrust at Kuryu. Laminated mudstone of the Kasama Complex and chert of the Takatori Complex are bounded by a westward-dipping fault. sil: siliceous, ms: mudstone, ss: sandstone.

trending faults are also recognized, but are not extensive; the length is about 1-2 km.

6. Summary

Geological research including field survey and analysis in laboratory has been carried out since 1993 under the mapping project of the Geological Survey of Japan, AIST. The results are as follows.

The Ashio Terrane in this district is divided into the Kasama and Takatori Complexes; the Kasama Complex is in fault contact with the overlying Takatori Complex. The Kasama Complex is mainly composed of predominating massive to stratified sandstone, laminated mudstone and a minor amount of pale green silty mudstone and chert. Although similar to the Kasama Complex in lithology as a whole, the Takatori Complex consists of laterally extending cherts and overlying mudstone and sandstone. These complexes dip

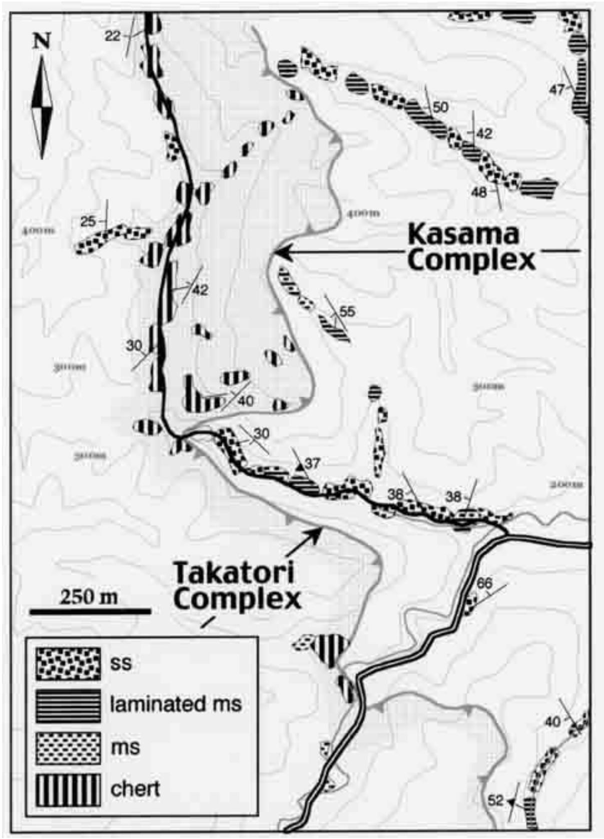

Fig. 21 An inter-complex thrust between the Kasama and Takatori Complexes, west of Tochihara. A westward-dipping thrust is inferred on the basis of the distribution mode of outcrops. Distribution of the basal chert of the Takatori Complex is shown by a dotted zone. ms: mudstone, ss: sandstone.

westward and are folded with E-W and NW-SE trending axes. Numerous subvertical faults, NNW-SSE and NE-SW trending, transect the complexes.

Acknowledgements: I thank Drs. F. Takizawa, Y. Kamata, and N. Hori for support in the early stage of the field survey and help in sample processing for radiolarian dating. Thanks are extended to Dr. C. Kurimoto and Mr. T. Yoshikawa for the referee reading.

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* : in Japanese with English abstract
** : in Japanese

Received September 28, 2005
Accepted March 2, 2006

茨城県北部・栃木県西部に位置する大子地域におけるジュラ紀付加複合体の層序と構造

中江　訓

要　旨

大子地域は茨城県北部-栃木県東部にかけての約420 km^{2}の範囲を持ち , 地形的に北東部の阿武隈山地 , 中央部の低地-丘陵地 , 西部の八溝山地に識別できる．棚倉構造線によって中央部と画された東側の阿武隈山地は , 阿武隈帯に属する白亜紀の変成岩と花崗岩からなり , またこれより西側には , 足尾帯に属する三畳紀-白亜紀初頭の付加複合体とこれを不整合に覆う中新世の堆積岩類・火山岩類が西部と中央部にそれぞれ分布する．調査範囲は西部の八溝山地に位置する．

八溝山地を構成する付加複合体は足尾テレーンと呼ばれ,遠洋域から陸源域の堆積環境を示す岩石類が破断した岩相を示し,ジュラ紀にイザナギプレートがアジア大陸に沈み込んだ収束境界に沿って形成されたと考えられている．大子地域の足尾テレーンは岩相・堆積年代・構造関係に基づき，笠間コンプレックスと高取コンプレックスに区分される．笠間コンプレックスは塊状-成層砂岩・葉理質泥岩・シルト質泥岩・チャートから構成され , 泥岩基質に砂岩・チャートなどの岩塊を含む泥質混在岩をわずかに伴う．高取コンプレックスは岩相的に笠間コンプレックスに類似するが，チャート・泥岩・砂岩から構成されるシークェンスの重複構造で特徴づけられる．笠間コンプレックスは上位の高取コンプレックスと衝上断層で接する．両コンプレックスは西に低角-中角で傾斜するとともにE-WとNW-SE 方向の軸を持つ褶曲構造を呈し，NNW-SSE と NE-SW の 2 方向の高角傾斜断層に切られている．

難解・重要地名

Daigo 大子 , Yamizo 八溝 , Ashio 足尾 , Kasama 笠間 , Takatori 高取 , Kuji-gawa 久慈川 , Osawa-gawa 大沢川 , Odaira 大平 , Shimotsuhara 下津原 , Onachi 大那地 , Kuryu 久隆 , Torinoko 鶏子 , Tochihara 栃原 , Hotogezawa 仏沢 , Nokura 野倉 , Irihizawa 入檜沢 , Kamihizawa 上檜沢 , Shimohizawa 下檜沢 , Morigane 盛金 , Nakanase 中那瀬